Guidance and Control Techniques for Titan Aerogravity Assist for Enceladus Observation

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Introduction

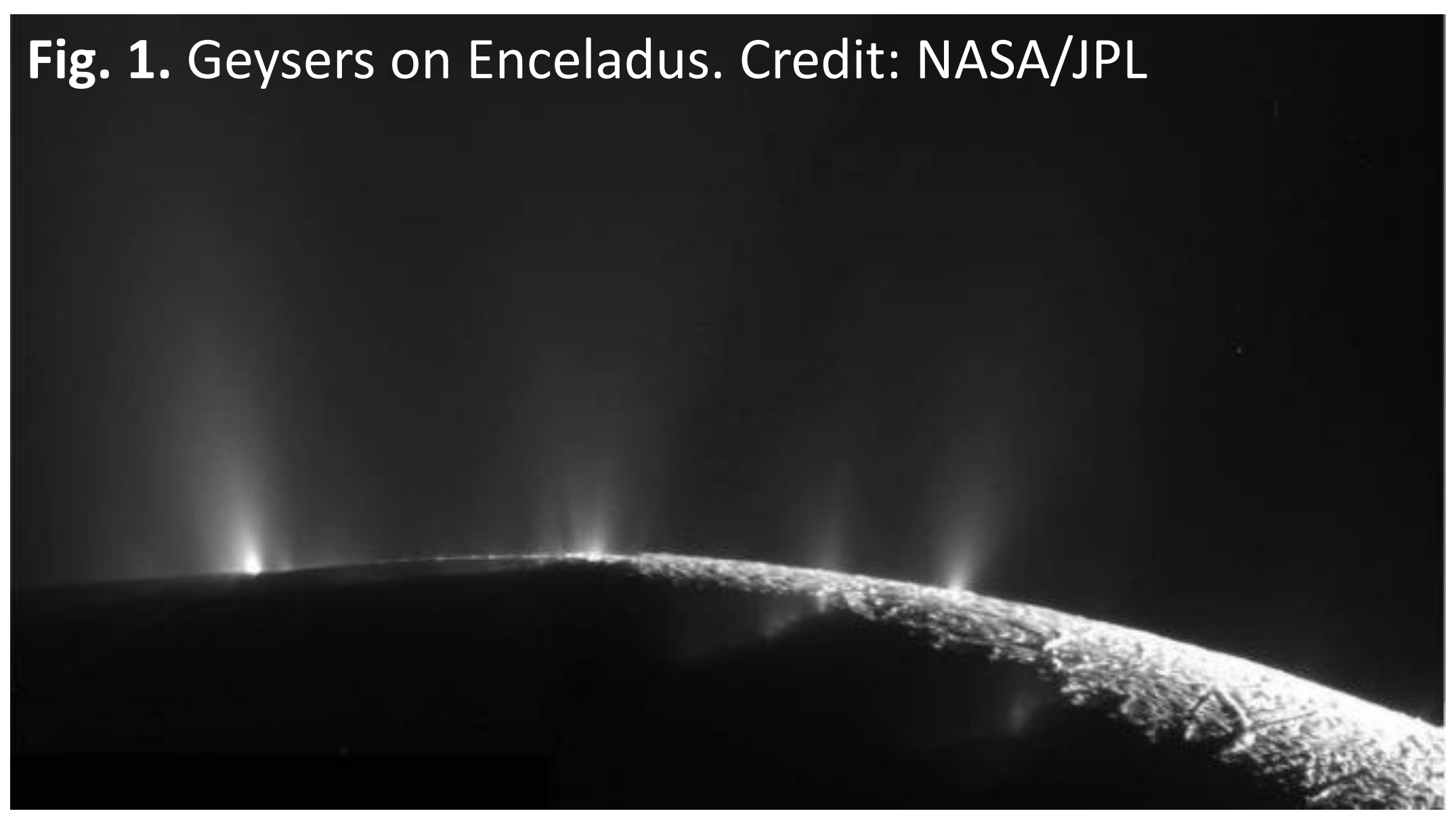
Fig. 1. Geysers on Enceladus. Credit: NASA/JPL

Enceladus is a prime scientific target due to active geological features and evidence of liquid water. The plumes (Fig. 1) from its rifts were sampled by the Cassini mission, which detected carbon, hydrogen, oxygen, and nitrogen– key signatures of potential life [1]. Mission design using traditional fully-propulsive orbit insertion maneuvers is expensive and time consuming. A prior study has ruled traditional chemical and solar electric propulsion-based missions infeasible [1]. An enabling alternative is Titan aerogravity assist [1-4].

Vehicle Design

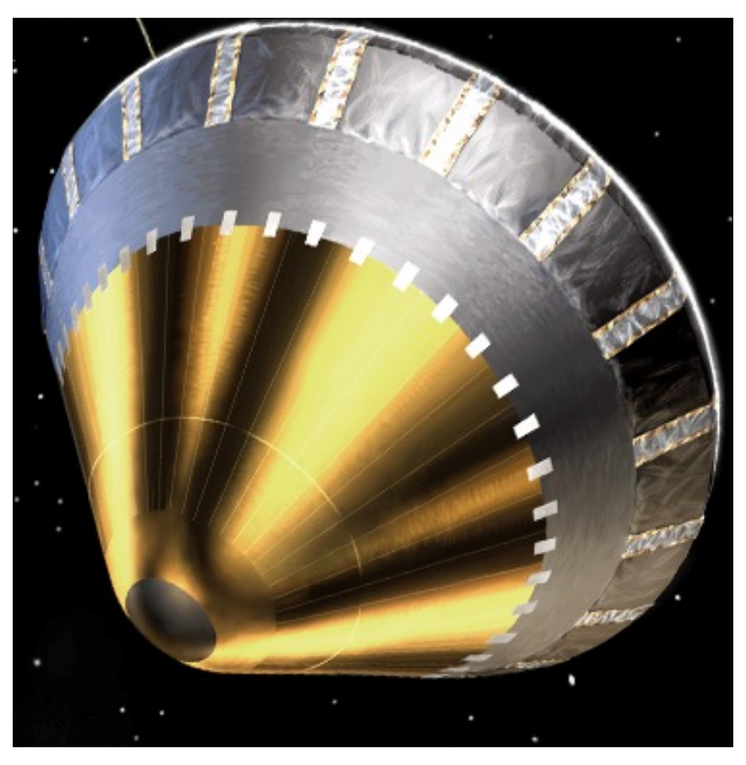
Fig. 4a. 45-deg. sphere-cone – Galileo. Credit: NASA

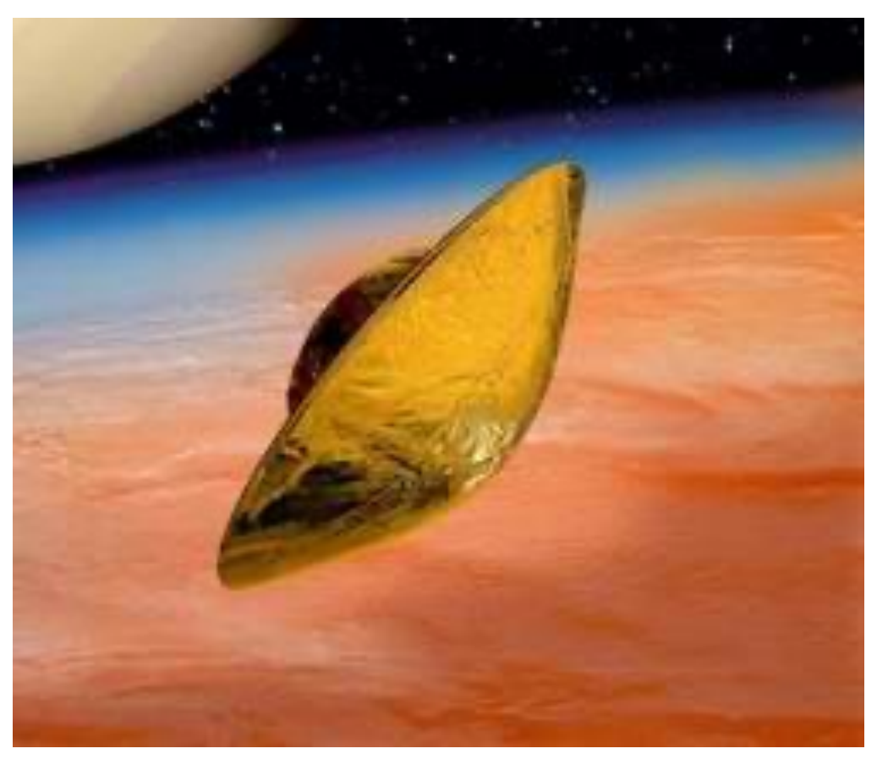
Fig. 4b. 60-deg. sphere-cone – Huygens. Credit: ESA


Fig. 4c. 70-deg. sphere-cone – Mars Science Lab. Credit: NASA

Blunt bodies (Fig. 4) were considered for Titan aerogravity assist. To stress the guidance and control mechanisms, 70-deg. sphere-cone was used, as it produces lower L/D than the 45 and 60 deg. sphere-cone shapes at equivalent angles of attack.

Guidance and Control Strategy

Guidance Scheme

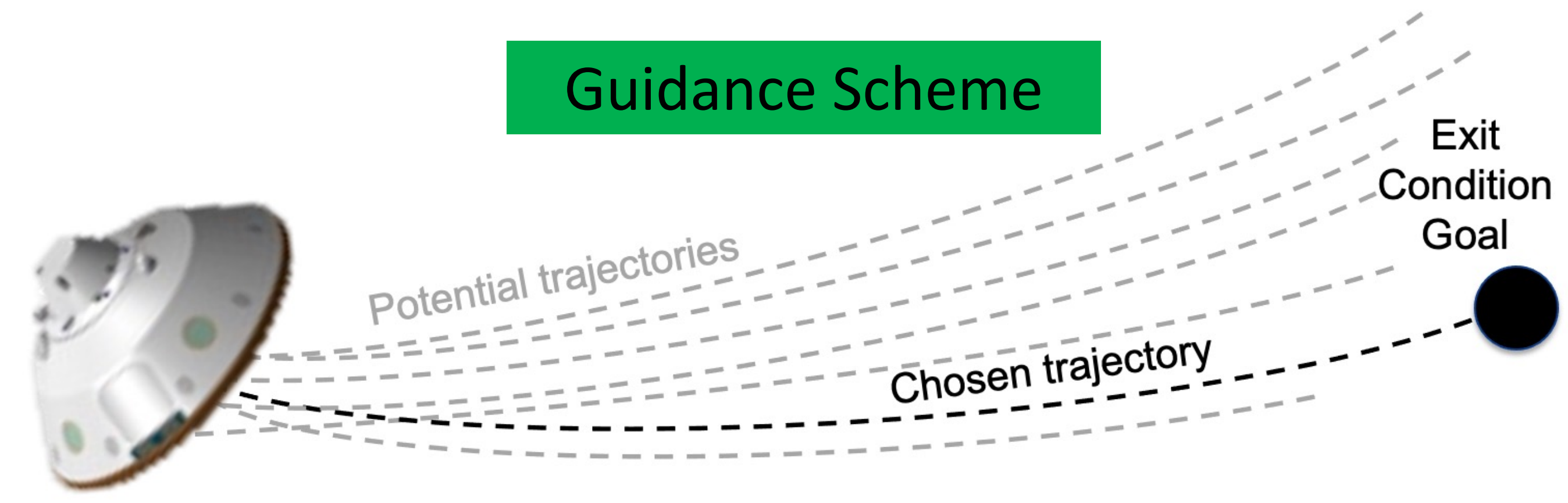

Fig. 5. Notional example of a **numerical predictor corrector (NPC)** guidance that propagates trajectories on-board to select the guidance commands that best achieves the exit goals.

Control Strategy

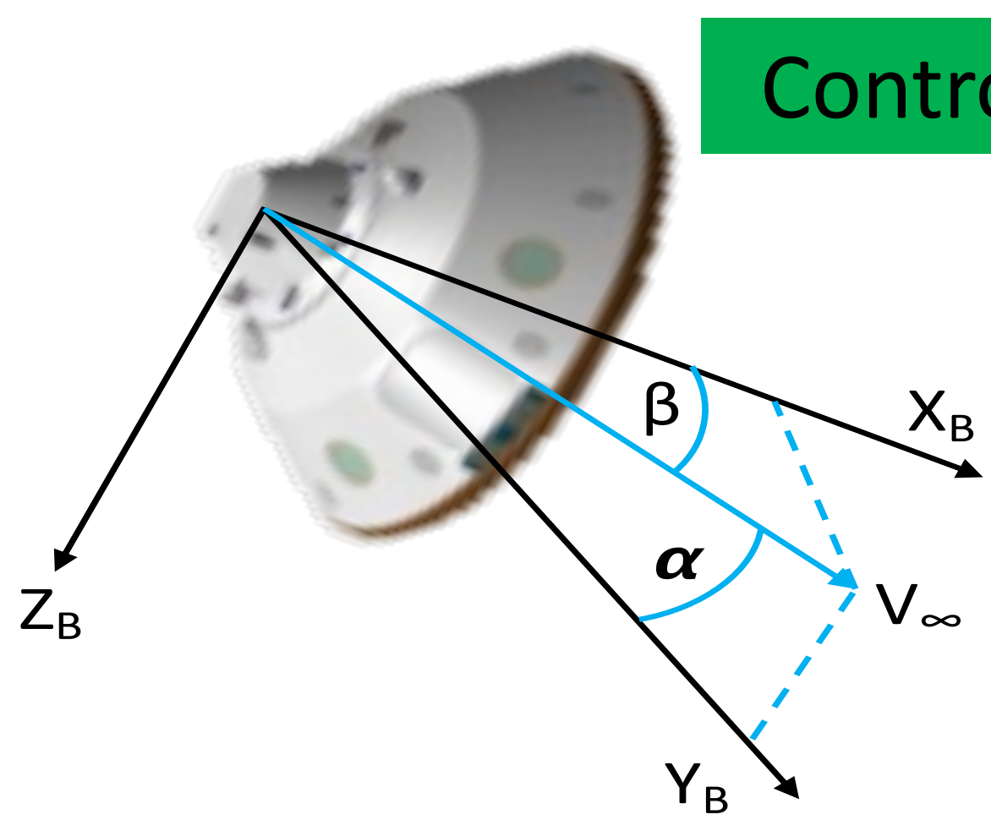

Fig. 6a. **Direct force control (DFC)** independently controls angle of attack (**α**) and sideslip (β).

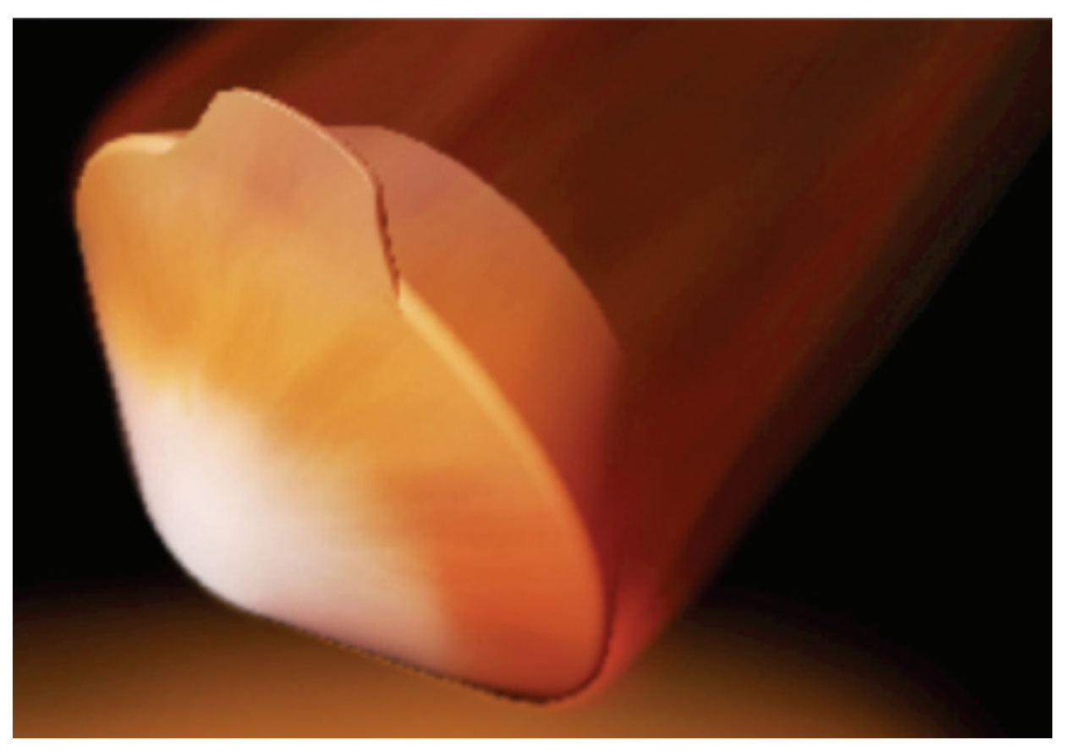
Fig. 6b. Example of a direct force control mechanism – trim tab. Credit: NASA.

Performance Statistics

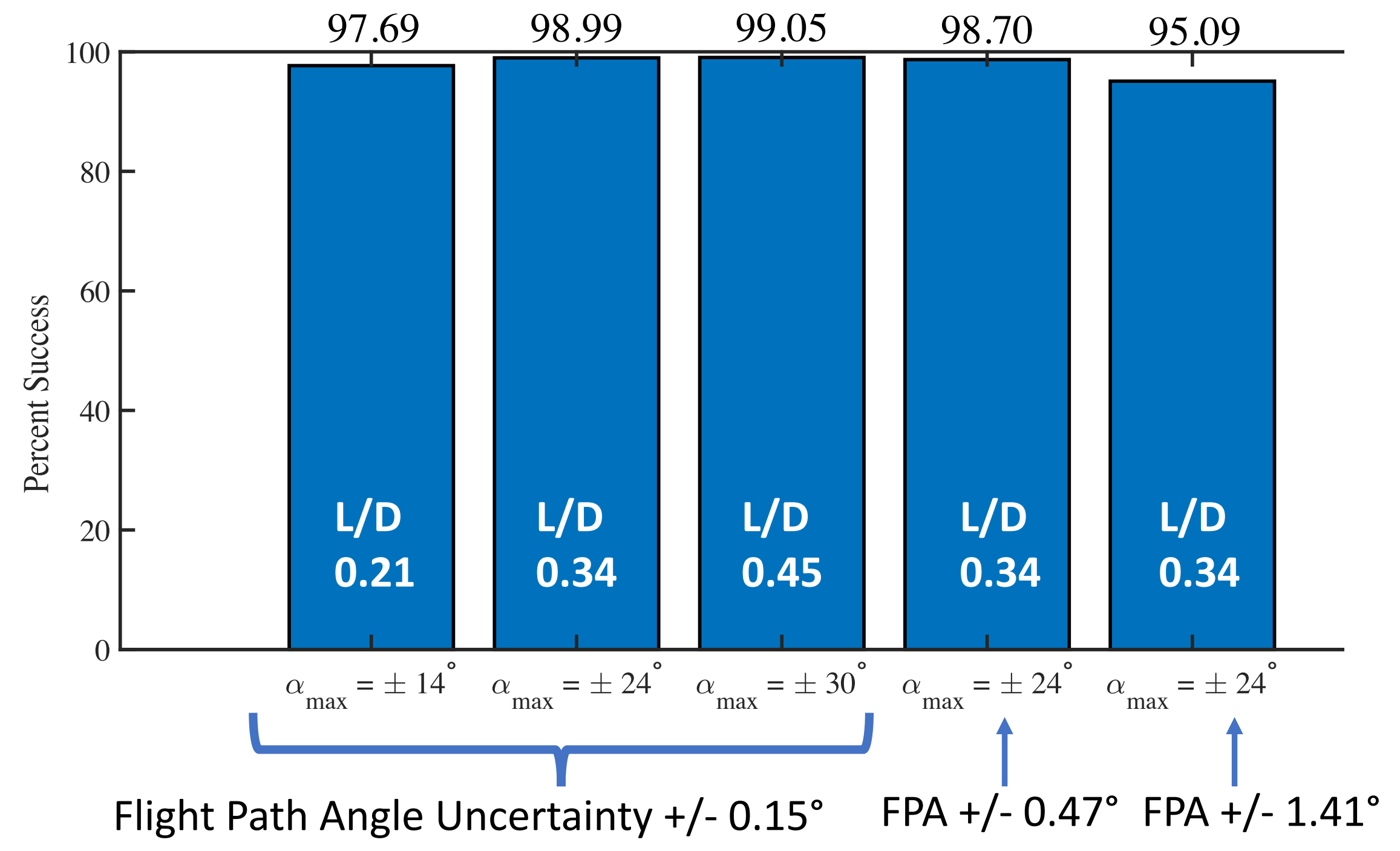

Fig. 8. Percent of cases with successful aerogravity assist.

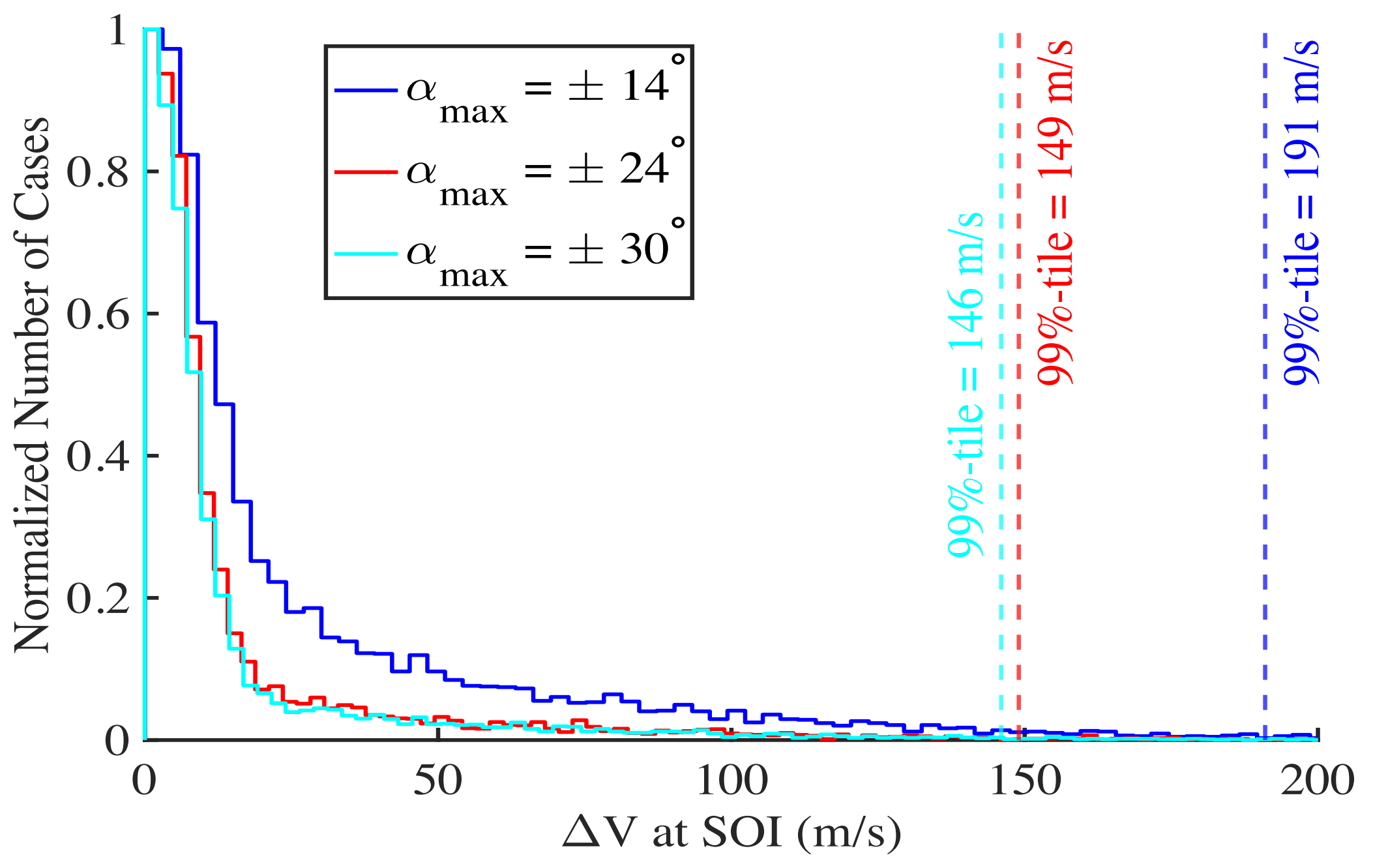

Fig. 9. ΔV at SOI for different aerogravity assist scenarios.

8000-case Monte Carlo

- Huygens covariance-based delivery states [9]
- Aero dispersion (MSL aerodatabase)
- Atmosphere dispersion (TitanGRAM)

Metrics

1. Percent success (within 20% of target energy)
2. Total ΔV at SOI

Reference case shows good success rate in achieving the target orbit while needing reasonable amount of ΔV at SOI. Good delivery flight path uncertainty from interplanetary navigation is important for the mission success.

Mission Design

2033 Launch Opportunity $C_3 = 16.3$ km²/s²

1. Venus Gravity Assist - 2033
2. Earth Gravity Assist – 2035
3. Deep Space Maneuver – 2037 ΔV = 59 m/s
4. Earth Gravity Assist – 2037
5. Deep Space Maneuver – 2038 ΔV = 218 m/s
6. Titan Arrival – 2043

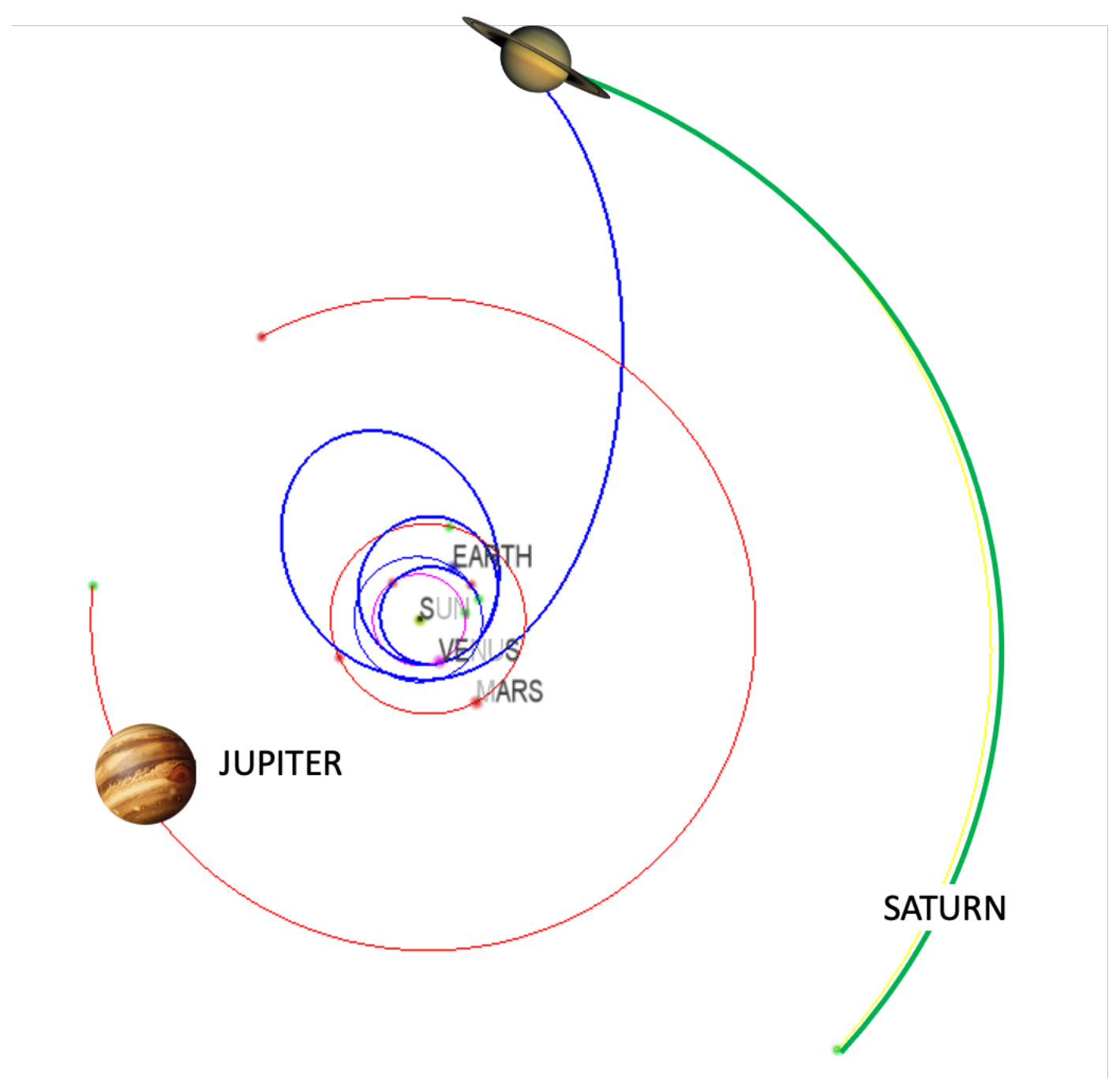

Fig. 2. Interplanetary mission design.

Aerogravity assist is a novel aerodynamic maneuver where the atmosphere and gravity of a planetary body provides the ΔV necessary to transition from a hyperbolic trajectory to a captured orbit. From the Saturnian viewpoint of a Titan aerogravity assist, the spacecraft approaches the system on a hyperbolic orbit, but after interaction with the Titanian atmosphere, the vehicle is in a Saturn captured orbit. Ensuing “pumpdown” maneuvers, consisting of small ΔV burns and gravity assists of various moons, bring the vehicle into the desired Enceladus flyby orbit [1,2].

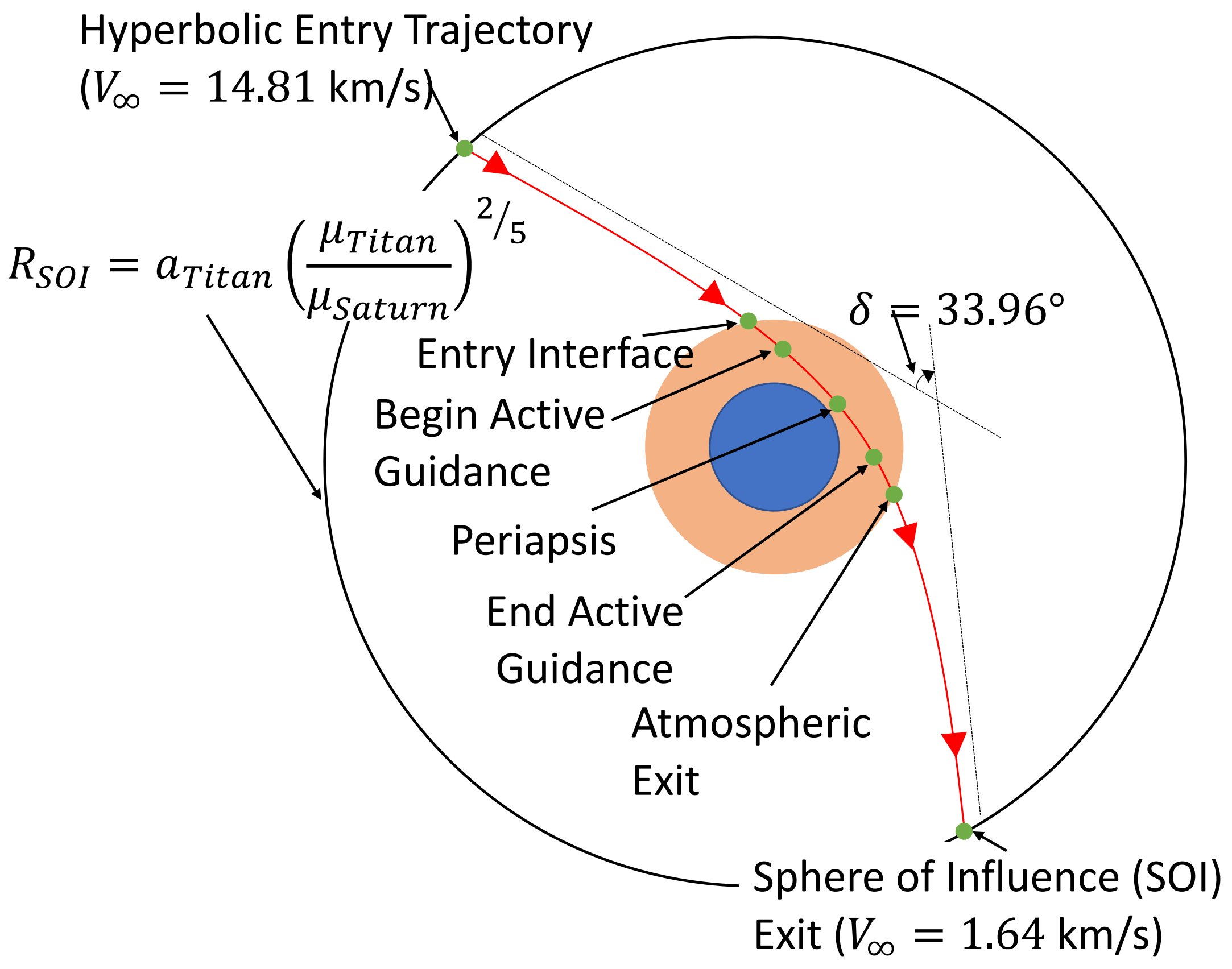

Fig. 3. Aerogravity assist from a Titan perspective [5]

Fig. 3 shows the maneuver with Titan as the central body. The spacecraft enters and leaves Titan’s sphere of influence (SOI) on a hyperbolic trajectory. An active guidance scheme reduces the Saturn-relative vehicle velocity and turns the trajectory of the vehicle to the desired orbital orientation.

Table 1. Potential List of Target Orbits for the 2043 Arrival Scenarios [3]

Arrival Date	V_∞ in, km/s	V_∞ out, km/s	Turn Angle, δ, deg.	ΔV to Enceladus, km/s
Feb. 11, 2043 (Direct)	11.7	3.3	14.3	3.9
Feb. 13, 2043 (Direct)	7.3	1.197	47.16	5.47
Feb. 23, 2043 (Direct)	14.8	2.6	18.5	3.8
Feb. 11, 2043 (Moon Tour)	11.3	1.64	23	0.18
Feb. 13, 2043 (Moon Tour)	7.3	1.252	45.633	0.618
Feb. 23, 2043 (Moon Tour)	14.81	1.64	33.96	0.17

Two families of target orbit after the aerogravity assist maneuver (see Table 1): Direct where the spacecraft goes directly to Enceladus’s vicinity and does an orbital capture burn; Moon Tour trajectories where the spacecraft is in a Saturn orbit visits other moons and does flybys of Enceladus. For guidance and control performance, the Feb. 23rd Moon Tour scenario was the most stringent due to the large ΔV and turn angle (δ) needed from the aeroassist maneuver. That is the scenario studied here.

Reference Case

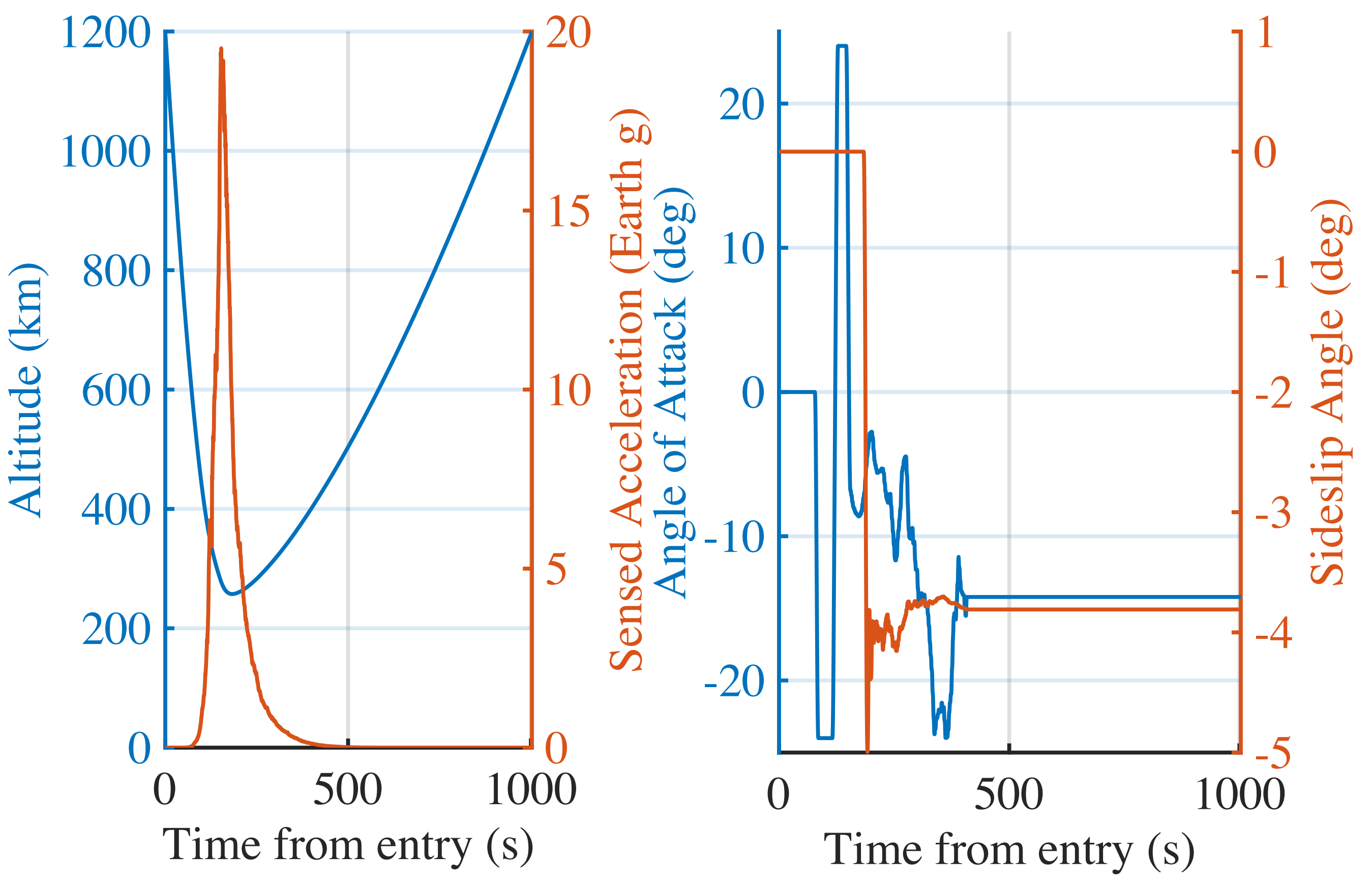

Fig. 7. Reference trajectory states.

- Max α: ±24° (L/D ~0.34)
- Flight Path Angle ± 3σ: 0.15°
- Ballistic coefficient: 128 kg/m²
- ΔV: 2.37 m/s at SOI
- ΔV: 12.2 km/s from aero-assist gravity
- δ: 33.96 deg
- Max. Sutton-Graves Heat Flux: 511 W/cm²
- Heat Load: 36 kJ/cm²

References and Acknowledgements

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