Aerocapture Assessment at Uranus and Neptune for NASA's Ice Giant Studies

PURDUE UNIVERSITY

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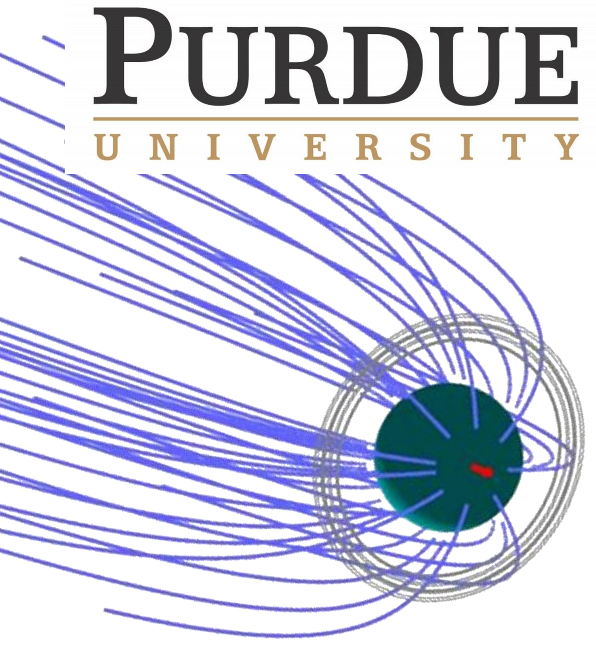
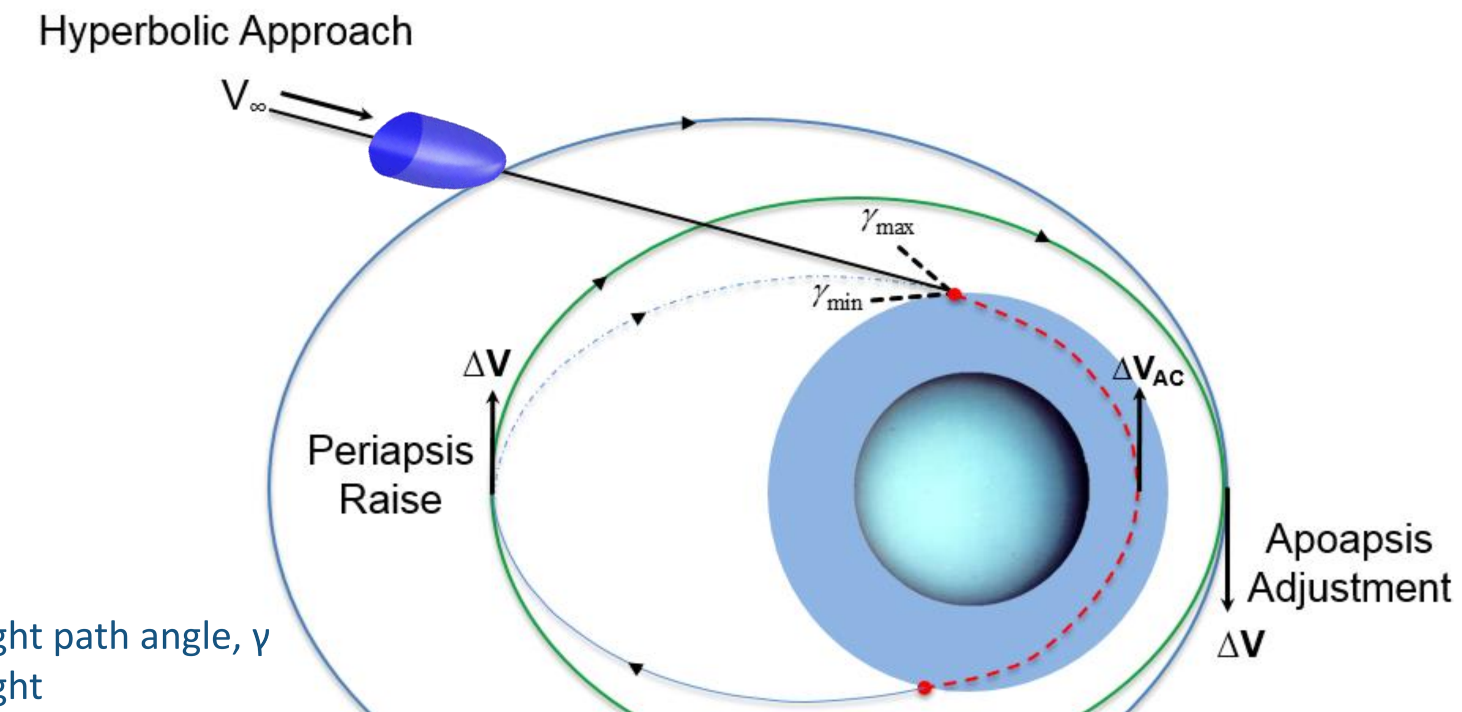




Phases of Aerocapture

1. Hyperbolic approach
2. Entry at a nominal entry flight path angle, γ
3. Atmospheric hypersonic flight
4. Atmospheric exit and Keplerian coast
5. Periapsis raise maneuver (chemical)
6. Apoapsis adjustment maneuver (chemical)

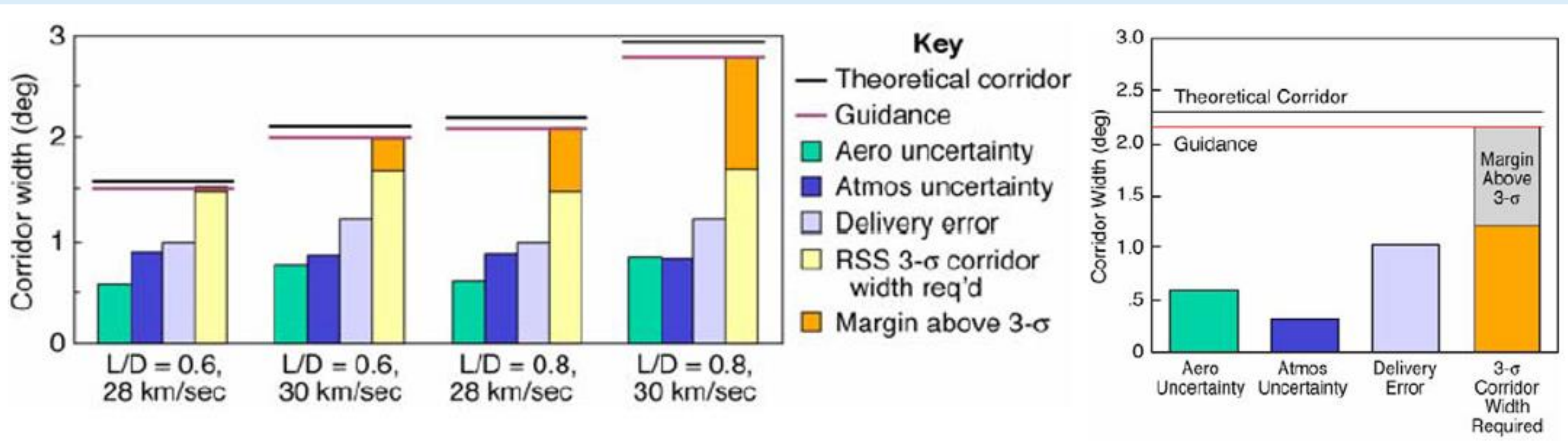
Aerocapture is Attractive, But …

- Can aerocapture provide the necessary orbital plane change?
- Can aerocapture bump up the "mass class" of a mission? E.g. From medium class with chemical propulsion to flagship class with aerocapture.
- Can aerocapture reduce flight time for orbital missions by three or more years, while maintaining the useful inserted mass and not switching to a bigger launch vehicle?

Why Do We Care About Theoretical Corridor Width (TCW)?

TCW determines the required vehicle performance during aerocapture to accommodate uncertainties, variability, and dispersions.

- Sources of uncertainty: aerodynamic, atmospheric, guidance, and navigational/delivery error (largest source)
- TCW is a function of the atmosphere (e.g. small scale height results in narrow TCW)
- TCW places a lower limit on the L/D of vehicles and incoming velocity
- Assumed required TCW of ~2° (based on 2004 NASA Neptune Aerocapture Study)



Left shows the TCW for two different L/D and velocities for Neptune aerocapture. Right shows how the TCW was calculated.

Theoretical Corridor Width (TCW) Dependence on L/D

- TCW is strongly dependent on both the L/D ratio of the aerocapture vehicle as well as the arrival V_∞
- TCW is weakly dependent on the ballistic coefficient
- Vehicles with significantly higher L/D (between 0.6 and 0.8 for TCW of 2 deg) required (Fig. A)
- Significantly higher arrival V_∞ (greater than 16.5 km/s) is required for aerocapture
- Required L/D can be reduced by minimizing uncertainties, thus required TCW

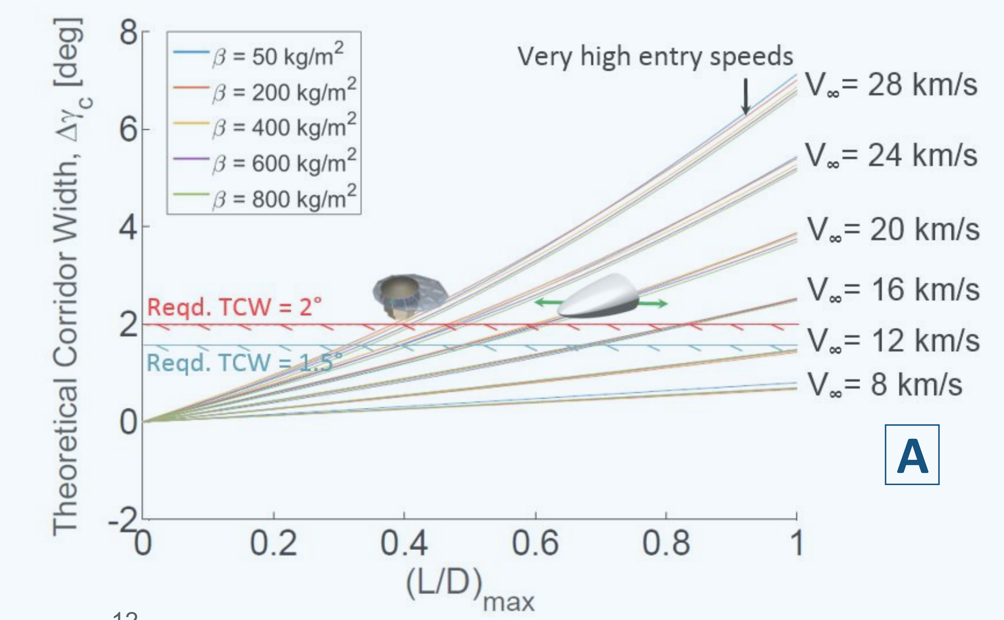
Aerocapture is Very Sensitive

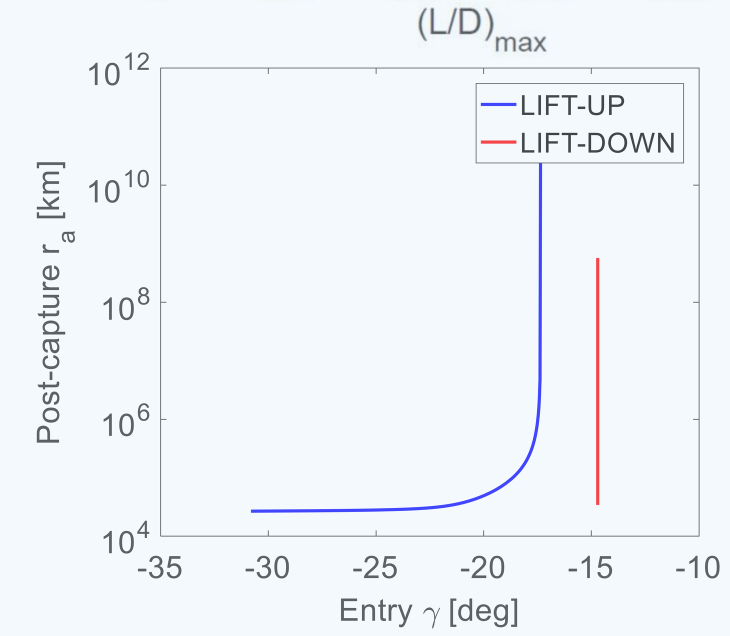
Due to the very large exit-to-escape speed ratios for Uranus and Neptune, the post-aerocapture orbit is sensitive to the atmosphere exit conditions—exit velocities and exit flight path angle.

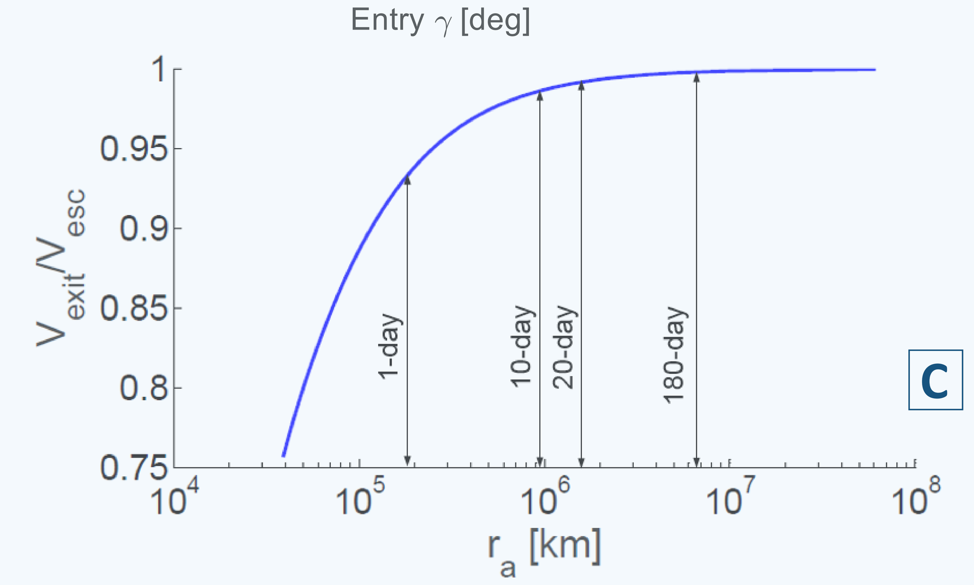
- As the post-capture apoapsis radius decreases, TCW increases significantly (Fig. B)
- For all practical orbits (with an apoapsis radius greater than 1×10^6 km) have essentially the same TCW (Fig. C)
- To establish 20-day post-aerocapture orbits, exit speeds of 20.57 km/s (99.1% of Uranus escape speed) and 22.89 km/s (99.1% of Neptune escape speed) are required (Fig. C)
- Post-aerocapture orbits are very sensitive to velocity at exit and less so for flight path angle at exit.

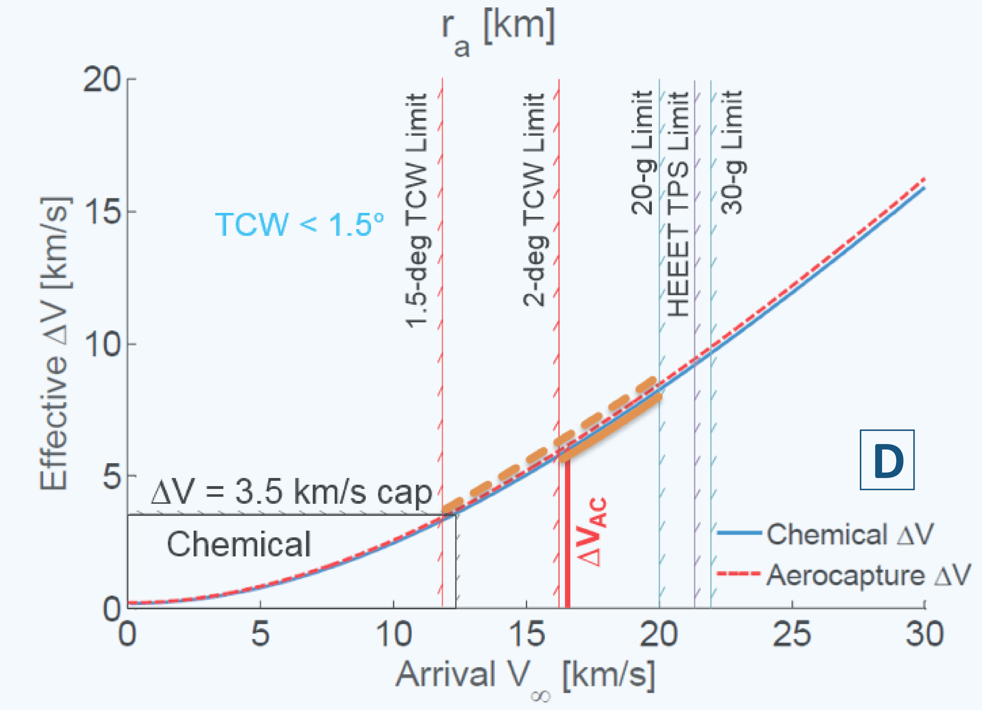
Aerocapture 101

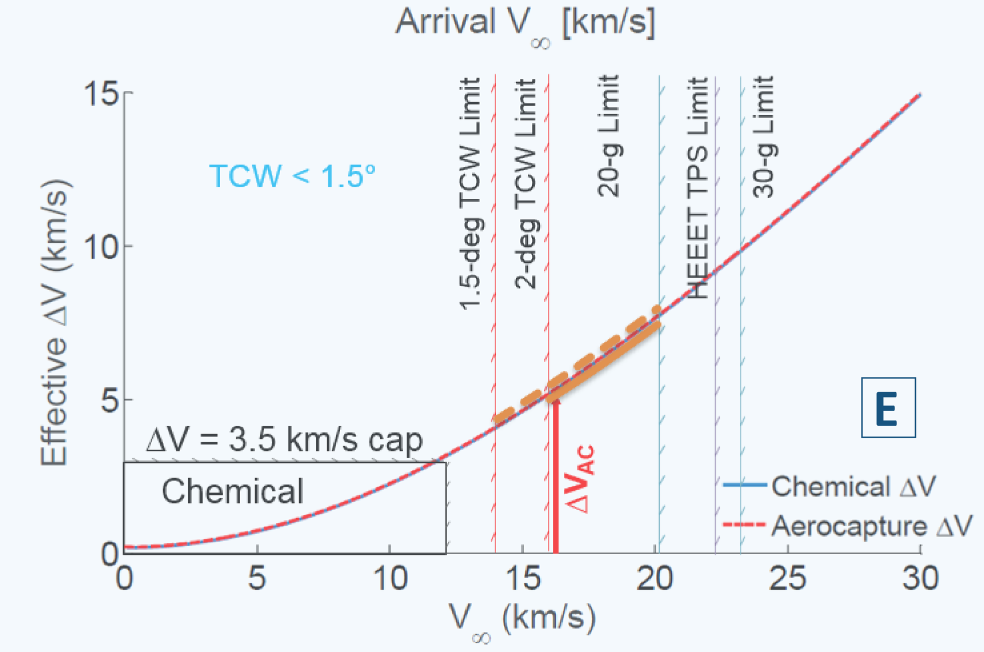
Aerocapture is a maneuver in which a spacecraft uses aerodynamic forces in a planetary atmosphere to autonomously guide itself from an unbounded hyperbolic orbit into a desired capture orbit.

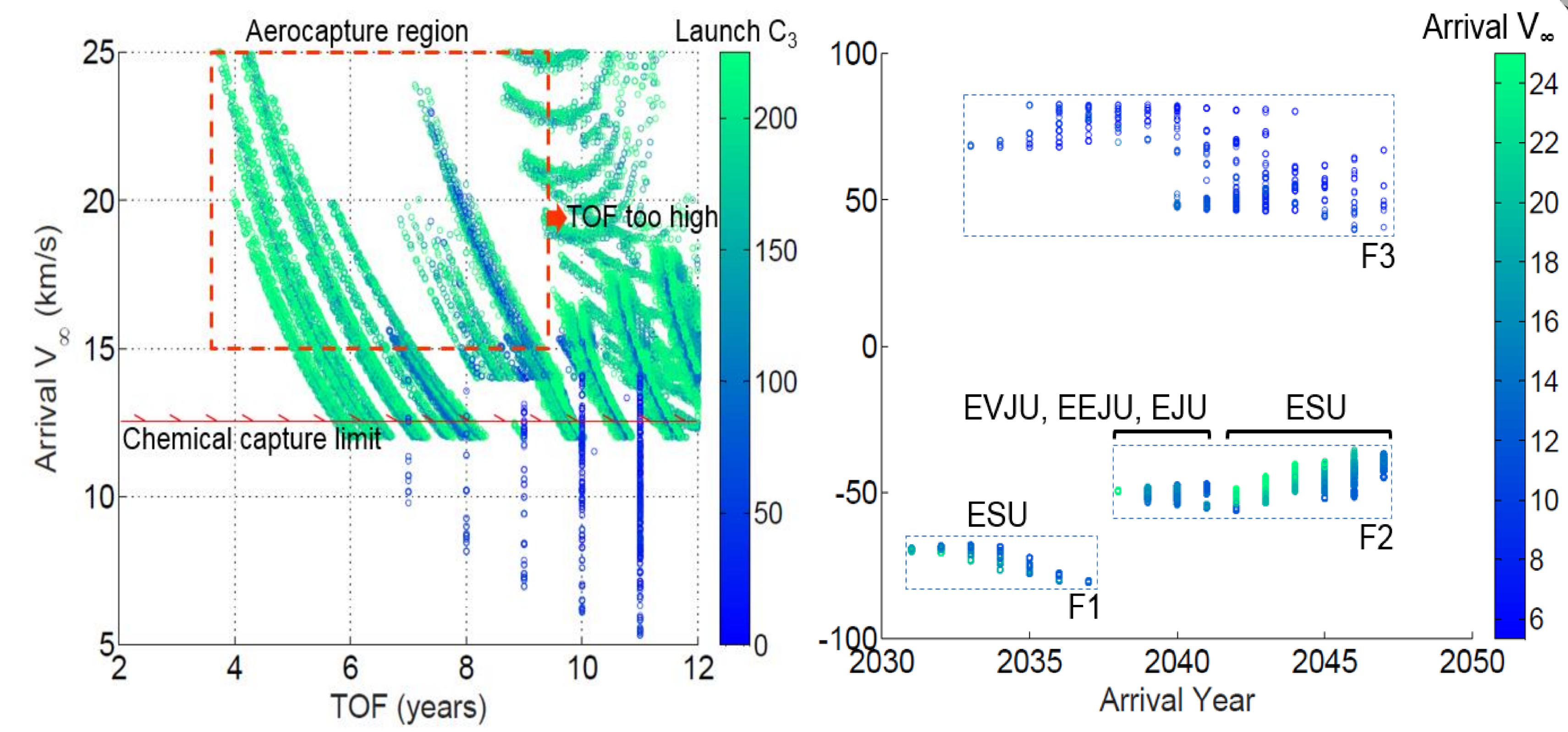












Should We Care for Interplanetary Trajectories For Aerocapture Analysis?

Interplanetary trajectories are tightly coupled with aerocapture. For e.g. arrival declination determines the minimum inclination post capture. Have to look at them together.

NASA's Ice Giant Mission Studies Baselines:

- Uranus: Launch in May 2031, C_3 of 11.91 km^2/s^2, TOF of 11.98 y
- Neptune: Launch in May 2031, C_3 of 20.99 km^2/s^2, TOF of 13 y
- Arrival V_∞ at Uranus and Neptune are large enough for aerocapture requiring a mid-L/D vehicle
- For Uranus, up to 4200 kg can be delivered for a TOF less than or equal to 10 years
- For Neptune, up to 2500 kg can be delivered for a TOF less than or equal to 10 years

Aerocapture Applicability and Feasibility Plot

Helps to define the range on V_∞ and the maximum ΔV for which aerocapture is feasible for a destination planet (Figs. D & E)

1. Lower limits on V_∞: Solely based on TCW constraint (capability to handle uncertainties)
2. Upper limits on V_∞:
   - Peak G-load (stresses on the aerocapture vehicle)
   - Peak heat-rate (limits of TPS material)
   - Total heat-load (total mass of TPS/ aerocapture mass fraction, ACMF)

Let Us Summarize

- A mid L/D (between 0.6 and 0.8) vehicle needed for aerocapture at both Uranus and Neptune
- Narrow shape of mid L/D aeroshells is not mass efficient: new spacecraft design for outer planes
- Ranges of the aerocapture applicability and feasibility for Uranus are generally wider than for the case of Neptune
- Clarifies the ranges of aerocapture applicability relative to chemical systems
- Low L/D vehicles such as rigid blunt body aeroshells (e.g. ADEPT, HIAD) are not applicable for aerocapture at the outer planets (except Titan)
- Identifies possible pathways to using proven aeroshell shapes for aerocapture by reducing uncertainties or by employing hybrid aerocapture-propulsive systems

Moving Forward: Phase II Study Goals

- Reducing Theoretical Corridor Width: Approaches to reducing the control authority requirements on the aerocapture system. This is expressed as a Theoretical Corridor Width (TCW) and is currently about 2 degrees. It is determined by the combined errors in knowledge of the atmosphere, aerodynamics, navigation and guidance accuracy.
- Hybrid Aerocapture Propulsion Approaches: Propulsion is used immediately after the aerocapture maneuver is completed to refine the initial orbit.
- Aerocapture Mass Fraction (ACMF): Determine the A*CMF for the system where A* includes both the aerocapture system and the increment in the chemical propulsion systems required to match the Medium to High L/D option.

Acknowledgments

The research described in this report was carried out at Purdue University and has been supported in part by the Jet Propulsion Laboratory, California Institute of Technology, under Contract Number 108436. For more information, see the Technical Report, PU-AAC-2016-MC-0002.