Exploring Venus' Atmosphere with a Semi-buoyant Air Vehicle

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Lifting Entry/Atmospheric Flight (LEAF) Systems

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LEAF on Venus - VAMP

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LEAF System Overview (Lifting Entry/Atmospheric Flight)

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What is LEAF?

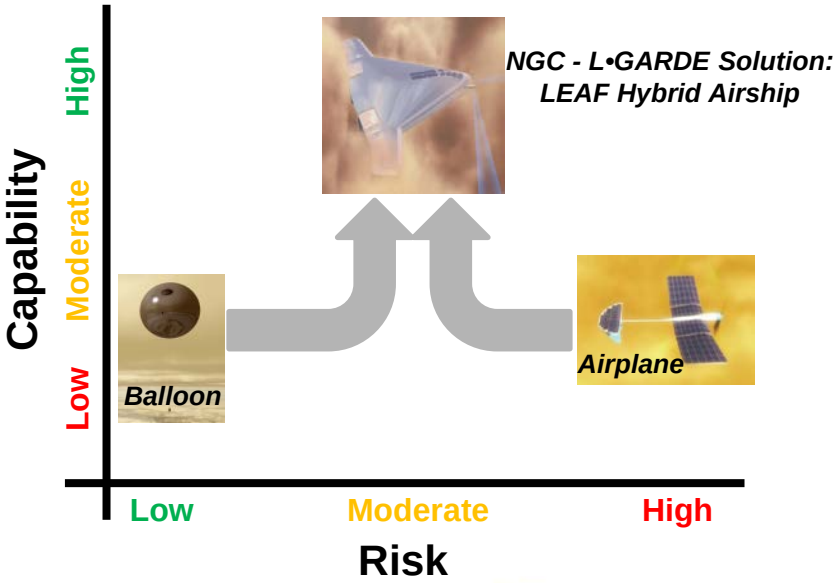
The LEAF system is an atmospheric rover for solar system bodies that combines the low risk attributes of a balloon with the maneuverability of an airplane into an integrated entry and flight package.

LEAF Key Features

- ***Benign entry:*** ultra-low ballistic coefficient lifting entry
- ***Atmospheric mobility:*** electric propellers, rudders, elevons
- ***Long-lived:*** limited only by membrane permeability
- ***Large payload capability:*** tradable with altitude range
- ***Controlled in space deployment:*** attached to carrier spacecraft
- ***Semi-buoyant:*** ~10-100% at operational altitudes
- ***Power source:*** combination of solar, RPS, battery, depending on specific target body

The Innovation

(As Formulated Originally for Venus)



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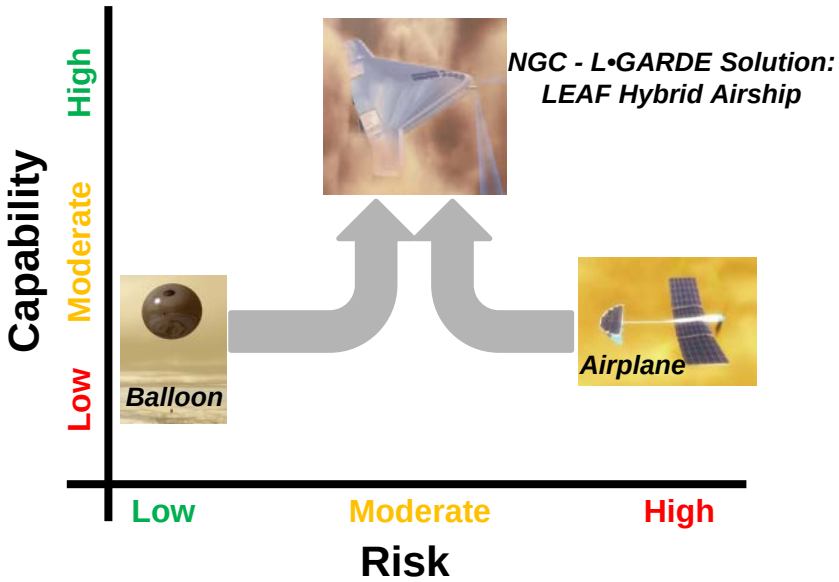
LEAF System Overview Continued

The Innovation

(As Formulated Originally for Venus)



LEAF Capabilities

The first planetary exploration "Sky Rover"

- Lifetime of months to years for extended science ops
- 3D (latitude, longitude, altitude) directional control

Maximizes payload accommodation

- Benign entry eliminates large mass impact of aeroshell
- Enhanced payload mass and power capability compared to balloons and deployable aircraft
- Payload mass and power are flexible and tradable with vehicle altitude performance
- Some instruments can safely operate during benign entry phase

LEAF Risk Advantages

Safe mode / power failure / propulsion failure all produce passively floating state

- Sinks to altitude of 100% buoyancy (51 km on Venus)
- Time for recovery limited only by violent weather patterns (>30 days until swept into polar vortex hurricane on Venus)

Reduces number of mission critical events

- Deploys and checks out slowly while in orbit, prior to atmospheric entry
- Entry is slow and generates minimal loads
- Simple day/night concept of operation and power cycling

Terrestrial demos can retire most technology risks

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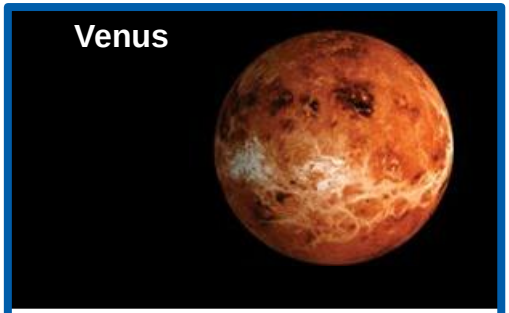
LEAF Targets and Missions

- The LEAF concept is applicable to any solar system body with an atmosphere
- The current mission targets include

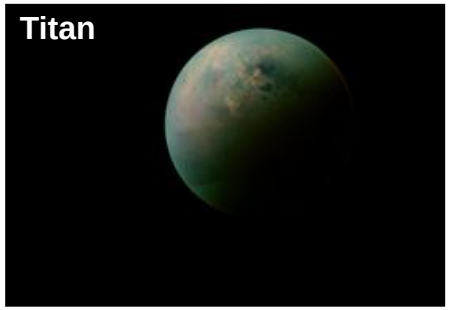


- Long duration flight at variable altitudes with revisit capability
- Atmospheric formation and evolution
- Characterization of atmospheric super-rotation and global circulation
- Determination of the temporal composition of “greenhouse” aerosols and gases

Current Focus Area: VAMP

- High altitude atmospheric science
- Surface science and/or support
- ISS experiment return
- Astronaut emergency return
- Low-g life science experiment return

- Controlled, targeted delivery of cargo(e.g., rovers, landers, supplies, etc.) to surface
- Maneuverable glider



- Long-lived flight at low altitudes with revisit capability
- High resolution surface imaging
- In-situ measurements of precipitation, fog, volcanism, etc
- Controlled, targeted delivery of boats/landers to surface

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Venus Atmospheric Maneuverable Platform (VAMP) Background and Overview

- Over the past years we have investigated a possible new approach to Venus upper atmosphere exploration by applying recent, non-NASA, Northrop Grumman and L•GARDE development programs to the challenges associated with Venus upper atmosphere science missions. Our concept is:
  - A ultra-low ballistic coefficient ($\beta < 10$ kg/m^2), semi-buoyant air vehicle
  - Deploys prior to entering the Venus atmosphere
  - Enters the atmosphere without heavy aeroshell
  - Provides a long-lived (months to years) maneuverable science platform capable of
    - Changing altitude between ~51 and 68 km
    - Steering in latitude to carry out science investigations of the Venus upper and middle cloud layers

- VAMP development is continuing and expanding in 2014, addressing all design aspects of the concept from orbit delivery, packaging and deployment, detailed planform shape, entry physics, flight performance, science payload accommodations, mission concept of operations, and end of mission possibilities.

- The following charts show intermediate results and potential capabilities from our study focusing on Venus atmospheric investigation

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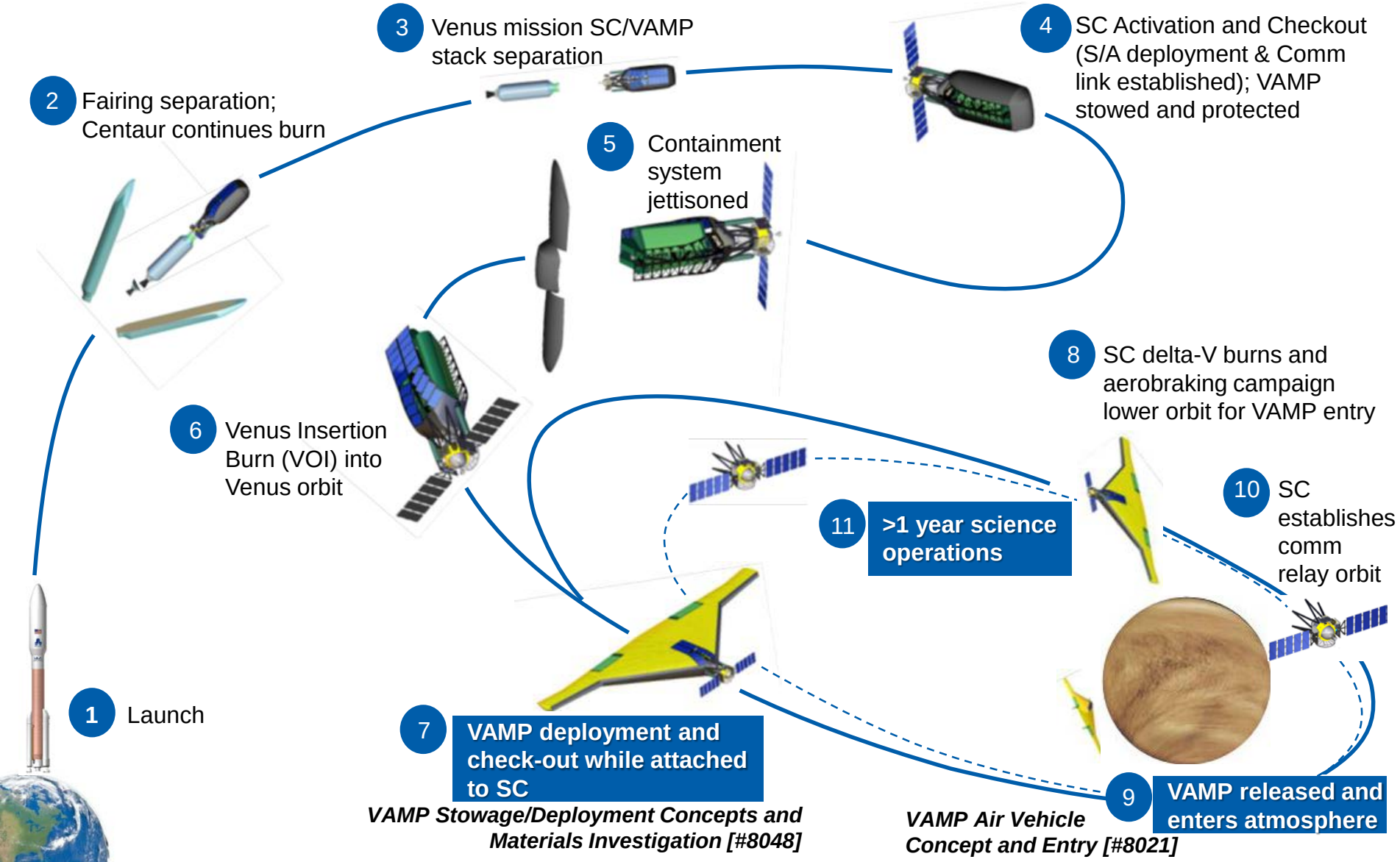
Notional VAMP Mission Sequence



VAMP Stowage/Deployment Concepts and Materials Investigation [#8048]

VAMP Air Vehicle Concept and Entry [#8021]

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VAMP Air Vehicle Parameters (As of June 2014)

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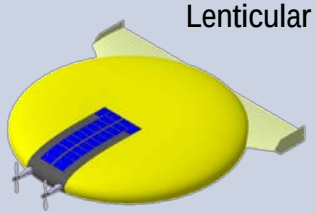
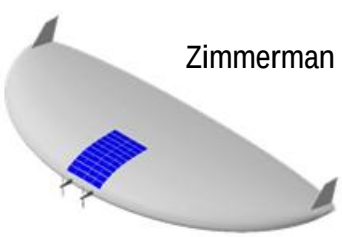
Planforms Under Consideration

Delta

Lenticular



Zimmerman



Parameter	Current Value or Range	Comments
Vehicle		
Wingspan	25-45 meters	Shape dependent
Length	15-25 meters	Shape dependent
Vehicle Mass	500-900 kg	Shape, structure, membrane, and TPS material dependent
Solar Array Power	> 8 kW	Dependent upon details of planform and solar cells
Minimum (100% buoyant) Altitude	51 to 54 km (BOL) ~49 km (EOL)	Drives Maximum Altitude Along with Percent Buoyancy Set by atmospheric environment
Maximum Altitude	65-68 km	Design and science dependent
Buoyancy Gas	H_2	
Buoyancy at Max Altitude	9% to 15%	Initial value, buoyancy will decline with lifetime due to loss of buoyancy gas
Maximum Speed	10-30 m/s	Depends upon shape and buoyancy
Maximum Climb/Fall rate	1 km in 3 minutes	At 55 km altitude
Payload Accommodation		
Mass	>50 kg	50 kg is a planning number. Mass is very dependent upon vehicle flight performance parameters (altitude, speed, etc), vehicle mass, etc. Payload mass will be refined as the design matures.
Power	TBD	Awaiting strawman payload assessment
Volume	> 10 cu. meters	
Data rate to orbiter	~2 Mbps	
Data rate direct to Earth	0.1-1 Mbps	Range dependent
Science Payloads Under Consideration		
TBD cameras	Aerosol Collector Pyrolyzer and Gas Chromatograph Mass Spectrometer	
Noble Gas Mass spectrometer	Polarization Nephelometer	
TBD Meteorological payload	3-D Ultrasonic Anemometer	
Attenuated Total Reflection	Electric Field Sensor	
UV Spectrometer	Optical Microscope	

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VAMP Deploys Slowly and Methodically To Assure Successful Deployment

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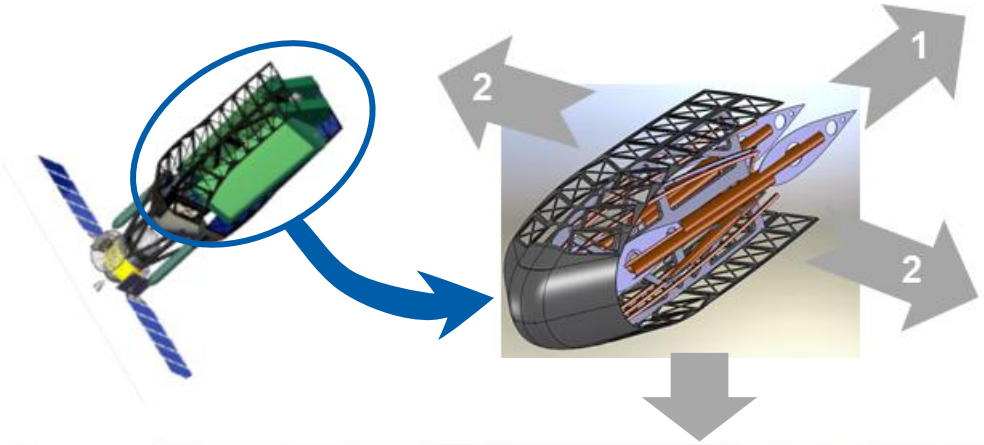
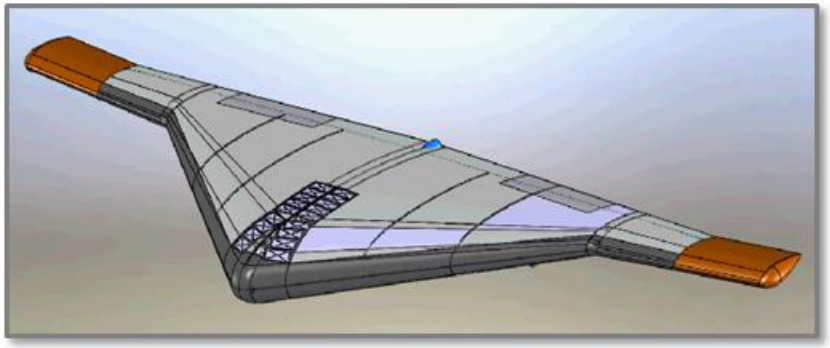
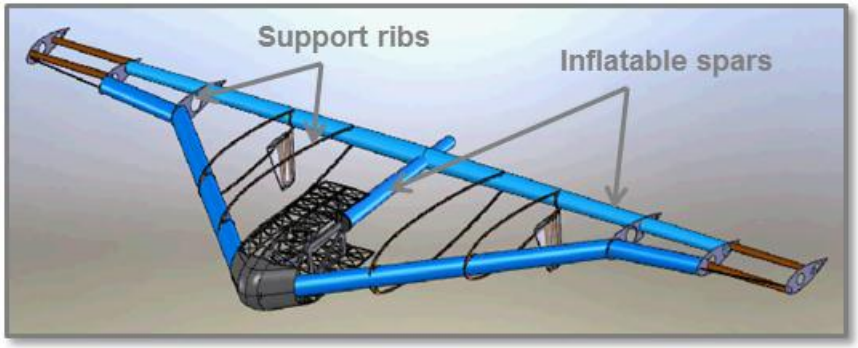
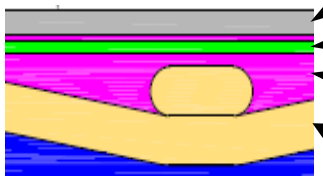
- Deploys in space while it is attached to the orbiter
- Deployment is driven by pressure inflation of spars using H_2
- Deployable membrane laminate is based on prior balloon membrane work

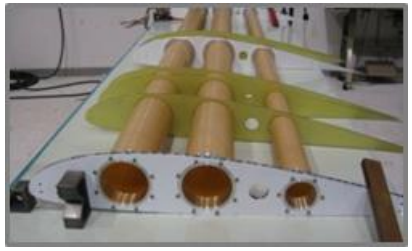








Prototype Membrane Deployment*



Prototype Deployed Wing*

Deployable Spar

* Developed on previous non-NASA projects

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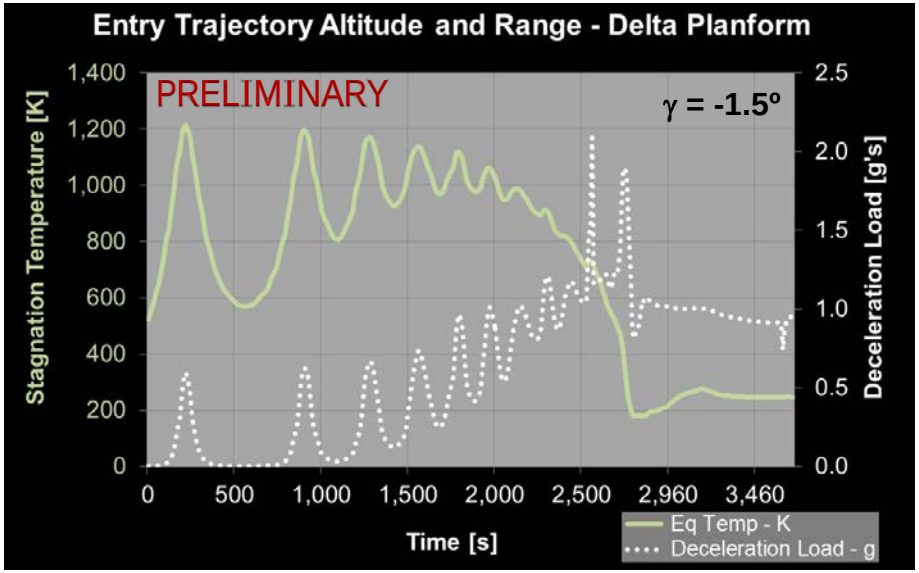
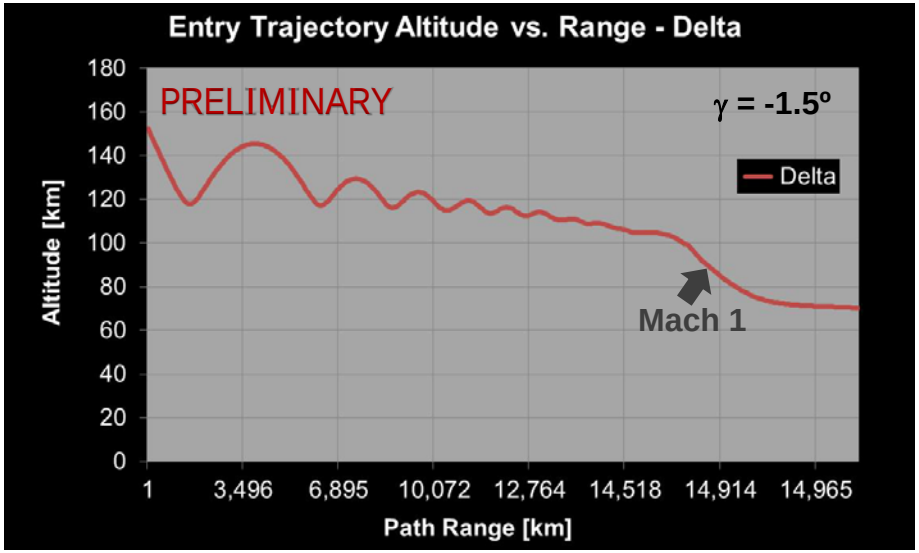
VAMP's Ballistic Coefficient Design Space and Lift-to-Drag Characteristics Enable Benign Entry

- VAMP's large area and low mass result in ultra-low ballistic coefficient (< 10 kg/m^2)
- Ultra-low β, in turn, enables benign entry conditions thereby reducing thermal and deceleration load requirements
  - Thermal heating loads are relatively low, with maximum stagnation temperature reaching ~1200 K for few hundred second intervals
  - Likewise, the deceleration loads are low, peaking ~2 g's
- The expectation is that science remote sensing and in situ sampling could occur during entry with path lengths of thousands of kilometers between an altitude of 120 km and the float possible.
  - Although dependent on the planform and entry specifics, our analysis shows that during entry the vehicle reaches Mach 2 ~100 km altitude and becomes subsonic ~90 km altitude (~46 minutes after entry)





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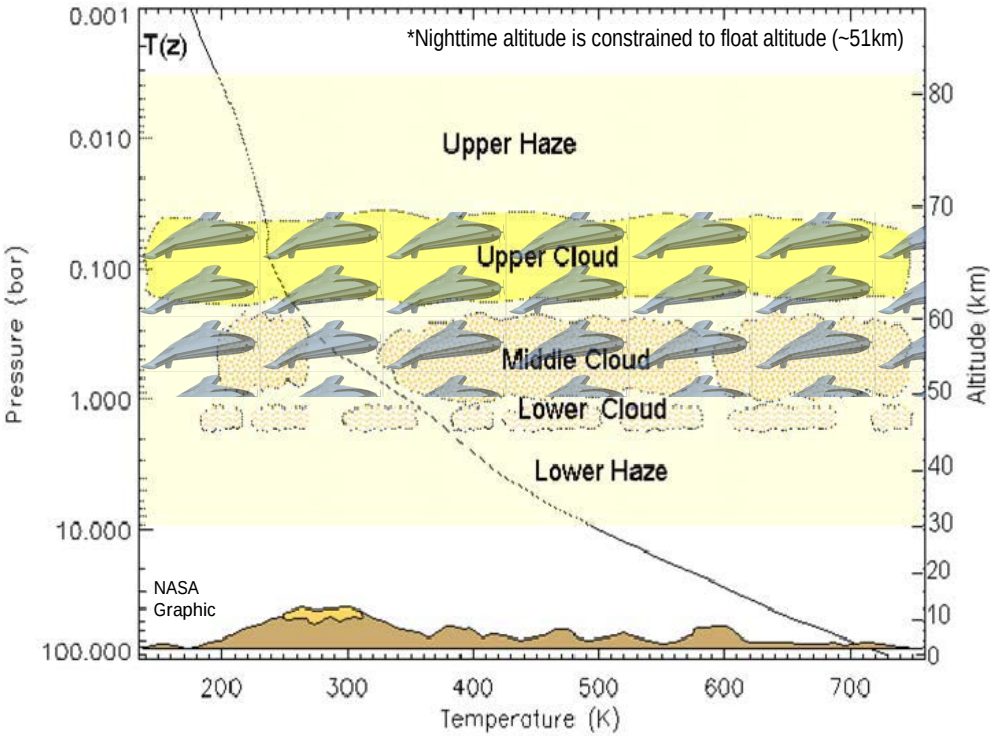
VAMP Baseline Science Capability
Exploration Domain

- VAMP is a highly versatile science vehicle that can be tailored to perform a number of Venus atmosphere missions
- To simplify development, our LEAF team has focused upon a "Pathfinder" VAMP that is designed with a focused science goal:
  - *to serve as a flying/floating laboratory for the long duration (up to 1 year) investigation of the Venus Upper and Middle Cloud layers*
- Once the pathfinder VAMP is mature we will look to expand capabilities for application at Venus and for other solar system bodies.

VAMP's Daytime Target Domain*



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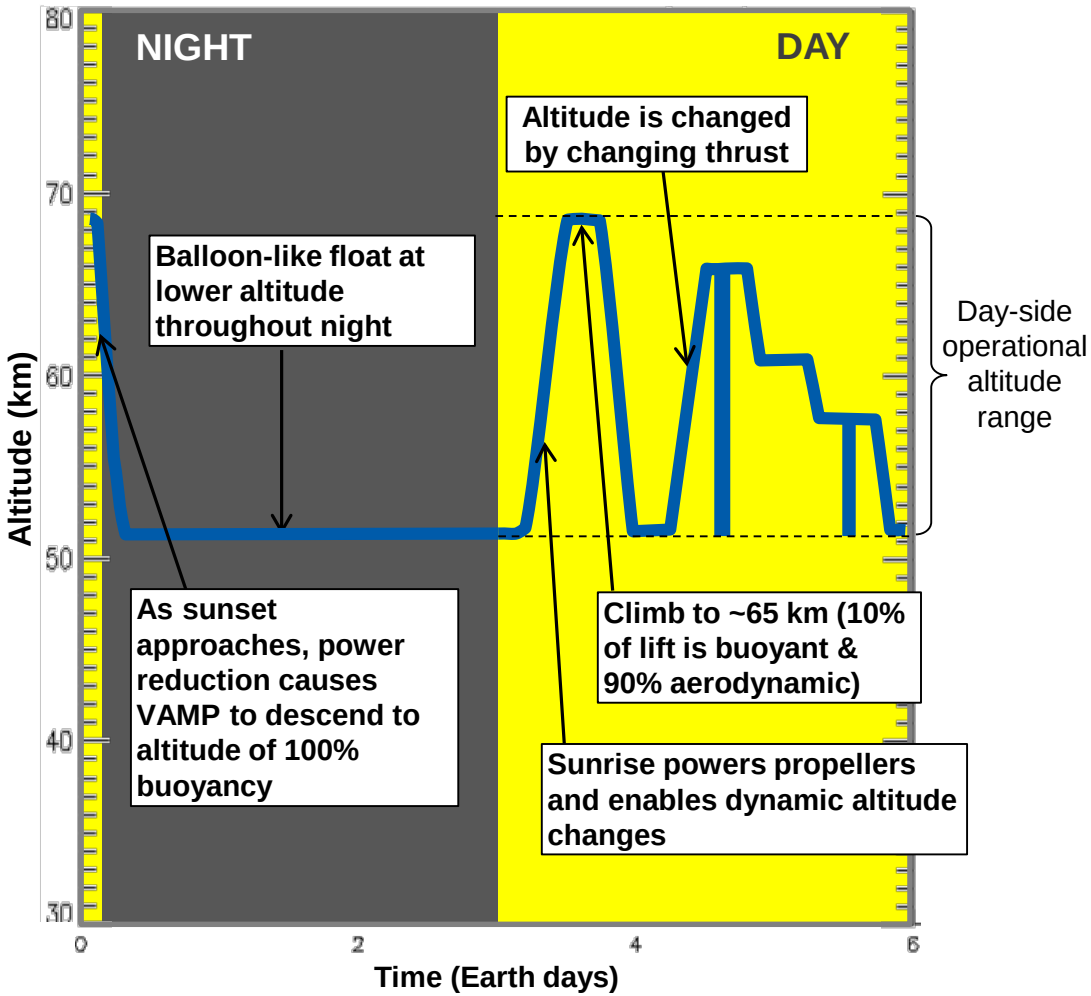
VAMP Baseline Science Capability

Day/Night Operations

- During night time there is insufficient power to generate aerodynamic lift so the vehicle will settle to its 100% buoyant, float altitude until sunrise
  - While there is insufficient power for propulsion at night, it is anticipated that there will be enough power to some instruments for periods of time during the night cycle
- During day time, solar arrays on the vehicle provide power to the propellers, producing lift as the airfoil moves through the Venus atmosphere
  - Varying the power to the propellers allows VAMP to fly at any altitude between the float altitude (low-50's km) to the peak altitude of 65-68 km
  - A level altitude can be sustained throughout the dayside or the altitude can be varied to achieve mission science goals

Example Altitude Trajectory for a Venus Circuit



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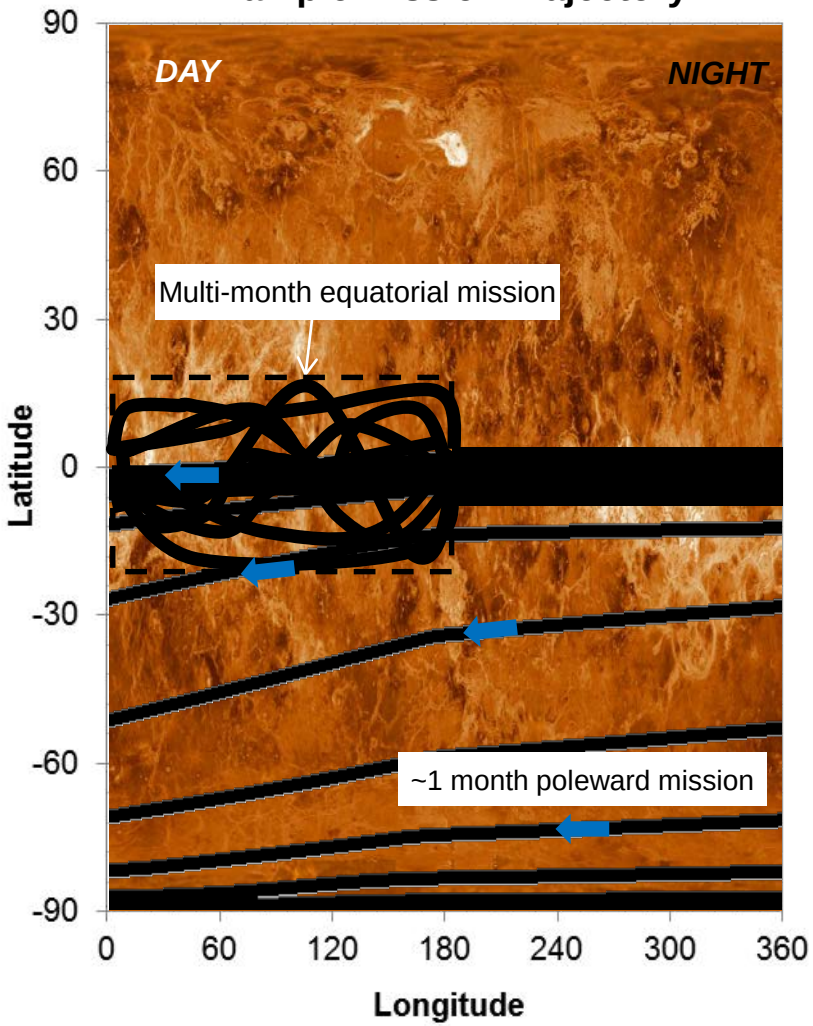
VAMP Baseline Science Capability

Latitude/Longitude Performance

- During the day VAMP will be able to fly faster than the meridional winds and should be able to maintain or change latitude
- But the vehicle speed will be insufficient to overpower the zonal winds so the vehicle will sweep around the planet every 6-7 days
- It is expected that VAMP would also be able to return to the same general latitude and longitude area on successive circuits if scientifically desired
- VAMP should be able to stay within an equatorial band (~ ±30°) for months to a year
  - The actual latitude range will be dependent upon flight performance (primarily a function of planform and solar array power) and the actual wind structure on Venus

Example Mission Trajectory



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VAMP Next Steps

- The Northrop Grumman/ L•GARDE team is continuing the development of VAMP in 2014 and expects to continue the maturation of the concept and the technology that would be needed to support it in future years

- VAMP is a concept in development and as such all parameters and characteristics are currently evolving
  - We anticipate having our first end-to-end quantitative assessment of VAMP by the end of 2014
  - In 2015, we plan to continue the technical development and begin building engineering components and prototypes for ground tests including wind tunnels, arc jets and atmospheric chamber tests

- We welcome dialog with the science and engineering/technology communities to help us evolve and mature the VAMP concept

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Additional VAMP information at Poster Sessions

- *Venus Atmospheric Maneuverable Platform (VAMP) — Air Vehicle Concept and Entry CONOPs* [#8021]
  - This presentation discusses the continued development of the Northrop Grumman/ L•GARDE team's long-lived, maneuverable platform to explore the Venus upper atmosphere. It focuses on the air vehicle design and entry CONOPs and their interdependencies.

- *Venus Atmospheric Maneuverable Platform (VAMP) — Stowage/Deployment Concepts and Materials Investigation* [#8048]
  - This presentation discusses the continued development of the Northrop Grumman/ L•GARDE team's long-lived, maneuverable platform to explore the Venus upper atmosphere. It focuses on vehicle stowage and deployment concepts, and materials investigation.

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