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VULCAN

Venusian Ultra Low Cloud Aerobot Navigator

TEAM 8

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AGENDA

- Mission Overview & Science Objectives
- Major Requirements & Constraints
- Vehicle Design
- Science Instrumentation and Payload
- Overall Mission Cost & Timeline
- Next Steps

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Mission Requirements

Req #	Requirement	Rationale
SYS.00	The system will investigate how Venus' planetary surface interacts with it's atmosphere	Aligned with Decadal question 6.4 (see science traceability narrative)
SYS.01	The system will survive the Venusian atmosphere for at least 36 hours	Previous Venusian aerobot missions (such as Vega in 1985) lasted approximately 46 hours
SYS.02	The system must not exceed 1m x 1m x 1m when stored in payload configuration	Defined by the launch and landing provider
SYS.03	The system must not exceed a total mass of 50 kg	Defined by the launch and landing provider
SYS.04	The system shall send and receive data to and from the orbiting Primary Spacecraft for relay back to Earth	Necessary for operations
SYS.05	The system will maintain safe operating temperatures for the duration of the mission	Necessary for operations
SYS.06	The system will maintain sufficient power for all subsystems for the duration of the mission	To enable peak operating conditions and prevent failure due to excessive heat
SYS.07	The system will handle all onboard computing requirements including for processing of relayed commands, semi-autonomous decision making, and data storage	Necessary for operations
SYS.08	The system will be capable of vertical manuevering, as well as limited attitude adjustment and lateral movement	To allow for marginal mobility and flexibility for data acquisition as the mission proceeds, as well as to avoid hazards
PM.00	The program will not exceed $200M in cost	Defined by customer
PM.01	The Aerobot system will be ready for integration with other mission systems by October 1st, 2028 at GSFC	Defined by customer
PM.02	The system will be ready for launch by March 1st, 2029 at KSC	Defined by customer
SCI.01	The system will determine the state of past and current volcanic activity on the surface of Venus	Derived from STM
SCI.02	The system will determine radiation amongst greenhouse gases in the atmosphere	Derived from STM
SCI.03	The system will determine the composition and interactions of cloud particles	Derived from STM
SCI.04	The system will determine the composition and distribution of cloud particles	Derived from STM
SCI.06	The system will determine the surface deformation and tectonic activity	Derived from STM
SCI.07	The system will determine Venusian surface composition	Derived from STM
INST.01	The system will feature an instrument capable of identifying specific wavelengths of SO2, H2O, CO, OCS, S2, HCl, and HF	Derived from STM
INST.02	The system will feature an instrument capable of detecting wavelength-specific greenhouse gas emissions (CO2, CH4, N2O, flourinated gases) and absorptions of heat	Derived from STM
INST.03	The system will feature an instrument capable of spectroscopy to identify gas composition and chemical transformations	Derived from STM
INST.04	The system will use laser reflectivity to map cloud opacity levels (ex: MOLA)	Derived from STM
INST.06	The system will feature an instrument capable of radar and topographic mapping	Derived from STM
INST.07	The system will feature an instrument capable of spectroscopy to identify elemental composition	Derived from STM
ENV.00	The system will maintain operability at average temperatures of 475 degrees Celsius (900 degrees Fahrenheit)	To enable peak operating conditions and prevent failure due to excessive heat
ENV.01	The system will maintain operability under corrosive conditions, including (but not limited to) extensive sulfuric acid droplet exposure	To prevent failure due to environmental exposure and degradation
CDH.00	System will be capable of receiving, processing, storing, and sending data, along with issuing commands to other subsystems	Necessary for operations
CDH.01	The system will be capable of transmitting data to the primary spacecraft	Necessary for operations
MECH.00	The system will feature an onboard system for control of the Aerobot's altitude	To allow for marginal mobility and flexibility for data acquisition as the mission proceeds, as well as to avoid hazards
MECH.01	The system will feature a framing and external structure sufficiently strong enough to withstand Venusian winds reaching up to 370 km/hr	In order to maintain structural integrity throughout mission timeline
MECH.02	The system will feature a limited propulsion system for attitude adjustments and minor manuevering within the atmosphere	To allow for marginal mobility and flexibility for data acquisition as the mission proceeds, as well as to avoid hazards

Science Traceability Matrix

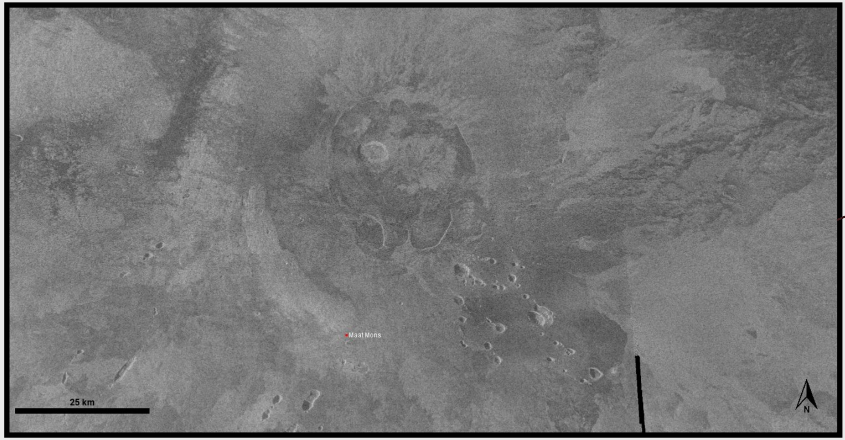
Science Goals	Science Objectives	Science Measurement Requirements		Instrument Performance Requirements		Predicted Instrument Performance	Instrument	Mission Requirements
		Physical Parameters	Observables					
How do planetary surfaces and interiors influence and interact with their host atmospheres? - (Origins, Worlds, and Life: A Decadal Strategy for Planetary Science and Astrobiology 2023-2032)	Determine the state of past and current volcanic activity on the surface of Venus	Identify trace gases that indicate volcanic outgassing (SO_2, H_2O, CO, OCS, S_2, HCl, and HF)	Use spectrometry to identify specific wavelengths of SO_2, H_2O, CO, OCS, S_2, HCl, and HF	Concentration for Detection	1 ppbv	0.5 ppbv	TLS (Tunable Laser Spectrometer) Mars Curiosity Mission	Vehicle must be able to shift altitude
				Effective path length	15 meters	16.8 meters		
	Determine radiation amongst greenhouse gases in the atmosphere	Identify the signatures and radiation levels of greenhouse gases (CO_2, CH_4, N_2O, flourinated gases)	Detect wavelength-specific greenhouse gas emissions and absorptions of heat	Spectral range	2.32-4.35 µm	2.2-4.3 µm	SOIR (Solar Occultation in the Infrared instrument) Venus Express Mission	Vehicle must be navgiate horizontally torwards clouds and areas of interest to maintain optimal sensor range
				Resolving power	23,200-43,100 lambda/ delta lambda	23,200-43,100 lambda/ delta lambda		
	Determine the composition and interactions of cloud particles	Identify chemical makeup and interactions within Venus' clouds	Use spectrometry to identify gas composition and chemical transformations	Pressure Stabilization	1/2000	1/2000	CRDS (Cavity Ring-Down Spectroscopy)	
				Effective Path Length	20 km	Up to 20 km		
	Determine the composition and distribution of cloud particles	Identify cloud particle distribution	Use laser reflectivity to map cloud opacity levels (ex: MOLA)	Wavelength	355 nm (UV) & 1064 nm (IR)	355 nm (UV) & 1064 nm (IR)	LIDAR (Light Detection and Ranging)	
				Vertical resolution	100m	100 m		
	Determine the surface deformation and tectonic activity	Identify fault lines, rift zones, and deformation features on Venus' surface	Use radar and topographic mapping	Range	900 km	best accuracy 10cm, worst accuracy 1 m	KaRIn Radar Altimeter	
				Look Angle	±4.5°	±4.5°		
				Radar Frequency	35.75 GHz	35.75 GHz (.86cm)		
				Swath width	120 km	120 km (2 x 60km)		

Science Objectives

Science Objectives	Science Measurement Requirements	
	Physical Parameters	Observables
Determine the state of past and current volcanic activity on the surface of Venus	Identify trace gases that indicate volcanic outgassing (SO2, H2O, CO, OCS, S2, HCl, and HF)	Use spectrometry to identify specific wavelengths of SO2, H2O, CO, OCS, S2, HCl, and HF
Determine radiation amongst greenhouse gases in the atmosphere	Identify the signatures and radiation levels of greenhouse gases (CO2, CH4, N2O, flourinated gases)	Detect wavelength-specific greenhouse gas emissions and absorptions of heat
Determine the composition and interactions of cloud particles	Identify chemical makeup and interactions within Venus' clouds	Use spectrometry to identify gas composition and chemical transformations
Determine the composition and distribution of cloud particles	Identify cloud particle distribution	Use laser reflectivity to map cloud opacity levels (ex: MOLA)
Determine the surface deformation and tectonic activity	Identify fault lines, rift zones, and deformation features on Venus' surface	Use radar and topographic mapping

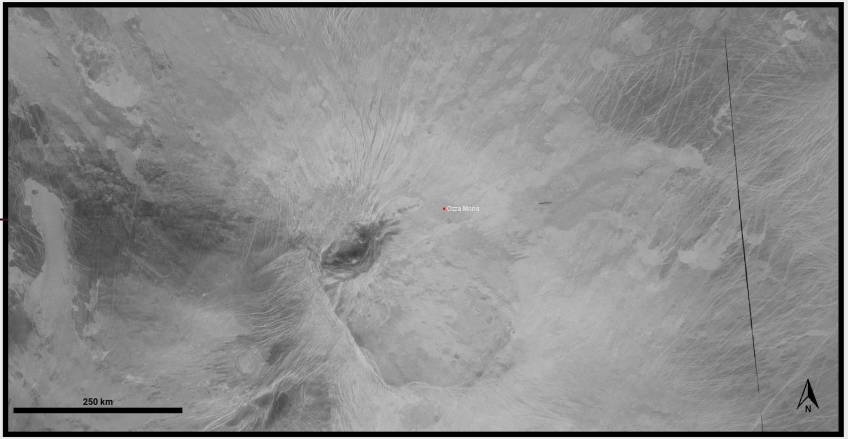
- The primary science objectives of the VULCAN mission are to investigate active geologic and atmospheric processes on Venus
- Focusing on:
    - Volcanic Activity
    - Greenhouse Gas Dynamics
    - Cloud Chemistry and Distribution
- Each objective is key to unraveling Venus' past and why it diverged so drastically from Earth

Mission Location

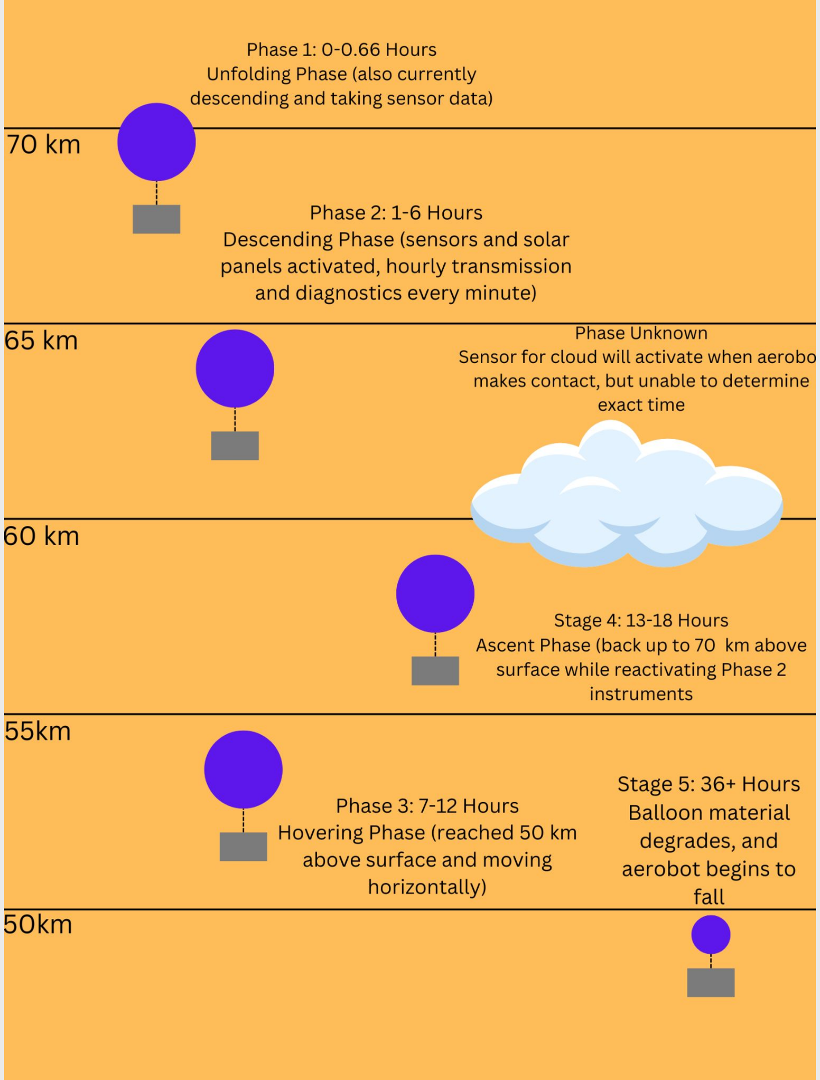


- Maat Mons is the tallest volcano on the surface of Venus
- Maat Mons rises ~8 km above the mean planetary radius and ~5 km above the surrounding plains.
- Maat Mons is roughly 395 km in diameter.

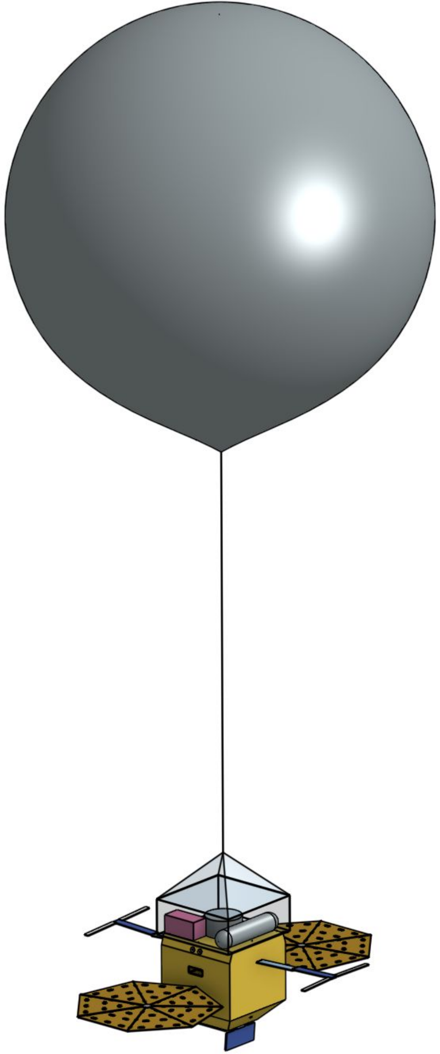
- Ozza Mons, a potentially active shield volcano.
- Ozza Mons is roughly 500 km in diameter.



Concept of Operations



VULCAN Aerobot Design



Mechanical Subsystem Overview

- Structural Integrity
- Protect and support scientific payload
- Enable navigation and data relay

Mechanical Subsystem Requirements

Req #	Requirement	Rationale	Parent Req	Child Req	Verification Method	Validation Method	Req met?
MECH.00	The system will feature a framing and external structure sufficiently strong enough to withstand the Venusian atmosphere	In order to maintain structural integrity throughout mission timeline	SYS.01	MECH.01.1 MECH.01.2 MECH.01.3	Test	Full-Scale Structural Demonstration in Relevant Environment	Met
MECH.00.1	The frame should withstand sulphuric acid clouds	The clouds in the atmosphere are made of sulphuric acid	-	-	Test	Validate by subjecting frame to strong acids	Met
MECH.00.2	The frame should withstand winds reaching up to 370 km/hr	The venusian atmosphere experiences strong winds	-	-	Test	Validate through wind tunnel testing at 30 m/s (plus margin).	Met
MECH.00.3	The frame should withstand lightning strikes	Some missions, such as the Soviet Venera, have detected lightning-like activity	-	-	Test	Validate by running high voltage through frame	Met
MECH.01	The system will feature a limited propulsion system for altitude adjustments and minor maneuvering within the atmosphere	To allow for marginal mobility and flexibility for data acquisition as the mission proceeds, as well as to avoid hazards	SYS.08	PROP.00	Inspection	Verify performance metrics (thrust, response time, control authority) against mission requirements for flight within the dense Venusian atmosphere.	Met

MECH.02	The system will be capable of determining orientation, approximate position, and altitude via a suite of sensors	Necessary for operations	SYS.08	NAV.00 NAV.01	Test	The system's sensor suite is validated by integrating it into hardware-in-the-loop tests and environmental chamber maneuvers that simulate Venusian conditions to confirm accurate orientation, position, and altitude determination.	Met
MECH.03	The system will contain all relevant instruments, sensors, etc. within a 1m x 1m x 1m volume, with opportunity for expansion beyond this volume upon detachment from the EDI	Defined by the launch and landing provider	SYS.02	-	Inspection	Conduct a final integration fit check to confirm the entire system (in its stowed configuration) does not exceed 1 m in any dimension.	Met
MECH.04	All system materials will be chosen to minimize weight and ensure a total weight less than 50 kg	Defined by the launch and landing provider	SYS.03	-	Analysis	Perform an official mass measurement (e.g., using calibrated scales) once all components are integrated to ensure the total system mass is under 50 kg.	Met

Mechanical Subsystem Components

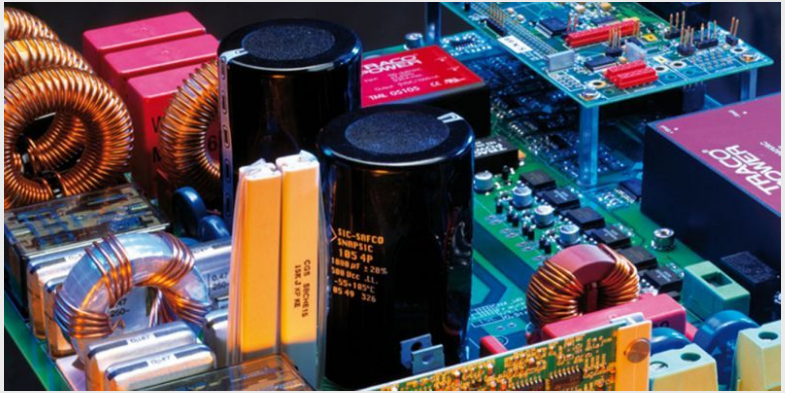
Subassembly	Mass	Dimensions (L×W×H)	Max Power(W)
Mechanical Subsystem			
Primary Structure (Chassis)	10	0.6 m × 0.6 m × 0.4 m	0
Instrument & Sensor Mounting Assembly	2	0.3 m × 0.3 m × 0.2 m	0
High-Temperature Data Communication Antenna Assembly	1	0.3 m × 0.3 m × 0.2 m	10
Aerobot Flight Control & Propulsion Support	3	0.5 m × 0.5 m × 0.3 m	20
Landing Gear & Impact Attenuation Assembly	2	0.4 m × 0.4 m × 0.3 m	0
Post-Landing Data Acquisition Module (LDAM)	1	0.2 m × 0.2 m × 0.2 m	15

Power Subsystem Overview

- The power subsystem will provide power to to enable the operations of all other subsystems, including mechanical, CDH, thermal, and payload.

- This subsystem must have meticulous fault detection, as a singular short or blown component can derail the entire mission.

- This subsystem is made up of four main subassemblies: power generation, power storage, power distribution, and power management.



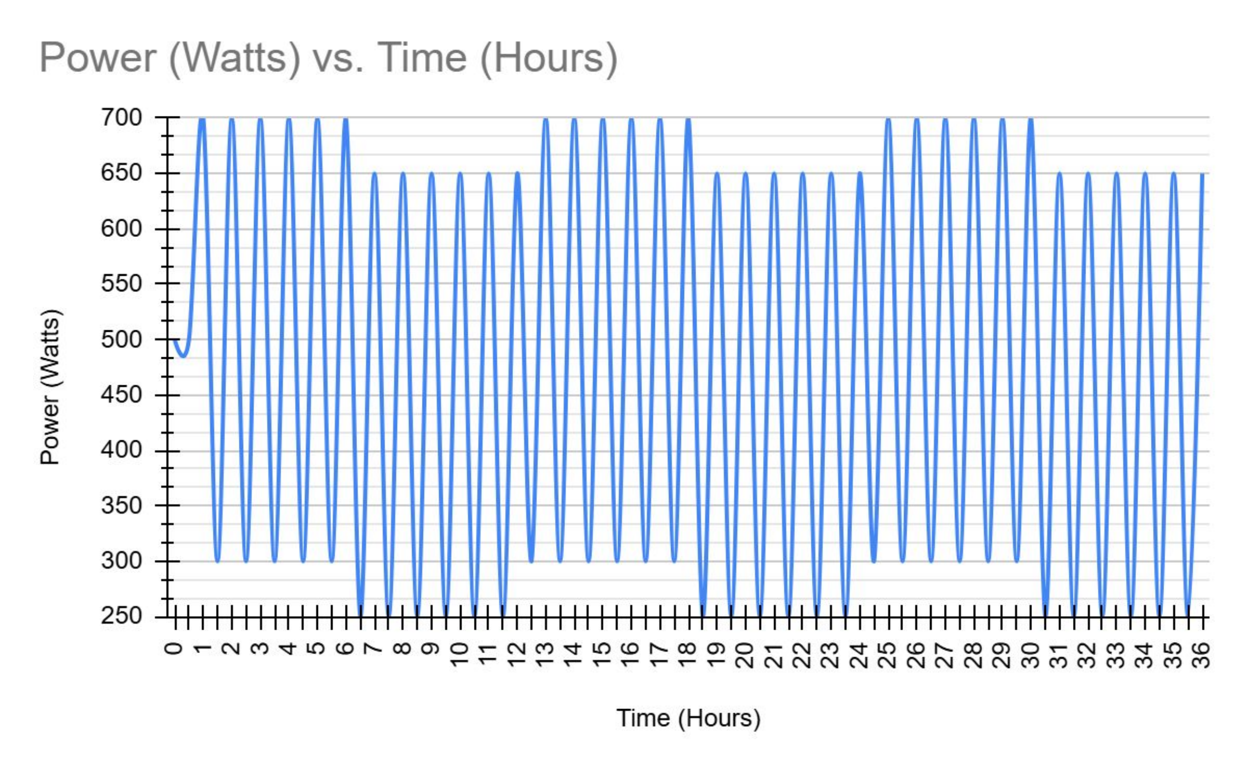
2.1.2.1 Power Subsystem Requirements

Req #	Requirement	Rationale	Parent Req	Child Req	Validation Method	Req met?
POW.0	The power subsystem shall power all operations on the spacecraft	Necessary for operations	ELEC.0-4	POW.0.0-3	Demonstration	Met
POW.0.0	The power generation subassembly shall generate power with solar panels	Without RTG, it was determined that solar energy was the most optimal power generation method	POW.0	POW.0.0.0-5	Demonstration	Met
POW.0.1	The power storage subassembly shall store power using solid-state batteries	Solid-state batteries will allow for reliable energy storage with higher energy density and greater reliability than traditional liquid electrolyte batteries	POW.0	POW.0.1.0-3	Demonstration	Met
POW.0.2	The power distribution subassembly must provide the appropriate amount of power to each subsystem	Ensures that each subsystem is receiving the appropriate amount of power, minimizing energy waste and preventing component damage	POW.0	POW.0.2.0-5	Test	Met
POW.0.3	The power management subassembly must monitor the power subsystem and send data to the CDH subsystem	Allows CDH subsystem to make decisions based on power subsystem status	POW.0	POW.0.3.0-5	Test	Met
POW.0.0.0	The solar panel's photovoltaic (PV) cells must be able to generate 300 watts of power continuously for normal operations	300 watts of power are required for normal operations based on the power draw of the other subsystems	POW.0.0		Test	Met
POW.0.0.1	The PV cells must be able to generate 700 watts of power for high-energy operations	700 watts of power are required for high-energy operations based on the power draw of the other subsystems	POW.0.0		Test	Met
POW.0.0.2	Solar panels will use corrosion resistant materials and coatings to prevent corrosion by Venus' atmosphere	Ensures solar panels can operate even under corrosive properties of Venus' atmosphere	POW.0.0		Demonstration	Met

POW.0.0.3	Solar panel must be mounted firmly and have folding capabilities by integrating with the mechanical subsystem	Must be able to unfold solar panels after the aerobot is deployed and during low sunlight availability periods. It must be mounted firmly due to the high speed winds of Venus	POW.0.0		Demonstration	Met
POW.0.0.4	The photovoltaic cells must be connected in parallel	Having photovoltaic cells connected in parallel provides more robust protection against shading, one cell doesn't drastically reduce performance, and is useful when high-voltage is not needed.	POW.0.0		Demonstration	Met
POW.0.0.5	Solar panels shall use reflective coatings, thermal coatings,and heat sinks, to maintain a temperature of -45°C to 85°C	Ensures solar panels are at acceptable temperature range for optimal performance	POW.0.0		Test	Met
POW.0.1.0	Power storage system must be able to store 1000 Wh	Since solar power generation conditions are ideal on Venus, it was determined that this was the ideal value for power storage	POW.0.1		Test	Met
POW.0.1.1	Power storage system must maintain a temperature of -45 to 85 by integrating with the thermal management subsystem	This is the safe temperature range for optimal performance of the solid-state batteries	POW.0.1		Test	Met
POW.0.1.2	Power storage system must be contained in vibration-resistant casings	This ensures that the power storage system is protected against physical damage, as solid-state batteries are more vulnerable in this area	POW.0.1		Demonstration	Met
POW.0.1.3	Power storage system must have overcharge protection to prevent overcharging of batteries	This ensures that batteries are not damaged by overcharging	POW.0.1		Test	Met
POW.0.2.0	Power distribution unit (PDU) shall use DC-DC converters to convert voltage to appropriate levels for all components	Different components have different ideal voltage levels for operations	POW.0.2		Test	Met
POW.0.2.1	PDU shall have relays and power switches to	Subsystems have a variety of requirements for power and it is necessary to to connect and disconnect from	POW.0.2		Demonstration	Met

	connect/disconnect other subsystems/assemblies	power for safety reasons / lack of use				
POW.0.2.2	PDU shall have a power conversion unit (PCU) to convert from AC-DC and vice versa	Other subsystems and sub-assemblies need both AC and DC power	POW.0.2		Test	Met
POW.0.2.3	Power bus must connect power generation subassembly to PDU to other subsystems that need power	Power generation unit must be connected to PDU for conversion to appropriate values before being used to power other subsystem/assemblies	POW.0.2		Demonstration	Met
POW.0.2.4	Power bus should have redundant power paths that activate upon the primary power path failing	In case one power path fails, redundant power paths will ensure continuous operation	POW.0.2		Demonstration	Met
POW.0.2.5	Power bus will use teflon insulated wires	Power bus must be able to handle high temperatures and corrosion from acid on Venus	POW.0.2		Inspection	Met
POW.0.3.0	Power management system shall have redundant voltage and current sensors	Necessary for measuring voltage and current throughout power subsystem	POW.0.3		Demonstration	Met
POW.0.3.1	Power management system shall have redundant temperature sensors	Necessary for sensing when temperature is reaching an unacceptable level	POW.0.3		Demonstration	Met
POW.0.3.2	Power management system shall have Power metering ICs to calculate power energy efficiency	Necessary for making sure power and energy efficiency are at appropriate levels	POW.0.3		Demonstration	Met
POW.0.3.3	Power management system shall have microcontrollers and a data bus to communicate with CDH subsystem	This is necessary for PMS to integrate with CDH and send it power status data so CDH can use autonomous power management algorithms to form decisions regarding the power subsystem	POW.0.3		Demonstration	Met
POW.0.3.4	Power management system shall use thermistors to	Necessary for the PMS to have the capability to take action after being notified that the power subsystem	POW.0.3		Demonstration	Met

	disconnect overheated components following commands from CDH	temperature is at dangerous value				
POW.0.3.5	Power management system shall use circuit breakers, fuses, crowbar circuits, and overvoltage and undercurrent protection circuits to fix detected power issues after receiving commands from CDH	Necessary for the PMS to have the capability to take action after being notified that the power subsystem voltage/current is at a dangerous value	POW.0.3		Demonstration	Met



Power (Watts) vs. Time (Hours)
Power (Watts)
700
650
600
550
500
450
400
350
300
250
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
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22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
Time (Hours)

Power Generation Subassembly

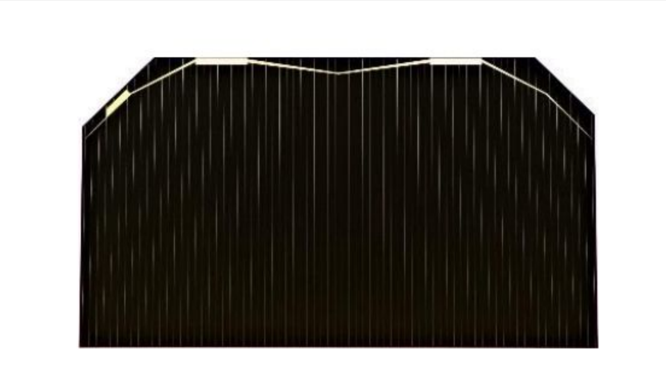
- The power generation subassembly will be primarily made up of GaAs Triple Junction Solar Cells, more specifically the Azur Space 3G300C - Advanced.

- High efficiency (30%), lightweight, flexible radiation resistant that protects from harmful cosmic rays and particles.

- Subassembly also includes an MPPT, junction box, and thermal and corrosion resistant-coating to protect the components from the Venusian environment.

- TRL is 8, since triple-junction solar cells have been widely used in space missions, with the first probes carrying them being used to explore Venus, along with all other generic electronics

- These will be brought from Azur Space and integrated into the aerobot in-house.



30	258	0.97	12.11%	26.89%	3.26%	Middle	85.1
35	215	0.97	13.49%	28.08%	3.79%	Middle	99.0
40	175	0.98	14.80%	29.01%	4.29%	Middle	112.2
45	137	0.98	23.06%	30.09%	6.94%	Middle	181.4
50	107	0.99	25.09%	39.02%	9.79%	Middle	256.0
55	69	1.01	27.65%	55.95%	15.47%	Middle	404.4
60	19	1.01	30.79%	69.47%	21.39%	Middle	559.2

Power Storage Subassembly

- The main component of the power storage subassembly is made up of solid-state battery cells that can store approximately 1000 Watt-hours of power.
- The QuantumScape QSE-5 was specifically chosen for its light weight and energy density, along with its ability to withstand a wide range of temperatures to account for Venusian environment
- There will be a custom designed battery management system (BMS) that will make interact with thermal to make sure the power storage subassembly does not overheat, and maintain optimal performance while interfacing with CDH
- TRL is 6, since solid-state batteries have been shown to successfully charge and discharge in space on the ISS, but have not been used on Venus missions

Power Distribution Subassembly

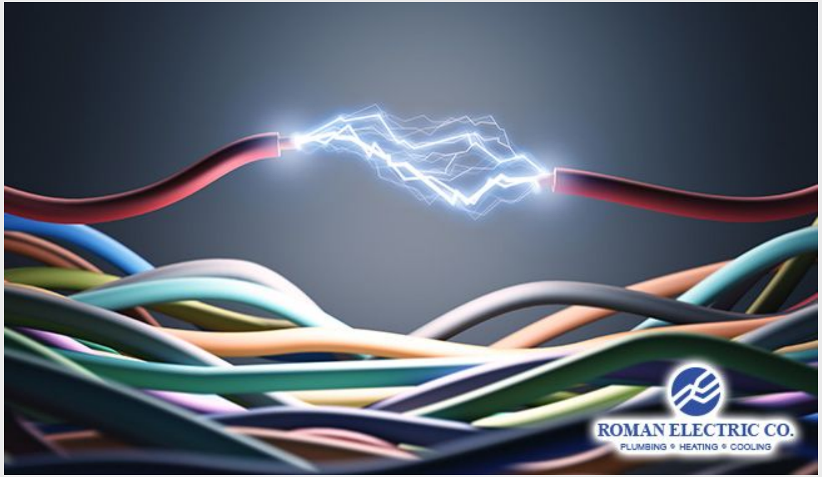
- The power distribution subassembly is less of a subassembly but more of the connector between the various subassemblies.

- The wiring of choice for this subassembly will be PTFE (Teflon) insulated wires due to its ability to withstand high temperatures, chemical corrosion, and lightweight.

- Different power buses will connect various components and regulate voltage and current values for optimal component performance.

- The power distribution subassembly will be designed in-house.

- TRL is 8, every aspect of the circuitry and wiring involved has been tried and tested throughout the history of electronics and space exploration



Power Management Subassembly

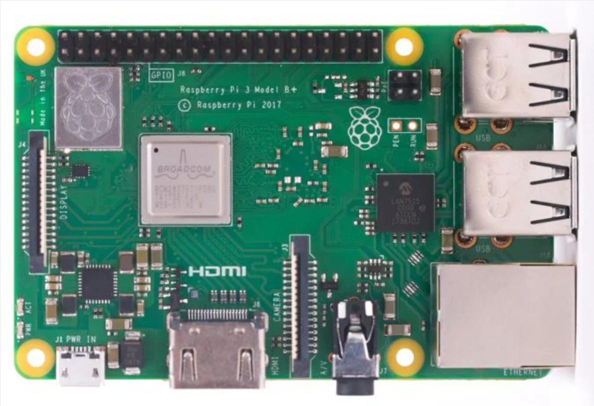
- The power management subassembly is the brain of the power subsystem, receiving sensor data and commands from CDH and sending out commands for appropriate actions in the subsystem.

- Responsible for collecting information about the state of the subsystem using voltage and current sensing ICs, current sensors, voltage sensors.

- Made up of microcontrollers connected via communication protocols that receive, process, and send data to CDH and the power subsystem.

- Responsible for detecting faults and activating protection circuits.

- TRL is 8, microcontrollers and embedded systems have been comprehensively used in space missions.



Power Subsystem Testing

- The main verification methods for the power subsystem will have to be testing, due to the nature of electrical engineering

- Power supplies, signal generators, oscilloscopes, digital multimeters, all of these tools must be used to make sure the correct readings are found in each part of the circuit, and this indicates that testing is required

- Demonstration will be used for the power subsystem unfolding and a mixture of demonstration and analysis will be used for the protections against Venusian environment

Power Subsystem Image Sources (in order of appearance)

1) https://www.studyforfe.com/blog/topologies-of-power-electronic-circuits/
2) Copied from PDR
3) Azur Space. 2019. 3G30C-Advanced Triple-Junction Solar Cell Datasheet. Accessed March 9, 2025. https://www.azurspace.com/images/006050-01-00_DB_3G30C-Advanced.pdf.
4) Landis, Geoffrey, and Emily Haag. n.d. "Analysis of Solar Cell Efficiency for Venus Atmosphere and Surface Missions." https://ntrs.nasa.gov/api/citations/20150016298/downloads/20150016298.pdf.
5) "Technology." n.d. QuantumScape. https://www.quantumscape.com/technology/.
6) https://romanelectrichome.com/blog/electrical-wiring-tips/
7) https://opensource.com/resources/raspberry-pi
8) https://www.rigolna.com/products/digital-oscilloscopes/

2.1.3.1 CDH Subsystem Requirements

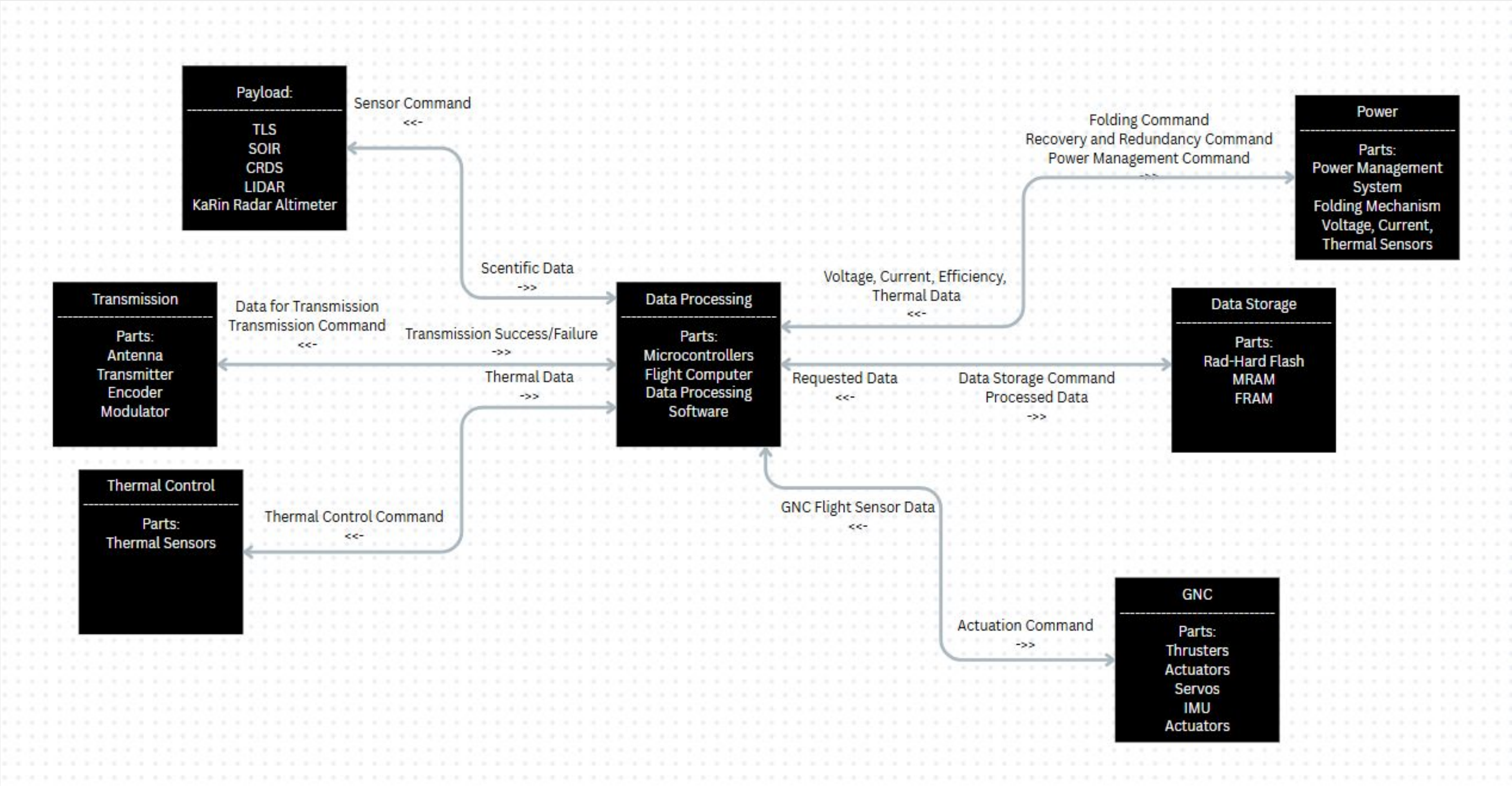
Table XX: Requirements Table for CDH Subsystem

Req #	Requirement	Rationale	Parent Req	Child Req	Validation Method	Req met?
CDH.0	System will be capable of receiving, processing, storing, and sending data, along with issuing commands to other subsystems	Necessary for operations	SYS.07	CDH.0.0-2	Test	Yes
CDH.1	The system will be capable of transmitting data to the primary spacecraft	Necessary for operations	SYS.04	CDH.0.0.3	Demonstration	Yes
CDH.0.0	Data processing sub-assembly shall process all information and make decisions based on data	Necessary to process different forms of data into more suitable forms and make decisions with dat	CDH.0	CDH.0.0.0-4	Demonstration	Yes
CDH.0.1	Data storage sub-assembly shall be able to provide a buffer of 2 hours	Transmissions every hour mean a large memory buffer is not needed	CDH.0	CDH.0.1.0-4	Testing	Yes
CDH.0.2	Communication sub-assembly shall receive and send information within CDH and from CDH to other subsystems	Aerobot subsystems and subassemblies must be able to communicate with one another	CDH.0	CDH.0.2.0-4	Demonstration	Yes
CDH.1.0	Transmission sub-assembly will transmit data to spacecraft every hour	Mission provides ideal environment for power generation, frequent transmissions will lower memory requirement	CDH.1	CDH.1.0.0-4	Demonstration	Yes
CDH.0.0.0	Data processing sub-assembly will use central flight computer to process data	Computer needed to process data, filter, issue commands, etc	CDH.0.0		Inspection	Yes
CDH.0.0.1	Data processing sub-assembly will be protected against Venusian conditions and radiation	Electronics are vulnerable in Venusian conditions, must be protected	CDH.0.0		Demonstration	Yes
CDH.0.0.2	Data processing sub-assembly will use microcontrollers to convert data to a form readable by flight computer	Sensor data needs to be converted to form understandable by flight computer	CDH.0.0		Demonstration	Yes

CDH.0.0.3	Data processing sub-assembly shall interface with communication sub-assembly to receive and sent data in addition to issuing commands	After processing data, data will be used to make decisions that must be carried along communication sub-assembly	CDH .0.0		Demonstration	Yes
CDH.0.0.4	Data processing sub-assembly will have watchdog-timer to reset processor in case of hardware or software fault	Recovery and redundancy for data processing sub-assembly, since it is vital for operation	CDH .0.0		Test	Yes
CDH.0.1.0	Memory hardware shall be able to withstand Venusian conditions and radiation	Memory hardware is highly vulnerable to Venusian conditions and radiation, must be protected	CDH 0.1		Demonstration	Yes
CDH.0.1.1	Storage subassembly shall organize data with time to ensure efficient transmission	Transmission is driven by the hour, so important to track what information to send	CDH 0.1		Test	Yes
CDH.0.1.2	Storage subassembly shall be able to store 1 GB of storage	1 GB of storage is more than enough to hold one hour's worth of data with room to spare in case of emergencies	CDH 0.1		Analysis	Yes
CDH.0.1.3	Storage subassembly shall be able to achieve a minimum of 100,000 write/erase cycles	Must be able to perform that many operations to continuously have data written and erased to be transmitted	CDH 0.1		Test	Yes
CDH.0.1.4	Storage subassembly should retain data for 15 minutes even with no power	Power can suddenly shut off under unexpected circumstances, important to preserve data	CDH 0.1		Test	Yes
CDH.0.2.1	Communication sub assembly should be able to use I2C, UART, and SPI	Allows for interaction with a variety of microcontrollers, sensors, computers, for comprehensive data	CDH 0.2		Test	Yes
CDH.0.2.1	Communication sub assembly should send diagnostics from every subsystem every 60 seconds	Ensures rapid fault recovery when something goes wrong	CDH 0.2		Test	Yes
CDH.0.2.1	Communication subassembly should have <500ms latency for fast fault response and for controlling GNC	Close to simultaneous operating speed necessary for navigation in GNC and to respond to detected issues ASAP	CDH 0.2		Test	Yes
CDH.0.2.1	Communication sub-assembly shall be resistant to Venusian conditions and space	Communication components are vulnerable to Venusian conditions and	CDH 0.2		Demonstration	Yes

	radiation	space radiation				
CDH.0.2.1	Communication sub-assembly should have redundant data paths	Redundancy in case data paths fail due to unforeseen circumstances	CDH 0.2		Demonstration	Yes
CD.1.0.0	Transmission subassembly should operate within X-band or (10 GHz)	Transmission must be able to pierce Venusian atmosphere and reach spacecraft while transmitting vast amounts of data, while not being too high such that it is affected by attenuation	CDH 1.0		Analysis	Yes
CDH.1.0.1	Transmitter, Antenna, Decoder, and Modulator will make up transmission sub-assembly	These are the main components needed to process data and transmit	CDH 1.0		Inspection	Yes
CDH.1.0.2	Transmission subassembly should resist Venusian conditions and radiation	Transmission components, especially antenna, are especially vulnerable to Venusian conditions and space radiation	CDH 1.0		Demonstration	Yes
CDH.1.0.3	Transmission will send processed science instrumentation data every hour	It must take processed data from data processing sub–assembly before transmitting	CDH 1.0		Test	Yes
CDH.1.0.4	Transmitter shall be capable of transmitting 50 kb	Must be able to transmit all information quickly at intervals of 1 hour	CDH 1.0		Test	Yes
CDH.1.0.5	Transmission subassembly will have multiple antennas	Antennas are especially vulnerable because they protrude out of the aerobot	CDH .1.0		Inspection	Yes

Command and Data Handling Subsystem



Data Processing and Storage Subassembly

- Both data processing and data storage will be handled by the Krysten-M3 On Board Computer, and a modified version will be purchased from AAC Clyde Space

- It was chosen for its speed, which can process data in a <100 ms loop, and compatibility with a variety of communication protocols and modifiability with custom PCB

- Comes with 4 GB built-in flash and 16 MB MRAM

- Light with high radiation and temperature tolerance with not much power draw

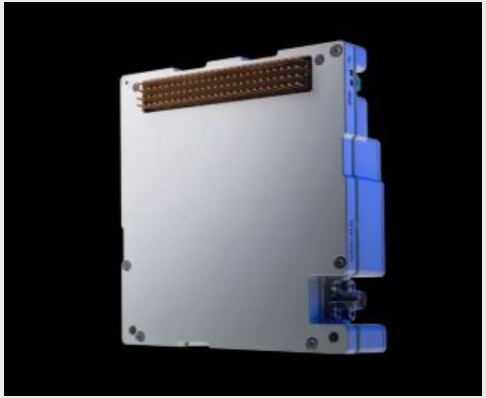
- TRL of 8, this computer has been extensively proven in space as a CubeSat Computer

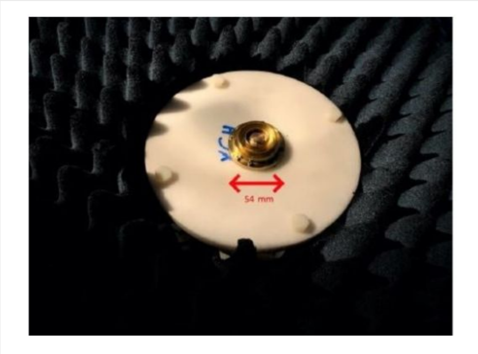
Communication Subassembly

- The communication subassembly is the intra-vehicle counterpart to the transmission subassembly
- Made up numerous connectors, wires, and digital communication buses that will communicate with other digital devices and utilize ADCs to convert analog data to digital data
- Primary communication protocol used by this subassembly will be SPI, due to its speed and reliability.
- This will be created in house at NASA, due to the need to connect every subsystem, meaning that it is most optimal for a big picture view
- TRL of 8, digital communication protocols and how to receive and transmit data have been tried and tested comprehensively in space

Transmission Subassembly

- The transmission subassembly is made up of four subcomponents, transmitter, antenna, modulator, and encoder
- Digital data stored on flight computer will be converted to analog signals using resistor networks
- Data will be transmitted in the X-band at 10 GHz due to suitability for Venusian environment
- Transmitter is EnduroSat X-Band Transmitter, and Antenna is high performance NASA developed X-band patch antenna
- TRL of 7 for transmitter and TRL of 5 for antenna





CDH Subsystem Testing

- The data storage and processing subsystems must be tested through a variety of software test cases, running through every function and edge case possible to ensure that the software will not fail even in unexpected circumstances

- Data transmission will ideally be tested with an actual orbiting spacecraft, but most likely it will be a receiver from a vast distance that will be tested to see if it can successfully receive the signal

- Data communication must demonstrated to successfully communicate, receive data, provide instructions and then have the other subsystems successfully perform the intended action to the specification of the desired instructions

CDH Image Sources (in order of appearance)

1) Software Architecture Flowchart from PDR
2) https://www.satcatalog.com/component/kryten-m3/
3) https://www.dreamstime.com/abstract-bus-network-vector-illustration-digital-marketing-communication-strategy-abstract-bus-network-concept-image347661937
4) https://www.endurosat.com/products/x-band-transmitter/
5)

Thermal Subsystem Overview

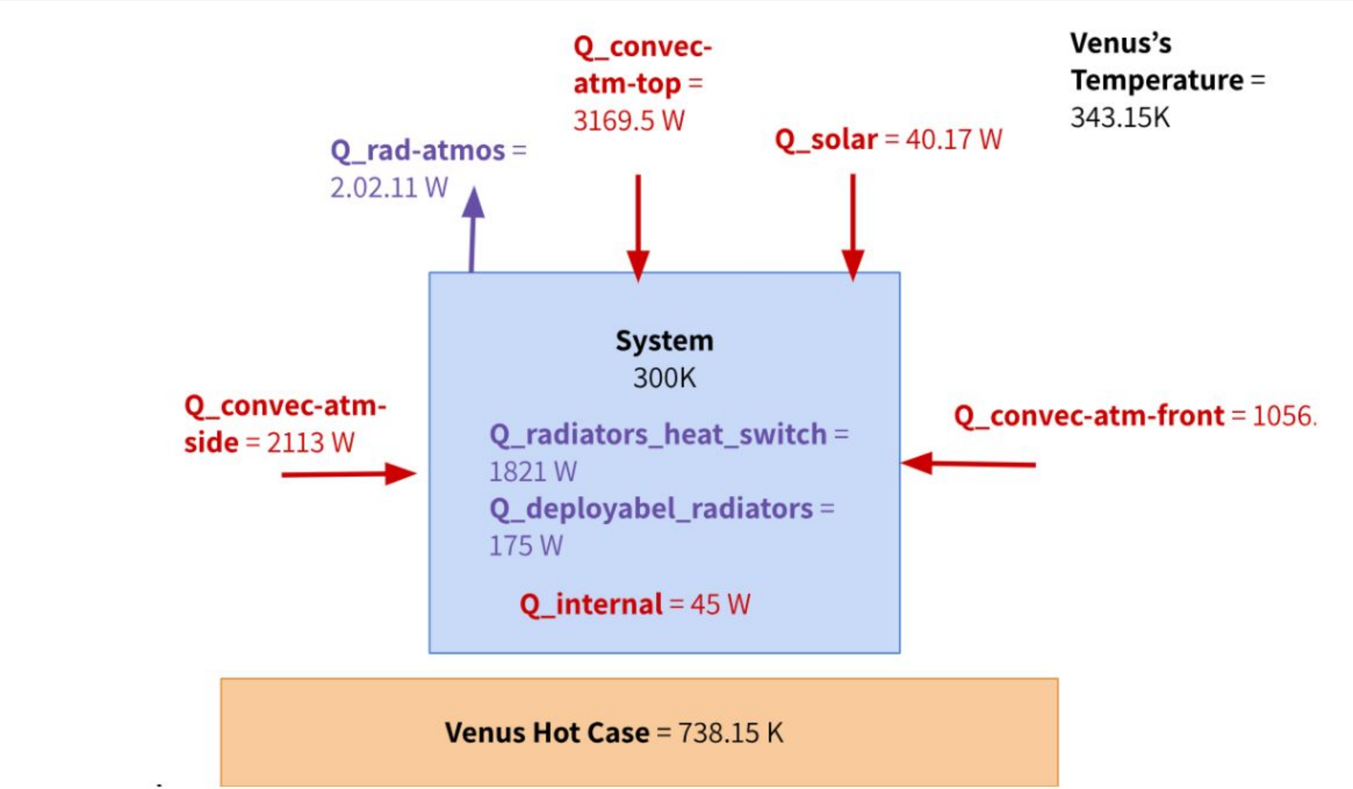
- The thermal subsystem will provides thermal insulation and dissipation of heat to allow all subsystems to maintain operational temperatures.
- Two main subassemblies: the External Thermal Protection System and Internal Thermal Control & Insulation Subsystem

Thermal Requirements

Req #	Requirement	Rationale	Parent Req	Child Req	Verification Method	Validation Method	Req met?
THE.00	The system will have a optimal operating temperature of 300K with a operating range of 250-350K	In order to maintain system and equipment operation aboard the aerobot	SYS.01	-	Test	Conduct thermal system test with simulated heat and cold environments	Met
THE.01	The system will contain all relevant external thermal devices, heaters, coolers, etc. within a constrained volume	Defined by spacing allocation defined through the mechanical subsystem	ME 0.3	THE01.1 THE01.2	Inspection	Conduct a final integration fit check to confirm the entire system (in its stowed configuration) does not exceed 1 m in any dimension.	Met
THE01.1	The external thermal control units will be no larger than 0.8 m × 0.8 m × 0.3 m	Defined by the mechanical subsystem as volume allocations for all required	THE.01	-	Inspection	Preform sizing checks as subsystem is developed before final system	Met

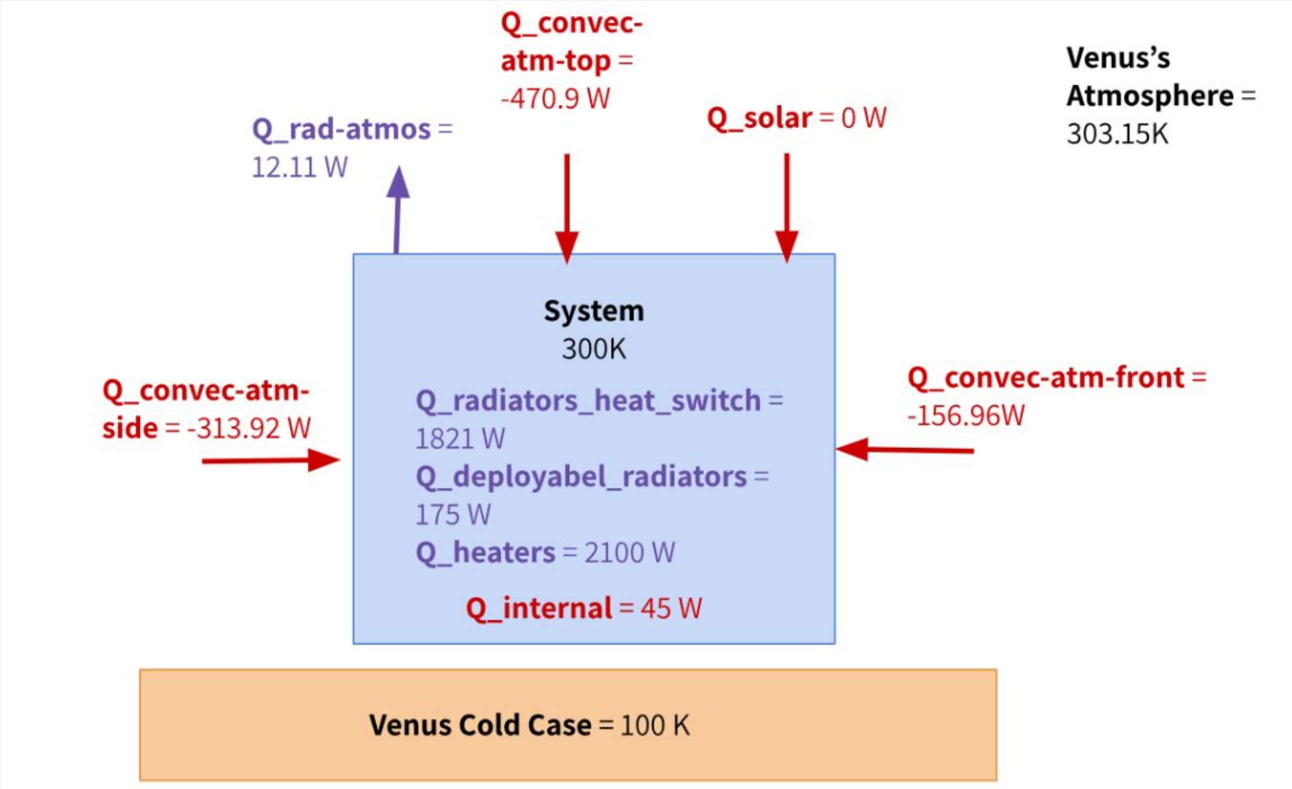
		subsystems				integration	
THE01.2	The internal thermal control and insulation subsystem shall be no larger than 0.4 m × 0.4 m × 0.3 m in volume	Defined by the mechanical subsystem as volume allocations for all required subsystems	THE.01	-	Inspection	Preform sizing checks as subsystem is developed before final system integration	Met
THE.02	All system materials and devices will be chosen to minimize weight and ensure a total weight less than 50 kg	Defined by the launch and landing provider	SYS.03	THE.02.1	Analysis	Perform an official mass measurement (e.g., using calibrated scales) once all components are integrated to ensure the total system mass is under 50 kg.	Met
THE.02.1	All system materials and devices will be chosen so the thermal system will be under the thermal control limit of 10 kg	Defined by weight allocations defined by mechanical subsystem	THE.02	-	Analysis	Perform an official mass measurement for individual components so total mass is under 10kg	Met

Heat Maps



Venus's Temperature = 343.15K
Q_convec-atm-top = 3169.5 W
Q_rad-atmos = 2.02.11 W
Q_solar = 40.17 W
System
300K
Q_convec-atm-side = 2113 W
Q_radiators_heat_switch = 1821 W
Q_deployabel_radiators = 175 W
Q_internal = 45 W
Q_convec-atm-front = 1056.
Venus Hot Case = 738.15 K

Heat Maps


Q_convec-atm-top = -470.9 W
Venus's Atmosphere = 303.15K
Q_rad-atmos = 12.11 W
Q_solar = 0 W
System
300K
Q_convec-atm-side = -313.92 W
Q_radiators_heat_switch = 1821 W
Q_deployabel_radiators = 175 W
Q_heaters = 2100 W
Q_internal = 45 W
Q_convec-atm-front = -156.96W
Venus Cold Case = 100 K

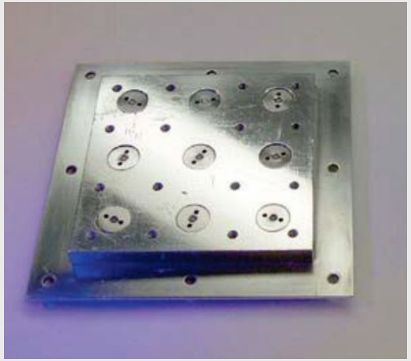
External Thermal Protection Subsystem

- External Thermal Protection System utilizes:
  - heat switches(x3)
  - deployable radiator
  - heaters (x2)
- External coating and material:
  - Silver, polished, un-oxidized material (a = 0.04)
  - Zerlauts Z-93 white paint coating (e = 0.92)

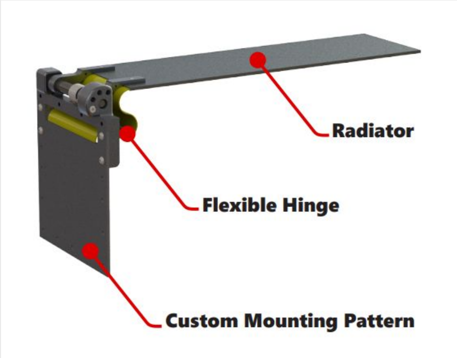
- High efficiency, lightweight, low volume,

- TRL = 7

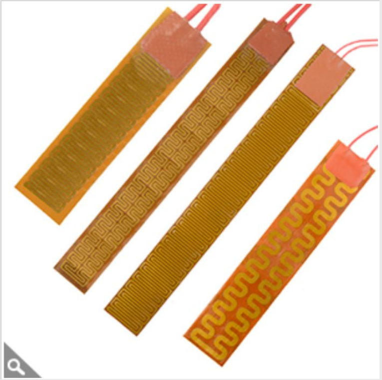
- Suppliers: Sierra Space, Red Wire, OMEGA



Sierra Space Thin Plate Thermal Switch



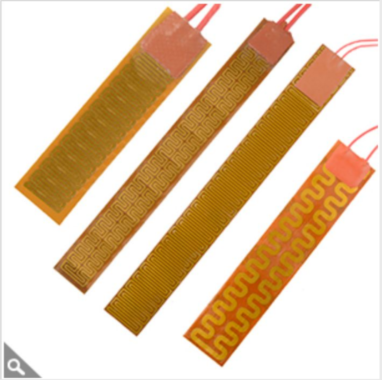
Redwire QRad Deployable Radiator



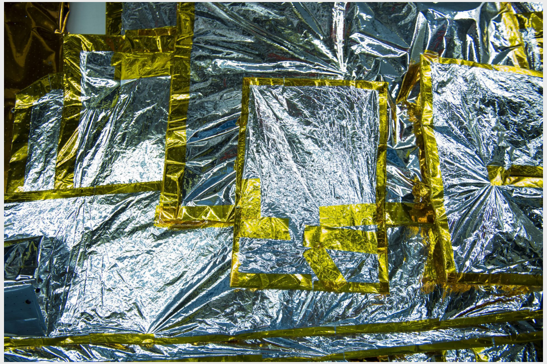
OMEGA Kapton Heaters (KHA-1012)

Internal Thermal Control & Insulation Subsystem

- Internal Thermal Control & Insulation Subsystem utilizes:
    - MLI Blanket (16 layers)
    - Kapton heaters (x1)
- High efficiency, lightweight, low volume,
- TRL = 7
- Suppliers: OMEGA, In-house



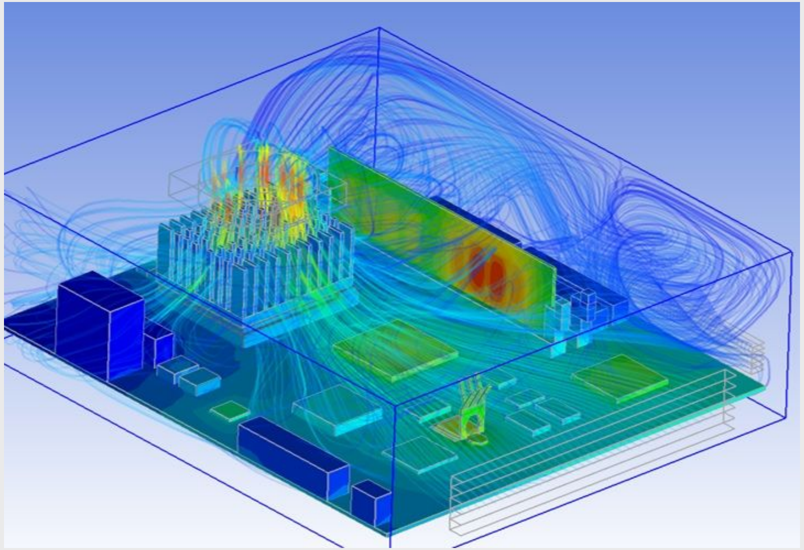
OMEGA Kapton Heaters (KHA-1012)



NASA MLI Blanket

Thermal Subsystem Testing

- Verification Methods used:
    - Test
    - Inspection
    - Analysis



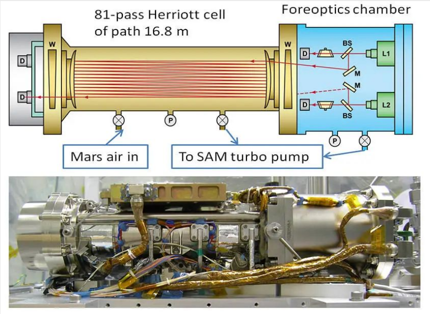
Thermal Image Sources (in order of appearance)

1) https://www.nasa.gov/missions/artemis/orion/engineers-refine-thermal-protection-system-for-orions-next-mission/
2) Thermal Requirements chart from PDR
3) Thermal Heat Flow Maps from PDR
4) https://www.sierraspace.com/wp-content/uploads/2024/01/THERMAL-CONTROL-SYSTEMS-Thin-Plate-Heat-Switch.pdf
5) https://redwirespace.com/wp-content/uploads/2023/06/redwire-qrad-flysheet.pdf
6) https://sea.omega.com/th/pptst/KHRA-KHLVA-KHA-SERIES.html
7) https://www.esa.int/ESA_Multimedia/Images/2016/08/Multi-layer_insulation_blankets
8) https://thermalds.com/thermal-analysis-thermal-modeling/

Payload Subsystem Overview

The payload consists of several scientific instruments that aid in achieving our mission objectives.

- TLS (Tunable Laser Spectrometer)
- SOIR (Solar Occultation in the Infrared Instrument)
- CRDS (Cavity Ring-Down Spectroscopy)
- LIDAR (Light Detection and Ranging)
- KaRIn Radar Altimeter



TLS

Science Instrumentation Requirements

Table 30: Science Instrumentation Requirements

WBS Level	Instrument	Requirement ID	Requirement	Parent Req	Child Req	Notes
Level 1	TLS (Tunable Laser Spectrometer) Mars Curiosity Mission	MIS-1	The TLS shall have a concentration for detection of 1 ppbv and an effective path length of 15 meters.		MIS-1.1	Derived from the Science Traceability Matrix
Level 2	SOIR (Solar Occultation in the Infrared instrument) Venus Express Mission	MIS-1.1	The Spectral Range for the SOIR shall be between 2.32-4.35 micrometers and the resolving power should be between 23,200-43,100 lambda.	MIS-1	SYS-1	Derived from the Science Traceability Matrix
Level 3	CRDS (Cavity Ring-Down Spectroscopy)	SYS-1	The CRDS shall have a pressure stabilization of 1/2000 and an effective path length of 20 km.	MIS-1.1	TCS-1	Derived from the Science Traceability Matrix
Level 4	LIDAR (Light Detection and Ranging)	TCS-1	The LIDAR instrumentation shall have a wavelength of 355 nm & 1064 nm and a vertical resolution of 100m.	SYS-1	TCS-1.1	Derived from the Science Traceability Matrix
Level 5	KaRIn Radar Altimeter	TCS-1.1	The KaRIn Radar Altimeter shall have a range of 900km, a look angle of 4.5 degrees, a radar frequency of 35.75 GHz, and a swath width of 120km.	TCS-1		Derived from the Science Traceability Matrix

Payload Subsystem Manufacturing and Procurement Plans

For the instrumentation, the main supp
are:

1. NASA’s Jet Propulsion Laborato
2. Royal Belgian Institute for Space Aeronomy (BIRA-IASB)
3. Picarro, Inc
4. Teledyne Optech

Table 31: Instrument Redundancy Matrix

Science Measurement Requirements				Instrument							
Physical Parameters	Observables	Baseline Performance Requirements		LIR (Longwave Infrared Camera) Akatsuki	TLS Tunable Laser Spectrometer (Mars Curiosity Mission)	SOIR	CRDS (Cavity Ring-Down Spectroscopy)	LIDAR (Light Detection and Ranging)	VIRTIS Infrared Spectrometer	KaRIn Radar Altimeter	LIBS (Laser Induced Breakdown Spectroscopy) (LIBS from Mars Curiosity)() Mars Code, Super Cam, Chem Cam)
Identify trace gases that indicate volcanic outgassing (SO2, H2O, CO, OCS, S2, HCl, and HF)	Use spectrometry to identify specific wavelengths of SO2, H2O, CO, OCS, S2, HCl, and HF	Concentration for Detection	1 ppbv	○	●	○	◑	◑	○	○	○
		Effective path length	15 meters								
Identify the signatures and radiation levels of greenhouse gases (CO2, CH4, N2O, flourinated gases)	Detect wavelength-specific greenhouse gas emissions and absorptions of heat	Spectral range	2.32-4.35 μm	◑	○	●	○	○	○	○	○
		Resolving power	23.200-43.100 lambda/ delta lambda								
Identify chemical makeup and interactions within Venus' clouds	Use spectrometry to identify gas composition and chemical transformations	Pressure Stabilization	1/2000	○	◑	○	●	◑	○	○	○
		Effective Path Length	20 km								
Identify cloud particle distribution	Use laser reflectivity to map cloud opacity levels (ex: MOLA)	Wavelength	355 nm (UV) & 1064 nm (IR)	○	◑	○	◑	●	○	○	○
		Vertical resolution	100m								
Identify fault lines, rift zones, and deformation features on Venus' surface	Use radar and topographic mapping	Range	900 km	○	○	○	○	○	○	●	○
		Look Angle	±4.5°								
		Radar Frequency	35.75 GHz								
		Swath width	120 km								
Identify mineralogical differences between current lava flow regions and older crust	Use spectroscopy to identify elemental composition	Wavelength	1067 nm	○	○	○	○	○	○	○	●
		Laser Frequency	1-10 Hz								
		Resolution	0.15-0.65								
		Operating range	-40/+30 °C								

Payload Image Sources (In Order of Appearance)

1. https://www.nasa.gov/image-article/tunable-laser-spectrometer-nasas-curiosity-mars-rover/

VULCAN Aerobot – Final Design Summary

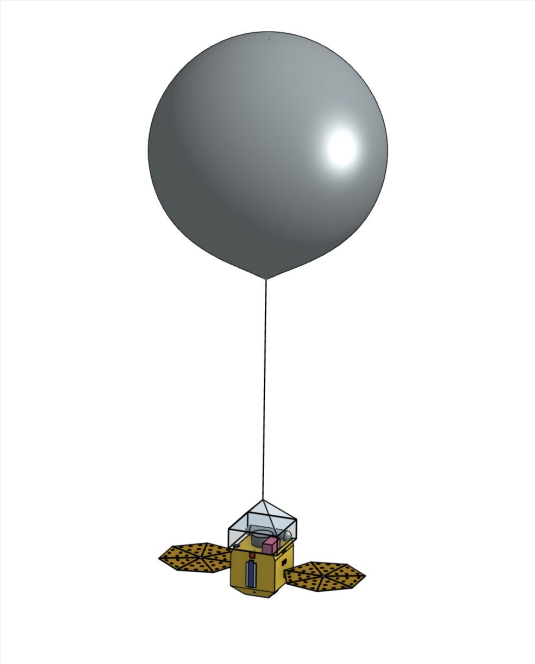
Purpose: Designed for Venus exploration via balloon-based deployment

External Components:

- Balloon, Balloon Line
- Pump,Canister, Helium Tank
- Solar Panels (expandable)
- Radiator, KaRIN, CRDS, Patch Antennas, LIDAR,TLS

Internal Components:

- Battery
- CDH Box
- Thermal Insulation & Switches
- Heat Patch
- Electrical Box



VULCAN Full Assembly

Dimensions & Structural Design

Overall Size of Chasis:

- (L × W × H): 900 mm × 950 mm × 970 mm

Solar Panel Design:

- 7 panels, each 7 mm thick → Total: 49 mm
- Solar cells: ~69 mm × 40 mm

TLS (Top Layer System):

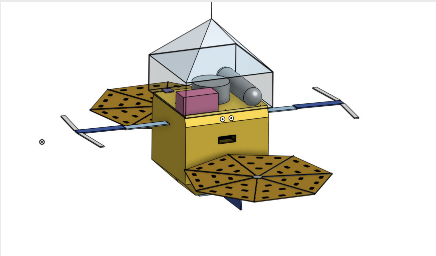
- Folded width: 25 mm (Expands via hinged plates)

Radiator:

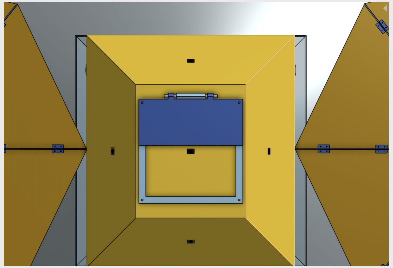
- Fin: 450 mm × 200 mm
- Structure: 450 mm × 450 mm
- Both Fin and Structure had 15mm plates, combined width of 30mm
- Include image of chassis, TLS, radiator, or solar panel CADs

LIDAR:

- 32 mm × 31 mm × 19.2 mm (×5)



Isometric View



Bottom View

Internal Layout & Power

Battery Volume: 0.0015 m^3

Electrical Box: 0.0045 m^3

CDH Box: 0.00155 m^3

Heat Patches: 120 mm × 100 mm × 0.254 mm

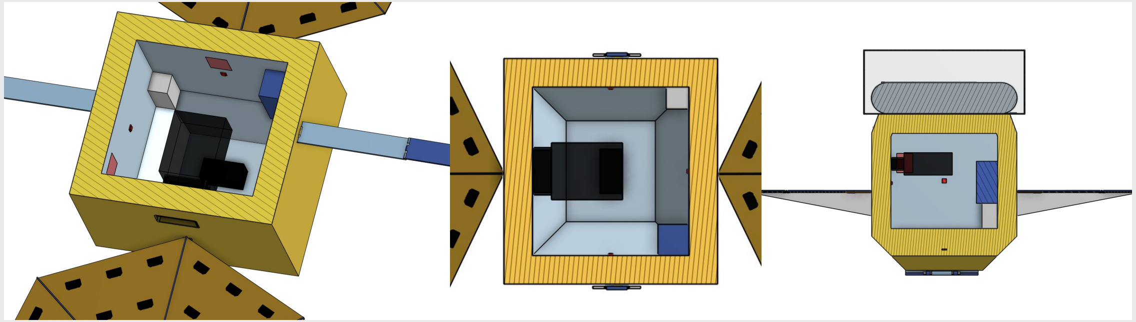
Thermal Switches: 1 in × 1 in × 0.32 in

Thermal Insulation Wall: 170 mm thickness

Power Considerations:

Solar cells optimized for compact stowage

Efficient deployment and energy collection for harsh environments



View of Internal Components

Aerobot Subsystems Masses

Subsystem	Mass (kg)	Notes
Mechanical	19	Includes chassis, propulsion, structure
Power	8	Includes batteries, MPPT, junction box
Thermal	8	Includes insulation, heat patches, radiator
Electronics (CDH)	2	CDH components and data handling electronics
Instrumentation (TLS, SOIR, CRDS, LIDAR, KaRIn)	11	Sum of all science instruments listed in PDR
Estimated Total	48	Under 50 kg mission requirement limit

Scientific Instrumentation

Instrument	Task	Key Instrument Performance Parameters	Instrument Performance Requirements	Science Objective
Tunable Laser Spectroscopy (TLS)	Identify trace gases that indicate volcanic outgassing	Concentration for Detection, Effective path length	**1 ppbv, 15 meters**	Determine the state of past and current volcanic activity on the surface of Venus
Solar Occultation in the Infrared instrument (SOIR)	Identify the signatures and radiation levels of greenhouse gases	Spectral range, resolving power	**2.32-4.35 µm, 23,200-43,100 lambda/ delta lambda**	Determine radiation amongst greenhouse gases in the atmosphere
Light Detection and Ranging (LIDAR)	Identify cloud particle distribution	Wavelength, vertical resolution	**355 nm (UV) & 1064 nm (IR), 100m**	Determine the composition and distribution of cloud particles
CRDS (Cavity Ring-Down Spectroscopy)	Identify chemical makeup and interactions within Venus' clouds	Pressure Stabilization, Effective Path Length	**1/2000, 20km**	Determine the composition and interactions of cloud particles
KaRIn Radar Altimeter	Identify fault lines, rift zones, and deformation features on Venus' surface	Range, Look Angle, Radar Frequency, Swath Width	**900km, ±4.5º, 35.75GHz, 120km**	Determine the surface deformation and tectonic activity

Data Collection

- The system will send and receive data to and from the orbiting Primary Spacecraft for relay back to Earth
- The system will handle all onboard computing requirements including for processing of relayed commands, semi-autonomous decision making, and data storage
- Safe mode to enable data transmission in the case of a malfunction

Risk Management

Rank	Risk ID #	WBS Element	Risk Owner	Category	Timeframe	Risk Title	Risk Statement	L	C	Rating
1	CDH.00	Antenna	Benson Zhuo	Loss of communication	Short Term	Failure of antenna system	Given that the Venusian atmosphere is highly hostile, there is a possibility of corrosion incapacitating the Aerobot's antenna, resulting in a failure to relay or receive science data and/or operator commands	3	3	Moderate
2	CDH.01	Onboard computer	Benson Zhuo	Loss of technical data	Medium Term	Failure of onboard computer	Given that Venus' atmosphere features high temperatures and corrosive substances, there is a possibility of impairment to the onboard computer responsible for data handling, automated operations, and interfacing with remote operators, which can result in a complete failure to retrieve mission data and/or troubleshoot through issues	3	4	Moderate
3	POW.00	Onboard battery	Benson Zhuo	Loss of power	Short Term	Reserve battery fails to provide sufficent power	Given the tumultuous conditions of atmospheric entry and descent, there is a possibility of damage to the onboard battery responsible for reserve power and storage of solar generated power, resulting in a diminishment or complete loss of onboard power	2	4	Moderate
4	POW.01	Deployable solar panels	Benson Zhuo	Loss of power	Medium Term	Failure of solar panel deployment	Given that Venus' atmosphere features high pressures, temperatures and wind speeds, there is a possibility of faulty panel deployment due to motor degradation or atmospheric disturbance, resulting in sub-optimal or non-existent solar power generation	3	2	Low
5	THERM.00	Cooling system	Rochelle Xavier	Loss of technical data	Medium Term	Failure of onboard cooling system	Given the destructive nature of Venus' atmosphere, there is a possibility of damage or overloading to the onboard cooling system responsible for maintaining nominal operating temperatures, resulting in catastrophic system shutdowns due to excessive temperatures	2	3	Moderate
6	THERM.01	Heat shielding and insulation	Rochelle Xavier	Loss of power	Medium Term	Breach of external insulation and shielding	Given the volatile nature of Venus and the stresses of atmospheric entry and deployment from the EDI, there is a possibility of a breach (either physical or chemical in origin) to the external heat shielding and insulation that helps maintain nominal operating temperatures, resulting in potential system degradation	1	2	Low
7	MECH.00	Mechanical frame	Vahin Pichairaj	Loss of technical data	Medium Term	Failure of Aerobot frame integrity	Given that Venus features highly corrosive compounds and strong winds, there is a possibility for the structural frame integrity to be compromised, which can result in internal instruments and components being exposed to the harsh Venusian atmosphere	1	3	Low

Rank	Approach	Trend	Mitigation Plans	Status of Mitigation Plans	Trigger Date	Trigger Event	Closure Date	Closure Event	Status Updates	Matrix Format
1	Accept (A)	Closed	Mitigation techniques will include redundant antenna designs, resilient antenna material choices, and safe slowing during turbulent periods of operations.	Closed	April 19th, 2025	Several days before PDR finalization and submission	April 21st, 2025	Submission of the PDR	(03/30/2025): Risk's L was changed from a 4 to a 3 to account for higher confidence in proposed mitigation plans following discussion with Engineering team. Assigned to Adam (4/18/2025): Risk's C changed from 5 to 3 to reflect mitigation plans outlined in section 2.1.3 of the PDR. Risk closed	1-CDH.00-A-C
2	Accept (A)	Closed	Proposed mitigation efforts include redundant data storage, reconfigurable data pipelines, and spatially separated computing modules.	Closed	April 19th, 2025	Several days before PDR finalization and submission	April 21st, 2025	Submission of the PDR	(03/30/2025): Risk was augmented for transition from basic to advanced log. Assigned to Adam (04/18/2025): Risk's C was lowered from 5 to 4 to reflect mitigation plans outlined in section 2.1.3 of the PDR. Risk closed	2-CDH.01-A-C
3	Accept (A)	Closed	Tactics such as solid state batteries, teflon coated wires, thermally conductive gap fillers, redundant power paths, and others have been incorporated into the power subsystem design	Closed	April 19th, 2025	Several days before PDR finalization and submission	April 21st, 2025	Submission of the PDR	(03/30/2025): Risk's L was changed from a 3 to a 2 and C was changed from a 5 to a 4 due to robust mitigation design techniques detailed in section 1.5.3 of the SRR. Assigned to Benson (04/18/2025): Risk accepted	3-POW.00-A-C
4	Accept (A)	Closed	Solar panel corrosion resistance and heat tolerance have been incorporated into power designs already, but additional mitigation can be achieved with charged backup power storage onboard and rigorous testing of the deployment mechanism	Closed	April 19th, 2025	Several days before PDR finalization and submission	April 21st, 2025	Submission of the PDR	(03/30/2025): Risk's L was changed from 4 to 3 to reflect mitigation design detailed in section 1.5.3 of the SRR. Assigned to Benson (04/18/2025): Risk's C was changed from 3 to 2 to reflect mitigation design detailed in section 2.1.2 of the PDR. Risk accepted	4-POW.01-A-C
5	Accept (A)	Closed	Multi-layer insulation (MLI); passive heat sinks; phase-change materials; conductive heat pathways; cry/thermoelectric coolers incorporated into design	Closed	April 19th, 2025	Several days before PDR finalization and submission	April 21st, 2025	Submission of the PDR	(03/30/2025): Risk's L was changed from 4 to 3 to reflect mitigation design detailed in section 1.5.5 of the SRR. Assigned to Rochelle (04/16/2025): Risk's L was changed from 3 to 2 and C changed from 5 to 3 to reflect mitigation design detailed in section 2.1.4 of the PDR. Risk accepted	5-THERM.00-A-C
6	Accept (A)	Closed	Implementation of phase change materials and a protective aeroshell ensure mitigation, also dependent on mechanical mitigation	Closed	April 19th, 2025	Several days before PDR finalization and submission	April 21st, 2025	Submission of the PDR	(3/30/2025): Risk's L changed from a 2 to a 1 to reflect mitigation efforts detailed in section 1.5.5 of the SRR. Assigned to Rochelle (04/16/2025): Risk's C changed from 3 to 2 to reflect mitigation efforts detailed in section 2.1.4 of the PDR. Risk accepted	6-THERM.01-A-C
7	Accept (A)	Closed	Refractory materials, multilayer insulation, high temperature materials optimized for high pressure environments all chosen in efforts to mitigate	Closed	April 19th, 2025	Several days before PDR finalization and submission	April 21st, 2025	Submission of the PDR	(03/30/2025): Risk's L was changed from 2 to 1 to reflect mitigation design detailed in section 1.5.2 of the SRR. Assigned to Vahin (04/16/2025): Risk's C was changed from 4 to 3 to reflect mitigation design detailed in section 2.1.1 of the PDR. Risk accepted	7-MECH.00-A-C

- Risks identified and tracked
    - Quantified with L and C scores (1-5)
    - Mitigation plans detailed and responsibility assigned
    - Changes recorded
- Failure modes tracked via Failure Mode Evaluation and Analysis (FMEA)
    - Risks re-formulated in terms of instrument/system
    - Severity score linked to C score
    - Occurence score linked to L score
    - Detection score tells ability to detect error

Function	Failure Mode	Effects	Sev	Cause	Occ	Prevention	Det	RPN	Actions
Antenna	Acidic corrosion	Loss of data/control, possible mission failure	7	Insufficent corrosion resistance in design	5	Choose materials/systems to manage corrosion and rigorously test	4	140	Reroute to redundant antenna
	Overheating	Loss of data/control, possible mission failure	7	Insufficient heat tolerance in design	5	Choose materials/systems to manage heat and rigorously test	4	140	Reroute to redundant antenna
	Dislodging due to wind	Loss of data/control, possible mission failure	7	Inadequete mechanical anchoring	5	Rigorously test mechanical anchoring	4	140	Reroute to redundant antenna
	Obscurement by heavy clouds	Infrequent or loss of data uplink	7	Inadequate signal frequency	2	Choose uplink frequency unaffected by clouds	4	56	Reroute to redundant antenna
Onboard computer	Acidic corrosion	Loss of data/onboard computing, possible mission failure	7	Insufficient corrosion resistance in design	5	Choose materials/systems to manage corrosion and rigorously test	4	140	Reroute to redundant processors
	Overheating	Loss of data/onboard computing, possible mission failure	7	Insufficient heat tolerance in design	5	Choose materials/systems to manage heat and rigorously test	1	35	Reroute to redundant processors, activate reserve cooling system
	Overvoltage	Loss of data/onboard computing, possible mission failure	6	Inadequate voltage controls	4	Institute circuit breakers, thermistors, voltage sensors, microcontrollers etc. to control voltage	1	24	Divert from problematic pathways, reroute to redundant processors if needed
	Loss of power	Loss of data/onboard computing, possible mission failure	7	Inadequete power pipelines and or lack of backup power source	4	Institute backup power sources, resilient wiring, and protective covers	2	56	Reroute to redundant processors/power
Onboard battery	Acidic corrosion	Loss of power, possible mission failure	6	Insufficient corrosion resistance in design	4	Teflon coated wires, strong mechanical shell, corrosion resistant materials	4	96	Reroute to redundant power
	Overheating	Loss of power, possible mission failure	6	Insufficient heat tolerance in design	5	Solid state batteries, teflon coated wires, thermally conductive gap fillers, and redundant power paths	1	30	Reroute to redundant power, trigger cooling system
	Mechanical leak	Loss of power, possible mission failure	6	Inadequate shielding and protective covers	3	Strong mechanical shell and protective covering of battery	5	90	Reroute to redundant power

Risk Management Outcomes

LIKELIHOOD	1	2	3	4	5
5					
4			5-POW.01-M-N		1-CDH.00-M-N, 4-THERM.00-M-N
3			7-PAY.00-M-N		2-CDH.01-M-N, 3-POW.00-M-N
2			8-PAY.01-M-N, 9-THERM.01-M-N	6-MECH.00-M-N	
1					10-MECH.01-M-N
	CONSEQUENCES				

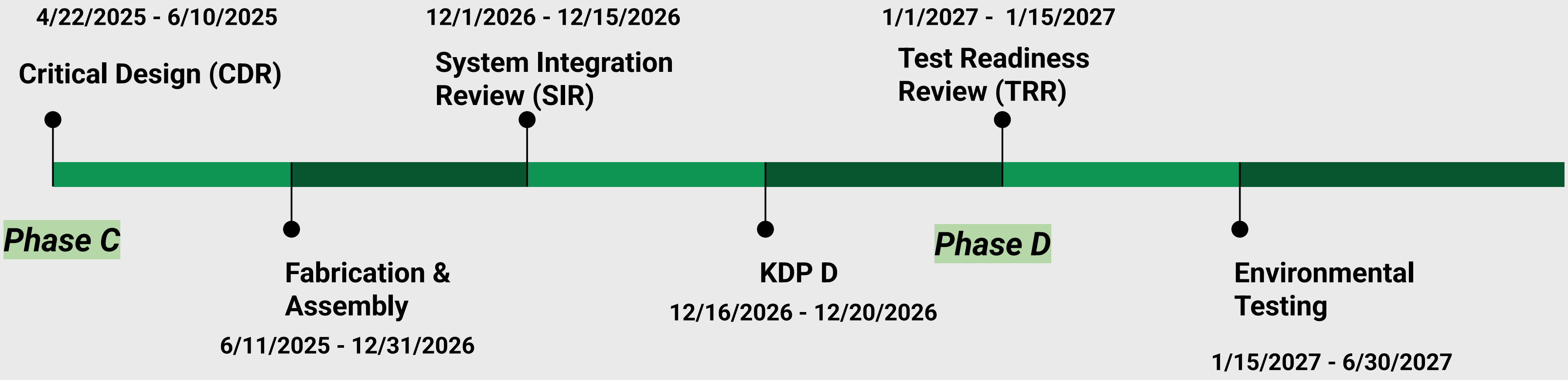
LIKELIHOOD	1	2	3	4	5
5					
4					
3		4-POW.01-A-C	1-CDH.00-A-C	2-CDH.01-A-C	
2			5-THERM.00-A-C, 14-PROG.02-A-C	3-POW.00-A-C	
1	10-PAY.01-A-C	6-THERM.01-A-C, 12-PROG.00-A-C, 13-PROG.01-A-C	7-MECH.00-A-C, 9-PAY.00-A-C, 11-PAY.02-A-C		8-MECH.01-A-C, 15-PROG.03-A-C
	CONSEQUENCES				

Budget Overview

	Personnel	Travel	Outreach	Direct	FY Total
FY 1	$3,641,734	$0	$0	$46,754,187	$52,960,921
FY 2	$3,833,566	$0	$0	$47,969,796	$54,467,730
FY 3	$4,236,250	$30,371	$425,639	$36,311,968	$43,089,152
FY 4	$4,633,578	$231,856	$436,159	$37,209,412	$44,670,890
FY 5	$2,559,487	$10,624	$0	$0	$2,570,111
FY 6	$2,240,209	$0	$0	$0	$2,240,209
Line Total	$21,144,823	$272,851	$861,798	$168,245,363	**$199,999,013**

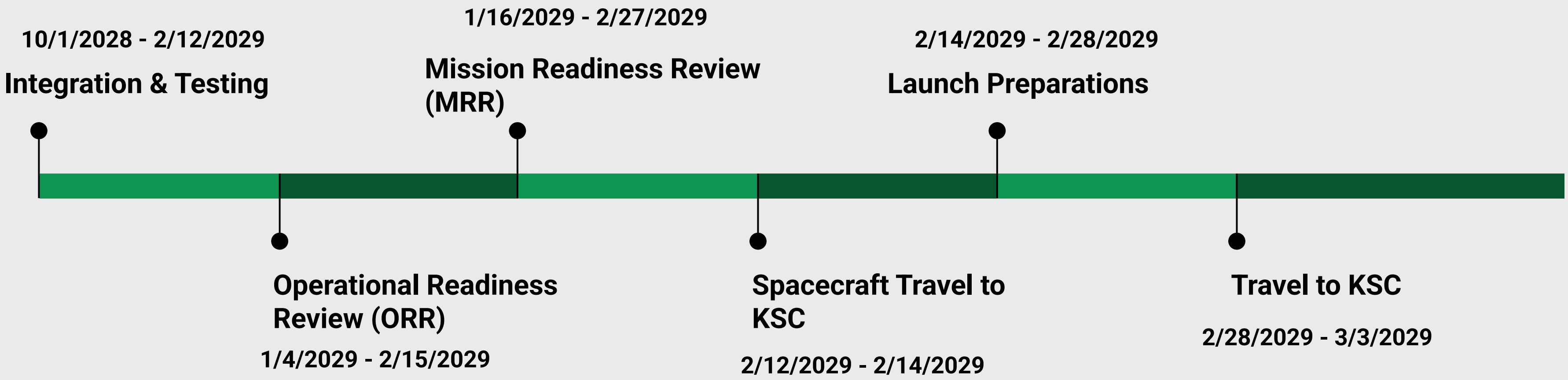
Total Budget Estimate: $199,999,013

Timeline

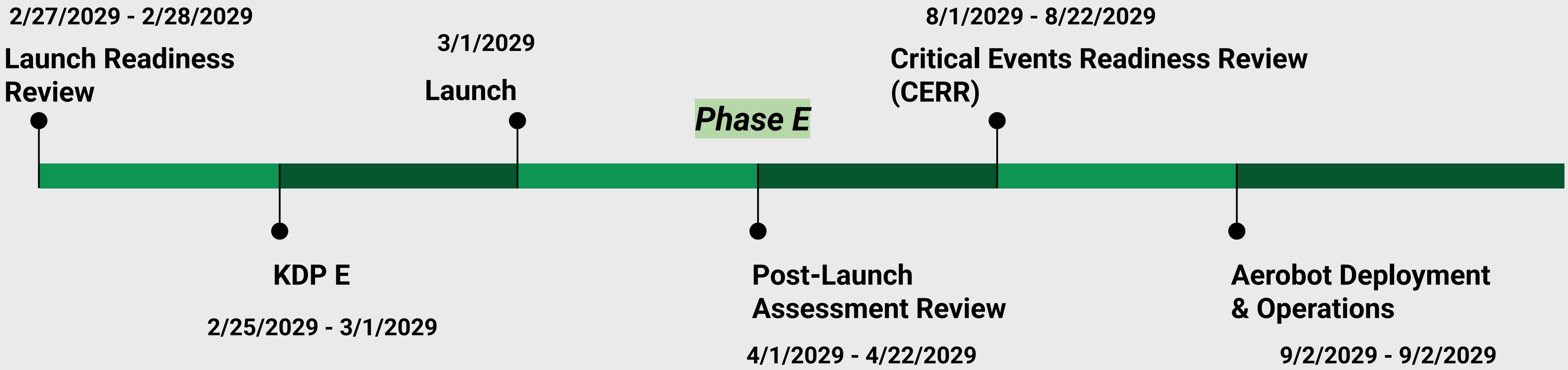


4/22/2025 - 6/10/2025
Critical Design (CDR)
12/1/2026 - 12/15/2026
System Integration Review (SIR)
1/1/2027 - 1/15/2027
Test Readiness Review (TRR)
Phase C
Fabrication & Assembly
6/11/2025 - 12/31/2026
KDP D
12/16/2026 - 12/20/2026
Phase D
Environmental Testing
1/15/2027 - 6/30/2027

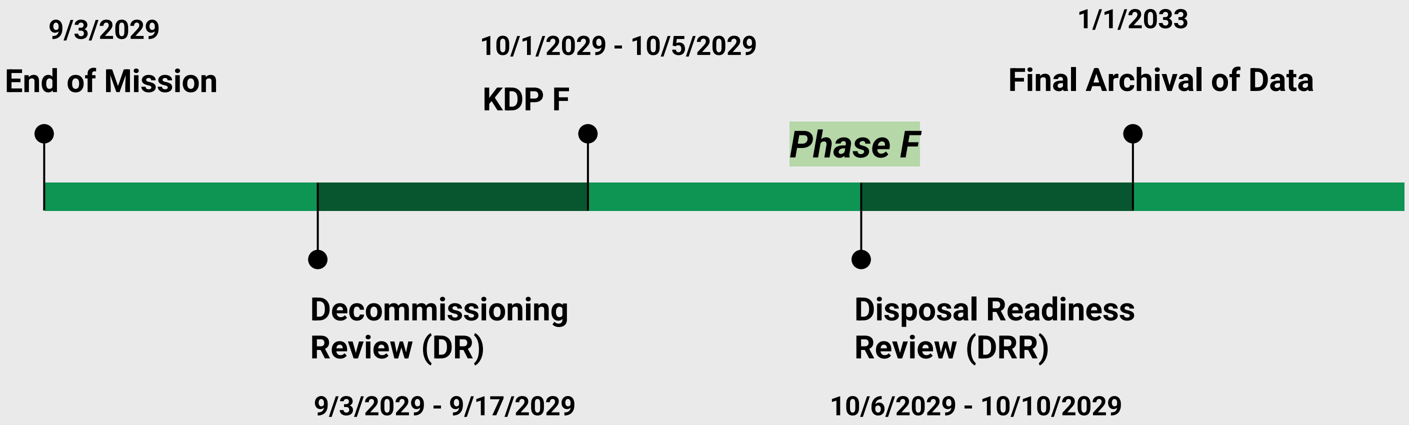
Timeline


10/1/2028 - 2/12/2029
Integration & Testing
Operational Readiness Review (ORR)
1/4/2029 - 2/15/2029
1/16/2029 - 2/27/2029
Mission Readiness Review (MRR)
Spacecraft Travel to KSC
2/12/2029 - 2/14/2029
2/14/2029 - 2/28/2029
Launch Preparations
Travel to KSC
2/28/2029 - 3/3/2029

Timeline


2/27/2029 - 2/28/2029
Launch Readiness Review
3/1/2029
Launch
Phase E
8/1/2029 - 8/22/2029
Critical Events Readiness Review (CERR)
KDP E
2/25/2029 - 3/1/2029
Post-Launch Assessment Review
4/1/2029 - 4/22/2029
Aerobot Deployment & Operations
9/2/2029 - 9/2/2029

Timeline



9/3/2029
End of Mission
10/1/2029 - 10/5/2029
KDP F
Phase F
1/1/2033
Final Archival of Data
Decommissioning Review (DR)
9/3/2029 - 9/17/2029
Disposal Readiness Review (DRR)
10/6/2029 - 10/10/2029

Image Sources (in order of appearance)

Power

1) https://www.studyforfe.com/blog/topologies-of-power-electronic-circuits/
2) Copied from PDR
3) Azur Space. 2019. 3G30C-Advanced Triple-Junction Solar Cell Datasheet. Accessed March 9, 2025. https://www.azurspace.com/images/006050-01-00_DB_3G30C-Advanced.pdf.
4) Landis, Geoffrey, and Emily Haag. n.d. "Analysis of Solar Cell Efficiency for Venus Atmosphere and Surface Missions." https://ntrs.nasa.gov/api/citations/20150016298/downloads/20150016298.pdf.
5) "Technology." n.d. QuantumScape. https://www.quantumscape.com/technology/.
6) https://romanelectrichome.com/blog/electrical-wiring-tips/
7) https://opensource.com/resources/raspberry-pi
8) https://www.rigolna.com/products/digital-oscilloscopes/

CDH

1) Software Architecture Flowchart from PDR
2) https://www.satcatalog.com/component/kryten-m3/
3) https://www.dreamstime.com/abstract-bus-network-vector-illustration-digital-marketing-communication-strategy-abstract-bus-network-concept-image347661937
4) https://www.endurosat.com/products/x-band-transmitter/

Thermal

5) https://www.nasa.gov/missions/artemis/orion/engineers-refine-thermal-protection-system-for-orions-next-mission/
6) Thermal Requirements chart from PDR
7) Thermal Heat Flow Maps from PDR
8) https://www.sierraspace.com/wp-content/uploads/2024/01/THERMAL-CONTROL-SYSTEMS-Thin-Plate-Heat-Switch.pdf
9) https://redwirespace.com/wp-content/uploads/2023/06/redwire-qrad-flysheet.pdf
10) https://sea.omega.com/th/pptst/KHRA-KHLVA-KHA-SERIES.html
11) https://www.esa.int/ESA_Multimedia/Images/2016/08/Multi-layer_insulation_blankets
12) https://thermalds.com/thermal-analysis-thermal-modeling/

TEMPLATE SLIDES BELOW

Add a title for your board meeting

Company Name

Company Name Q1 / Month	Year

Today's agenda

→ Add a meeting topic

→ Add a meeting topic

→ Add a meeting topic

→ Add a meeting topic

→ Add a meeting topic

→ Add a meeting topic

Today's agenda

A summary of today's meeting topics

1. Add a meeting topic

Provide a high-level topic overview.

2. Add a meeting topic

Provide a high-level topic overview.

3. Add a meeting topic

Provide a high-level topic overview.

4. Add a meeting topic

Provide a high-level topic overview.

5. Add a meeting topic

Provide a high-level topic overview.

6. Add a meeting topic

Provide a high-level topic overview.

7. Add a meeting topic

Provide a high-level topic overview.

8. Add a meeting topic

Provide a high-level topic overview.

Today's agenda

Summarize your meeting topics

1

Add a meeting topic

2

Add a meeting topic

3

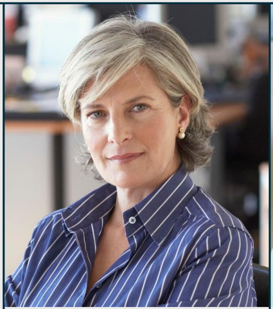
Add a meeting topic

4

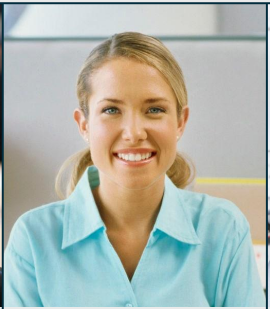
Add a meeting topic

Meeting attendees

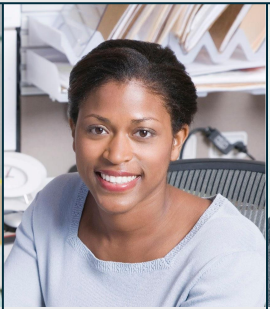
Team Name



Full Name
Title



Full Name
Title

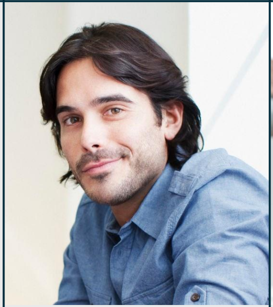


Full Name
Title

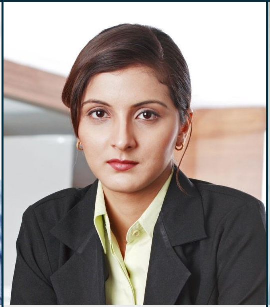
Full Name
Title

Full Name
Title

Team Name



Full Name
Title



Full Name
Title

Full Name
Title

Full Name
Title

Full Name
Title

Key milestones

Q1

Milestone 1

Briefly highlight the year's most important achievements or events, quarter by quarter.

00k

Q2

Milestone 2

You might have reached a revenue target, or launched a new product or service.

00M

Q3

Milestone 3
Key achievement

For major milestones, draw attention to them with a larger font and a unique background. Make sure you explain why you're highlighting this particular milestone.

Milestone 3A

To show more information about this milestone, use these text blocks.

Milestone 3B

To show more information about this milestone, use these text blocks.

Q4

Milestone 4

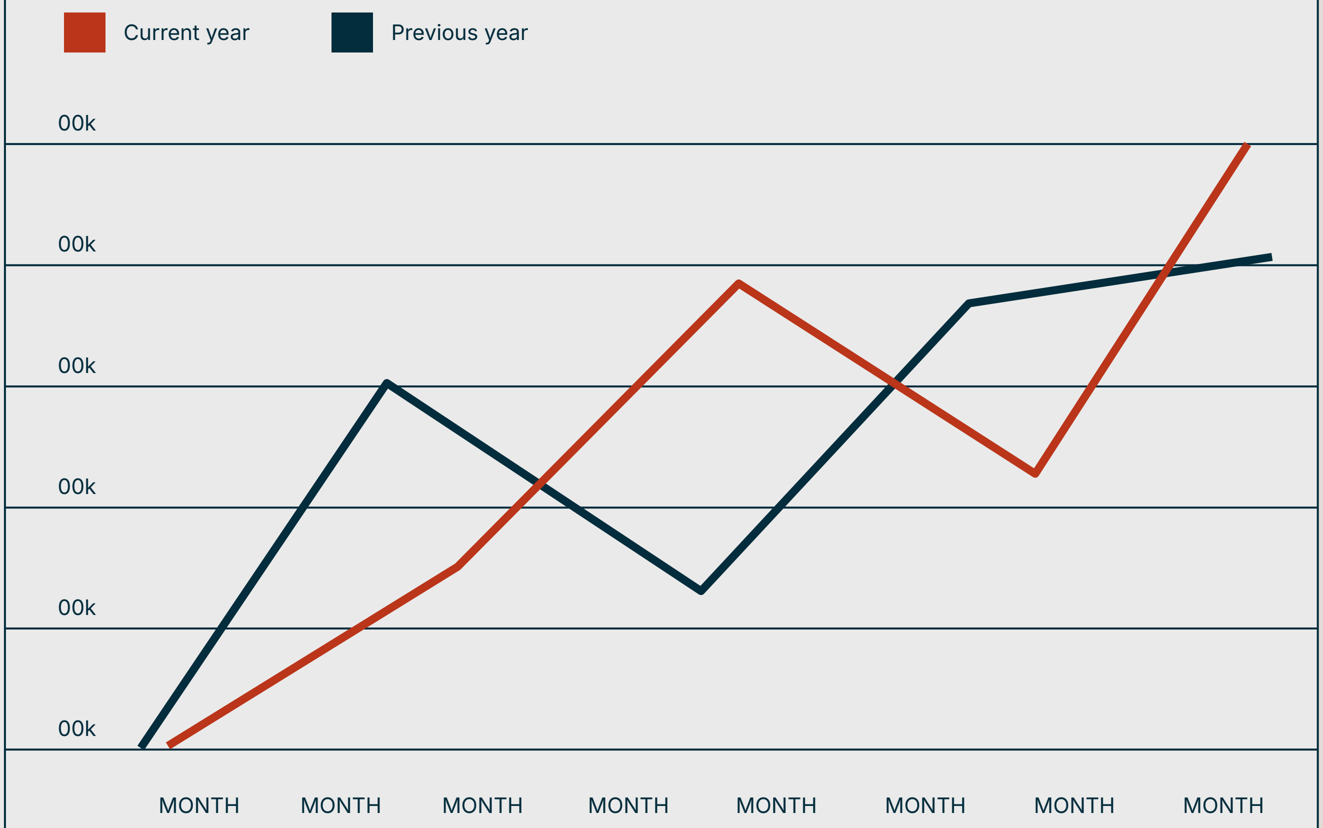
To show more than one milestone in a single time frame, stack them like this.

Q4

Milestone 5

To show more than one milestone in a single time frame, stack them like this.

Year-on-year revenue growth

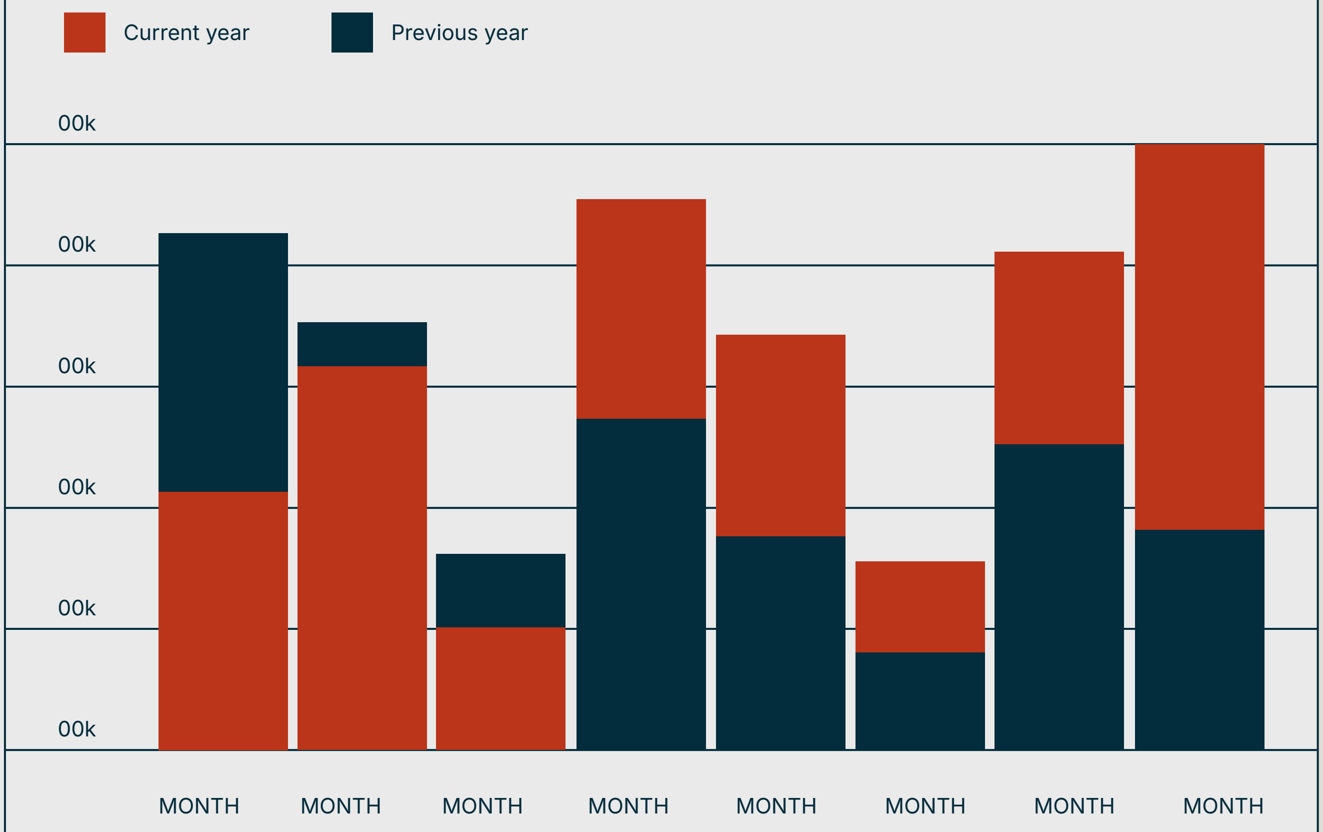


Add a short headline about your growth

Use this slide to showcase your company's year-on-year (YoY) revenue growth. Write a summary here, then visualize your financial performance in a graph or chart.

You can also mention the milestones from the previous slide if they visibly impacted revenue over the last year.

Year-on-year revenue growth



Add a short headline about your growth

Use this slide to showcase your company's year-on-year (YoY) revenue growth. Write a summary here, then visualize your financial performance in a graph or chart.

You can also mention the milestones from the previous slide if they visibly impacted revenue over the last year.

Project Name

Financial highlights

Gross profit for this year

$00M

$00M

Previous year

Net profit for this year

$00M

$00M

Previous year

Use this slide to provide an at-a-glance overview of your company's financial data. Write a short statement about what the data means for your company.

The metrics suggested here are for reference. Add the financial data that makes sense for your purposes.

Costs

$00M

Cost of goods sold (COGS)

$00M

Operating expenses

$00M

Research & development

→

00%

Return on investment

Key performance indicators

This year's objectives

Marketing objectives	Communication objectives	Business objectives
Your marketing goals should be aimed at engaging your target audience at every touchpoint, whether online or in-store.	Your communication goals can be both internal and external. Think about brand awareness or employee retention.	Your business goals are overarching objectives. From annual revenue to market share, everything contributes to these overall goals.
KPI 00%	**KPI** 00%	**KPI** 00%
00%	**00%**	**00%**
KPI 00%	**KPI** 00%	**KPI** 00%
00%	**00%**	**00%**
KPI 00%	**KPI** 00%	**KPI** 00%
00%	**00%**	**00%**

Project Name

Project status

Status update

Use this slide to explain an ongoing or upcoming project. What makes this project relevant? What impact will it have on company finances, internal workflow, or brand positioning?

Progress

Tell this project's story. Explain how it got started and how it's going right now. Mention key milestones, deliverables, and achievements. Point out the current stage of this project. What work is being carried out at the moment? What teams are involved?

Client	Client name	**Department**	Department name
Team	Team name	**Lead**	Full name
Starting date	Date	**Current status**	Status
Delivery date	Date	**Next milestone**	Date

Project Name

Preparing for the next deadline

Use this slide to explain an ongoing or upcoming project. Tell this project's story. Explain how it got started and what it hopes to achieve.

What makes it relevant? What impact will it have on company finances, internal workflow, or brand positioning?

You can also introduce the teams, leads, and stakeholders involved.

Link to the project deck

Project progress

Date Tell this project's story. Explain how it got started and how it’s going right now. Mention key milestones, deliverables, and achievements.

Date Point out the current stage of this project. What work is being carried out at the moment? What teams are involved?

Date Look ahead to upcoming dates and milestones. What are the upcoming deadlines? Are we on track to meet them?

Date What are the project goals? What will be produced in the end and who will benefit?

“Add a quote that introduces or summarizes the project.”

Use this slide to explain an ongoing or upcoming project. Tell this project's story. Explain how it got started and what it hopes to achieve.

What makes it relevant? What impact will it have on company finances, internal workflow, or brand positioning?

You can also introduce the teams, leads, and stakeholders involved.

Link to project deck

Status

Kickoff **Production** **Launch**

Explain how this project is coming along. Is it on track? What work is being carried out at the moment?

Budget

$00

Projected ROI (return on investment)

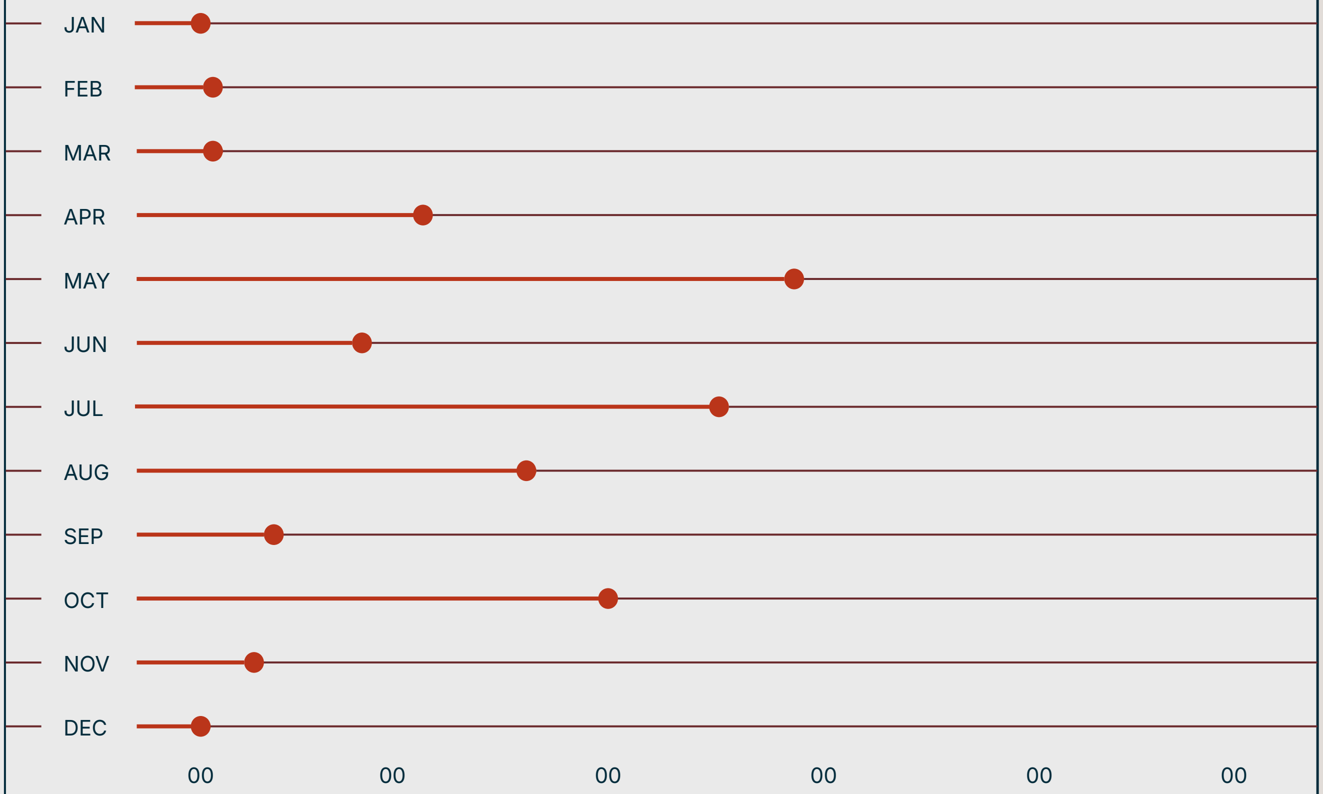
$00

Project status update

Project name	Department	Team	Status
Project name	Department name	Team name	Pending review
Project name	Department name	Team name	Client feedback
Project name	Department name	Team name	In progress
Project name	Department name	Team name	On hold
Project name	Department name	Team name	Not started
Project name	Department name	Team name	Approved

Company Name Q1 / Month Year

Team growth



New hires

Month-by-month

Use this slide to show how the company has grown over the past year. Mention events that visibly affected hiring rates, such as a new project or product launch.

00

This is your current headcount. Celebrate your growth and mention your goal for next year.

Team growth

00

Employees

Use this slide to show how your company has grown over the years.

20XX

00

Employees

For each year, add context about what was happening at the company.

20XX

00

Employees

Total headcount

Subtitle

Did a project or product launch require new talent? Did you expand into another market?

This is your current headcount. Celebrate your growth and mention your goal for next year.

20XX

Company Name	Q1 / Month	Year

Priority 1

Based on your business objectives, describe one of your company's top priorities for next year.

Initiative	Description
Project owner	Name
Other details	Details

Priority 2

For example, if you want to meet a revenue target, new market expansion might be a priority.

Initiative	Description
Project owner	Name
Other details	Details

Priority 3

Each priority should guide your decision-making, resource allocation, and overall direction.

Initiative	Description
Project owner	Name
Other details	Details

Add a statement about the industry challenges you anticipate in the near future

Upcoming challenge 1	Talk about challenges and obstacles that might surface next year. These might be in areas such as shifts in the global supply chain, emerging customer trends, or tech adoption.	1	To get people thinking, suggest a solution or area for growth.
		2	Propose another solution to spark discussion.
Upcoming challenge 2	Talk about challenges and obstacles that might surface next year. These might be in areas such as shifts in the global supply chain, emerging customer trends, or tech adoption.	1	To get people thinking, suggest a solution or area for growth.
		2	Propose another solution to spark discussion.
Upcoming challenge 3	Talk about challenges and obstacles that might surface next year. These might be in areas such as shifts in the global supply chain, emerging customer trends, or tech adoption.	1	To get people thinking, suggest a solution or area for growth.
		2	Propose another solution to spark discussion.

Timeline

Upcoming milestones

Concept						Process			Final product		
Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month	Month
Phase 1 Phase name											
			Phase 2 Phase name								
						Phase 3 Phase name					
									Phase 4 Phase name		

Phase 1

Summarize the months or quarters ahead. Edit the time frame to suit your needs.

Phase 2

For each phase or period of time, anticipate future projects, industry events, and other milestones on the horizon.

Phase 3

You can also mention metric or performance goals that you need to meet, as per your business priorities.

Phase 4

Add as many phases, steps, or months as you need. Duplicate this slide if you need more space.

Company Name | Q1 / Month | Year

Timeline

Upcoming milestones

	Owner	Status	Month	Month	Month	Month	Month	Month
Upcoming project								
Task 1								
Task 2								
Task 3								
Upcoming project								
Task 1								
Task 2								
Task 3								
Upcoming project								

Thanks for participating

Let's discuss these topics

1

Topic for live discussion

Summarize the topic. Refer to what was discussed during the presentation. Then prompt your audience with questions.

2

Topic for live discussion

Summarize the topic. Refer to what was discussed during the presentation. Then prompt your audience with questions.

3

Topic for live discussion

Summarize the topic. Refer to what was discussed during the presentation. Then prompt your audience with questions.

4

Topic for live discussion

Summarize the topic. Refer to what was discussed during the presentation. Then prompt your audience with questions.

Thank you

If you have any questions, contact:
name@example.com