



UCF

Beyond the One-Pass Probe

A Fixed-Wing UAV for Long-Duration In-Situ Exploration of Uranus

K. Johnson, P. do Vale Periera
University of Central Florida



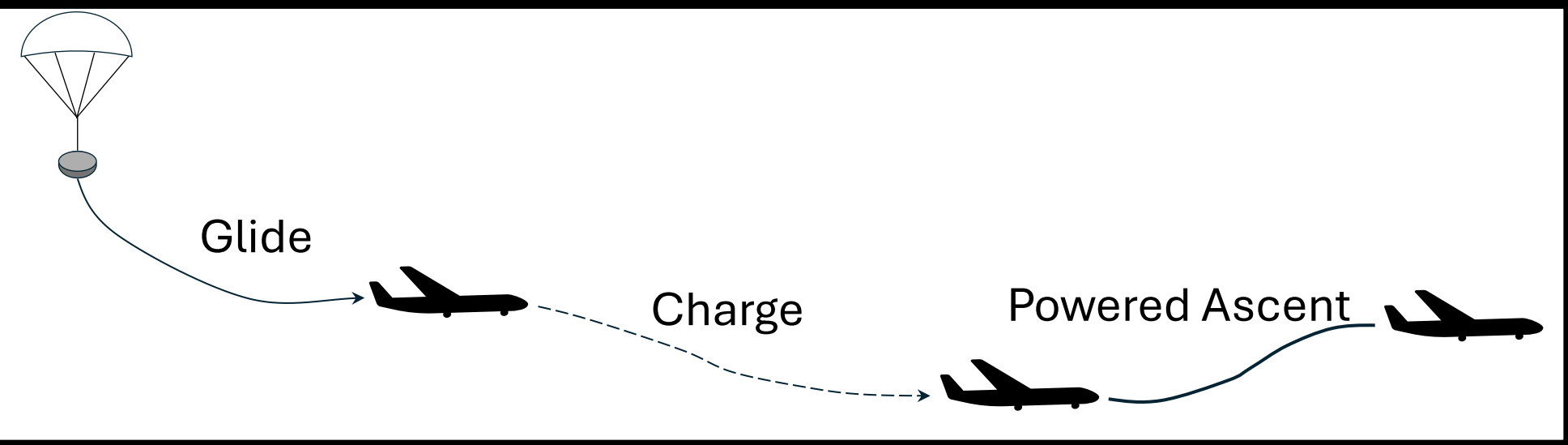
UCF

Introduction

Understanding the atmospheres of ice giants like Uranus is a key priority for planetary science. Despite their scientific richness, these environments remain largely unexplored in situ. To date, only two atmospheric probes have returned data from gas giants or moons — **Galileo** at Jupiter and **Huygens** at Titan — both surviving just hours before succumbing to extreme conditions ([1], [2]).

The **2023–2032 Planetary Decadal Survey** prioritizes a **Uranus Orbiter and Probe**, recognizing the critical need for direct atmospheric sampling at an ice giant ([5]). However, short-lived drop probes provide only vertical, time-limited snapshots, constraining our ability to understand regional and temporal variability.

This work proposes a new paradigm: a **fixed-wing, powered UAV** for Uranus capable of sustained flight and autonomous navigation. Leveraging **the fixed wing frame**, a hybrid power system, and novel heat retention this platform could deliver **30+ days** of in-situ science, offering a transformative approach to atmospheric exploration. ([3],[4])



Motivation

- Uranus is the least explored planet** in the Solar System—last visited by Voyager 2 in 1986.
- No in situ atmospheric measurements** have ever been made beyond Jupiter.
- Ice giants are **key to understanding planetary formation**, both in our system and exoplanetary systems.
- In situ data provides **ground truth** for remote sensing and climate models.
- UAVs enable **4D sampling** (vertical + horizontal + time) across dynamic atmospheric layers.
- Supports high-priority goals in the **Planetary Science Decadal Survey (2023–2032)**.
- Direct exploration of Uranus addresses **fundamental science questions** about climate, composition, and magnetism.

Science Targets

Science Target	Objective	UAV-Enabled Capability
Atmospheric Structure	Measure vertical profiles of temperature, pressure, and winds	Repeatable profiling across altitudes and regions
Gas Composition	Determine abundances of H ₂ , He, CH ₄ , NH ₃ , etc.	Spatially diverse and multi-altitude sampling
Cloud & Aerosols	Characterize cloud layers and haze particle properties	In-layer traversal and loitering for detailed microphysics
Atmospheric Dynamics	Study wind shear, turbulence, and wave activity	Persistent, guided flight enables weather tracking and dynamic sampling
Ortho/Para H ₂ Ratio	Trace atmospheric mixing and thermodynamic history	Sampling over pressure and latitude gradients
Energy Balance	Measure thermal emission and infer heat transport mechanisms	Radiative flux mapping during steady horizontal flight

Vehicle Concept

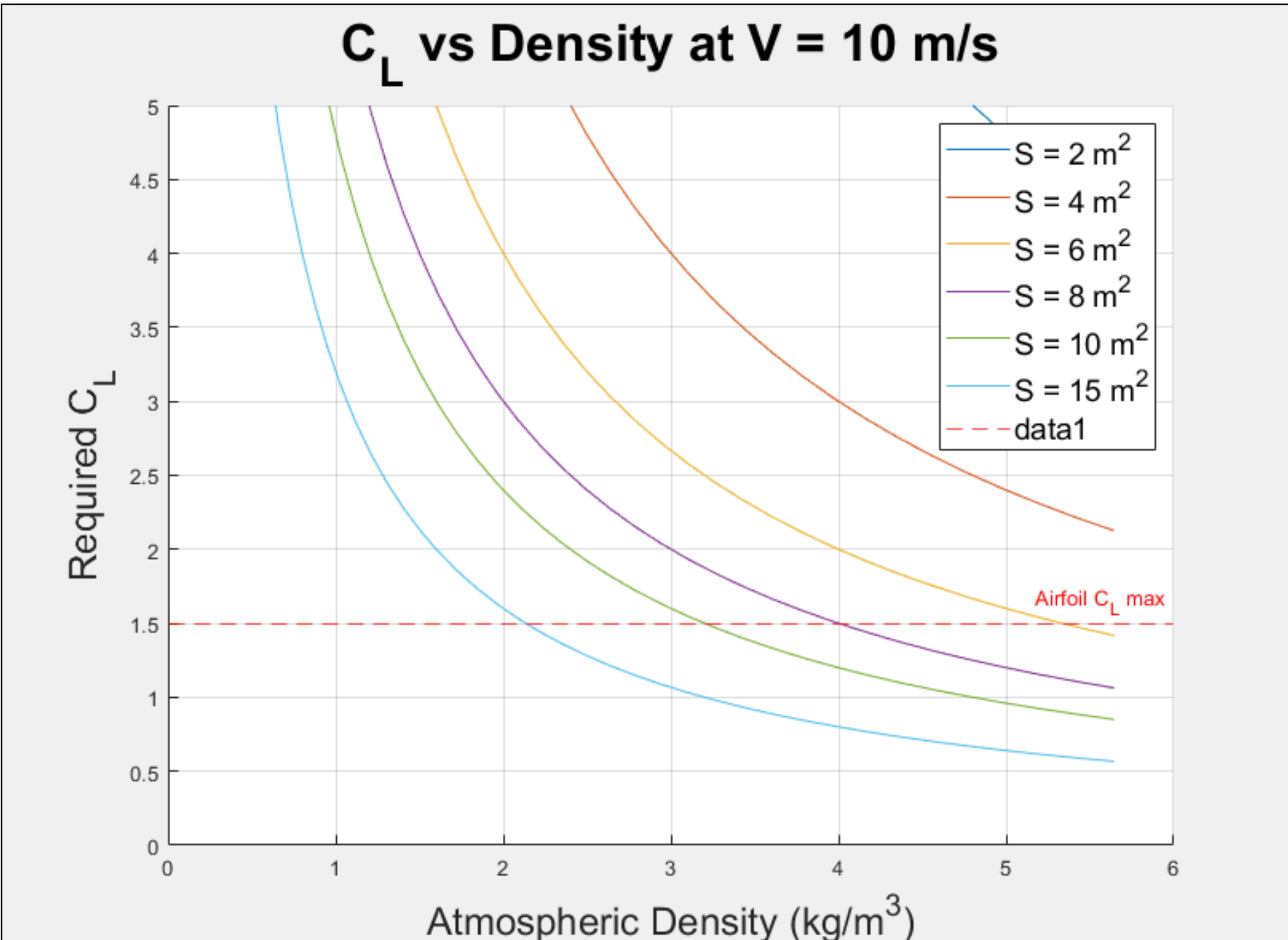
The notional **Uranus UAV** is a fixed-wing, powered aerial platform designed for extended flight in the planet’s upper atmosphere. Total system mass is estimated to be **~326 kg**, including an entry aeroshell and parachute system for atmospheric insertion.

A hybrid power approach is baselined: a **radioisotope power source** (RPS) provides continuous energy with batteries to handle peak loads (~1 kW during bursts; ~0.3 kW average). The science payload, selected based on [6], draws ~30–70 W and includes instruments for composition, clouds, and atmospheric structure, duty cycled as needed. Entry is via parachute, followed by autonomous glide-out and powered cruise.

Subsystems	Weight (kg)	Power Draw (W)	Data Rate (bps)
Instruments			
• <i>Mass Spectrometer</i>	17.3	41	885
• <i>Atmospheric Structure Inst.</i>	2.5	10	18.5
• <i>Nephelometer</i>	4.4	11.3	10
• <i>Ortho-Para H₂ Analyzer</i>	3.5	1	10
• <i>Net-Flux Radiometer</i>	2.4	5.2	124
• <i>Helium Abundance Detector</i>	1.4	0.9	2
Structure	60		
Power			
• <i>RTG (Next Gen Mod 2)</i>	56	(400)	
• <i>Batteries</i>	30		
Communication	5.3		
Avionics	2.6	26.2	
Propulsion	10	200	
Entry	121.2		

Environmental Challenges

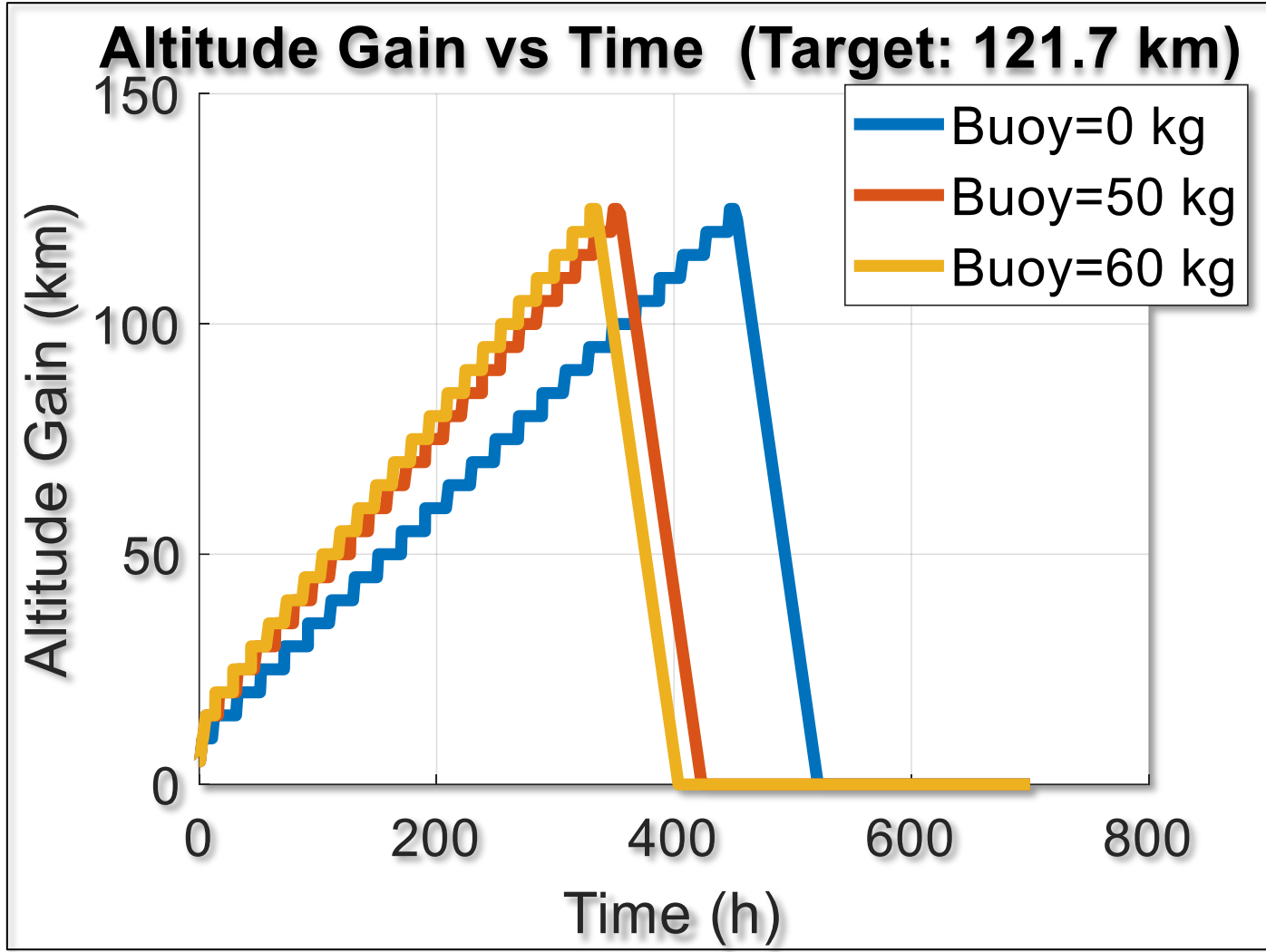
- **Extreme Cold**
 - Atmospheric temperatures can drop below **80 K** near the tropopause.
 - Requires advanced thermal insulation and/or active heating (e.g., RTG waste heat recovery).
- **High Wind Speeds**
 - Zonal wind speeds may exceed **250 m/s** at cloud-top levels.
 - UAV must be capable of flying **into strong shear layers** and maintaining control in gusty flows.
- **Unknown Density Gradients**
 - Atmospheric structure is poorly constrained below 1 bar.
 - UAV must adapt to **unexpected changes in lift and drag forces** during descent and cruise.
 - Lower atmosphere projects 4x density of Earth, enabling slower steady-level flight
- **Limited Communication Windows**
 - Long round-trip light time (~5.3 hours) to Earth limits real-time command.
 - Demands **autonomous navigation and control** for flight and science operations.



Curves show C_L profile for a given span width at different atmospheric densities. Redline is used to show what a standard airfoil’s max C_L typically is

Mission Profile

The proposed mission features a fixed-wing UAV designed to sustain long-duration flight within Uranus’s hydrogen-rich, cryogenic atmosphere. After deployment at high altitude (~0.5 bar), the UAV descends gradually to denser atmospheric layers (approaching ~20 bar), where **increased air density provides enhanced aerodynamic lift and buoyant support**, enabling it to operate efficiently while charging its onboard batteries using a hybrid RTG-battery system. Once charged, the UAV initiates a **stairstep ascent**—climbing in stages while harvesting solar or waste heat energy and optimizing buoyancy through onboard heating of atmospheric hydrogen. This cycle of powered descent and staged ascent repeats, enabling **continuous atmospheric profiling and long-term scientific observation** over extended mission durations.



Conclusions

This study proposes a powered fixed-wing UAV capable of sustained flight in Uranus’s upper atmosphere—enabling **30+ days of in-situ science**, a dramatic improvement over the <3-hour lifetimes of past probes like Galileo and Huygens. By integrating structured duty cycling, a continuous RTG power source, low drag design, and a stair-step mission profile, science return and duration are drastically improved. Our notional design addresses critical challenges in **thermal protection, energy management, and guidance**, showing that long-duration, intelligent flight is not only feasible but transformative.

This platform redefines how we explore ice giant atmospheres—shifting from one-time snapshots to sustained, adaptive observations.

Future Work

We are advancing a feasible UAV architecture for sustained atmospheric flight at Uranus, with emphasis on **power, thermal protection, and aerodynamic performance**. Current efforts include finalizing the **link budgets**, optimizing **duty cycling**, and evaluating effects of buoyancy through **heated gas** on the system. We are also refining **aero-thermal models**, including 3D CFD, to validate vehicle behavior. These developments will support future mission proposals aligned with NASA’s ice giant exploration goals.

References

1. Young, R.E., et al., *Science*, **272**, 837–839, 1996.
2. Lebreton, J.-P., et al., *Nature*, **438**, 758–764, 2005.
3. Braun, R.D., et al., *J. Spacecraft Rockets*, **43**(5), 1026–1035, 2006.
4. Bessette, E., et al., AIAA SciTech 2022, Paper 2022-0250.
5. National Academies of Sciences, *Planetary Science and Astrobiology Decadal Survey: 2023–2032*, 2022.
6. Hofstadter, M.D., et al., *Ice Giants Pre-Decadal Study: Final Report*, JPL D-100520, 2017.