SpaceOPS 2018

Marseille, France

May 28 – June 1, 2018

Europa Lander Concept: High fidelity system modeling informing flight system and concept of operations years before launch

Steven Wissler

Chief Engineer

Mission Systems and Operations Division

Jet Propulsion Laboratory

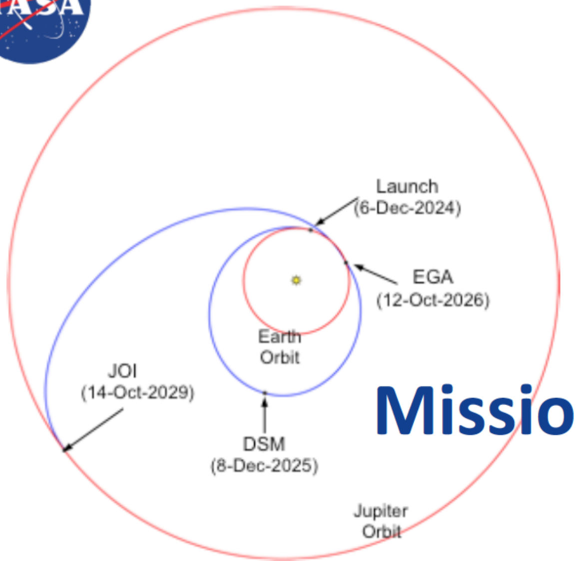
California Institute of Technology

Co-Authors (JPL)

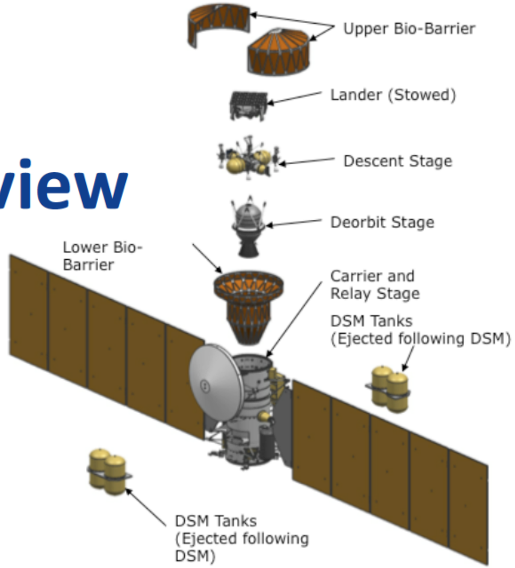
- Christopher Lawler
- Tejas Kulkarni
- Miles Smith
- Eric Ferguson
- Pierre Maldague

Mission Concept Overview

- Proposal to land a battery operated spacecraft on the surface of Jupiter’s moon Europa.
- Asses the habitability and search for life.
- Characterize the surface and sub-surface properties.
- Original concept had a carrier/relay spacecraft.
- 20 day prime mission on the surface of Europa.
- Collect and analyze 5 surface samples.



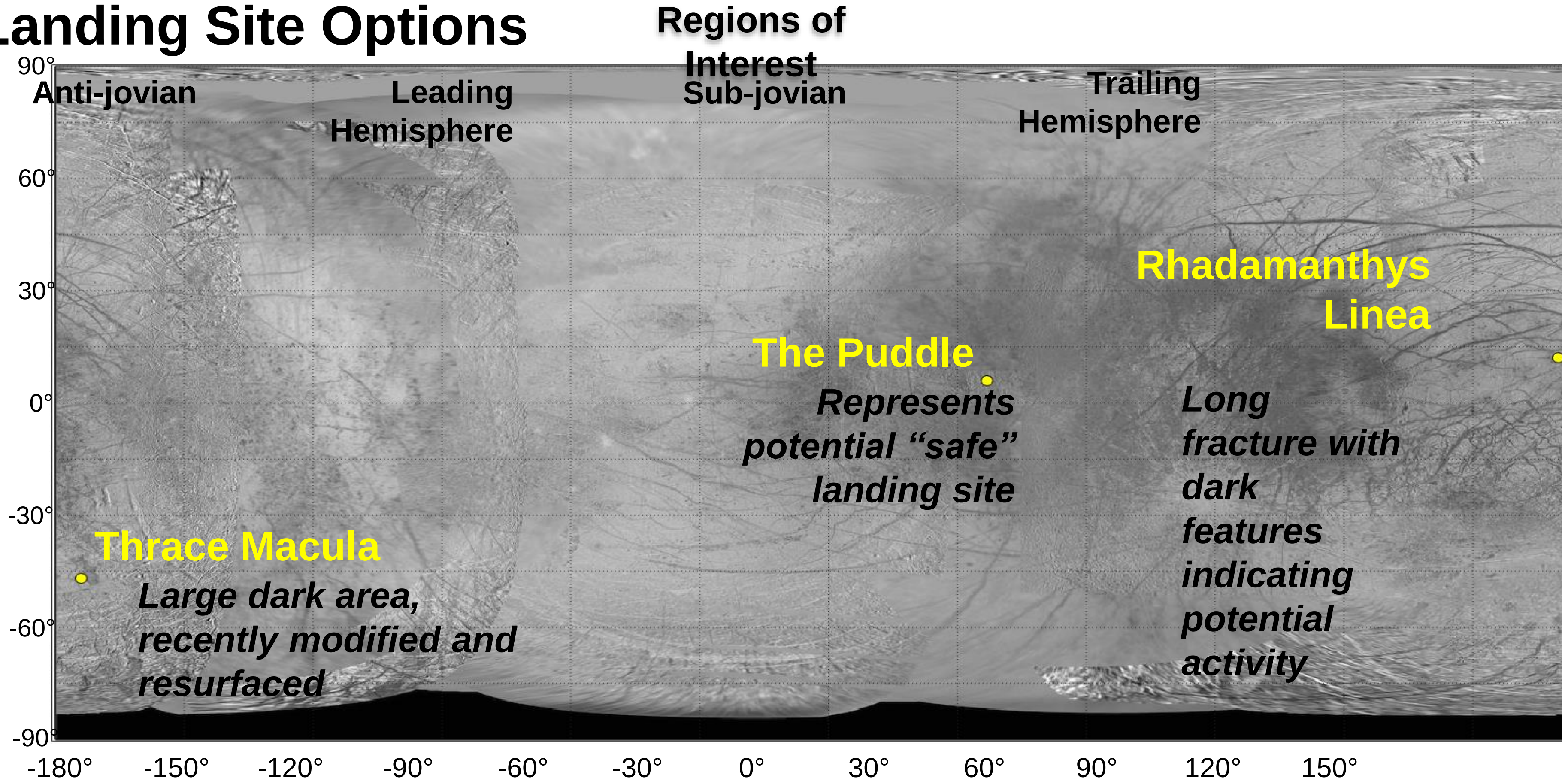
Mission Concept Overview



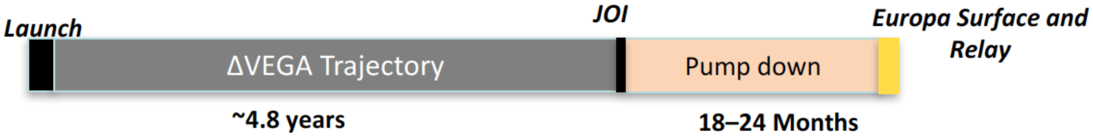
Landing Site and Relay Orbit Options

- 3 different landing sites
  - Rhadymanthus (12N, 170E)
  - Thrace (47S, 186E)
  - Puddle (6N, 37E)
- 2 different relay orbits
  - Groomed dog – elliptical 2-body orbit
  - Ball of yarn – 3-body orbit

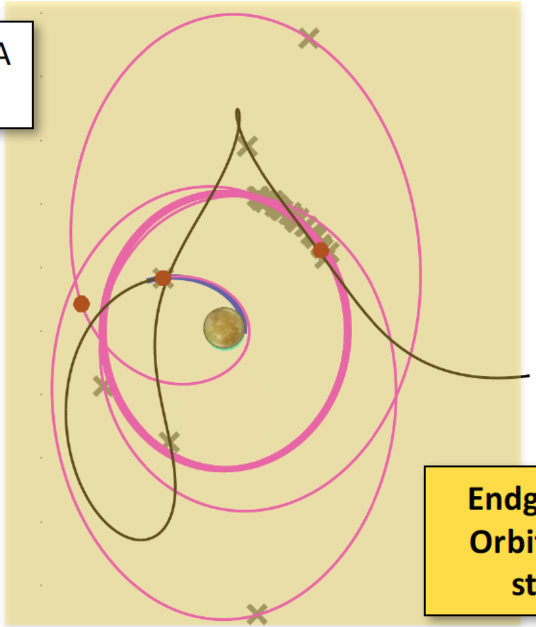
Landing Site Options

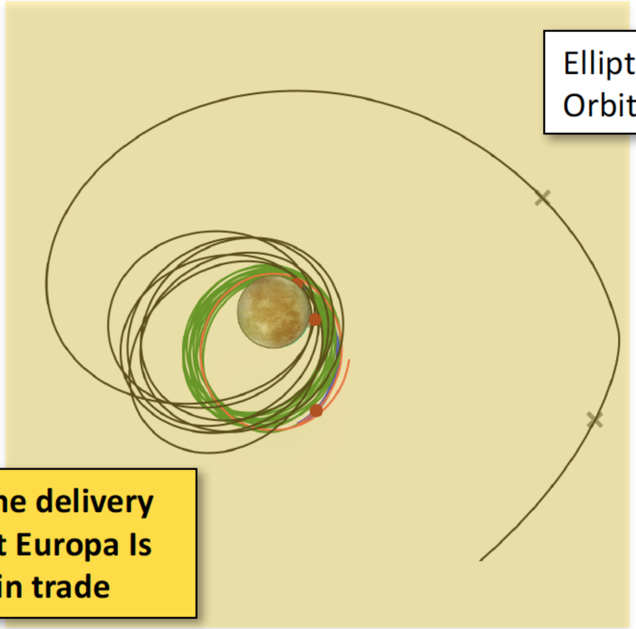


Relay Orbit Options



3-Body Orbit AKA Groomed Dog

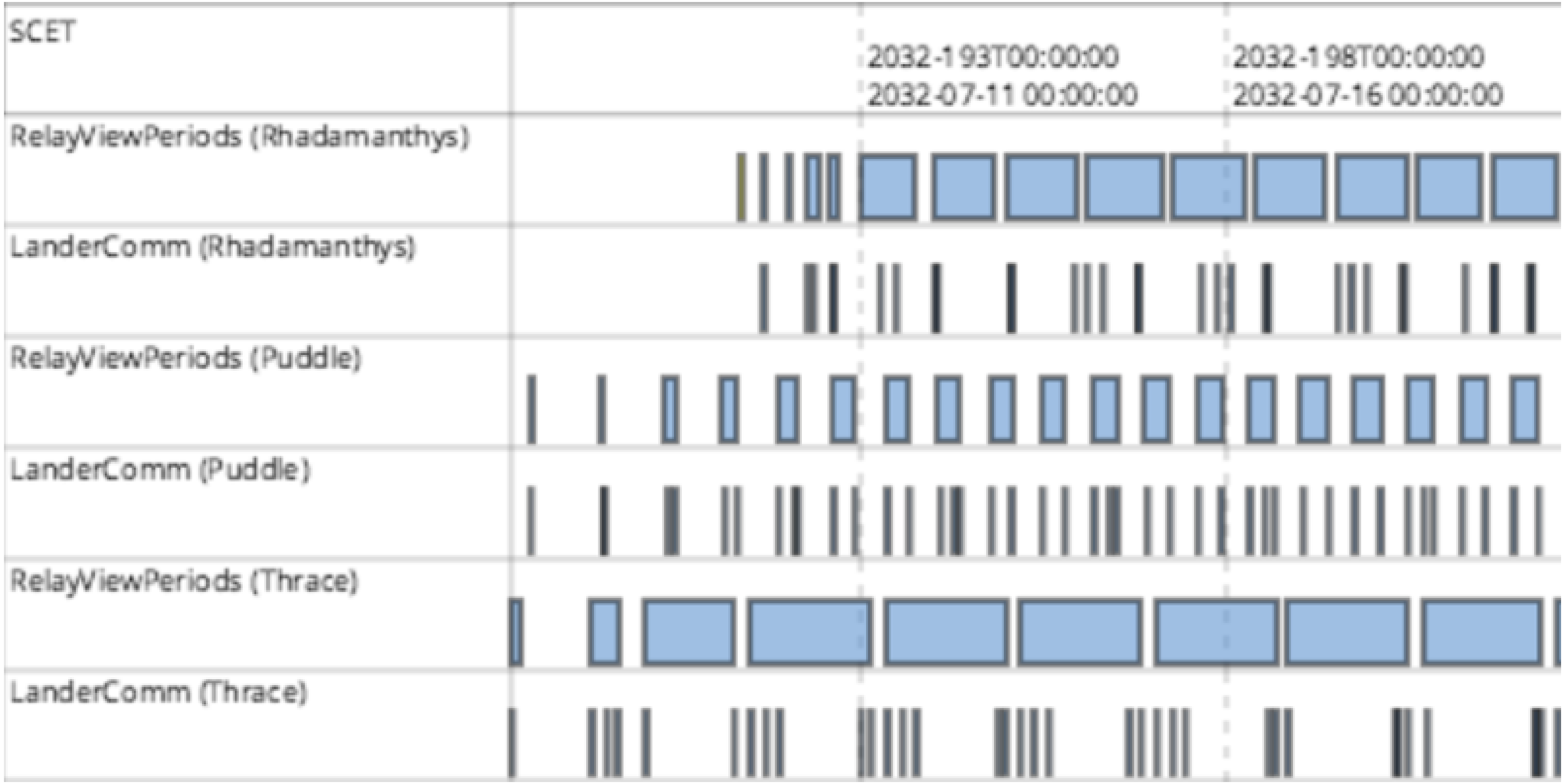




Elliptical (2-Body) Orbit for Delivery

Endgame delivery Orbit at Europa Is still in trade

Relay Opportunity Geometry for Different Landing Sites



Operations Concept Development

- Needed to develop, analyze and validate end to end operations concept, including ground in the loop tactical science planning.
- Lander separation and landing.
  - Orbiter observability of landing and initial post-landing activities.
  - Power analysis for carrier during separation and descent monitoring.
- Lander surface deployments, science and engineering operations.
  - Interaction between timing of overflights for commanding and data return
  - Deployment and science activities

Operations Concept Development

- Carrier relay operations.
  - Multiple contacts per overflight, timing and duration of slews, lander commanding and data return.
- End to end uplink and downlink data flows.
  - Lander to carrier link, carrier on-board store and forward.
  - Decisional engineering and science data latencies.
  - Command uplink to carrier and relay to lander.
- Ground science and engineering tactical processes.
  - Timing margins on turning daily data products around for generation/uplink of next science and engineering operations

Trade Studies

- Determined the impact of losing the HGA and having to perform the Lander-Carrier relay on the LGA.
  - Apgen already computed the position of the Carrier with respect to the lander and it's position in the LGA pattern and was able to calculate the impact on data return.
- Landing Site and Relay Orbits
  - Simulation highly parameterized making it easy to swap out landing sites and relay trajectories, to understand the impact on data volume and sampling margin.

Simulation Heritage

- Apgen (Activity Plan Generator) currently in use for Europa-Clipper project
- CRS (Carrier Relay Spacecraft) shared much of Clipper design
- Many Apgen adaptations are based on multi-mission models who’s heritage traces back to Mars Polar Lander and continuing with Mars Odyssey, Deep Impact/EPOXI, Phoenix, Mars Exploration Rovers, Mars Science Laboratory, JUNO, Insight and Europa Clipper.
- Models are parameterized and easily updated to a new mission.

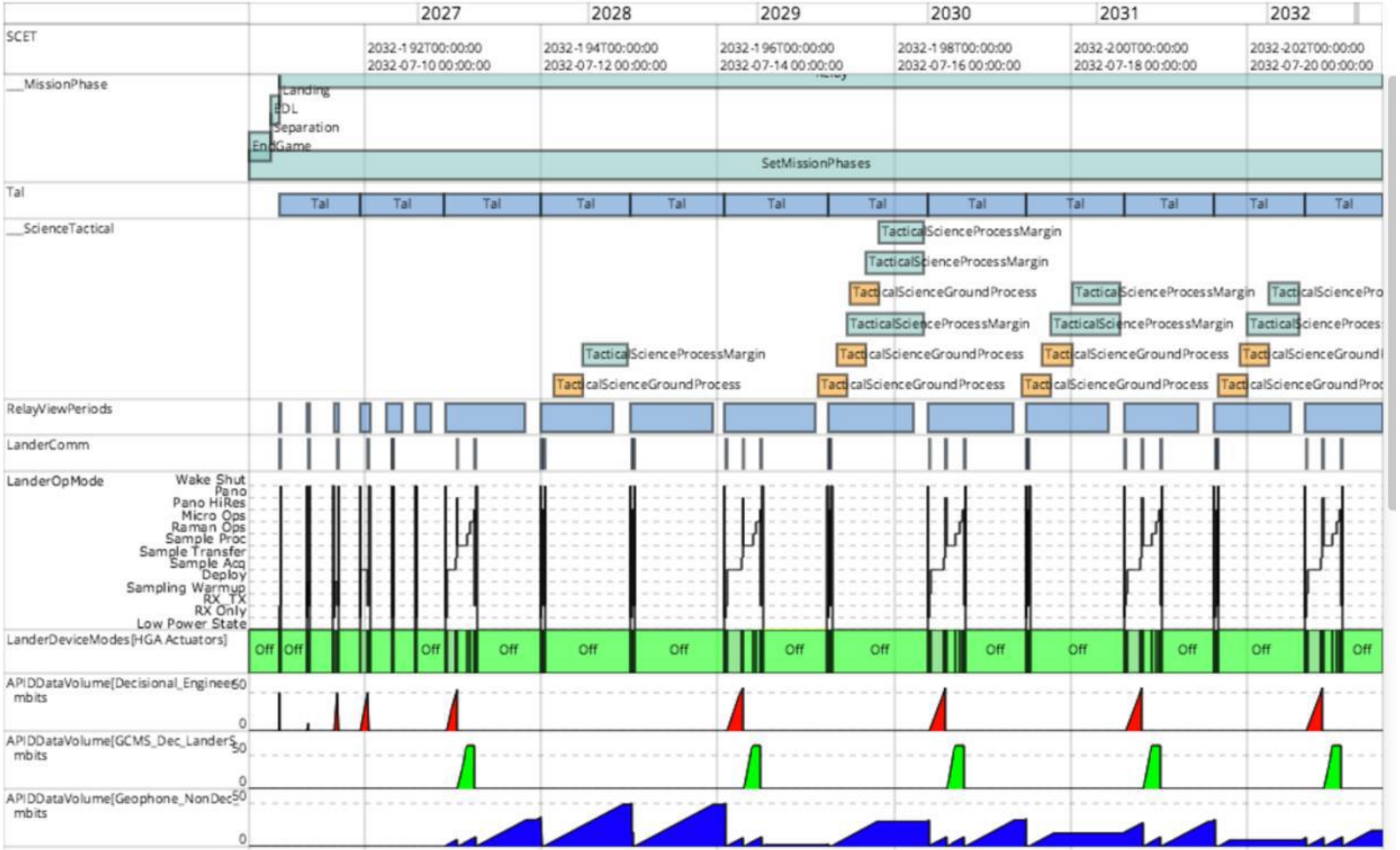
Apgen Key Characteristics

- Multi-mission core software
  - Activity and resource timeline display
  - Activity editing
  - State and resource modeling engine
- Project customization
  - Text files “Adaptation” for specifications of
    - Spacecraft activities and commands
    - Deep Space network activities
    - Mission Operations Process activities
    - State and resource models
    - Flight and mission rules
  - User-defined function Interface
    - Allows for interface to external model libraries

Europa Lander Simulation Models

Order	Name	Description
1	Geometry model	Takes as input Carrier ephemeris then uses SPICE to calculate timing of Periapses, Apoapses, Occultations, and Eclipses of Europa and Jupiter. Saves all information as activities.
2	TCM model	Takes as input TCM times for the given trajectory and places TCM activities. Simulates Carrier attitudes leading up to and during the manuevers and saves out attitude resource history.
3	View periods simulation	Takes as input Carrier ephemeris then uses SPICE to calculate when Carrier is in view of DSN stations. Writes DSN .VP view period file.
4	Allocations scheduler	Takes as input .VP file, geometric resources, and Carrier attitudes, and writes DSN .SAF allocations file.
5	Lander activities scheduler	Takes as input Carrier ephemeris and windows of Carrier unavailability due to TCMs and schedules sample cycles according to a deterministic algorithm. Forward link is initiated when the Carrier is available, sampling and analysis are performed, then downlink to Earth is initiated when the Carrier is next in view after processing.
6	Lander resource simulation	The Lander activities placed by the scheduler change the state of the Lander, and those state changes affect power use and data rates. The remodel integrates those to generate resource histories of their integrals and other Lander resources.
7	Carrier activities and ground cycle scheduler	Now that the Lander has determined the relay periods, the Carrier scheduler can calculate its attitude for the entire mission, and decide when to downlink to Earth and when commands need to be uplinked. From these times, the length of science and engineering ground cycles can be calculated and are saved as activities.
8	Carrier resource simulation	Finally, the accumulation of all activities placed by previous schedulers are simulated, which calculates how hundreds of different resources on both spacecraft evolve over time.

RAVEN Timeline Display



Cosmographia Movie of Simulation

Experience and Results

- Initial simulations were up and running in a matter of days and refined over a few weeks.
- Replaced assumptions and simplifications with simulated behaviors.
    - It was assumed that the CRS would always be overhead during operations and that a ground-in-the loop cycle would have the same period as the CRS orbit. These assumptions had to be rethought when they turned out not to be flexible enough to accommodate a wider range of scenarios.
- Having the ability to simulate the operations concept, resulted in quick understanding of flaws and strengths in the concept, which led to rapid evolution of the operations concept.

Experience and Results

- Simulations showed original concept of relay orbiter slewing back and forth multiple times per overflight, based on the Clipper reaction wheel design was not possible. This led to a requirement for larger reaction wheels.
- Especially valuable in Lander simulations was the flexibility to explore different landing sites and characterize different relay trajectories.
- APGen results provided a great way to incorporate non-intuitive constraints into the planning process. Conflicts between subsystems or geometric constraints, such as TCMs being needed during relay or Jupiter occultations of Earth, that resulted in uncaught CRS relay unavailability were discovered and resolved in a matter of hours.

Experience and Results

- The MCR board seemed to appreciate the level of detail that APGen simulation helped bring to scenarios, stating “The team is technically strong and this work is at significantly higher fidelity than is generally anticipated for a Pre-Phase A study.”
- Post-MCR, due to mission cost constraints, the pre-project is exploring putting more emphasis on Direct-to-Earth (DTE) and the Clipper for relay as a backup, as well as using less Clipper heritage on the Carrier stage.