Space Logistics Exploration Campaign Scenario Specification for SpaceNet

AIAA SciTech Forum

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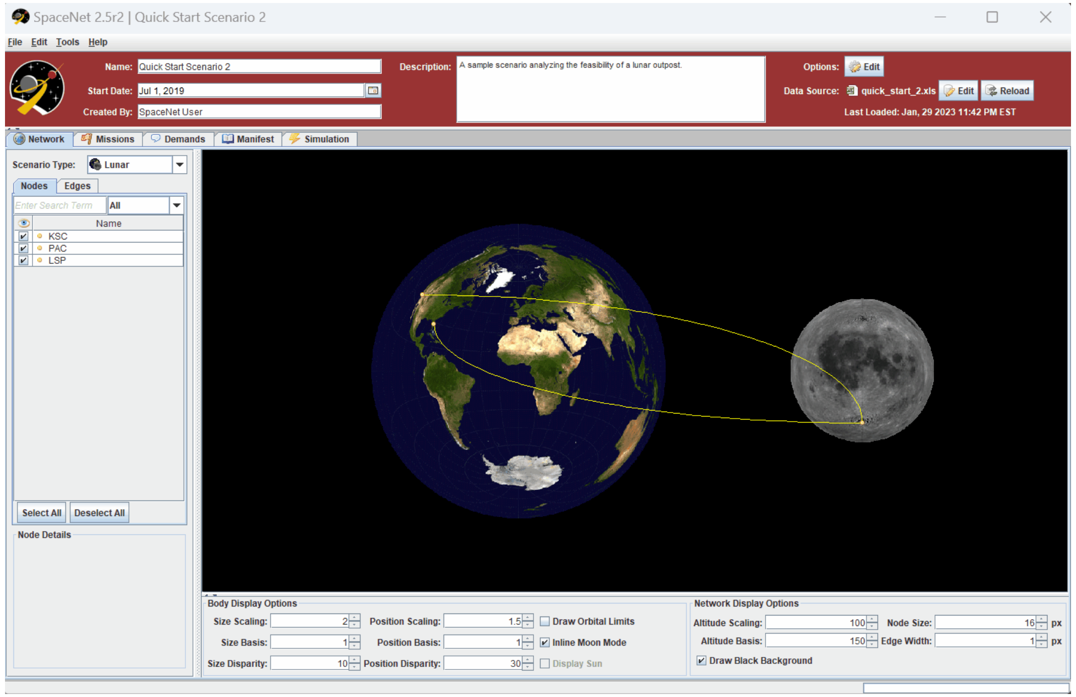
Overview

- SpaceNet Overview
- Artemis III Quick Start Scenario
- Analysis Capabilities
- Software Interfaces

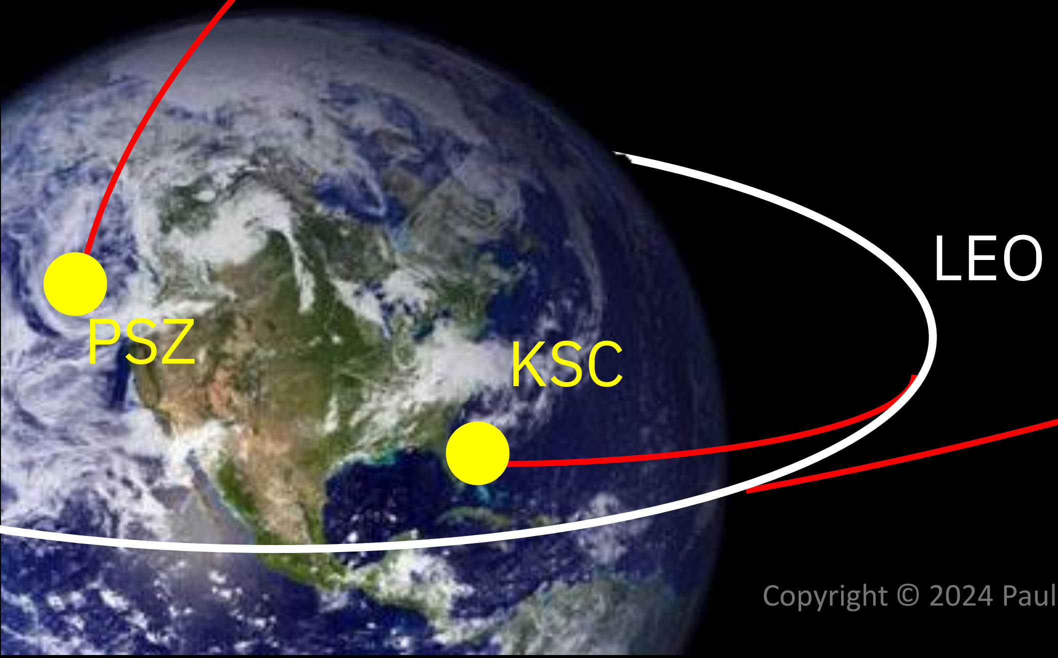
SpaceNet Campaign Logistics Tool

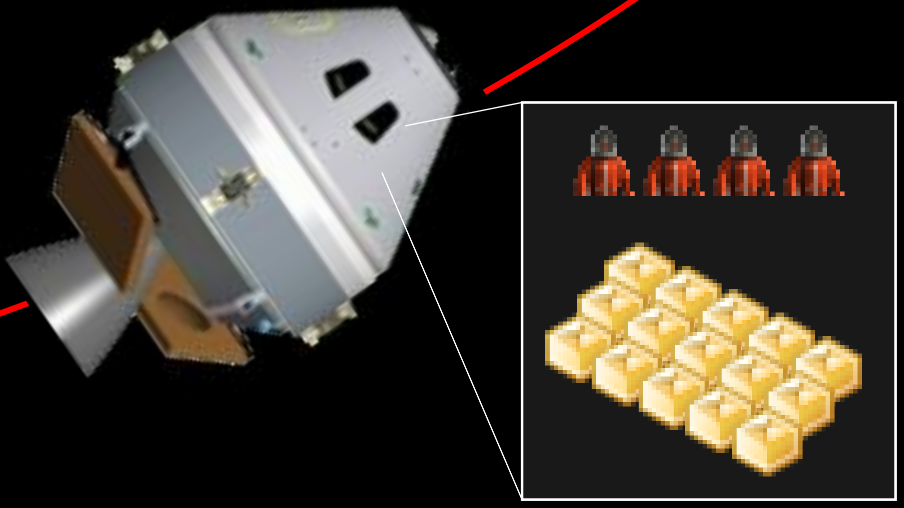
- Originally developed by MIT’s Space Logistics Project under NASA’s Constellation Program
  - 2004-2010 (Java); 2020-Present (Python)
- Model & simulate campaign logistics:
  - Compose integrated scenario
  - Evaluate propulsive feasibility
  - Evaluate logistical feasibility
  - Measure key performance indicators
- Open-source repositories:
  - SpaceNet Java: github.com/space-logistics-org/spacenet-java
  - SpaceNet “Cloud”: github.com/space-logistics-org/spacenet



SpaceNet Simulation State

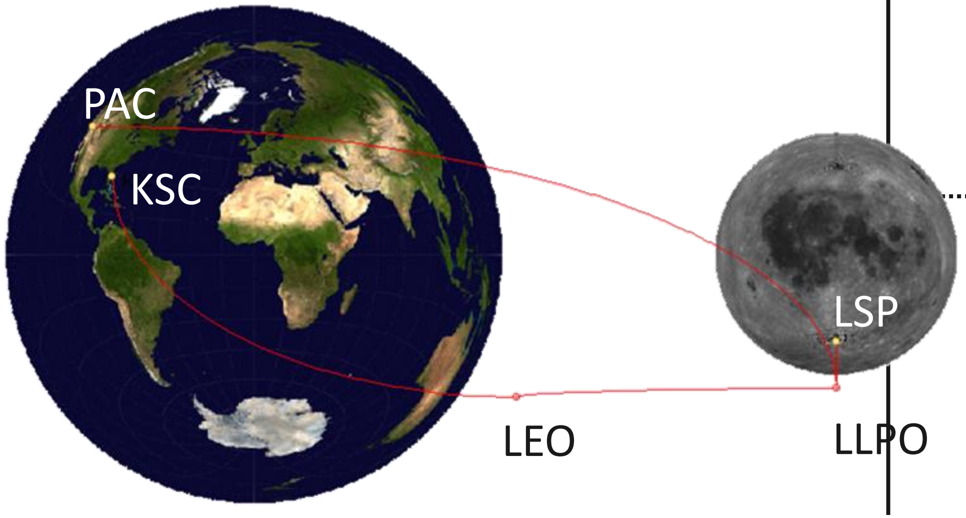
- Exploration Network
  - Nodes: Orbit, Surface, Lagrange
  - Edges: Space, Surface, Flight
- Elements
  - Crew Members
  - Element Carriers
    - Propulsive Vehicle
    - Surface Vehicle
  - Resource Containers



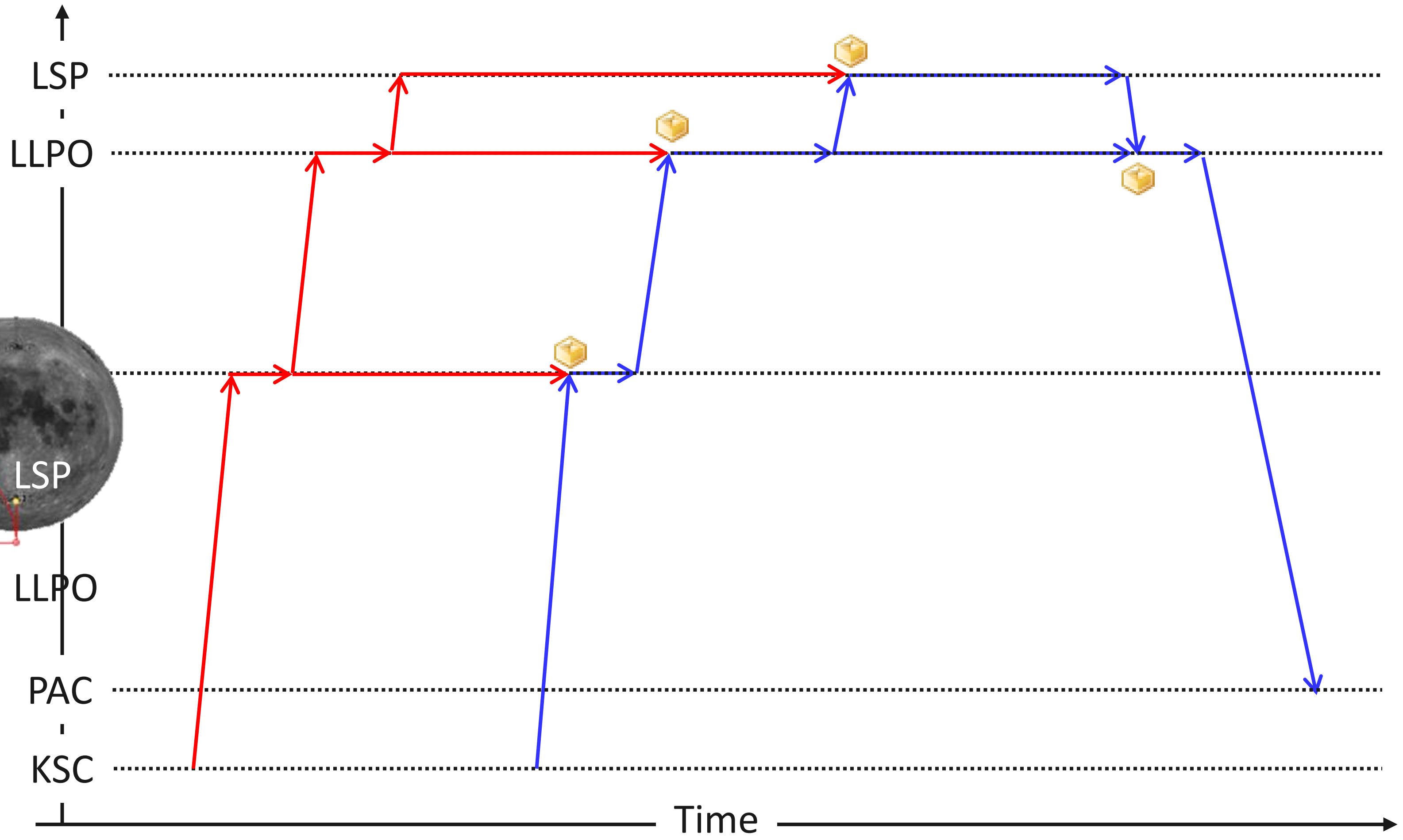


Interplanetary Supply Chain Network

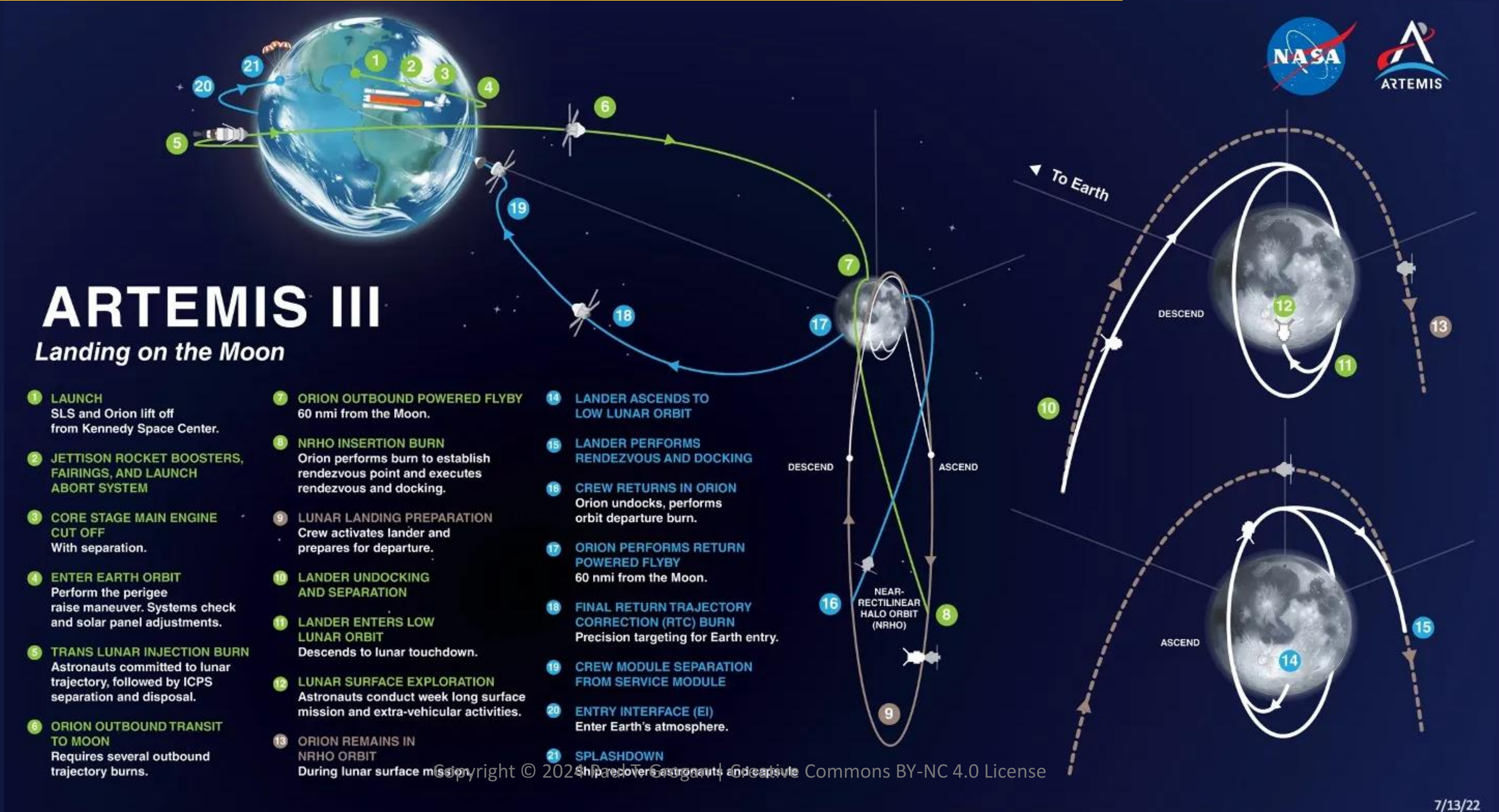
Static Network



Time-expanded Network



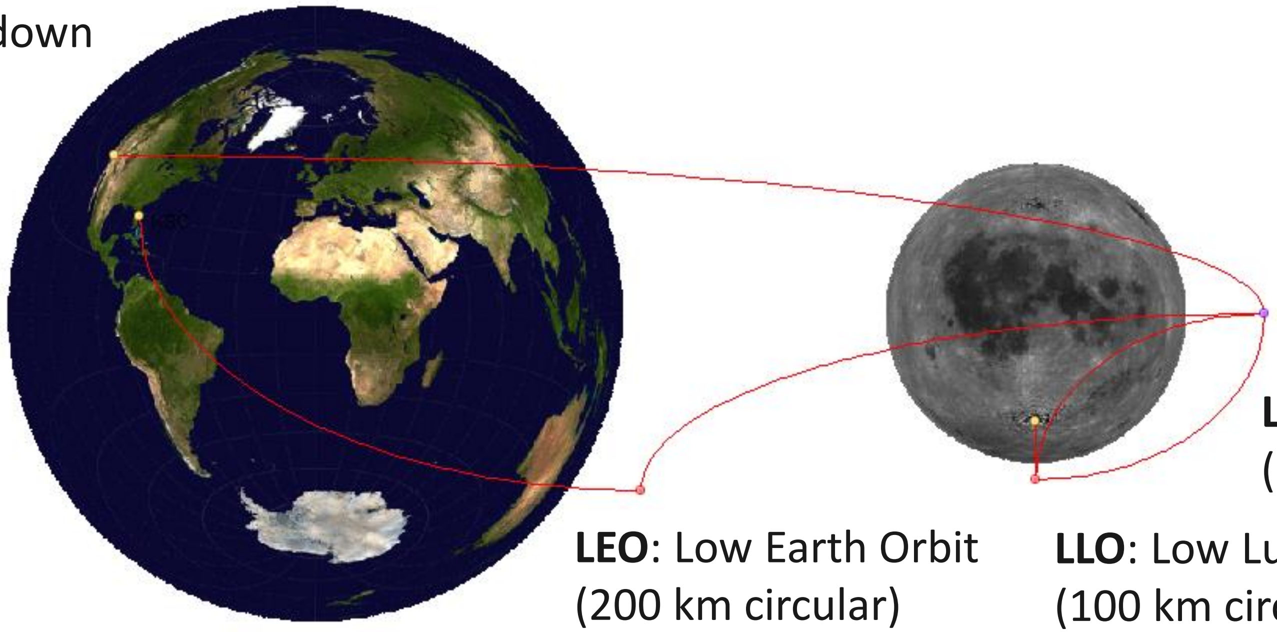
Quick Start Scenario 3: Artemis III



Artemis III Exploration Network

PAC: Pacific Ocean Splashdown
(35.0° N, 117.9° W)

KSC: Kennedy Space Center
(28.6° N, 80.6° W)



NRO: Near Rectilinear Halo Orbit (Earth-Moon L2)

LSP: Lunar South Pole
(89° S, 180° W)

LEO: Low Earth Orbit
(200 km circular)

LLO: Low Lunar Orbit
(100 km circular)

KSC-LEO: Earth Ascent

1. 0.0: 9500 m/s

LEO-NRO: Trans-Lunar Injection

1. 0.0: 3124 m/s
2. 0.3: 30 m/s
3. 3.1: 242 m/s
4. 4.4: 1 m/s
5. 6.4: 126 m/s

NRO-LLO: Low Lunar Orbit Transfer

1. 0.0: 20 m/s
2. 0.5: 648.6 m/s

LLO-LSP: Lunar Descent

1. 0.0: 19.4 m/s
2. 0.2: 1692.5 m/s

LSP-LLO: Lunar Ascent

1. 0.0: 1692.4 m/s
2. 0.2: 19.4 m/s

LLO-NRO: Halo Orbit Transfer

1. 0.0: 649.2 m/s
2. 0.5: 125.1 m/s

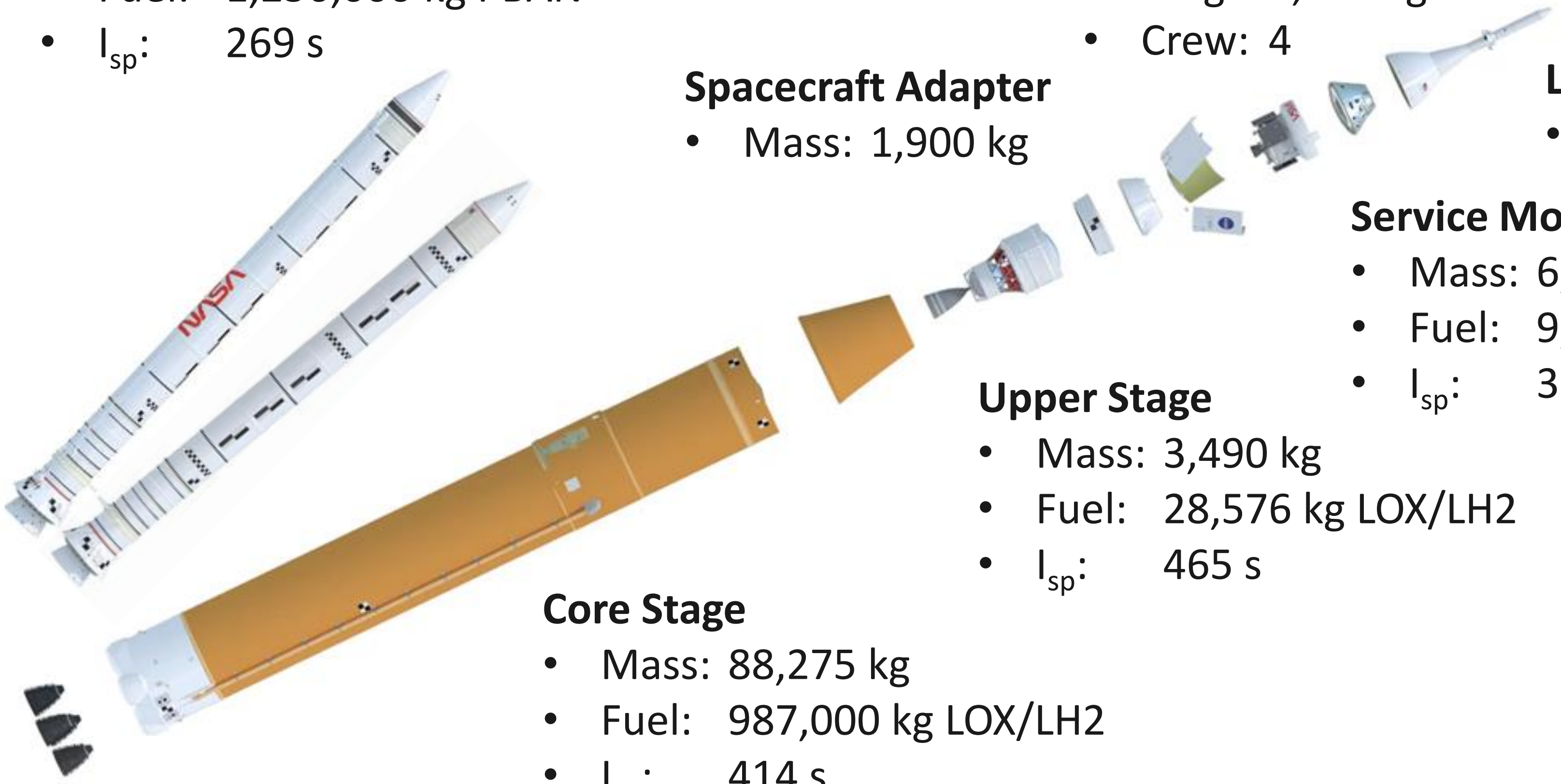
NRO-PAC: Earth Return

1. 0.0: 147 m/s
2. 1.6: 2 m/s
3. 2.8: 263 m/s

Artemis III Element Templates

Crew Member
- Mass: 100 kg

Lunar Samples
- Mass: 100 kg



Solid Rocket Boosters (2)
- Mass: 195,000 kg
- Fuel: 1,256,000 kg PBAN
- I_{sp}: 269 s

Crew Module
- Mass: 9,300 kg
- Cargo: 1,100 kg
- Crew: 4

Spacecraft Adapter
- Mass: 1,900 kg

Launch Abort System
- Mass: 7,250 kg

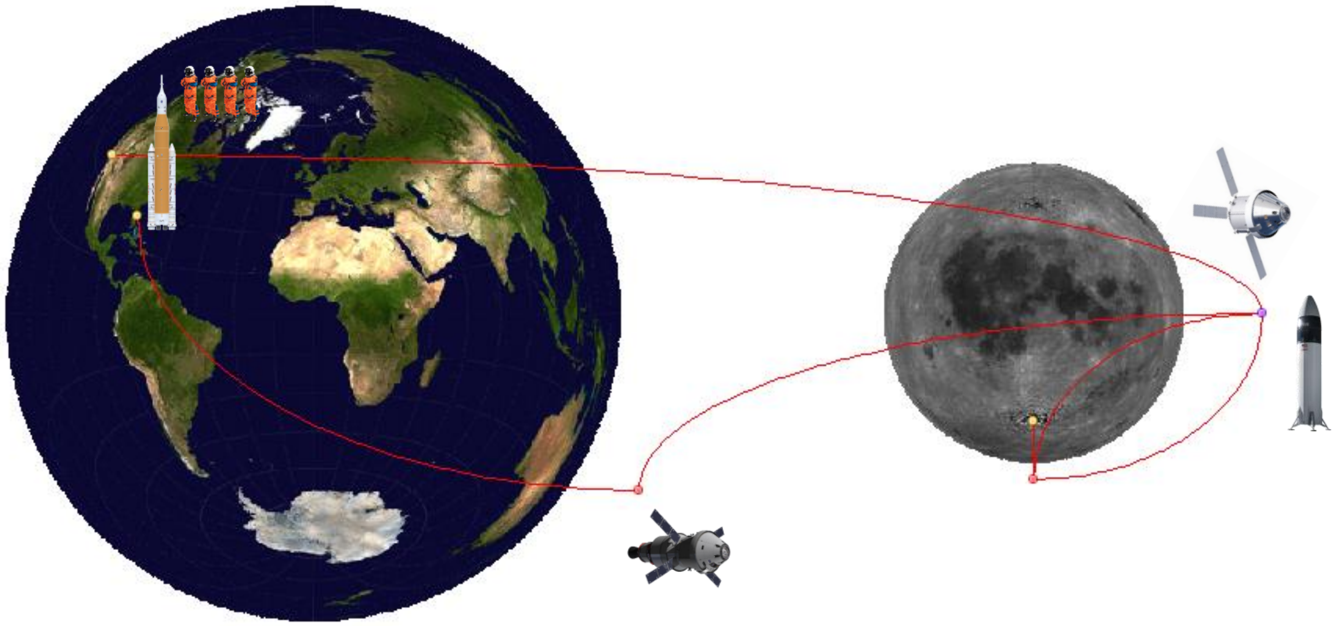
Service Module
- Mass: 6,185 kg
- Fuel: 9,276 kg N2O4/MMH
- I_{sp}: 316 s

Upper Stage
- Mass: 3,490 kg
- Fuel: 28,576 kg LOX/LH2
- I_{sp}: 465 s

Core Stage
- Mass: 88,275 kg
- Fuel: 987,000 kg LOX/LH2
- I_{sp}: 414 s

Human Landing System
- Mass: 8,149 kg
- Cargo: 900 kg
- Crew: 2
- Fuel: 32,285 kg LOX/LCH4
- I_{sp}: 363 s

Artemis III Mission Events



0.0 **Create HLS.1 at NRO**

0.0 **Create SRB.1, CS.1, US.1, SA.1, SM.1, CM.1, LAS.1 at KSC**

0.0 **Create C.1, C.2, C.3, C.4 in CM.1**

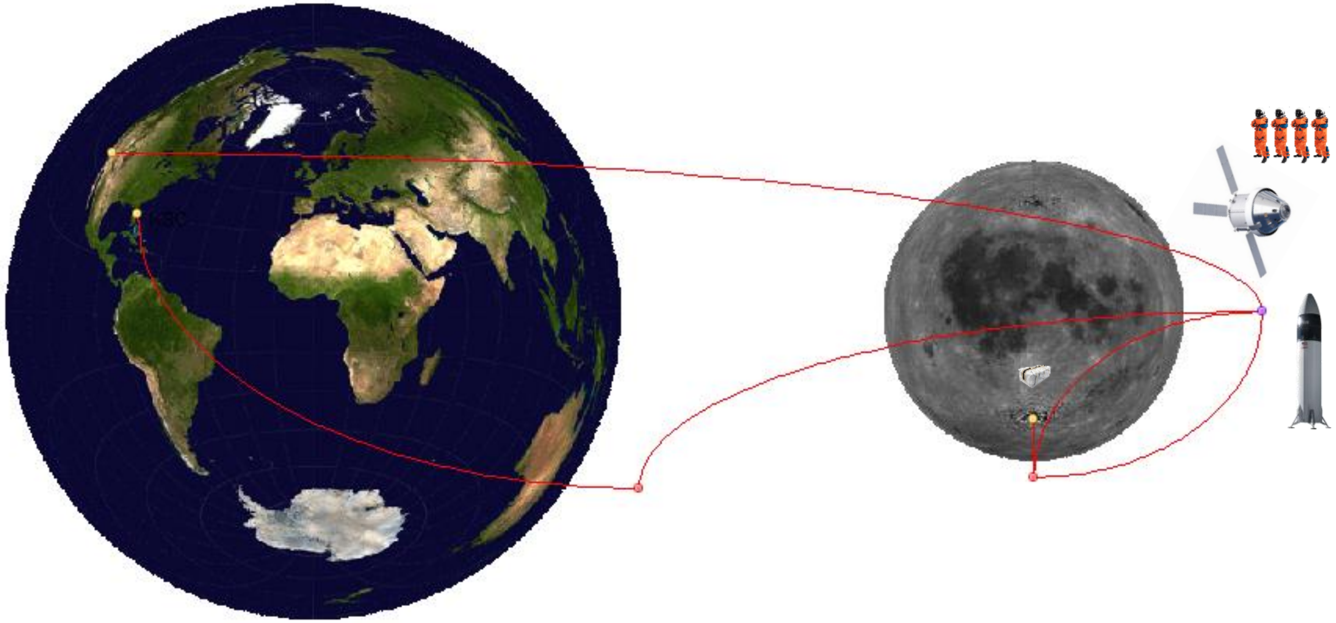
0.0 **Transport SRB.1, CS.1, US.1, SA.1, SM.1, CM.1, LAS.1 on KSC-LEO**

(1) Burn SRB.1, Stage SRB.1, Stage LAS.1, Burn CS.1, Stage CS.1, Stage SA.1

1.0 **Transport US.1, CM.1, SM.1 on LEO-NRO**

(1) Burn US.1, Stage US.1
(2) Burn SM.1
(3) Burn SM.1
(4) Burn SM.1
(5) Burn SM.1

Artemis III Mission Events



8.0 **Move C.1, C.2 to HLS.1**

9.0 **Transport HLS.1 on NRO-LLO**
- (1) Burn HLS.1
- (2) Burn HLS.1

10.0 **Transport HLS.1 on LLO-LSP**
- (1) Burn HLS.1
- (2) Burn HLS.1

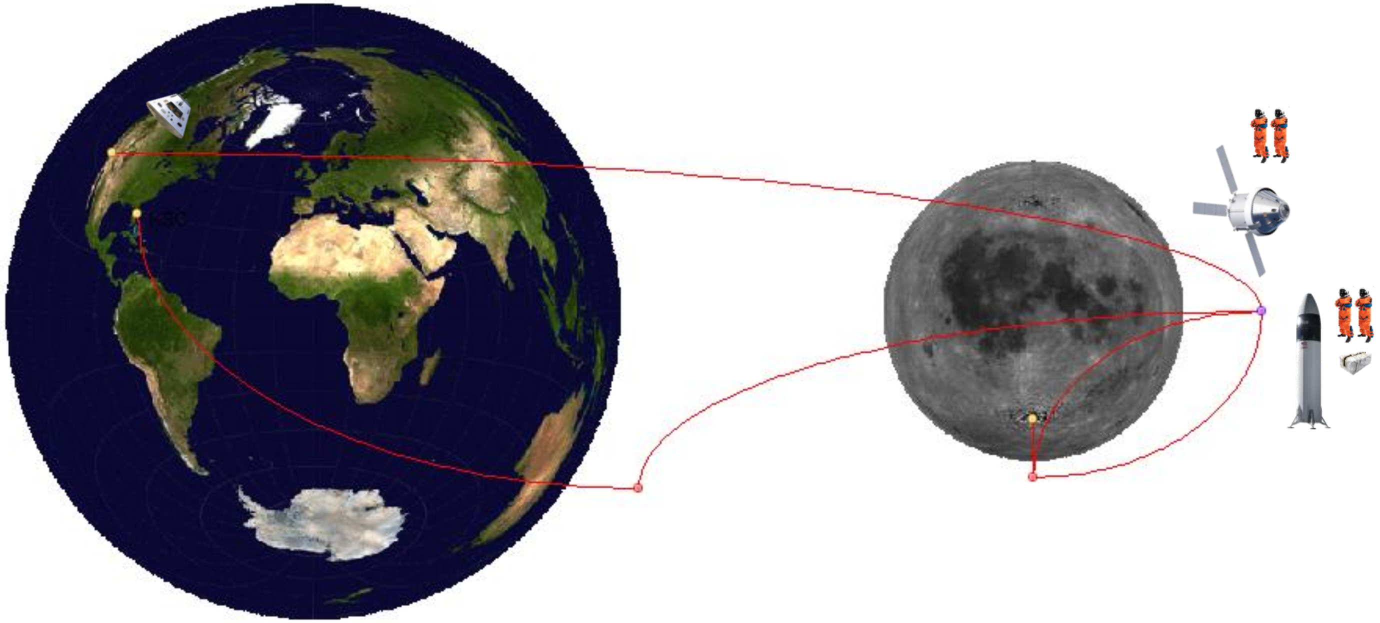
11.0 **Surface Exploration**

18.0 **Create S.1 in HLS.1**

18.0 **Transport HLS.1 on LSP-LLO**
- (1) Burn HLS.1
- (2) Burn HLS.1

19.0 **Transport HLS.1 on LLO-NRO**
- (1) Burn HLS.1
- (2) Burn HLS.1

Artemis III Mission Events



20.0 **Move C.1, C.2, S.1 to CM.1**

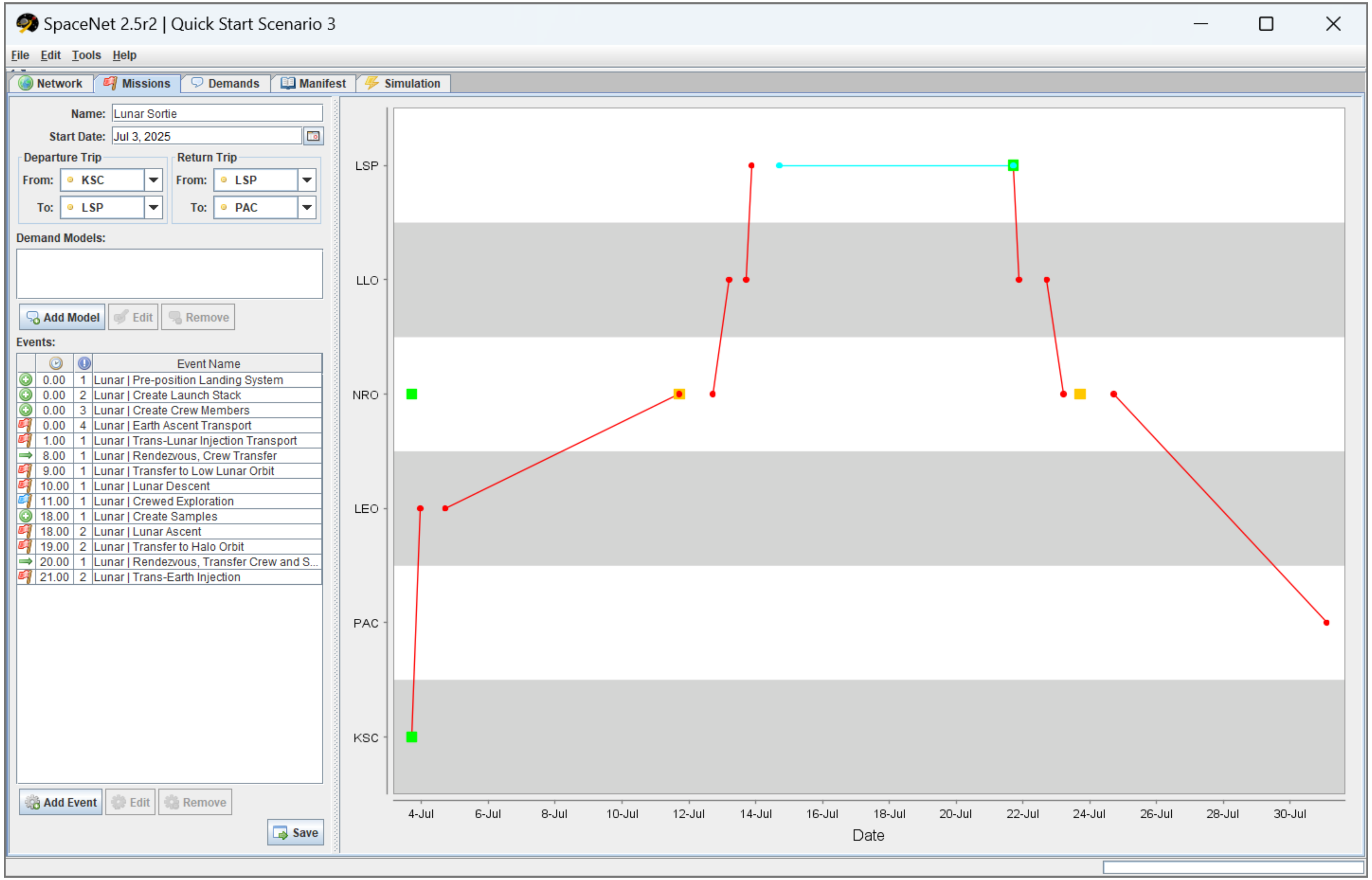
21.0 **Transport CM.1, SM.1 on NRO-PAC**

(1) Burn SM.1

(2) Burn SM.1

(3) Burn SM.1, Stage SM.1

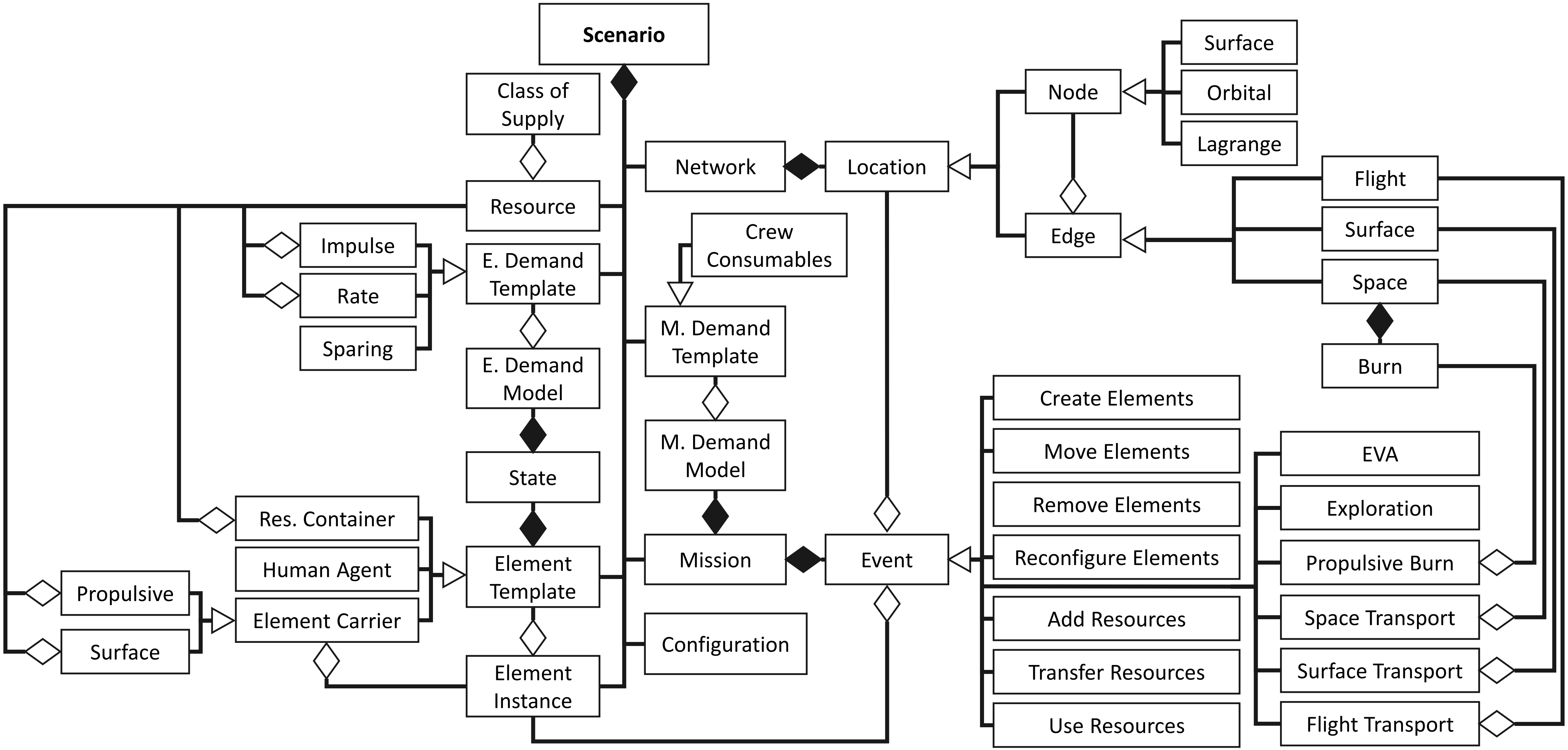
Artemis III Time-Expanded Network



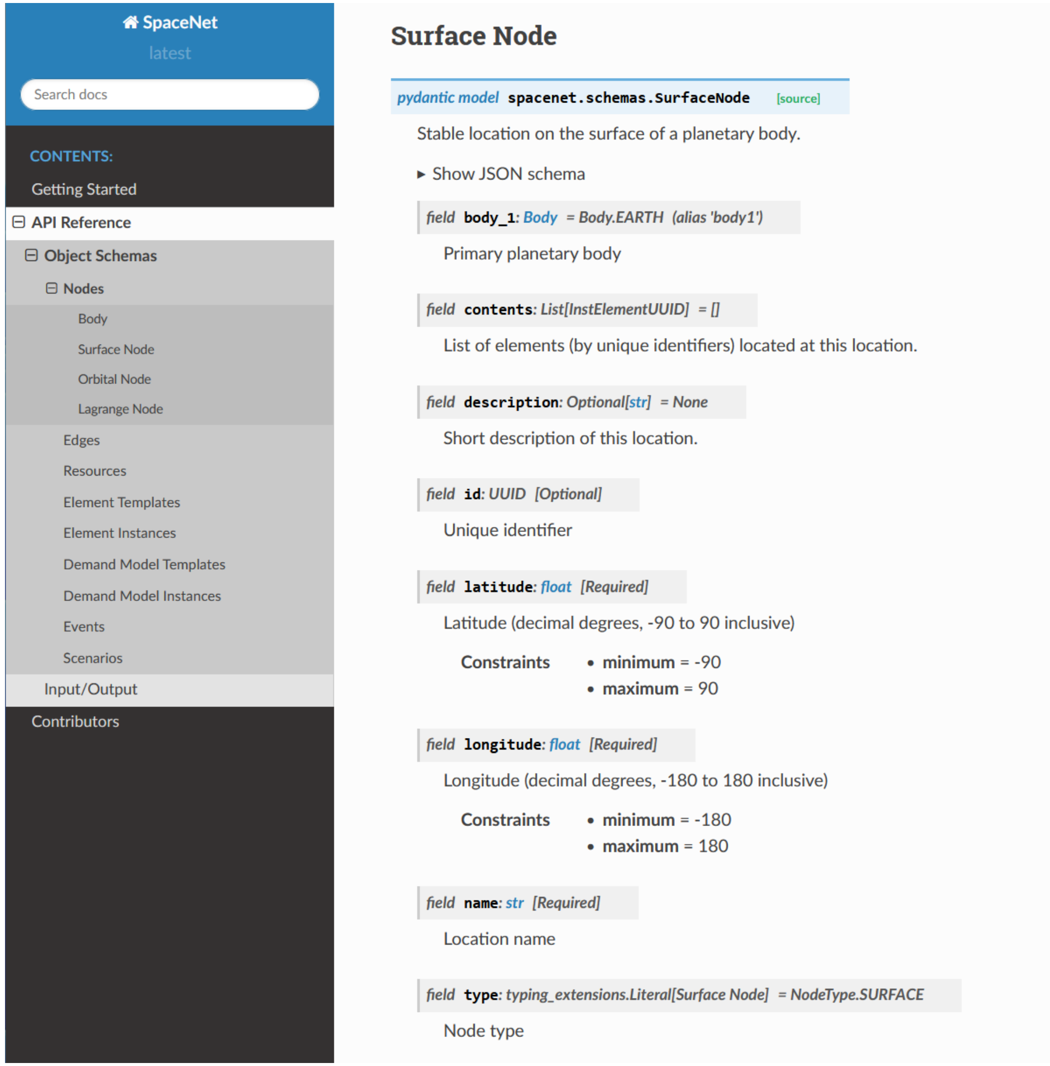
Propulsive Feasibility Analysis

Element	Initial Fuel (kg)	Final Fuel (kg)	Margin (%)
SRBs	1,256,000	0	0.0
Core Stage	987,000	20,807	2.1
Upper Stage	28,576	201	0.7
Landing System	32,285	1,656	5.1
Service Module	9,276	3,472	37.4

Scenario Object-Class Diagram (Simplified)



SpaceNet Object Schemas API



- SpaceNet “Cloud” code base:
  - https://github.com/space-logistics-org/spacenet
- Sphinx-based source code auto-documentation
- Published to ReadTheDocs:
  - https://spacenet.readthedocs.io/

Pydantic Models and JSON Schema

- Transition to JSON serialization over the past 2 years:
  - Pydanic models for each class
  - Exportable to JSON Schema

```
class SurfaceNode(Node):
    type: Literal[NodeType.SURFACE] = Field(
        NodeType.SURFACE,
        title="Type",
        description="Node type",
    )
    latitude: float = Field(
        ...,
        title="Latitude",
        description="Latitude (decimal degrees, -90 to 90 inclusive)",
        ge=-90,
        le=90,
    )
    longitude: float = Field(
        ...,
        title="Longitude",
        description="Longitude (decimal degrees, -180 to 180 inclusive)",
        ge=-180,
        le=180,
    )
```

- Programmatic scenario construction:

```
from spacenet import schemas

ksc = schemas.SurfaceNode(
    name="KSC",
    description="Kennedy Space Center",
    body1="Earth",
    latitude=28.6,
    longitude=-80.6,
)
leo = schemas.OrbitalNode(
    name="LEO",
    description="Low Earth Orbit",
    body1="Earth",
    inclination=28.5,
    periapsis=296.0,
    apoapsis=296.0,
)
ksc_leo = schemas.SpaceEdge(
    name="KSC-LEO",
    description="Earth Ascent",
    origin=ksc.id,
    destination=leo.id,
    duration=timedelta(hours=6),
    burns=[schemas.Burn(time=timedelta(0), delta_v=9500.0)],
)
```

JSON-serialized Scenario


```json
{
  "name": "Quick Start Scenario 3",
  "startDate": "2025-07-04T00:00:00+00:00",
  "scenarioType": "Lunar",
  "network": {
    "nodes": [
      {
        "id": "8dcb20f6-2d80-40c4-8a0b-571b768d7b7f",
        "name": "KSC",
        "description": "Kennedy Space Center",
        "contents": [],
        "type": "Surface Node",
        "body1": "Earth",
        "latitude": 28.6,
        "longitude": -80.6
      },
      {
        "id": "5117e973-31ca-4b6c-955e-62012b8f4b59",
        "name": "LEO",
        "description": "Low Earth Orbit",
        "contents": [],
        "type": "Orbital Node",
        "body1": "Earth",
        "apoapsis": 296.0,
        "periapsis": 296.0,
        "inclination": 28.5
      },
```

```json
    "edges": [
      {
        "id": "cfe856f2-c6a7-494b-aac8-7da95b920b0f",
        "name": "KSC-LEO",
        "description": "Earth Ascent",
        "contents": [],
        "type": "Space Edge",
        "origin": "8dcb20f6-2d80-40c4-8a0b-571b768d7b7f",
        "destination": "5117e973-31ca-4b6c-955e-62012b8f4b59",
        "duration": 21600.0,
        "burns": [
          {
            "id": "4db34826-c49a-4308-a2c7-d6410a743414",
            "time": 0.0,
            "deltaV": 9500.0
          }
        ]
      },
```

Current Development Work

- Transition SpaceNet Java analysis functions to SpaceNet Cloud:
  - Decompose monolithic application into discrete analysis services
  - Create well-defined input and output interfaces (JSON)
  - Host services on cloud/distributed computation platforms
- Create scenario for baseline Artemis Program campaign
  - Probe inconsistencies across multiple missions over 10+ year campaign
  - Evaluate propulsive and logistical feasibility
  - Evaluate logistics strategies such as pre-positioning, ISRU, depots, etc.

Questions and Answers

- Paul Grogan, paul.grogan@asu.edu

- Open-source software repositories:
  - SpaceNet Java: github.com/space-logistics-org/spacenet-java
  - SpaceNet “Cloud”: github.com/space-logistics-org/spacenet