

Planetary Science Mission Architecture (PLASMA)

Exploration Tool: Pilot Phase Study Report

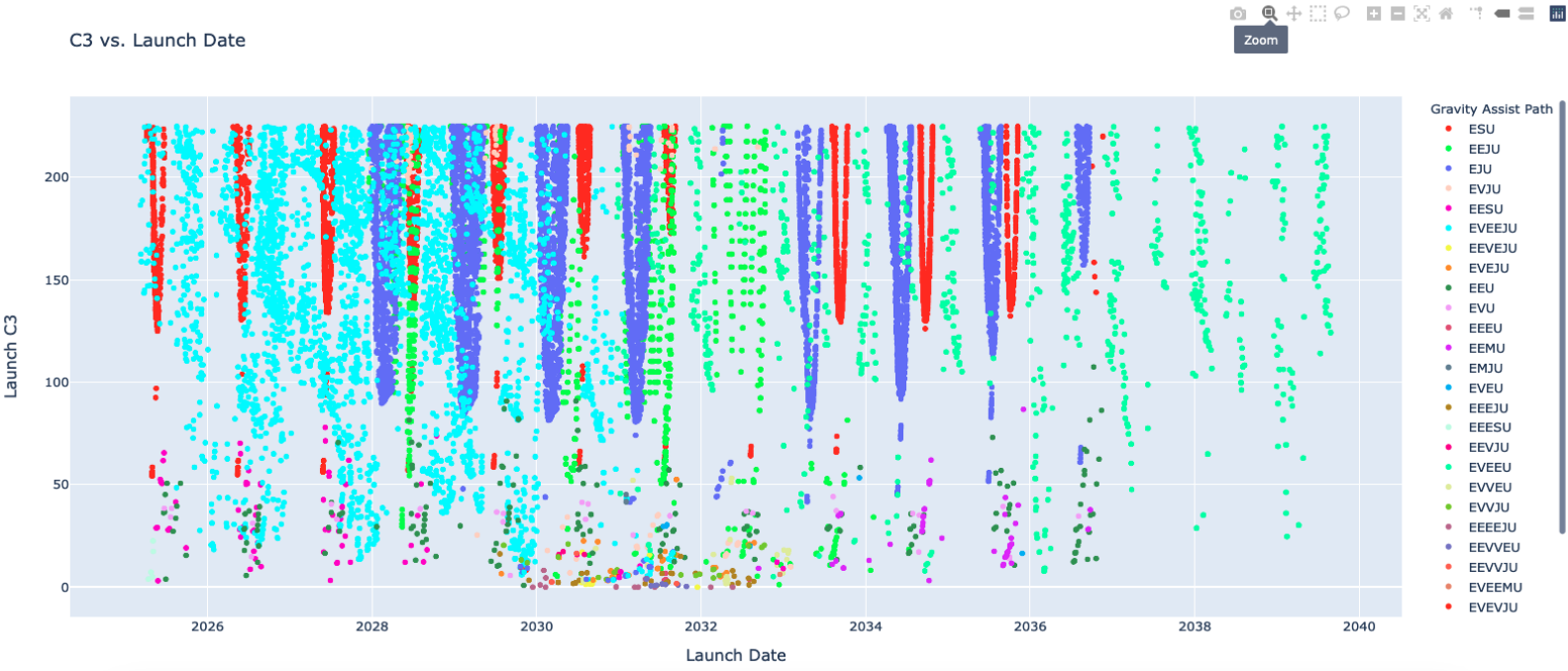
Prepared by: Dr. Athul Girija

Select Launch Window
03/09/2025 → 08/31/2039

Select Max. C3: 225
Select Max. ToF: 15
Select Max. Vinf: 25
Max. DSM DV: 1

Select Gravity Assist Flyby Bodies: Venus Earth Mars Jupiter Saturn
Select Trajectory Type: Ballistic Solar Electric Propulsion

C3 vs. Launch Date



December 31, 2023



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Planetary Science Mission Architecture (PLASMA) Exploration Tool: Pilot **Phase Study Report**

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December 31, 2023

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Executive Summary

The identification of trajectories and promising mission architectures that enable planetary missions or significantly reduce their cost is a highly valuable asset for the planetary science and mission engineering community. The 2023-2032 Planetary Science Decadal Survey underscored the importance of programs to bridge opportunity gaps by increasing access to information about mission concept formulation, development, and proposals for future NASA missions.

Currently, there exists no easy-to-use tool that allows planetary scientists, mission designers, and program managers to quickly evaluate the design options for a mission concept. The high-level objective of this work is to create a proof-of-concept easy-to-use mission design suite aims to fill this gap, by providing the community with a new state-of-the-art mission design suite to enable rapid, early-stage end-to-end planning for NASA's future planetary science missions.

In this report, the work done in the pilot phase of Planetary Science Mission Architecture (PLASMA) Exploration Tool, its current capabilities, and technical details are discussed. The pilot phase study has been completed and a proof-of-concept version of the PLASMA tool has been developed and made available for use online at <http://45.56.66.11/>*. PLASMA currently has an interplanetary trajectory database for Uranus, a launch vehicle performance calculator, an approach and orbit insertion calculator, an aerocapture tool, and a link budget analysis tool. Future phases of the project will expand the interplanetary trajectory dataset to include more Solar System destinations, add more mission design capabilities, and improve the overall end user experience.

Dr. Athul Girija,
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December 31, 2023

*Accessible until June 30, 2024

1. Introduction

The identification of trajectories and promising mission architectures that enable planetary missions or significantly reduce their cost is an essential and highly cost-effective element in the community's tool kit. The 2013-2022 Planetary Science Decadal Survey recommends a sustained investment in the development of new trajectories and techniques that would provide a rich set of options for future missions [1, 2]. More recently, the 2023-2032 Decadal Survey underscored the importance of programs to bridge opportunity gaps by increasing access to information about mission concept formulation, development, and proposals for future NASA missions [3].

Currently, there exists no easy-to-use tool that allows planetary scientists, mission designers, and program managers to quickly evaluate the design options for a mission concept. The high-level objective of this work is to create an easy-to-use mission design suite aims to fill this gap, by providing the community with a new state-of-the-art mission design suite to enable rapid, early-stage end-to-end planning for NASA's future planetary science missions [4, 5]. Such a capability allows easy exploration of the available trajectories to a destination, launch vehicle options, approach and orbit insertion methods and select promising candidates for more detailed mission studies. In this report, the work done in the pilot phase of Planetary Science Mission Architecture (PLASMA) Exploration Tool, its current capabilities, and technical details are discussed.

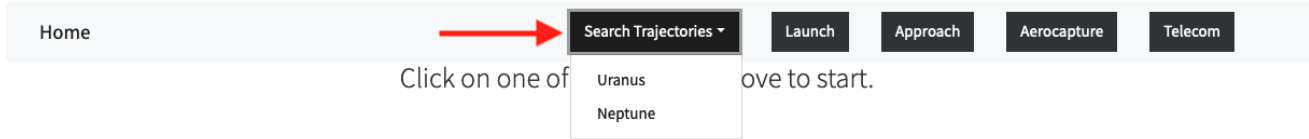
PLASMA consists of a set of tools that enable a user to start from a set of simple mission requirements (destination, launch dates, allowable flight time etc.) and select a set of options (launch vehicle, interplanetary trajectory, orbit insertion technique etc.) to accomplish the mission objectives. The suite provides the user with a low-to-mid fidelity mission concept which if promising, can then be analyzed in further is made available to the end users (planetary scientists, mission designers, executives, program managers and executives) as an interactive, easy-to-use web-browser interface on the cloud, along with documentation, tutorials, and examples. The pilot version of PLASMA is accessible online at <http://45.56.66.11/>[†]. The remainder of the report provides an overview of the capabilities of PLASMA, which is a web application built using the Dash framework. Video presentation links are available in Appendix A. Technical details are provided in Appendix C.

[†] Accessible until June 30, 2024

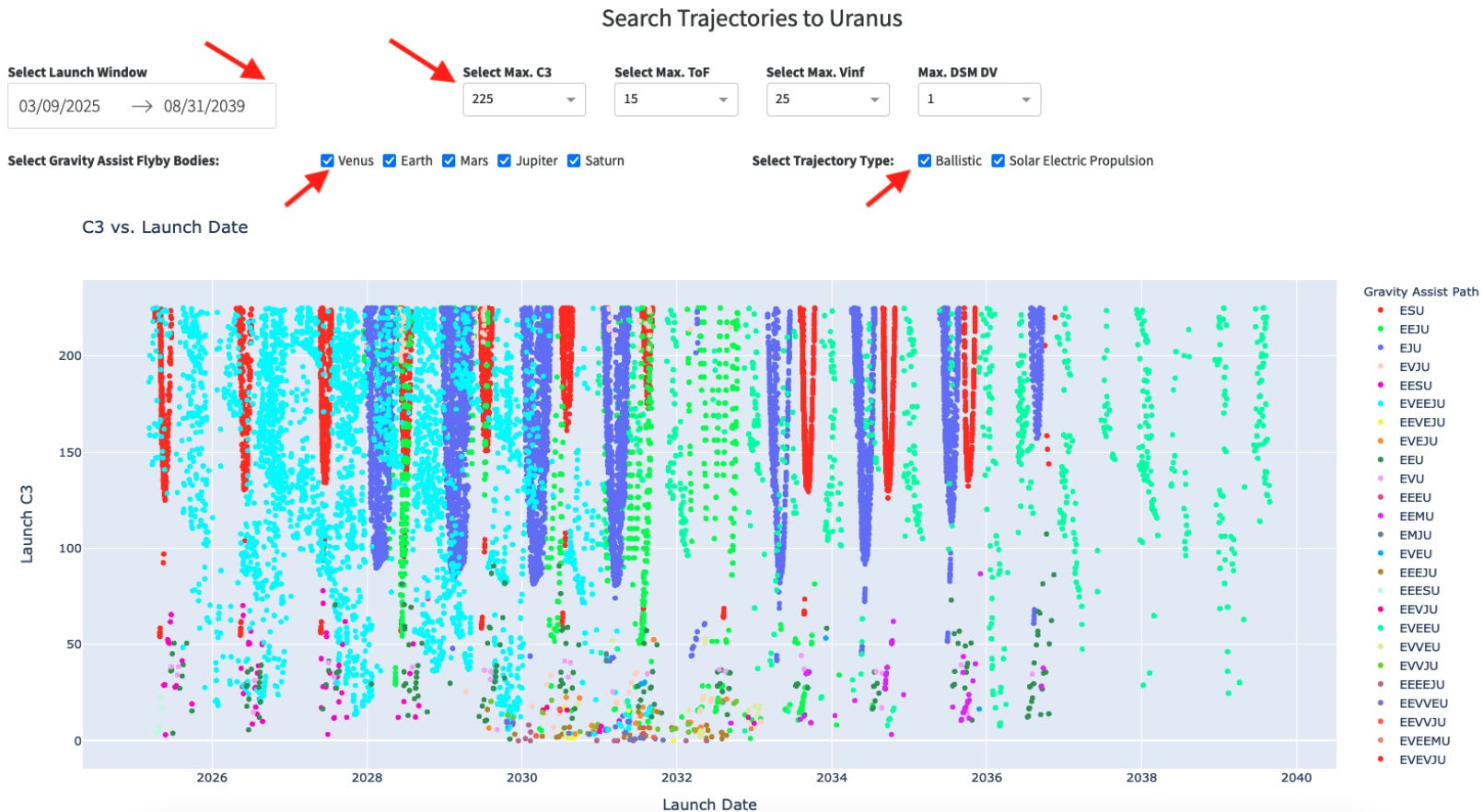
2. Trajectory Search

The trajectory search section of the tool can be accessed by clicking on "Search Trajectories" in the home page and then clicking on an available destination from the list as shown below.

Planetary Science Mission Architecture (PLASMA) Exploration Tool

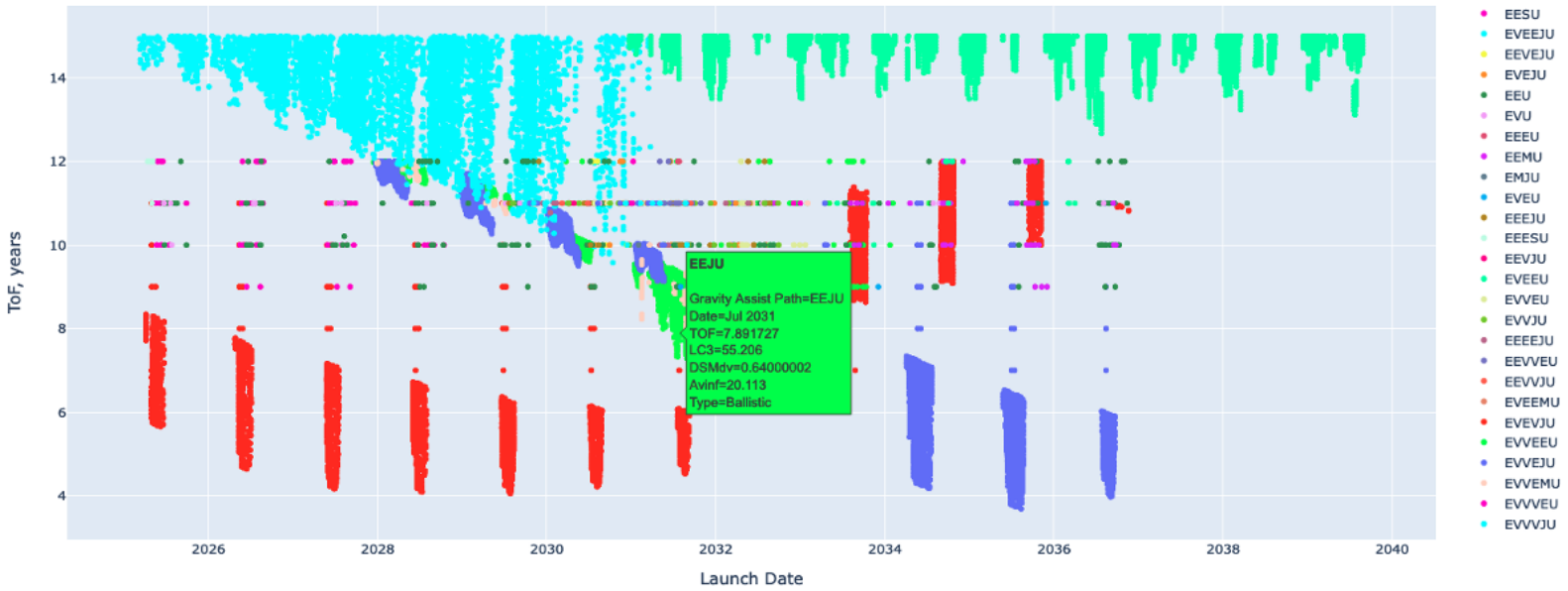


The user is then presented with a set of search filters and charts which show the available trajectories from a database which have been pre-computed using STAR [6]. The user can select the allowable launch window, and the maximum allowed C_3 , ToF, arrival V_∞ and deep space maneuver ΔV . The user can also select/deselect allowable gravity-assist flyby bodies, and chemical/SEP type trajectories. The first chart shows the C_3 of the trajectories, colored by the gravity assist path.



The user can double-click on one gravity-assist path isolate the path. Clicking on other gravity-assist path(s) after the first double click adds more paths to the chart. Double-clicking again on any of the selected path resets the view to all available paths. In addition to the C_3 , the user is also shown charts of the flight time and arrival V_∞ as a function of the launch date as shown below. Hovering over any of the points on the chart shows more detailed information on the trajectory.

TOF vs. Launch Date



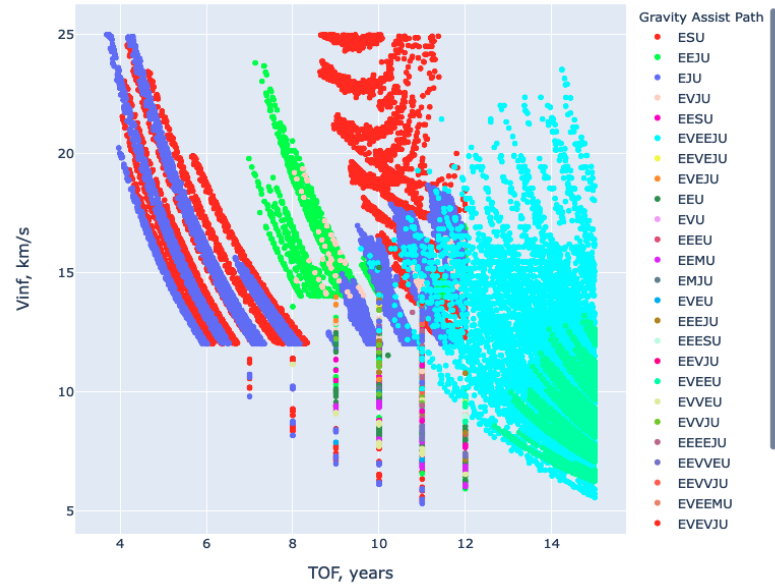
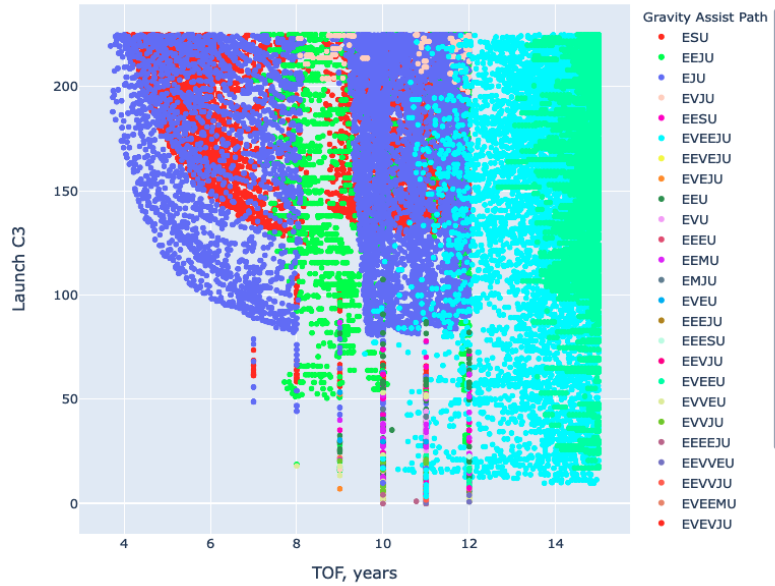
Arrival Vinf vs. Launch Date



The user is also provided with two additional charts comparing the C_3 vs flight time, and the arrival V_∞ vs flight time for exploration of the interplanetary trajectory trade space. The page also allows the user to select a launch vehicle from the list and see the available launch capability.

C3 vs. TOF

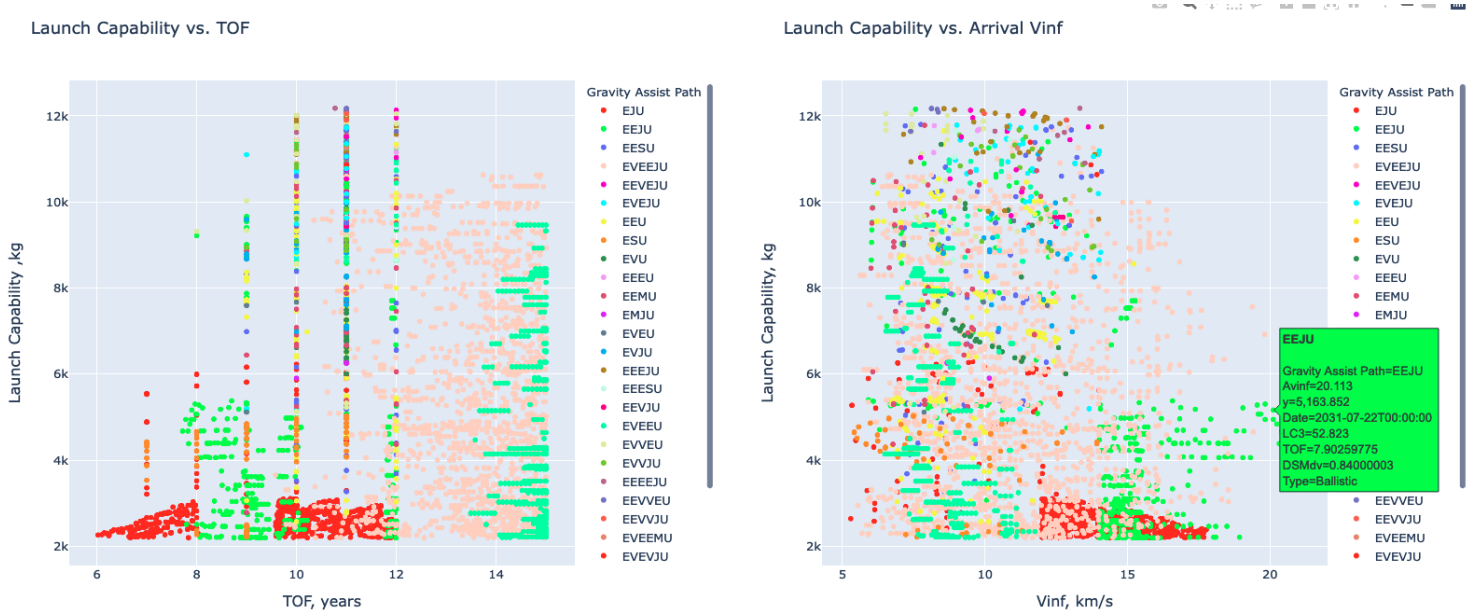
Avinf vs. TOF



Launch Capability vs. Launch Date



For the selected launch vehicle, two additional charts show the trade space of launch capability vs. flight time, and launch capability vs. arrival V_{∞} . Selecting a different launch vehicle automatically updates all the launch capability charts. The search filters applied at the top of the page are applied throughout the page, hence only the trajectories that satisfy the filters are shown in the launch capability charts, and the trajectory search results table at the bottom of the page.



The trajectory search results table at the bottom of the page shows the relevant details of all the trajectories that match the search criteria entered by the user in a paginated tabular format.

Trajectory Search Results

Path	Times	Lcdate	Arrival Date	LC3	TOF	DSMdv
367	2025-04-06 2028-08-17 2032-12-25	4/6/2025	12/25/32	223.783	7.71937029	0.93499998 [-1.6601841449737549 13
367	2025-04-06 2028-08-21 2033-01-04	4/6/2025	1/4/33	223.052	7.7467488	0.93499998 [-1.655523419380188 13
367	2025-04-06 2028-09-06 2033-02-08	4/6/2025	2/8/33	220.242	7.84257358	0.93499998 [-1.639940619468689 13
367	2025-04-06 2028-09-06 2033-02-08	4/6/2025	2/8/33	220.242	7.84257358	0.93499998 [-1.639940619468689 13
367	2025-04-06 2028-09-06 2033-02-28	4/6/2025	2/28/33	220.242	7.8973306	0.93499998 [-1.6271474361419678 12
367	2025-04-06 2028-09-06 2033-02-28	4/6/2025	2/28/33	220.242	7.8973306	0.93499998 [-1.6271474361419678 12
367	2025-04-06 2028-09-10 2033-02-18	4/6/2025	2/18/33	219.568	7.86995209	0.93499998 [-1.6353877782821655 13
367	2025-04-06 2028-09-10 2033-02-18	4/6/2025	2/18/33	219.568	7.86995209	0.93499998 [-1.6353877782821655 13

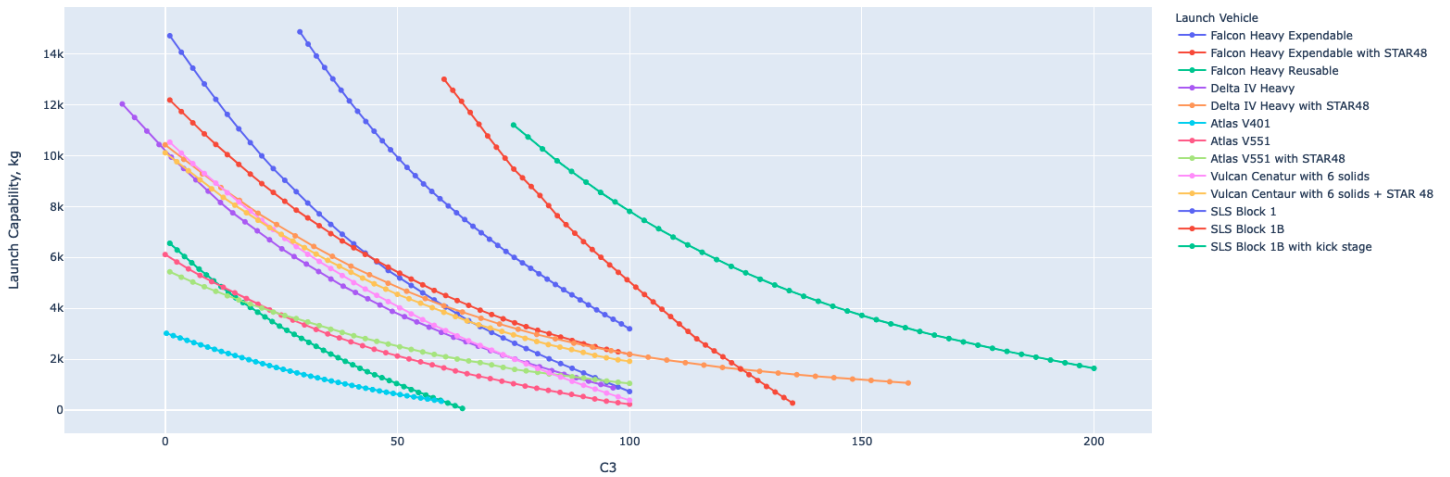
3. Launch Performance

In addition to the launch vehicle capability on the Search Trajectories page, PLASMA also provides a stand-alone performance calculator with data for several launch vehicles [7].

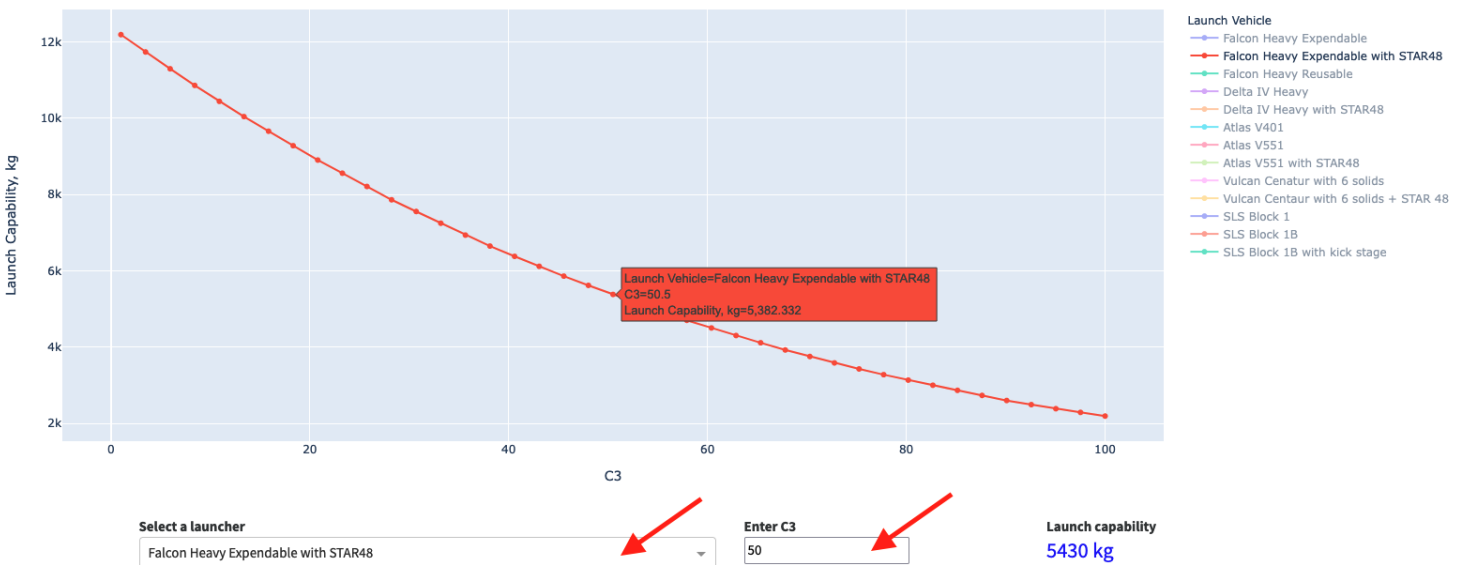
Launch Vehicle Performance Calculator

Available Launch Options

- Falcon Heavy Expendable
- Falcon Heavy Expendable with STAR48
- Falcon Heavy Reusable
- Delta IV Heavy
- Delta IV Heavy with STAR48
- Atlas V401
- Atlas V551
- Atlas V551 with STAR48
- Vulcan Centaur with 6 solids
- Vulcan Centaur with 6 solids + STAR 48
- SLS Block 1
- SLS Block 1B
- SLS Block 1B with kick stage



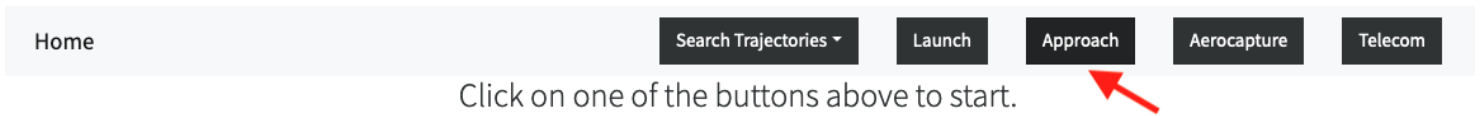
The user can double click on a launcher label on the right to isolate the trace. The user can also select a launcher from the available dropdown list and enter a C_3 to estimate the launch performance.



4. Approach and Orbit Insertion

PLASMA provides a tool to analyze approach and orbit insertion from interplanetary trajectories, which can be accessed by clicking on the "Approach" button on the home page as shown below.

Planetary Science Mission Architecture (PLASMA) Exploration Tool



The tool allows the user to select a planet, enter an arrival V_∞ vector in ICRF, and select an approach type: flyby, atmospheric entry, or orbiter. The user can change the periapsis altitude, and the B-plane angle to achieve all possible approach trajectories as shown in the 3D visualization. For atmospheric entry, a table with the entry state conditions is provided below the 3D viewport.

Approach Trajectory Calculator

Select a planet

Uranus

Enter V_∞ vector, km/s (ICRF)

-9.625,16.511,7.464

Select approach type:

Flyby Atmospheric entry Orbiter

Orbit insertion DV, m/s:

Select periapsis alt., km

-1211

-4000 km +1000 km +4000 km

Select B-plane clock angle., deg

183

0 deg. 90 deg. 180 deg. 270 deg. 360 deg.

Enter orbit apoapsis alt., km

400000

4000 km +900K km +2M km +4M km

Approach Results (Entry state / orbital parameters)

Altitude, km	Longitude, deg (BI)	Latitude, deg (BI)	Speed, km/s (atm. rel)	EFPA, deg. (atm. rel)	Heading angle, deg.
1000	-19.62	47.4	29.25	-20.35	89.17

In addition to providing the atmospheric entry state, PLASMA allows the user to specify a vehicle configuration for an entry probe (mass, diameter, nose radius) and analyze the entry trajectory [8]. The user is provided with the ballistic coefficient for the values entered, and plots of the evolution of altitude, deceleration, heat rate, and heat load as a function of time [9]. Any updates to the inputs at the approach trajectory page (periapsis altitude, B-plane angle etc.) automatically updates the 3D view port, the results table, and the entry trajectory charts. Updating the entry probe design parameters will only update the entry trajectory charts. PLASMA uses the AMAT Python package (<https://pypi.org/project/AMAT/>) [10] to compute the approach trajectory, and the entry trajectory. The tool can be used for comparative studies of atmospheric entry trajectories [11, 12].

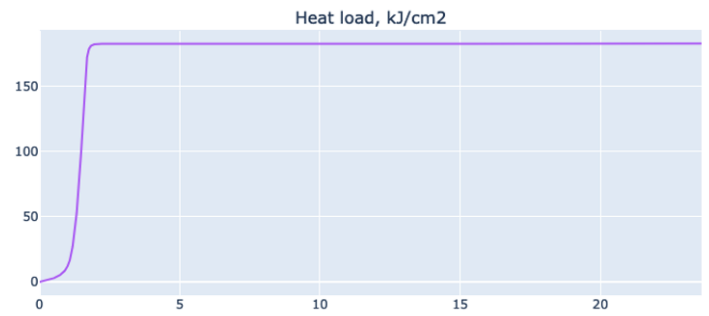
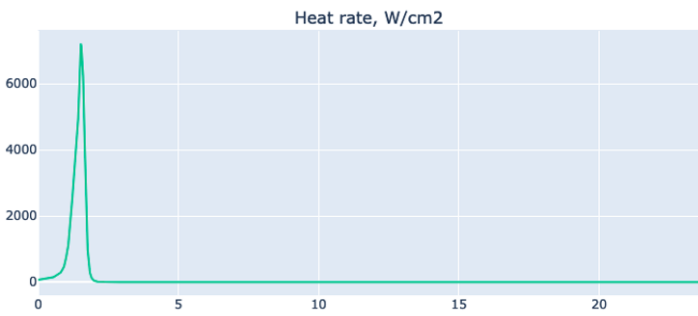
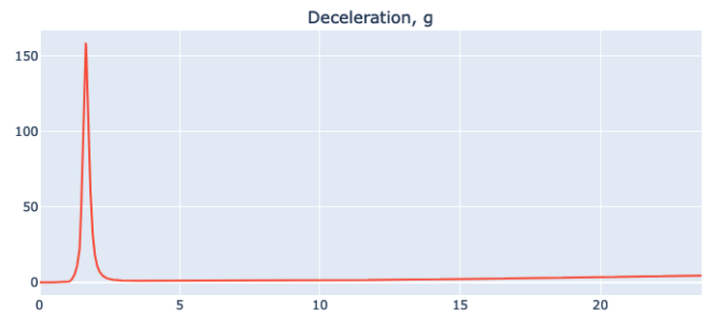
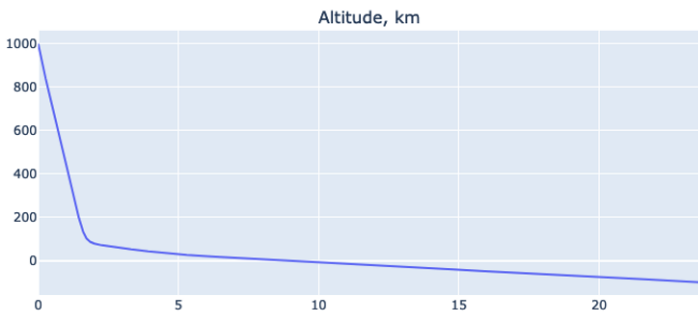
Approach Results (Entry state / orbital parameters)

Altitude, km	Longitude, deg (BI)	Latitude, deg (BI)	Speed, km/s (atm. rel)	EFPA, deg. (atm. rel)	Heading angle, deg.
1000	-19.62	47.4	29.25	-20.35	89.17

Entry probe design parameters

Vehicle mass, kg ← 300
 Vehicle diameter, m ← 1.2
 Vehicle nose radius, m ← 0.2
 Ballistic coefficient, kg/m²: 265.3

Entry Trajectory vs Time (mins)



The user can select the 'Flyby' option for the approach type to visualize the flyby trajectory in

the 3D viewport. Upon selecting the planet and entering a V_{∞} vector, the periapsis altitude and the B-plane angle can be adjusted to obtain any possible flyby trajectory for the given arrival V_{∞} vector.

Approach Trajectory Calculator

Select a planet: Uranus

Enter V_{∞} vector, km/s (ICRF): -9.625,16.511,7.464

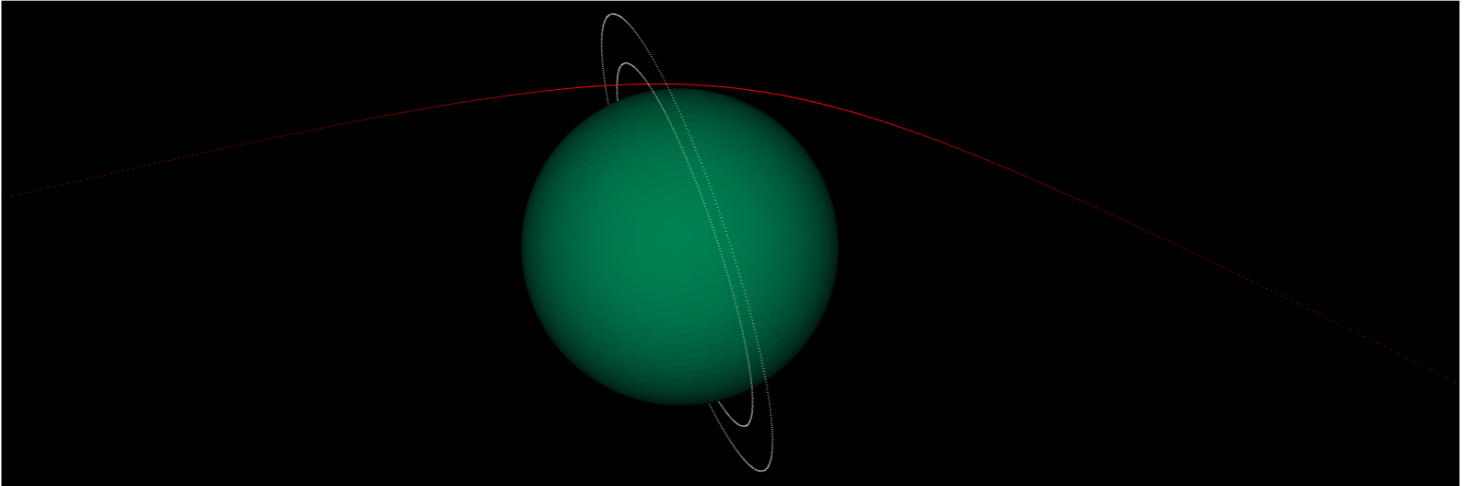
Select approach type: Flyby Atmospheric entry Orbiter

Orbit insertion DV, m/s:

Select periapsis alt., km: 2078

Select B-plane clock angle., deg: 180

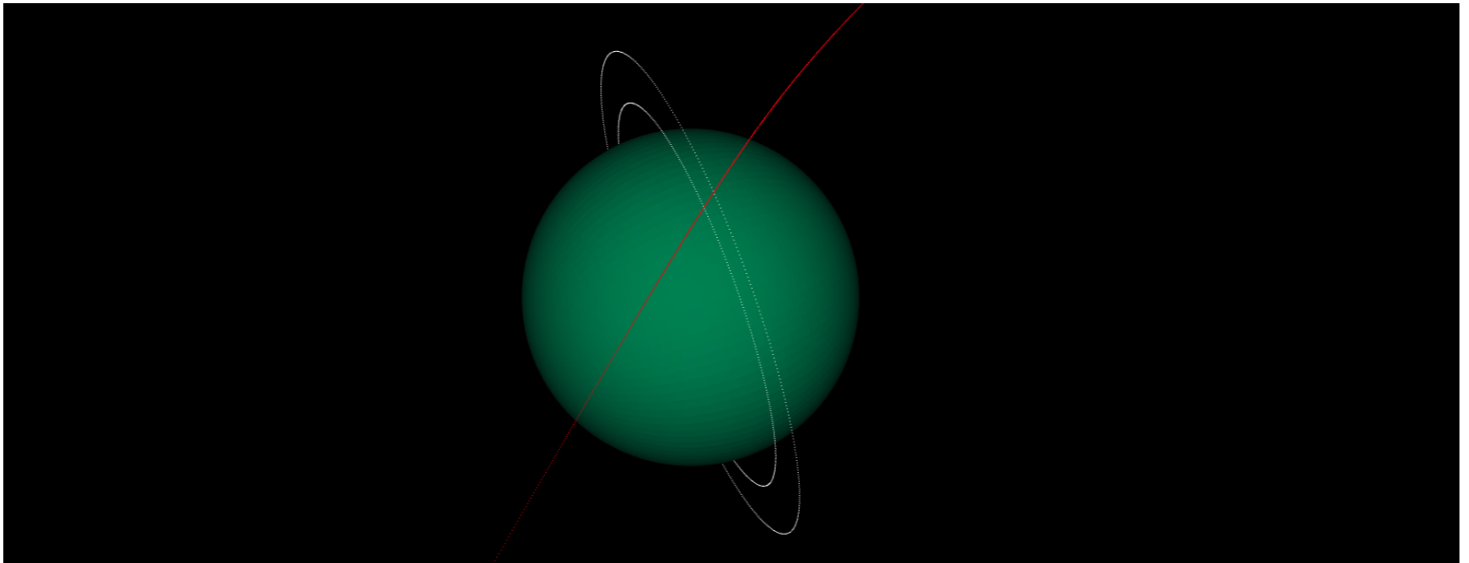
Enter orbit apoapsis alt., km: 400000



Select periapsis alt., km: 2078

Select B-plane clock angle., deg: 270

Enter orbit apoapsis alt., km: 400000



The user can select the 'Orbiter' option for the approach type for an orbiter mission. Upon

selecting the periapsis altitude, B-plane angle, and the apoapsis altitude, the orbit is shown in the 3D viewport, along with the orbit insertion ΔV , and a table below containing the orbital elements. The visualizations from the tool have been used in a Uranus orbiter mission concept study [13].

Approach Trajectory Calculator

Select a planet: Uranus

Enter V_{∞} vector, km/s (ICRF): -9.625,16.511,7.464

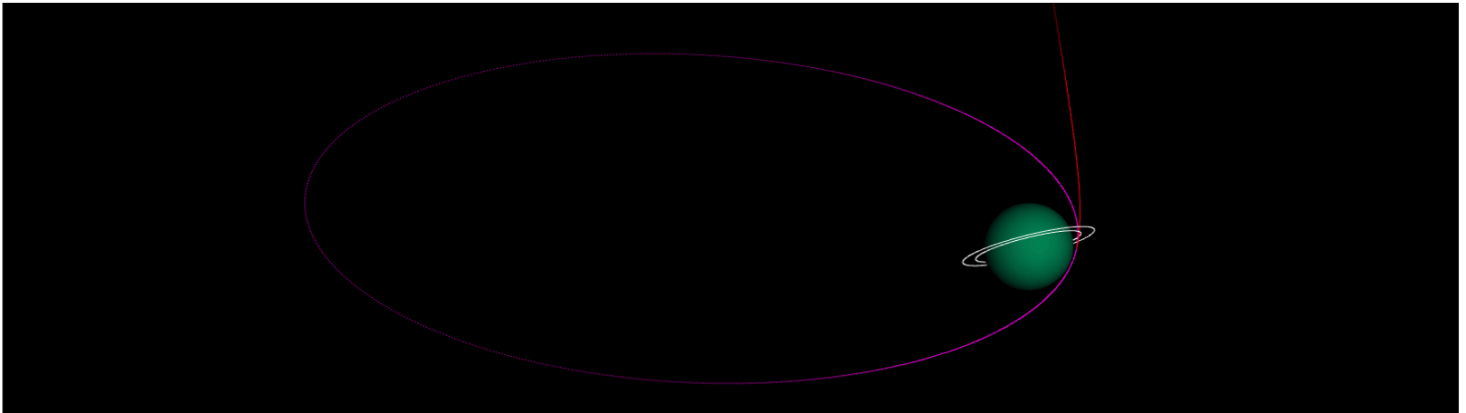
Select approach type: Flyby Atmospheric entry Orbiter

Orbit insertion ΔV , m/s: 9215

Select periapsis alt., km: 2672

Select B-plane clock angle., deg: 270

Enter orbit apoapsis alt., km: 400000



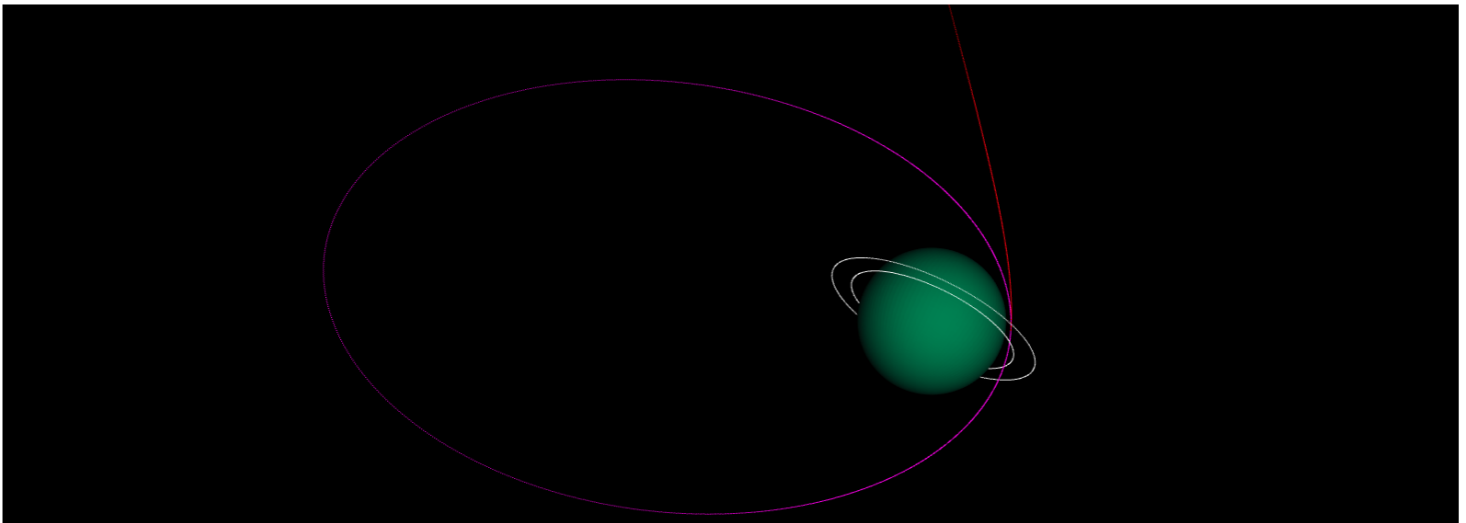
Approach Results (Entry state / orbital parameters)

Perigee, km	Apogee, km	Inclination, deg	RAAN, deg	AoP, deg
2672	184460	88.03	342.52	158.06

Select periapsis alt., km: 2672

Select B-plane clock angle., deg: 183

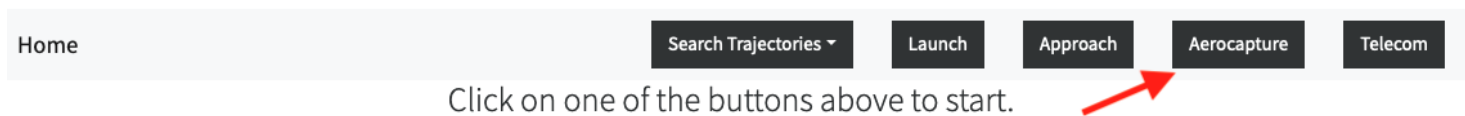
Enter orbit apoapsis alt., km: 184460



5. Aerocapture

PLASMA provides a tool to perform analysis of aerocapture mission concepts [14, 15], which can be accessed by clicking on the "Aerocapture" button on the home page as shown below.

Planetary Science Mission Architecture (PLASMA) Exploration Tool



The user can select a planet from the drop-down list (Venus, Mars, Uranus, Neptune), select the vehicle type (lift or drag modulation [16]), and the target apoapsis altitude for the capture orbit. In addition, the vehicle design parameters such as mass, diameter, L/D or ballistic coefficient ratio can be set. For the vehicle entry conditions, the entry interface altitude and a default entry speed is automatically populated for the selected planet. The user can change the entry speed as needed. Any change to the input values triggers a recalculation of the aerocapture corridor which can take a few seconds. To avoid repeated re-calculation while the inputs are being adjusted, the "Automatic Update" can be set to "Off". It is recommended to keep the setting "Off" while the input configuration is being set. Once all inputs are set, it can be set to "On" and the automatic calculation will resume. For the selected configuration, the overshoot, undershoot limits and the corridor width are shown.

Aerocapture Trajectory Calculator

Select a planet: Uranus

Select vehicle type: Lift Modulation Drag Modulation

Target apoapsis altitude, km: 450000

Vehicle design parameters:

- Vehicle mass, kg: 3000
- Vehicle diameter, m: 4.5
- Vehicle nose radius, m: 1
- Lift-to-drag ratio, L/D: 0.36
- Ballistic coefficient ratio, (DM): 7
- Ballistic coefficient, kg/m²: 188.6

Vehicle entry conditions:

- Altitude, km: 1000
- Longitude, deg: 0
- Latitude, deg: 0
- Atm. rel. speed, km/s: 28
- Heading, deg: 0

Overshoot limit, deg: -9.211

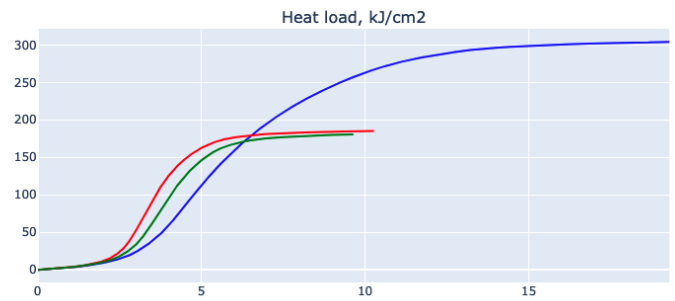
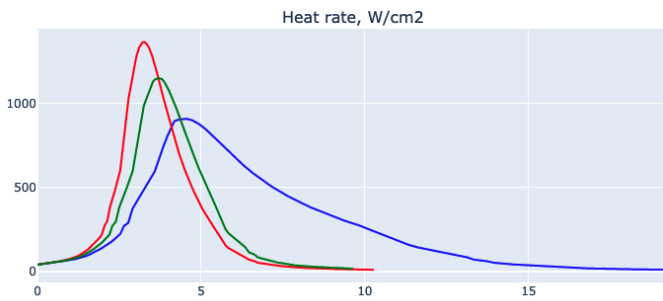
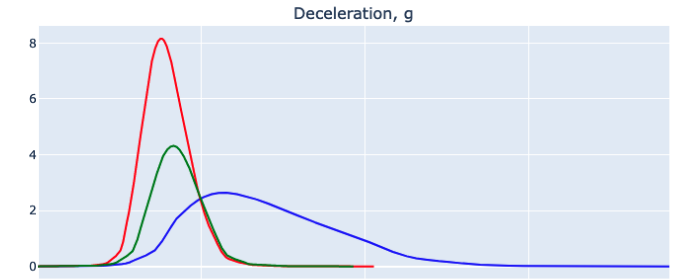
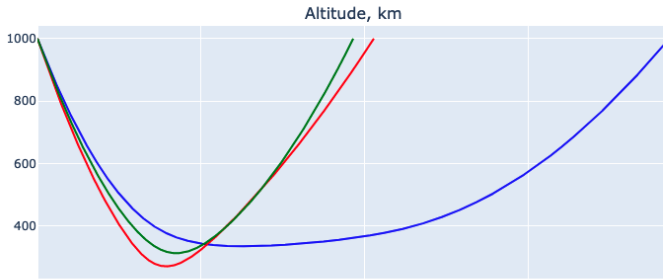
Undershoot limit, deg: -10.575

Corridor width, deg: 1.36

Automatic Update: On Off

For the selected configuration of a lift modulation vehicle with $L/D = 0.36$ entering Uranus at 28 km/s, charts of the trajectory altitude, deceleration, heat rate, and heat load are shown [17, 18].

Undershoot [red], nominal [green] and overshoot [blue] trajectories vs time (min)



The tool can also be used to analyze other mission concepts [19, 20]. The configuration for a drag modulation vehicle with $\beta_2/\beta_1 = 7$ entering Venus at 11 km/s targeting a 400 km apoapsis is shown below, along with the computed available corridor which to accommodate uncertainties [21].

Aerocapture Trajectory Calculator

Select a planet: →

Select vehicle type: Lift Modulation Drag Modulation →

Target apoapsis altitude, km: ○

Vehicle design parameters

Vehicle mass, kg:

Lift-to-drag ratio, L/D:

Vehicle diameter, m:

Ballistic coefficient ratio, (DM): →

Vehicle nose radius, m:

Ballistic coefficient, kg/m²:

Vehicle entry conditions

Altitude, km:

Longitude, deg:

Latitude, deg:

Atm. rel. speed, km/s:

Heading, deg:

Overshoot limit, deg:

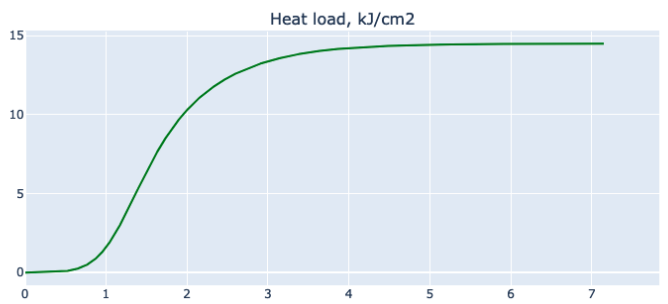
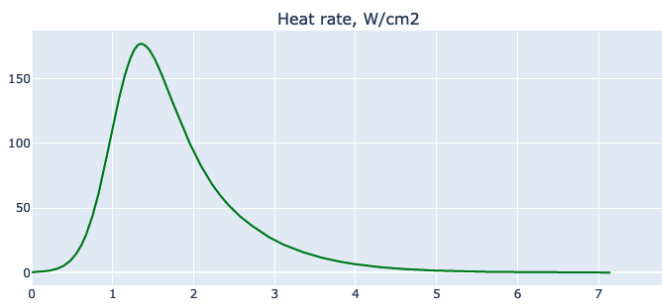
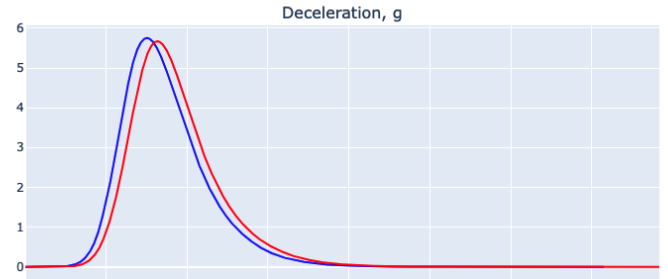
Undershoot limit, deg:

Corridor width, deg:

Automatic Update: On Off

The computed trajectory, deceleration, heat rate and heat load charts for the small satellite drag modulation aerocapture configuration at Venus in the earlier figure are shown below.

Undershoot [red], nominal [green] and overshoot [blue] trajectories vs time (min)



6. Telecom

PLASMA provides a tool to perform link budget analysis, which can be accessed by clicking on the "Telecom" button on the home page. The tool includes several preset link budgets which the user can use as a starting point. Upon entering values for the frequency, transmit power, transmit gain, range, the data rate and the E_b/N_0 required, the available E_b/N_0 and the margin are displayed. The outputs are automatically updated when the link budget input configuration is adjusted.

Link Budget Calculator

Automatic Update: [?](#)
 On Off

Presets: [?](#)
 Cassini Downlink Cassini-Huygens Relay Oceanus Downlink Oceanus Saturn Probe Relay Oceanus Uranus Probe Relay Dragonfly DTE

Frequency, GHz ? 8.425	Transmit power, W ? 20	Transmitter gain, dBi ? 47.2	Receiver gain, dBi 68.24	System Noise Temp., K 40.5
Range, km 1500000000	Transmitter Loss, dB 1	S/C Circuit Loss, dB 0.2	Atmospheric loss, dB 0.35	Other losses, dB 0.55
DSN system loss, dB 1	Data rate, kbps 14	E_b/N_0 required 0.31	E_b/N_0 : 1.94	E_b/N_0 margin: 1.63

7. Summary

The pilot phase study has been completed and a proof-of-concept version of the PLASMA tool has been developed and made available for use online at <http://45.56.66.11/>[‡]. PLASMA currently has an interplanetary trajectory database for Uranus, a launch vehicle performance calculator, an approach and orbit insertion calculator, an aerocapture tool, and a link budget analysis tool. Future phases of the project will expand the interplanetary trajectory dataset to include more Solar System destinations, add more mission design capabilities, and improve the overall end user experience.

Acknowledgements

We would like to thank Mr. Eric Ianson, Deputy Director of the Planetary Science Division of the Science Mission Directorate at NASA Headquarters for supporting this research work.

[‡]Accessible until June 30, 2024

Appendix A: Video Tutorials

Two video tutorial presentations are available for the PLASMA pilot phase[§]:

- Short presentation with automated voice over (7 minutes). [\[Google Drive Link\]](#).
- More detailed presentation by Tyler Hook (15 minutes). [\[Google Drive Link\]](#).

Appendix B: Conference Presentations

- Hook, T. E., Giriya, A. P., Saikia, S. J., Longuski, J. M., Cutts, J. A., & Matousek, S. E. (2023). JPL-Purdue Rapid Mission Design Pilot Study. 54th Lunar and Planetary Science Conference 2023, The Woodlands, TX. (LPI Contrib. No. 2806). [\[Abstract\]](#). [\[e-Poster PDF\]](#)

[§]Google Drive links available until June 30, 2024.

References

- [1] National Academies of Sciences, *Vision and Voyages for Planetary Science in the Decade 2013-2022*, National Academies Press, 2012.
- [2] Girija, A. P., “Aerocapture Design Reference Missions for Solar System Exploration: from Venus to Neptune,” *arXiv preprint arXiv:2308.10384*, 2023. doi:10.48550/arXiv.2308.10384.
- [3] National Academies of Sciences, *Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032*, National Academies Press, 2022.
- [4] Girija, A. P., “ADEPT Drag Modulation Aerocapture: Applications for Future Titan Exploration,” *arXiv preprint arXiv:2306.10412*, 2023. doi:10.48550/arXiv.2306.10412.
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