System Design Review: Exploring the Feasibility of Human Life on Venus

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Storyboard

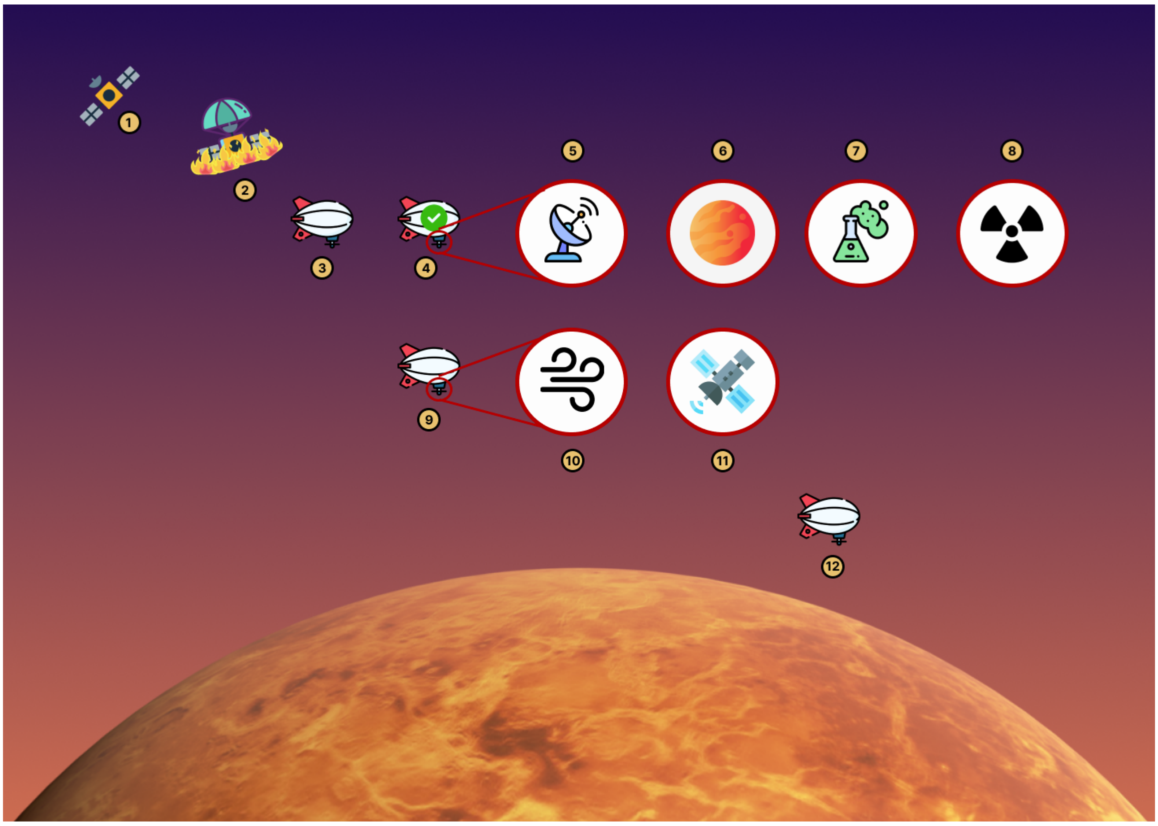

Figure 1: Storyboard of VISTA [7] [8]

#	Event	Description	Timeline
1	Venus Transfer & Arrival	After a 6-month cruise from Earth, VISTA arrives at Venus and begins orbit insertion using onboard propulsion and precise attitude control. A final burn is completed in the Hohmann Transfer.	Unknown
2	Aerobraking & Entry	VISTA uses controlled atmospheric drag to slow down and transition from interplanetary orbit into an entry trajectory toward the upper atmosphere.	Within hours of arrival
3	Envelope Deployment & Inflation	At 50 km altitude, VISTA ejects its aeroshell and autonomously inflates its helium-based aerostat. Proper deployment is essential for buoyant operation. **(Partial Mission Success)**	30–60 minutes after entry
4	System Check	VISTA performs a full systems health check, verifying thermal control, pressure integrity, sensor baselines, and communication links.	15–30 min after inflation
5	Instrument Activation	Onboard science payloads power on and calibrate to begin habitability-focused atmospheric monitoring.	10–15 min after system check
6	Atmospheric Composition Survey	Instruments record continuous measurements of pressure, temperature, gas concentration, and chemical composition to assess environmental viability. **(Full Mission Success)**	Begins 1 hr post-deployment; ongoing
7	Acidic Cloud Sampling	Exposed materials are evaluated for corrosion resistance by direct interaction with sulfuric aerosols to inform future habitat shielding needs.	Begins 2–3 hrs after deployment; ongoing
8	Radiation & Solar Monitoring	VISTA measures incident solar flux and ambient radiation to understand long-term exposure risks in Venus' upper atmosphere.	Begins alongside Event 6; continuous
9	Altitude Modulation	Using gas and ballast control, VISTA adjusts its altitude to profile different atmospheric layers and test buoyancy control mechanisms.	Begins Day 2; occurs regularly
10	Wind & Turbulence Mapping	Wind speed, direction, and shear are recorded to evaluate airship station-keeping feasibility and atmospheric stability.	Begins Day 1–2; sampled frequently
11	Data Transmission	VISTA transmits high-priority science and system health data to Earth, either directly or via a Venus-orbiting relay satellite.	Begins Day 1; occurs daily
12	Extended Mission / Descent	If viable, VISTA continues long-term monitoring or initiates a controlled descent to deeper atmospheric layers for stretch science goals. **(Extended Mission)**	Begins Day 30+ (if successful)

Table 1: VISTA Mission Timeline with Key Success Milestones and Approximate Timing

It is important to note that the timeline for event one is unknown as there is a trade-off to be discussed on the travel of VISTA from low Earth orbit (LEO) to low Venusian orbit (LVO). This trade-off is regarding the use of chemical propulsion or electric propulsion and is largely time dependent.

Narrative

Overview

The Venusian In Situ Tropospheric Aerostat (VISTA) is a robotic balloon-based platform designed to operate in Venus' upper atmosphere at approximately 50 km altitude for a minimum of 30 Earth days. The idea of human life in the Venusian atmosphere has been pondered, but there is still too much inherent danger for a real human mission. Therefore, VISTA aims to collect high-fidelity data on thermal conditions, atmospheric chemistry, radiation levels, and wind dynamics through a robotic payload. This section presents the functional baseline for the VISTA system, organized by subsystem, emphasizing the space segment, the ground segment, key performance metrics, and the rationale behind selected subsystem architectures through relevant trade studies.

Subsystem Overview

The VISTA spacecraft is organized into the following subsystems:

1. **Payload**
2. **Communications**
3. **Power Generation and Storage**
4. **Buoyancy and Altitude Control**
5. **Command & Data Handling (C&DH)**
6. **Thermal Control**
7. **Attitude Determination & Control (ACS)**
8. **Structure and Materials**

Each subsystem performs essential functions to support the scientific and operational goals of the mission. Each subsystem will be briefly discussed, but for the sake of this report, only four of these—Payload, Communications, Power, and Buoyancy/Altitude Control— will be discussed in detail due to their central role in enabling habitability assessment and maintaining system viability in Venus' harsh environment.

Key Subsystems

Payload

The payload is the foremost important subsystem as it determines the rest of the mission architecture. In the case of VISTA, the payload consists of environmental sensors, imaging devices, and chemical analysis tools designed to characterize the upper atmosphere of Venus. These instruments include UV/IR spectrometers, pressure/temperature sensors, gas chromatograph, and high-resolution cameras. It is in the best interest of the mission to use commercial-off-the-shelf (COTS) components for the payload to leverage proven performance and cut on development costs. However, the 96% sulfuric acid aerosol environment at 50 km altitude requires that any COTS component be coated or enclosed in corrosion-resistant housings.

To achieve the desired mission goal, three components are necessary: a spectrometer, pressure/temperature sensors, and a camera system. On the discussion of spectrometers, Ocean Insight's Flame-T and Hamamatsu's mini-spectrometers (e.g., C12880MA) offer UV/VIS/NIR coverage in compact, space-adaptable formats. These sensors are most pertinent to the chemical composition of Venus and the underlying metals which could possibly collide with the aerostat, causing mission failure. To gauge pressure and temperature, rugged balloon-borne sensors can be adapted to withstand the harsh Venusian atmosphere. Paroscientific's MET4 is found to be a cost efficient solution, but it is not rated for the increased temperature at this altitude of Venus' atmosphere [6]. One solution is to utilize this sensor in conjunction with TEConnectivity's FLIR A700, which is rated for a higher temperature. In terms of camera systems, space-hardened versions of Teledyne e2v CMOS sensors and FLIR's Quark thermal imaging cores offer modular imaging solutions [4]. Using a COTS approach, it is easier to determine a preliminary power, weight, and size estimation (PWaS) as a summation of all the values from the specification sheets:

Component (COTS Product)	**Mass (kg)**	**Power (W)**	**Volume (m^3)**
Ocean Insight Flame-T Spectrometer (2x)	0.27	3.6	0.0004
Hamamatsu C12880MA Mini Spectrometer (Backup)	0.005	0.1	0.000025
TE Connectivity MS8607 P/T Sensors (4x)	0.004	0.2	0.00001
Custom MEMS Gas Chromatograph (est.)	1.2	8.0	0.001
FLIR Quark 2 Thermal Imaging Core	0.05	2.0	0.0001
Total (COTS Payload)	**1.53**	**13.9**	**0.0015**

Table 2: COTS-Based Payload PWaS Estimate (Converted to m^3)

Communications

According to the System Requirements Review, the VISTA mission will need a high bandwidth, low-latency communication system to transmit atmospheric data. This is to be accomplished via direct transmission to Earth or through an orbiter relay satellite. As Venus is 38 million kilometers away from Earth at its closest approach, the direct-to-Earth transmission approach yields higher delay times (5 - 15 minutes). Optical communications were considered to mitigate this lag, but this requires precise pointing, which is infeasible in the Venusian atmosphere, where sulfuric clouds block laser communication and winds rage up to 240 km/hr [12]. While a dedicated relay satellite is ideal for continuous communication, there is currently no operational Venus orbiter equipped to serve as a communication relay for interspacecraft links. JAXA's Akatsuki remains active but is not configured for relay operations [9]. NASA's upcoming Venus missions, VERITAS and DAVINCI, are scheduled for launch no earlier than 2031. These orbiters may become potential relay assets depending on their architecture and inter-satellite compatibility, but they are not guaranteed resources for a VISTA mission launched in the near term [3] [10].

Additionally, the VISTA system operates in the X-band, which is commonly used for planetary communications due to its lower susceptibility to atmospheric attenuation and its balance between antenna size and bandwidth. Ka-band offers significantly higher data rates and spectral efficiency, but is more prone to signal degradation from Venus' thick clouds and requires more precise pointing and more complex hardware. Given these tradeoffs, X-band is preferred for reliability and power efficiency in this mission context.

The power estimates for the communications subsystem are based on benchmarks from NASA's Iris X-band transponder and small satellite communication FPGAs, which draw between 25 and 35 W during burst transmission. Processing power (7 W) accounts for data compression, routing, and transmission scheduling onboard [5].

To validate feasibility of communication over interplanetary distances, the power flux density at Earth from VISTA can be modeled using the inverse square law:

$$P_{\text{flux}} = \frac{P_T}{4\pi R^2}$$

Assuming a transmitter power $P_T = 28\,\text{W}$ and Venus-Earth closest approach distance of $R = 3.8 \times 10^{10}$ m, we get:

$$P_{\text{flux}} \approx \frac{28}{4\pi(3.8 \times 10^{10})^2} \approx 1.55 \times 10^{-22}\,\text{W/m}^2$$

This received power level is extremely low, but remains within the detectable range of the Deep Space Network (DSN) when using a high-gain directional antenna, justifying VISTA's communication architecture.

The volume of the communications subsystem is based on the envelope required to house the X-band transceiver, processing electronics, and a steerable high-gain antenna system. Based on dimensions from small satellite platforms (e.g., Iris or Innocomm X-band radios), we estimate a volume of approximately 0.012 m^3. This accommodates heat shielding, RF isolation, and cable routing. This also correlates to a mass of about 10 kg.

Power

The power subsystem comprises of deployable solar panels and high-density battery storage. As VISTA's operational lifetime may exceed the nominal mission duration, it is essential to provide a regenerative power source. Venus offers an unusually high solar flux (approximately 1.9 times greater than that at Earth) making solar power a particularly attractive solution for sustained operations in its upper atmosphere. The solar panels on the aerostat are therefore the main power source, optimized for diffused light through the dense cloud layer of Venus. Batteries provide power continuity during night-side operations or periods of obscuration.

The power system's total average output and component sizing were determined based on subsystem-level power draws and the expected operational profile. The following equations were used to estimate the required solar array area and battery storage:

1. **Total Power Budget (with margin):**

   $$P_{\text{total}} = \sum P_i + M_p \quad \text{(where margin } M_p = 30\%)$$

   Assuming $P_i \approx 180\,\text{W}$, we obtain:

   $$P_{\text{total}} = 180 \times 1.3 = 234\,\text{W}$$

2. **Solar Array Area:**

   $$A_{\text{array}} = \frac{P_{\text{total}}}{\eta \cdot S_{\text{Venus}}}$$

   Where:

- $\eta = 0.28$ (solar array efficiency)
- $S_{\text{Venus}} \approx 2611\,\text{W/m}^2$

$$A_{\text{array}} = \frac{234}{0.28 \cdot 2611} \approx 0.32\,\text{m}^2$$

3. **Battery Storage for Eclipse or Obscured Periods:**

$$E_{\text{battery}} = \frac{P_{\text{avg}} \cdot t_{\text{dark}}}{\eta_{\text{battery}}}$$

With $P_{\text{avg}} = 180\,\text{W}$, $t_{\text{dark}} = 1$ hour, and $\eta_{\text{battery}} = 0.9$, we get:

$$E_{\text{battery}} = \frac{180 \cdot 1}{0.9} \approx 200\,\text{Wh}$$

This confirms that the selected battery capacity of approximately 800 Wh is more than sufficient to handle multiple cycles of low-light operation, with redundancy and buffer.

Buoyancy and Altitude Control

Once the aerostat has been deployed, it is important to remain at 50 km in altitude for data return as the cloud deck at 50 km contains sulfuric acid aerosols and dynamic chemistry that influence the planet's radiation balance and atmospheric structure. Studying this layer allows VISTA to directly measure variables like UV absorption, sulfur chemistry, trace gas content, and vertical wind shear, which are all relevant to evaluating the habitability and stability of a floating platform.

To accomplish this, VISTA aims for passive buoyancy control while enabling controlled modulation of altitude for science operations. Lift is generated through a large, helium-filled balloon envelope constructed from acid-resistant film. This will ensure the passive state of VISTA in the atmosphere, whereas the active control will be achieved through gas venting and ballast ejection. The venting is used to decrease volume and reduce buoyancy if descent is required. This process can be managed by automated vent valves connected to internal pressure sensors. To ascend or regain altitude lost due to atmospheric variability, the system can release a small amount of stored solid or liquid ballast, reducing mass and increasing net lift. This capability allows VISTA to perform vertical profiling of the atmosphere over time.

To calculate the volume of helium required to support the system at 50 km altitude in Venus' atmosphere, we use Archimedes' principle, where we imply the total system mass as 200 kg [1]:

$$\Delta M = V \cdot (\rho_{\text{atm}} - \rho_{\text{He}})$$

Where:

- ΔM: net lift mass (kg), equal to system mass
- V: volume of the balloon (m^3)
- $\rho_{\text{atm}} = 1.2$ kg/m^3: density of Venus' atmosphere at 50 km
- $\rho_{\text{He}} = 0.18$ kg/m^3: density of helium at the same altitude

Solving for V:

$$V = \frac{M_{\text{sys}}}{\rho_{\text{atm}} - \rho_{\text{He}}} = \frac{200}{1.2 - 0.18} \approx 196.1\,\text{m}^3$$

Assuming a spherical balloon, the radius r is calculated using the volume formula:

$$V = \frac{4}{3}\pi r^3 \quad \Rightarrow \quad r = \left(\frac{3V}{4\pi}\right)^{1/3}$$

$$r = \left(\frac{3 \cdot 196.1}{4\pi}\right)^{1/3} \approx 3.60\,\text{m} \quad \Rightarrow \quad \text{Diameter} = 2r \approx 7.21\,\text{m}$$

This balloon sizing provides sufficient lift to counteract a 200 kg payload, with margin for ballast, thermal expansion, and operational altitude variability. As the buoyancy system is mostly passive, there is no power requirement other than a brief pulse for altitude gain/loss around 1-2 W.

Other Subsystems

Command & Data Handling (C&DH)

The C&DH subsystem serves as the central processing unit of VISTA, coordinating command execution, subsystem interfacing, data routing, and autonomous operations. It collects telemetry and science data from all onboard systems, applies data compression and prioritization routines, and schedules packets for transmission via the communications subsystem. The C&DH system continuously monitors spacecraft health, runs a real-time fault detection and recovery (FDIR) routine, and can reconfigure key functions in response to anomalies. It operates with a low-power processor or FPGA, interfacing with redundant non-volatile memory for data buffering. The architecture supports autonomous operations for up to 30 days without Earth intervention, ensuring mission continuity even during communication blackouts.

Thermal Control

The thermal control subsystem ensures that all onboard systems remain within operational temperature limits despite Venus' challenging thermal environment. At 50 km altitude, ambient temperatures range from approximately 70℃ to 120℃. VISTA uses a combination of multilayer insulation (MLI), acid-resistant thermal blankets, and passive radiators to manage heat exchange. Internally, heat pipes conduct excess heat away from sensitive electronics to external radiators. Most thermal regulation is passive to conserve power, but the system includes a limited number of active thermal switches or thermostatically controlled heaters to protect batteries and compute elements during night-side operation or transient cooling events. The gondola structure is thermally isolated from the balloon envelope to reduce external heat conduction, and thermal coatings are used to reflect a portion of the intense solar flux at Venus' proximity to the Sun.

Attitude Determination & Control (ACS)

The attitude control system for VISTA must perform maneuvering both in Venusian orbit and control of the aerostat once it has been deployed. If possible, it would be ideal to use similar components for the in-orbit and on-planet attitude control systems. For in-orbit attitude control, typical technologies include reaction wheel arrays (RWAs), control moment gyros (CMGs), and cold-gas thrusters. A further discussion on the Attitude Control System can be found below in the trade studies.

Structure and Materials

As pictured in the SRR, VISTA's structural system is designed to provide mechanical support, environmental protection, and modular integration of all subsystems while minimizing mass. The gondola frame is constructed from lightweight titanium alloy, selected for its excellent strength-to-weight ratio and inherent resistance to high temperatures and sulfuric acid corrosion. External panels are coated in PTFE (Teflon) to provide chemical shielding against the dense acidic aerosol layer at 50 km altitude. All seams and cable interfaces are sealed using gaskets and boots to prevent acid ingress. The balloon envelope is fabricated from fluorinated ethylene propylene (FEP) or ETFE, which offer the flexibility needed for deployment and inflation, along with sufficient tensile strength and resistance to UV degradation. The structural design must accommodate launch loads, thermal expansion, and vibration, as well as maintain gondola integrity during descent and inflation events. Internal mounting racks are thermally isolated and vibration-damped to protect COTS electronics and instruments.

Total Size Weight and Power (SWaP) Estimation

From all the previous subsystems, we can tabulate all sizes, weights, and power intakes to find the total system SWaP estimation:

Subsystem	**Volume (m^3)**	**Mass (kg)**	**Power (W)**
Payload (COTS + science instruments)	0.0015	18	40
Communications (X-band, steerable)	0.012	10	35
Power System (solar + batteries)	0.025	25	200 (gen.)
Buoyancy/Altitude Control	196.15	15	5
C&DH	0.005	8	20
Thermal Control	0.010	5	5
ADCS (reaction wheels, IMUs)	0.008	6	10
Structure and Materials	0.150	100	0 (passive)
Total (Estimated)	**196.3265**	**187**	**115 (avg)**

Table 3: Estimated Volume, Mass, and Power Consumption by Subsystem

Trade Studies

Communications Options

As previously discussed, the atmosphere of Venus makes it exceedingly difficult to utilize any communication technologies which require precise pointing. Given this constraint along with limited onboard power, the communication system must balance performance, reliability, and simplicity. Two architectural options were considered: direct-to-Earth (DTE) communication and a relay satellite configuration.

Direct-to-Earth (DTE) communication allows VISTA to transmit signals directly to Earth-based receivers, such as NASA's Deep Space Network (DSN). While this approach simplifies mission architecture and avoids the need for a secondary spacecraft, it has several drawbacks. The balloon platform lacks the pointing precision of an orbiting satellite or stabilized spacecraft, making it difficult to align a narrow high-gain antenna with Earth. A relay satellite architecture addresses many of these challenges, in which VISTA transmits data to an orbiting spacecraft, which then relays the information to Earth. This enables lower-power burst transmissions from VISTA and offloads the high-gain, Earth-pointing communications to the relay. It also increases the frequency of communication windows and reduces the pointing requirements. However, no such relay currently exists at Venus. NASA's VERITAS and DAVINCI missions, both scheduled to launch no earlier than 2031, may offer future opportunities if they are equipped for inter-spacecraft communication. For a near-term VISTA mission, this would require launching a dedicated relay satellite as part of the mission architecture.

Ultimately, a relay satellite is chosen as the preliminary design choice for VISTA for its higher efficiency and reliability. As CONOps for VISTA is taking place in 2025, it is likely that it would not launch before NASA's VERITAS and DIVINCI missions, so relay communication options will be available.

Attitude Control

VISTA's ACS must operate across two fundamentally different mission environments: space and atmosphere. During the interplanetary cruise and Venus arrival, precise attitude control is needed to align solar arrays, correct trajectory, and orient the aeroshell for atmospheric entry. During the balloon phase, attitude control becomes a matter of gondola stabilization, sensor pointing, and solar tracking. With these dual-phase requirements, several candidate architectures were evaluated.

The first option is a reaction wheel and IMU system, commonly used in small spacecraft. Reaction wheels offer low-power, precise 3-axis control and are ideal for cruise operations and fine stabilization once deployed. However, they saturate easily and may struggle to maintain control during the dynamic entry phase. Their performance is ideal during long, stable operations but limited during high-torque events. The second option is a reaction control system using cold gas thrusters. Thrusters provide the most forceful attitude corrections, which is advantageous during orbital insertion and especially reentry, where the aeroshell must maintain a heat-shield-forward orientation. While this makes RCS attractive for critical entry moments, it is not sustainable for long-duration atmospheric operation due to propellant constraints, especially on a mass-limited balloon platform. A third option, control moment gyroscopes (CMGs), was considered but ruled out due to their mechanical complexity, high power draw, and torque levels being unnecessary for a platform of VISTA's mass and stability requirements.

The proposed design solution for VISTA is a hybrid system: a thruster-based system for coarse attitude maneuvers and reentry orientation during the orbital phase, and a reaction wheel + IMU package for low-power pointing and gondola stabilization in the atmospheric phase. This approach ensures high control authority when it matters most and energy-efficient, passive stability once deployed in Venus' upper atmosphere.

Structure and Materials

VISTA's structural and material choices are driven by three primary environmental challenges: (1) long-duration exposure to sulfuric acid aerosols at 50 km altitude, (2) ambient temperatures ranging from 70–120 ℃, and (3) the need for a lightweight but mechanically robust frame that supports the gondola, instrumentation, and balloon interface.

For the gondola frame, three material options are considered: aluminum alloys, titanium alloys, and carbon fiber composites. Aluminum is lightweight and cost-effective but is highly vulnerable to corrosion in acidic environments and loses strength at elevated temperatures. Carbon fiber offers exceptional strength-to-weight performance but is sensitive to both chemical degradation and temperature cycling. Titanium alloys (e.g., Ti-6Al-4V) offer the best compromise: they are naturally corrosion-resistant, retain strength at high temperatures, and have extensive flight heritage in chemically aggressive environments. The trade-off is higher cost and slightly higher density, but the penalty is acceptable within the structural budget of VISTA.

For the external skin and protective housing, the team compared PTFE (Teflon), ETFE (Ethylene Tetrafluoroethylene), and PEEK (Polyether ether ketone). PTFE is highly flexible, chemically inert, and exceptionally resistant to sulfuric acid, making it a strong candidate for both the gondola outer layer and exposed sensor covers. ETFE is lighter and easier to thermobond, but less resistant to chemical attack. PEEK offers excellent mechanical properties and thermal stability, but is significantly more expensive and heavier. PTFE was selected due to its excellent acid resistance, flexibility, and long-duration durability, particularly in high-altitude balloon applications.

The balloon envelope material must be lightweight, strong, and gas-retentive while resisting UV degradation and sulfuric acid. A multi-layer fluoropolymer laminate with a base of FEP (Fluorinated Ethylene Propylene) or ETFE was selected. FEP offers better acid resistance and has a proven record in stratospheric balloon systems, while ETFE offers better tensile strength. The final material choice will depend ultimately on manufacturability.

Propulsion System

VISTA requires a propulsion system capable of transferring the spacecraft from low Earth orbit (LEO) to Venus. Two primary trajectory architectures were considered: a chemical Hohmann transfer and a low-thrust electric propulsion spiral trajectory. The selected propulsion system directly influences launch vehicle requirements, mission duration, and system complexity.

The first option is a chemical propulsion system, which would perform a traditional Hohmann transfer, which uses a single impulsive maneuver to escape Earth's gravity well and inject the spacecraft on a heliocentric transfer trajectory to Venus. Upon arrival, a second burn (or aerobraking) is used to insert into Venus' atmosphere[2]. This approach is well-understood, offers short transfer times of approximately 120–180 days, and minimizes spacecraft complexity. The downsides are the requirement for a significant amount of chemical propellant and a high-thrust engine, which increases the spacecraft's mass and volume.

The second option considered was a low-thrust electric propulsion system (e.g., ion or Hall-effect thrusters), which slowly spirals out of LEO over several months before reaching an interplanetary trajectory. This method is highly propellant-efficient, requiring far less onboard fuel, and is attractive for mass-limited missions. However, it demands a continuous, high-power electrical supply, increasing the burden on the power system. Additionally, electric propulsion would lengthen the transfer time to 9–12 months or more, delay mission science, and require the spacecraft to operate autonomously for a prolonged period in deep space.

After evaluating the trade-offs, the chemical propulsion + Hohmann transfer approach was selected. It offers the best balance of speed, simplicity, and compatibility with shared launch scenarios. Since the spacecraft already includes thermal protection and attitude control systems for Venus aerobraking and descent, the addition of a short-duration high-thrust system aligns well with the mission's architecture without further complicating the design.

Risk Assessment

Technical Risks

Balloon Deployment

Perhaps the most pertinent risk to mission success is the deployment of the aerostat itself. For most satellites with deployable structures, deployment is the most critical part of the mission architecture. However, most of these spacecraft are in orbit, while VISTA must deploy the aerostat as it reenters the atmosphere of Venus— timing is crucial. If the balloon fails to fully deploy or inflate at the target altitude (50 km), VISTA may descend uncontrollably or be rendered inoperable. This risk stems from the mechanical complexity of deploying a large, folded envelope in an acidic, turbulent environment while ensuring proper inflation sequencing with helium or ammonia gas. Venus' super-rotating winds may further complicate inflation dynamics.

To mitigate this risk, research will be conducted on the best deployment methods for high altitude balloon missions (NASA, JAXA, etc.). Furthermore, an optimization study will be conducted for an ellipsoidal balloon to find desirable geometry characteristics such as throat radius, chord radius, height, etc. If there was not a financial constraint, VISTA's deployable structure could be fabricated and subject to different vibrational and temperature tests.

Communications Blackout

Due to the thick cloud cover of Venus and the long interplanetary communication link, there is a significant risk of communication degradation or loss during mission operations. VISTA relies on burst-mode data transmission using X-band systems to transmit atmospheric and health data either directly to Earth or via a relay satellite. Given that no operational Venus relay currently exists, communications may be limited by geometry, antenna gain, and atmospheric attenuation. Extended communication loss could result in lost data, reduced situational awareness, or an inability to issue corrective commands. These outages could also delay science return or disrupt onboard mission scheduling.

To mitigate this risk, VISTA will implement a backup S-band, low data-rate, low bandwidth system. This way, if the X-band system of communication is lost VISTA can still transmit data back to Earth. Furthermore, VISTA will size the system with buffering capacity to store 7-10 days of data on board. If VISTA experiences blackout, there is a time delay for data so that 'lost' data can be transmitted after blackout. More research will be conducted on communications budget from past Venus missions to establish a blackout tolerance and protocols for if such an event occurs.

Long Term Corrosion

VISTA is intended to operate for a minimum of 30 days in Venus' upper atmosphere, where it will be continuously exposed to sulfuric acid aerosols. While the airship will use acid-resistant materials, there remains a risk that long-term corrosion could degrade structural elements, power conductors, sensor housings, or communication apertures. Corrosion-related failure could compromise data integrity, weaken structural supports, or disable critical systems. The challenge lies not just in selecting acid-resistant materials, but also in ensuring that all exposed seals, joints, and cable interfaces remain intact over time.

Materials such as PTFE, FEP, titanium alloys, and fluoropolymer-coated surfaces will be used in all externally exposed areas [11]. The design will avoid crevices and unshielded fasteners to reduce acid ingress. Components will be validated via accelerated corrosion testing, including spray chamber exposure, to simulate the mission duration. Additionally, VISTA will include redundant sensors and environmental monitoring to detect early signs of degradation, allowing the system to take preemptive action if necessary.

Cost Risks

Launch Integration Delays

As a secondary payload or co-manifested mission, VISTA may rely on shared launch infrastructure with a relay orbiter or future planetary science mission. Any delay or restructuring of the primary launch manifest could cause schedule slippage or force costly design changes to meet new vehicle constraints. This integration dependency introduces uncertainty into the program timeline, with cascading impacts on hardware delivery, testing schedules, and operational planning. In the worst case, if no compatible primary mission emerges, VISTA would require a standalone launch, increasing cost and complexity.

To adhere to these constraints, VISTA will ensure that it fits within reasonable size and mass constraints (e.g., 1.5 m fairing diameter, 200 kg wet mass). This way, VISTA can find other rideshare options if a partnership causes the launch to be delayed in any way.

Component Acquisition

Long Lead Items

The first item of procurement that should be mentioned is the FLIR A700 STD Science Kit from TEquipment. This kit is equipped with Gigabit Ethernet and can handle the intense temperature range that VISTA will experience. Although this is a COTS component, it falls in the long lead section as there are several adjustments that need to be made to the product for functionality in VISTA. The expectation of the FLIR A700 is to handle any necessary imaging required from VISTA's scientific mission goals.

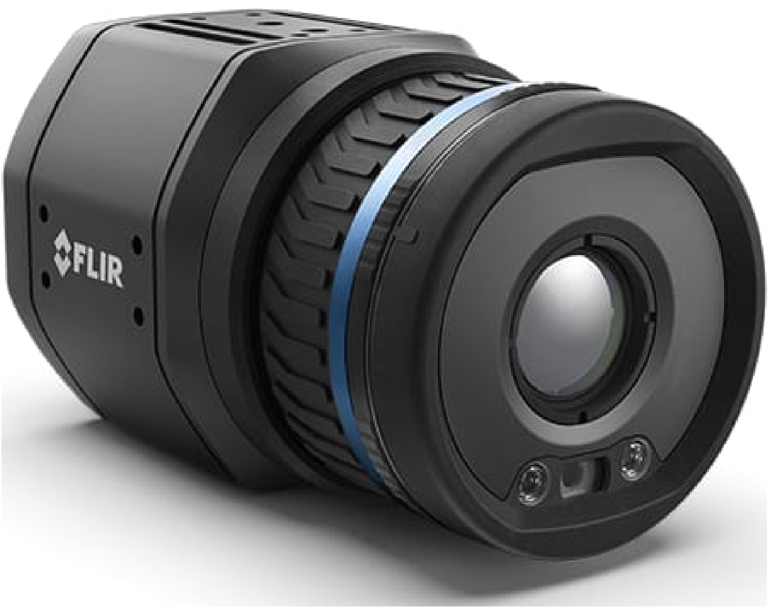

Figure 2: TEquipment FLIR A700 Science Kit [4]

A second long lead item is a custom pressure and temperature sensor suite capable of operating in the extreme conditions expected during the mission. Sensors rated for near-space or upper-atmospheric use often need to be specially ordered. A sensor of particular interest is the MET4-4A from Parascientific. In this case, the sensor must be modified to meet size, weight, and interface constraints, which can introduce additional delays. Given their importance in thermal modeling and environmental data collection, these sensors are crucial and should be addressed foremost in PDR.

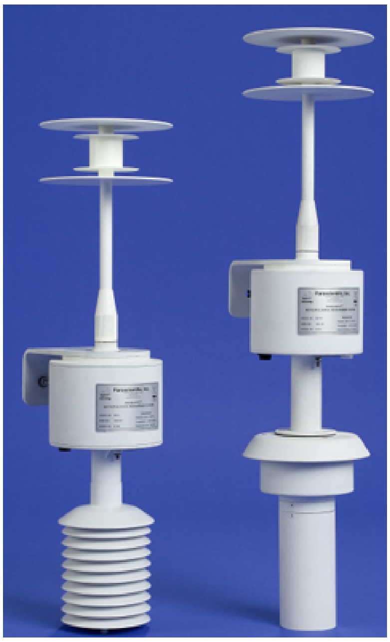

Figure 3: MET4 and MET4-A from Parascientific [6]

Another key long lead component is the structural mounting assembly, including precision-machined brackets, fasteners, and thermal insulation elements. These mounts must be designed to securely hold scientific equipment like the FLIR camera while minimizing thermal gradients and vibration during ascent. As VISTA plans to have a corrosion resistant wrapping around the truss structure, this falls later into consideration for the design. Machining and integrating with materials such as multilayer insulation (MLI) or aerospace-grade foam can involve significant lead times, especially if modifications are needed after the first fabrication run. A decision between these processes or a simple approach of COTS composite or aluminum parts will be addressed in PDR. In regards to the location of this structure, please reference the initial concept devised in the SRR.

Finally, the mission will require a high-performance onboard computer or data acquisition unit (DAQ) to collect, store, and potentially pre-process science data. These systems face component shortages and long supplier lead times, particularly if custom firmware or breakout boards are needed for interfacing with sensors and cameras. Therefore, it had been identified as a long lead item and the modularity of such system should be heavily considered for PDR. These units also play a critical role in system integration and power budgeting, so they should be identified and ordered as early as possible to avoid downstream delays.

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