Aerosciences Implications for Uranus Aerocapture

Eli Shellabarger[1]
J. Scoggins[1], A. Hinkle[1], S. Dutta[1], R. Deshmukh[2]

[1]NASA Langley Research Center
[2]Analytical Mechanics Associates at NASA Langley Research Center

Overview

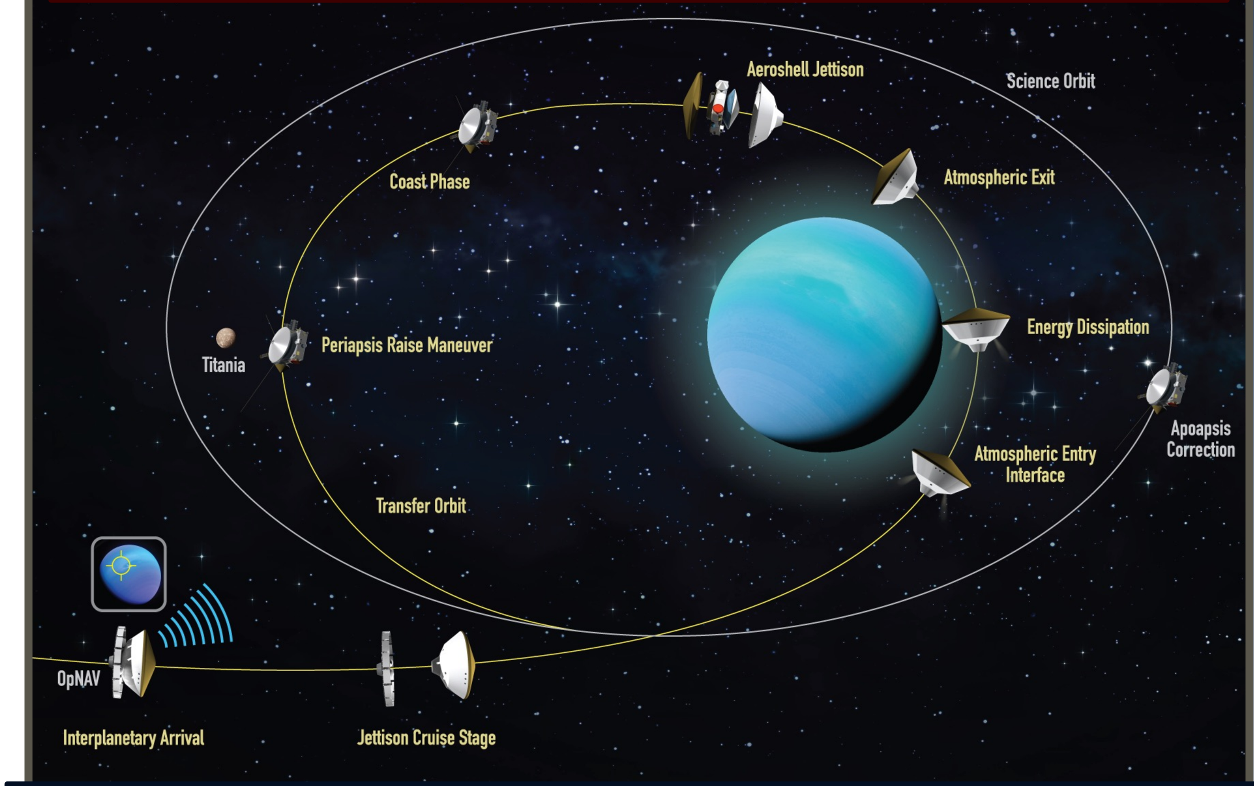
- Motivation
- Introduction
- Atmospheric Model and Flight Conditions
- Flight Vehicle Aerodynamics
- Aerothermodynamic Environments
- Future Work
- Summary
- References
- Questions

Motivation

- **Uranus:**
  The Highest Priority Planetary Science Destination for a New NASA Flagship Mission [1]
  - Propulsive-capture orbiters can expect [2]:
    - 13–15-year travel times
    - Propellent requiring two-thirds of orbiter launch mass budget
- **Aerocapture:**
  Orbit Insertion via Aerodynamic Forces from Atmospheric Flight [3,4]

> - **Reduces onboard fuel requirements**
> - **Allows for faster interplanetary travel**

See additional presentations by: S. Dutta, R. Deshmukh

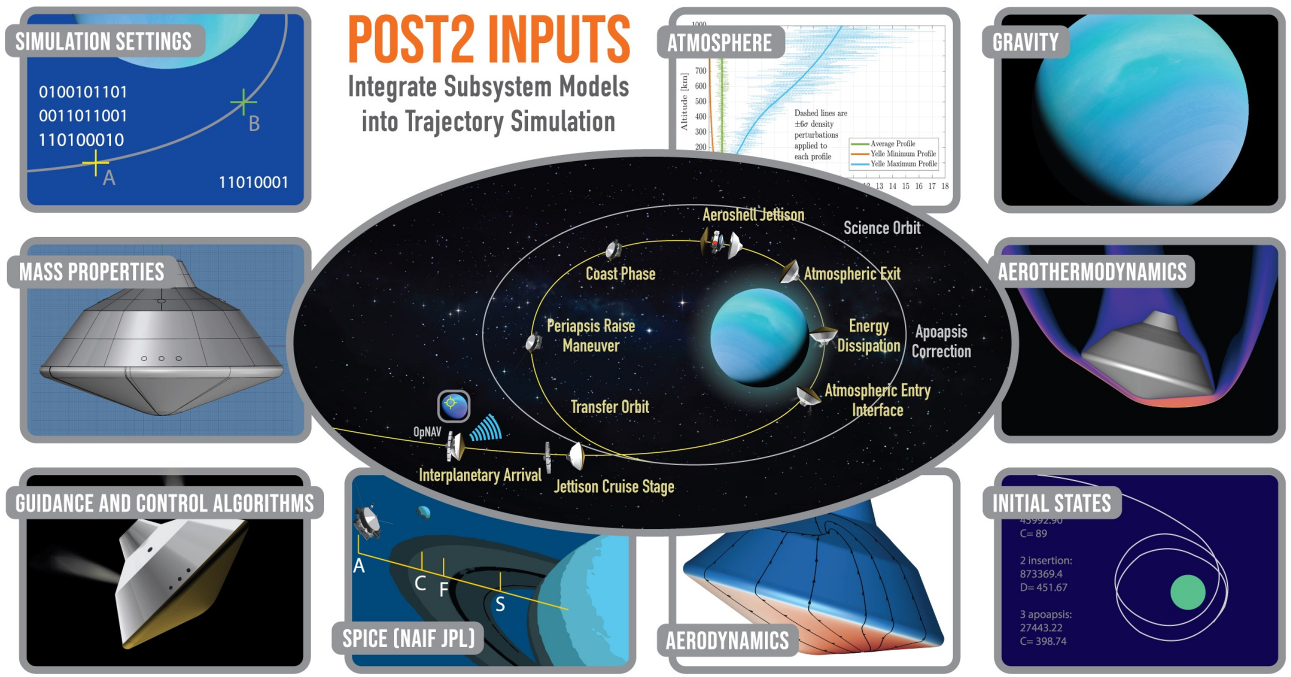


Project Objective: Evaluate the advantages of aerocapture for use in delivering a planetary science mission to Uranus using a heritage flight vehicle design.

This project is a NASA Science Technology Mission Directorate (STMD) funded Early Career Initiative.

Introduction

- **Trajectory Simulation in POST2 [5,6]**
  - Heritage framework for NASA Entry, Descent, and Landing (EDL) missions
    - Used for Mars Science Laboratory (MSL) and Mars 2020 missions
  - Uranus application requires new aerodynamic and aerothermodynamic models for trajectory simulation
- **POST2 inputs of interest:**
  - Atmosphere
  - Aerodynamics
  - Aerothermodynamics
- **Bonus: Future value for Uranus probe entry vehicle design**
  - No Gas Giant probes since Galileo



Aerosciences Objective: Determine the specific implications related to vehicle aerodynamics and aerothermodynamics that are required to properly simulate flight along entry trajectories through Uranus' atmosphere.

Atmospheric Model and Flight Conditions

Uranus Global Reference Atmospheric Model (GRAM) [7]

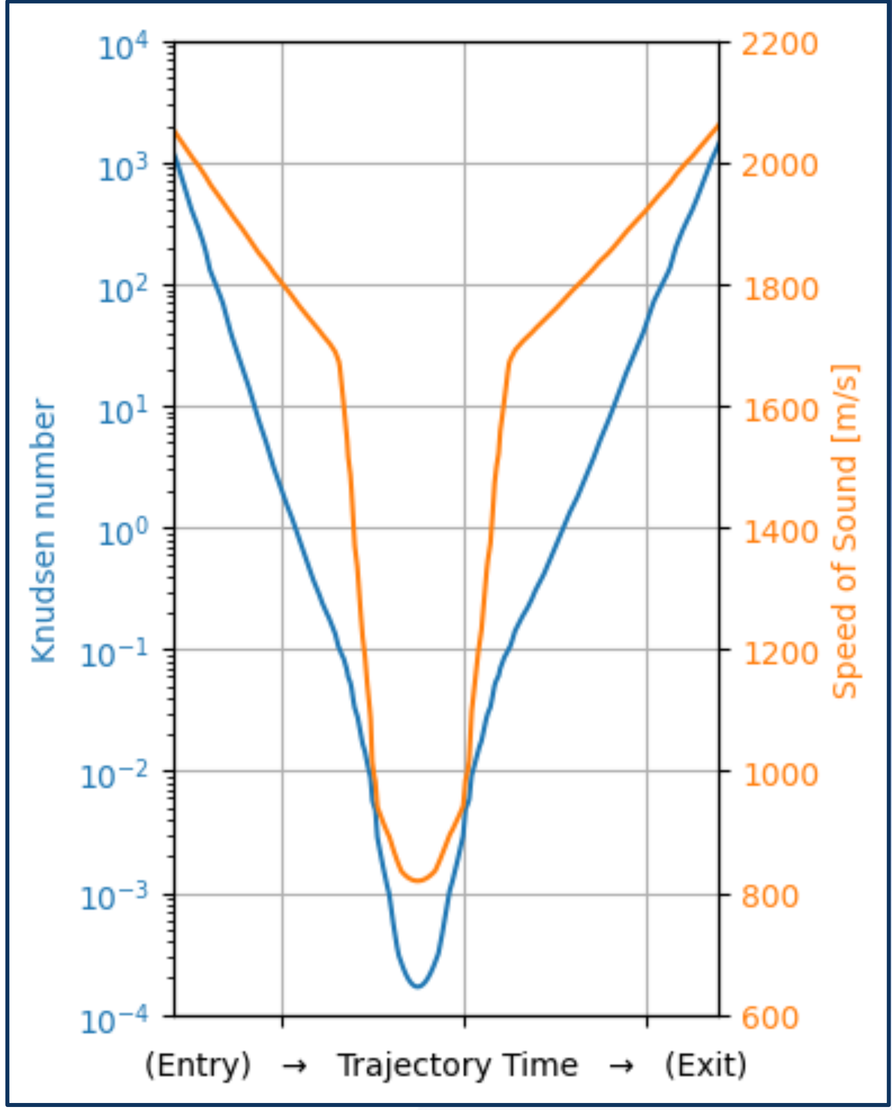
- Based on engineering model rooted in three papers grounded in Voyager 2 fly-by data (circa late 1980s) [8,9,10]
- Remaining properties calculated by Chemical Equilibrium with Applications (CEA) [10], required modified polynomials for Uranus' low temperatures due to CEA limitations [7]

Modifications to Atmospheric Data

- Replace CEA-variables with improved up-to-date thermodynamic and transport properties via Mutation++ library [11]

Unique Attributes

- Far reaching atmosphere challenges typical norms
  - Light gas medium results in low density, high Knudsen regions
  - Requires starting farther out from planet
- High Speed of Sound
  - Results in relatively low Mach numbers for large entry speeds



Flight Vehicle Aerodynamics

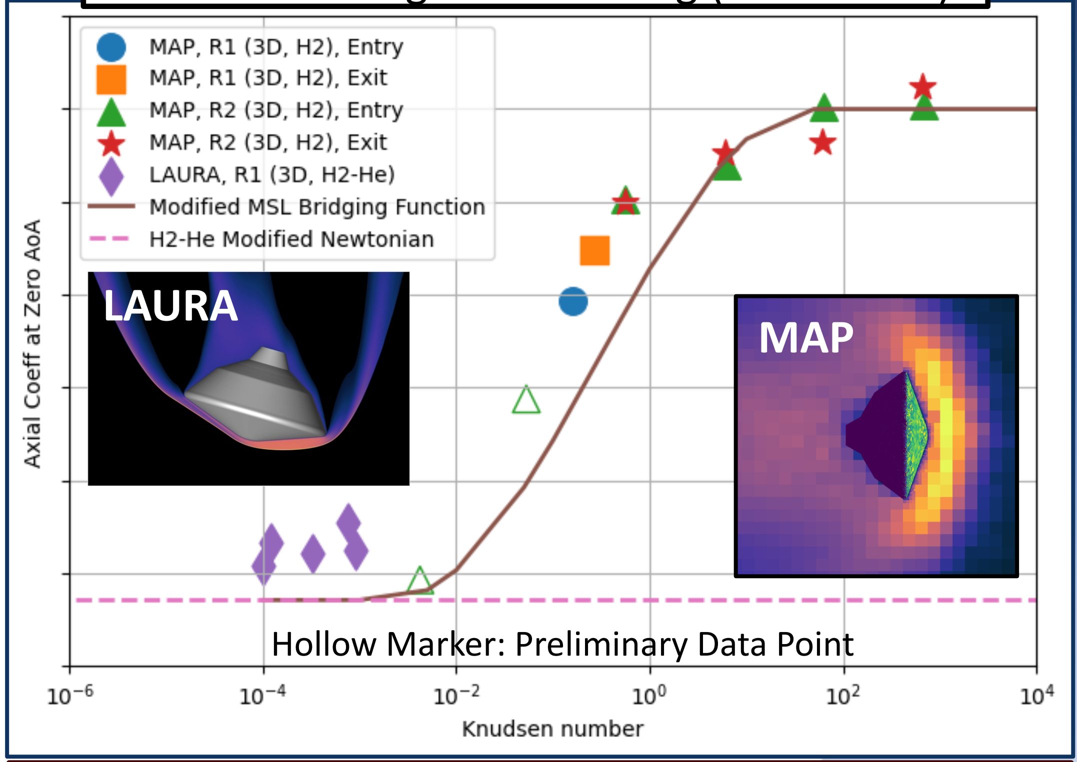
Aerocapture Flow Regimes
- Simpler than your average entry sequence

Early Approximation
- Modified MSL Bridging Function with First Order Data
  - Continuum bound: H2-He Modified Newtonian
  - Free Molecular bound: MER DSMC (CO2) [13]

Increasing Model Fidelity
- Rarefied Gas Dynamics: MAP [14]
- Continuum Gas Dynamics: LAURA [15,16]

Aerodatabase formulation
- Rooted in MSL Aerodatabase to leverage heritage work
- Updating data tables as H2-He data becomes available
- Resolving free molecular bound requires trajectories to be carried to high altitudes (~4000 km)

Transitional Regime Modeling (AoA = Zero)



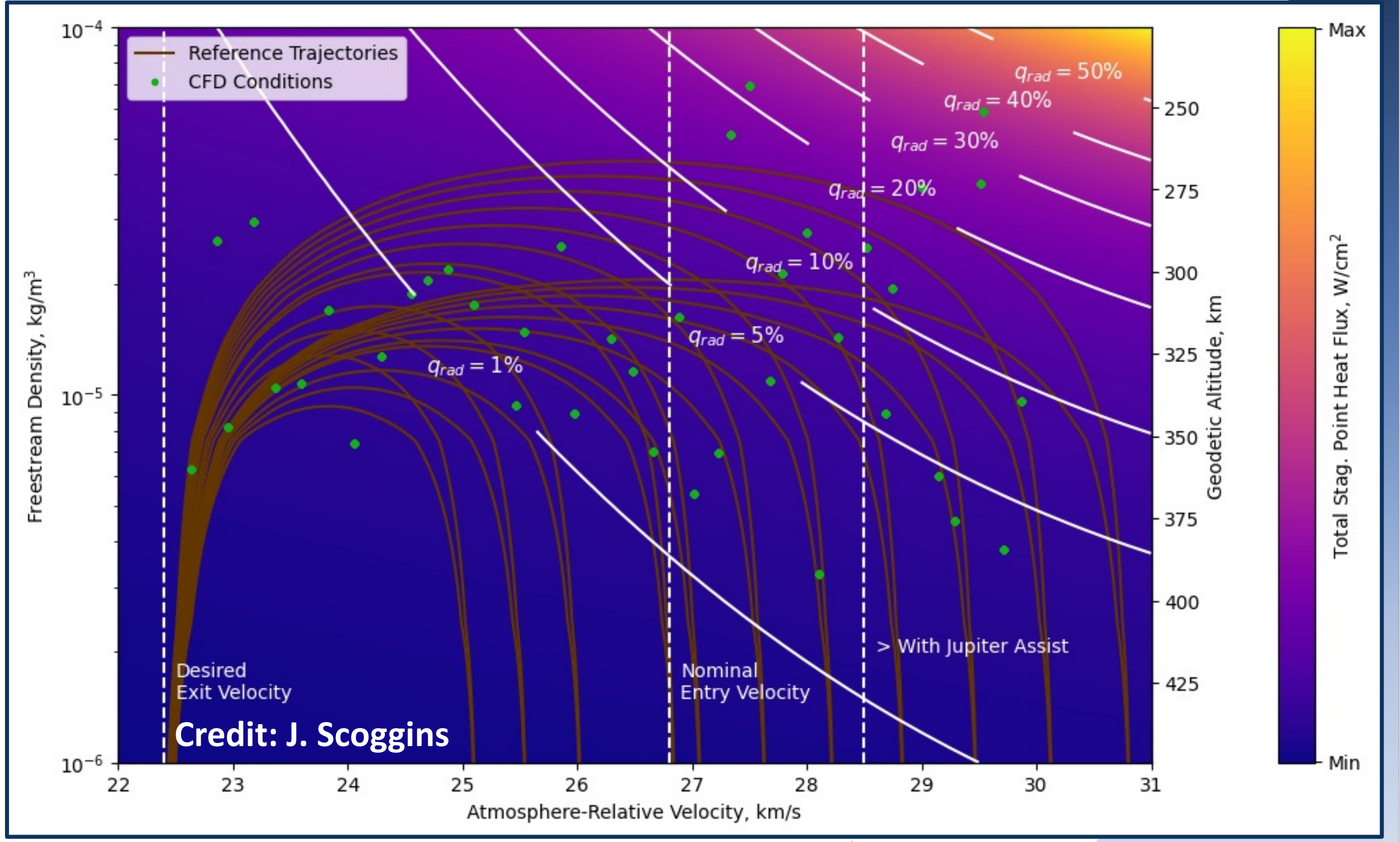
Early CFD results indicate that while adjustments are needed as more data becomes available, initial approximations are within reason

Simulation Credit
LAURA: J. Scoggins
MAP: A. Hinkle

Aerothermodynamic Environments

- **Generation of Aerothermal Database**
  - Surrogate model via Gaussian Process Regression (GPR) handles uncertainty of trajectory design space
  - Quantities of interest calculated from GPR surrogate built with / bounded by CFD data
- **LAURA-HARA [16] investigation of radiation shows low contributions for possible trajectory space**
  - Aerocapture trajectories expected to stay well above CH_4 concentrations residing in lower atmosphere

Carbon-phenolic TPS materials have flight and ground test heritage at these conditions. Thickness solutions are manufacturable.



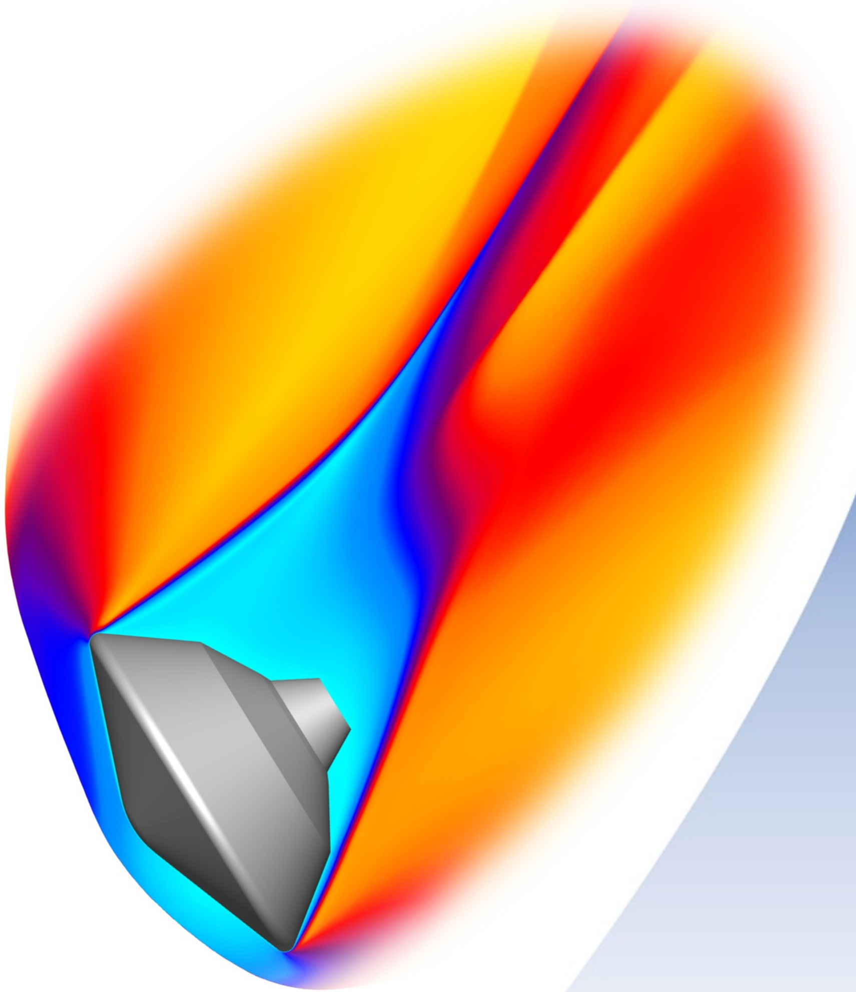
Study Nominal Arrival

Approximate Fastest Arrival (Without a Jupiter Assist)

Arrival State Expected to Limit Radiative Heating Environment

Future Work

- **Continuing to refine models and improve robustness**
- **Current Aerosciences Focuses**
  - Increase fidelity of rarefied modeling with MAP DSMC data
  - Incorporate 3D LAURA data into aerodynamics database
  - Move towards dispersed 6-DOF trajectory simulation
- **Another year remaining in current effort**
  - Dig further into uncertainties
- **Targeting AIAA SciTech 2024 special session**



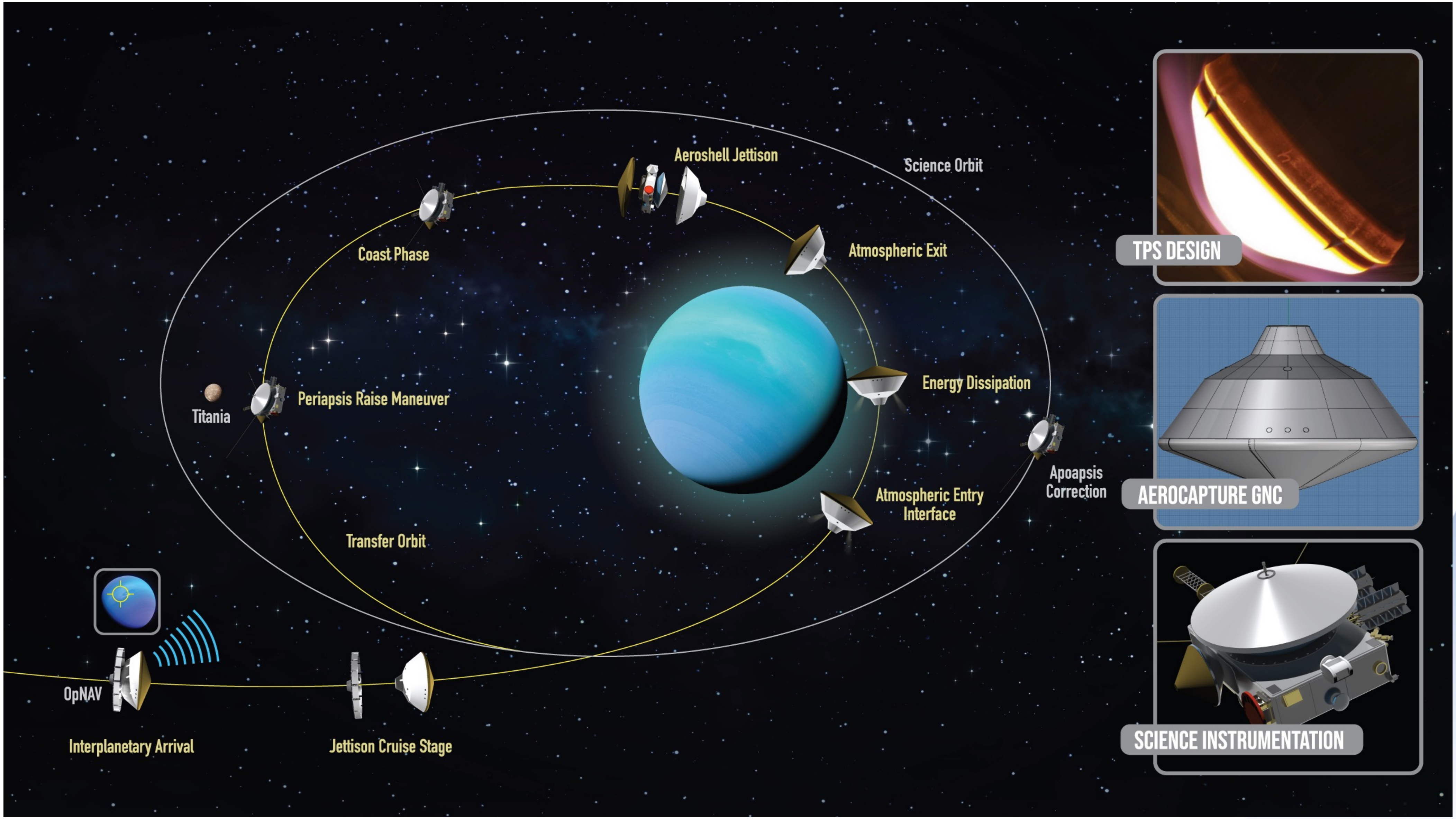
Summary

- **A NASA STMD effort is investigating aerocapture as an enabling technology for future missions to Uranus and other Ice Giant planets**
  - Uranus is the number one destination for the next proposed NASA Flagship planetary science missions
    - No Gas Giant missions with an atmospheric probe since Galileo (Jupiter, 1995)
  - Effort is driving a need to better understand implications of Ice Giant atmospheres for aerosciences of entry vehicles
- **Three primary factors are currently under investigation:**
  - Atmospheric Flight Conditions
  - Flight Vehicle Aerodynamics
  - Aerothermal Environments
- **Uranus has unique characteristics that require expanding knowledge from Entry, Descent and Landing at terrestrial bodies**
  - Extended rarefied flight
  - Non-intuitive thermal environments

References

1. “Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032,” (2022)
2. Simon, A. et al, “Journey to an Ice Giant System: Uranus Orbiter and Probe,” (2021)
3. Dutta, S. et al, (2021), *Bulletin of the AAS*, Vol. 53, No. 4, #046
4. Girija, A.P., (2022), *Acta Astronautica*, Vol. 202, pp 104-108
5. Lugo, R. A., et al, (2017), *AAS Space Flight Mechanics Meeting*, AAS 17-274.
6. Williams, R. A., et al, (2023), *AIAA SciTech* 2023, AIAA 2023-0148
7. Justh, H.L. et al, (2021), *NASA Technical Reports* Server, NASA TM-20210017250
8. Lindal, G.F. et al, (1987), *Journal of Geophysical Research*, Vol. 92, No. A13, pp. 14,987-15,001
9. Herbert, F. et al, (1987), *Journal of Geophysical Research*, Vol. 92, No. A13, pp. 15,093-15,109
10. Bishop, J. et al, (1990), *Icarus*, Vol. 88, pp. 448-464
11. Gordon, S. et al, (1994), *NASA Technical Reports Server*, NASA RP-1311
12. Scoggins, J.B. et al, (2020), Mutation++, SoftwareX 12:100575
13. Schoenenberger, M. et al, (2005), *43rd AIAA Aerospace Sciences Meeting and Exhibit*, AIAA 2005-0056
14. Liechty, D.S., (2015), *Journal of Spacecraft and Rockets*, Vol. 52, No. 6, pp. 1521-1750
15. Gnoffo, P., (1990), *NASA Technical Reports* Server, NASA TP-2953
16. Thompson, K.B., (2020), *AIAA Aviation* 2020, AIAA 2020-3030

Questions


Aeroshell Jettison
Science Orbit
Coast Phase
Atmospheric Exit
Titania
Periapsis Raise Maneuver
Energy Dissipation
Apoapsis
Correction
Atmospheric Entry
Interface
Transfer Orbit
OpNAV
Interplanetary Arrival
Jettison Cruise Stage
TPS DESIGN
AEROCAPTURE GNC
SCIENCE INSTRUMENTATION