Space Exploration Logistics Analysis

Lunar South Pole Scenario

Introduction

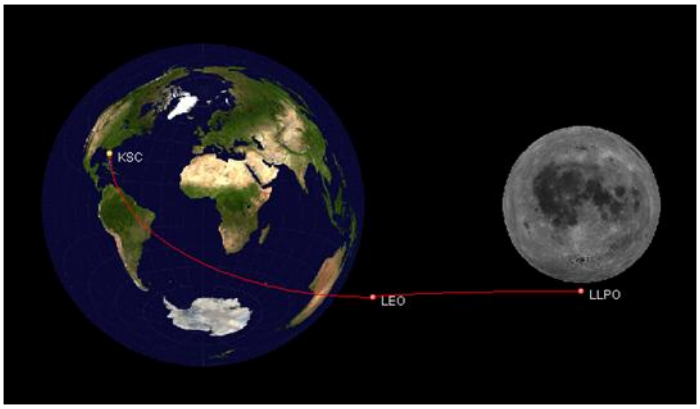
This scenario analyzes aspects of a proposed mission to explore the Lunar South Pole in two parts:

- Part I will create a model to analyze a cargo resupply mission to lunar orbit.
- Part II will modify an existing model of a human exploration mission to maximize effectiveness.

Part I – Cargo Resupply Mission

Part I of this scenario models a single cargo resupply mission between the Earth and the Moon. Your goal is to verify there is sufficient fuel to complete the mission and deliver 13,000 kilograms of crew provision resources to lunar orbit.

Reference Information



Nodes (Locations)

KSC	Kennedy Space Center
LEO	Low Earth Orbit
LLPO	Low Lunar Polar Orbit

Edges (Transports)

KSC-LEO	Launch (9800 m/s)
LEO-LLPO	Earth Departure (3150 m/s) Moon Arrival (950 m/s)

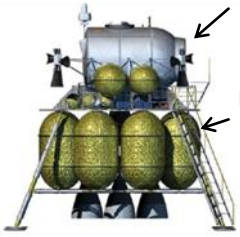
Heavy Lift Launch Vehicle

Upper Stage — 3rd stage of the launch vehicle (specific impulse: 448 s)
Empty mass: 26,000 kg Fuel capacity: 250,000 kg

Core Stage — 2nd stage of the launch vehicle (specific impulse: 414 s)
Empty mass: 175,000 kg Fuel capacity: 1,500,000 kg

Solid Rocket Boosters — 1st stage of the launch vehicle (specific impulse: 270 s)
Empty mass: 210,000 kg Fuel capacity: 1,375,000 kg

Cargo Lander



Cargo Module — In-space vehicle to carry cargo
Empty mass: 2,000 kg Cargo capacity: 15,000 kg

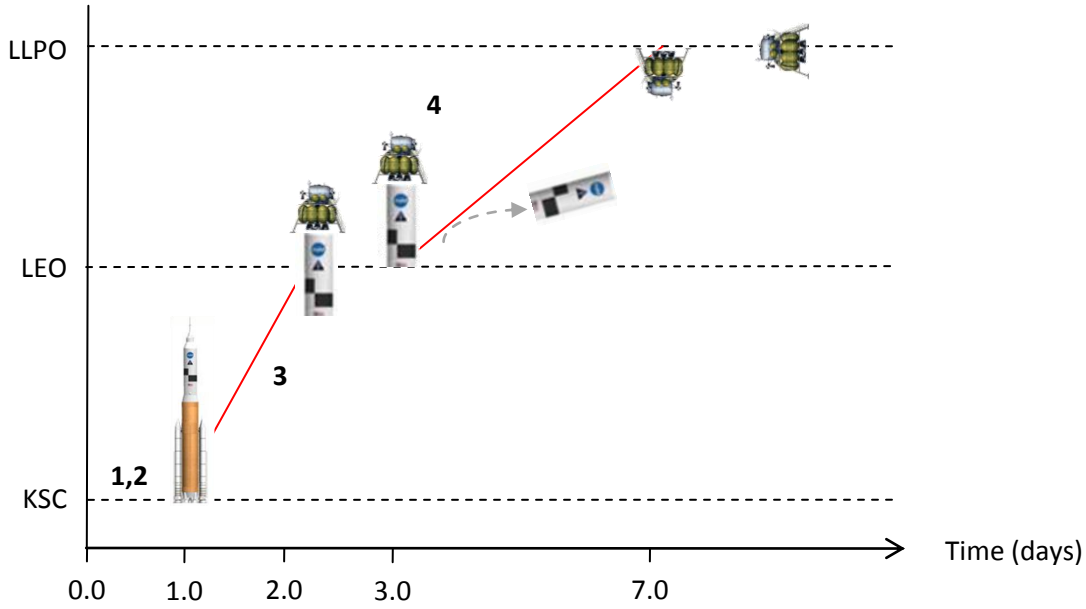
Propulsion Module — In-space vehicle with propulsion (specific impulse: 448 s)
Empty mass: 10,000 kg Fuel capacity: 26,000 kg

Other Elements

Cargo Container — Resource container for cargo resupply missions, packed with 13,000 kg of crew provisions resources (COS 2)
Empty mass: 2,000 kg Resource capacity: 13,000 kg

Mission Outline

The mission takes place over the span of 7 days, completing the transfer of cargo from the launch site (Kennedy Space Center, KSC) through Low Earth Orbit (LEO) and to a Low Lunar Polar Orbit (LLPO).



This mission is based on NASA Constellation Scenario 12.0.3 Mission 3 (Unpublished).

Mission Events

1. (T+0.0) Create complete launch stack at Kennedy Space Center (KSC)
    - Launch Vehicle: Solid Rocket Boosters, Core Stage, Upper Stage
    - Cargo Lander: Cargo Module, Propulsion Module
2. (T+0.0) Add Cargo Container to Cargo Module
3. (T+1.0) Launch stack to low Earth orbit (LEO)
    - *Burn and stage (discard) the Solid Rocket Boosters.*
    - *Burn and stage (discard) the Core Stage.*
    - *Burn the Upper Stage to complete the launch burn.*
4. (T+3.0) Transfer in-space vehicle to low lunar polar orbit (LLPO)
    - *Burn and stage (discard) the Upper Stage for the Earth departure burn.*
    - *Burn the Propulsion Module for the Moon arrival burn.*

Analysis Objectives

Your analysis should confirm of the following results:

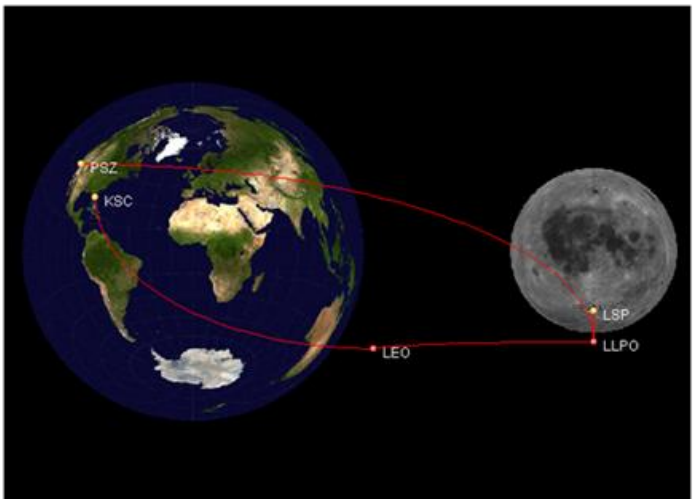
- Proposed mission is feasible (sufficient fuel for all burns)
    - **Upper Stage residual fuel** (after Earth departure burn): **3,777 kg**
    - **Propulsion Module residual fuel** (after Moon arrival burn): **15,697 kg**

Part II – Lunar South Pole Mission

Part II of this scenario models a 5-day human exploration mission to the Lunar South Pole. Your goal is to modify the baseline mission to provide the maximum *relative exploration capability* while satisfying all demands for resources and fuel.

Astronauts require 7.5 kilograms per person per day for provisions. This covers water, food, oxygen, and other required items (hygiene, etc.). All pre-specified payload items (rovers, etc.) and any Exploration/Research resources in containers at the Lunar South Pole directly contribute to Exploration Capability. Provisions and containers contribute only by enabling exploration.

Reference Information



Nodes (Locations)

KSC	Kennedy Space Center
LEO	Low Earth Orbit
LLPO	Low Lunar Polar Orbit
LSP	Lunar South Pole
PSZ	Pacific Splashdown Zone

Edges (Transports)

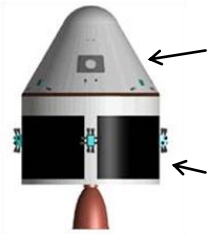
KSC-LEO	Earth Launch (9800 m/s)
LEO-LLPO	Earth Departure (3150 m/s)
	Mon Arrival (950 m/s)
LLPO-LSP	Moon Landing (2030 m/s)
LSP-LLPO	Moon Launch (1875 m/s)
LLPO-PSZ	Moon Departure (1850 m/s)

Human Rated Launch Vehicle

Upper Stage — 2nd stage of the launch vehicle (specific impulse: 448 s)
Empty mass: 12,000 kg Fuel capacity: 125,000 kg

First Stage — 1st stage of the launch vehicle (specific impulse: 270 s)
Empty mass: 105,000 kg Fuel capacity: 620,000 kg

In-space Crew Vehicle



Crew Module — In-space vehicle to carry crew
Empty mass: 8,000 kg
Cargo capacity: 500 kg Crew capacity: 4

Service Module — In-space vehicle with propulsion (specific impulse: 320 s)
Empty mass: 3,000 kg Fuel capacity: 10,000 kg

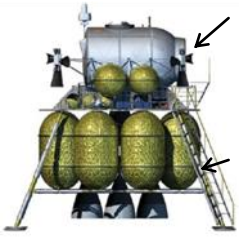
Heavy Lift Launch Vehicle

Upper Stage
3rd stage of the launch vehicle (specific impulse: 448 s)
Empty mass: 26,000 kg Fuel capacity: 250,000 kg

Core Stage
2nd stage of the launch vehicle (specific impulse: 414 s)
Empty mass: 175,000 kg Fuel capacity: 1,500,000 kg

Solid Rocket Boosters
1st stage of the launch vehicle (specific impulse: 270 s)
Empty mass: 210,000 kg Fuel capacity: 1,375,000 kg

Crew Lander



Ascent Module
Ascent vehicle to carry crew and cargo (specific impulse: 320 s)
Empty mass: 3,000 kg Fuel capacity: 3000 kg
Cargo capacity: 500 kg Crew capacity: 4

Descent Module
Landing-capable vehicle with propulsion (specific impulse: 448 s)
Empty mass: 12,000 kg Fuel capacity: 25,000 kg
Cargo capacity: 500 kg

Other Elements

Astronaut
Astronaut crew member
Mass: 100 kg Demands: 7.5 kg/day Crew Provisions

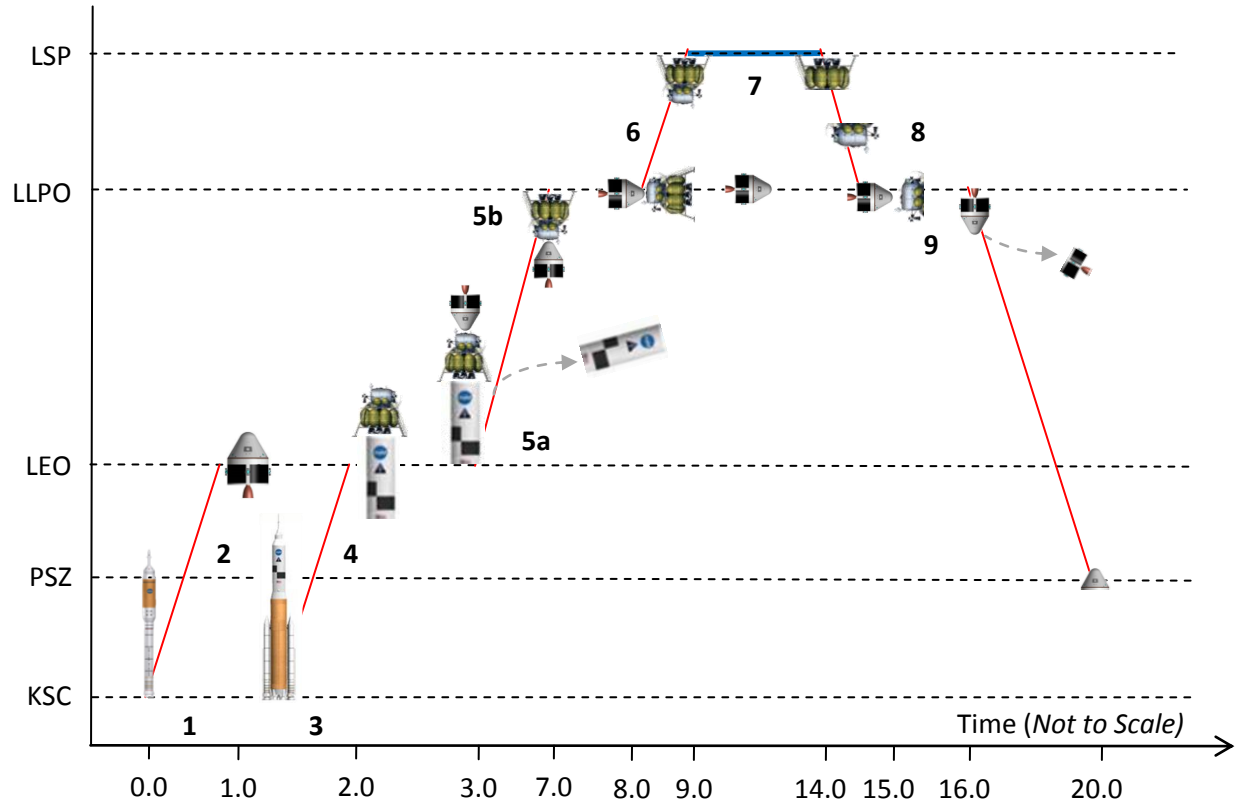
Crew Module Container
Resource container for the Crew Module
Empty mass: 50 kg Resource capacity: 450 kg

Ascent Module Container
Resource container for the Ascent Module
Empty mass: 50 kg Resource capacity: 450 kg

Descent Module Container
Resource container for the Descent Module
Empty mass: 50 kg Resource capacity: 450 kg

Autonomous Rover
Autonomous rover for exploring the surface
Mass: 230 kg

Mission Outline



This mission is based on NASA Constellation Scenario 12.0.3 Mission 2 (Unpublished).

Baseline Mission Overview

1. Create Human-rated Launch Stack at KSC
   - First Stage
   - Upper Stage
   - Service Module
   - Crew Module
     - 4 Astronauts
     - Crew Module Container + Resources
2. Launch Human-rated Stack to Low Earth Orbit
   - Burn/Stage First Stage
   - Burn/Stage Upper Stage
3. Create Heavy-lift Launch Stack at KSC
   - Solid Rocket Boosters
   - Core Stage
   - Upper Stage
   - Descent Module
     - Descent Module Container + Resources
   - Ascent Module
     - Autonomous Rover
     - Ascent Module Container + Resources
4. Launch Heavy-lift Stack to Low Earth Orbit
   - Burn/Stage Solid Rocket Boosters
   - Burn/Stage Core Stage
   - Burn Upper Stage
5. Transport from Low Earth Orbit to Low Lunar Polar Orbit

   a) Earth Departure: Burn/Stage Upper Stage

   b) Moon Arrival: Burn Descent Module
6. Move astronauts to Ascent Module and Land at the Lunar South Pole
   - Burn Descent Module
7. 5-day Exploration at the Lunar South Pole
   - Offload Rover from Ascent Module
8. Launch from the Moon to Low Lunar Polar Orbit
   - Burn Ascent Module
9. Move astronauts to the Crew Module and Depart the Moon
   - Burn/Stage Service Module
   - Direct Re-entry to the Pacific Ocean

Analysis Objectives

Modify the baseline mission to maximize the relative exploration capability while satisfying all astronaut demands. The baseline relative exploration capability is **1.16**.

Note that relative exploration capability can be increased through three strategies:

1. Increase Crew Time (longer surface explorations)
2. Increase Science/Exploration Mass (deliver more science/exploration resources)
3. Reduce Launch Mass (launch fewer provisions or fuel)

In this scenario, you **may** do any of the following:

- Decrease initial fuel levels for propulsive vehicles (including launch vehicles) to reduce the initial launch mass from Earth.
- Add or remove cargo (Crew Provisions or Science/Exploration resources) to sustain crew or provide more science/exploration mass during exploration.
- Transfer Science/Exploration or Crew Provisions resources between co-located containers, for example, to reduce launch mass for the Ascent Vehicle.
- Modify the exploration duration to change the amount of time spent on the Moon's surface.

You **may not**:

- Remove the pre-defined autonomous rover.
- Define new types of elements for use.
- Change element attributes (empty mass, fuel capacity, specific impulse, or cargo capacity).
- Add or remove astronauts or change the demands astronauts require.