PROJECT PHOENIX

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Introductions

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Mechanical Engineering - Computer Science

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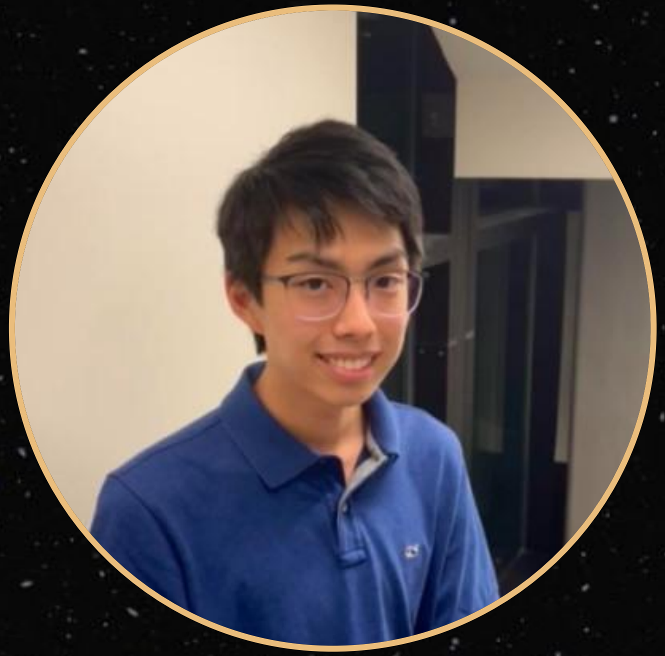

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Applied Math - Computer Science

01 Mission Goals

Mission Statement

We aim to investigate the specific mechanisms of Venus's superrotation by measuring vertical momentum transfer through updrafts over extreme geological formations. Our mission will deploy an orbiter and three specialized gliders to collect comparative wind velocity data at 50km altitude above three distinct topographical features—Maat Mons, Maxwell Montes, and Phoebe Regio—to determine how planetary-scale topography influences atmospheric dynamics and contributes to the 60-day superrotation phenomenon.

Why Venus’ Superrotation

Venus's superrotation presents one of the most significant unsolved mysteries in planetary science. While superrotation exists on several bodies in our solar system, Venus's atmosphere circulates 60 times faster than the planet itself rotates—a phenomenon that defies current atmospheric models. By investigating how geological formations create updrafts that potentially transfer momentum between atmospheric layers, we will:

- Identify mechanisms that maintain atmospheric angular momentum against friction
- Determine how localized topographical features influence global circulation patterns
- Provide critical data to constrain and improve climate models for Venus and exoplanets
- Advance our understanding of extreme climate phenomena relevant to Earth's changing climate

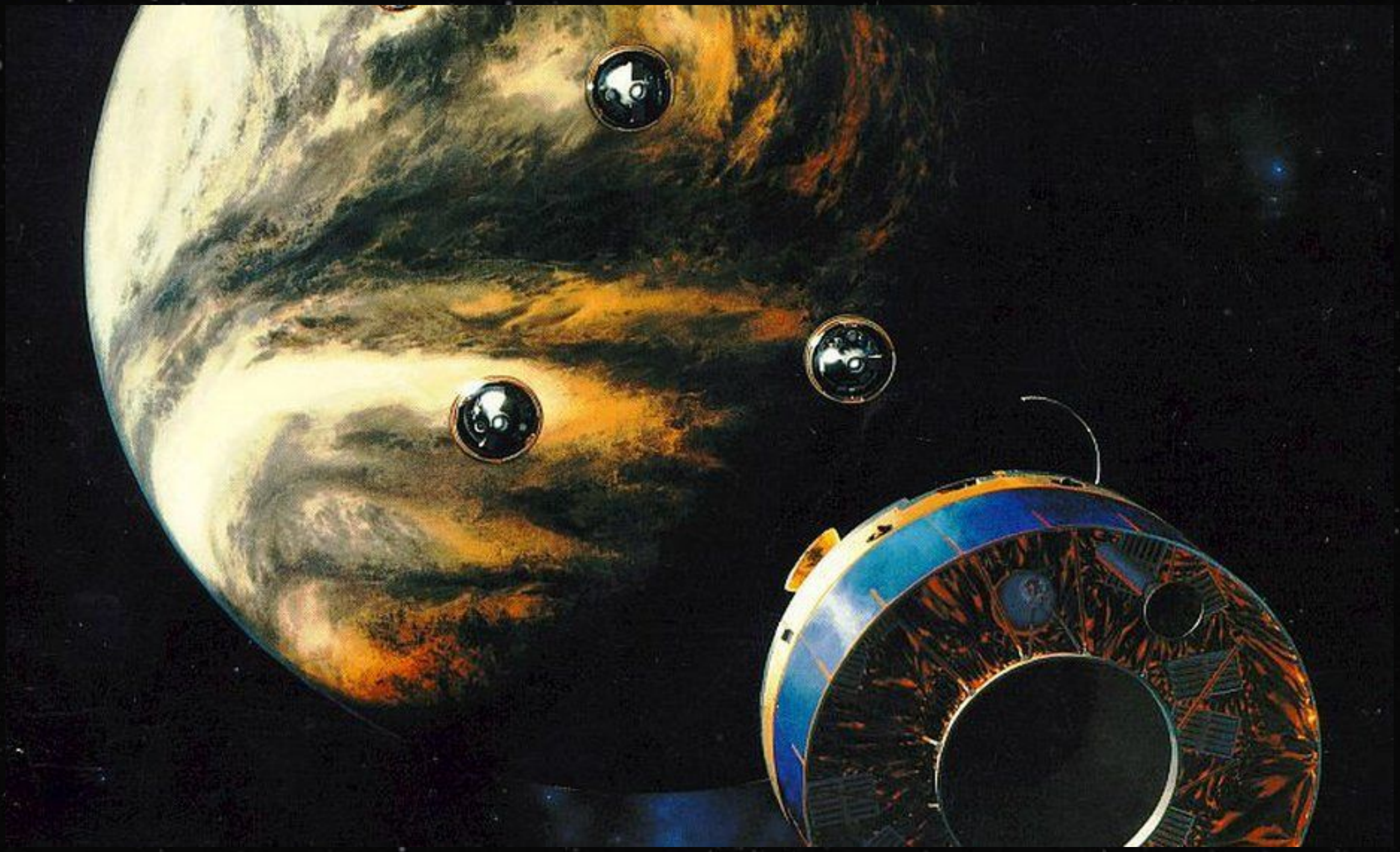
Our Focus

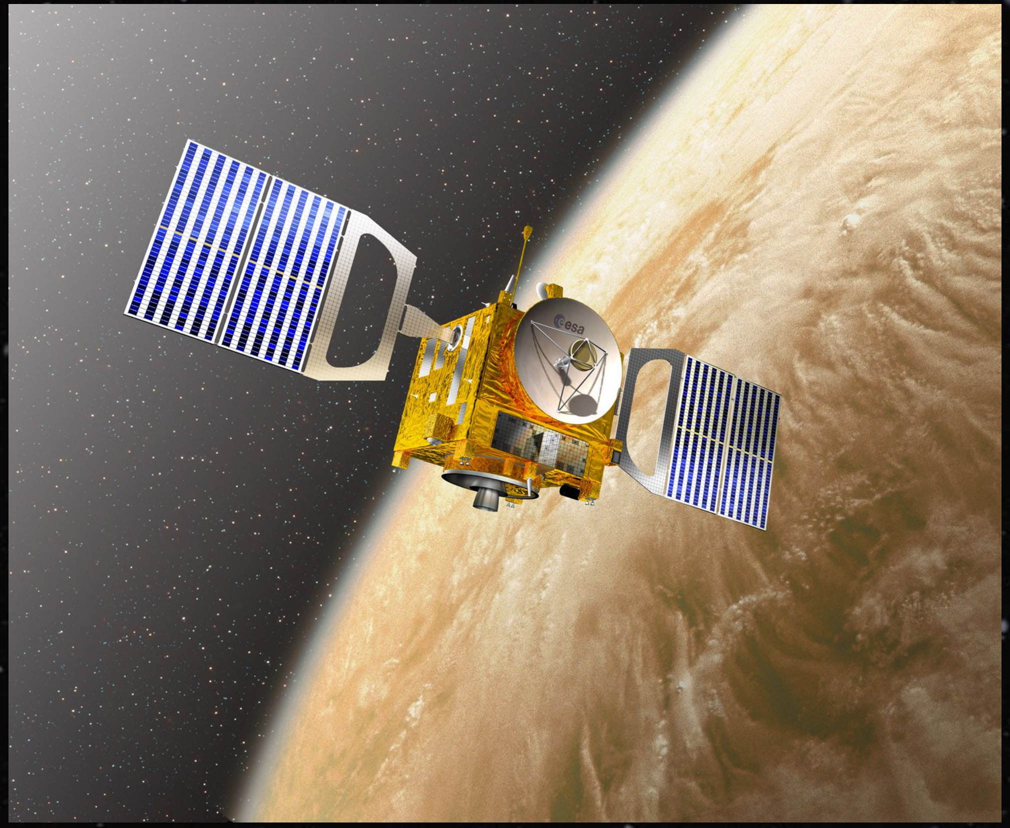
Our build focuses specifically on the directional communications system between gliders and orbiter—a mission-critical subsystem enabling data transfer despite extreme atmospheric conditions, high winds, and continuous relative motion between spacecraft. This communications architecture represents the highest technical risk and greatest innovation in our mission design, requiring stabilized pointing in 60 m/s winds.

Top Level Requirements

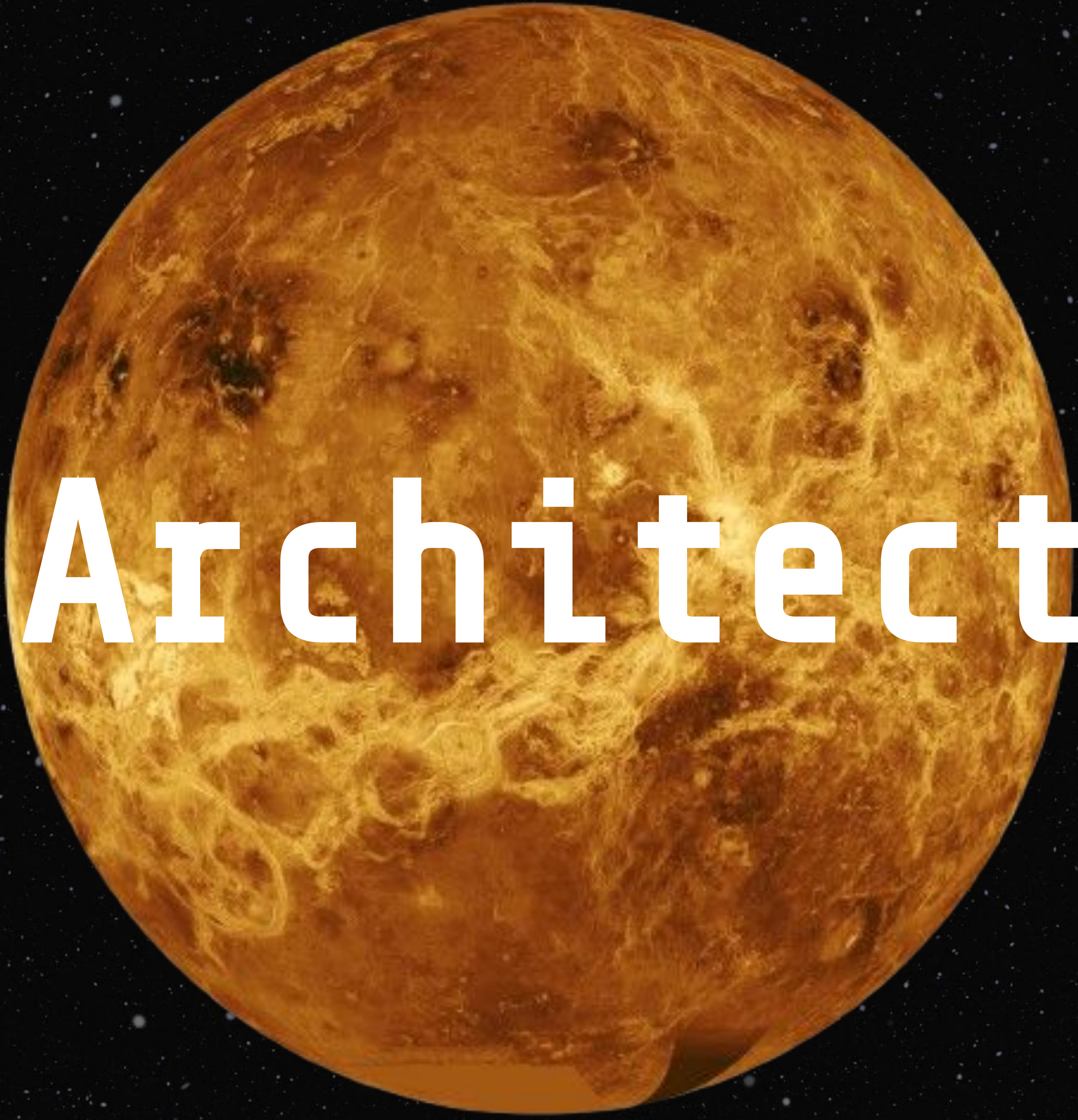
1. Launch orbiter into stable Venusian orbit
2. Deploy drones to collect data
   a. Place drones in key locations with high altitude to investigate super-rotation
   b. Transmit data from drones

Visual Inspiration





02 Architecture



Mission Architecture/Tradeoff Process

To decide the appropriate path for our mission architecture/design, we considered the following questions:

1. **Overall Mission -** What orbiter/deployable data collection structure best suits our mission?
2. **Deployable Structure -** What deployable architecture (winged, balloon, or drone) would allow for the most data to be collected?
3. **Operating Altitude -** What operating altitude will our deployable operate at? What are the environmental conditions we are willing to handle?
4. **Subsystem Decisions -** What subsystem choices will be most cost effective and suitable for our mission for the drone?

Mission Architecture/Tradeoff Process

For each of our overall mission questions we follow a 3 Step Process:

1. **Requirements** - What do we need from this aspect of the mission to achieve our goals?
2. **Tradeoffs** - What are the benefits and drawbacks of each potential approach
3. **Selection** - What approach did we choose and why, design ramifications

Overall Mission Requirements

- What orbiter/deployable data collection structure best suits our mission?
  - Currently, it is difficult to model how the venusian atmosphere acts below the cloud layer
  - Data that must be collected to draw new conclusions about superrotation
    - Altitude:30 km - 55 km (To see below cloud layer)
    - Data Types:
      - East-west and north-south wind speeds to track atmospheric momentum transfer. (Necessary to characterize atmospheric motion)
      - Magnetic and thermal data (Would be nice to investigate effects of sun and solar winds)
    - Locations:
      - Variety of longitudes - equatorial, polar regions
      - Variety of altitudes - mountain regions
    - Collection Time:
      - At mid atmospheric range, to go across Venus' largest mountain range, Data collection time minimum = (530 miles)/(134mph) = 3 hours 57 minutes = = 14220s
      - Data collected = 64.8 + 4.3 = 69.1 kB (See bit budget)

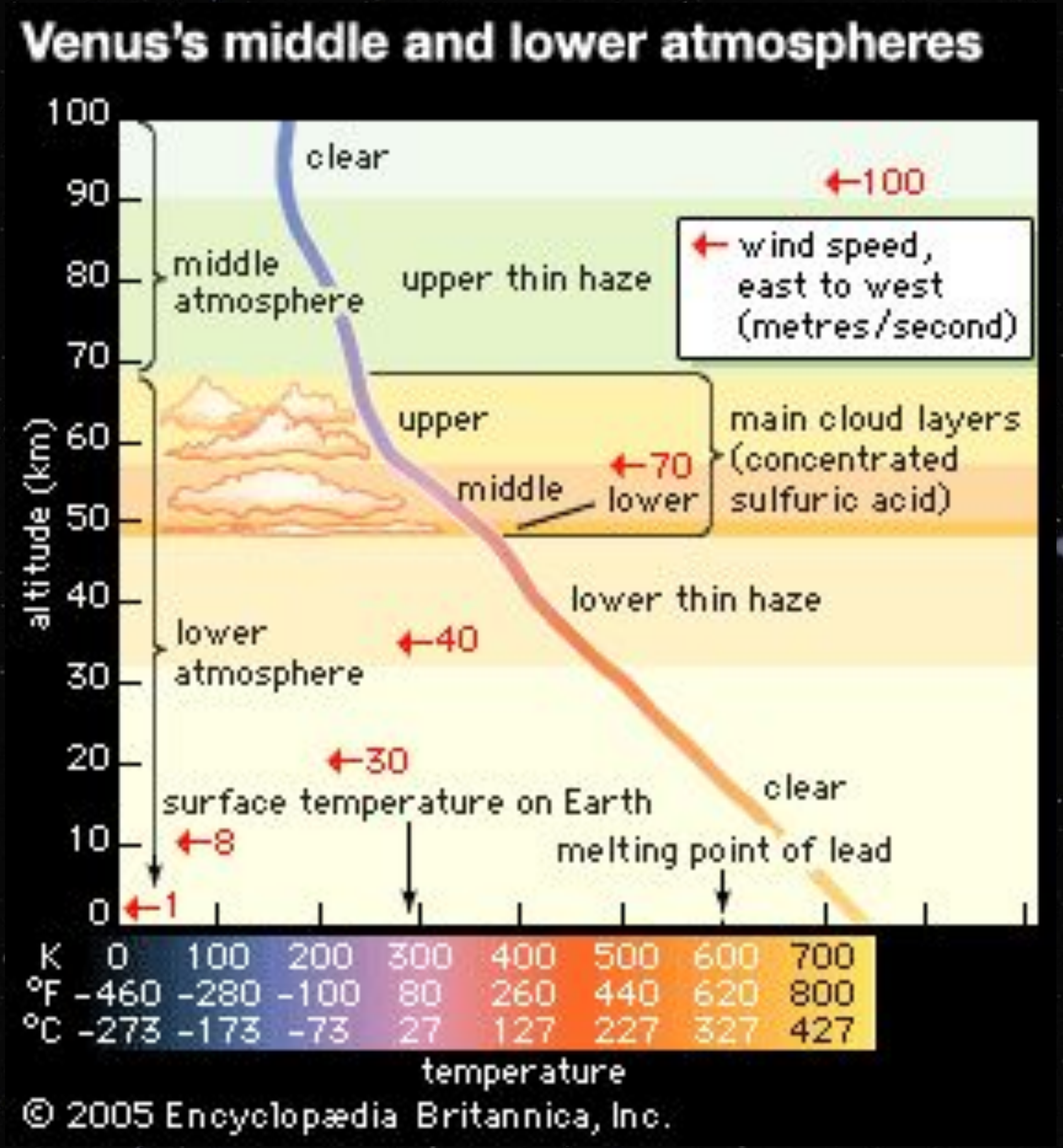
Overall Mission Structure Tradeoffs

- What orbiter/deployable data collection structure best suits our mission?

Option	Benefits	Drawbacks
Orbiter Only, Data Collection by slowdown of orbit to crash into atmosphere	• No deployables, simple architecture • Potential for high complexity and size subsystems	• Orbiter must be designed for both space flight and atmospheric entry, more complex • No backups, only one shot at data collection for a few hours
Orbiter High Atmosphere Data Collection, Non-autonomous Deployables for Low Atmosphere Data Collection and Transmission	• Use of heritage atmospheric data collection methods on the orbiter • Simple deployable design • Data transmission directly from deployables, simplifying comms	• Lidar/high altitude data has already been collected on orbiters in other missions • Venera probes only obtained a few minutes of data in lower atmosphere, not significant for conclusions about superrotation • Atmospheric capsules for deployables, highly complex
Orbiter Communication Hub, Autonomous Deployables for Mid to Low Atmosphere Data Collection (selected)	• Days to weeks of data collection • Ability to decide what regions of Venus we will explore • More robust, long term atmospheric exploration with range of altitude • Less thermal shielding	• Complex, directional communication from deployable to orbiter through Venus' atmosphere • Navigation and control algorithms necessary for flight paths • Complex delivery of deployables

Altitude Requirements/Tradeoffs

Option	Benefits	Drawbacks
High Atmosphere (>70km)	• Low temp • Thin atmosphere	• High Wind Speed (100m/s) • Low data availability
Mid Atmosphere (40-70 km)	• Earth temp/pressure • High range of explorable altitudes	• Strong Winds (70m/s) • Sulfuric Acid Clouds
Low Atmosphere (<40km)	• Lots of uncollected data	• High temperature • High pressure • Unsurvivable conditions for more than minutes



https://www.britannica.com/place/Venus-planet/The-atmosphere

Altitude Selection

- **Target Altitude:** 50km
  - 60 m/s winds
  - Sulfuric acid clouds
  - Approximately earth-like temperatures and pressures
  - Low visibility due to dense atmosphere/cloud cover

- **Why?:**
  - Earth Like conditions make this a particularly suitable region for drone deployment.
  - Able to collect wind speed, temperature, and composition data about venus' atmosphere necessary to investigate super-rotation.

Altitude Ramifications

- **Problem**: Passing Through Sulfuric Acid Clouds
- **Approach**: Necessary to ensure that vital electronics are sealed from the surrounding atmosphere. Magnetic propellers to reduce exposure to elements. Sulphuric acid resistant materials such as teflon and titanium used in probes.

- **Problem**: Dense Venusian Atmosphere Causing Decreased Solar Efficiency
- **Approach**: Probe can perhaps ascend to higher altitudes to reclaim power, onboard batteries to allow for longer operation. Selected sensors need to be effective in low visibility conditions. Suitable for our mission, where we are measuring wind speeds and temperature fluctuations.

- **Problem**: Surviving Atmospheric Entry
- **Approach**: Gliders are deployed from the orbiter using NASA LOFTID heat shield

Drone Architecture Requirements

- **Probe Durability:** Must survive in Venus' upper atmosphere (**50 km altitude**) for at least **48 hours** before failure.
  - **Why?** Ensuring a minimum operational time frame allows sufficient data collection through varying altitudes around geographic features. With more time, can create geographic data align longitudinal line.
- **Wind Resistance:** Probe must maintain stable flight in **60 m/s super-rotational winds**.
  - **Why?** Stability is critical to prevent loss of control, ensure data accuracy, and maintain communications with the orbiter.
- **Power Requirement:** The probe must have access to around 1518W (see Power Budget slide) through a combination of solar and pre-stored battery power.
  - **Why?** Adequate power is needed to operate instruments, sustain communication, and maintain controlled flight over the mission duration.

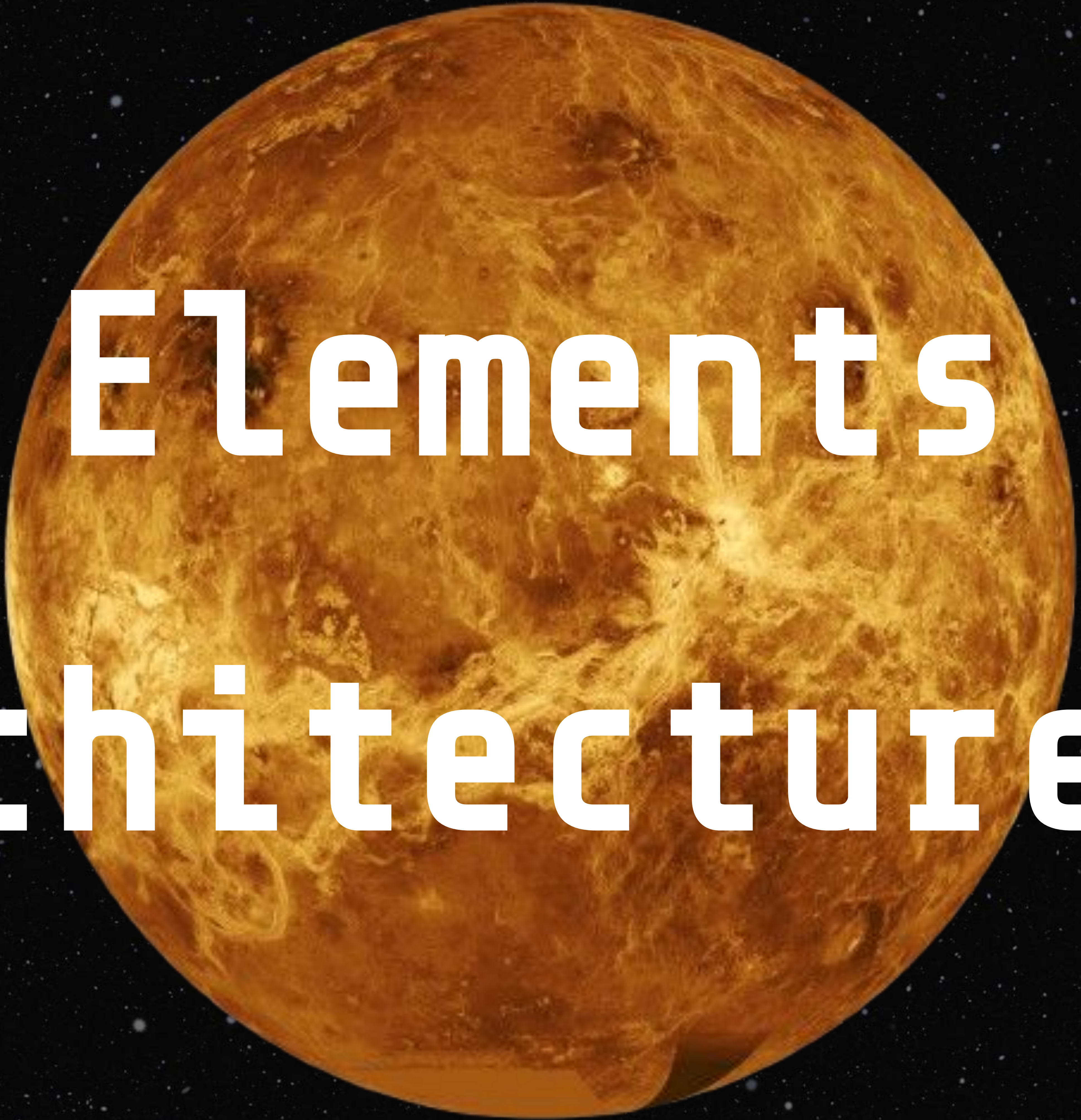
Drone Architecture Tradeoff

Winged Glider (Chosen)	● Can generate lift for extended loiter time.- Enables controlled flight path for targeted data collection. ● Reduces drift caused by Venus' high winds. ● Large wing surface area allows us to collect power	● Requires more complex navigation. ● High-energy demand for control surfaces.
Balloon	● Simple design, minimal power needs. ● Passive data collection possible.	● Drifts uncontrollably with winds. ● Limited altitude control.
Disk Drone	● Higher aerodynamic efficiency. ● Better stability in turbulence.	● Complex manufacturing. ● Limited deployability in Venus’ atmosphere w/ sulfuric acid interference to propellers/high speed motors

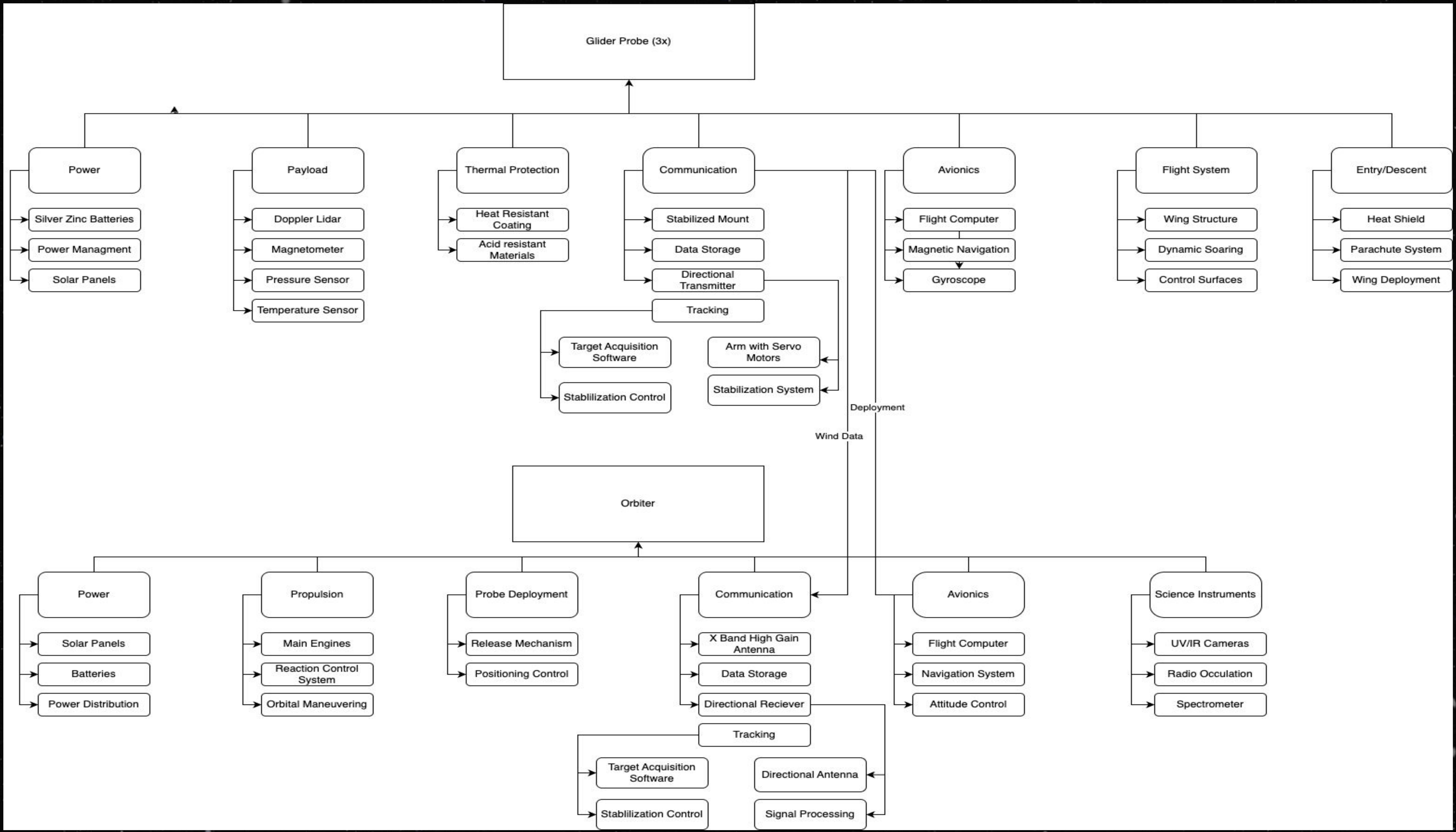
Subsystem Tradeoffs

Subsystems	Options	Tradeoffs	Selection/Ramifications
Propulsion	• Electric induction propellers **(selected)** • Passive Gliding • Combustion Thrusters	• Sulphuric Acid Interferes with unsealed electronics • Need 10 N/m thrust loading to go through crosswinds, navigate to interest zones	Electric induction propellers can be sealed from the outside environment while providing enough thrust for crosswind navigation. Stronger thrusters are unnecessary for this application.
Power Sources	• Solar Panels **(selected)** • Onboard Chemical Reactions	• Some solar loss due to venus atmospheric conditions • Volatile chemicals necessary for power production	Solar panels, even with atmospheric losses, provide a relatively risk free means of saving power and prolonging survey time.
Navigation	• Magnetometer for magnetic pole navigation • Gyroscopic/inertial navigation **(selected)** • Transmitted GPS/mapping data from orbiter	• Very small magnetic field on Venus, only induced by solar winds inconsistently • Multiple orbiter satellites would be necessary to maintain contact w/ drone	Gyroscopic/inertial navigation is the only realistic means of navigation with Venus' atmospheric constraints. Perhaps some heading can be found from communications transmissions.
Data Collection	• Lidar **(essential)** • Infrared Radiometer **(nice to have)** • UV/IR Cameras • Mass Spectrometer • Magnetometer	• Limited energy budget for sensing on drones, high cost • Composition/temperature data not necessary to draw conclusions about superrotation	Lidar allows for wind speed collection, which is the most essential data for this project. IR radiometer would be nice to investigate temp distribution and underlying causes.

03 Elements of Architecture I



Block Diagram for Project Phoenix



Glider Subsystems

Power

Source
- $2m^2$ high efficiency solar panels integrated into wing surface

Storage
- Pre-charged silver-zinc batteries are robust for Venus' atmosphere

Generation
- At 50 km, solar intensity is similar to Earth (~1300 W/m^2)
- Under ideal conditions, 1300 W/m^2 * $2m^2$ * 25% efficiency = <u>650 watts</u>

Backup Systems
- Communication and navigation systems are prioritized during energy shortages

Payload

Doppler LIDAR

- **Purpose** : Measures wind speed at different altitudes by using Doppler shift in laser pulses reflected from atmospheric particles
- **Why:** We can identify how updrafts over extreme geological features affect super rotation
- **Relevance:** Directly measure three-dimensional wind field around geological features

Structure

Design
- Fixed-wing glider with 3m wingspan using airfoils for the dense Venus atmosphere

Material
- Titanium-silicon carbide composite

Thermal Protection
- Heat resistant coating and passive heat pipes to transfer heat to radiator surface

Flight Characteristics
- Designed for stable flight in 60 m/s crosswinds

Glider - Orbiter Communication

Primary component

- Gimbal-mounted directional transmitter with active stabilization

Pointing mechanism

- Dual-axis mechanism with stepper motor for 360 degree horizontal rotation, and servo motor for 180 degree vertical range

Tracking

- Using directional antennas, use signal strength to isolate glider direction and use predictive path calculation using ephemeris data

Signal

- X-band transmission up to 256kbps during optimal alignment

Backup

- Omnidirectional UHF antenna for emergency location tracking

Avionics and Navigation

Flight Computer
- 64-bit processor

Navigation: Inertial Navigation System (INS)
- 3-axis rate gyroscope and accelerometer
- Estimates glider position, velocity, and attitude by integrating measurements from accelerometers and gyroscopes over time

Guidance Algorithm
- Autonomous path planning including real-time wind compensation

Flight System and Propulsion

Hybrid system combining dynamic soaring and solar-electric propulsion

Dynamic Soaring
- Leverages super rotational winds to generate lift and propulsion between atmospheric layers
- Reduces reliance on stored energy

Solar-electric propulsion
- Uses electric motor propellers for controlled maneuvering
- Unlimited energy supply in upper atmosphere
- Requires battery

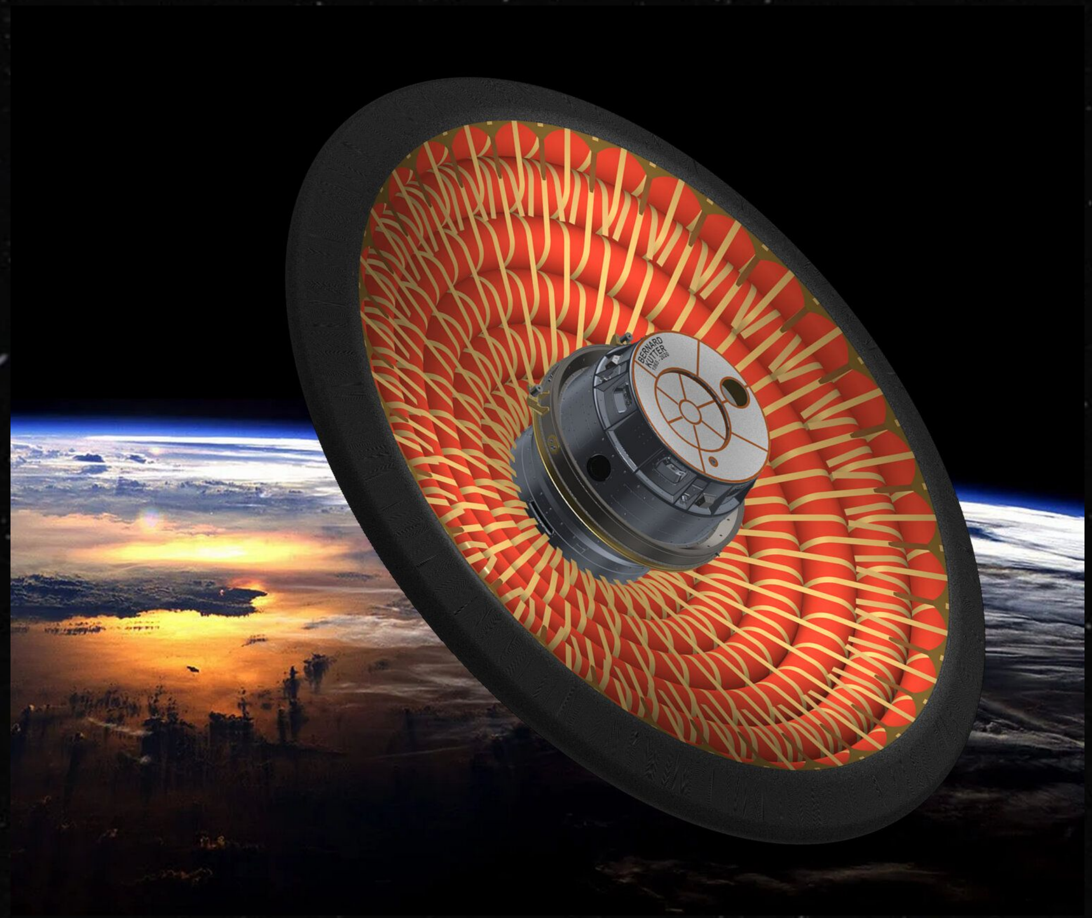
Controls
- Elevons for pitch and roll control, and rudder for yaw stability

Entry and Descent

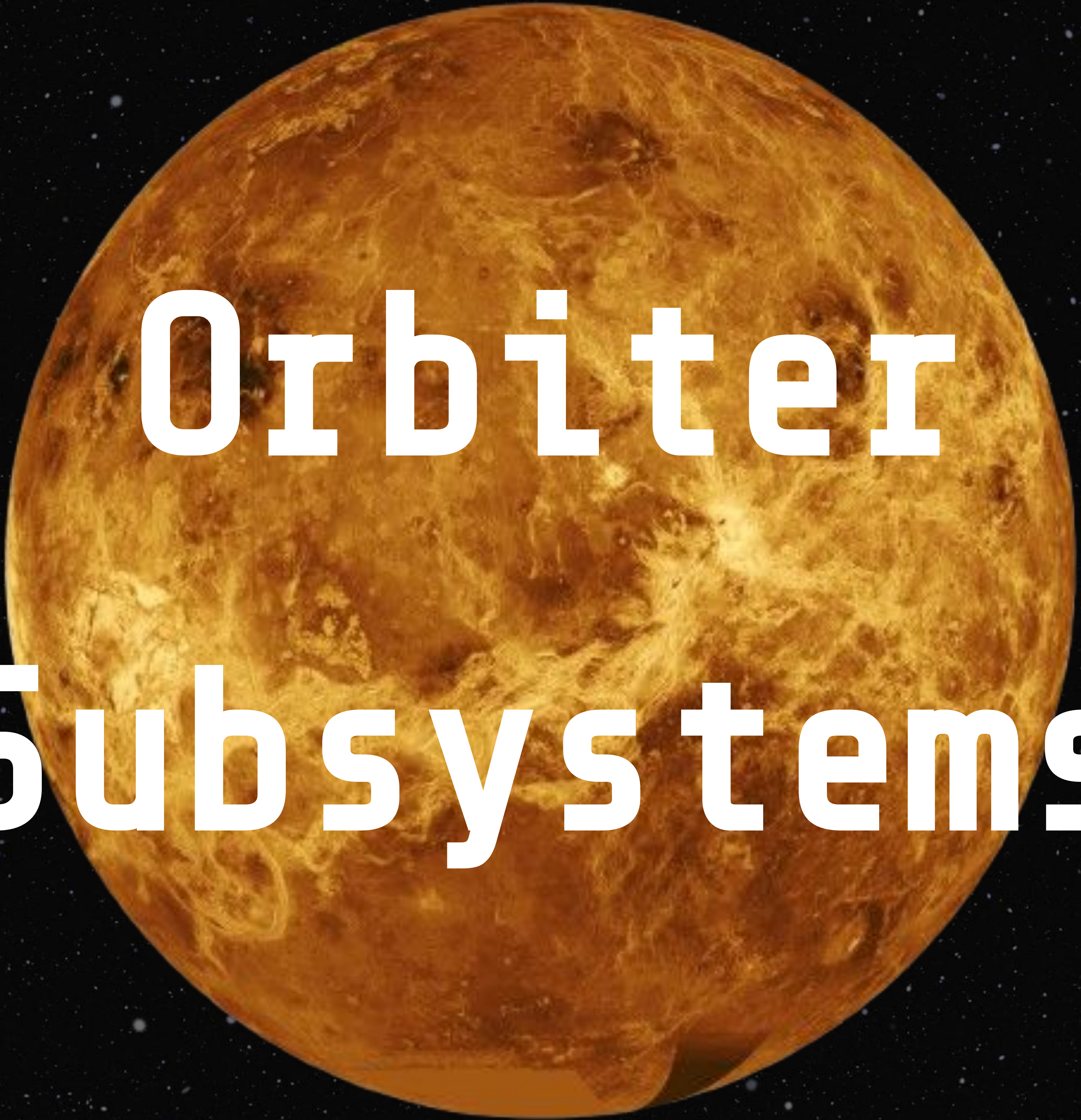
Gliders are deployed from the orbiter using NASA LOFTID heat shield

LOFTID

- System uses large inflatable heat shield, made of multiple layers of heat-resistant materials
- The Glider is wrapped with LOFTID
- When it enters the atmosphere, the aeroshell inflates, creating a large surface area that generates significant drag



Orbiter Subsystems



Power

Source
- Large solar panel array for sustained power in Venus orbit

Storage
- Lithium-ion battery with radiation hardening
- Multiple redundant batteries

Generation
- Capacity of 2500 watts at Venus distance from Sun

Propulsion

Main Engines
- Bipropellant propulsion system using hydrazine and nitrogen tetroxide

Reaction Control System
- Small thrusters for precise attitude control
- Redundant thruster array

Probe Deployment

Release Mechanism

- Deploys 3 LOFTID aeroshells, each containing a Glider

Positioning Control

- Because of Inertial Navigation System, we need accurate orientation control during deployment
- Ensures proper entry angle and trajectory for each glider

Orbiter Communication

Primary component
- Gimbal-mounted directional transmitter with active stabilization

Pointing mechanism
- Dual-axis mechanism with stepper motor for 360 degree horizontal rotation, and servo motor for 180 degree vertical range

Earth Communication
- High Gain X-Band antenna for communication with Earth up to 256kbps during optimal alignment
-

Glider Communication
- Directional receiver with wide scanning range to track gliders

Avionics

Flight Computer
- 64-bit processor capable of autonomous flight during communication blackouts

Navigation
- Star trackers and sun sensors for attitude determination
- Inertial measurement units for continuous position tracking

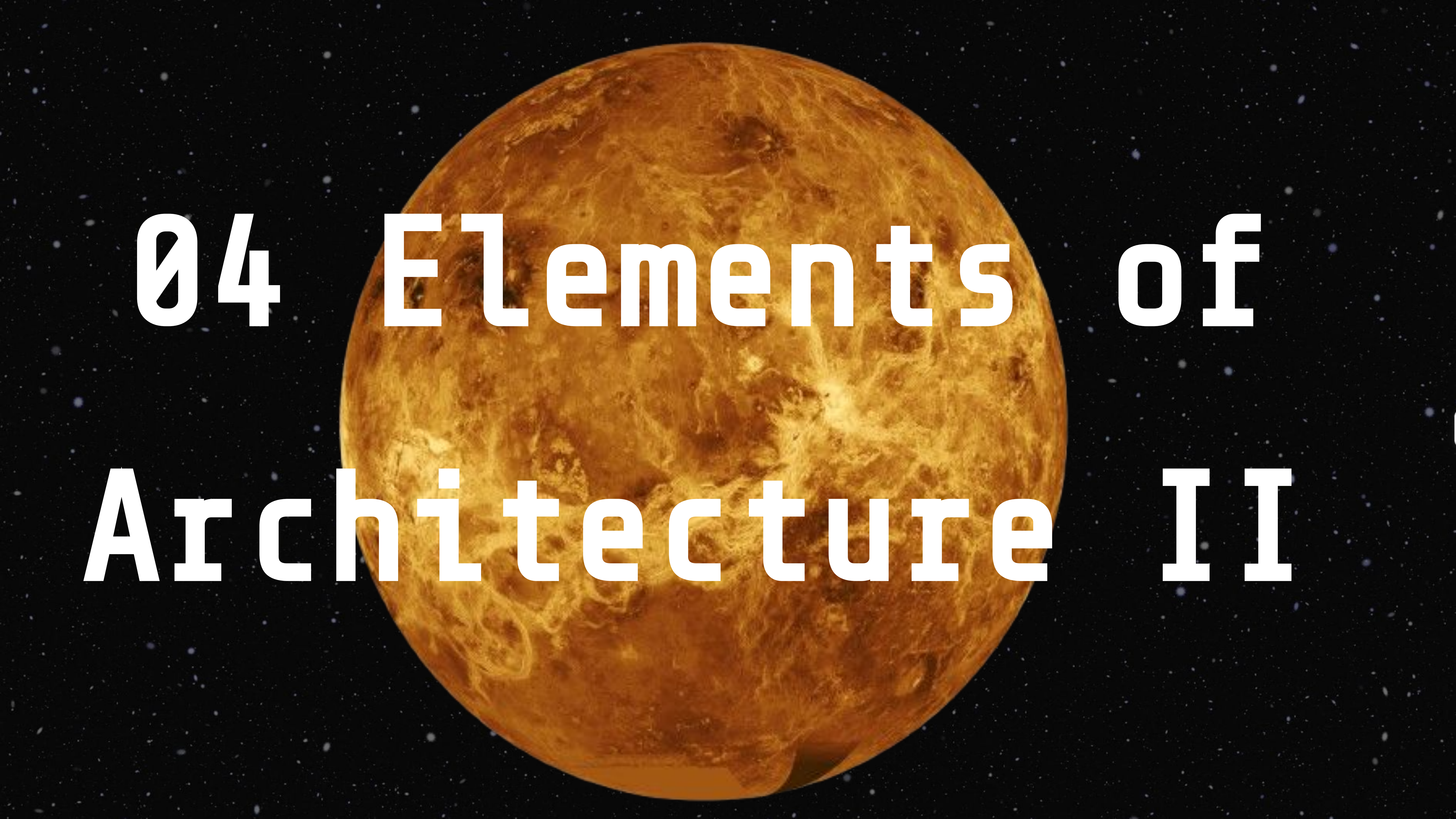
Science Instruments

UV and Infrared Cameras

- **Purpose:** Track cloud movement
- **Why:** Provides spatial understanding of temperature variations
- **Relevance:** Identifies heat distribution driving atmospheric motion

Radio Occultation Instrument

- **Purpose:** Measures temperature, pressure, and density of atmosphere by analyzing how radio waves are refracted as they pass through different layers of atmosphere
- **Why**: Analyze vertical temperature fluctuations
- **Relevance:** Complements Doppler Lidar and cloud tracking to link temperature variations to wind speed and superrotation


04 Elements of
Architecture II

Launch Infrastructure

Launch Infrastructure:

- **Launch Vehicle -** Falcon Heavy
- **Launch Site -** Kennedy Space Center, FL (SLC-39A)
- **Earth Departure Strategy -** Trans-Venus Injection (TVI) using Hohmann Transfer
- **Launch Window -** Every ~19 months for optimal alignment
- **Orbital Insertion -** Venus Orbit Insertion (VOI) with aerobraking

Ground Station:

- **Primary Network -** NASA Deep Space Network (DSN)
- **Frequencies Used -** X-band (data uplink/downlink), S-band (backup)
- **Latency Considerations -** ~5-15 minute one-way light travel time.
- **Tracking & Telemetry -** At least three DSN stations (Goldstone, Canberra, Madrid)
- **Data Relay Strategy -** Orbiter buffers and transmits when Earth is in view.

Launch & Orbit

Step 1: Launch & Earth Departure

- Use a **Falcon Heavy** to launch the orbiter into **low Earth orbit (LEO)** .
- Perform a **trans-Venus injection (TVI)** burn to set the orbiter on a **Hohmann transfer trajectory** toward Venus.

Step 2: Cruise & Mid-Course Corrections

- The spacecraft will **coast for ~4-6 months** , adjusting its trajectory with **small thruster burns** to ensure proper alignment with Venus.

Step 3: Venus Orbit Insertion (VOI)

- As the orbiter approaches Venus, it will conduct a **major braking burn** (aerobraking or retrograde engine burn) to **slow down and be captured by Venus' gravity** .
- The burn will place it into an **elliptical orbit** , which can be adjusted later.

Step 4: Orbital Adjustments & Science Operations

- Perform final orbit **circularization burns** to achieve the desired operational orbit.
- Begin **science operations** , collecting data and transmitting it back to Earth.

Quick Launch Explanation

A **Trans-Venus Injection (TVI)** is a high-speed maneuver that sends a spacecraft from **low Earth orbit (LEO) onto an interplanetary trajectory toward Venus**. This maneuver is executed by firing the spacecraft's **main engine** (or an upper stage) at a precise point in Earth's orbit to give it the **necessary velocity to escape Earth's gravity and enter a heliocentric (solar) orbit** that intersects Venus' path.

- **Timing:** The TVI burn is carefully timed so that Venus will be at the correct position when the spacecraft arrives. This is based on launch windows, which occur **every ~19 months** when Earth and Venus are optimally aligned.
- **Delta-v (Δv):** The required change in velocity depends on the spacecraft and rocket, but it's typically around **3-4 km/s** beyond Earth's escape velocity (~11.2 km/s).
- **Result:** After TVI, the spacecraft is now in an orbit around the Sun, gradually making its way toward Venus.

A **Hohmann transfer** is the most **fuel-efficient** way to move a spacecraft from one circular orbit (Earth) to another (Venus) using **two engine burns**:

1. **First Burn (TVI)** → Places the spacecraft into an elliptical orbit around the Sun, where its **aphelion (farthest point)** is at Earth's orbit and its **perihelion (closest point)** is at Venus' orbit.
2. **Second Burn (Venus Orbit Insertion - VOI)** → When the spacecraft reaches Venus' orbit, it fires its engines again to slow down and enter Venus' gravitational influence.

Since Venus is **closer to the Sun than Earth**, the spacecraft must **reduce its heliocentric velocity** so that the Sun's gravity pulls it inward. This is why TVI doesn't just push the spacecraft away—it actually **lowers its solar orbit to intersect with Venus.**

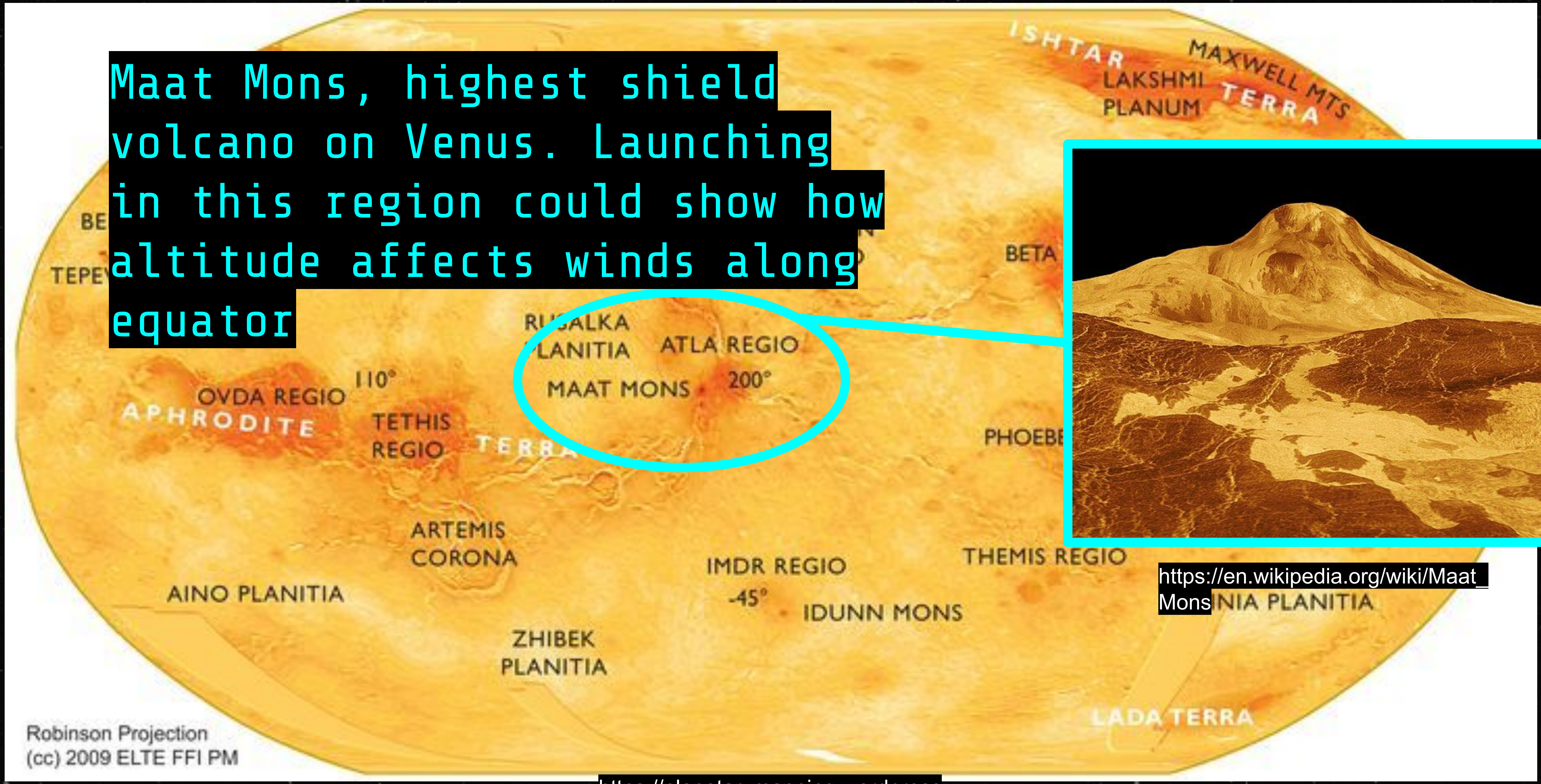
- **Time to reach Venus:** About **4 to 6 months** depending on the exact trajectory.
- **Efficiency:** This method minimizes fuel use but requires precise timing.

Probe Deployment & Reentry

1. **Thermal Protection + Orbit Preparation:**
   - **Heat-resistant tiles and ablative shielding** protect the orbiter during atmospheric entry.
   - The orbiter performs an orbital adjustment to align with the designated drop zones (Maat Mons, Maxwell Montes, Phoebe Regio).
   - The drones are prepped for release, with internal batteries charged and communications tested.
2. **Atmospheric Entry Sequence:**
   - The orbiter releases the capsule at an altitude of **240 km** above Venus.
   - The capsule enters the atmosphere at a velocity of **~7.5 km/s** /
3. **Deceleration:**
   - **Parachute deployment at ~65 km altitude** slows capsule descent to ~40 m/s.
   - As the capsule slows down, the bottom side opens to deploy the probe drones into Venus.
   - Aerodynamic glider wings unfold once velocity is reduced to a safe level (~20 m/s).
4. **Glide & Navigation Phase:**
   - Drones transition from free-fall to controlled gliding.
   - **Magnetic navigation recalibrates using Venus' weak induced magnetosphere** .
   - Dynamic soaring techniques are activated to extend flight duration.
5. **Science Data Collection & Transmission:**
   - Gliders at **50 km** capture wind speed (updraft wind speed), as well as possibly collecting data on pressure and temperature.
   - Data is sent in packets to the orbiter, which transmits it to Earth.

Engineering Requirements

Launch into various geographic regions of Venus (1 glider per region)



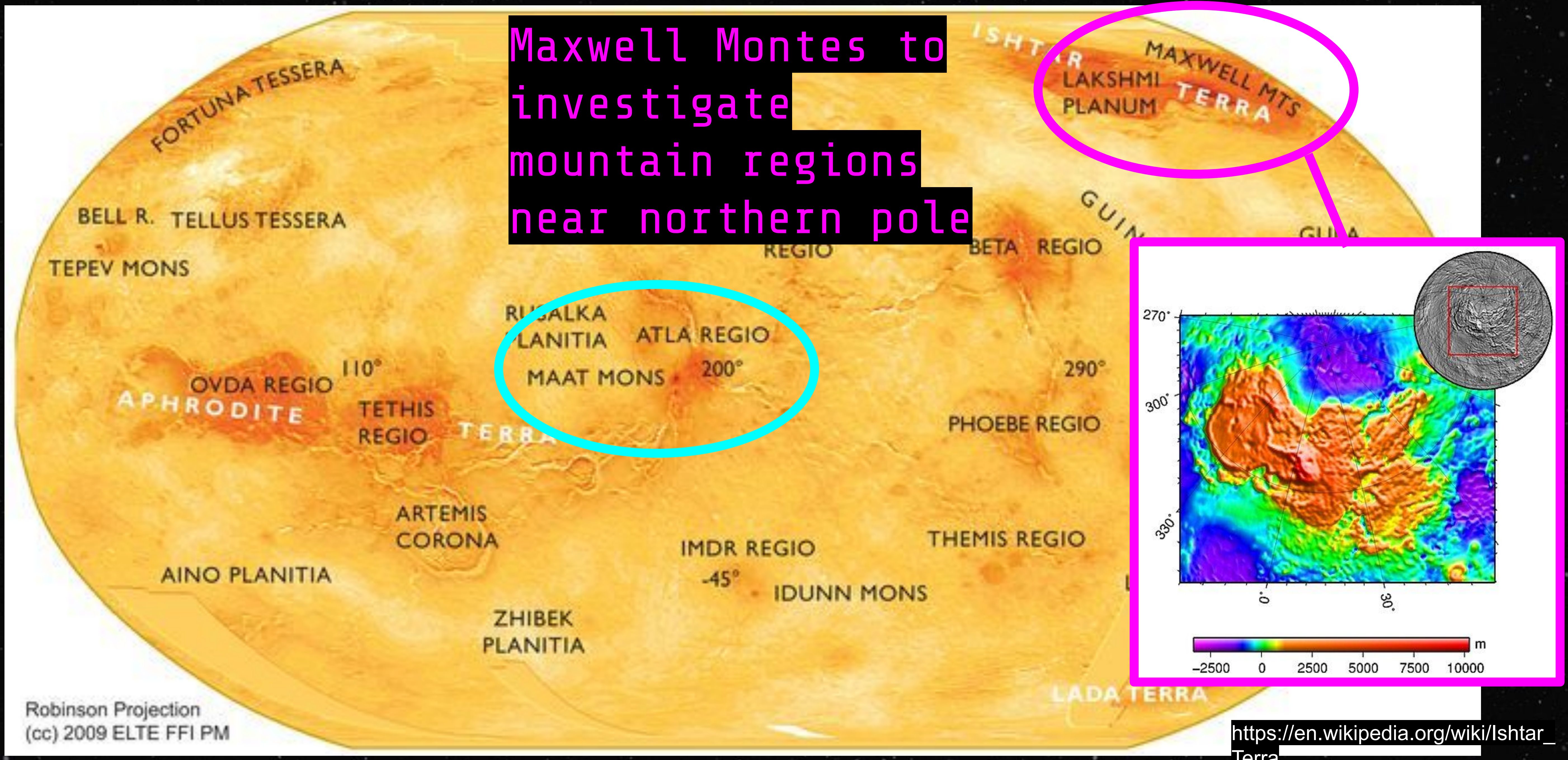
Maat Mons, highest shield volcano on Venus. Launching in this region could show how altitude affects winds along equator

https://en.wikipedia.org/wiki/Maat_Mons

https://planetarymapping.wordpress.com/wp-content/uploads/2016/02/venus_big.jpg

Engineering Requirements

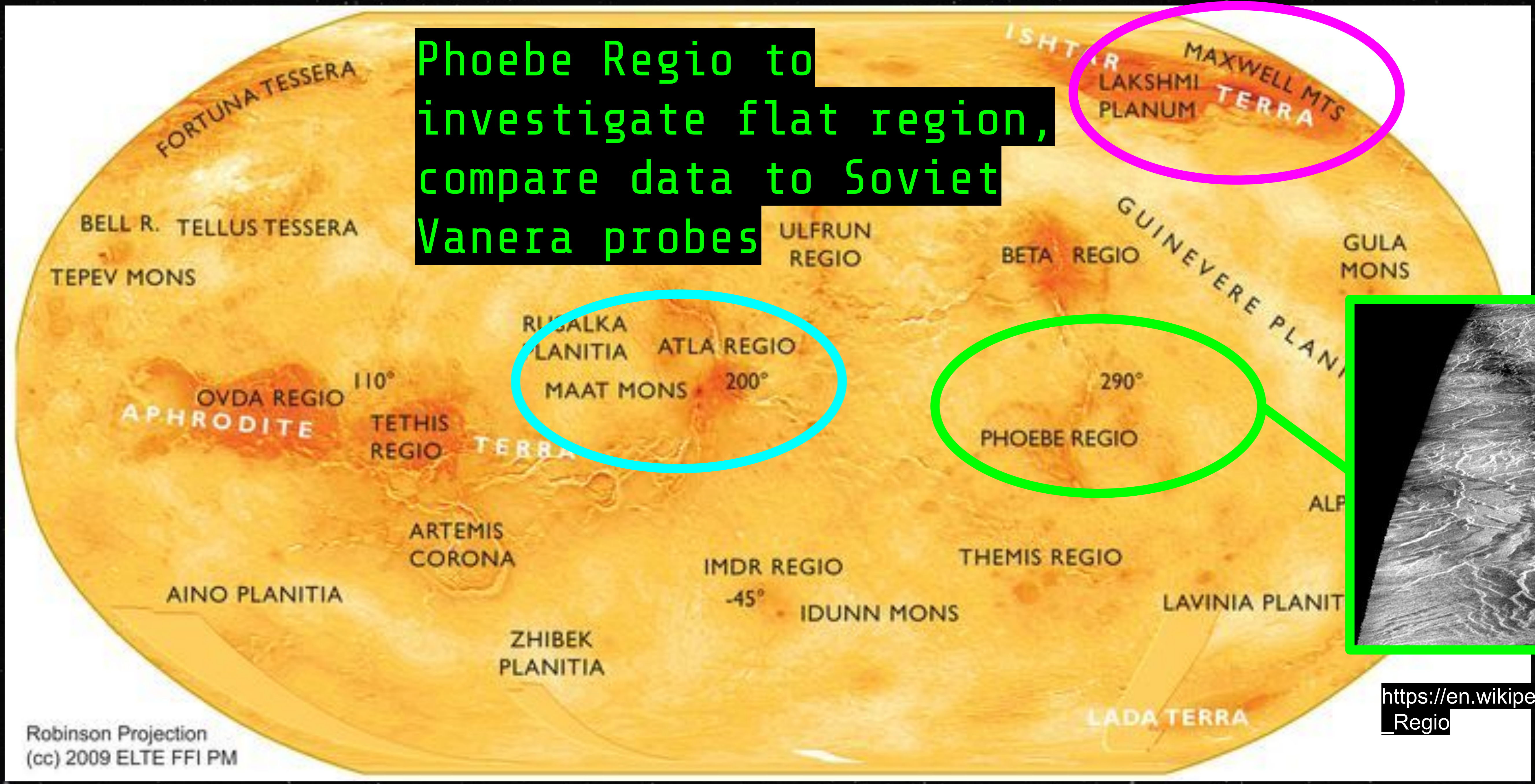
Launch into various geographic regions of Venus (1 glider per region)



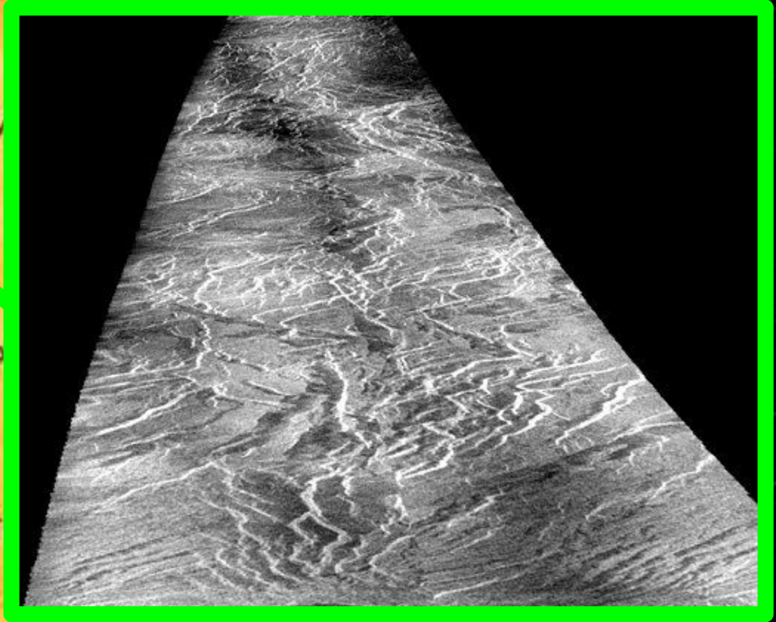
https://en.wikipedia.org/wiki/Ishtar_Terra

Engineering Requirements

Launch into various geographic regions of Venus (1 glider per region)



Phoebe Regio to investigate flat region, compare data to Soviet Vanera probes



https://en.wikipedia.org/wiki/Phoebe_Regio

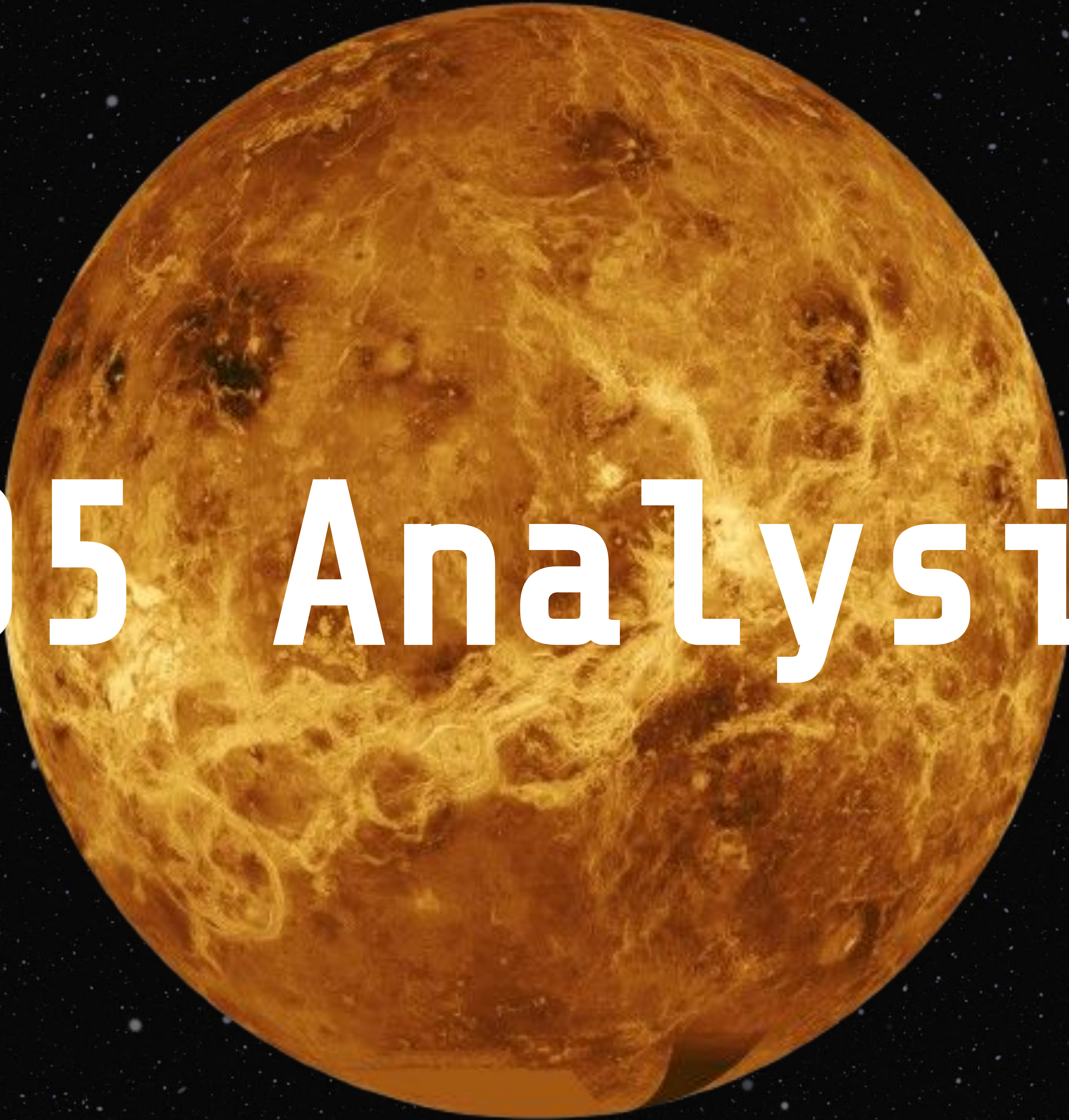
Engineering Requirements

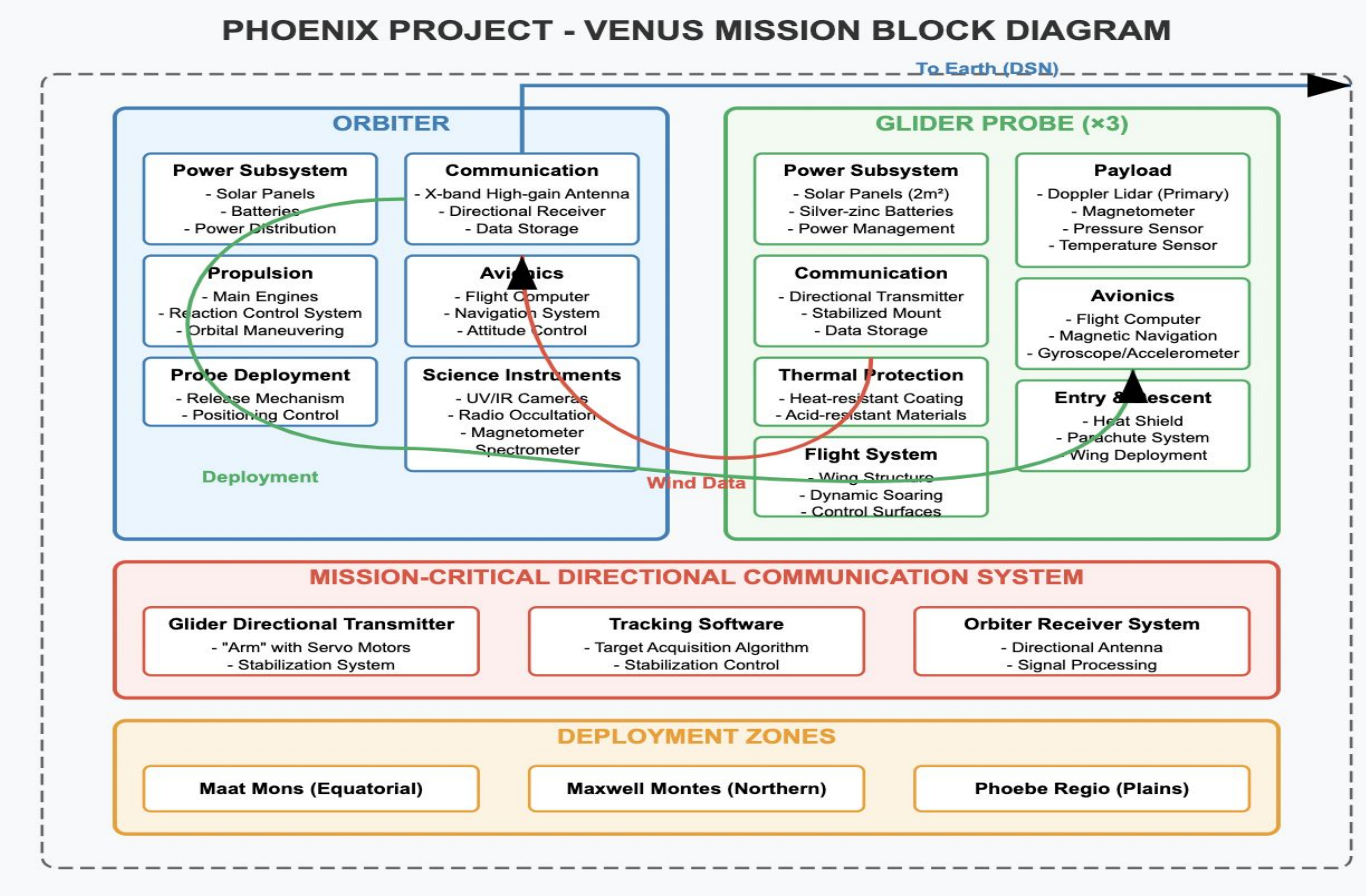
Venus Orbit Insertion & Probe Deployment:

- Orbiter enters polar orbit, enabling global coverage over three target regions:
  - Maat Mons (equatorial volcanic region).
  - Maxwell Montes (mountainous terrain, northern pole).
  - Phoebe Regio (flat plains for comparative analysis).

- At each region, the orbiter deploys one probe:
  a. Low-Altitude Probe (LAP) (~50 km) → captures atmospheric wind speeds, temperature, pressure, and magnetospheric fluctuations.
- Orbital maneuvering ensures precise probe drop timing and positioning.

05 Analysis





PHOENIX PROJECT - VENUS MISSION BLOCK DIAGRAM
To Earth (DSN)
ORBITER
Power Subsystem
- Solar Panels
- Batteries
- Power Distribution
Communication
- X-band High-gain Antenna
- Directional Receiver
- Data Storage
Propulsion
- Main Engines
- Reaction Control System
- Orbital Maneuvering
Avionics
- Flight Computer
- Navigation System
- Attitude Control
Probe Deployment
- Release Mechanism
- Positioning Control
Science Instruments
- UV/IR Cameras
- Radio Occultation
- Magnetometer
- Spectrometer
Deployment
Wind Data
GLIDER PROBE (×3)
Power Subsystem
- Solar Panels (2m²)
- Silver-zinc Batteries
- Power Management
Payload
- Doppler Lidar (Primary)
- Magnetometer
- Pressure Sensor
- Temperature Sensor
Communication
- Directional Transmitter
- Stabilized Mount
- Data Storage
Avionics
- Flight Computer
- Magnetic Navigation
- Gyroscope/Accelerometer
Thermal Protection
- Heat-resistant Coating
- Acid-resistant Materials
Entry & Descent
- Heat Shield
- Parachute System
- Wing Deployment
Flight System
- Wing Structure
- Dynamic Soaring
- Control Surfaces
MISSION-CRITICAL DIRECTIONAL COMMUNICATION SYSTEM
Glider Directional Transmitter
- "Arm" with Servo Motors
- Stabilization System
Tracking Software
- Target Acquisition Algorithm
- Stabilization Control
Orbiter Receiver System
- Directional Antenna
- Signal Processing
DEPLOYMENT ZONES
Maat Mons (Equatorial)
Maxwell Montes (Northern)
Phoebe Regio (Plains)

Other Necessary Hardware

Radio Communications

- Directional radio needed for communication glider and orbiter
- High-gain directional antenna needed for communication with Earth

Cooling System (possibly)

- Probe may benefit from on-board cooling system to allow it to survive harsher temperatures at lower altitudes

Memory System

- probes will need to be able to store information on-board until the next pass over of the orbiter, at which point data will be transferred to orbiter and subsequently transmitted back to Earth

Control Sensor Hardware:

- magnetometer as a reference point, gyroscope & accelerometer sensors for orientation

Important Notions

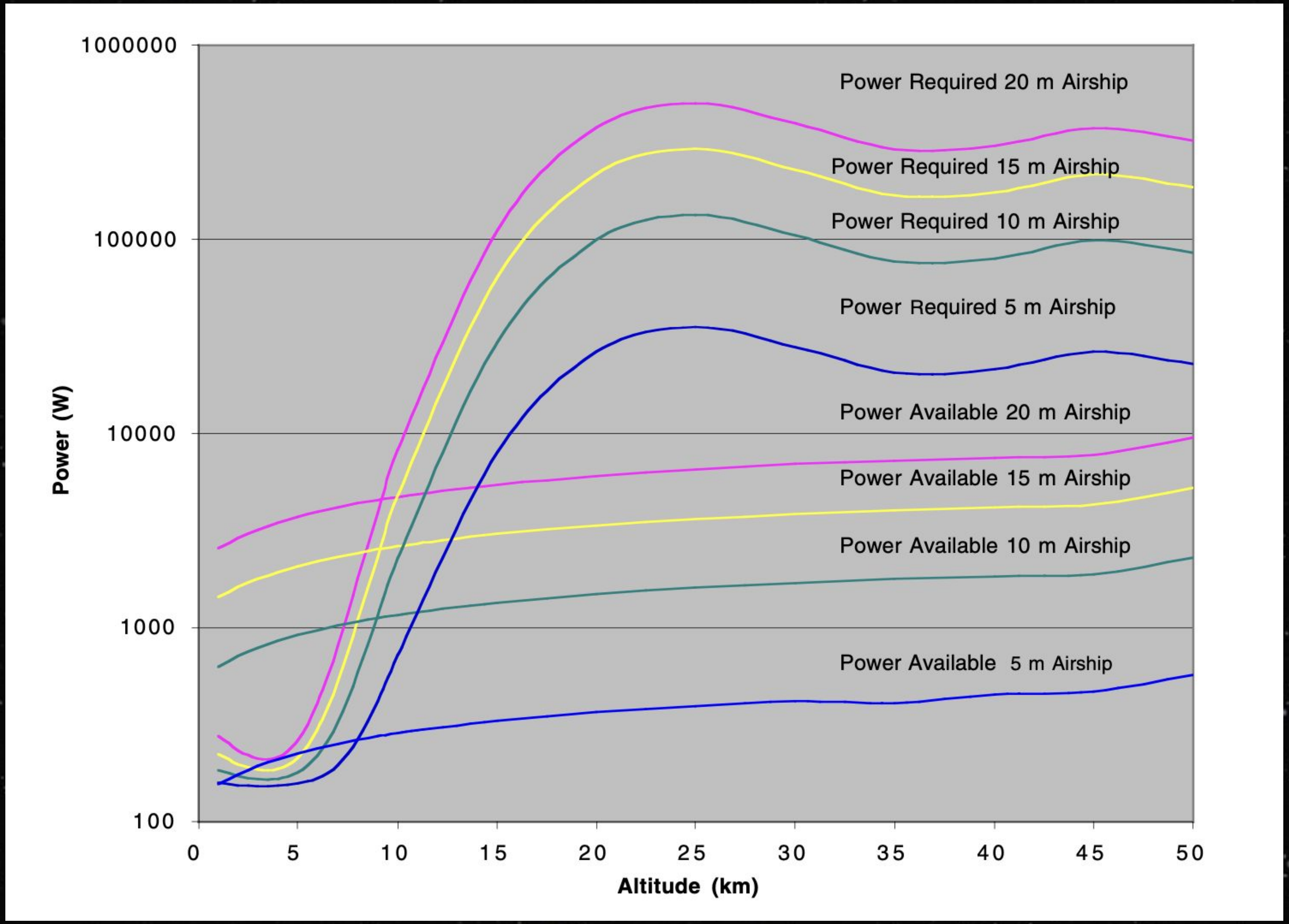
Wind speeds at 50 km are around 60 m/s

Drone must generate significant power to avoid drift

Additionally, some concerns are:

- High Energy Demand: Propulsion must overcome strong atmospheric winds, increasing power consumption

- Power Limitations: Solar power may be insufficient in cloud-covered regions below 65 km (problem for us since we are aiming to fly at 50 km → will need to supplement with batteries).



Mission Critical Technologies

- Payload Subsystem:
  - Holds our instruments critical to the mission
- Power Subsystem:
  - Must ensure our power subsystem can fully support the payload weight and navigate long distances.
- Radio Communication Subsystem:
  - Necessary to transmit data to and from the earth so it can be useful to researchers on Earth.
  - High-gain directional antenna, X-band relay system, onboard storage.
- Environmental Resilience:
  - Necessary to sustain the extreme temperatures of Venus.
  - Thermal shielding, acid-resistant teflon coatings, Silver-zinc batteries to supply stable power, solar panels for supplemental power.

Main Build Overview

- One critical aspect of our mission is communication between the orbiter and the glider system. We will focus on this aspect of the design by developing a directional transmitter/receiver system that will allow the transmitter on the glider to accurately point toward the receiver on the orbiter (and vice versa) as both move along their respective routes.
  - **Physical system:** the transmitter will need to be mounted on a robotic "arm" to allow it to point in any direction
  - **Stability Control:** the glider's movement is unstable, so we will need to stabilize the transmitter as it attempts to point at the target
  - **Tracking Algorithm** : we will need to develop some way to allow the transmitter to find the position of the receiver and keep that position as the glider moves
  - **Main Tasks:** develop physical "arm" with servos and gyro/accelerometer sensors, develop all control and stability algorithms, attach our transmitter device to a drone and test whether it can track a moving ground target (using either a laser or radio)

Project Plan

Phase 1: Concept Development & Feasibility (Months 1-6)

- Define key mission objectives and science goals.
- Select orbiter and probe payloads (LIDAR, spectrometer, magnetometer).
- Conduct initial simulations for orbital trajectory feasibility.

Phase 2: Engineering Design & Prototyping (Months 7-14)

- Construct orbiter and probe prototypes, focusing on thermal shielding (Venus heat resistance), power management (solar vs. RTG feasibility), and communications testing (orbiter-to-probe link validation).
- Perform wind tunnel and vacuum chamber tests for Venus' conditions.

Project Plan, Continued

Phase 3: Integration & System Testing (Months 15-22)

- Assemble final flight model with all subsystems integrated.
- Conduct rigorous vibration tests for launch coordinates.
- High-altitude balloon trials to simulate Venus’ upper atmosphere.

Phase 4: Launch Preparation & Deployment (Months 23-30)

- Secure launch vehicle (Rocketlab Electron or Falcon 9).
- Perform final system validation at launch site (Cape Canaveral/New Zealand).
- Align launch with optimal Venus transfer window (every ~19 months).

Phase 5: Mission Execution & Data Collection (Months 30+)

- Perform Venus Orbit Insertion (VOI) and deploy probes.
- Monitor and analyze wind speeds, pressure, temperature variations.
- Transmit scientific findings back to Earth.

Mission Plan - Coordinated Data Collection

Two-Tiered Transmission Process:

1. Probe navigates magnetically:
   a. Uses magnetometer guidance to maintain position despite Venus’ extreme winds.
   b. Captures real-time atmospheric fluctuations, ensuring extended data collection.
2. Orbiter transmits to Earth:
   a. Stores and forwards data to Deep Space Network (DSN) via X-band high-gain antenna.
   b. Enables continuous scientific monitoring across different atmospheric regions.

Mission Plan - Mission Execution

Sequential Region Deployment Strategy:

- After completing Maat Mons observations, the orbiter executes a controlled orbital shift to deploy the next glider at Maxwell Montes, followed by Phoebe Region.
- Each glider system remains operational for several days, ensuring:
  - Stable magnetometer-based navigation prevents uncontrolled drift.
  - Extended atmospheric sampling provides unparalleled climate data.
  - Comparative analysis across all three regions enhances planetary models.

Scientific Goals and Future Impact:

- Unlocking Venus’ superrotation mechanics through studying effects of updraft in geologically extreme locations.
- Refining planetary climate models for future Venus and exoplanet missions.
- Pioneering magnetic-field-guided flight for sustained atmospheric exploration.

Business Case (Source of Funding)

Main selling point: All-purpose probe that can withstand extreme environments

Type	Pros	Cons
Government Space Agencies (NASA + JAXA)	1. Expertise in space missions/have tools and equipment to make it happen 2. Prioritizes research and discovery	1. Lengthy Bureaucratic Processes 1. Funding depends on political priorities
Defense Organizations (US Space Force)	1. US funnels money into our military 2. Expertise in space missions/have tools and equipment to make it happen	1. Military Alignment 1. Limited focus on exploration and research
Private Space Sponsorships/VC	1. More willing to take risks/experiment with approaches 1. Can hit the ground running (vs bureatic process)	1. Loss of Creative Control/control over mission 1. Profit Oriented over scientific exploration

Red Tape

Legal Considerations:

1. *Data Sharing/Licensing*: Intellectual Property protection, open data policy (NASA) vs data restrictions (Military), technology licensing for software and hardware

1. *International Space Law:* Liability Convention :(1972)-> financially responsible for any damage caused by mission, Registration Convention (1976) -> prove will need to be registered with UN's Office of Outer Space Affairs with detailed intentions/mission parameters,

1. *US Regulations*: a lot more restrictions if mission involves a private company

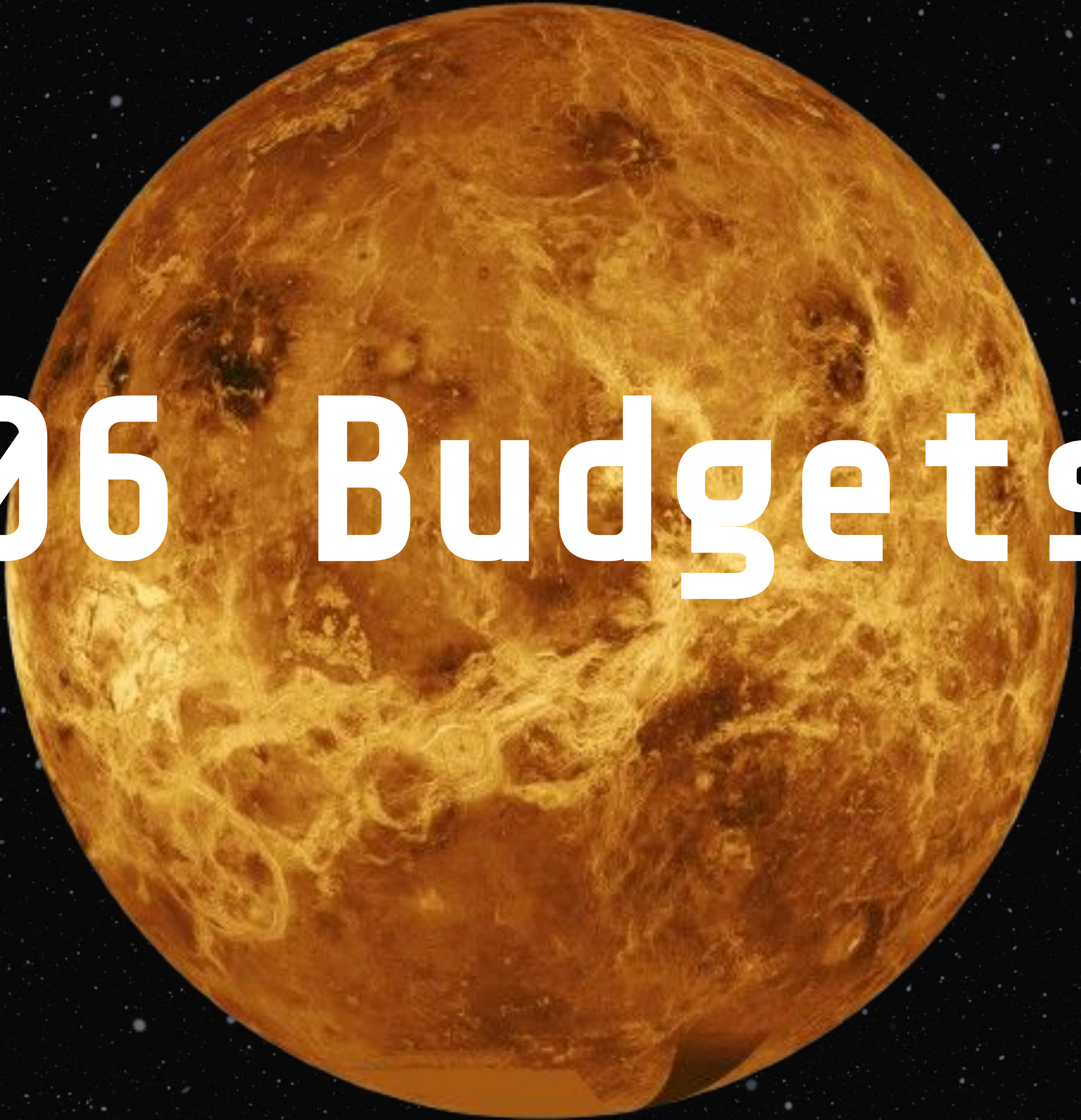
Safety Considerations

1. *Launch Safety:* work to minimize risk of launch failure and any injuries that come with it

1. *Planetary Protection:* Minimize any contamination of Venus from Earth based Microorganisms

1. *Spacecraft Safety:* Probe withstand Venus' extreme environment -> rigorous testing ->work to minimize any injuries/disasters go with trial and error

06 Budgets



Thermal Budget

Environmental Parameters

Parameter	Value	Notes
Surface Temperature	462 °C	Venus surface (not mission operational altitude)
Temperature at 50 km Altitude	27 °C	Primary operational altitude for gliders
Solar Flux at Venus	~2600 W/m^2	Double Earth's solar constant
Albdeo at Cloud Tops	0.77	Venus has high reflectivity
Temperature Range (Day/Night)	Minimal variation	Due to thick atmosphere and slow rotation

Orbiter Budget

Component	Operating Temperature Range	Max Heat Load (W)	Cooling Method	Thermal Margin (°C)
Avionics Bay	-10 to 40	120	Radiative panels	±10
Communication System	-10 to 40	150	Passive/radiative	±15
Propulsion System	-30 to 113.5	100 W (idle), 1000 W (during burn)	Passive/radiative	±25
Science Instruments	-20 to 60	100	Active cooling	±5
Power System	-20 to 60	100	Heat pipes	±15
Solar Array	-100 to 75	N/A	Passive	±30
Structure	-50 to 60	N/A	Multi-layer insulation	±20

Glider Budget

Component	Operating Temperature Range	Max Heat Load (W)	Cooling Method	Heat Rejection (W)	Thermal Control Mass (
Wings & Structure	-10 to 80	N/A	Multi-layer insulation	N/A	0.1
Avionics	-20 to 70	20	Passive, heat sinks	10	0.5
Communication System	-20 to 60	15	Passive, heat sinks	10	0.3
Doppler LIDAR	-10 to 40	40	Passive, heat sinks	20	0.8
Battery System	0 to 40	25	Passive, heat sinks	12.5	0.6
Solar Panels	-10 to 80	N/A	Conductive to structure	N/A	0.2
Motors/Servos	-10 to 60	50	Passive, heat sinks	25	0.5

Power Budget

Glider Power Budget

Subsystem	Component	Power (W)	Duty Cycle (%)	Avg Power (W) (Initial Deployment)	Power (W)	Duty Cycle (%)	Avg Power (W) (Max Sun)	Power (W)	Duty Cycle (%)	Avg Power (W) (Min Sun)	Notes
Payload	Doppler Lidar	5	60	3	5	100	5	5	50	2.5	Measures wind velocity
	Payload Total			3			5			2.5	
Attitude Control	IMU (Gyroscope & Accelerometer)	2	100	2	2	100	2	2	80	1.6	Stability control
	Reaction Control System (RCS)	20	30	6	20	50	10	20	50	10	Thruster control
	ACS Total			8			12			11.6	
Communication	X-band Transmitter	15	50	7.5	15	100	15	15	100	15	Data relay to orbiter
	Receiver	5	50	2.5	5	100	5	5	100	5	Receiving commands
	Comm Total			10			20			20	
Onboard Processing	Flight Computer	10	100	10	10	100	10	10	100	10	Main processor
	Processor Total			10			10			10	
20% Power Margin				10.2			19.6			19.6	
Spacecraft Total				31			47			44.1	"Orbit average power"

Power System Breakdown

Component	Power (W) (Initial Deploymen	Power (W) (Max	Power (W) (Min Sun)	Notes
Battery Charge Regulator (5% Tax)	3.83	5.88	5.88	Losses to power conversion
Batteries (Charging)	20	0	50	W-hr made up in eclipse
Power Regulators (95%) (5% Tax)	4	6	10	
Power Conversion (80%) (20% Tax)	16	23.5	32	
Spacecraft Required Power	120.43	147.98	215.48	

Solar Array Sizing

Factor	Max Sun	Min Sun
Power Required (W)	147.98	215.48
Packing Factor (%)	90	90
Temperature Factor (%)	85	90
Solar Array Power (BOL)	180	245
Power Margin (BOL) (%)	15.32	15.32
Solar Array Power (EOL)	147.98	215.48
Power Margin (EOL) (%)	0	0

Bit Budget

Data Flow Overview

Stage	Source	Destination	Data Type	Rate (kbps)	Duration	Total Data (MB)	Notes
Glider Data Generation	Sensors & Cameras	Glider Storage	Science Data	320	3.95 hours	542.4499512	Includes dopler LIDAR + Nav Sensors
Glider → Orbiter Transmission	Glider	Orbiter	Science Data	320	4 hours/day	542.4499512	UHF transmission, lossy compression
Orbiter Storage	Orbiter	Onboard Memory	Science Data	-	365-day mission	1627.349854	High-capacity SSD storage
Orbiter → Earth Transmission	Orbiter	DSN (Earth)	Science Data	500	3 hours/day	1627.349854	X-band high-gain directional antenna

Data Generation

asusming 48 hours

Subsystem	Instrument	Bit Rate (kbps)	Data Per Hour (MB)	Total Mission Data (GB)	Compression Factor	Final Data (GB)	Column 1	normal bit r
Payload	Doppler Lidar	300	1350	64.8	2:1	32.4	https://space.oscar.wmo.int/instruments/view/caliop	332
	Spectrometer	40	180	8.6	2:1	4.32	https://nssdc.gsfc.nasa.gov/nmc/experiment/display.actio	47.15
	Magnetometer	3	13.5	0.6	1.5:1	0.432	https://science.nasa.gov/mission/cassini/spacecraft/cassin	3.6
Nav & Comm	IMU & Nav Sensors	20	90	4.3	1.5:1	2.88	https://descanso.jpl.nasa.gov/DPSummary/Descanso14_N	5-25
Total Data Generated (Glider)	-	**363**	**1633.5**	**78.4**	**Compressed to ~9,180 MB**	**40.032**		

Only doppler lidar and IMU/Nav sensors transmitted to orbiter to get spatial distribution of wind speed data

Link Budget 1 (Earth/Orbiter)

	Orbiter/Earth Link Budget						
Reference link to useful paper where many of these numbers came from: https://ipnpr.jpl.nasa.gov/progress_report/42-236/42-236A.pdf							
earth rad (km)	6371	*earth_rad*					
c (Gm/s)	0.3						
Eb/No at 1e-6 (dB)	-26.56269961	ıd noise spectral density, as well as on bit rate from bit budget					
				Noise dB ∑	**Noise dB**	**Signal dBw**	**Signal dBw ∑**
distance from Earth (km)	261000000	*(max distance from*	to calc distance for 4 π r^2	**0.00**	**red is negative**		**0.00**
carrier freq (GHz)	1.668	L-band (recommended from paper--see page 3 & Fig		**0.00**			**0.00**
antenna diam (m)	70	*ant_diam*	see pg. 3 of paper	**0.00**		**35.85**	**35.85**
system noise (K)	277	*noise_temp*	from paper (pg. 4)	**144.07**	**144.07**		**35.85**
Tx power (W)	40	*Tx_power*	from Fig. 7 in paper	**144.07**		**16.02**	**51.87**
bit rate (bps)	512,000	*bit_rate*	Rcvr BW = 2x data rate	**144.07**			**51.87**
s/c ant. gain (dB)	60.99	*sc_gain*	from Fig. 7 in paper	**144.07**		**60.99**	**112.86**
Boltzmann's Const	0	*Joules / K*	to calc noise floor	**144.07**	**Used in Noise BW (bps x 2)**		**112.86**
				144.07			**112.86**
wavelength (m)	0.18	calculated	(ignore for this calc)	**144.07**			**112.86**
antenna G/T	34.37	calculated	of groundstation dish	**144.07**			**112.86**
			(ignore for this calc)	**144.07**			**112.86**
				144.07			**112.86**
Losses (dB)				**144.07**			**112.86**
RF losses -s/c	1	Ltx		**144.07**			**112.86**
atmospheric loss	0.5	Latm	atmospheric loss from Earth's atn	**144.07**			**112.86**
polarization loss	0.1	Lp	from Fig. 7 in paper	**144.07**			**112.86**
modulation loss	1	Lmod		**144.07**			**112.86**
demod loss	2	Ldmod		**144.07**			**112.86**
pointing loss	0	Lpt	from Fig. 7 in paper	**144.07**			**112.86**
Receiver Circuit Loss	0.1		from Fig. 7 in paper	**144.07**			**112.86**
Lt (dB)	4.7	Lt		**144.07**		**-4.70**	**108.16**
			∑ Noise, ∑ Signal	**-144.07**			**108.16**
elevation (degrees)	0	5	15	30	60	89	
alpha (radians)	0.00	0.00	0.00	0.00	0.00	0.00	
slant range (km)	261,006,371	261,005,816	261,004,722	261,003,185	261,000,854	261,000,001	
Sphere area (m^2)	8.56E+23	8.56E+23	8.56E+23	8.56E+23	8.56E+23	8.56E+23	
Spreading Loss	**-239.33**	**-239.33**	**-239.33**	**-239.33**	**-239.32**	**-239.32**	
Unspread signal	**108.16**	**108.16**	**108.16**	**108.16**	**108.16**	**108.16**	
Signal dB	**-131.16**	**-131.16**	**-131.16**	**-131.16**	**-131.16**	**-131.16**	
Noise dB	**-144.07**	**-144.07**	**-144.07**	**-144.07**	**-144.07**	**-144.07**	
Signal / Noise	**12.91**	**12.91**	**12.91**	**12.91**	**12.91**	**12.91**	
Eb/No at 1e-6 (dB)	**-26.56**	**-26.56**	**-26.56**	**-26.56**	**-26.56**	**-26.56**	
Link Margin	**39.47**	**39.47**	**39.47**	**39.47**	**39.47**	**39.47**	

- Values based Fig.7 in this NASA JPL paper, although not all values match the paper's recommendations exactly because Fig. 7 considers a lander/Earth connection, while we are considering a Orbiter/Earth connection.
- This link budget covers both uplink and downlink for the orbiter/Earth link as both connections should be similar
- Link to google sheets

Link Budget 2 (Orbiter/Glider)

	Orbiter/Glider Link Budget						
Reference link to useful paper where many of these numbers came from: https://ipnpr.jpl.nasa.gov/progress_report/42-236/42-236A.pdf							
venus rad (km)	6051	*venus_rad*					
c (Gm/s)	0.3						
Eb/No at 1e-6 (dB)	9.09550065	density reported in Fig. 6, as well as bit rate calculated in bit budget					
				Noise dB ∑	**Noise dB**	**Signal dBw**	**Signal dBw ∑**
orbit altitude (km)	190	*altitude*	to calc distance for 4 π r^2	**0.00**	**red is negative**		**0.00**
carrier freq (GHz)	0.3	lower end of UHF--trying to reduce frequency as mu		**0.00**			**0.00**
antenna diam (m)	0.38	*ant_diam*	receiver patch antenna diameter (	**0.00**		**9.45**	**9.45**
system noise (K)	877	*noise_temp*	from paper (pg. 13)	**141.01**	**141.01**		**9.45**
Tx power (W)	10	*Tx_power*	from Fig. 6 in paper			**10.00**	**0.55**
bit rate (bps)	327,680	*bit_rate*	Rcvr BW = 2x data rate				**0.55**
s/c ant. gain (dB)	10.91	*sc_gain*	from Fig. 6 in paper			**10.91**	**11.46**
Boltzmann's Const	0	*Joules / K*	to calc noise floor		**Used in Noise BW (bps x 2)**		**11.46**
							11.46
wavelength (m)	1.00	calculated	(ignore for this calc)				**11.46**
antenna G/T	-30.84	calculated	of groundstation dish				**11.46**
			(ignore for this calc)				**11.46**
							11.46
Losses (dB)							**11.46**
RF losses -s/c	1	Ltx					**11.46**
atmospheric loss	5	Latm	from Fig. 6 in paper				**11.46**
polarization loss	0.5	Lp	from Fig. 6 in paper				**11.46**
modulation loss	1	Lmod					**11.46**
demod loss	2	Ldmod					**11.46**
pointing loss	0.1	Lpt	from Fig. 6 in paper				**11.46**
Receiver Circuit Loss	2		from Fig. 6 in paper				**11.46**
Lt (dB)	11.6	Lt				**-11.60**	**-0.14**
			∑ Noise, ∑ Signal	**-141.01**			**-0.14**
elevation (degrees)	0	5	15	30	60	89	
alpha (radians)	1.32	1.31	1.21	1.00	0.51	0.02	
slant range (km)	1,528	1,089	622	364	218	190	
Sphere area (m^2)	2.93E+13	1.49E+13	4.86E+12	1.67E+12	5.99E+11	4.54E+11	
Spreading Loss	**-134.68**	**-131.73**	**-126.87**	**-122.22**	**-117.77**	**-116.57**	
Unspread signal	**-0.14**	**-0.14**	**-0.14**	**-0.14**	**-0.14**	**-0.14**	
Signal dB	**-134.82**	**-131.88**	**-127.01**	**-122.36**	**-117.92**	**-116.71**	
Noise dB	**-141.01**	**-141.01**	**-141.01**	**-141.01**	**-141.01**	**-141.01**	
Signal / Noise	**6.19**	**9.13**	**13.99**	**18.65**	**23.09**	**24.29**	
Eb/No at 1e-6 (dB)	**9.10**	**9.10**	**9.10**	**9.10**	**9.10**	**9.10**	
Link Margin	**-2.91**	**0.03**	**4.90**	**9.55**	**13.99**	**15.20**	

- Values based Fig. 6 in this NASA JPL paper
- This link budget covers both uplink and downlink for the orbiter/glider link as both connections should be similar (both pointed directional transmitters and receivers)
- link to google sheets

Mass Budget

Mass Budget

Category	Component	Orbiter Mass (kg)	Glider Mass (kg) (each)	Total Mass (kg)	Notes
Structure & Thermal	Structural Frame	300	5	305	Titanium alloys, aerogels for thermal resistance
	Thermal Protection System	50	2	52	Heat shielding (carbon–phenolic)
Avionics & Control	Flight Computer	30	0.1	30.1	Central processor for autonomous control
	Inertial Measurement Unit (IMU)	10	1	11	Gyroscopes, accelerometers
	Navigation Sensors	5	1	6	GPS-like positioning for orbital control
Power System	Solar Panels	200	2	202	Triple-junction solar cells (~2 m² per glider)
	Batteries	50	1	51	Silver-zinc battery storage
	Power Management System	20	1	21	Regulates power flow
Communications	X-band Transmitter	75	1	76	High-gain directional antennas
	Data Storage Unit	20	1	22	Flash memory for data caching
Science Instruments	Doppler Lidar	40	2	42	Measures wind velocities
	Spectrometer (IR/Vis)	20	2	22	Captures atmospheric composition
Propulsion	Main Thrusters (Orbiter)	400	N/A	400	Bipropellant thrusters for orbit adjustment
	Reaction Control System (RCS)	50	2	52	Small thrusters for attitude control
Entry & Descent	Aerobraking Shield	N/A	5	5	Used to reduce descent velocity
	Parachute/ HAID Capsule Deployment	700	N/A	700	Slows initial descent phase
Safety & Redundancy	System Redundancy (20%)	394	5.22	399.22	Accounts for structural, electrical, and software backups
Total Mass Estimate	Final Total	2364	31.32	2395.32	

Mass For Each Glider

Component	Mass (kg)	Size Estimate
Frame & Wings	5-7	2.5-3.5m span, foldable
Battery & Solar Panels	3-4	~2 m² panel area
Avionics & Control	2-3	Integrated flight control
Science Instruments	2-4	Magnetometer, IR sensor
Comms (UHF/X-band)	1-2	Directional tracking antenna
Thermal Protection	2-3	Heat-resistant coatings
Propulsion (Minimal)	1-2	Small RCS for reentry control
Margin (~20%)	3-5	Extra safety factor
Total	**19-32**	**Compromise would be 25**

Delta V Budget

Delta V Breakdown

Maneuver	Delta V (m/s)	Propellant Mass (kg)	Notes	Source
Earth Departure Phase				
Earth to LEO	10,000	11,000	Kennedy Space Center to LEO	https://en.wikipedia.org/wiki/Delta-v_budget, https://www.projectrho.com/public_html/rocket/appmissiontable.php
Trans-Venus Injection (TVI)	3450	229	LEO to Venus, Hoffman Orbit	https://en.wikipedia.org/wiki/Delta-v_budget, https://www.projectrho.com/public_html/rocket/appmissiontable.php
Mid-Course Corrections	50	4	Multiple small adjustments during transit	
Venus Arrival Phase				
Venus Orbit Insertion (VOI)	1200	92	Reduced by aerobraking	https://ntrs.nasa.gov/api/citations/20070014649/downloads/20070014649.pdf
Orbit Circularization	250	21	Adjust to final science orbit	
Science Operations Phase				
Station-Keeping	100	9	Orbit maintenance	https://sci.esa.int/documents/34571/36233/1567255504981-VenusExpressDefStudyRep.pdf
Maat Mons Deployment	30	3	Orbital adjustment for deployment	https://ntrs.nasa.gov/api/citations/20190026585/downloads/20190026585.pdf
Maxwell Montes Deployment	40	4	Orbital adjustment for deployment	
Phoebe Regio Deployment	35	3	Orbital adjustment for deployment	
Contingency & End-of-Mission				
Collision Avoidance	50	4	Emergency maneuvers if needed	
Deorbit/End-of-Mission	150	12	Optional - planetary protection	
Contingency (20%)	1071	2276.2	Standard mission planning reserve	
Total	**16426**	**13657.2**		
Total (Before Contingency)	**15155**	**11381**		

Analysis By Phase

Earth to Venus Transit	Column 1
Transit Time	4-6 months
Departure Window Constraints	Every ~19 months
Planetary Alignment Efficiency	Medium
C3 Energy Requirement	7.5 km^2/s^2
Venus Orbit Insertion Efficiency	
Aerobraking Savings	~800 m/s
Periapsis Altitude	130 km
Maximum g-force	3 g
Aerobraking Duration	30-45 days
Orbital Operations	
Initial Capture Orbit	400 x 75,000 km
Final Science Orbit	300 x 300 km
Inclination	85 degrees
Orbital Period	90 minutes
Glider Deployment	
Release Velocity	2 m/s
Attitude Control	0.5 degrees precision
Post-Release Drift Rate	< 10 m/s relative velocity

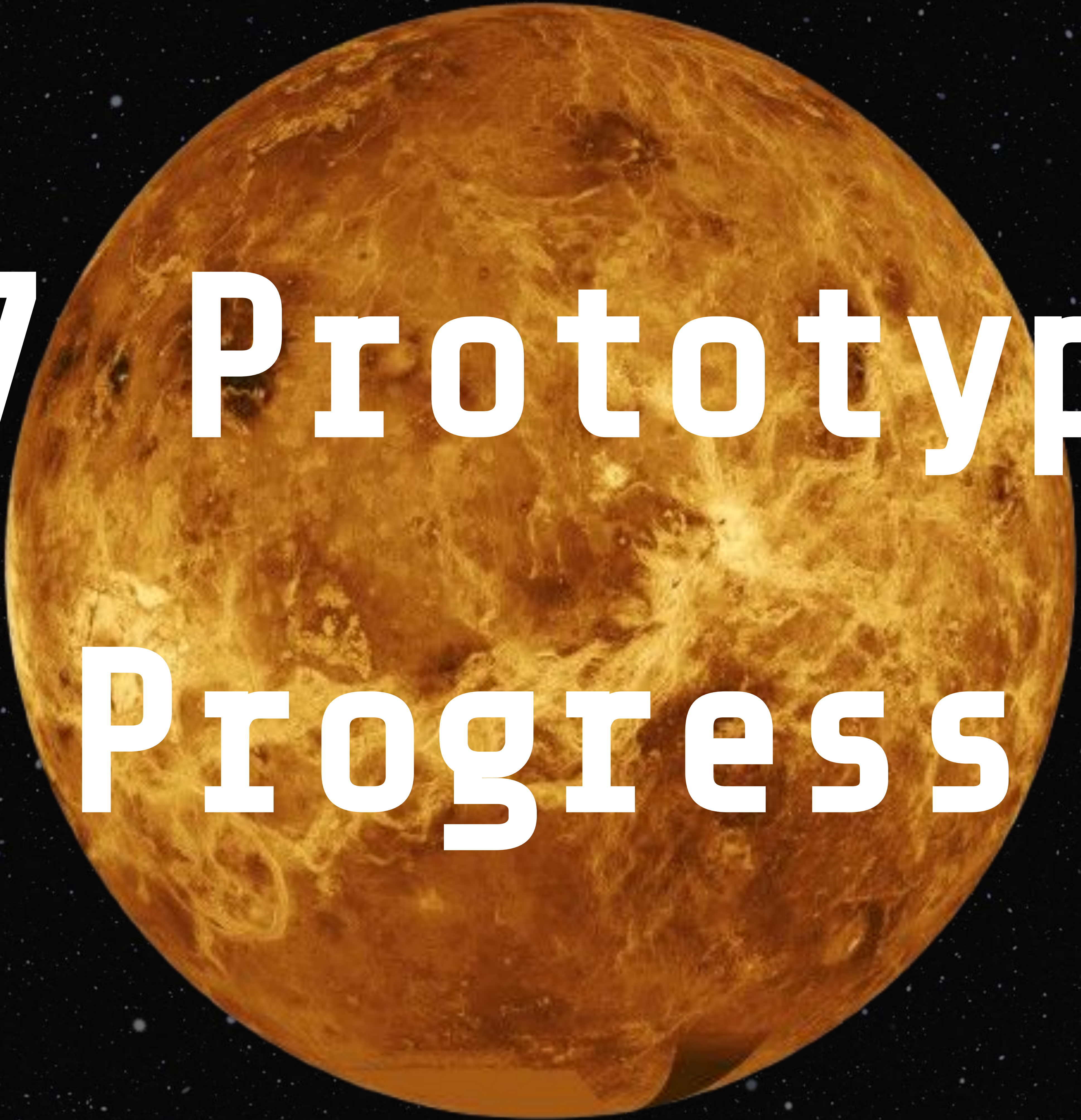
Feasibility

Subsystem	Feasibility	Challenges
Aerodynamics/Propulsion	**Feasible**	Varying Wind Speeds
Navigation/Software	**Somewhat Feasible**	Novel Control Algorithms, Multi Body Problem
Power	**Somewhat Feasible**	High energy load for cooling/navigation… solar power may be intermittent
Environmental Hardening	**Feasible**	Done on past missions, heat in lower atmosphere most difficult
Communication System	**Feasible**	Orbiter needs to be in range, data needs to be stored
Sensors (Lidar, Radiometer)	**Feasible**	Weight Constraints

Viability (Costs)

Subsystem	Price
Orbiter Architecture/Manufacturing	50,000,000
Drone Propulsion	10,000
Power + Batteries	1,000
Environmental Hardening/Thermal	10,000
Communication System	100,000
Lidar/Radiometer/Magnetometer (3x)	128,000
Labor	30,000,000
Entry/Descent	40,000,000
R/D & Testing (probe/orbiter)	50,000,000
Launch Costs	100,000,000
Total	270,249,000

07 Prototype Progress



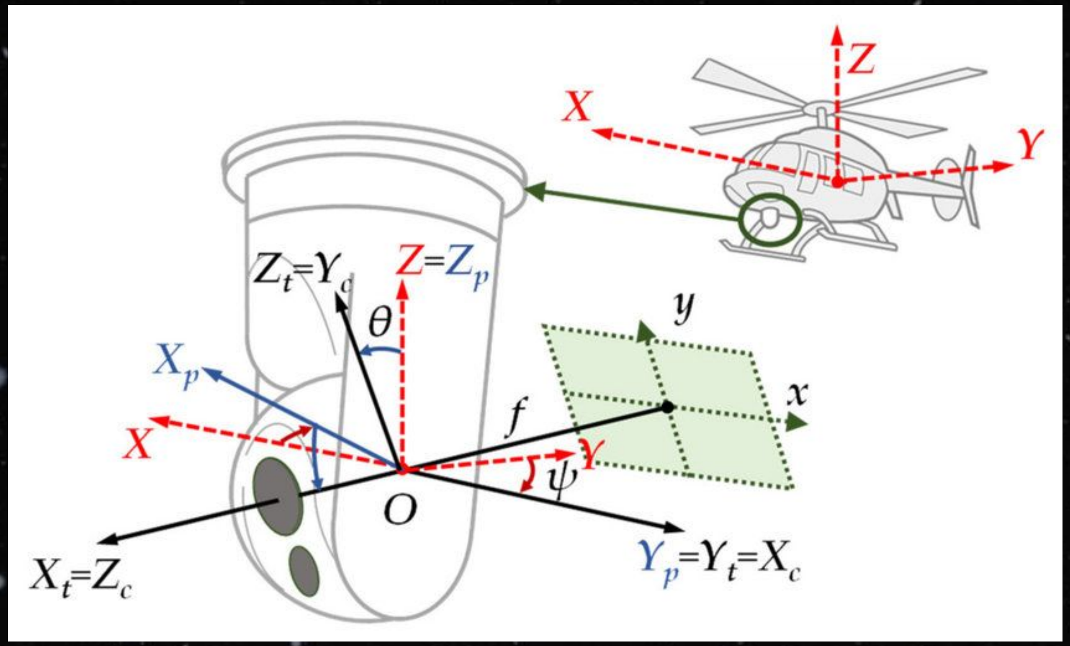
Our Timeline -> Comm/Control of Glider

March 16-21	Monday: Review and prioritize feedback from Preliminary Design Review (PDR), Identify critical challenges for the directional communication system, Develop improvement plan for transmitter/receiver pointing mechanism Section: Present our response strategy to instructor feedback, Discuss technical requirements for stabilizing the robotic arm in high winds, explore solutions for maintaining signal lock in 60 m/s Venusian winds Sunday:Implement major design improvements based on section feedback, begin integration of orientation sensors (gyroscope and accelerometer), update system diagrams to reflect new design direction
March 22-29	**SPRING BREAK**
April 1st-5	Monday:Test probe control system with sensors and power supply, verify data collection from orientation sensors (gyroscope, magnetometer, accelerometer), evaluate control response in simulated wind conditions Section: Ask/clear up questions that come up from Monday session Sunday: Implement control system improvements based on instructor feedback, refine stabilization algorithms for the pointing mechanism.
April 6-12	Monday: Test data transmission between probe and simulated orbiter, measure signal strength across different pointing angles, evaluate tracking algorithm accuracy during movement simulation Section: Review communications test results with instructors, discuss data transmission protocols and efficiency, address questions about signal reliability in challenging conditions
April 13-19	Monday: Test wind speed data collection working together with communications system, Evaluate system performance during communication interruptions (ie Test backup data storage and transmission recovery mechanism) Section: Begin drafting final system performance metrics.
April 20-26	Monday 7-9 : Compile all test results for presentation, Prepare demonstration scenarios for final review

Prototype Plan

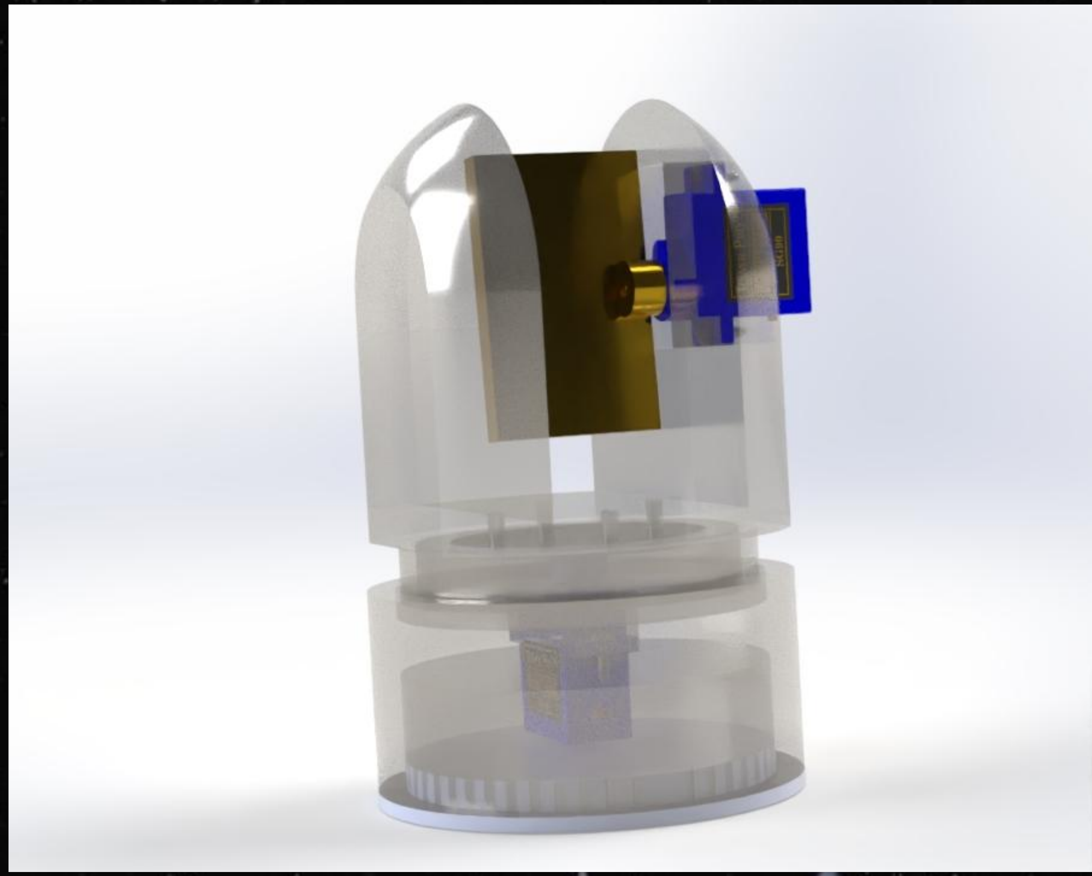
- One critical aspect of our mission is communication between the orbiter and the glider system. We will focus on this aspect of the design by developing a directional transmitter/receiver system that will allow the transmitter on the glider to accurately point toward the receiver on the orbiter (and vice versa) as both move along their respective routes.

- **Physical system:** the transmitter will need to be mounted on a robotic gimbal to allow it to point in any direction, similar to current land and sea based systems
  - Sources:
    - A Nonlinear Backstepping Controller Design for High-Precision Tracking Applications with Input-Delay Gimbal Systems
    - (PDF) A Study on Vision-Based Backstepping Control for a Target Tracking System

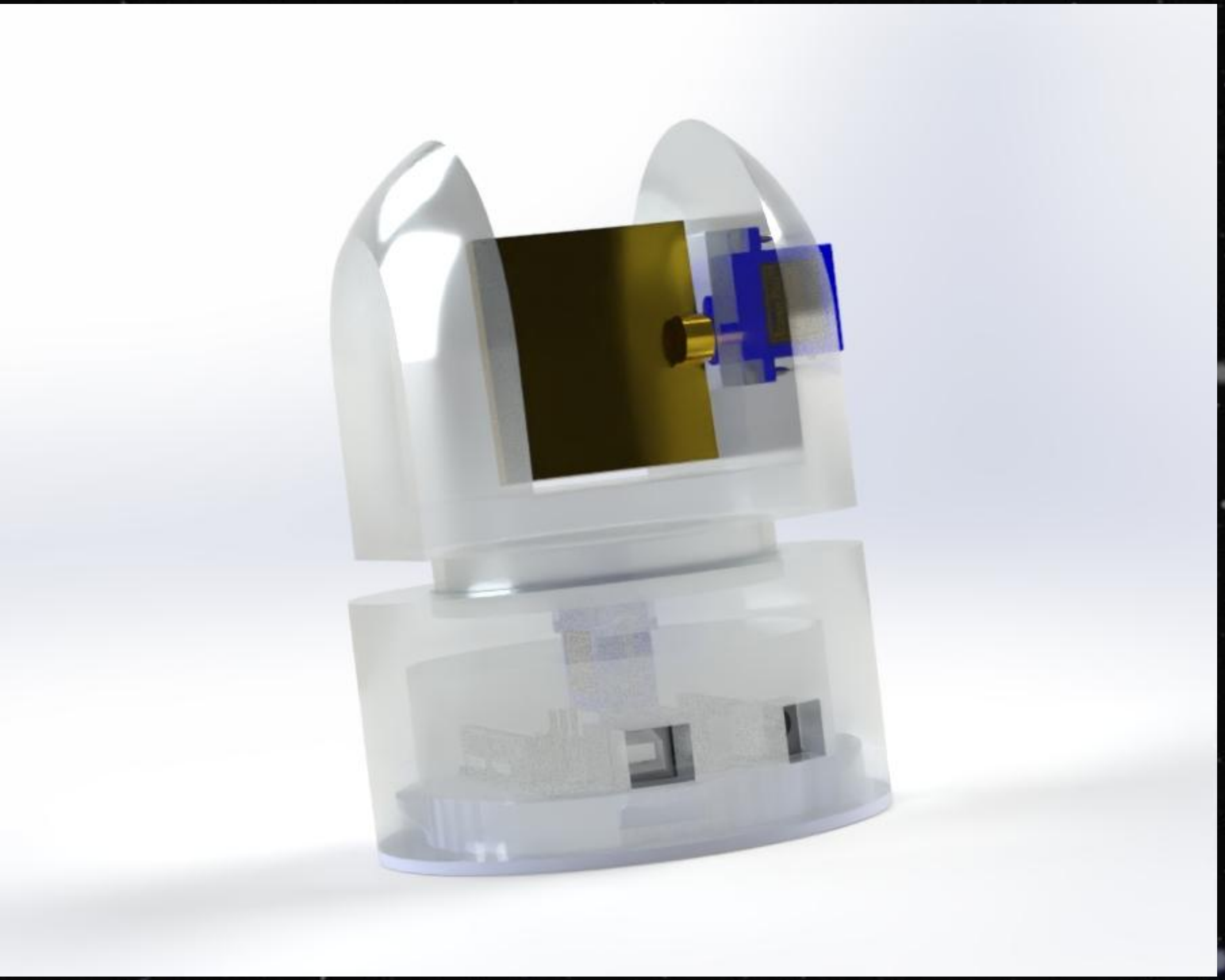


- **Components:**
  - **3D Printed Chassis**
  - **Radio transmitter and receiver**
  - **Gyroscope/Accelerometer**
  - **Servos/Stepper Motors**
  - **Tracking and Stability Control Algorithms**

Prototype CAD Models



Small gimbal utilizing arduino nano, attached to drone



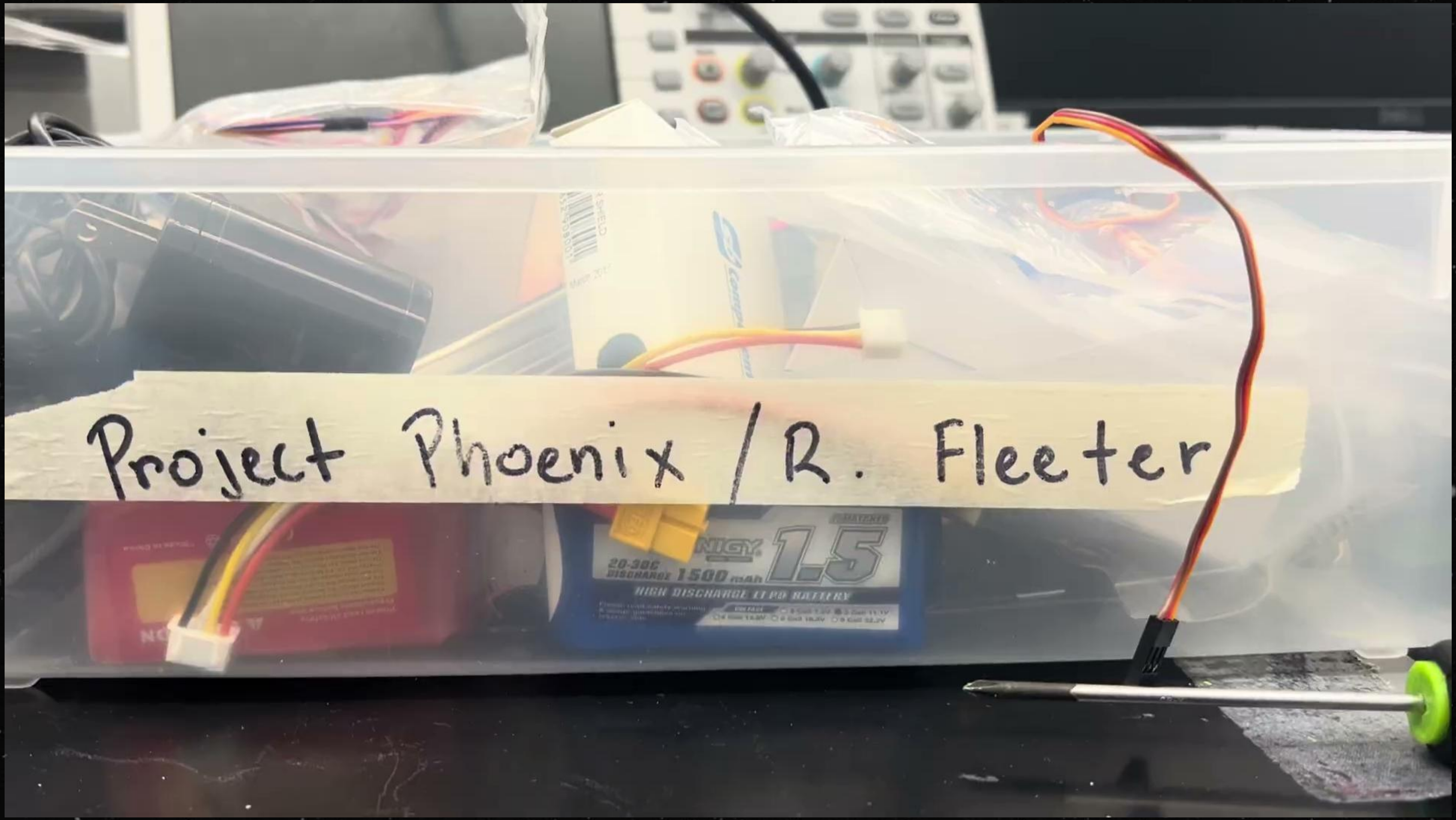
Small gimbal utilizing arduino uno, ground station

Prototype CAD Models

Mockup of Gimbal Attachment to Drone

Build Portion Demo

Link to video:
https://drive.google.com/file/d/143CcrT08JLb4Vt26lUjdBw5SRb6tC-uf/view?resourcekey



Video Demo of Build Portion of PDR

Resources & Citations

- Could Dark Streaks in Venus' Clouds Be Microbial Life? | News | Astrobiology
- Anduril's Lattice: a trusted dual use — commercial and military — platform for public safety, security, and defense
- The Forces Behind Venus' Super-Rotating Atmosphere | Smithsonian
- Venus Fact Sheet
- Venus Express - Spacecraft
- How waves and turbulence maintain the super-rotation of Venus' atmosphere | ISAS
- Akatsuki/Planet-C
- Venus Climate Orbiter AKATSUKI
- Doppler Lidar - an overview | ScienceDirect Topics
- Kepler's Laws of Orbital Motion | How Things Fly
- Infrared and Ultraviolet Imaging | Museum Conservation Institute
- Atmospheric Probe Shows Promise in Test Flight - NASA

Resources & Citations

Venus Superroation

- Superrotation - an overview | ScienceDirect Topics.
- Exploring the Venus global super-rotation using a comprehensive general circulation model - ScienceDirect

Fixed Wing Gliders on Venus

- Power minimization of fixed-wing drones for Venus exploration in various altitudes - ScienceDirect

Dead Reckoning

- Inertial navigation system - Wikipedia

Gimbal

  - A Nonlinear Backstepping Controller Design for High-Precision Tracking Applications with Input-Delay Gimbal Systems
  - (PDF) A Study on Vision-Based Backstepping Control for a Target Tracking System

THANK YOU !

Power Budget (Rough Estimates)

Component	Power Consumption (W)
Avionics (Flight Computer, Sensors)	**5W**
Communication System	**7W**
Actuation System (Motors, Servos)	**1500W**
Science Instruments (LIDAR, Spectrometer, Magnetometer)	**6W**
Total Estimated Power Requirement	**1518W**

Solar Power Generation Feasibility

- Surface Area of Solar Panels: 2 m^2 (approx. for 3-3.5 m wingspan plane)
- Expected Solar Intensity: 1300 W/m^2 (at 50 km altitude)
- Solar Panel Efficiency: 32% (Triple Junction space grade with protective enclosure & AR coating added)
- Actual power acquisition efficiency: 25% (very rough estimate-see note below for justification)
- Total Power Generated: ~650W (Requires backup battery for energy shortfalls → can charge battery pre-flight on orbiter.)

*Note: Because a Venusian day is very long (around 243 Earth days), we can deploy each drone when the Sun is incident upon the target area, thus drastically improving the performance of our solar cells and allowing us to avoid efficiency losses due to the angle of the Sun. For this reason, we are leaving the estimated actual power acquisition efficiency of the solar cells high, at around 25%, which is a rough estimate.

Mass Budget (Rough Estimates)

Components	**Orbiter Mass (kg)**	**Drone Mass (kg) (each)**	**Total Mass (kg)**
Structural & Thermal Shielding	300	10	330
Avionics & Control System	50	5	65
Power System (Solar + Battery)	200	8	224
Communications System	75	3	84
Science Instruments	100	6	118
Propulsion (Main & RCS)	400	4	412
Parachute/Aerobraking System	N/A	5	15
Margin (20%)	225	8	249
Total Mass Estimate	**1350 kg**	**49 kg**	**1497 kg**

Optimized Mass Budget for Probe (20-25 kg)

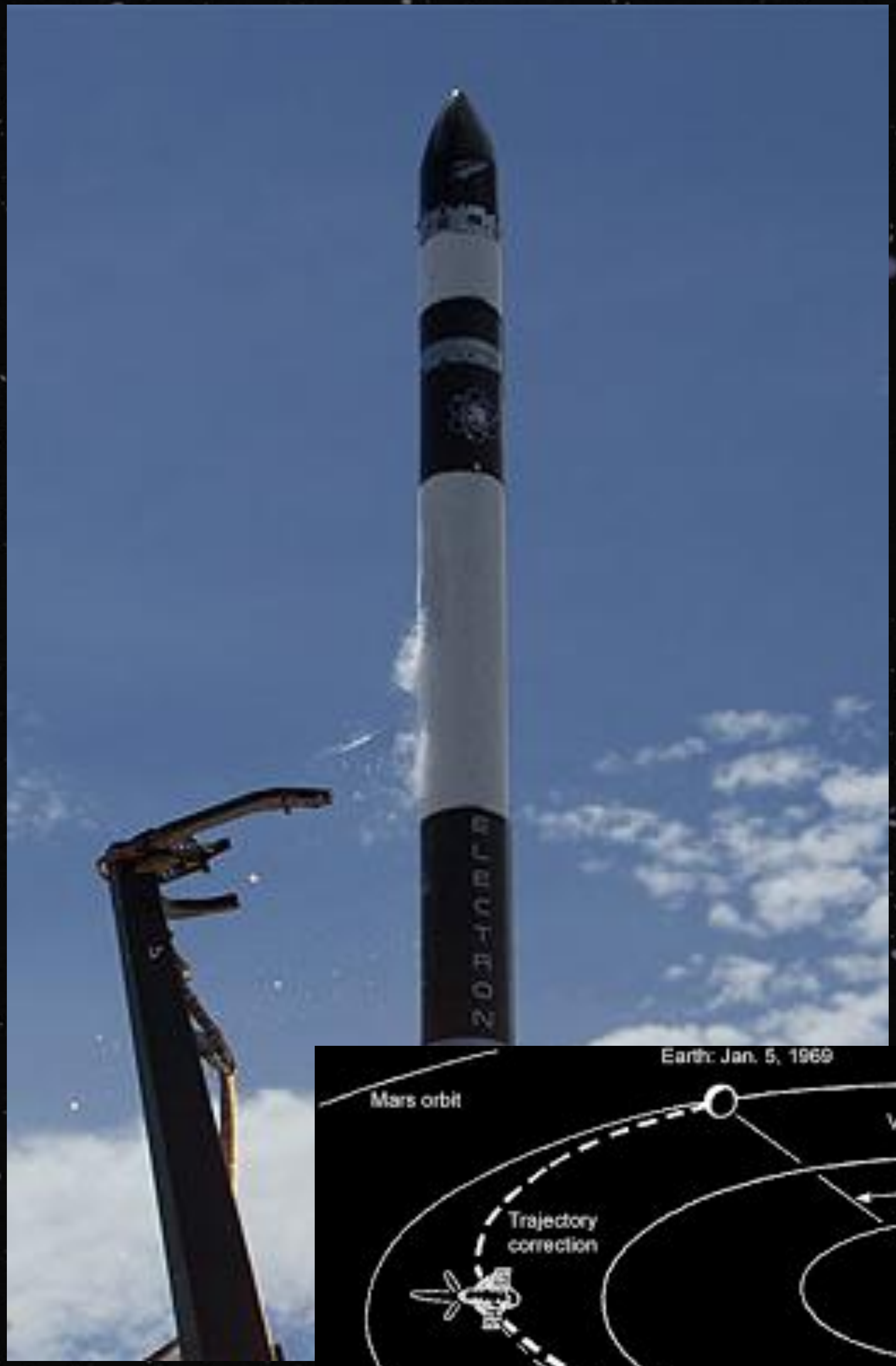
Component	Mass (kg)	Size Estimate
Frame & Wings	5-7	2.5-3.5m span, foldable
Battery & Solar Panels	3-4	~2 m^2 panel area
Avionics & Control	2-3	Small board, integrated sensors
Science Instruments	2-4	magnetometer, IR sensor
Comms (UHF/X-band)	1-2	directional tracking antenna (transmitter)
Thermal Protection	2-3	Heat-resistant coating
Propulsion (Minimal)	1-2	Small RSC for reentry control
Margin (~20%)	3-5	Extra safety factor

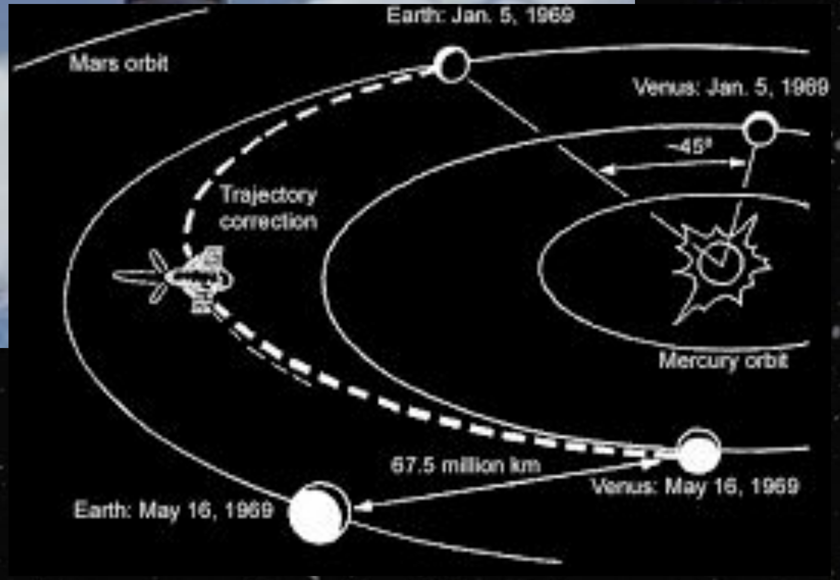
Mass Budget Justifications

- **Structural & Thermal Shielding (Orbiter: 300 kg, Drone: 10 kg)** : Derived from past planetary missions (e.g., Magellan, Akatsuki). Includes high-temperature-resistant materials such as titanium alloys and aerogels, with estimates based on existing aerospace-grade shielding weights.
- **Avionics & Control System (Orbiter: 50 kg, Drone: 5 kg)** : Modeled after avionics packages in previous Venus and Mars missions (e.g., MAVEN, Akatsuki). Weight accounts for redundancies and radiation-hardened components.
- **Power System (Orbiter: 200 kg, Drone: 8 kg)** : Based on solar panel mass-energy ratios from ESA/NASA deep-space probes. Lithium-ion battery estimates drawn from high-altitude UAVs and previous Venus balloon mission designs.
- **Communications System (Orbiter: 75 kg, Drone: 3 kg)** : Mass derived from high-gain X-band antenna weights on spacecraft like Mars Reconnaissance Orbiter and Earth-Venus distance power constraints.
- **Science Instruments (Orbiter: 100 kg, Drone: 6 kg)** : Estimated using instrument payloads on comparable missions (e.g., Venus Express). Individual instrument weights taken from manufacturer specifications where available.
- **Propulsion (Orbiter: 400 kg, Drone: 4 kg)** : Calculated based on required delta-v for Venus orbit insertion, with mass breakdowns drawn from known bipropellant thruster specifications (e.g., LEROS-1b engines used in interplanetary missions).
- **Parachute / Aerobraking System (Drone: 5 kg)** : Derived from past atmospheric entry systems, including Mars Science Laboratory parachute masses scaled for Venus' dense atmosphere.
- **Margin (20%) (Orbiter: 225 kg, Drone: 8 kg)** : Standard industry practice contingency applied based on historic aerospace mission deviations.

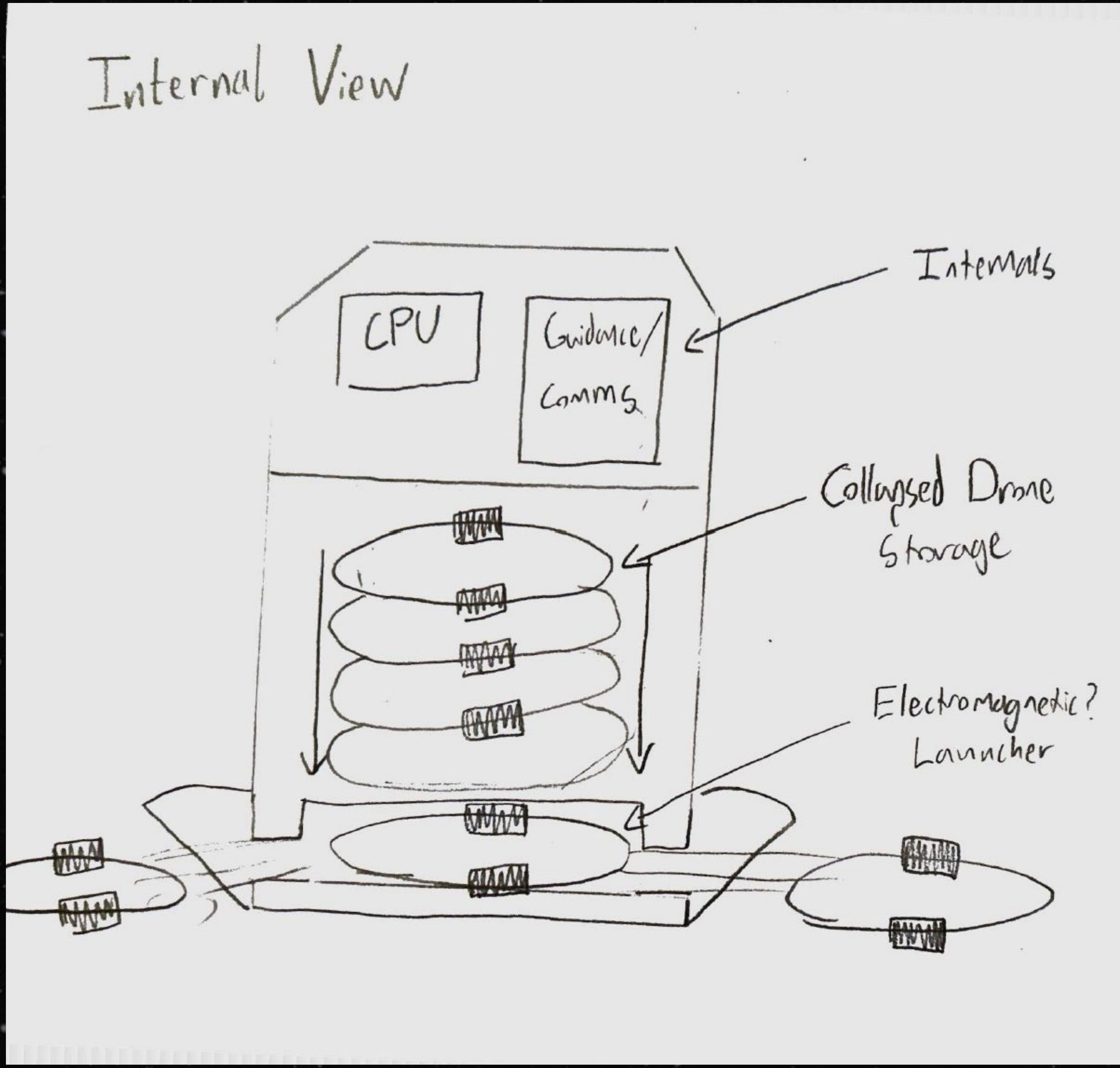
Engineering Requirements

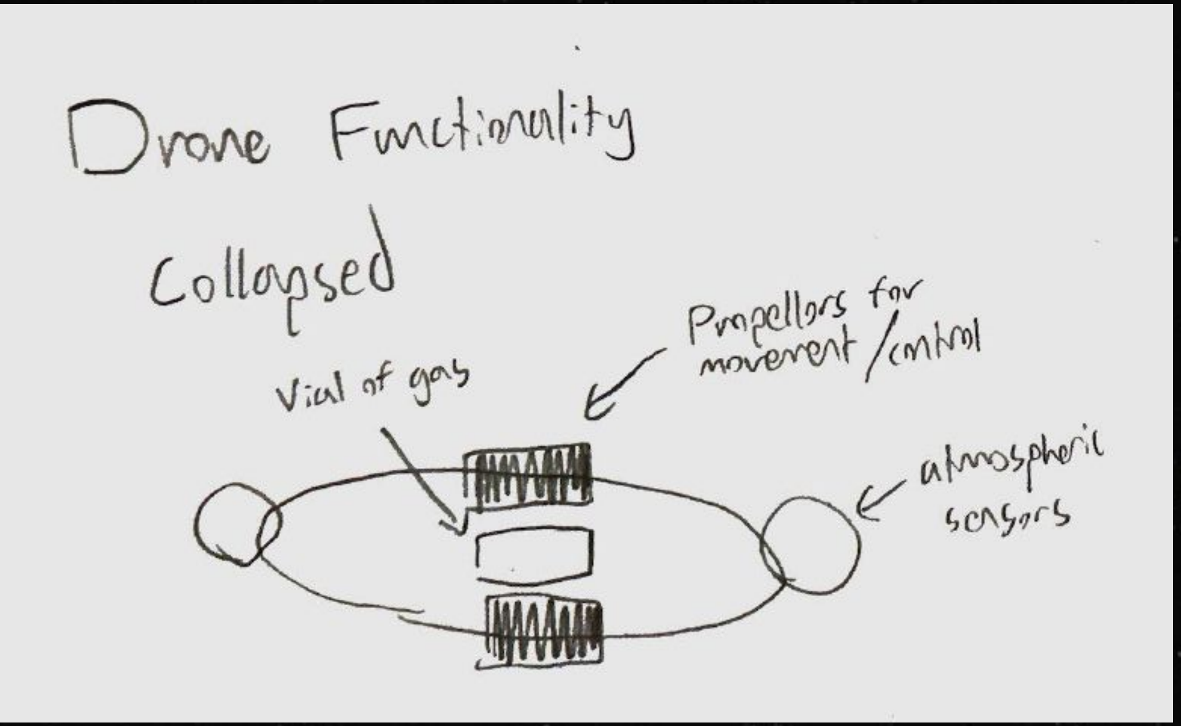
1. Launch orbiter into stable Venusian orbit
    a. Utilize RocketLab Electron launch vehicle for private mission to Venus (https://www.rocketlabusa.com/missions/upcoming-missions/first-private-mission-to-venus/?utm_source=chatgpt.com)
    b. Utilize interplanetary slingshots to optimize orbiter location (https://www.sciencedirect.com/science/article/pii/S0273117723001758)
    c. Launch within window where Earth is closest to Venus. (http://mentallandscape.com/V_VenusMissions.htm)

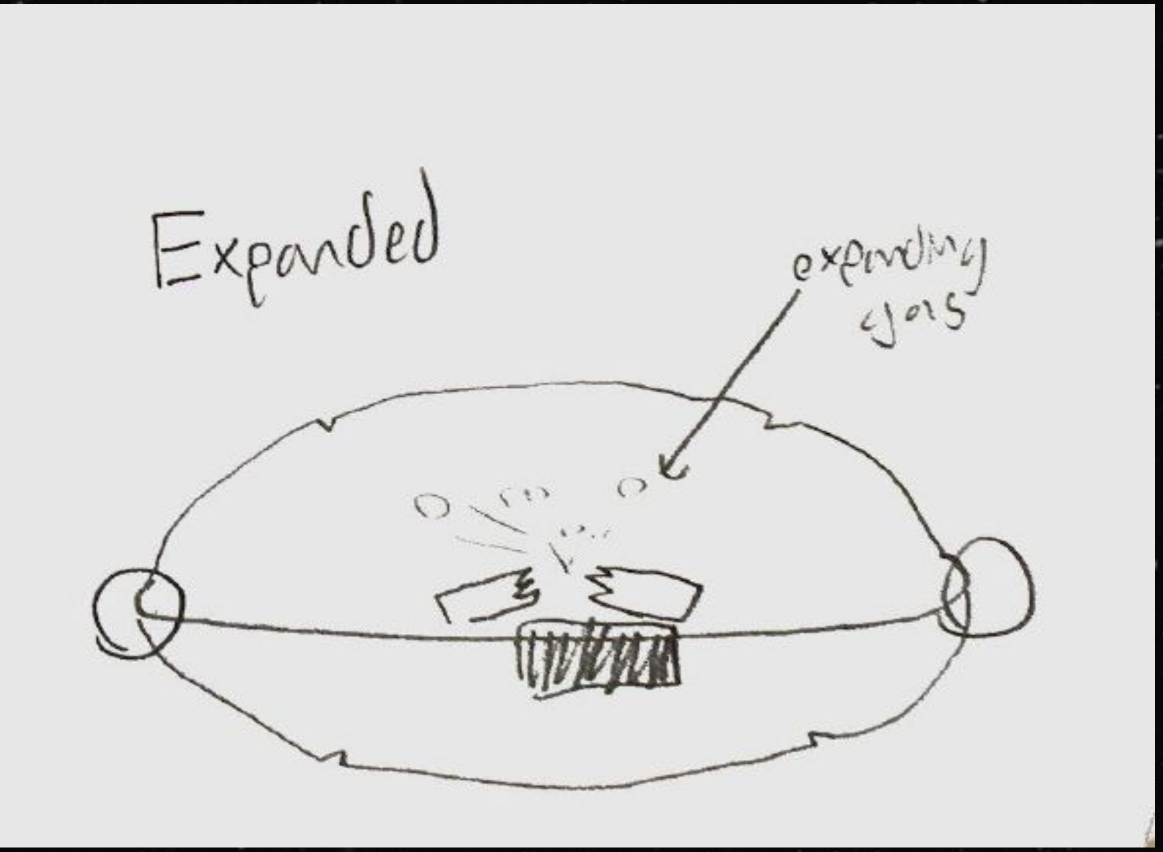




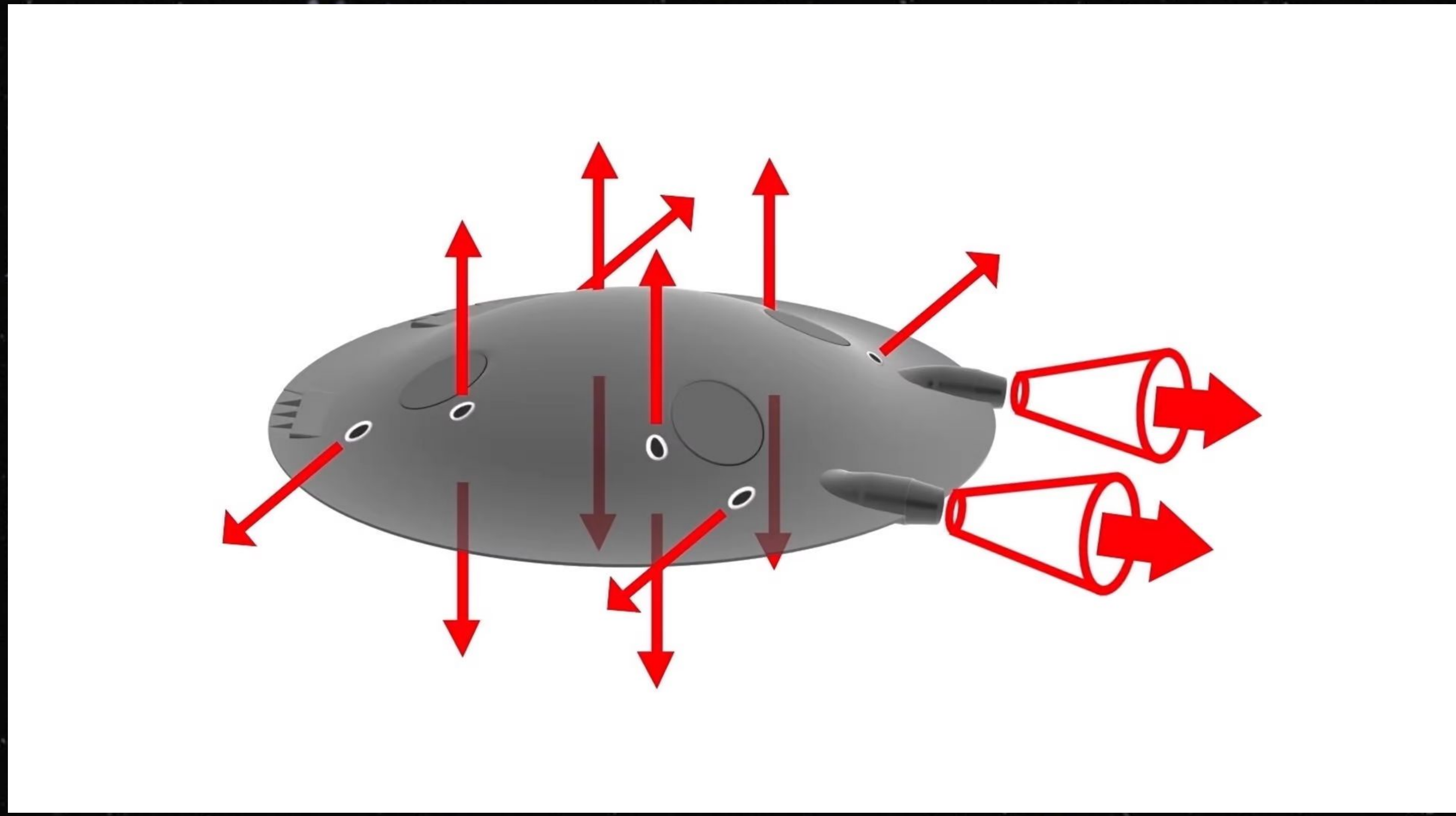
Qualitative Overview - Balloon Drones







Drone Ideas



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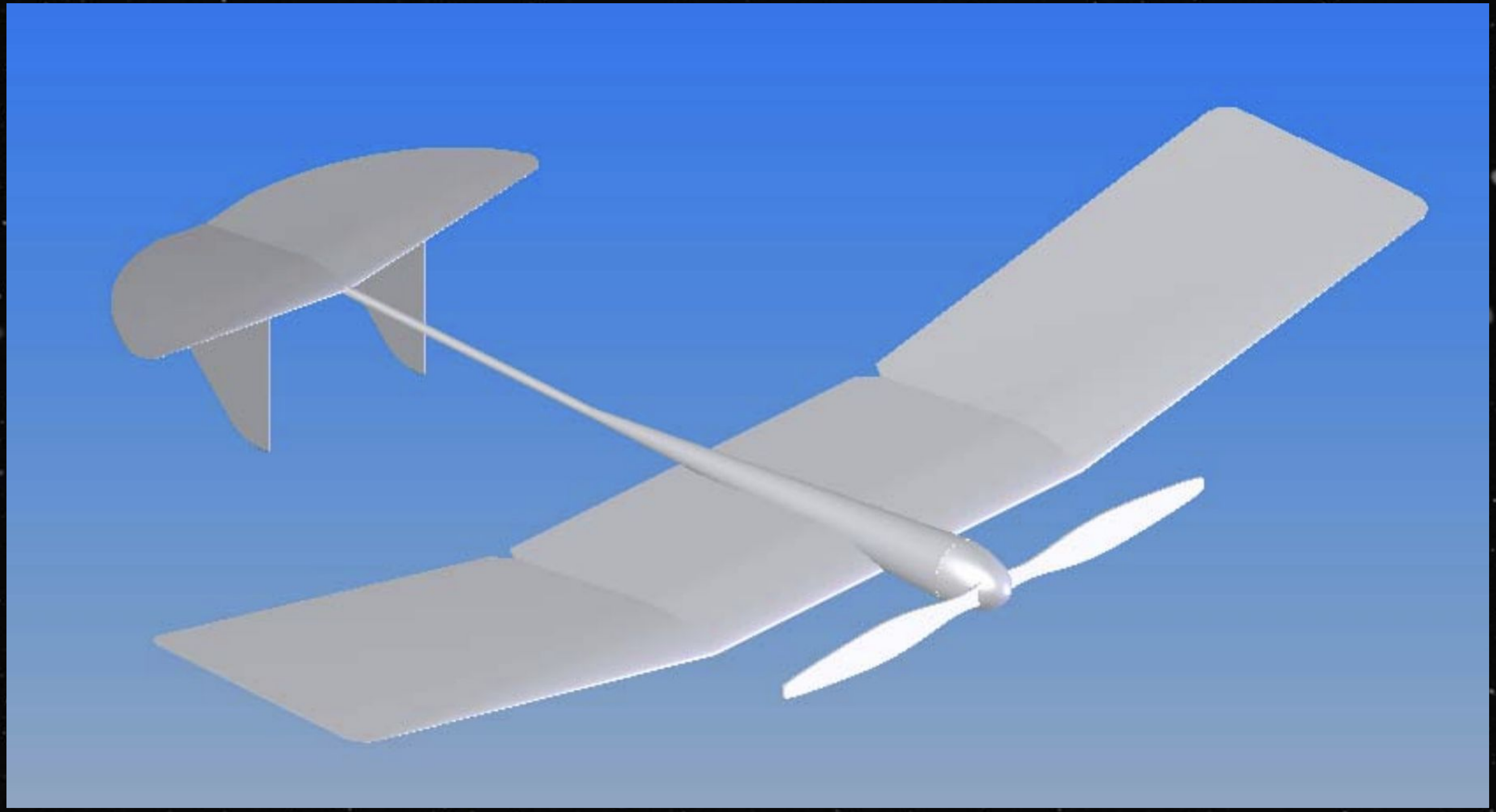
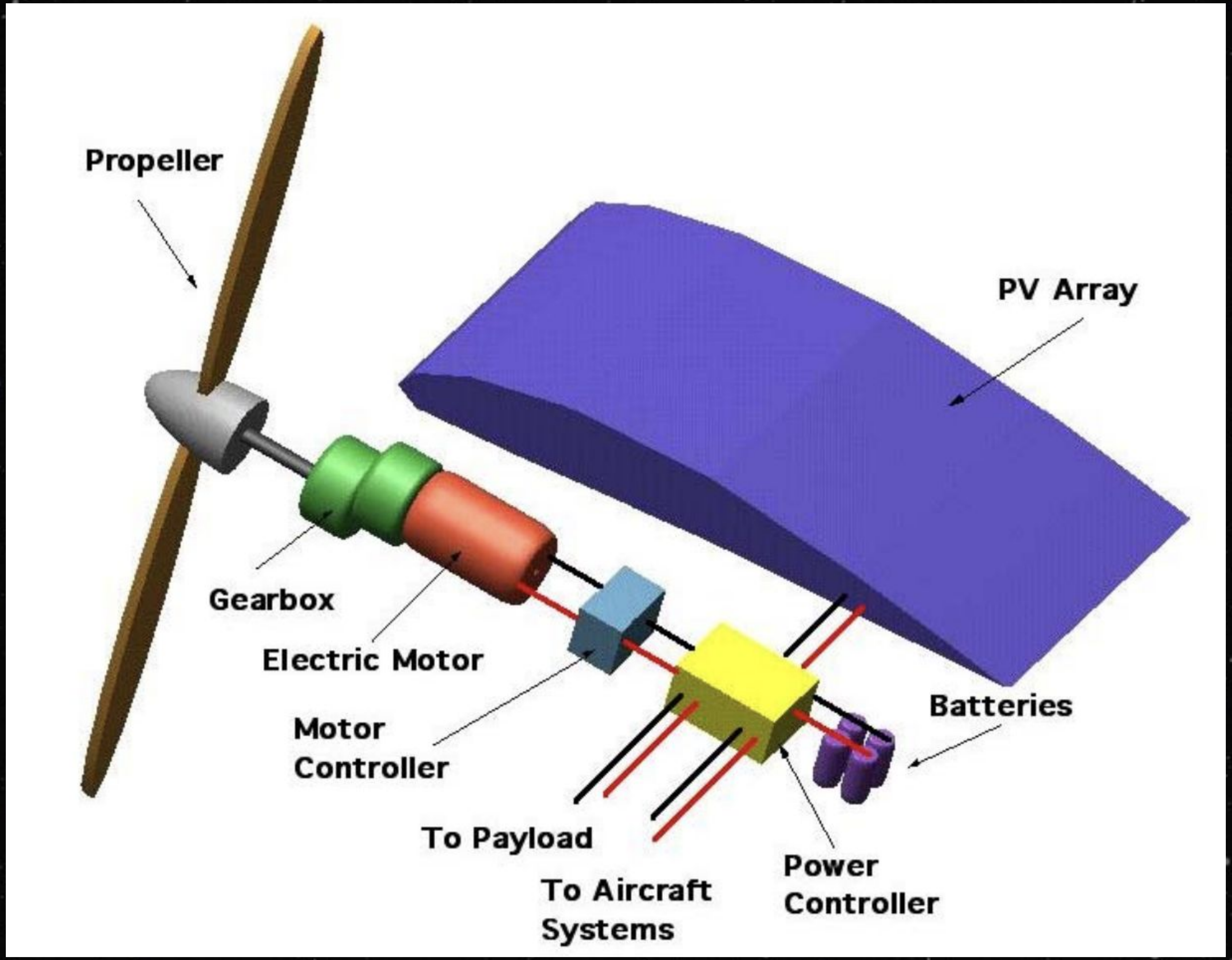
gree-surveillance/article34183091/

Basic Glider Ideas (Source Paper Linked Below)





https://ntrs.nasa.gov/api/citations/20040070782/downloads/20040070782.pdf

Probe Sensor Array (Non-Essential)

Pressure Sensor

- **Purpose:** Measure pressure gradients at different altitudes
- **Why:** Can detect small scale atmospheric waves and turbulence that might contribute to momentum transfer
- **Relevance:** Helps explain how momentum is being transferred in Venus' atmosphere

Cloud Particle Analyzer

- **Purpose:** Measure size, concentration, and other distribution of cloud particles
- **Why:** Help understand how cloud formation and particle interaction might contribute to momentum transfer
- **Relevance:** Cloud particles act as tracers that reveal the strength/characteristics of updrafts

Non-Essential (Nice to Have) Payload Subsystem Overview: The Glider

Infrared Radiometer

- **Purpose:** Measures temperature at different altitudes by measuring thermal infrared radiation
- **Why:** Thermal tides are caused by temperature differences
- **Relevance:** Interaction between thermal tides and planetary waves might contribute to super rotational winds

Spectrometer (High-Resolution Visible & Infrared)

- **Purpose:** Analyzes the composition of Venus' atmosphere and presence of different gases
- **Why**: Gases like CO2 and SO2 contribute to atmospheric temperature
- **Relevance:** Quantify effect of radiative heating on thermal tides

Other Non-Essential (Nice to Have)

Payload Subsystem Overview: The Orbiter

UV and Infrared Cameras

- **Purpose:** Track cloud movement
- **Why:** Provides spatial understanding of temperature variations
- **Relevance:** Identifies heat distribution driving atmospheric motion

Radio Occultation Instrument

- **Purpose:** Measures temperature, pressure, and density of atmosphere by analyzing how radio waves are refracted as they pass through different layers of atmosphere
- **Why**: Analyze vertical temperature fluctuations
- **Relevance:** Complements Doppler Lidar and cloud tracking to link temperature variations to wind speed and superrotation