Preliminary Design Review

Venus Atmospheric Strategic Science Investigation

Team 16: “The Sky Walkers”
L’SPACE Mission Concept Academy

Spring 2021

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1. Introduction and Summary

1.1 Team Introduction

Team 16, The Sky Walkers, consists of 13 individuals that contributed to this Preliminary Design Review. Each team member brings impressive experiences and skills that are necessary to the success of the mission.

Jennifer Barkley is a senior at Fayetteville State University in Fayetteville, North Carolina studying Chemical Engineering and she is the Science Lead and Astrophysicist for the team. Jennifer is the President of the American Chemical Society, and has completed NPWEE Fall 2020 and MITTIC 2020. She is currently in MITTIC 2021 and is a math tutor and an undergraduate learning assistant. She is also in the Gautam research group performing research on polymer use in sensors by testing thermal, electronic, and light harvesting properties.

Alexander Dieppa is a senior studying Mechanical Engineering at the University of Central Florida in Orlando, Florida and he is the Mechanical Engineer of the team. Some experience and skills he brings to the team include 3D CAD design, 3D printing, and stress/fluid simulation. Alexander gained these skills through various projects in his undergraduate career including the ASME Student Robot Design Competition, NASA SpaceTrek weather balloon, and his senior design project involving the design of a NASA CubeSat. He loves space and NASA and cannot wait to use his skills to make his team successful!

Rajaa Elhassan is a sophomore studying Chemical Engineering with a minor in Child Psychology at New York University in New York City, New York and she is the Chemist of the team. Rajaa is a current UNCF Scholar, Coca-Cola Scholar, and MLK Scholar. She ran an all-girls robotics team in high school that went to world championships two years in a row and won the NYC regional in 2019. Her team's coverage included Forbes, TeenVogue, and the Today Show on top of having their own PBS docu-series being made about them! Rajaa continues her robotics journey in college as part of NYU's Robotics Design Team, participating in the NASA Lunabotics competition. She is also an avid Model UN debater and has done it for the last 5 years.

Melany Evangelista is a senior studying Electrical Engineering at George Mason University in Fairfax, Virginia and she is the Electrical Engineer of the team. Melany is currently an engineering intern with the Federal Aviation Administration supporting the Very High Frequency Omnidirectional Range (VOR) Minimum Operational Network project through data analysis, data visualization, and programming in MATLAB and Python. She has worked as an Early Identification Program STEM Specialist at George Mason University where she provided academic assistance to high school students by helping them strengthen their understanding of scientific and mathematical concepts and by facilitating the learning experience using motivating and thought-provoking teaching processes. She also worked on a college team and helped develop a Mini-Line Tracer Robot which won the award for best project among a class of 50+ students. Some of the components used were infrared sensors, infrared LEDs, photodiodes placed side-by-side for directionality.

Luis Rivera Gabriel is a Junior at the University of Puerto Rico at Mayagüez studying Physics and he is the Astronomer for the team. Luis had the privilege of being part of the winning team, the Boriken Voyagers, in the New Arecibo Space Message Challenge, where his team composed a new message to be sent to the depths of space in honor of the original Arecibo message. He’s currently a researcher for SEDS Goes Green, a student initiative focused on the development of agricultural methods in low-gravity environments.

Sanja Kirova is a sophomore studying Mechanical Engineering at Columbia University in New York City, New York and she is the Engineering Lead and Materials Engineer for the team. Sanja has six years of experience with competitive robotics and has been involved in Project Lead the Way which does pre-engineering courses. She is also a board member of the Formula SAE team and is a mechanical engineering lead for the Robotics Club on her campus.

Alberto Leon is a freshman at Drew University in Madison, New Jersey studying Physics, and he is the Outreach Director for the team. Alberto is very passionate about two things: NASA and the aerospace industry. He has worked with multiple small businesses in the past and graduated in the top 10% of his high school class. While he is a freshman in college, he still brings knowledge and looks forward to new and important experiences.

Robert Minor is a freshman at ECPI University in Virginia Beach, Virginia studying Engineering Technology, and he is the Project Manager and Physicist for the team. Robert has been in the mechanical industry for many years. He has led a multitude of projects from conception to completion, most recently guiding the completion of a multi-million dollar manufacturing facility, and a multi-million dollar expansion of that same facility.

Nimra Shakoor is a sophomore at Cornell University in Ithaca, New York studying Earth Science, and she is the Business Administration Lead and Logistics Administrator for the team. She has experience on a robotics team and has ample research experience. Currently, she is doing remote sensing research. She also programs in Python and Java, and has mentored students in programming.

Matthew Swanson is a junior at West Virginia University in Morgantown, West Virginia studying Aerospace and Mechanical Engineering and he acts as Deputy Project Manager and Record Keeper for the team. Matthew has over 6 months of experience working in the solenoid industry throughout his internships. He also has experience in Microgravity Research where he worked on a team that successfully tested Direct Ink Writing of Titanium Dioxide foam in a reduced-gravity inducing aircraft. Currently, Matt is working as a teaching assistant for a mechatronics course at his university and continuing his Microgravity Research, working on a new experiment that was recently approved for the NASA Flight Opportunities Grant for 2021 and 2022 flights.

Sandibell Vega is a senior at the University of Advancing Technology in Tempe, Arizona studying Robotics and Embedded System and Artificial Intelligence, and she is the Robotics & Embedded Systems Engineer for the team. She has had numerous achievements, including the successful completion of the Dean list Awards in Fall 2019, Summer 2020, Fall 2020 awards, won UAT Data Science fake news detection competition 2020, Futures and Options 2019 Summer Internship Program, winning second place at the annual Society of Women in Engineering conference at Columbia University in March 2018, winning the most innovation in December 2020, winning the Outstanding Achievement in Engineering and Robotics, and earning the Teaching Assistant Scholar Award in mathematics. She has experience using Python, Java, C++, Arduino, MySQL, Autodesk Inventor, Solidworks, machine learning, Artificial intelligence, and circuits. Sandibell Vega gained these skills through various projects in his undergraduate career including SIP Project, Underwater Robots, and 4-in-1 contest. (https://sandibellvega.weebly.com/).

Alex Xu is a junior at Duke University in Durham, North Carolina studying Electrical and Computer Engineering with a certificate in entrepreneurship. He is the Financial Planner for the team. He currently leads a student organization on campus focused on developing UAVs, and is involved with undergraduate research. He brings past experience in electronics hardware design, software development, and business/financial planning.

Andy Zhou is a junior attending The City College of New York in New York City, New York studying Computer Engineering and he is the Aerospace Engineer for the team. Andy specializes in 3D printing, and coding. While he is a Computer Engineering student, during his spare time, he participates in projects to learn more about other aspects of other fields of engineering. Because of this, he learned CAD, the art of HAM Radio, and acquired knowledge in regards to rocketry. His greatest accomplishment is his Fusion Core 3D printer which is a CoreXY configured 3D printer with 3 subsections configured for each appropriate component (https://github.com/andyzhou443/FusionCore).

1.2 Mission Overview

1.2.1 Mission Statement

The goal of this atmospheric mission to Venus is twofold. The first objective is to investigate the origins of recently-detected phosphine gas in the atmosphere of Venus. This phosphine gas is hypothesized to be of either biological or geological origin. On Earth, phosphine gas is only known to be produced by microbial life, so the existence of phosphine gas on Venus may be a sign of extraterrestrial life. Data collected on this mission with regards to the locations, variations, and concentrations of phosphine gas in the Venusian atmosphere would be used to confirm the presence of phosphine gas and elucidate these relationships.

Second, the mission will collect data on the locations and concentration levels of phosphine, methane, oxygen, and nitrous oxide. These gases are often produced through biological processes here on Earth, making them known biomarkers on Earth, so data collected can further support investigations into the existence of life (past or present) on Venus. This would allow scientists to better understand the planet's history and the development of early life in the solar system. Furthermore, observational data would be highly valuable in developing a detailed atmospheric map of Venus in terms of composition, gas concentrations, and location. This will be valuable in planning future atmospheric or terrestrial missions to Venus.

1.2.2 Mission Requirements and Constraints

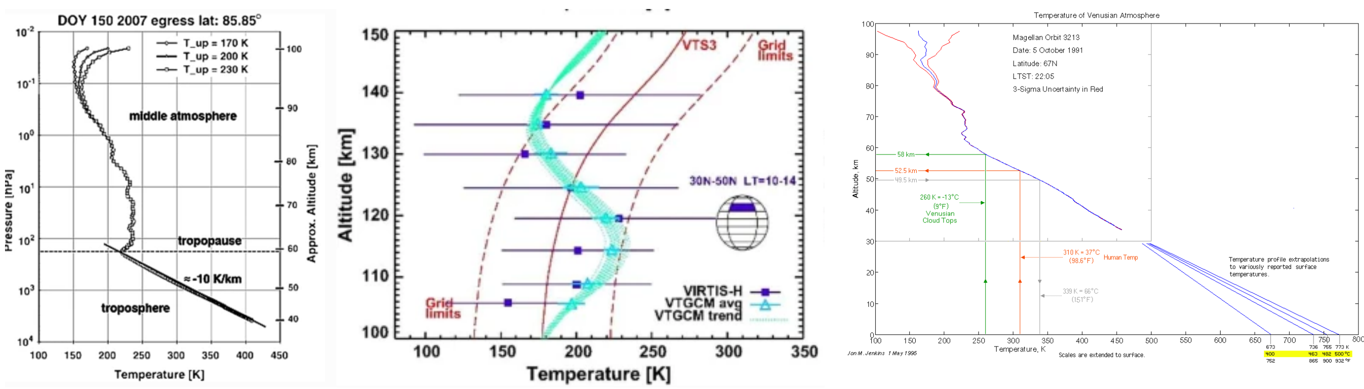
1.2.2.1 Vehicle Requirements

A. The vehicle and payload will maintain an altitude of 50-55 km above the surface of Venus, and not venture outside of the 50-70 km altitude range.
B. The vehicle and payload shall be packaged to fit within the volume of 60 cm x 70 cm x 90 cm in their stowed configuration.
C. The vehicle will withstand temperatures between 150 K (at 140 km) and 350 K (at 50 km).
D. The vehicle will withstand pressures between hard vacuum to 1013.25 hPa (~1 bar).
E. The vehicle will be capable of traveling among wind speeds of 70-100 m/s (east to west).
F. The vehicle shall be resistant to damage caused extended exposure with sulfuric acid in concentrations of (70-99 wt%).
G. The vehicle shall communicate with the main orbiter, 200-8,000 km away.
H. The vehicle will utilize passive thermal protection to maintain an internal temperature of 298 ± 5 K.

I. The vehicle shall regulate electromagnetic interference to minimize disruption of data collection.
J. The vehicle should take advantage of control surfaces for smooth sailing to maximize stability.
K. The vehicle shall prevent thermal shock to internal systems during entry burn.

Figure 1

Graphs of Temperature vs Pressure & Altitude (Venus atmosphere temperature and Pressure Profiles), (Limaye et al., 2018)



1.2.2.1.1 Vehicle System Requirements: Power

A. The power generation system (solar panel array) will provide enough constant voltage to power all vehicle and payload operations necessary 24/7 while on the dayside.
B. The battery will store enough power for 48 hours of operation while sampling the night side of Venus.
C. The power generation system (solar panel array) will be passively protected from harsh conditions of Venus' atmosphere.

1.2.2.1.2 Vehicle System Requirements: Altitude Control

A. The altitude control system shall deploy a parachute at 80 km in altitude to slow descent.
B. The altitude control system shall inflate the balloon within 30 minutes.
C. The altitude control system shall maintain an altitude of 53 ± 5 K throughout the duration of the mission.

1.2.2.2 Payload Requirements

A. The payload shall contain a filtration system to remove 96% of sulfuric acid droplets entering the spectrometer for sampling.
B. The payload shall be airtight to prevent exposure of instruments to sulfuric acid.
C. The payload will withstand temperatures of 298 ± 5 K.
D. The payload shall contain a cooling system to maintain internal payload temperatures at 298 ± 1 K cool down Venus air entering the spectrometer for sampling.
E. The payload will withstand pressures between hard vacuum and 1013.25 hPa (1 bar).

1.2.3 Mission Success Criteria

A successful mission would include entry into the atmosphere of Venus with a target altitude of 50-70 km. The instruments would maintain altitude by use of a balloon mechanism to keep it afloat in the top-mid cloud layers of Venus's atmosphere.

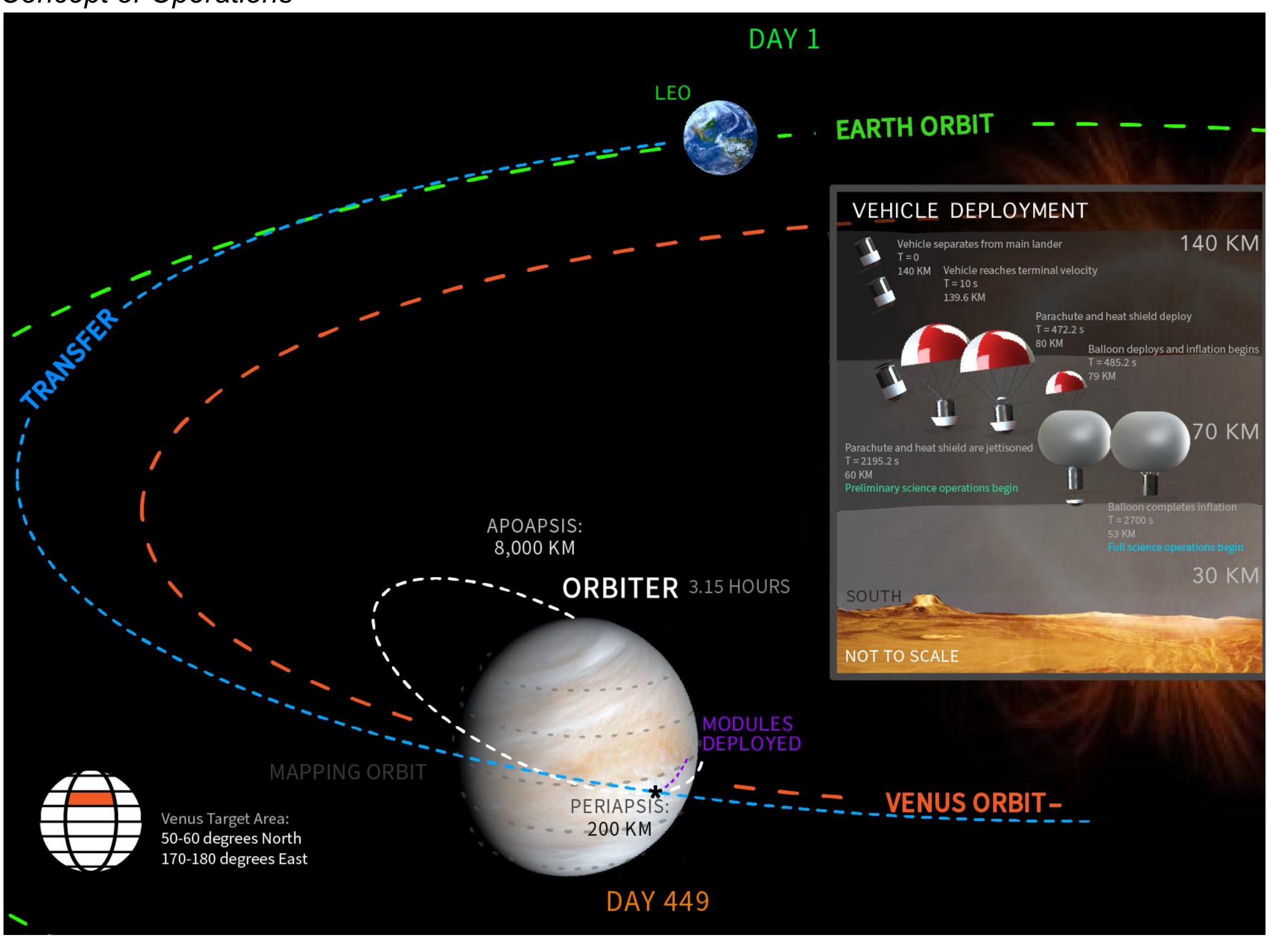
A successful mission would also include being able to determine where on Venus the phosphine concentrations are highest relative to the overall environment with 90%+ accuracy. In addition to measuring the concentration of phosphine, the instrument would also measure ethane, methane, carbon dioxide, ozone, ammonia, ethylene, and water vapor in ppb, measure temperature, the pressure, sulfuric acid concentration alongside other readings to get a feel of the atmospheric conditions. Successful mapping of placement of gases found on Venus would occur with communication of 100% of data back to earth. The team's mission will have a goal of collecting data covering greater than 70% of Venus's atmosphere.

Since a great deal of Venus's surface has been mapped using SAR, the vehicle would fly over certain geological formations and determine whether phosphine levels are higher near these regions and determine if said phosphine could be of geological origin. The mission would utilize previous mapping of Venus to determine where the vehicle will focus on mapping (*In depth* 2021). The payload may remain in the atmosphere after the mission is over, descending in altitude as the helium runs out and eventually crash landing and melting in the high Venus surface temperatures.

1.2.4 Concept of Operations (COO)

Figure 2

Concept of Operations



Timeline of Operations
Day

1	The spacecraft containing the main lander and secondary payload will launch from Cape Canaveral, FL in the direction of Earth spin, taking advantage of Earth's substantial rotational speed.
1	The spacecraft accelerates until it reaches at least orbital velocity and escapes Earth's gravitation.
3	The spacecraft enters Hohmann's interplanetary transfer orbit to perform a Type II transfer, lasting approximately 1.23 years. The spacecraft begins cruising for the next 12,104 km to Venus.
449	The spacecraft encounters Venus, deploying the orbiter which begins insertion operations around Venus. The orbiter takes up an elliptical orbit around Venus which lasts 3.15 hours with an apoapsis at 8,000 KM altitude and a periapsis at 200 KM altitude.
449	At periapsis, the orbiter deploys a deceleration module containing both the secondary payload and the main lander.
449	At 140 KM altitude, the deceleration module is jettisoned, and the secondary payload and main lander separate. Upon separation, the vehicle (secondary payload) powers on and the solar panel arrays begin charging. The vehicle travels at an initial downward velocity of 35 m/s and reaches terminal velocity of 125 m/s after 7.5 minutes of free fall.
449	At 80 KM altitude, the drogue parachute and balloon deploy simultaneously, the heat shield is jettisoned, and balloon inflation begins. Data communication with the orbiter (temperatures, pressures, voltages, and angular positions) stabilizes.
449	At 60 KM altitude, the drogue parachute is jettisoned and the balloon is 95% inflated. The vehicle is carried by wind speeds of 70 m/s (East to West) and begins recording atmospheric data.
449	At 53 KM altitude, the balloon achieves neutral buoyancy.
473	The payload has completed its mission and may continue recording data of Venus while spiraling along the surface of Venus.

1.2.5 Major Milestones Schedule

Table 1

Major Milestones Schedule

Phase & Timeframe	**Milestones**
A 01/12/21–	**Pre Phase A:** Conceptual Study

02/15/21	The team aims to study the presence of phosphine gas in Venus's atmosphere as it is a well-known biosignature for anaerobic microbes. Goals include determining if it is present, where it is present, what type of qualities the gas has, if it is conducive to any form of life, and what its source is (biological or geological). **Phase A:** Preliminary Analysis The team has concluded that in order to form a successful plan and subsequently a successful launch and exploration, they must develop some initial schematics and a budgeting plan for the launch. Some potential plans are bluetooth 5.0 for communication, creating a map of phosphine around planet, understanding its volume and weight, its contact with earth, and being able to collect data on other compounds present The group's first step is to complete the Preliminary Design Review (PDR). The **first milestone** is to introduce the idea and proposal and give a summary of how they plan to accomplish their task (completion by 02/15/21).
B 02/16/21–04/16/21	**Phase B:** Definition The group is divided into three sub-teams, Engineering, Science, and Business Administration, each with their own leads and each person designated a role. All three sub-teams will begin to strategize efficient ways for a successful launch. The initial proposal is to create a vehicle/instrument that will have sensors to detect 8-10 different chemicals (life markers) in the atmosphere, with a GPS system, and use elements of Venus (solar) with the assumption that phosphine will be the largest compound of interest. Engineering and Science will begin to create their initial plans involving the spacecraft utilizing materials resistant to sulfuric acid in concentrations from 0 to 90 % and process temperatures up to 84° F.. The **second milestone** is mainly focused on the business side and how they will budget their expenses and also give exposure to their launch (completion by 2/22/21). The **third milestone** shifts the focus to the engineering and science teams and their specifics on maneuvering and the overall design of their vehicle, the payload, and other instruments to be used on launch (completion by 3/14/21). Also, determining which instruments will be good to manufacture potential sensors such as spectrometers for concentration like the Lucy Thermal Emission Spectrometer (L'TES) from the Lucy mission as they will have to be completely exposed to the air while in testing range, but not in range it needs to be protected. **Milestone 4** reverts back to the safety officer and deputy safety officer as well as the business administrators and how they will handle the safety of the group and for the vehicle and payload, making sure for a clean and hazard-free launch (completion by 3/21/21). The **5th and 6th milestones** coincide with each other as the PDR will be fully completed and presented (completion by 4/07/21 and 4/16/21, respectfully).
C/D	**Phase C/D:** Design and Development

04/17/21–09/15/22	Now the focus is moved to the Critical Design Review (CDR), where any new changes made since the PDR are highlighted and presented to a panel consisting of scientists, engineers and safety experts. The assembly, integration, and all technicalities are checked over to be on track to complete the flight and ground system with a completion by 08/02/2021. From 08/15/2021 to 12/10/2021, the team plans to start and complete manufacturing of all components for the mission, adhering to set safety guidelines. The final review before formal testing (the Test Readiness Review (TRR)) shall assess all objectives, methods and procedures and safety and officially plan test of spacecraft with a completion by 01/29/2022. Testing for readiness for a safe and successful flight/launch and for operations now begins. This step includes ATLO (assembly, test, and launch operations), when spacecraft components and instruments are delivered to the clean room and integrated and tested using computer programs for command and telemetry. The spacecraft will also be transported to an environmental test lab where it is installed on a shaker table and subject to launch-like vibrations as well as in a thermal-vacuum chamber to test thermal properties while communicating with engineers. The full extent of testing should be completed by 09/15/2022.
E 11/29/22–07/01/25	**Operations Phase & Mission End:** The group's vehicle will be launched on 11/29/2022, and will arrive on Venus on 02/20/2024, successfully gathering all data on the phosphine gas and any other compounds found (*Trajectory browser*). The team has a minimum expectation for time in the goal atmosphere range to be 21-26 days. Data is expected to return to Earth by 03/25/2024 and analyzed until 07/01/2025.

1.3 Descent Maneuver and Vehicle Design Summary

Figure 3

Descent Maneuver

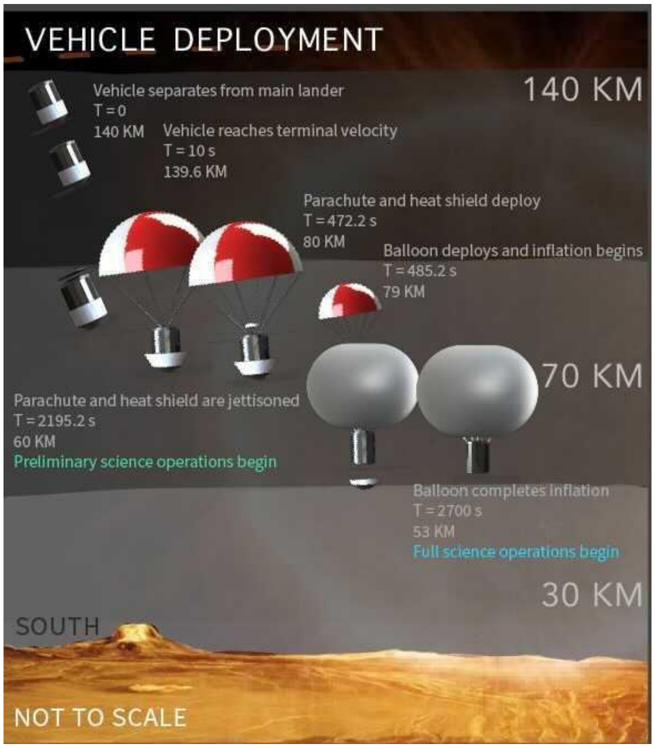


Table 2

Vehicle Description Values

Vehicle Description	**Value**
Weight	175 kg (w/ payload)
Entry altitude	140 km
Entry velocity (downward)	35 m/s
Entry velocity (horizontal)	48.4 m/s
Entry angle	28.9°
Ballistic Coefficient	0.136
Terminal velocity	125 m/s
Velocity (westward)	70 m/s
Maximal Surface Heating	107 kJ--
Mach number	0.30-1.08

Table 3

Location Data Values

Location Data	Value
Periapsis altitude	200 km
Apoapsis altitude	8,000 km
Periapsis latitude, north	50 deg
Orbit period	4 hrs

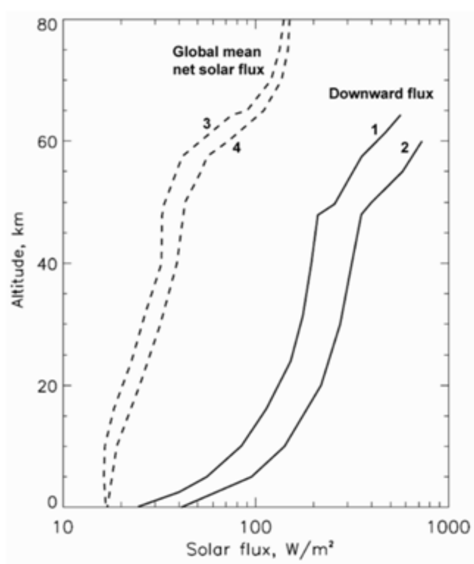
Based on past Venera missions 13 and 14 which included a successful soft landing, the vehicle should be deployed by the orbiter after the deceleration module enters the atmosphere at 50 degrees North (Dutta, Smith, Prabhu, Venkatapathy, 2012). The entry angle is chosen to eliminate ballistic effects and minimize the deceleration the instruments experience.

1.3.1 Power Sources

Solar panels. Of all the available energy sources, the Sun is one of the most powerful. Solar panels supply energy to power the sensors, active cooling, and telemetry. Solar panels are also useful to power spacecraft altitude control. Solar panels need to have a large surface area that can face the Sun as the spacecraft moves. A more exposed surface area means that the solar panels can convert more electricity from sunlight. Depending on how small the vehicle is, this limits the amount of energy that it can produce. At any one point during dayside travel, half of the solar panels will receive sunlight. Power sources must be small, reliable, strong for good performance and operational life in the harsh environment of outer space. Moreover, solar panels should be able to provide high power to the vehicle for at least several years.

Figure 4

Solar Flux vs Altitude (Titov, Bullock, Crisp, Taylor, & Zasova, 2007)



The figure above represents the vertical profiles of the downward solar flux (solid lines) and global mean net solar flux (dashed lines) in the Venus atmosphere.

1.3.2 System Descriptions

Altitude and Orbit Control (AOCS). This system controls movement of the spacecraft in the Z axis. For this specific mission it may be important for the spacecraft to move upward vertically to avoid collisions and extreme temperature and wind conditions. This will be done by inflating a balloon.

Electrical Power System (EPS). The EPS controls power acquisition, storage, and distribution. For this mission solar panels will be used to acquire the power.

Communications. The communications system is responsible for relaying data from the payload to the orbiter. Two transceivers and three antennae will be used to accomplish this.

Command and Data Handling. This subsystem will be responsible for collecting the data and allocating it to the memory. This system is also responsible for the safe delivery of data packets to the communications system so that no data is lost.

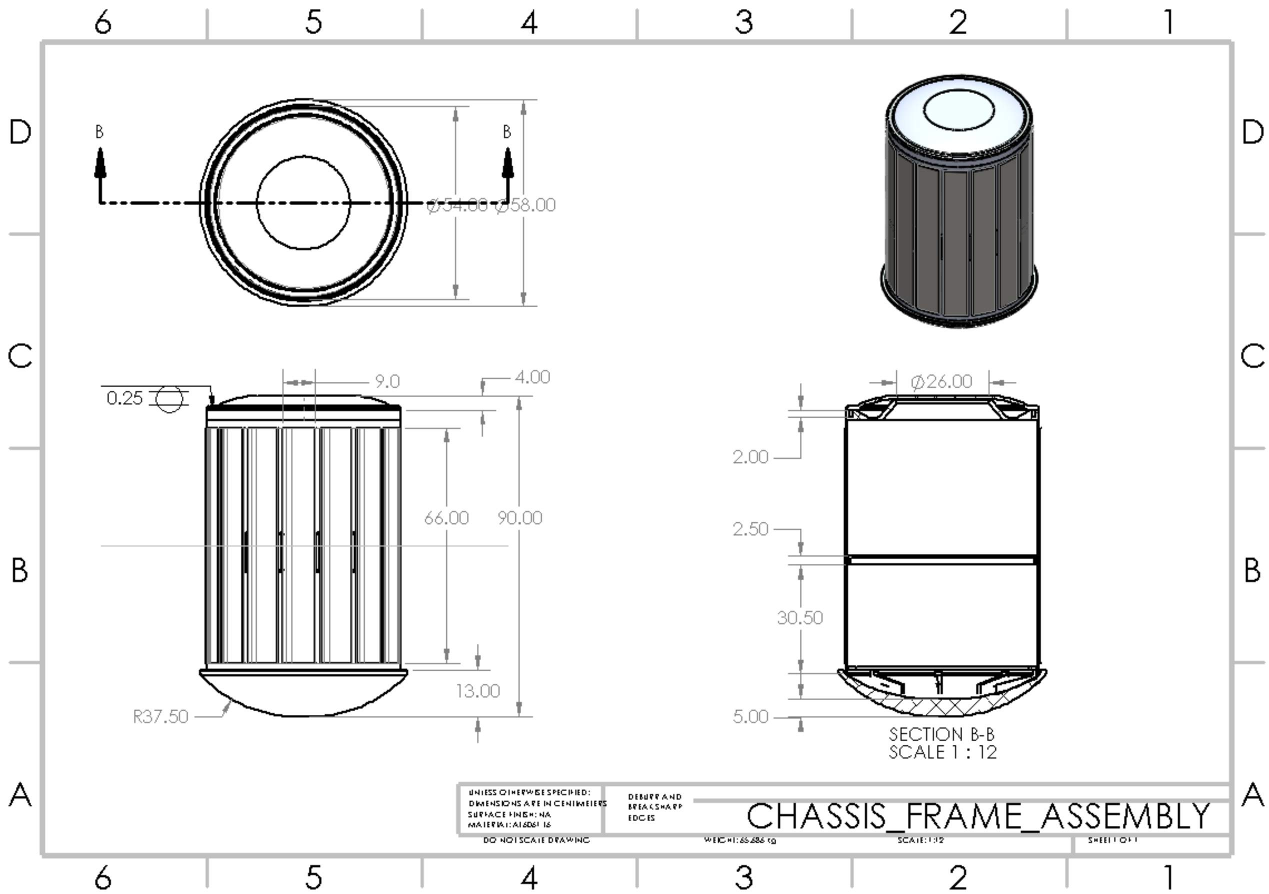
Payload. This system houses all science instruments. This includes sensors, spectrometers, temperature gauges, and more as well as an air filtration and cooling system.

Structures. This system is responsible for the structural portions of the spacecraft as well as the management of heat (disposable aeroshell and backshell).

1.3.3 Vehicle Design

Figure 5

Vehicle Design: Chassis Frame Assembly in centimeters



1.4 Payload and Science Instrumentation Summary

In order to study the chemical composition of Venus‘s atmosphere and detect the concentrations of the previously mentioned gases, certain methods and instruments are available. As this mission has certain budget and space limitations for the scientific payload, the final decision has considered budget, dimensions of said devices, and capabilities. Among the devices considered for the detection of said gasses is a mass spectrometer, such as the Cassini Spacecraft's Ion and Neutral Mass Spectrometer (INMS), which reports the identity of atoms or molecules that enter the instrument.

Another instrument that will be used on this mission is a polarimeter. Polarimeters are optical instruments that measure the direction and extent of the polarization of light reflected from their targets. They consist of telescopes fitted with a selection of polarized filters and optical detectors. Careful analysis of polarimeter data can suggest information about the composition and mechanical structure of the objects reflecting the light, such as various chemicals and aerosols in atmospheres, rings, and satellite surfaces, since they reflect light with different polarizations. A polarimeter’s function may be integrated with another instrument, such as a camera, or the Voyager photopolarimeter that combines functions with a photometer. In this case, it may function tangentially to a modified version of the Mars Color Imager.

The next instrument system is the Heterodyne Instrument for Planetary Wind and Composition (HIPWAC) as it enables astronomers to look in detail at the behavior and characteristics of specific molecules of gas in a planetary atmosphere. The instrument is precise enough to detect and unambiguously identify many of the most important gasses in planetary atmospheres, including but not limited to ethane, methane, carbon dioxide, ozone, ammonia, ethylene, and water vapor. Additionally, HIPWAC has proven to be able to measure the flow of winds on other planets, including Venus, Mars, and Saturn's moon Titan. Last but not least, this instrument provides data that can be used to determine how gas abundance, pressure, and temperature in a planetary atmosphere vary with altitude. Precise measurements of molecular abundances provide insight into photochemical processes in planetary atmospheres and guide the development of theoretical models of atmospheres.

In addition, a device similar to NASA's Mars Color Imager (MARCI) which produced a global weather map of Mars and detects variations in ozone, dust clouds, and CO_2 changes in the atmosphere using visible-light bandstand could be used to further study the atmosphere of Venus. The original MARCI was designed to take 7 pictures per orbit in 7 different wavelengths over a period of years to establish Martian seasons, however, the team has different goals in mind for the modified instrument. Specifically, because phosphine is not known to be produced by anything other than organic life on Earth, it is theorized that if phosphine is detected on Venus it could be from unknown geological activity or processes. This modified MARCI instrument would be able to visualize the atmosphere of Venus as well as compounds in the atmosphere like carbon dioxide, nitrogen, and sulfur dioxide by using various preselected wavelengths.

Aside from these previously detailed devices meant for chemical analyses, communication devices will be used to transmit recollected data back to Earth. A communication system similar to NASA's Mars Perseverance Rover, which uses a radio-based communications device to transmit binary radio signals using X- band antennas, could be implemented. Depending on how fast data needs to transmit, high and low gain antennas will be placed 90 degrees from each other to provide 360 degree coverage.

The overall payload will be enclosed within a spacious compartment in the bottom of the vehicle. This will allow the payload to be exposed and collect necessary information as the vehicle orbits around Venus. All of the components in the payload will be concealed during entry into the atmosphere of Venus in order to protect them. They will be revealed during orbit at 50-70 km in order to collect and record gas sensor readings.

Table 4

Comparison of Methods of Detection

Method	Advantages	Disadvantages
Direct Methods		
Optical spectroscopy: measurement of optical absorption, emission or scattering	Offers a direct and rapid, and often highly selective means, of measuring gas concentration with good sensitivity.	The gas must have a significant and distinct absorption, emission or scattering in a convenient region of the optical spectrum.
Mass spectrometry	Very accurate and highly selective means of detecting concentrations of gas, including isotope abundance, etc.	Slowly acting. Very bulky. Very expensive. Not easy to use on-line, as gas sampling necessary.
Gas chromatography	Very accurate and highly selective means of detecting concentration.	Very expensive Not easy to use on-line, as gas sampling necessary.
Indirect Methods		
Interaction with a chemical indicator	Can be highly specific, if suitable indicator. Can measure total exposure over time (dosimetry), if a non-reversible reaction is used. Can allow operation at a convenient wavelength, when gas has no convenient absorption in that spectral range.	Poisoning can occur, and is easily fouled. Sensitive to groups of chemicals, Eg. acid gases, rather than to a specific gas. May exhibit non-reversible behaviour, which, in many cases, may be undesirable. May need water vapour present, to act as a catalyst, if "dry" reaction is too slow.
Sensors involving interaction with the surface of a semiconductor , or ceramic layer, e.g.(CHEMFETS and other electrochemical sensors)	Low cost. Can measure total exposure over time, if a non-reversible reaction is used.	Poisoning can occur. May exhibit non-reversible behaviour, which may be undesirable. May consume analyte.
Catalytically induced combustion and measurement of the heat change (Pellistor gas sensors)	Low cost and practical means of detecting presence of flammable gases.	Poisoning can occur. Sensitive to groups of gases, rather than specific gas in a group. If other flammable gas is present, may give reading which is not predictably related to the lower explosive limit (LEL).

2. Evolution of Project

2.1. Evolution of Mission Experiment Plan

During the formulation of the mission to Venus, the plan changed slightly as the proposed mission progressed. Originally, the mission was to detect levels of phosphine on Venus. However, once research began, the mission expanded to over eight different biomarkers for life that are usually found on planets including Earth.

The mission's original objective included the potential to retrieve samples of phosphine gas to bring back to Earth for further testing. However, once mission planning began, it was determined that the payload would not be retrieved from Venus's atmosphere. The mission was then limited to testing Venus's atmosphere using the instruments aboard the payload.

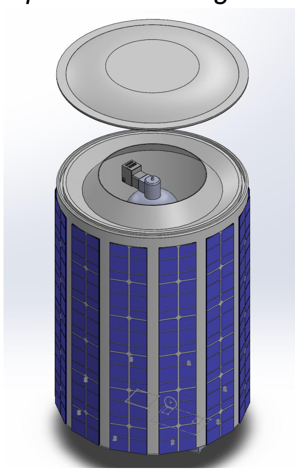
Additionally, as a method of maneuvering through Venus's atmosphere, a propulsion system was considered but later changed to a simple balloon design. The propulsion concept would enable the vehicle to orbit and map 70% of Venus's atmosphere in a controlled, spherical path from 50 degrees latitude North to 50 degrees latitude South. Due to design constraints, the team transitioned into the idea of utilizing a balloon to reach neutral buoyancy within Venus' atmosphere and to use the natural winds in the atmosphere to navigate it. This method requires significantly less fuel while still allowing the mission to cover the necessary terrain.

2.2. Evolution of Descent Maneuver and Vehicle Design

2.2.1. Chassis Evolution

Figure 6

Cylindrical Spacecraft Design



There were two original Venus spacecraft concept designs. One was rectangular, focusing on maximizing space and solar panel area, while the other design was cylindrical, focusing on being more aerodynamic. Ultimately the cylindrical design was selected because it had a sleek profile that would induce less twisting, it could more easily be protected with a heat shield, and it required less material resulting in a cheaper spacecraft.

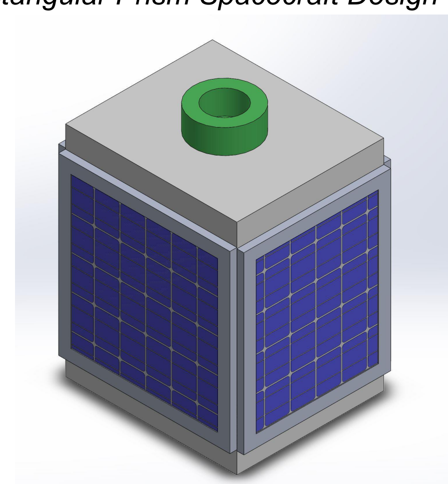
The sleek profile of the cylindrical design overall produces less pressure drag since the design is more streamlined as compared to the rectangular surfaces of the first design. This will reduce the twisting because less air pressure will build up on the edges of the spacecraft. Additionally the cylindrical profile is symmetric about any line that crosses its center. In other words, if a gust of wind were to come from a different angle the twisting response would be the same, unlike the rectangular design which could twist more wildly. This is better for the longevity of the balloon and sensors/components because the vehicle would be more stable in the hurricane force winds of the Venus atmosphere.

For the cylindrical design it is much easier to fit a heat shield to it versus the rectangular design. This is for a couple of reasons, firstly a heat shield is typically conical. This makes it easier to mate to the bottom of a cylinder versus a rectangle. Additionally less heat shield would be needed to fully protect the spacecraft, reducing cost and manufacturing time. At the end of descent the heat shield could easily be dropped, reducing the weight and increasing the range of the spacecraft.

Finally, the cylindrical design would require much less material, making it a cheaper alternative. The total surface area of the rectangular spacecraft is 31,800 cm^2 and the total surface area of the cylindrical spacecraft is 22,619.47 cm^2 meaning the cylindrical craft uses 28% less surface area which drives down the cost of raw material by a significant amount, if both designs use the same thickness of material throughout.

Figure 7

Rectangular Prism Spacecraft Design



2.2.2. Orbit

In the conceptualizing phase of the mission, the science mission objectives required a vehicle which could circumnavigate the globe in order to accurately map out chemical concentrations throughout the atmosphere at the 50-60 km range. Basic orbital mechanics calculations, included below, provided that a horizontal speed of 7,000 m/s would be required to maintain an altitude of 50-60 km assuming no lift. After analyzing the system requirements and constraints, the team realized that an orbiting speed of 7,000 m/s would not be possible due to limitations of propellant, extreme air drag on Venus, and the size of the vehicle.

$$v = \sqrt{\frac{2\mu}{r} - \frac{\mu}{a}} = 7.27867\ km/s$$

$z = altitude,\ z_{min} = 50km,\ z_{max} = 70km$ $a = semi - major\ axis = 6111.8\ km$

$r = radius = 6051.8km$ $v = velocity$

$\mu = standard\ gravitational\ parameter = 3.24$

A simpler design was chosen which would allow the vehicle to circumnavigate while being pushed by the high winds on Venus. In exchange for the inability to propel the vehicle and payload, the vehicle design focused on durability, reliability, and stability, i.e., remain in the atmosphere and support experimentation for as long as possible, minimize the likelihood of system failures, and support experimentation in relatively stable conditions.

2.2.3. Submarine Hatch vs. Frangible Nuts

During the drafting phase of the vehicle design, one of the issues that the team faced was designing the vehicle to be airtight until the proper moment for heat and air composition control. Originally, the vehicle utilized a submarine hatch-like mechanism to release the balloon after it reached a certain level of Venus atmosphere. However, this method was determined to be wasteful in materials and budget, and also is not ideal in regards to aerodynamic properties. Submarine hatches are meant to be secure, airtight, and reliable since they are designed to be frequently used. However, for the proposed mission, the hatch would only be released once and would then stay open on one end of the vehicle, which would move the overall center of mass and center of pressure of the vehicle away from the center.

The second idea was to use frangible nuts, which have been commonly used in previous NASA space missions. The overall idea behind frangible nuts is that they are explosively-splittable, and break apart during the appropriate time and release. However, frangible nuts are known to produce debris and high levels of vibration, potentially making the vehicle unstable and introducing unnecessary failure modes.

After researching more about frangible nuts, another option for the parachute deployment system was revealed. Frangible joints work similarly to frangible nuts, but instead of having the pyrotechnic aspects on the nuts, it is instead on the joints. Research indicated that frangible joint parachute deployment methods are more reliable than frangible nuts. Specifically, frangible joints are known to cause less debris and vibration, making them a more suitable option. Because of this, the team agreed that frangible joints would be the best option for the vehicle and the base design of the vehicle was created around this mechanism.

As shown in Figure 7 below, before the detonation, there will be no space between the top cover and the top of the main vehicle body (represented by the yellow line). The red box is where the linear explosive charge will be placed. After it is activated, the force from the explosion will break the top cover of the chassis away from the main body. The part circled in green is the only place where the top cover and the main vehicle body will be welded together, only breaking apart after the explosive charge detonates. After detonation, there is a small chance that some debris will propel towards the center of the vehicle and interfere with the ejection of the parachute and balloon. To mitigate the chances, the top of the main vehicle is angled to decrease the chances of the debris affecting the release of the balloon, as shown in orange, preventing the debris from entering the opening of the top of the vehicle.

Figure 8

Chassis Section View of Top Cover

2.2.4. Solar Panel Design Changes

Solar panels reduce the electricity usage from grids and absorb large amounts of intense solar energy. Photovoltaic power systems have been used in the past for robotics science and human exploration missions. However, high Venus temperatures and radiation pose a challenge to solar cell efficiency. According to research, the European Space Agency is able to exploit a wider range of solar radiation if the solar cells are separated by an aluminum strip that helps to reject heat. For example, Figure 8 displays a schematic with a solar panel for the mission showing how the power source works.

One of the initial designs for the vehicle included the use of two solar panels in total. However, the design was changed to having four solar panels instead, for stability and efficiency purposes, as the four panels adapt best to the shape of the vehicle and battery/power performance. Another change made to the solar panels was the reduction of power supplied by the Power Distribution Unit (PDU), which went down from 900 W to 300 W in maximum power capability. The overall size of the solar panels was reduced from 3 m^2 to 0.9504 m^2, which led to having a final and total count of 192 triple-junction GaAs cells (12 cells in each panel).

Figure 9

Solar Panel & Power Schematic

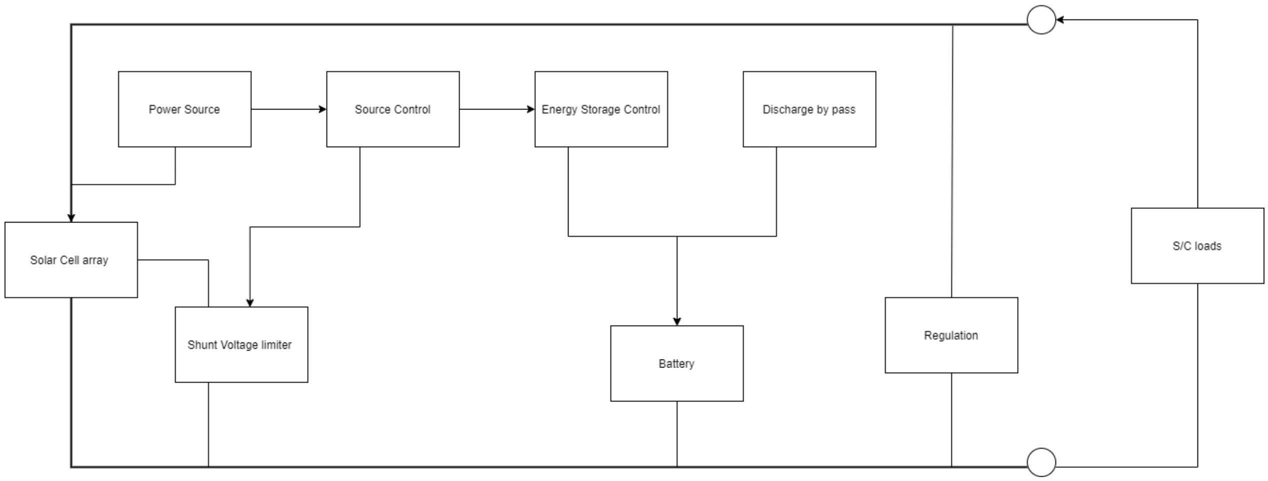
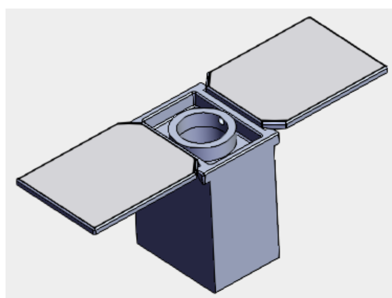


Figure 10a

Solar Panel Design with Wings

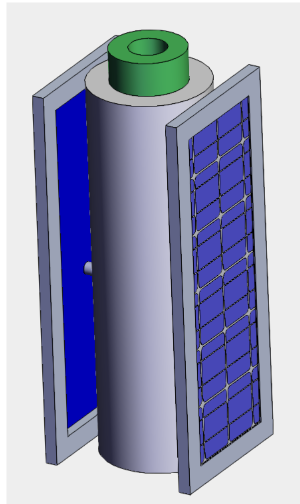


At minimum, the vehicle must have a way of providing power to the scientific instruments in the payload section of the mission aircraft. Initially, two retractable wings were considered, providing ~1.12 m^2 of solar panel surface area with a mechanism to extend the solar panels at the target altitude. This preliminary design became unappealing because extending two solar panel wings on both sides of the vehicle, each almost a meter long, would result in a large moment around the center of the body. With winds as high as 100 m/s, any opportunity that the vehicle received to spin would be detrimental to the suspension system of cables used to hold the vehicle below the balloon. Realizing that the sides of the vehicle were left empty throughout the design process, an alternative design rose: solar-panel siding.

The design pictured in Figure 9b features two solar panels which would be stationary in their positions throughout the duration of the mission. While not the final design, this concept put an emphasis on decreasing the amount of joints on which the vehicle must rely on to provide power to the payload components. This also decreases the spinning effect, but does not minimize it. Still, this concept provides the same 1.12 m^2 surface area.

Figure 10b

Solar Panel Design with Siding



At the altitude of 50-60 km, light flux is almost equivalent from the sides and from the top, especially due to the layers of clouds above and below the vehicle.

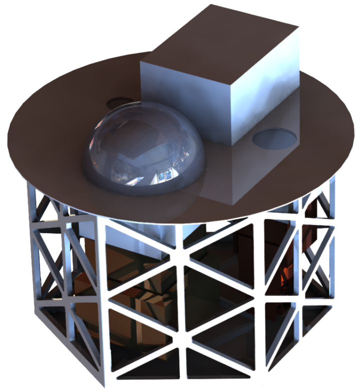
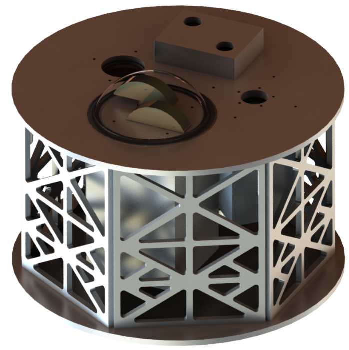
A step above this design is the third and final: wrapping solar cells around the entire vehicle (Figure 5). This final design decreases the surface area to 0.9504 m^2 but allows for maximum interior space available by minimizing moving parts, and distributes solar cell weight equally across the surface of the vehicle.

2.3. Evolution of Payload and Science Instrumentation

2.3.1. Payload structure
The payload platform onto which the scientific instruments reside was initially exposed to the elements throughout the duration of the mission and descent maneuver. This is problematic, however. because high surface heat flux during descent maneuver (upwards of 120 W/m^2) could damage the various glass openings and the airway into the spectrometer. A heat shield was deemed necessary and added into the final design (described in Section 3.2.1). In addition, the science instrument platform was pushed into the vehicle by 3 cm from its end to make space for the heat shield and to provide better side protection from dust or other particles which may erode or obstruct the view of the glass openings. To avoid conflicts with the heat shield components and to reduce the overall height of the design, the glass MARCI opening and spectrometer cooling chamber were fitted to the instruments. Lastly, the frame and instrument casings were redesigned to offer better structural support to the entire vehicle, minimize deformation, and fit within a smaller diameter (24 cm versus 27 previously without the heat shield).

Figure 11

Payload Before and After

2.3.2. Science Instruments
While science lab instruments are readily available as off-the-shelf components, scientific instruments which fit on satellites and are specialized to perform and transmit specific analysis in a non-user-friendly manner are not widely available. Most scientific instruments used in space missions are also the most recent technological developments, so they do not exist commercially or do not share the same public applications. At the same time, recently developed instruments can be risky investments and require additional resources for extraneous testing on Earth before they can be flown. Therefore, the team sought historically used instruments used on CubeSat missions that could be improved for application on Venus instead - these instruments fit the size and function requirements.

Initially, the team planned on using commercial Fisher Scientific polarimeters. These polarimeters however included unnecessary features (like displays, integrated storage, etc.). The casings were also made to be ergonomic rather than compact. Many searches later, the HARP (Hyper-Angular Rainbow Polarimeter) polarimeter was found to better suit the mission needs. This small polarimeter has remarkable resolution, can be easily calibrated by rotating the lens, is the size and weight of a handheld camera, and has a minimum lifespan of 7 months.

The array of scientific instruments on-board also first included both an Ion Neutral Mass Spectrometer (INMS) and a Gas Chromatography/Mass Spectrometer (GC/MS). The GC/MS was later eliminated because both the INMS and GC/MS accomplish the same objective of measuring concentrations of chemicals but through different methods. However, the GC/MS instrument would require the heating up of the sample to the point of separation of gases and the use of a carrier gas to transport the samples to the space for analysis. On the other hand, the INMS relies on light to test samples at a wide range of ambient temperatures.

3. Descent Maneuver and Vehicle Design

3.1 Selection, Design, and Verification

3.1.1 System Overview
In its stowed configuration, the vehicle is an aluminum cylinder with a heat shield and backshell at 60 cm diameter and 90 cm in height. The vehicle carries the payload, supporting systems and consumables, along with a polyester and nylon parachute and superpressure helium balloon made of teflon cloth matrix used for descent and altitude control throughout the mission. A heat shield composed of a PICA aeroshell and extendable carbon fiber textile protects the vehicle and payload during entry burn. The heat shield, backshell, and parachute are jettisoned once

the vehicle reaches 60 km. The helium inflated balloon provides lift throughout the mission on Venus, maintaining altitudes between 50 and 55 km. The science instruments and data logger are housed in the bottom half of the vehicle. Each instrument is thermally insulated and enclosed, with glass protected or air filtered openings for data collection accessing the Venusian environment from the bottom of the vehicle. The bottom of the vehicle is only revealed after the heat shield detaches, so science operations begin at 60 km altitude.

Recent developments in technology and an emerging interest in exploring the Venusian atmosphere have enabled the development of similar designs in the last 5-10 years. The current design was carefully selected to accomplish feats like extended stay at 50-55 km altitude, a fast descent maneuver with a high ballistic coefficient, prolonged resistance to sulfuric acid, and operation during travel on the night side of Venus.

Figure 12a

Integrated Vehicle and Payload CAD Model

Figure 12b

Vehicle Descent Maneuver

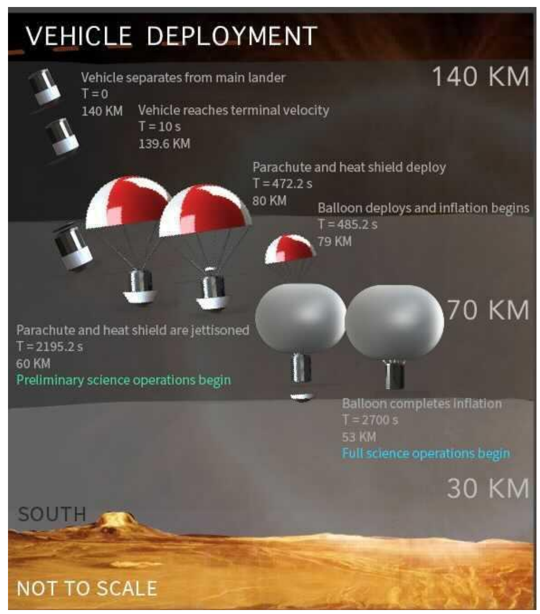


Table 5

Estimated Weight Breakdown by System

System	**Materials**	**Estimated Weight (kg)**
Vehicle Chassis	Aluminum 6061	52.7 kg
Payload	Titanium	55 kg
Altitude Control System	Teflon Cloth Matrix, Liquid Helium, Aluminum	47.8 kg
Temperature Protection System	Woven Carbon Fiber, Aluminum 6061, PICA	10 kg

3.1.2 Subsystem Overview

3.1.2.1 Vehicle Structure

3.1.2.1.1 Chassis

The vehicle chassis shall be able to withstand compressive wind loading, sulfuric acid corrosion, be airtight, and protect payload against radiation while also being lightweight to travel further. Being a strong and lightweight material will be prioritized here as these factors will immediately be tested upon deployment of the vehicle, while the effects of radiation and sulfuric acid will likely not have immediate effects. The vehicle chassis shall be made out of aluminum 6061 sheets. This material was selected based on a weighted rating comparison of three of the most common aerospace materials (that are lightweight and strong). To summarize, aluminum 6061 features the lowest density, high strength (both tensile and compressive), has a high hardness, and is widely available and cheaper than titanium. This material meets all of the criterion layed out for the chassis except for sulfuric acid corrosion protection and radiation protection. These issues can be mitigated by use of thermal coating discussed in section *3.1.2.1.4*.

Table 6

Properties of Aluminum 6061

Density	2.70 g/cc
Brinell Hardness	123
Tensile Strength (Yield)	455 MPa
Compressive Strength (Yield)	241 MPa

Figure 13

Section View of Vehicle Chassis

3.1.2.1.2 Altitude Control

For this mission, only lift control is required to ensure the spacecraft remains at the required 50-70 km altitude for as long as possible. Because of this, a teflon cloth matrix balloon and liquid helium tank will be used. This balloon envelope and gas were selected based on their previous success in the Soviet Union Venera missions, losing only a small percentage of helium and a few hundred meters of altitude throughout its flight. To extend the duration of the mission, two additional features will be implemented in altitude control. One will be adding a thin layer of aluminum reflective coating to reduce variation in internal temperature of the balloon. The reasoning behind this is that the atmospheric temperature will average 98 degrees Fahrenheit, quickly heat up the helium inside the balloon (helium is a good heat conductor), and result in variations of helium density (helium density going down and the net lifting force going up) which could cause the spacecraft to exit the target altitude. Additionally, a valve control system will be used to release helium from the liquid helium tank and deposit helium in a discharge helium tank to avoid overpressurizing. This system will autonomously add or release helium as needed to make small changes in the spacecraft's altitude.

Helium was chosen for use due to its large expansion ratio from liquid to gas (1:757), low reactivity, and low molecular weight. The temperature of liquid helium is self-regulating, so no additional temperature control system is required to maintain liquid helium in the liquid state in the dewar (tank). The liquid helium tank is directly connected to the balloon envelope via a one-way valve. A second balloon envelope one-way valve connects to a compressor and helium discharge tank (~10 x 20 cm). The helium discharge tank is connected to the one way valve of the liquid helium tank so that extra helium can be re-inserted into the balloon for use.

Figure 14

Altitude Control System Diagram

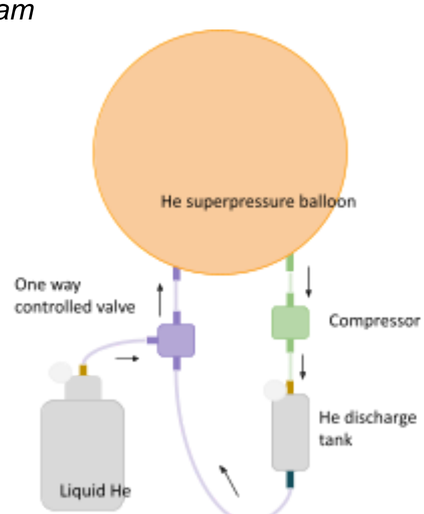


Table 7

Information on Balloon and Helium Tank

Balloon Material	Teflon Cloth Matrix
Balloon Diameter	15.68 m

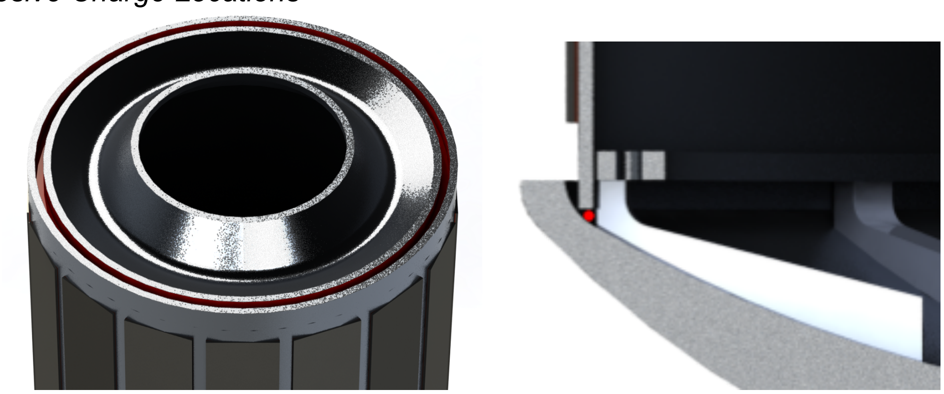
Helium Weight	37.8 kg LHe, 99%
Helium Tank Dimensions	40 cm x 30 cm
Helium Tank Material	Aluminum
Helium Tank Shield	Vapor Shielded
Helium Tank Weight	10 kg (empty)

3.1.2.1.3 Parachute / Heat Shield

The vehicle will have a given downward velocity of 35 meters per second and will be dropped perpendicular to the ground. In order to slow the descent and give more time for the balloon to inflate, a parachute will be deployed immediately after vehicle deployment. The parachute shall be circular with a diameter of 8.72 m and be made of polyester and nylon and use 8 kevlar ropes. The parachute material was selected because of its low density and excellent tensile strength. Additionally, this material was used on the descent parachute for the NASA Exploration Mars rover which had a successful descent and landing. Kevlar ropes were selected to attach the parachute to the chassis. Kevlar was chosen because of its excellent tensile strength and durability. The specific cords selected have a weight rating of 9341 N which is more than enough to sustain the weight of the chassis at 1552.25 N. Also the weight will be distributed across 8 separate kevlar cords meaning each cord will only see 194.03 N which is well below the weight rating. The reason so many cords are used is as a redundancy such that if any one of the cords fails the vehicle will remain in aerodynamic equilibrium.

Figure 15

Linear Explosive Charge Locations



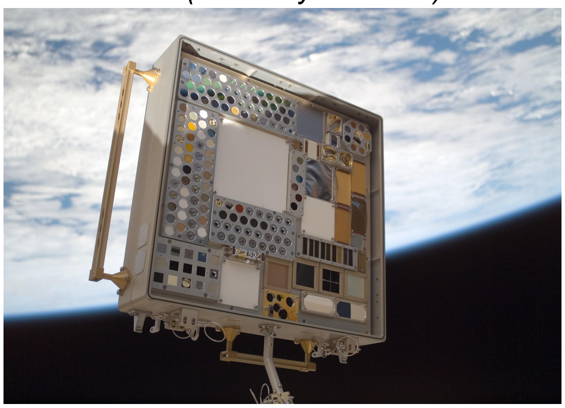
When the vehicle reaches the appropriate height of Venus' atmosphere, an electric signal will be sent to the linear explosive charge. A small explosion will occur between the inner linings of the vehicle (highlighted in red in the image) and will use enough force to detach the top cover from the vehicle and launch it away. The parachute and balloon will then freely deploy in the top opening of the vehicle.

Once the balloon is inflated to 90% of its capacity (at ~60 km altitude) the heat shield will similarly be detached by an electric signal sent to a linear explosive charge and reveal the instruments for data collection to begin.

3.1.2.1.4 Thermal Control

Figure 16

AZ-93 Thermal Coating being tested on NASA MISSE (Courtesy of NASA)



A passive approach will be taken for thermal control of the vehicle as environmental temperatures will not exceed 86 degrees Fahrenheit. Additionally, sensitive payload instruments will have further protection as they will get their own layer of insulation so there is no need for active and advanced thermal protection. The coating selected for this mission is the AZ-93 white thermal control inorganic coating. This was selected because it has been thoroughly tested by NASA and has been used on spacecraft such as the ISS and the MISSE. Additionally, this coating was selected for its superior thermal properties including a 0.91 $\pm\ 0.02$thermal emittance and 0.15 $\pm\ 0.02$ thermal absorptivity. This will result in great amounts of thermal radiation heat transfer being reflected away and keeping the internal components within operating temperature range.

In order to provide protection during entry and descent, a heat shield composed of a PICA tiled nose cone and 3D woven carbon-fiber textile mechanically expanded to 20° away from the vehicle chassis to further prevent heating up of the solar panels, antennae, and interior of the vehicle (Cassell et al., 2018). PICA (phenolic impregnated carbon ablator) material is a low density, low strength, ablative material that erodes during entry, absorbing and shedding the heat away in its mass. Its density is 0.27 g/cm (Huang, 2017).

3.1.2.2 Power

The vehicle's power is regulated by the Power Control Unit (PCU) which will provide a +20V supply for the entire vehicle and the payload units. The electrical power of the vehicle is provided by four solar-array wings composed of 192 triple-junction GaAs cells. The 192 triple-junction GaAs cells (12 cells in each panel) interlaced with aluminum strips to minimize heating were chosen as they are more suitable to handle Venus's hot and extreme atmospheric temperatures. There are 12 solar panels to provide stability and more power supply to the vehicle with a total area of 0.9504 m^2. Each solar panel has a mass of 2.2 kg (8.8 kg for all 12 solar panels in total), and the power/energy is stored in three 24-Ah lithium-ion batteries which are powered by the solar panels and used to power the vehicle when the solar panels are not facing the sun.

Figure 17

Solar Panel Layout

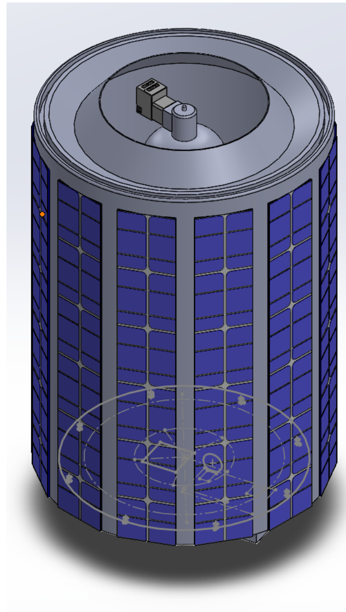


Table 8

Power Usage and Generation Information

Power Generation	12 solar panels (30% efficiency)
Power Storage	3 Li-Ion batteries (24 Ah)
Power Conditioning Unit (PCU)	+20 V (±1%) power bus
Power Distribution Unit (PDU)	300 W maximum power capability
Heater Distribution Unit (HDU)	5 HDUs

Solar Cells	192 triple-junction GaAs cells
Total Area	0.9504 m^2
Total Weight	8.8 kg

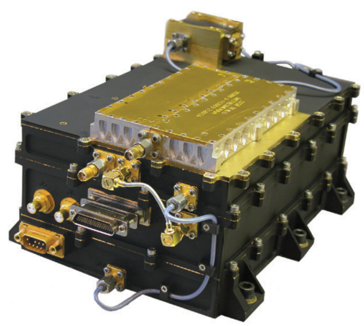
System	Power	Operating Voltage
MARCI	5 W	20 VDC
Spectrometer	1.8 W	20 VDC
Polarimeter	10 W	20 VDC
HIPWAC	15 W	20 VDC
Sensors, Data Logger	10 W	5-20 VDC

Transceiver	60 W	22-36 VDC
Valve controllers	50 W	20 VDC
Cooling	75 W	5-20 VDC

3.1.2.3 Communication

Figure 18

Transceiver



The spacecraft delivers the vehicle and payload to Venus from transfer orbit and then is inserted into orbit around Venus. The orbiter performs data relay from the descent vehicle and payload to Earth.

The most reliable method for long-distance communication is the use of UHF radio frequency bands. A high-frequency band allows for long-distance communications without the refraction caused by the ionosphere. Another benefit of the UHF band is the ability to transmit more data due to its high frequency.

Because of this, the transceiver that will be used is a modified version of the C/TT-510 Electra-Lite Transceiver that will be more suited for the Venus atmosphere. This transceiver was used in the Mars Perseverance Rover mission and has been proven many times how capable it is in long-distance missions and the various features it has. Specifically, the transceiver will be set to full-duplex operation in order to allow simultaneous transmit and receive function to use to its full capabilities. The transmitter will be set to receive frequency on 450MHz and the transmit frequency on 405MHz. This is the highest frequency the transmitter can use and will be the least likely to refract and cause interference.

This transceiver has the capability to transmit and receive 8, 32, 128, and 256 kbps. The scientific instruments altogether require at minimum 125 kbps of data to be simultaneously transmitted. Therefore, this transceiver has the capacity to handle all of the necessary data plus information about the payload and vehicle operations. Over the duration of the mission, an estimated 230,000 terabytes of data will be shared.

There will be 2 different types of antennas connected to the two transceivers, a high-gain antenna, and low-gain antenna. A second transceiver is needed to act as a backup in case the primary transceiver fails. A demultiplexer software will automatically switch to the backup if the primary transceiver happens to fail. The antennas are microstrip patch antennas acting at frequencies of 400MHz. This was chosen due to its compact form factor. Custom microstrip patches will be manufactured and will be placed 90° from one to the other, allowing a wide range of receiving signals.

The high-gain antenna will primarily send and receive information to the orbiter. Due to how narrow the signal the antenna emits, it is more susceptible to signal loss. However, it is capable of high rates of data transmission and must be towards the direction of the orbitor.

The low-gain antenna will serve as a means of emergency communication. With its wider range and lower rate of data transmission, it is capable of sending and receiving commands if the high-gain antenna is out of reach.

3.1.2.4 Data Handling

To handle data, the various pieces of equipment are available based on silicon-on-insulator technology toward high-temperature SOI. These parts are available from Honeywell. Handling data aspects involve programming so that the information is gathered and input into a data sheet. Programming will also allow the team to draw connections to different aspects of the data later on using graphs and charts.

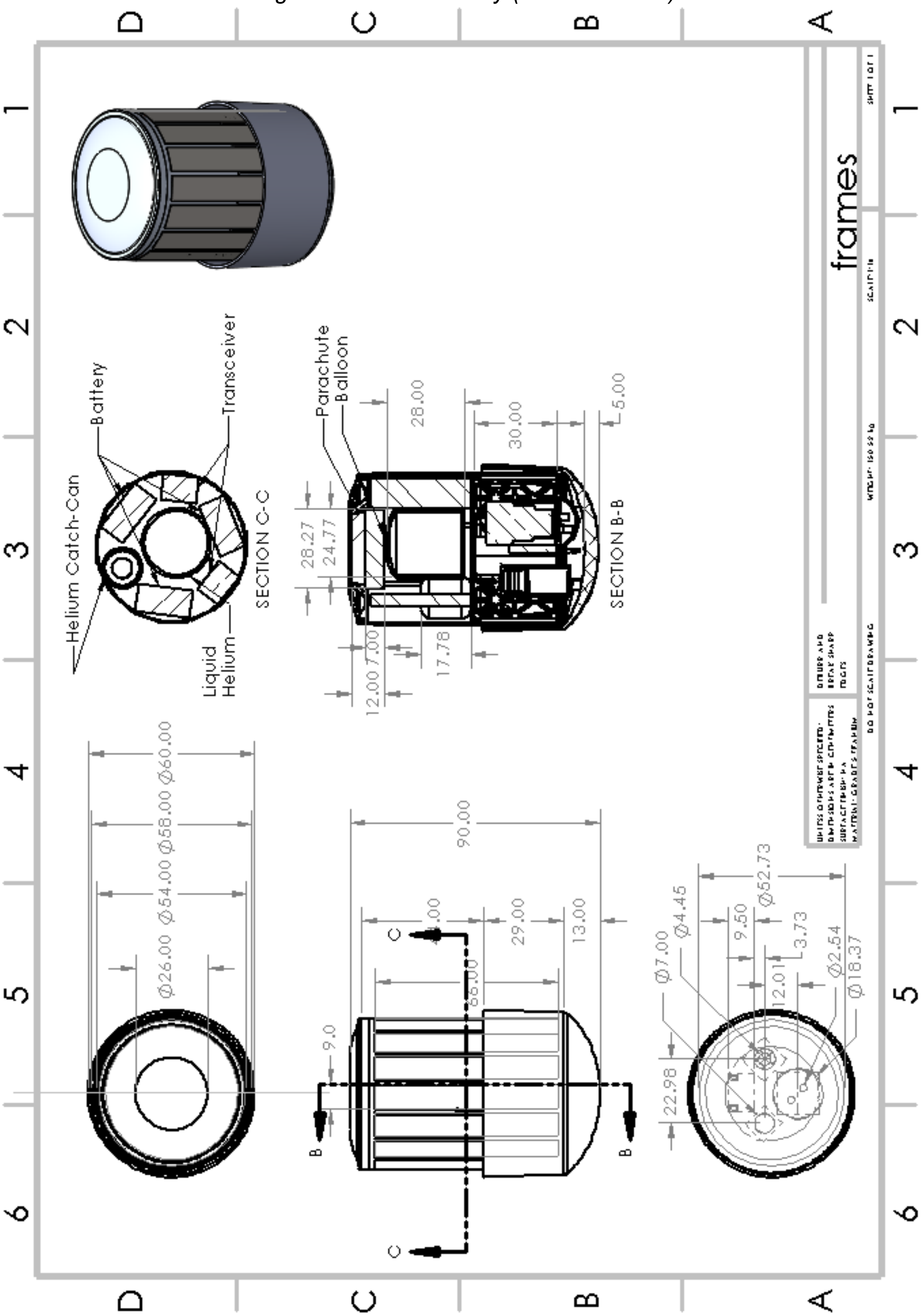
The components that will be brought to Venus must be operational at 300°C for extended times to collect the requested data. To be successful, the team must have customized capabilities for the electronics. For example, several electronic components will need to have high-temperature design services. It has been demonstrated that a differential Amplifier IC output can function for 5000 hours at 500°C. This indicates that the inverting amplifier IC output can function well compared to other high-temperature electronics.

The sensor that will be used is a six-channel handheld rechargeable temperature data logger. Also, thermocouple wires or heating wires and cables will be used in the payload design. Due to the magnitude of data collected, it will be nearly impossible to manually sort and handle data, so machine learning will be employed for processing. Furthermore, collecting image data helps out toward the research aspect of the payload design since the team must deal with Venus's harsh environment, which tends toward pressure of 90 bar, and has sulfuric acid particles in the cloud deck.

3.1.3 Dimensioned CAD Drawings of Entire Assembly

Figure 19

Dimensioned CAD Drawings of Entire Assembly (in centimeters)

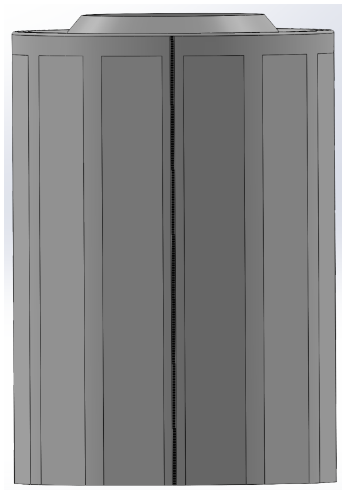


3.1.4 Manufacturing and Integration Plans

3.1.4.1 Manufacturing: Vehicle

Figure 20

Weld Seam of Vehicle Chassis



The vehicle chassis will use stir friction welding, which is commonly used to construct NASA spacecraft. Specifically, it uses a rotating tool pin that uses friction and applied pressure to merge two metals together, making it as if it is one piece of metal with minimal changes to properties or characteristics. Aluminum 6061 sheets shall be rolled into the appropriate cylindrical shape then be stir friction welded at the end to ensure a strong seal. It is estimated the time to finish stir welding the whole vehicle would be about 6 hours, with 2 hours of set up time in between the various manufacturing processes. Microscopic analysis of welds will be performed to ensure high structural integrity of the chassis is maintained.

After the linear explosive charge is set properly into the vehicle, the top cover will also be stir friction welded to the chassis but with significantly less force. This will allow the top cover to merge with the vehicle chassis while also make it easier for the explosive charges to blow it off during the appropriate timing.

The top of the chassis and cover will need to be CNC machined to ensure the tight tolerances are met. This can be done with help from the CAD drawing as well as appropriate manufacturing software. A manufacturing process plan will be developed and be inspected at each major point of production to ensure quality standards are met.

Lastly, the vehicle and the payload platform will be assembled together using a soft gasket material and bolt pattern, making the vehicle and payload assembly easily serviceable during integration, but reliably airtight throughout the mission.

3.1.4.2 Manufacturing: Power

The Power Control Unit converts the power from the solar wings and batteries inputs to a regulated main bus voltage of 20 V. The EPS (Electrical Power System) consists of three subsystems: power reactant storage and distribution, fuel cell power plants (electrical power generation), and the electrical power distribution and control. Before launch, the electrical power is provided by ground power supplies and the onboard fuel cell power plants. The fuel cell power plants generate heat and water as by-products of electrical power generation, are reusable and restartable, and are located under the payload.

The vehicle will use the CubeSat Electrical Power System (EPS) from Nano Avionics. The NanoAvionics EPS Maximum Power Point Tracking (MPPT) power conditioning and distribution unit (EPA) is compatible with the solar panels and does need any additional hardware or software configuration as it equipped with four MPPT converters, two of which can be voltage configured (3-18 V), with ten configurable output channels, allowing a high number of subsystems to be connected to the EPS and ensure reliable power distribution to be integrated. NanoAvionics EPS comes with ready-to-use onboard Lithium-Ion batteries with an integrated Battery Management System (BMS) which helps prolong mission lifetime and ensure appropriate operating conditions.

To manufacture spacecraft-grade solar cells, crystalline ingots will be grown and then sliced into wafer-thin discs, and metallic conductors will then be deposited onto each surface. Spacecraft solar panels are constructed of these cells trimmed into appropriate shapes and cemented onto a substrate, with protective glass covers. Manufactured solar cells will be purchased in trimmed sizes. Electrical connections are made in series-parallel to determine total output voltage. This procedure results in solar panels. The cement and the substrate must be thermally conductive, because in flight the cells absorb infrared energy and can reach high temperatures, though they are more efficient when kept to lower temperatures.

3.1.4.3 Manufacturing: Data Handling/Communication

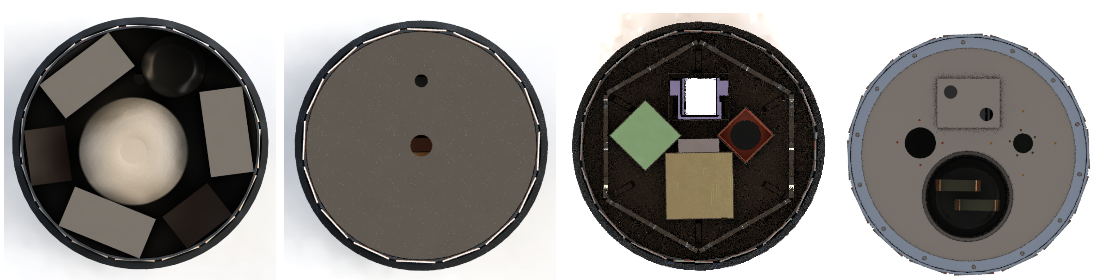
The sensors, transceivers, and antennae systems will be off-the-shelf components which will be integrated per manufacturer specifications onto the vehicle. These sensors and devices will undergo thorough testing prior to integration to ensure reliable data is collected.

3.1.4.4 Integration

The vehicle and payload chassis will be two separate vessels which will be filled with electronics and scientific instruments and lastly assembled together. The balloon and parachute are compactly folded and layered, ready for deployment as the top cover is separated from the vehicle. “Consumables” like the parachute and heat shield will be added lastly (and jettisoned later in flight). The modular design allows for ease of serviceability during testing.

Figure 21

Payload & Chassis Section Views by Level



The liquid helium tank is integrated into the rest of the design. Rather than being jettisoned, the liquid helium tank is kept throughout the entire flight as it will contain spare helium to account for any depletion of helium due to deficiencies in the materials (like the balloon) and for the purpose of altitude control.

The helium tank is tightly secured above the payload structure so that the payload structure can access its vent for the cooling system.

Figure 22

Payload Platform Science Instrument Layout

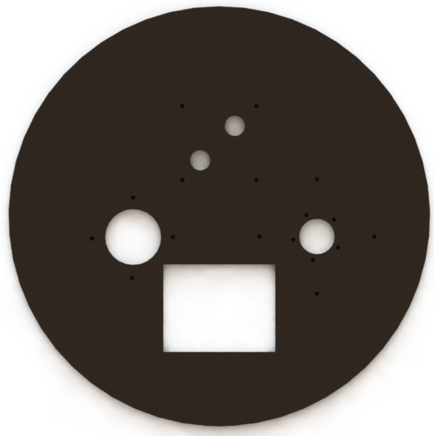


Table 9

Verification and Validation Plans

System	**Requirement**	**Verification**	**Validation**
Parachute	Parachute deploys within 0.7 seconds of top cover separation.	Difference in time from top cover separation and full parachute in a **wind tunnel** should be less than 0.7 seconds.	**Drop test** in pressures between 0 and 1 atm, temperatures 150 to 350 K, horizontal wind speeds between 0-200m/s.
Parachute	Material (including ropes) can support 1552.25 N load.	Perform **tension tests** to ensure that the ropes can withstand 1552.25 N of tension applied and that this does not degrade when temperatures, load position and orientation, or chemical coatings are varied.	**Drop test** in pressures between 0 and 1 atm, temperatures 0 to 350 K, and horizontal wind speeds between 0-200 m/s with a 159 kg mass attached. Place the material in **chemical baths** to ensure that the material has a high resistance to corrosive substances like sulfuric acid among other substances found in the atmosphere of Venus.
Parachute	Parachute effectively slows descent from 125 m/s to under 10 m/s in under 8 minutes.	**Optimize** the area of the parachute for drag based on Venus atmospheric density.	**Drop test** in pressures between 0 and 1 atm, temperatures 150 to 350 K, and horizontal wind speeds between 0-200 m/s with a 159 kg mass attached.
Vehicle Chassis	Vehicle chassis effectively offers	Test whether the chassis is waterproof/airtight under a	Place the material in **chemical baths** to ensure

	protection from the elements to components inside.	shower of moisture.	that the material has a high resistance to corrosive substances like sulfuric acid among other substances found in the atmosphere of Venus.
Vehicle Chassis	Separates top cover from vehicle chassis with no damage/minimal damage done to vehicle.	**Explosive Charge Test:** find the ideal explosive charge force that releases the top cover front the chassis without inducing noticeable damage to the vehicle.	**Explosive charge test** during a **drop test** in pressures between 0 and 1 atm, temperatures 150 to 350 K, and horizontal wind speeds between 0-200 m/s with a 159 kg mass attached.
Vehicle Chassis	Internal temperatures do not vary more than +/- 5 K.	**Thermal Cycle Test:** Vary temperatures from 86 degrees fahrenheit to as low as 60 degrees fahrenheit and measure internal temperature	Calculate and measure thermal flux during a **drop test** and determine whether the vehicle cover is a sufficient heat shield.
Balloon	Fully inflated within 30 minutes	**Balloon Verification Test:** Measure how long it takes to inflate a balloon.	Perform Balloon Verification test during a **Drop Test**.
Balloon	Internal temperatures do not vary more than +/- 10 K	**Thermal Cycle Test:** Vary temperatures from 86 degrees fahrenheit to as low as 60 degrees fahrenheit and measure internal temperature inside of the balloon.	**Heat chamber test:** place the inflated balloon in a 350 K heat chamber with radiation equivalent to that on Venus at an altitude of 60 km and measure internal temperature change over a period of time.

3.1.6 FMEA and Risk Mitigation

Function	Failure Mode(s)	Effect(s)	Severity	Cause(s)	Occurance	Design Controls (Prevention)	Design Controls (Detection)	Detection	RPN	Recommended Action(s)
Vehicle	Chassis Cover does not come off via explosives	Balloon system cannot launch	9	If the explosives do not provide enough force to launch the top chassis cover	3	Explosion releasing balloon system will be rigorously tested on Earth	Altimeter would indicate rapidly decreasing altitude	4	108	Perform testing and ensure proper selection of explosions
	Shrapnel caused from the top cover explosion damages components	Components damaged	7	Too much force from explosion	3	Explosion releasing balloon system will be rigorously tested on Earth	No design controls that can detect this cause, but it may be self evident	5	105	Perform testing and ensure proper selection of explosions
	Chassis is damaged by Venusian elements	Components damaged	7	Compressive wind loading or sulfuric acid corrosion	2	Chassis was designed around Venusian elements in order to withstand them	Instruments may detect harsher than nominal element conditions before chassis fails	5	70	1. Perform testing in simulated extreme environments 2. Increase max stress/strain tolerances
	Vehicle chassis weight is out of tolerance	Vehicle may travel out of altitude range	6	Improper/incorrect ground testing of mass	2	Redundant weight and net force testing will be done on	Altimeter would indicate altitude changes	2	24	
	Vehicle chassis is damaged at welds	Vehicle may not be airtight, components may be damaged	6	Improper welding	2	Stir friction welding will be performed to prevent any changes of metal property or characteristics	No design controls that can detect this cause, but it may be self evident	4	48	
Altitude Control	Balloon is overinflated	Exceeding the altitude requirement and potentially popping balloon	7	Too much helium is supplied to balloon	2	There will be valve control system	Altimeter detects altitude greater than 70 km	3	42	Alternate/backup entry and descent path
	Balloon is underinflated	Balloon is unable to maintain altitude requrement and will potentially crash	7	Not enough helium is supplied to balloon	2	There will be valve control system	Altimeter detects altitude lower than 50 km	3	42	Alternate/backup entry and descent path
	Section of balloon freezes and ruptures	Vehicle will crash	9	Liquid helium comes into contact with balloon	4	There will be valve control system and ground testing to ensure this cannot happen	Altimeter would indicate rapidly decreasing altitude	5	180	Look into more design controls for this failure mode
Parachute/Descent	Parachute fails to deploy	Vehicle drops below the target altitude	8	Top cover does not correctly seperate	3	Earth testing for proper seperation parameters	Altimeter would indicate altitude changes	2	48	Alternate/backup entry and descent path
	Parachute deploys too early	Vehicle will not be on its intended path and can potentially crash	8	Top cover does not correctly seperate	4	Earth testing for proper seperation parameters	Altimeter would indicate altitude changes	2	64	Alternate/backup entry and descent path
	Parachute deploys too late	Vehicle will not be on its intended path and can potentially crash	8	Top cover does not correctly seperate	4	Earth testing for proper seperation parameters	Altimeter would indicate altitude changes	2	64	Alternate/backup entry and descent path
	Parachute is damaged upon release	Vehicle will not be on its intended path and can potentially crash	8	Parachute gets caught on vehicle body and possibly tears	3	Parachute material chosen to not tear and rigorous Earth tests will be performed	Altimeter would indicate altitude changes	2	48	
				Vehicles entry speed is too high and parachute/ropes cannot withstand stress/strain	4	Parachute material chosen to not tear and rigorous Earth tests will be performed, systems will be in place to ensure proper entry velocity	Altimeter would indicate altitude changes and velocity	2	64	
	Parachute gets tangled	Vehicle will not be on its intended path and can potentially crash	8	Parachute gets caught in rope and its own material and cannot properly deploy	3	Parachute will be stored properly and deployed meticulously to prevent this from happening and rigorous Earth tests will be performed	Altimeter would indicate altitude changes	2	48	
Thermal Control	Temperature of vehicle is too high	Damaged components and/or inaccurate readings	6	Total failure of thermal control system or unpedictable atmospheric condiditons	3	Thermal control system will be rigorously testing on Earth	Sensors would detect change in temperature	2	36	
	Temperature of vehicle is too low	Damaged components and/or inaccurate readings	6	Total failure of thermal control system or unpedictable atmospheric condiditons	2	Thermal control system will be rigorously testing on Earth	Sensors would detect change in temperature	2	24	
Power	Certain instruments draw too much power	Total power loss	9	Components are wired incorrectly or incorrect calculations	2	Rigorous ground power draw testing will be performed	No design controls that can detect this cause, but it may be self evident	4	72	Have backup systems in place
	Solar cells are unable to operate in extreme temperatures	Total power loss	9	Solar cells were insufficiently tested or incorrectly chosen	2	Rigorous functionality testing will be performed in simulated extreme conditions	No design controls that can detect this cause, but it may be self evident	4	72	Have backup systems in place
Communication	Loss of communication	Data is not sent/recieved	8	Damaged communication components	4	Communication components will be tested to ensure they can maintain function throughout several listed failure modes	No design controls	6	192	Have design controls in place to detect communication systems failure
	Communication is corrupted	Strong interference and signal refraction	5	Improper frequency selected	2	Will receive frequency on 450MHz and transmit frequency on 405MHz, highest frequency the transmitter can use and will be the least likely to refract and cause interference	Interferance would be easily detectable in communication	2	20	
	Wrong transmit and receive frequencies on devices	Strong interference or no connection at all	7	Improper frequency selected	2	Frequency must be set at 450MHz to receive and 405 MHz to trasmit	interferance would be easily detectable in communication	2	28	
Data Handling	Lost data when sending to Earth	Partial or complete loss of data	9	Weak connection between team and payload	4	Wireless six-channel handheld rechargeable temperature data logger.	Handheld data logger	3	108	
	Data becomes corrupted	Partial or complete loss of data	9	Weak connection between team and payload	4	Wireless six-channel handheld rechargeable temperature data logger.	Handheld data logger	3	108	
	Data takes longer than expected to reach Earth	Halting results and study	3	Weak connection between team and payload	4	Wireless six-channel handheld rechargeable temperature data logger.	Handheld data logger	3	36	

Descent Manuever and Vehicle Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Chassis cover does not come off	2	5	NEW	R	Would be a result of explosives not providing enough force	N/A
2	Chassis is damaged	2	4	NEW	M	Can be caused by Venusian elements or improper welding	N/A
3	Parachute fails to deploy as intended	2	5	NEW	R	Can deploy too early or late, or be damaged or tangle	N/A
4	Temperature of vehicle is incorrect	1	3	NEW	M	Temperatures too high or low can damage components	N/A
5	Balloon is not inflated the right amount	2	4	NEW	M	May be overinflated or underinflated	N/A
6	Vehicle experiences loss of communication with Earth	1	5	NEW	R	Data cannot be sent or recieved without communication	N/A
7	Extreme temperatures affect solar cells' ability to operate	1	5	NEW	W	results in total power loss	N/A
8	Readable data is not returned	2	5	NEW	R	Data may become corrupted or lost	N/A

Approach	Criticallity	LxC Trend	L = Likelyhood (1-5)
A - accept	HIGH	↓ - Decreasing (improving)	1 = not likely
M- mitigate	MED	↑ - increasing (worsening)	5 = extremly likely
W - watch	LOW	→ - unchanged	**C = Consequence (1-5)**
R - research		**NEW** - added this month	1 = low consequence
			5 = high consequence

LIKELIHOOD	1	2	3	4	5
5					
4					
3					
2				2,5	1,3,8
1			4		6,7
	CONSEQUENCES				

Criticallity	LxC Trend
HIGH	↓ - Decreasing (improving)
MED	↑ - increasing (worsening)
LOW	→ - unchanged
	NEW - added this month

3.1.7 Performance Characteristics and Predictions

3.1.7.1 Vehicle

The vehicle's primary function is to carry the payload for as long of a distance as possible. Excluding the balloon's contribution to that function the vehicle can also travel further distances by utilizing drag. Since the wind will be carrying the vehicle, the more drag the vehicle offers, the farther it can be carried. The below calculation shows this performance, using the drag equation and solving for the drag force. Then,the basic gliding range equation is used to solve for maximum range.

F_D: Drag Force

$\frac{\rho V^2}{2}$: Dynamic Pressure

C_D: Drag coefficient

A: Cross sectional area

$$F_D = \frac{\rho V^2}{2} * C_D * A$$

$$F_D = 0.4*70^2 * \frac{1}{2} * 0.65*0.9*0.6$$

$$F_D = 343.98 \text{ N}$$

Gliding Ratio: $\frac{R}{H} = \frac{L}{D}$

Range: $R = H*(\frac{L}{D})$

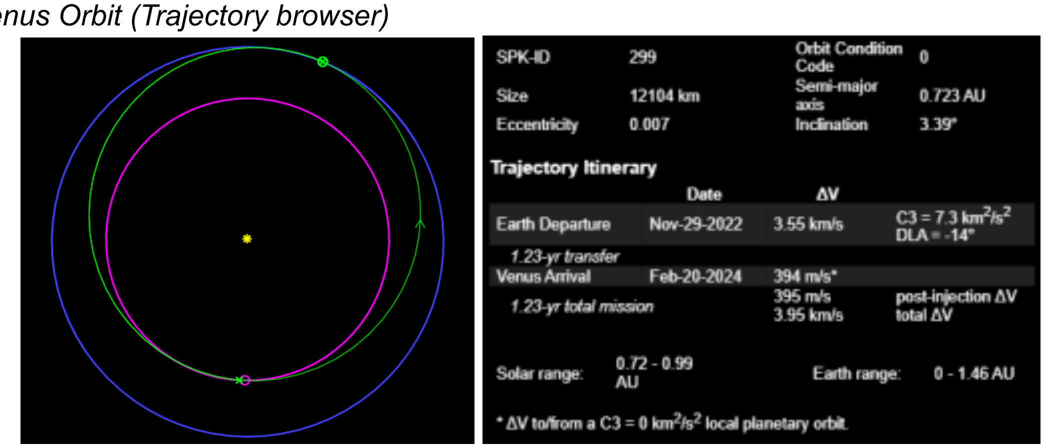
$R = (70e3 - 50e3)*(\frac{175*8.87}{343.98})$= 90.25 km (56.1 miles) before dipping below 50 km

3.1.7.2 Descent Maneuver and Inflation (EDI)

The mission vehicle must enter the atmosphere and go into "orbit" around Venus at an altitude of 50-70 km on February 20, 2024.

Figure 23

Entry to Venus Orbit (Trajectory browser)



The entry mass of the balloon, vehicle, and payload is 120 kg before adding system margins. Once 37.8 kg of liquid helium has been added as well as various system margins, the total launch mass will be 175 kg.

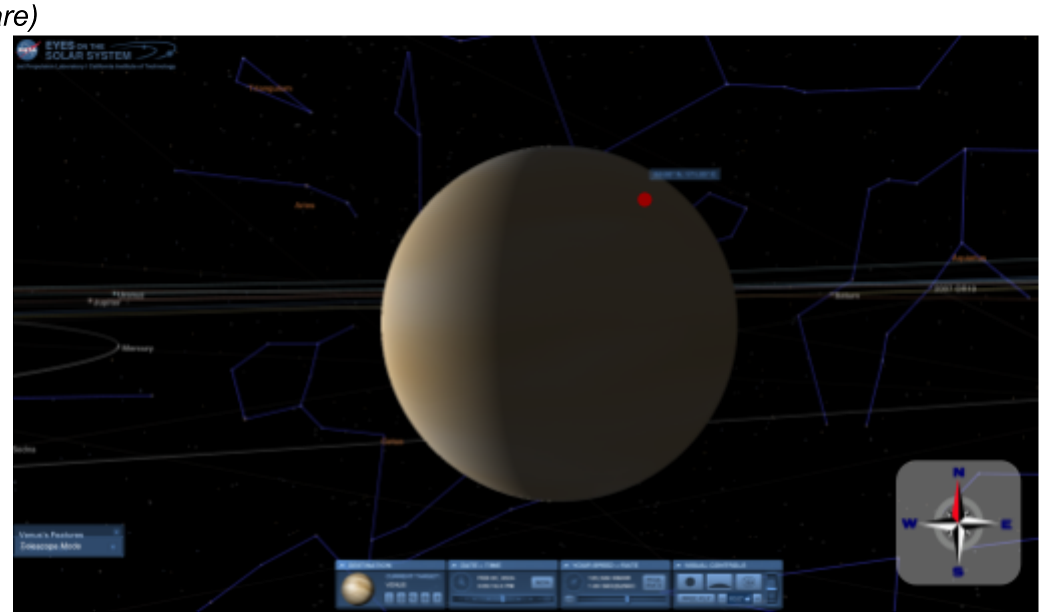
In order to lift a 175 kg (1552.25 N) load, the balloon, which will primarily inflate and reside in 0.53 atm atmospheric pressure at a 55-60 km elevation and among air density at 300 K of 0.4 kg/m^3, will need to be inflated with 37.8 kg of helium.

A suitable flight profile will be obtained by adjusting the pressure within the airtight balloon envelope. The entry of the vehicle and payload into the atmosphere begins at an altitude of 140 km with a downward velocity of 35 m/s and at an entry flight path angle of 28.9° in the direction of the wind.

The trajectory of the orbiter and the vehicle can be modeled by $r = r_p \frac{1+e}{(1+e)cos\theta} = \frac{a(1-e^2)}{(1+e)cos\theta}$ where $r_p = r_{periapsis} = 6,251.8\ km$, or the shortest distance between the orbiter and the center of Venus. With a periapsis of 200 km and apoapsis of 8,000 km (largest distance from the spacecraft and the center of Venus) above Venus's surface, the orbiter's eccentricity e will be given by $e = \frac{r_{apoapsis} - r_{periapsis}}{r_{apoapsis} + r_{periapsis}} = 0.38417$where $r_{periapsis} = 6,251.8\ km$ and $r_{apoapsis} = 14,051.8\ km$.The orbiter will deploy the vehicle at an altitude of 140 km, so $r_{entry} = 6,191.8\ km$. The semimajor axis $a = \frac{r_{apoapsis} + r_{periapsis}}{2} = C + r_{periapsis} = 10,151.8\ km$, so the distance between Venus's center and that of the transfer ellipse is 4,100 km. Let $r(\theta_e) = r_e$ be the value of theta (with respect to the x-axis) at which the vehicle reaches 140 km altitude above the surface. Using the original trajectory equation, $\theta_e = arccos(\frac{a}{r_e}(\frac{1-e^2}{e}) - \frac{1}{e}) = 88°$. Then, the flight path angle at entry interface γ_e is given by $\gamma_e = \frac{\pi}{2} - \theta_e + arctan[(\frac{ae}{r_e sin\theta_e} - \frac{1}{tan\theta_e})(1 - e^2)] = 28.9°$.

Figure 24

Venus Desired Landing Location on February 20, 2024 (generated using NASA's Eyes Software)



The vehicle is deployed vertically oriented with a center of gravity at the centroid maintained by the placement of the helium tank. 10 seconds after deployment, the vehicle reaches a terminal velocity of $v_t = \sqrt{\frac{2mg}{\rho A C_{drag}}} = \sqrt{\frac{2(175kg)(8.81\frac{m}{s^2})}{(0.4\frac{kg}{m^3})(\pi(0.3m)^2(1.75)}} = 125\frac{m}{s}$ (or a free fall drop of 800 m). The vehicle can travel at terminal velocity until 80 km.

At 80 km (after 7.87 minutes of travel at terminal velocity), a parachute will be released to both help slow down the vehicle's descent to 10 m/s and pull out the folded balloon envelope for easier inflation.

$$\frac{1}{2}C_{drag}rv^2A = W = 1552.25\,N$$

$$F_{drag} - F_{weight} = 0$$

$$C_{drag} = 1.75\ (typical)$$

$$r = 0.4\frac{kg}{m^3}\ (air\ density)$$

$$A = \pi(4.36m)^2\ (parachute\ area)$$

$$v_o = 125\frac{m}{s}$$

$$v = v_o + at,\ a = 8.81\frac{m}{s}$$

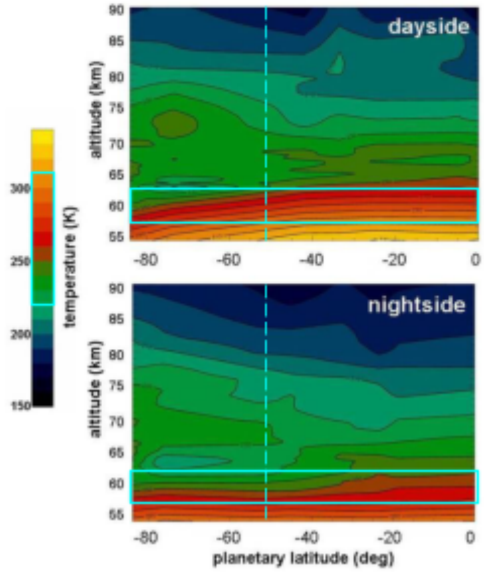
The vehicle will have slowed to 10 m/s after traveling for 13 seconds. During that time, it will have traveled an additional 900 m (to 79.1 km). Inflation can begin at 79 km (the haze layer, entering temperatures of 200 K and wind speeds below 100 m/s). In order to reach a neutral equilibrium at 60 km, the balloon shall inflate within 30 minutes (with valves releasing helium at 0.264 m^3/s). During the inflation phase, the parachute will be jettisoned at 60 km to lessen the load and the balloon and payload will be allowed to descend at a rate of 5 m/s until the 60 km mark is reached (plus, by the time time vehicle has reached 60 km, the balloon itself provides drag to act as a parachute). At this point, the valves to helium will only operate to stabilize the altitude between 55 and 60 km and scientific operations begin.

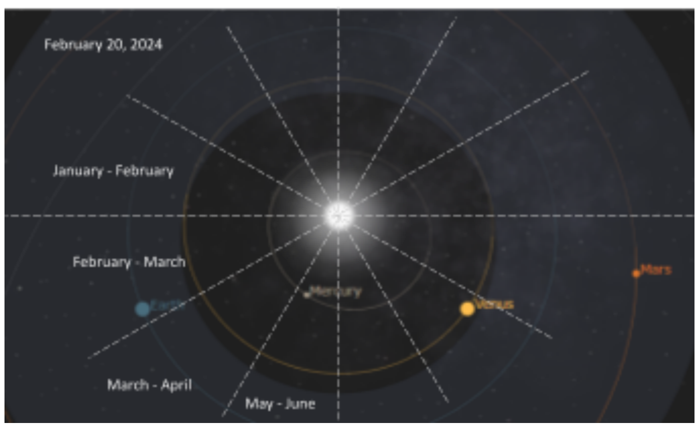
These estimations confirm a proportional relationship (x3) between the weight of the payload and the balloon size when compared with design estimations proposed by JPL in their development of a super durable balloon for Venus travel (18' diameter for a 45 kg payload) (Hall, J. L., & Cutts, J. A. 2013).

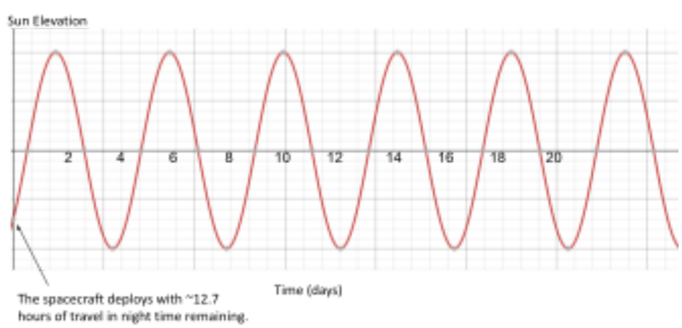
In total, the descent of the vehicle and payload through the atmosphere will take around 45 minutes. The vehicle and payload will experience atmospheric temperatures from 150 to 350 K during its descent, pressures from 0 atm to 1 atm, wind speeds between 60 and 100 m/s, and between 0 and 1.2 g's.

Figure 25

Dayside vs Nightside Entry (Bertaux, et al. 2007)







The entry takes place on the nightside (for safer balloon deployment) and in the target latitude range at the beginning of its mission (50-60 degrees N (local)). The balloon will not be visible from Earth when it begins descent, so it must be able to navigate autonomously using surrounding landmark tracking.

At night, the temperatures of Venus's atmosphere can become up to 50 K cooler. Since the liquid helium will be vaporized upon entrance into the balloon, latent heat will be released rapidly during the inflation phase. Cooler temperatures may also help mitigate any challenges that arise from this heating.

Moreover, the balloon, traveling with the wind (west to east), will be on the dayside every 2 Earth days for 2 Earth days before entering the nightside. Therefore, the balloon is planned to experience five cycles in 21 days (mapped as $sin(t - \frac{140}{180})$).

3.1.7.3 Data Handling

The system is proven that it can operate under the expected conditions using Silicon On an Insulator (SOI), which is operational to 300C. The team also needs to test out all electronic components to ensure they function in the extreme temperatures before launching the devices and have a cooling system that will handle the system to allow it to collect the data that it needs. The data handling system will need to be proven to be functional with no errors in the code before being sent to Venus. An analysis of failure modes will also be necessary in evaluating the relationship between software and hardware. Also, analyzing more deep-space optical communications to reinforce the performance of the system toward the vehicle that collects the data. The vehicle will also have pressure and temperature sensors that continuously collect data. For the vehicle the proposed Ex-Proof Spring Loaded RTD Sensor will be used, which is a spring-loaded temperature sensor assembly. This is used in electric motors and generators for continuous sensing of the temperature of the bearings. Approved for use in explosion-proof and flameproof applications.

3.1.8 Confidence and Maturity of Design

The last successful atmospheric missions were completed almost four decades ago. Since then, the enabling technology for long-term travel through Venus's atmosphere has developed and matured, with multiple NASA, JAXA, and ESA missions planned for launch in the future using these advanced technologies. The current design cherry-picks and integrates top ideas, materials, and technologies which have been proposed for use since the Vega missions. For example, the design utilizes superpressure balloons built with materials known to withstand exposure to corrosive chemicals and high temperatures. This design is currently under development at JPL. Thanks to a larger size allowance, the design also incorporates advanced altitude control and cooling systems to take more accurate measurements of chemicals in the atmosphere. The Earth-like temperatures in the atmosphere and a fairly small difference in gravity at the target altitude also make it possible for these systems to be thoroughly tested on Earth (especially through drop tests, chemical exposure tests, and wind tunnels). Equipped with a multitude of sensors and sophisticated scientific instruments to monitor both atmospheric conditions and the performance of these advanced technologies in space, the designs are carefully chosen to balance risk and usefulness for future missions to Venus.

3.2 Recovery/Redundancy System

3.2.1 Vehicle

When the vehicle reaches the Venus atmosphere, the explosive charge inside the vehicle will detonate and release the top cover. After that, the parachute will deploy, allowing the vehicle to slowly descend while the balloon is inflating. In the case that the parachute fails, the accelerometer will detect a high rate of acceleration which will signal the computer to increase the flow of helium to the balloon based on the rate of acceleration. Theoretically, this will allow the balloon to be fully inflated at the proper altitude.

In the possibility of the balloon sustaining damage, the pressure sensor inside the balloon can detect the pressure of the atmosphere which will adjust the amount of helium being released to the balloon. This will allow the vehicle to autonomously adjust how high it is flying so that it can follow the trajectory path. However, if that fails, commands can be sent from the NASA center to manually control how high the balloon is flying.

3.2.2 Power

The solar cells or photovoltaic cells, convert sunlight directly into electricity. These solar cells are equipped with rechargeable batteries that receive a charge from the common distribution circuit, called a main bus when the solar panels are in the sunlight, and discharge into the bus to maintain its voltage whenever the solar panels are not facing the sun rays from the sun. When the solar panels are not facing the solar rays, the vehicle will be powered by 3 Li-Ion batteries (24 Ah).

Virtually every electrical or electronic component on a spacecraft may be switched on or off via command. This is accomplished using solid-state or mechanical relays that connect or disconnect the component from the main bus. On some spacecraft, it is necessary to power off some set of components before switching others on in order to keep the electrical load within the limits of the supply.

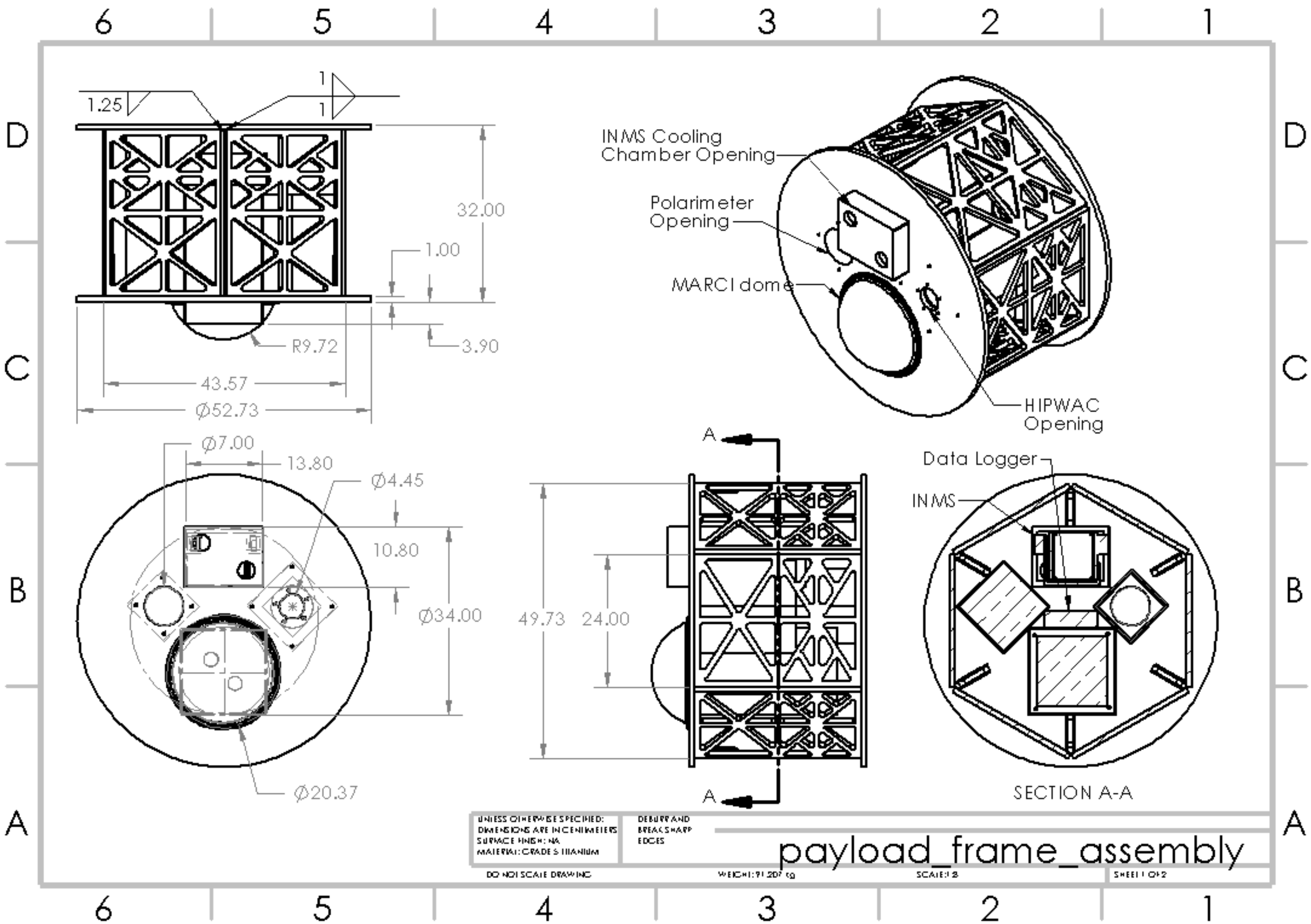
3.2.3 Data Handling and Communication

When communications fail, multiple autonomous procedures will be conducted. If the primary transceiver is detected to be faulty, the demultiplexer will automatically switch to the backup transceiver and test if everything is operational. However, if there is an issue with connectivity, the transceiver can be programmed to automatically change frequencies and attempt to reconnect to the NASA center. The low gain antenna will also attempt to try to receive and send signals. Until the low gain antenna detects a signal, the data gathered can also be stored temporarily or permanently in the vehicle until the communication system is operational.

3.3 Payload Integration

Figure 26

Payload Frame Assembly (in centimeters)


1.25
1
1
32.00
1.00
3.90
R9.72
43.57
Ø52.73
INMS Cooling
Chamber Opening
Polarimeter
Opening
MARCI dome
HIPWAC
Opening
Ø7.00
13.80
Ø4.45
10.80
Ø34.00
Ø20.37
A
A
49.73
24.00
Data Logger
INMS
SECTION A-A
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTIMETERS
SURFACE FINISH: NA
MATERIAL: GRADE 5 TITANIUM
DEBURR AND
BREAK SHARP
EDGES
payload_frame_assembly
DO NOT SCALE DRAWING
WEIGHT: 91.207 kg
SCALE: 1:8
SHEET 1 OF 2

4. Payload Design and Science Instrumentation

4.1 Selection, Design, and Verification

4.1.1 System Overview

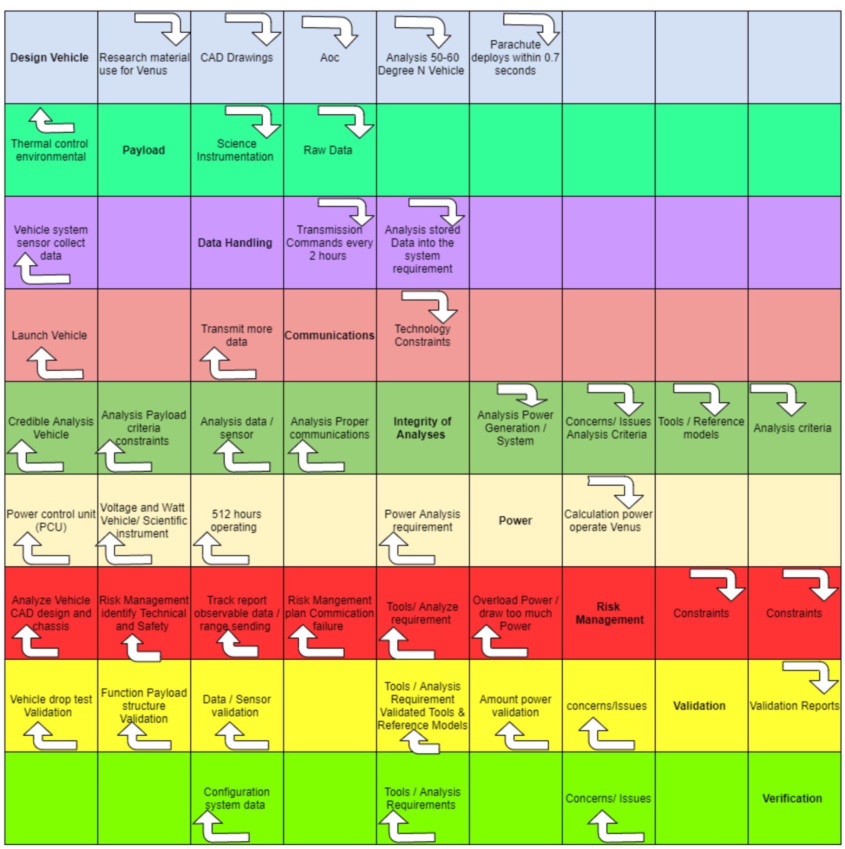
4.1.1.1 Payload

The vehicle photovoltaic system generates enough electricity to power all vehicle and payload operations. A power breakdown is included in *Section 3.1.2.2.* In summary, 300 W of power can be generated, with under 250 W required for full operation. The power system supports the operation of scientific instruments and additional sensors, altitude control system, thermal control system, and communication system. The scientific instruments and sensors each require 0.1-10W (estimated higher bound). Most of the power is dedicated to maintaining cool temperatures within the payload structure (75W) and appropriate pressures within the balloon for stable navigation (50W (actuators)).

Data collected from the scientific instruments and sensors throughout the vehicle and payload subsystems are held in a data logger as well as being transmitted back to the orbiter. Data from the sensors provides valuable feedback so that the vehicle can make appropriate adjustments (for example, release helium to drop in altitude or cycle more liquid helium to cool electronics to lower temperature).

Figure 27

N^2 Chart



4.1.2 Subsystem Overview

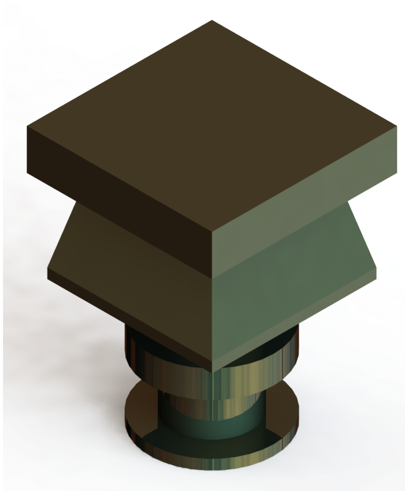
4.1.2.1 Payload

A previous mission to Venus has tested for phosphine gas among other compounds. The accuracy of the results are in question. The purpose of our mission is to collect this data in addition to other data and connect it to a GPS location on Venus, in addition to creating high-resolution images which will be used to ensure the accuracy of the collected results. This mission will provide data about where the collected concentrations of gases are located, including topographical images of the locations.

HIPWAC

Figure 28

Heterodyne Instrument for Planetary Wind and Composition



The Heterodyne Instrument for Planetary Wind and Composition (HIPWAC) enables astronomers to look in detail at the behavior and characteristics of specific molecules of gas in a planetary atmosphere. This is precise enough to detect and unambiguously identify many of the most important gasses in planetary atmospheres, including but not limited to ethane, methane, carbon dioxide, ozone, ammonia, ethylene, and water vapor. Additionally, HIPWAC has proven to be able to measure the flow of winds on other planets, including Venus, Mars, and Saturn's moon Titan. Lastly, this instrument provides data that can be used to determine how gas abundance, pressure, and temperature in a planetary atmosphere vary with altitude. Precise measurements of molecular abundances provide insight into photochemical processes in planetary atmospheres and guide the development of theoretical models of atmospheres.

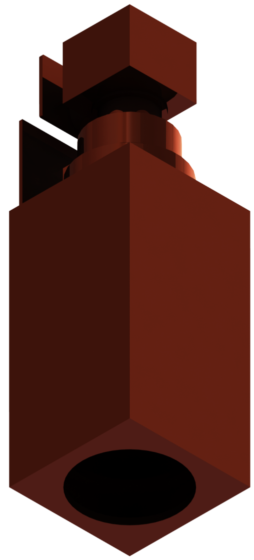
Polarimeter

Polarimeters are optical instruments that measure the direction and extent of the polarization of light reflected from their targets. Polarimeters consist of a telescope fitted with a selection of polarized filters and optical detectors. Careful analysis of polarimeter data can infer information about the composition and mechanical structure of the objects reflecting the light, such as various chemicals and aerosols in atmospheres, rings, and satellite surfaces, since they reflect light with different polarizations. A polarimeter's function may be integrated with another instrument, such as a camera, or the Voyager photopolarimeter that combines functions with a photometer.

The polarimeter, through detecting the polarization of light on Venus, would be used to gain a better understanding of the composition and mechanical structure of objects reflecting the light, including various chemicals and aerosols in Venus' atmosphere. This information would contribute to the current understanding of Venus's atmosphere by enabling research into its current weather and history through the data collected.

Figure 29

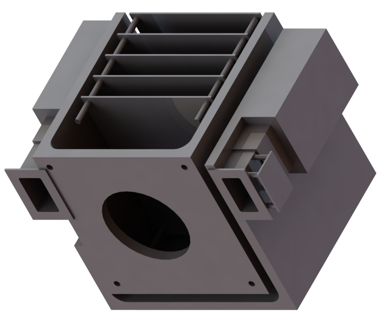
Polarimeter



INMS

Figure 30

Ion and Neutral Mass Spectrometer



In order to study the chemical composition of Venus's atmosphere and detect the concentrations of the previously mentioned gases, certain methods and instruments are available. As this mission has certain budget and space limitations for the scientific payload, the final decision is to be taken after great consideration regarding budget, dimensions of said devices and capabilities. Among the devices considered for the detection of said gasses is a mass spectrometer, such as the Cassini Spacecraft's Ion and Neutral Mass Spectrometer (INMS), which reported the species of atoms or molecules that enter the instrument.

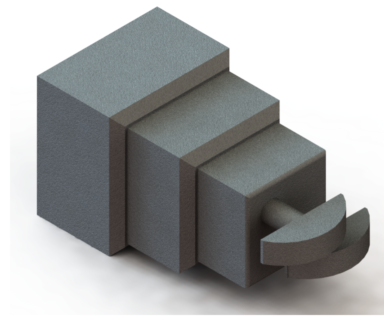
The usage of this device would allow the team to study, first-hand, the chemical makeup of the Venusian atmosphere. Instead of utilizing long-distance tools such as radio telescopes, Ii would grant us the opportunity to analyze physical samples from the atmosphere itself. The possible detection of phosphine through the usage of Mass spectrometry would provide further evidence to back previous discoveries. The ion and neutral mass spectrometer that is going to be used for this mission takes inspiration from the NSF's Exocube GSFC mini. It has exact dimensions in Length x Width x Height of 9 x 10 x 13 cm, a mass of 560 g, a nominal data rate of 13.7kbps, and a power usage of 1.8 W. In terms of main power supply, it has +3.3V, +/-5V, +12V options for internal LVPS cards with single +12V from main craft or external power source as well as a LSDV & SPI Serial data interface.

MARCI

In addition, a device similar to NASA's Mars Color Imager (MARCI) which produced a global weather map of Mars and detects variations in ozone, dust clouds, and CO2 changes in the atmosphere using visible-light bandstand could be used to further study the atmosphere of Venus. The original MARCI was designed to take 7 pictures per orbit in 7 different wavelengths over a period of time of years to establish Martian seasons, however, the team has different goals in mind for the modified instrument. Specifically, because phosphine is not known to be produced by anything other than organic life on Earth, it is theorized that if phosphine is detected on Venus it could be from unknown geological activity or processes. This modified MARCI instrument would be able to image the atmosphere of Venus as well as compounds in the atmosphere like carbon dioxide, nitrogen, and sulfur dioxide by using various wavelengths.

Figure 31

Mars Color Imager



The MARCI instrument will have a spatial resolution selectable from 0.6 mile (one kilometer) per pixel to 6 miles (10 kilometers) per pixel, a data interval/bit rate of 6.2 Gbits/day, and requires 5 watts. The instrument will have dimensions of 9.2 x 7.2 x 14.0 centimeters in L x W x H as well as a mass of 481 grams.

4.1.2.1.1 Payload Chassis

The payload structure houses the scientific instruments, ensuring that each instrument can take accurate measurements and remain in stable conditions throughout the entire mission. The payload structure accomplishes this by providing secure attachment methods for the four instruments onboard a platform and hexagonal, airtight, temperature, and pressure-controlled housing. It is made of Grade 5 titanium wrapped in polyamide and aluminum multilayer insulation film/fabric, and placed inside of a fitted, airtight Grade 5 titanium sheet container. Aluminum and titanium layers between the vehicle and the payload structure are sealed together using a bolt pattern with gasket material between.

Grade 5 titanium is used for its structural efficiency and low thermal expansion, as well as resistance to corrosion and non-magnetic property. The use of titanium for the interior structure also maximizes interior space available. The structure utilizes a truss pattern and hexagonal shape to prevent the displacement of instruments should the outside shell of the vehicle begin deforming.

Of the four instruments aboard, only the ion and neutral mass spectrometer require exposure to Venusian air. A filtration and temperature-controlled chamber are added to the spectrometer which supports a constant intake of air at 25 degrees Celsius and 0.5 atm and removes H_2SO_4, SO_2, and CO_2 from the samples of air. The remaining four instruments rely on a view of the Venusian atmosphere. Both the heterodyne and polarimeter instruments are provided with circular openings. The openings are made of two layers of aluminum silicate glass (outer, thermal pane) and fused silica glass (pressure pane) with a soft polyvinyl butyral middle layer that provides specific spacing. Meanwhile, the MARCI instrument requires a full 180-degree view, so its cameras are placed within a two-panel, transparent dome on one half the platform, with an unobstructed panoramic view. The glass openings are sealed to the external titanium platform using viton fluoroelastomer sealant, gasket material, and bolt patterns.

Figure 32

Payload Chassis

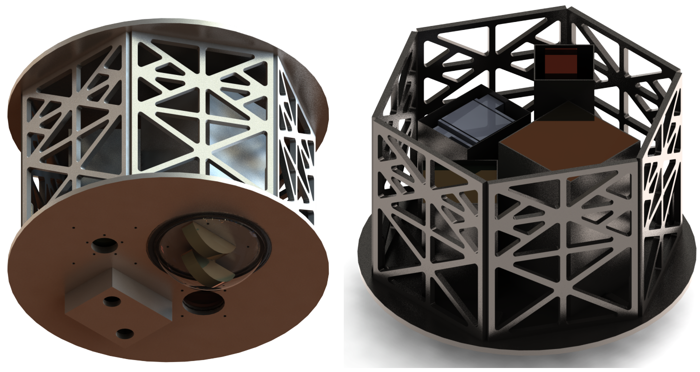


Table 10

Payload Chassis and Instruments Characteristics

Dimensions	44 x 40 cm
Weight (w/o instruments)	37.34 kg
Internal Temperature	25°C
Internal Pressure	0-1 atm

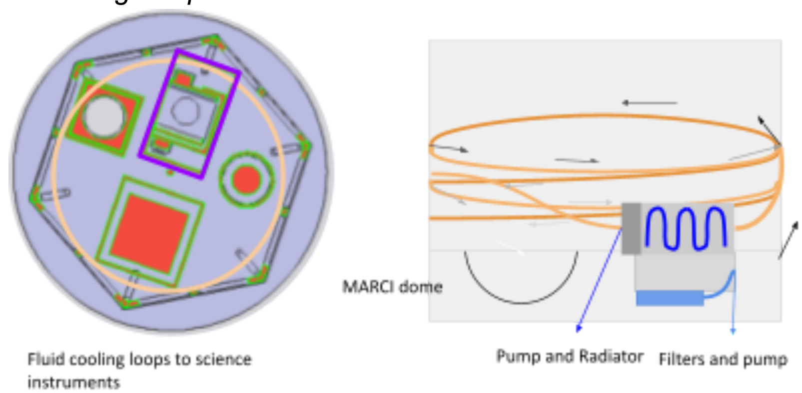
Instrument / System	**Mass**
MARCI	481 g
Spectrometer	560 g
HIPWAC	500 g
Polarimeter	1,700 g

4.1.2.1.2 Thermal Control

A photovoltaic thermal control system is used to maintain internal temperatures at 25 degrees Celsius while the vehicle enters and descends through the atmosphere and throughout its circumnavigation of Venus. Atmospheric temperatures can range from 0 to 360 K during a 2 minute free fall from 140 to 70 km. Ideally, this descent will last closer to one hour so that the spacecraft will not experience thermal shock.

Figure 33

Thermal Control Fluid Cooling Loops



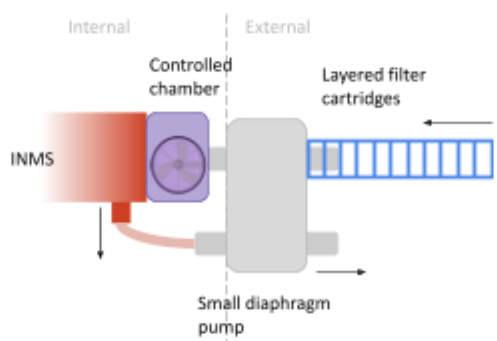
Fluid cooling loops are placed around the inside of the payload structure to keep the electronics cool. Heat dissipation units can be included to maximize cooling. The liquid used for cooling is to be decided, but one logical option is to pass liquid helium through the cooling system before adding it to the balloon.

While the electronics can safely operate in the 50-70 km range, the INMS requires for air intake at a constant temperature, so this instrument, highlighted in purple above, also requires a chamber with a small fan and parts of the fluid cooling loops to cool incoming air before allowing it to enter the spectrometer for testing.

4.1.2.1.3 Filter

Figure 34

Filter



Venusian air is sucked into a chamber in front of the INMS which removes H_2SO_4 through a series of consumable Ultrahigh molecular weight polyethylene (UPE) filter cartridges with pore sizes ranging from 0.05 to 4 microns. The cartridges are layered in front of the pump to provide full protection for 80 hours of testing, and decreased effectiveness after 80 hours.

UPE filers have superior performance when compared with commercially available PVDF or PTFE membranes thanks to reduced resistance to airflow and improved efficiency (Avramescu, Kamp, Burgt, Steenbakkers, & Wit, 2014).

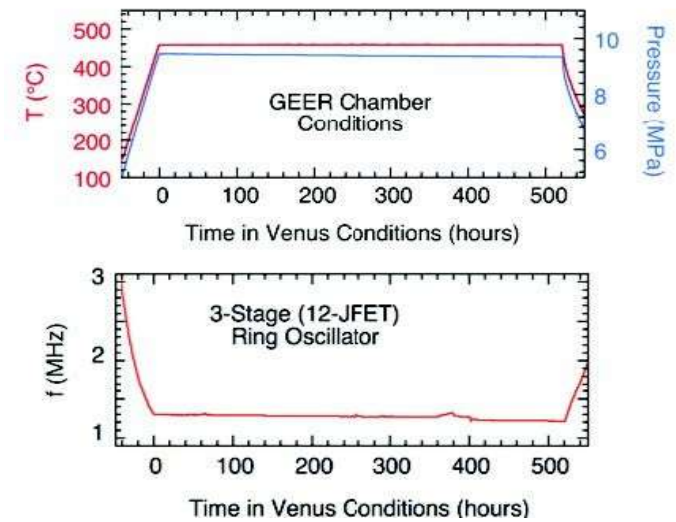
4.1.2.4 Data Handling

According to Venus Express (VEX) a European Space Agency (ESA) mission, was designed to perform a global investigation of the Venusian atmosphere and the plasma environment. NASA Glenn demonstrated electronics for longer Venus surface missions that were incredible; the circuits withstood the Venus surface temperature and atmospheric conditions for 521 hours – operating more than 100 times longer than previously demonstrated Venus mission electronics.

However, these are simply not capable of operating in the temperature and pressure conditions that exist on the surface of Venus and therefore required that they have protective casings and cooling systems. We need to use an expendable fluid cooling system. The fluid would evaporate in the structural shell, absorbing heat coming from the ambient environment, keeping the shell relatively cool compared to the ambient temperature. We need to structure the electronics and cooling system to last longer and collect all the necessary data.

Figure 35

Venus Conditions Over Time



4.1.3 Manufacturing Plan

Grade 5 titanium sheets are commercially available and can be cut to size. Instrument compartments are made of smaller titanium sections cut to size and welded together onto a platform. The openings from the payload platform will be purchased from an approved vendor. The chassis, or "shell," of the payload system can be manufactured in parallel to the manufacturing of the vehicle chassis.

In the meantime, limited COTS instrumentation exists for this mission, so most of the scientific instruments will be built by the design team using plans produced in a research setting by various institutions and for CubeSAT missions. The instruments will be reduced in size to a smaller scale based on off the shelf instruments. All of the instruments will be in a miniaturized version sized less than 1 cubic ft. The MARCI camera is the only instrument which will not require minor modification, but it will be reproduced by the design team using the design currently being used on the Mars Reconnaissance Orbiter. All of the instruments used in the payload have well documented manufacturing processes, which allows engineers on the team to assemble the instruments along with the assistance of hired professionals when necessary. The heterodyne, polarimeter, and spectrometer will be produced in house as well, with the possibility of outsourcing production of the spectrometer to the organization which initially created it in the compact state perfect for CubeSAT missions.

However, at this current stage it is difficult to foresee difficulties down the road with this process which may result in relying on contractors to produce the modified instruments. Selecting a collaboration between universities and well known NASA contractors to produce these instruments may be the best course of action if it proves to be an inefficient use of the engineers time on the team.

The production of all instruments should begin in parallel with the chassis. Due to the modular design, instruments can be integrated into their compartments at any point into the vehicle from the bottom of the payload structure and vehicle. The entire payload structure and scientific instruments will need to undergo extensive thermal, vibration, and chemical bath testing to verify their ability to perform in Venus conditions and identify the limits of operation.

4.1.4 Verification and Validation Plan Tables

Table 11

Payload Chassis Requirements

System	Requirement	Verification	Validation
Cooling	Maintain internal temperature of the spectrometer chamber at 25 degrees Celsius. Internal temperature of the payload chassis does not vary more than 1 degree Celsus per hour.	Effectively maintains internal temperature at 25 +/- 1 degree Celsius when placed in temperatures greater than 30 degrees Celsius for 36+ hours autonomously.	Internal temperature of the payload chassis does not vary more than 1 degree Celsius per hour while in 310 K surroundings with radiation equivalent to that on Venus in a 50-55 km altitude atmosphere for 36+ hours. Simultaneously **cycle air** at 310 K through the chamber.
Filtration	Filter 99% of sulfuric acid, carbon dioxide, and sulfur dioxide.	**Cycle air** with sulfuric acid (70-99 wt%), carbon dioxide, nitrogen, and sulfur dioxide through the layered filters and measure concentration in a vacuum.	Perform chemical exposure air cycles for 180+ hours to optimize filtration system for longer period of operation. Test for safe transmission of other substances (which *should not* be affected).
Chassis	Able to withstand compressive lateral loads of 100-120 kg.	Perform **load test** by placing masses on various areas on the top of the chassis.	Measure **forces** during **drop test** and inspect the chassis for damage or fractures after.
Chassis	Payload chassis is airtight and watertight.	Perform a **vacuum test** and measure pressure and humidity changes inside.	Test whether the sealants retain their integrity after prolonged exposure to corrosive substances in a **chemical bath**.

Table 12

Science Instruments Requirements

System	Requirement	Verification	Validation
HIPWAC	The instrument must be able to use wavelengths to collect data. Lasers and ultraviolet wavelength light will be used to analyze data to determine emission spectra from the data.	The instrument must be calibrated to an accuracy of within 0.1 nm.	The instrument will be calibrated to a 0.0 nm baseline and all readings compared to the calibration samples to determine accuracy.
Polarimeter	Must be able to measure the direction and extent of the polarization of light reflected from particles in Venus' atmosphere	Must be calibrated and verified using crystalline quartz oriented and cut in such a way that it matches the optical rotation of a sugar solution	It should be able to accurately measure the direction and extent of polarization of light according to expected values
INMS	Must be fully capable of detecting surrounding ions and neutrals with 99% accuracy; should be able to detect presence and concentrations of gasses it is exposed to.	Must be placed within a **controlled environment** with constant airflow containing dissolved gasses such as oxygen, nitrogen and phosphine at varying concentrations.	It should be able to accurately detect the presence and concentrations of the gasses present in the controlled environment with 99% accuracy.
MARCI	The camera must be able to distinguish between subtle differences in wavelengths of light as the camera moves across the atmosphere.	The camera will use a target frame with items of known wavelength colors as well as filters of known wavelength colors to calibrate color images in post processing.	Scientists in post processing should be able to get wavelength accurate images both in the visible color spectrum and in ultraviolet.

4.1.5 FMEA and Risk Mitigation

Function / System	Failure Mode(s)	Effect(s)	Severity	Cause(s)	Occurance	Design Controls (Prevention)	Design Controls (Detection)	Detection	RPN	Recommended Action(s)
Payload Structure	External face platform starts deforming	Would lead to seals breaking, so a change in temperature/pressure	8	Temperature or pressure beyond spec	6	titanium I beams for structural support	MARCI instrument data shows a "titled"view	5	240	thicken the platform and add support beams
	Break in the frame	If no collapse, no detection. If collapse, there would be physical consequence (like crushed and malfunctioning components)	8	Temperature or pressure beyond spec	3	multiple trusses and sectioned off modules	in the extreme cases, electronics may begin malfunctioning if physical damage occurs	7	168	thicken the truss members and add structural support to components above the frame which utilize the vehicle walls
	Air leak in the frame	Unexpected temperature/pressure increase/decrease	5	Punctures or loosened air locks	8	welded or gasket and bolt patterned mating of different materials; sealants; corrosive resitant materials inside of the vehicle regardless	unexpected pressure and temperature changes	5	200	over-engineer the cooling system to be able to support added heat
	Instruments get rattled around tm due to vibration, etc.	Might affect pre-calibrated instruments or cause failure of components	5	Violent atmosphere entry or launch forces that are out of spec	8	secure mounting points, separation of instruments into fitted compartments	misaligned / miscalibrated or malfunctioning instrumets	5	200	add more mounting points and add physical obstacles for the instruments to move out of their compartments
	Corrosion eats away at the external platform	Seals might start breaking / loosening and leading to change in temperature/pressure	3	Chemical and/or physical corrosion	8	corrosive resistant material and coating	air leaks (unexpected pressure and temperature chanes)	5	120	over-engineer the cooling system to be able to support added heat
	Corrosion eats away the glass protection	Inconsistent results / calibration will be off (the light coming in will be different on brand new versus worn and torn glass bc layer thickness, etc. will have changed)	3	Chemical and/or physical corrosion	8	corrosive resistant material and coating	air leaks (unexpected pressure and temperature chanes); damage to the instrument's ability to sense data accuately	7	168	thicken glass, add coating
	Glass peep holes shatter/fracutre/break	Change in temp/pressure, malfunctioning instruments	5	Heat expansion/contraction, or physical collision	3	soft material between panels to absorb shock	air leaks (unexpected pressure and temperature chanes); damage to the instrument's ability to sense data accuately	7	105	thicken glass, add coating
	Dust/scratches on the surface of the peep holes	Instrument readings don't change due to obstruction or change in a way that doesn't match with literature review; on camera, can be seen	5	Physical collisions from abrasive particulate matter in the Venus atmosphere	6	surfaces exposed to the wind, so dust cannot be stationary	instrument disability / inaccurate measurements	3	90	abrasion resistant and polarized (?) coating
	Seals break (between platform and vehicle)	Unexpected temperature/pressure increase/decrease	5	Environmental corrosion or unexpected physical tear from incorrect maneuver	3	vehicle flange supports and overlaps with platform to prevent fallout	unexpected pressure and temperature changes	5	75	over-engineer the cooling system to be able to support added heat; also, add connecting points between payload structure and vehicle for added support
	Seals break (between openings and platform)	Unexpected temperature/pressure increase/decrease	5	Environmental corrosion or unexpected physical tear from incorrect maneuver	6	instruments are in their own individual compartments and corrosive resistant materials are used for internal componenets too	unexpected pressure and temperature changes	5	150	over-engineer the cooling system to be able to support added heat and seal the instrument compartments, too
	Seals break (inside, between connectors on the top cover)	Unexpected temperature/pressure increase/decrease	5	Excessive vibration or collision with internal components, caused jointly from other failures	3	insulated vehicle so this should not cause extreme differences in performance	unexpected pressure and temperature changes	5	75	over-engineer the cooling system to be able to support added heat; also, secure vehicle components to vehicle walls (not payload structure);
	Fasteners for instruments become unsecured (e.g. screws)	This failure would lead to instruments moving inside the payload structure, out of their orignial places. This would cause failure of components or miscalibrations	7	Not tightening fasteners to required spec; unexpected failure of fastener components	4	sandwich methods between welded metal parts (their compartments)	instument disability/inaccurate measurements	5	140	Create fitted openings which prevent instruments from sliding
Polarimeter	Angle of rotation miscalibrated due to abnormal concentration of the sample	Data collected with be miscalibrated and inaccurate	6	abnormal concentration of the sample	5	Rigourous Earth testing and sufficient redundancies	No design controls in place, but failure mode may be self evident in data	4	120	
	Wavelength of light passing through the sample is incorrect	Data collected with be miscalibrated and inaccurate	6	Insufficient Earth testing and selection	3	Rigourous Earth testing and sufficient redundancies	No design controls in place, but failure mode may be self evident in data	3	54	
	Temperature of the sample is incorrect	Polarimeter data will not be accurate	6	Insufficient Earth testing and selection	4	Rigourous Earth testing and sufficient redundancies	No design controls in place, but failure mode may be self evident in data	4	96	
	Length of the sample cell is incorrect	Data collected with be miscalibrated and inaccurate	6	Insufficient Earth testing and selection	3	Rigourous Earth testing and sufficient redundancies	No design controls in place, but failure mode may be self evident in data	3	54	(input by the user into most automatic polarimeters to ensure better accuracy)
	Filling conditions are incorrect	Polarimeter data will not be accurate	6	bubbles, temperature and concentration gradients are out of nominal	4	Rigourous Earth testing and sufficient redundancies	No design controls in place, but failure mode may be self evident in data	3	72	
MARCI	Failure to power up	Would lead to not being able to map gas location	9	Electrical transmission line failure; battery failure	2	Redundant backup power system and power start	No images taken	7	126	Redundant power supply design with instrument-specific backup batteries and independent transmission cables
	Damage to lens	Not being able to take accurate images	9	Fracture due to physical impact or heat changes that are out of spec	7	Rigourous Earth testing and sufficient redundancies and part selection	Blurry or distorted images	2	126	
	Loss of communication	Images would not be transfered back to earth	9	Failure in communications transmission line to the communications module	3	Testing and verification of communication systems will take place	Earth not receiving images	7	189	
	issues with focusing	Inaccurate images	6	Failure in focusing motor on lens, or controls line is damanged, or incorrect calibration of autofocusing software	3	Focusing parameters and troubleshooting will be optimized on Earth	Blurry or distorted images	3	54	
	Debris on lens	Inaccurate images	6	Atmospheric particles sticking onto lens. Failure or wearing away of lens coating	4	Payload will be designed in a fashion to prevent this outcome	Blurry or distorted images	3	72	
Spectrometer	Failure to properly calibrate device before use	Would lead to inaccurate results, rendering the mission useless	10	Human error in preparing mission, or misconfigured calibration tools	3	Calibration testing, verification, and validation will take place before launch	Inaccurate values of control group sample	6	180	
	Lack of power to device	Would inhibit device to power on, no data would be collected	10	Electrical transmission line failure; battery failure	4	Backup power system and electronics redundancies will be in place	No response or information from spectrometer	6	240	
	Inability to filter out sulfuric acid	Tamper with the concentration detection of other chemicals, leading to inaccurate results	5	Sulfic acid filter damaged, or sulfiric acid is too concentrated	5	Filters will be thoroughly tested and selected	No detection of other chemicals except sulfuric acid	2	50	
	Sulfuric acid corrodes instrument end	Tamper with the concentration detection of other chemicals, leading to inaccurate results	8	Damaged hardware due to high concentration of sulfuric acid	5	Instruments will be in the airtight vehicle	No detection of other chemicals except sulfuric acid	3	120	
	Obscured view	Would lead to altered data that is collected. The spectrometer would not be serving its purpose of collecting atmospheric spectra	9	Debris or failure of protection coating	7	Payload will be designed to prevent this failure mode	No detection of other chemicals except sulfuric acid	2	126	
HIPWEC	Failure to properly calibrate instrument prior to use	Inaccurate results	5	Human error in preparing mission, or misconfigured calibration tools	3	Calibration testing, verification, and validation will take place before launch	Instrument is not calibrating to expected value	4	60	
	Power failure	Unable to use instrument	10	Electrical transmission line failure; battery failure	4	Backup power system and electronics redundancies will be in place	Intrument is not able to communicate or record	6	240	
	Failure of communication devices	Unable to relay data back to earth	9	Failure in communications transmission line to the communications module	5	Testing and verification of communication systems will take place	No feedback from instruments	7	315	
	Damage to the sensor reading the data	Inaccurate results	5	Physical or heat damage to sensor, caused by failure of protection system (seals, shielding)	5	Payload will be designed to prevent this failure mode	Sensor is reading at inaccurate or unexpected results	5	125	
General Failures	Unsuccessful protection of payload instrumentation leading to severe damage	Damage to instruments and/or supporting equipment, resulting in loss of ability to collect and store data from samples	9	Unaccounted for physical or heat damage	4	Payload will be designed to prevent this failure mode	No design controls in place, but failure mode may be self evident in data	4	144	
	Failure in detaching from the main mission transport device, subjecting the orbiter (subject to change) to extreme temperatures and pressures it is unable to withstand.	Mission will no longer proceed. No data will be collected.	10	Software failure, malfunctioning mechanism (motors, etc.) or damage	5	This process will be tested thoroughly on Earth before launch	No design controls in place, but failure mode may be self evident in data	4	200	
	Failure to power on once detached from main transport.	No power to instruments would cause no data to be collected by any of the instruments	9	Failure in power supply transmission lines or battery.	5	Payload will be designed to prevent this failure mode	No design controls in place, but failure mode may be self evident in data	4	180	Redundant power supply design with backup batteries and independent transmission cables
	Incorrect calibration of science instrumentation	Unreliable results	8	Human error in preparing mission, or misconfigured calibration tools	3	This process will be tested thoroughly on Earth before launch	No design controls in place, but failure mode may be self evident in data	4	96	
	Communications failure	No data would be received, and no commands can be sent. Essentially loss of all mission function, and all systems must operate autonomously.	10	Communications module signals obscured by particulate matter. Or can be caused by physical/heat damage. Or not enough gain on the device due to underpower. OR failure in directional calibration	5	Testing and verification of communication systems will take place	No design controls in place, but failure mode may be self evident in data	5	250	
	Inability to locate or maneuver orbiter (navigational failure)	Unable to maneurver into planned flight path. May lead to catastrophic loss of craft and instruments, or at the very least, the data collected would not be that of the intended target.	8	Software bug in navigational controls. Failure of location sensors and system. Failure of thrusters.	4	This process will be tested thoroughly on Earth before launch	No design controls in place, but failure mode may be self evident in data	4	128	
	Failure to deploy science payload for sample recollection and analysis	No data would be collected. No samples would be recollected.	9	Software failure, malfunctioning mechanism (motors, etc.) or damage	4	This process will be tested thoroughly on Earth before launch	No design controls in place, but failure mode may be self evident in data	6	216	

Payload and Instrument Risk Summary

ID	Summary	L	C	Trend	Approach	Risk Statement	Status
1	Corrosion eats away at vehicle parts	2	4	R	NEW	Caused by sulfuric acid	N/A
2	Frame is damaged	3	3	M	NEW	The frame can break or have an air leak	N/A
3	Seals break	2	3	M	NEW	Seals can be broken between the platform and vehicle or between connectors	N/A
4	Vibrations affect instruments	3	2	R	NEW	Instruments can be rattled around and their fasteners may become unsecured	N/A
5	Calibrations or measurements are not precise	2	4	M	NEW	Includes angle of rotation of polarimeter, wavelength of light through the sample, and temperature and length of samples	N/A
6	Damage to sensors	2	5	R	NEW	Physical or heat damage to sensor, caused by failure of protection system (seals, shielding) leads to inaccurate results	N/A
7	Power failure	2	5	R	NEW	May result from electrical transmission line failure or battery failure, and renders the instrument unusable	N/A
8	Communication failure	3	5	R	NEW	Failure in communications transmission line to the communications module means no data is relayed back to Earth	N/A
9	Unsuccessful protection of instruments	2	5	W	NEW	Leads to severe damage of payload	N/A
10	Inability to filter out sulfuric acid in measurements	1	4	R	NEW	Tampers with the concentration detection of other chemicals, leading to inaccurate results	N/A
11	Navigational failure	2	4	W	NEW	Inability to locate or maneuver orbiter	N/A
12	Failure to detach from main mission transport device	3	5	R	NEW	Subjects the orbiter to extreme temperatures and pressures it is unable to withstand	N/A
13	Failure to deploy science payload for sample recollection and analysis	2	5	R	NEW	Can be caused by software failure, malfunctioning mechanism (motors, etc.) or damage	N/A
14							
15							
16							
17							
18							
19							
20							

Approach	Criticallity	LxC Trend	L = Likelyhood (1-5)
A - accept	HIGH	↓ - Decreasing (improving)	1 = not likely
M- mitigate	MED	↑ - increasing (worsening)	5 = extremly likely
			C = Consequence (1-5)
W - watch	LOW	→ - unchanged	
R - research		**NEW** - added this month	1 = low consequence
			5 = high consequence

LIKELIHOOD	1	2	3	4	5
5					
4					
3		4	2		8,12
2			3	1,5,11	6,7,9,13
1				10	
	CONSEQUENCES				

Criticallity
HIGH
MED
LOW

LxC Trend
↓ - Decreasing (improving)
↑ - increasing (worsening)
→ - unchanged
NEW - added this month

4.1.6 Performance Characteristics
This mission is intended to be a year long mission and will encompass all seasons and times of the Venusian year. The research will take place during day and night times in order to accurately collect data during all types of environments.

HIPWAC:
The instrument will be concealed inside of the payload with protective glass shields over its single opening. The instrument utilizes laser and UV lightwaves to analyze data which are compatible with the atmosphere. The HIPWAC will be able to survive any condition that the entire payload can survive due to being protected inside the shell of the payload.

Ion Neutral Mass Spectrometer:
The instrument would be concealed inside of the payload with protective layers of glass and/or titanium, as they are both known for their remarkable resistance to acid. The opening of said instrument, it's only contact with the outside world, is to be concealed when not in use by a layer of protective material deemed strong enough to withstand sulfuric acid, such as glass or titanium When in use, Its interior components should be lined with titanium, if possible, to prevent damage from corrosion.

Polarimeter:
The instrument will be concealed within the payload within a titanium structure. It will be insulated using an aerogel-type insulation and support with sealed glass openings. The instrument utilizes polarized light through an optically active substance to measure the angle of rotation caused. The polarimeter will be able to withstand the conditions in the Venusian atmosphere due to its concealment within the payload.

MARCI:
This instrument will be housed inside of the payload and will be able to view the outside of the payload through a transparent sealed glass dome. After calibration, which occurs by using several color filters to look at a calibration target, the camera can take high resolution long span images of the atmosphere of Venus and potentially the surface, provided the rare event that the cloud layer is thin enough and ultraviolet filters can pick up minute details. The original MARCI took seven images per orbit, but this camera would take a mucher higher rate of image collection more suitable to the proposed vehicle's path. The camera would be able to take images of the atmosphere of Venus in an attempt to find notable clouds or areas of interest.

4.2 Science Value

4.2.1 Science Payload Objectives
The mission will be to collect data on the locations and concentration levels of phosphine, methane, oxygen, and nitrous oxide. These gases are often produced through biological processes here on Earth, making them known biosignatures on Earth, so data collected can further support investigations into the existence of life (past or present) on Venus. This would allow scientists to better understand the planet's history and the development of early life in the solar system. Furthermore, observational data would be highly valuable in developing a detailed atmospheric map of Venus in terms of composition, gas concentrations, and location. This will be valuable in planning future atmospheric or terrestrial missions to Venus.

The team aims to study the presence of phosphine gas in Venus's atmosphere as it is a well-known biosignature for anaerobic microbes. Goals include determining if it is present, where it is present, what type of qualities the gas as if it is conducive to any form of life, and what its source is (biological or geological).

The team has concluded that in order to form a successful plan and subsequently a successful launch and exploration, they must develop some initial schematics and a budgeting plan for the launch. Some potential plans are Bluetooth 5.0 for communication, creating a map of phosphine around the planet, understanding its volume and weight, its contact with the earth, and being able to collect data on other compounds present

The initial proposal is to create a vehicle/instrument that will have sensors to detect 8-10 different chemicals (life markers) in the atmosphere, with a GPS system, and use elements of Venus (wind/solar) for propulsion with the assumption that phosphine will be the largest compound of interest. Engineering and Science will begin to create their initial plans involving the spacecraft utilizing karbate, carbon, and graphite as its suitable for sulfuric acid concentrations from 0 to 90% and process temperatures up to 84° F, along with Aluminum Anodized type 2 that makes aluminum become more resistant to sulfuric environments.

In order to study the chemical composition of Venus's atmosphere and detect the concentrations of the previously mentioned gases, certain methods and instruments are available. As this mission has certain budget and space limitations for the scientific payload, the final decision is to be taken after great consideration regarding budget, dimensions of said devices, and capabilities. Among the devices considered for the detection of said gasses is a mass spectrometer, such as the Cassini Spacecraft's Ion and Neutral Mass Spectrometer (INMS), which reported the species of atoms or molecules that enter the instrument. Another example of similar capabilities is the Huygens' Gas Chromatograph Mass Spectrometer (GCMS), which analyzed the atmosphere of Titan as the probe parachuted toward Titan's surface in 2004. One advantage to this instrument is after landing, it also reported on surface composition.

Another instrument being used for this mission is a polarimeter. Polarimeters are optical instruments that measure the direction and extent of the polarization of light reflected from their targets. Polarimeters consist of a telescope fitted with a selection of polarized filters and optical detectors. Careful analysis of polarimeter data can infer information about the composition and mechanical structure of the objects reflecting the light, such as various chemicals and aerosols in atmospheres, rings, and satellite surfaces since they reflect light with different polarizations. A polarimeter's function may be integrated with another instrument, such as a camera, or the Voyager photopolarimeter that combines functions with a photometer.

Another instrument system is the Heterodyne Instrument for Planetary Wind and Composition (HIPWAC) or a scaled-down version of it, as it enables astronomers to look in detail at the behavior and characteristics of specific molecules of gas in a planetary atmosphere. This is precise enough to detect and unambiguously identify many of the most important gasses in planetary atmospheres, including but not limited to ethane, methane, carbon dioxide, ozone, ammonia, ethylene, and water vapor. Additionally, HIPWAC has proven to be able to measure the flow of winds on other planets, including Venus, Mars, and Saturn's moon Titan. Last, but not least, this instrument provides data that can be used to determine how gas abundance, pressure, and temperature in a planetary atmosphere vary with altitude. Precise measurements of molecular abundances provide insight into photochemical processes in planetary atmospheres and guide the development of theoretical models of atmospheres.

Aside from these previously detailed devices meant for chemical analysis, communication devices are to be used to transmit recollected data back to Earth. A communication system similar to NASA's Mars Perseverance Rover, which uses a radio-based communications device to transmit binary radio signals using X- band antennas could be implemented. Depending on how fast data needs to transmit, high or low gain antennas will be needed which will determine if the antenna will need to point in a specific direction. In addition, a device similar to NASA's Mars Color Imager (MARCI) which produced a global weather map of Mars and detects variations in ozone, dust clouds, and CO_2 changes in the atmosphere using a visible-light bandstand could be used to further study the atmosphere of Venus.

While the current configuration and dimensions of the payload are unknown, the overall payload will be enclosed in the vehicle which will have a spacious opening compartment in the middle. This will allow the payload to be exposed and collect the necessary information when needed as the vehicle orbit atmospheres around Venus. All of the sensors will be concealed during entry into Venus in order to protect the instruments. They will be revealed during orbit at 50-70 km in order to collect and record gas sensor readings.

Objectives of the Venusian Mission: Collect data on various gases including phosphine, to match the concentration of gases to specific locations, to communicate all data back to earth, to collect visual images of gas concentration locations, and to navigate through top-mid layer clouds.

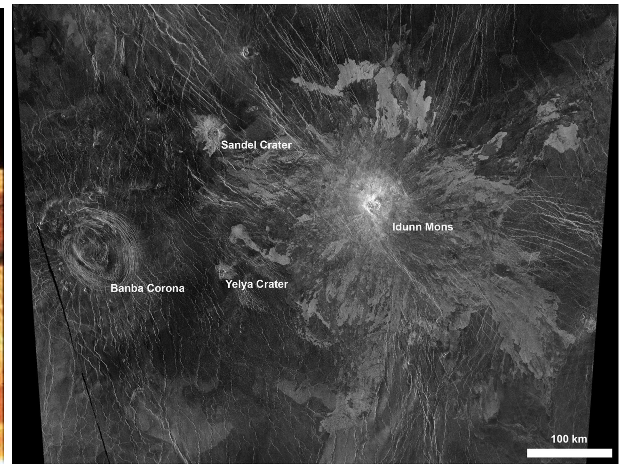
4.2.2 Creativity/Originality and Significance

This Venus mission is based off of previous Vega missions from the 1980's utilizing the previously proven technology to try to detect and map biomarkers for life on Venus's atmosphere. Previous missions have mapped around 70% of Venus's surface while tangentially in a separate mission, levels of phosphine gas were collected. The data collected was later questioned for accuracy, resulting in a veil of mystery around the specifics of Venus' atmosphere. This mission aims to validate the data collected in the previous mission while simultaneously mapping the surface of Venus to match the concentrations of gases with specific locations of Venus. Additionally, in previous probes like the Pioneer Venus Orbiter, which carried similar instruments, were not able to examine the atmospheric range of 50-70km that the scientific community. The Pioneer Venus Orbiter could only maintain a periapsis of 150-250km before disintegrating into Venus' atmosphere. The proposed payload would essentially be a unique combination of proven technology as well as an investigation into currently relevant and important scientific data.

Additionally, the range of Venus' atmosphere which the payload would be traversing is a range of interest and would allow for a significant insight into habitability of that portion of Venus, as well as imply the possibility of life on Venus. The implications of detections of biomarkers as well as phosphine would be scientifically significant as well as propelling the understanding of Venus' history and atmosphere.

Figure 36

Maat Mons and Idunn Mons (NASA)



The image displayed on the left of Figure 32 is a three-dimensional perspective of Maat Mons, the largest mountain on Venus and, possibly, an active volcano. The picture on the right is an aerial view of Idunn Mons and the surrounding geological formations. Said images were -or are based on, in Maat Mons' case- taken by Magellan probe. Both of these geological formations are of relevance to our mission as these, and other similar structures will be studied in detail, to determine if the phosphine on venus -if found- is of geological origin.

4.2.3 Payload Success Criteria

A successful mission would include entry into the atmosphere of Venus with a target altitude of 50-70 km. The instrument would maintain altitude by use of a balloon mechanism to keep it afloat in the top-mid cloud layers of Venus's atmosphere.

A successful mission would also include being able to determine where on Venus the phosphine concentrations are highest relative to the overall environment with 90%+ accuracy. In addition to measuring the concentration of phosphine, the instrument would also measure ethane, hydrogen, methane, carbon dioxide, ozone, ammonia, ethylene, and water vapor in ppb, measure temperature, the pressure, sulfuric acid concentration alongside other readings to get a feel of the atmospheric conditions. Successful mapping of placement of gases found on Venus would occur with the communication of 100% of data back to earth. Our mission would have a goal of collecting data of greater than 70% of Venus's atmosphere.

Since a great deal of Venus's surface has been mapped using SAR, we would fly over certain geological formations and determine whether phosphine levels are higher near these regions and determine if said phosphine could be of geological origin. Our mission would utilize the previous mapping of Venus to determine where we will focus our current mapping (Barnett, 2021). The payload would not need to be collected for the mission to be considered successful.

When working on said mission, it is crucial to consider situations that could lead to difficulties and possible failures

Possible failure modes during the Venusian mission include: Unsuccessful protection of payload instrumentation leading to severe damage, rending onboard devices unable to analyze samples or transmit information back; Failure in detaching from the main mission transport device, subjecting the orbiter (subject to change) to extreme temperatures and pressures it is unable to withstand; Failure to power on once detached from main transport; Incorrect calibration of science instrumentation, leading to unreliable results; Inability to communicate with nearby spacecraft; Inability to locate or maneuver orbiter (navigational failure); Failure to deploy science payload for sample recollection and analysis; Unpredictable weather conditions lead to damage/difficulties with communication hardware and science payload.

4.2.4 Experimental Logic, Approach, and Method of Investigation

The instruments will be tested and calibrated individually first and then all together in the prototype design. Once a final prototype design is reached, the final design will be tested and calibrated again to ensure all instruments work together accurately and seamlessly. Testing will ensure that each instrument can withstand the conditions in Venus's atmosphere while accurately collecting data on the various compounds present in the atmosphere. The data will be transmitted back to earth to analyze. All data will be compared to the previous mission as well as data collected on earth to verify and validate previously collected data as well as newly collected data.

HIPWAC

After calibration prior to deployment, the instrument will be held in calibration by controlling temperature and keeping it sealed until arrival in Venus's atmosphere. The instrument will be detecting each of the following gases: ethane, methane, carbon dioxide, ozone, ammonia, ethylene, and water vapor. The instrument would continuously detect levels of these gases in the air while the MARCI is simultaneously photographing locations of the gas concentrations. The GPS coordinates would be mapped to match with the detected levels of gases.

Polarimeter

The instrument will be calibrated prior to deployment using crystalline quartz oriented and cut in such a way that it matches the optical rotation of a sucrose solution to the expected value. The instrument will measure the physical orientation of light waves as they move and twist through Venus' atmosphere to determine the composition of Venus' clouds. The polarimeter will work in tandem with the HIPWAC by determining the composition of Venus' clouds while the HIPWAC detects concentrations of gases within the atmosphere. The GPS system will be used to map the detected composition of various clouds with geological activity as detected by MARCI.

INMS

The Ion Neutral Mass Spectrometer, after calibration, will collect samples from the venusian atmosphere. The presence and concentrations of these gasses will be measured and matched with the MARCI camera to ensure the highest concentrations of the studied gasses are correlated with geological activity detected by MARCI. The INMS will work in collaboration with the polarimeter and the HIPWAC to delineate the composition of venusian clouds.This information will be compiled and shared through the communication system.

MARCI

The MARCI camera will be continually taking images from the atmosphere in an attempt to correlate notable images with concentrations of compounds detected by the HIPWAC. The images taken by the MARCI will be immediately transmitted by the communication system to be processed into different wavelengths such that the images can be converted to accurate color images in post processing. Additionally, the MARCI camera will be looking for any sign of atmospheric anomalies that would indicate geological activity.

Powering on and calibration for all instruments will occur prior to leaving the shuttle. Sample testing will occur in a controlled environment in order to properly calibrate the instruments prior to release into Venus's atmosphere. Once in the 50-70km range of the cloud layers, testing will begin. All instruments should be held at a constant temperature to ensure accuracy and hold calibration.

4.2.5 Testing and Calibration Measurements

Testing for each instrument will be conducted on earth during development of prototypes. Samples of the various gases will be tested to ensure that the instruments can accurately detect the compounds. Expected conditions for Venus's atmosphere will be simulated to give the instruments accurate testing conditions in order to detect the various compounds in. Since Venus's clouds are composed of sulfuric acid, varying levels of this compound will be used in a simulated atmosphere to ensure the instruments can function properly. The winds on Venus are known to be turbulent at times so high wind speeds will be simulated to ensure that the instruments can both withstand the pressure and accurately detect the compounds. 100 hours of testing per instrument will be conducted prior to assembly into a prototype. Testing will be completed on each prototype with a minimum of 100 hours of testing on the final prototype. Goals of 95% accuracy for each instrument will be required for testing to be complete. Testing will be conducted in stages beginning as individual instruments and ending with completed prototype testing.

A baseline for calibration will be established prior to arrival in the top to mid range cloud layer on Venus. Calibration will begin aboard the spacecraft in a controlled environment using samples with known values. Samples will be tested in a controlled environment to test for accuracy and calibration of the instruments. Each instrument will be analyzing specific compounds. A sample of the specific compound will be available during calibration to ensure accuracy of results once the payload is deployed. The samples will have known values which the instrument will be tested to ensure it is reading at the known value for each sample. This will be the method of calibration for each instrument.

HIPWAC

The HIPWAC will have samples of the following gases available to use for calibration prior to deployment into Venus's atmosphere; ethane, methane, carbon dioxide, ozone, ammonia, ethylene, and water vapor. The instrument will be calibrated to ensure that it is reading at the expected levels for these samples prior to deployment.

Polarimeter

The polarimeter can be calibrated with a blank solution, which will be available. As long as the reading that is taken with the blank is the same as what is expected, the polarimeter is properly calibrated.

INMS

The Ion Neutral Mass Spectrometer will be sterilized for a period of ten days prior to the launch, and once approaching the target, it will be pumped with samples of gases that will be studied once the device reaches the desired location and altitude, whose ion masses are known. The device will measure the weight of said ions and identify them, in order to prove its function (Mahaffy, et al. 2012).

MARCI

The MARCI instrument will be calibrated using a proven method that has been used to calibrate countless cameras on probes and rovers, even the latest Martian rover Perseverance. The camera will have 5 color filters in front of it which will pass over a calibration target, which consists of several wavelengths of colors. In post processing, the images can be analyzed by comparing known filter wavelengths to known target color wavelengths, which will allow scientists to produce full color images from the data.

4.2.6 Precision of Instrumentation, Repeatability of Measurement, and Recovery System

HIPWAC

Data will be continuously communicated back to earth using an onboard computer. The data will be communicated continuously to prevent data loss in the event of power loss or payload failure. Data will be compared to previously collected data from the previous mission to Venus testing levels of phosphine gas. The instrument will be using wavelengths to collect data. Lasers and ultraviolet wavelength light will be used to analyze data to determine emission spectra from the data. The instrument will be accurate to 0.1 nm. The instrument will be calibrated to a 0.0 nm baseline and all readings compared to the calibration samples to determine accuracy (Takada, 2013).

Polarimeter

Spatial resolution should be able to be given at under 4 km accuracy, and polarization should be able to be given at under 2% error.

Ion Neutral Mass Spectrometer

Ideally, the device should be able to detect an approximate mass range of 1-40 amu (atomic mass units), ions with densities ranging from 1xe3cm^3 to 1xe8 cm^3, neutral densities ranging from 1xe4cm^3 to 1xe8 cm^3, all in a time span ranging from 0.1s to 10s.

MARCI

The precision of the MARCI camera would be verifiable if the calibration target imaging process was able to be processed. Additionally, the data consisting of images taken by the camera would be transmitted via the communication system to be processed. The MARCI camera can also function consistently regardless of the operation time and altitude.

4.2.7 Expected Data and Analysis

HIPWAC

The data would be continuously sent back to earth by means of an onboard computer system. The data will be compared to data collected on earth as well as the previous mission to Venus. Example data is shown below. Our data would be specifically for ethane, methane, carbon dioxide, ozone, ammonia, ethylene, and water vapor. The error calculations would be performed after comparing to data collected on earth and previous missions to Venus.

Error calculations would be based on spectral noise found in the instrument and could follow a method used by other researchers. The method is as follows: We calculate the root mean square (rms) value of the spectral noise caused by optical path phase measurement errors in a spatial heterodyne spectrometer (SHS) featuring a complex Fourier transformation. In our calculation the deviated phases of each Mach-Zehnder interferometer in the in-phase and quadrature states are treated as statistically independent random variables. We show that the rms value is proportional to the rms error of the phase measurement and that the proportionality coefficient is given analytically. The relationship enables us to estimate the potential performance of the SHS such as the sidelobe suppression ratio for a given measurement error (Takada, 2013).

Figure 37a

Graphs of Expected Data for the HIPWAC (Takada, 2013)

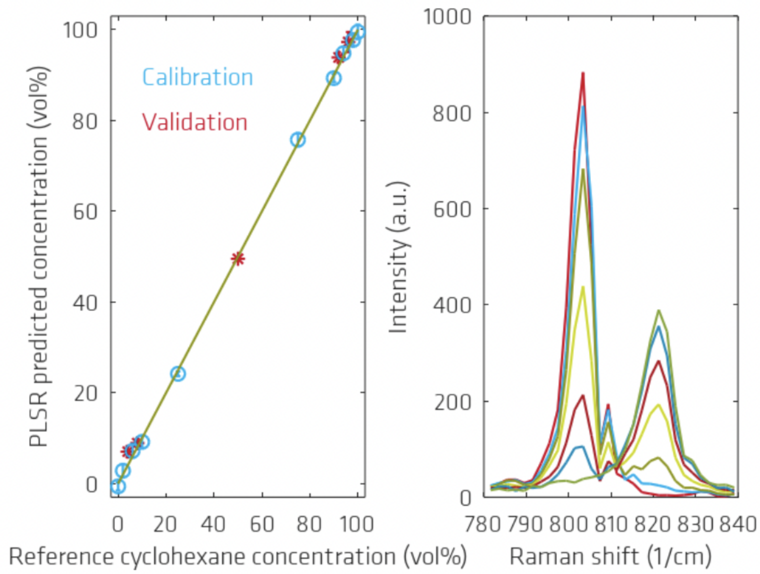
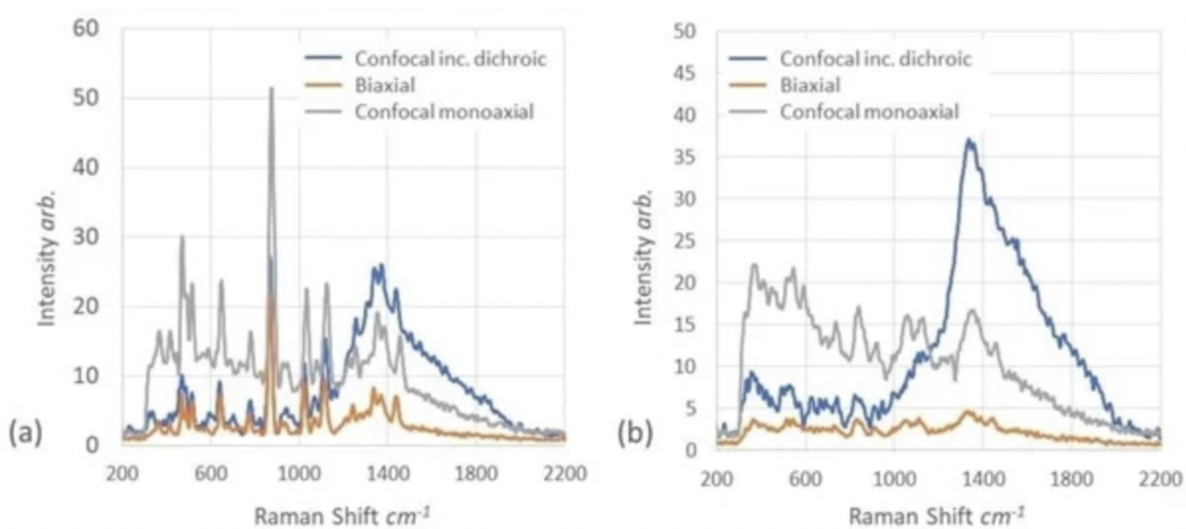


Figure 37b

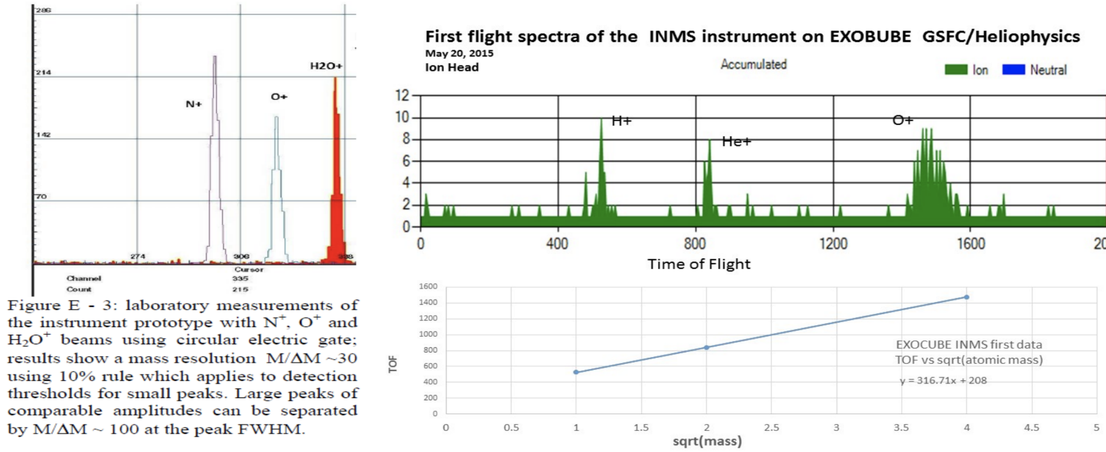
Graphs of Expected Data for the HIPWAC (IS-Instruments, 2020)



Ion Neutral Mass Spectrometer:

Figure 38

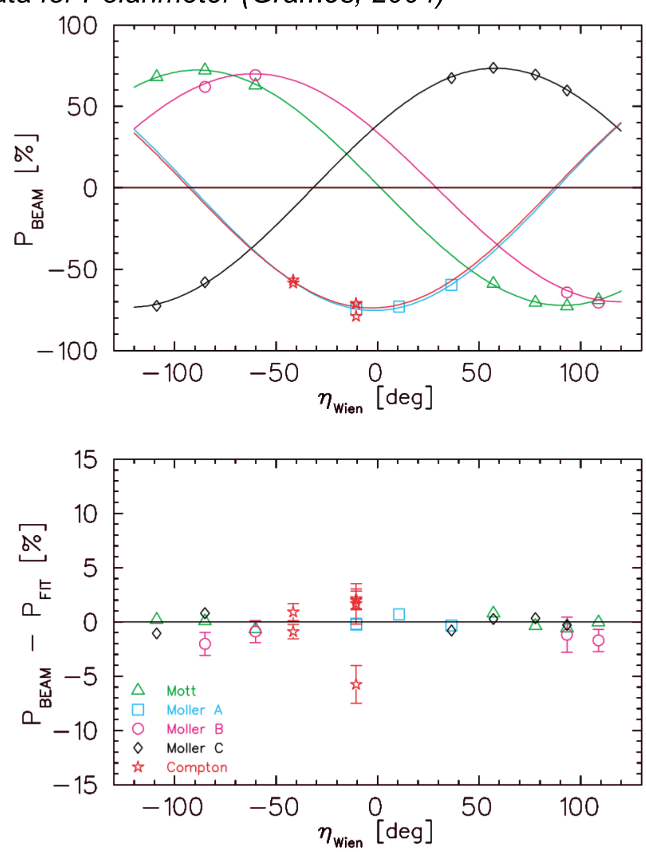
Data Expected of the INMS (NASA Goddard Space Flight Center, 2015)



The INMS would measure the TOF of ionized particles derived from vaporized samples taken on the Venusian clouds. The data at hand was taken by the INMS on the NSF's EXCOCUBE. Possible errors could be identified through the comparison with previous missions.

Figure 39

Graphs of Expected Data for Polarimeter (Grames, 2004)



Polarimeter

The polarimeter would measure the polarization of light through an optically active substance to determine its angle of rotation. This data will be used to determine the composition of Venus' clouds by detecting the polarization of light through the particles within the clouds. The data above represents the expected data for an electron polarimeter by measuring percentage of polarization.

MARCI

The anticipated data for the MARCI instrument consists of high resolution images that would be processed after images of the calibration target would be received in order to restore images to full color with accurate wavelengths. The optimal data would reflect variations in ozone, carbon dioxide, clouds, and potentially ultraviolet data that would indicate surface geological activity. Additionally, the calibrated images would be able to verify data from other instruments such as the HIPWAC in identifying certain compounds through their wavelengths.

5 Safety

5.1 Personnel Safety

5.1.1 Safety Officer

The team decided to name its Outreach Director, Alberto Leon, the safety officer for this mission. His main responsibility is to monitor and assess any hazardous and unsafe situations. Currently, for the duration of the PDR, the team has been meeting on Zoom. Once the team moves on to the next phase, his responsibilities will expand to include supervising the team's work and assuring safety equipment is worn and proper procedures followed. Before the team begins to work in a lab, Alberto will ensure that everyone understands the rules and regulations by providing training to the team on NASA standards and protocols to make sure all requirements are met. Since he is somewhat the "law enforcer" for the team, Alberto is required to maintain full awareness of active and developing situations and report all unsafe acts, conditions, illnesses, and injuries to the appropriate person, along with having the authority to prevent unsafe acts with immediate action.

Due to the current COVID-19 pandemic, the team will have to adhere to ongoing and future COVID regulations such as temperature checks, face masks, and to social distance when possible. The team decided to nominate the Aerospace Engineer, Andy Zhou, as deputy safety officer. The deputy's role would entail attending events that the safety officer cannot attend as well as being another individual ensuring guidelines and precautions are followed.

5.1.2 List of Personnel Hazards

1. Machining/Manufacturing *("OSHA's 5 Workplace Hazards," n.d.)*
    a. Improper Machine Usage
        i. Loose clothing being caught in machines.
        ii. Hair or body parts being pulled into machines.
        iii. Debris may fly out of a machine and into one's eye.
        iv. Fingers, toes, or other limbs are lacerated by fast moving machine parts.
        v. Lasers may be shone into eyes, causing blindness.
        vi. Operating equipment that produce sparks or flame
        vii. Burning injury when operating equipment that produces high temperatures
        viii. Freezing injury when operating equipment that produces low temperatures
        ix. Unattended equipment in operation
        x. Hearing impairment due to loud noises produced by machines

   xi. Damaged, broken, or worn machine being used when it's not supposed to be
   xii. Shavings or debri getting sucked into/caught in machines; machines are not properly cleaned (jammed machines)
   xiii. Improper use of hand tools or improper choice of tools.
 b. Facility and Operations Hazards
   i. Slipping hazard in facility
   ii. Fire hazard in facility (flammable materials)
   iii. Handling sharp materials
   iv. Muscle injury when carrying heavy loads
   v. Concussion hazard with moving equipment or objects
   vi. Two or more team members may collide or interfere with each other while working with equipment.
   vii. Unattended or misplaced belongings (clothing, etc) on premises
   viii. Automated machine systems inadvertently starting
   ix. Team members not knowing how to handle equipment; not knowing where the moving parts are
   x. Dim lighting which make it hard to see in the facility or around machines
   xi. Temperature in facility is out of a machine's safe operating range
   xii. Inhaling dust or other chemicals (Improper ventilation)
   xiii. Electric shock risk when handling exposed wires, circuits, or batteries
   xiv. Explosion risk when handling inflammable materials or batteries
 c. Labor
   i. Injury due to repetitive motion
   ii. Failure to act during a safety emergency
2. Chemicals (Handling and Storage) *(Gislason, 2018)*
   a. Chemicals may cause burning injury.
   b. Chemicals not being stored properly, or coming into contact with other substances.
   c. Contamination of chemicals in storage, transit, or use.
   d. Biological growth in chemicals due to improper storage or sterilization.
   e. Chemicals releasing poisonous or hazardous gases
   f. Chemicals being exposed to certain light which cause property changes.
   g. Chemicals being exposed to extreme temperatures.
   h. Chemicals being misused in situations (e.g. using improper cleaning substance).
   i. Chemicals being confused for one another.
   j. Bloodborne pathogens infection spreading in the group
3. COVID-19
   a. A COVID-19 outbreak can occur in the team, causing team members to fall seriously ill.
   b. Team members may become disease carriers of COVID-19, and spread infection to others during travel.
4. Travel
   a. Members may be seriously injured or killed in traffic accidents when traveling (i.e. to the launch or outreach events).

5.1.3 Hazard Mitigation

1. Machining / Manufacturing
   a. All team members who are working in a machining/manufacturing facility or lab must complete safety training and pass a safety knowledge exam.

   b. All team members must pass a working knowledge test of equipment and machinery they wish to work with prior to entering the facilities.
      i. Watch required safety videos to prepare for the test.
   c. All team members must wear appropriate and relevant PPE, including:
      i. Gloves when using machines that pose a risk to hands
         1. In certain instances, gloves will not be required in order to decrease risk of arm getting caught in a machine
      ii. Goggles when using machines that pose risk to eyes
      iii. Close-toed footwear and steel-toed or rubber footwear where appropriate
2. Chemicals
   a. All team members who are working in a science lab must complete safety training and pass a safety knowledge exam.
   b. Eye-washing stations will be present in all labs.
   c. All toxic chemicals will be appropriately stored away until use.
   d. Close-toed shoes, gloves, and goggles should be worn at all times inside the lab.
3. Health
   a. All team members will have full health insurance coverage in case of emergencies.
   b. Team members will have allotted sick days off in addition to access to virtual work so that they do not need to work in case they are feeling under the weather.
   c. All team members will be vaccinated prior to work.

Table 13

Vehicle/Payload Safety

ID	**Identify Technical**	**Environmental Hazard (5.2.1)**	**Mitigation (5.2.2)**
1	Communication	Volcanic activity can externally affect data collection and communication (Johnston, 2007).	Easy-to-develop systems that take advantage of open-source software and implement a cooling system for the space system used to collect data.
2	Data handle	High temperatures in the atmosphere cause shorts between electronic components (by melting internal materials).	Developments in high-temperature electronics focus on low data volume measurements. Design operations scheme for the system and use SiC Electronics To Enable Long-Lived Chemical Sensor Measurements at the Venus Surface
3	Data handle	Higher temperature range operations electronics	High-temperature memory electronics provide unique memory capabilities that notably change.

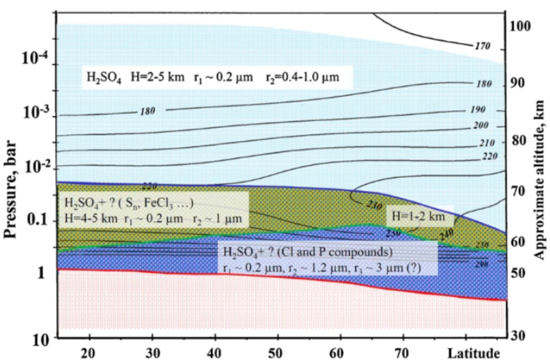
4	Communication	Directional Antenna Radiation	Only licensed and trained radio operators may operate on the directional antenna.
5	Power	Spacecraft charging can cause arch discharges (strong electrical currents)	Avoid exposure to extreme solar flare particles and severe charging events
6	Power	Transient Radiation Environments damages the functionality of electronics	Materials that withstand best against radiation, and electromagnetic radiation shield
7	Power	Solar Storms (Geomagnetic storm) could de-orbit the vehicle and threaten electrical components	Electromagnetic shield
8	Power	Impact damage to spacecraft	Point vulnerable systems away from the incoming impact Power down-sensitive instruments to minimize damage in the event of a collision
9	Power	Clouds of space dust damages the electronic systems	Map dust clouds and calculate their orbits
10	Payload	Rapid temperature change during free fall	Robust materials with low thermal expansion coefficients.
11	Payload	Dust in the wind erodes	Abrasive-resistant materials.
12	Payload	High temperatures can cause thermal expansion and deformation	Materials with high heat tolerance.
13	Payload	Prolonged sulfuric acid exposure can erode and compromise the structural integrity of the frame	Airtight case and filtration system to let in the air in a controlled way.
14	Payload	Humidity/Condensation can cause shorting between electronics	Fill the airtight case with pure oxygen if anything at all.
15	Chassis	High temperatures and radiation damage internal components	Utilize white thermal coating on the exterior of the chassis

16	Chassis	Sulfuric acid damages parachute	Utilize sulfuric acid resistant parachute
17	Chassis	Sulfuric acid corrodes the helium tank	Apply corrosion protecting coat to a helium tank
18	Chassis	Sulfuric acid corrodes balloon	Utilize sulfuric acid resistant balloon
19	Chassis	Sulfuric acid corrodes bolts and eventually shears them off	Utilize bolts with high corrosion resistance and strength

5.2.1 Atmospheric Challenges

Figure 40

Atmospheric Pressure vs Altitude on Venus (Titov, et al. 2018)



The atmospheric composition of Venus is 96.5% CO_2 and 3.5% N_2 by Volume, with traces of SO_2, Ar, H_2O, and CO. SO_2 at 150 ppm also blankets the planet upward of 48 km altitude. The sulfuric acid in the atmosphere of Venus could significantly impact the success of the mission, not only because of its corrosive properties but also because it successfully distorts light and contributes to an albedo higher to that of Earth. Between 50 and 70 km in altitude, sulfuric acid droplets range in sizes of 0.15 to 3.5 microns (Titov, et al. 2018).

At cloud heights, atmospheric temperature and pressure are similar to those at the Earth’s surface. While ambient temperature throughout the mission will not pose significant challenges, the temperature and pressure atmospheric profile (with large vertical gradients) of Venus suggests that poor altitude control could send the spacecraft in layers of atmosphere that behave like a supercritical fluid.

Additionally, a convective region between 50 and 55 km altitude may pose a challenge for navigation and maintenance of the internal temperature at the time, but this is also the region which most interests scientists because it provides a view of a less in-situ-explored altitude of atmosphere and enables the gathering of data critical for future mission planning.

Throughout the mission, the spacecraft will encounter winds ranging between 70 and 100 m/s between the altitude of 50 and 70 km.

5.2.2 Atmospheric Challenges Mitigation

5.2.2.1 Structural Elements

In order to manage stable temperatures, robust materials with low thermal expansion coefficients must be used for the vehicle chassis, body, and the structure of the payload. Titanium and aluminum have two of the lowest thermal expansion coefficients of all metals. Additionally, various coatings and materials are considered for resistance to abrasion and corrosion and high reflectivity. Namely, aluminum and PTFE coatings are used to reduce internal temperatures and to protect against corrosion from sulfuric acid.

5.2.2.2 Power

Spacecraft charging is the buildup of charge on spacecraft surfaces or in the spacecraft interior. This can cause arc discharge/electric arcs (strong electrical currents) that may damage electrical components or cause fires. The major natural space phenomena which contribute to spacecraft charging include the thermal plasma environment, high energy electrons, solar radiation, and magnetic fields. Charging could destroy solar arrays due to arcing happening between solar cells on the solar array. Arcs can also damage electronic components, sensors, thermal control coatings, altitude control systems, etc. Archs emit electromagnetic radiation and cause interference by preventing the functionality of incoming and outgoing commands/controls and data signals. Differential charging is the most damaging because arcs originating in a certain location can damage systems on another part of the spacecraft.

In transient radiation environments, the radiation sources are hazardous to electronics since energetic particles can deposit energy inside microelectronic circuits and disrupt their proper operation. Electronics can break down when cosmic rays pass through critical parts and short the circuits. Ions or electromagnetic radiation can affect the output or operation of an electronic device.

- Solar cosmic rays: During increased solar events the ion flux may increase and could cause considerable damage to electronics.
- Galactic cosmic rays: Originate from far reaches of the galaxy. The galactic cosmic rays are energetic and can have energies in the order of GeV/nucleon. Therefore, they are capable of penetrating deep into semiconductor devices.
- Geomagnetic field effect: Solar storms portray a threat to the electrical components in space as they are an episode of violent space weather resulting from particles streaming outward from the Sun.

Colliding with another object in space pertains to a serious threat to spacecraft electronics. Meteoroids can pose a risk to the spacecraft's power system, by blasting holes in solar panels, pitting surfaces, and shorting electronics. When a meteoroid hits a spacecraft, the meteoroid can disintegrate, creating a cloud of plasma that could set off a chain reaction.

Clouds of space dust result in wrong instrument readings, vision/optical system obscuration, performance reduction, altered thermal properties, and equipment failure.

5.2.2.3 Data Handling & Communication

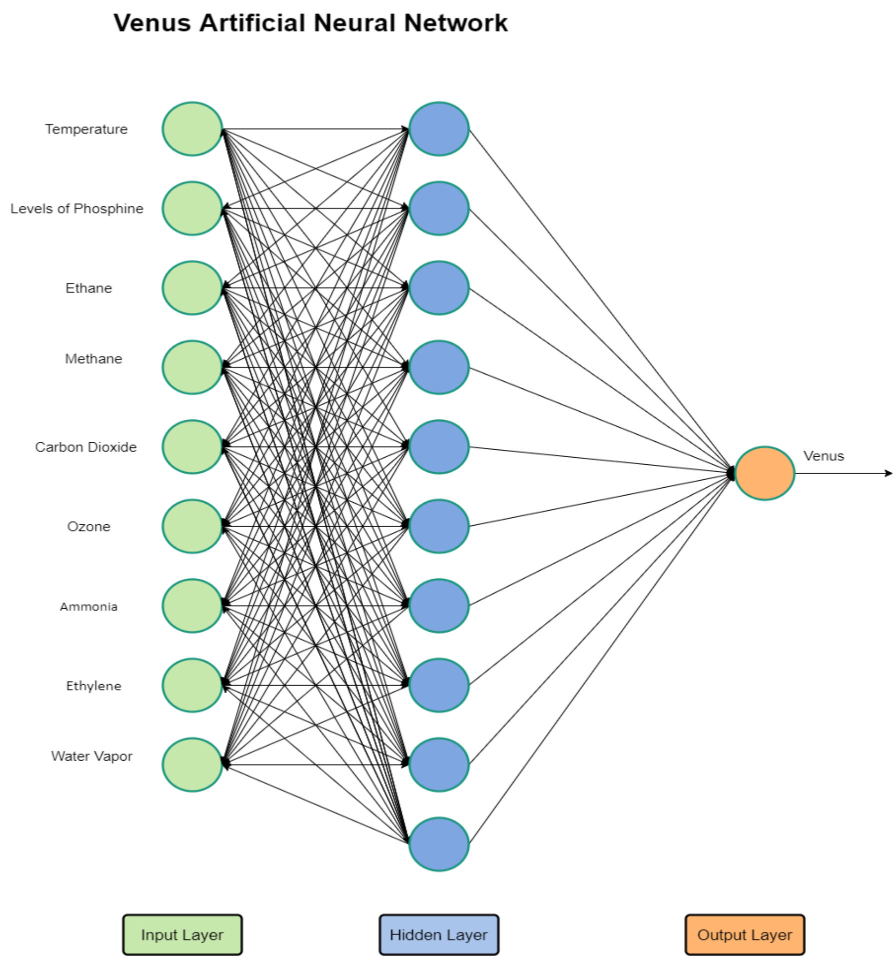
Venus is one of the most dangerous planets in the solar system due to its proximity to the Sun, chemical composition of the atmosphere, and thick cloud layers and high wind speeds. Use of high temperature operating technology reduces risk of failure. The system must also be prepared to read and interpret data properly by analyzing previous atmospheric records of Venus by using an Artificial Neural Network (ANN) (pictured below in Figure 37). For example, images taken of Venus can help the team focus on investigating above volcanic areas. In the case where only atmospheric data is available, the concentrations can be used to guess the location using machine learning (this method allows the team to reverse engineer the process of building maps and filling in gaps of human knowledge, which this mission strives to do).

An underestimated challenge will be processing and accessing information and data which was initially collected during missions decades ago and has many missing values. Machine learning can be used to make assumptions and fit models in the team's preparation and predictions.

Lastly, transmitted data must travel over long distances through the atmosphere (up to 8,000 km). Some data may be lost in transmission, so sending it via various frequencies and sending it via multiple rounds of transmission might also mitigate loss of data or inaccurate data transmission.

Figure 41

Venus Artificial Neural Network



6 Activity Plan

6.1 Budget

HOW TO USE THIS SPREADSHEET: Enter information ONLY into those boxes with a red outline/fill. All other cells will autopopulate. Additional information and instructions are given on the "INSTRUCTIONS" sheet (second sheet tab)

If you have questions about how a quantity is calculated, or what information should go in certain rows, see the "HELP COLUMN" in the row you want to know more about.

**Updated: 2/16/2021

Additional Information

	# People on Team	FTE Year 1	FTE Year 2	FTE Year 3	FTE Year 4	FTE Year 5	FTE Year 6	HELP COLUMN
Science Team:	4	1	1	1	0	0	0	?
Engineering Team:	5	1	1	0.2	0	0	0	
Administrative Team:	4	1	1	0.25	0	0	0	
(Total)	13							

NASA L'SPACE Mission Concept Academy Budget - Team *Sky Walkers*

Year	Yr 1 Total (2021)	Yr 2 Total (2022)	Yr 3 Total (2023)	Yr 4 Total	Yr 5 Total	Yr 6 Total	Cumulative Total	HELP COLUMN
PERSONNEL								
Science Team	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ -	$ -	$ -	$ 960,000.00	
Engineering Team	$ 400,000.00	$ 400,000.00	$ 80,000.00	$ -	$ -	$ -	$ 880,000.00	
Administrative Team	$ 320,000.00	$ 320,000.00	$ 80,000.00	$ -	$ -	$ -	$ 720,000.00	
Total Salaries	$ 1,040,000.00	$ 1,040,000.00	$ 480,000.00	$ -	$ -	$ -	$ 2,560,000.00	
Total ERE	$ 290,264.00	$ 290,264.00	$ 133,968.00	$ -	$ -	$ -	$ 714,496.00	?
TOTAL PERSONNEL	$ 1,330,264.00	$ 1,330,264.00	$ 613,968.00	$ -	$ -	$ -	$ 3,274,496.00	
TRAVEL								
Total Flights Cost	$ -	$ 2,632.00	$ -	$ -	$ -	$ -	$ 2,632.00	?
Total Hotel Cost	$ 5,400.00	$ 6,812.00	$ -	$ -	$ -	$ -	$ 12,212.00	?
Total Transportation Cost	$ 5,000.00	$ 3,167.20	$ -	$ -	$ -	$ -	$ 8,167.20	?
Total Per Diem Cost	$ 2,840.00	$ 5,076.50	$ -	$ -	$ -	$ -	$ 7,916.50	?
Total Travel Costs	$ 13,240.00	$ 17,687.70	$ -	$ -	$ -	$ -	$ 30,927.70	
OTHER DIRECT COSTS								
Total Outsourced Manufacturing Cost	$ 19,444,345.57	$ -	$ -	$ -	$ -	$ -	$ 19,444,345.57	
|> Science Instrumentation	$ 6,753,399.00	$ -	$ -	$ -	$ -	$ -	$ 6,753,399.00	?
|> Other COTS Components	$ 12,690,946.57	$ -	$ -	$ -	$ -	$ -	$ 12,690,946.57	?
Total In-House Manufacturing Cost	$ 2,425,444.15	$ -	$ -	$ -	$ -	$ -	$ 2,425,444.15	
|> Materials and Supplies	$ 2,425,444.15	$ -	$ -	$ -	$ -	$ -	$ 2,425,444.15	?
Total Equipment Cost	$ 100,571,480.48	$ -	$ -	$ -	$ -	$ -	$ 100,571,480.48	
|> Manufacturing Facility Cost	$ 26,430,053.00	$ -	$ -	$ -	$ -	$ -	$ 26,430,053.00	?
|> Test Facility Cost	$ 74,141,427.48	$ -	$ -	$ -	$ -	$ -	$ 74,141,427.48	?
In-House Manufacturing Margin	$ 51,498,462.32	$ -	$ -	$ -	$ -	$ -	$ 51,498,462.32	?
Total Direct Costs	$ 175,283,236.52	$ 1,347,951.70	$ 613,968.00	$ -	$ -	$ -	$ 105,422,368.78	?
Total MTDC	$ 24,426,015.80	$ 1,347,951.70	$ 613,968.00	$ -	$ -	$ -	$ 4,850,888.30	?
FINAL COST CALCULATIONS								
Total F&A	$ 2,442,601.58	$ 134,795.17	$ 61,396.80	$ -	$ -	$ -	$ 2,638,793.55	?
Total Projected Cost	$ 177,725,838.10	$ 1,482,746.87	$ 675,364.80	$ -	$ -	$ -	$ 179,883,949.77	
Total Cost Margin	$ 53,317,751.43	$ 444,824.06	$ 202,609.44	$ -	$ -	$ -	$ 53,965,184.93	?
Total Project Cost	$ 231,043,589.53	$ 1,927,570.93	$ 877,974.24	$ -	$ -	$ -	$ 233,952,374.7	?
						Money Left	$ 16,047,625.30	***250M Budget***

********** Do not change percentages in the boxes below unless mission concept instructions specify otherwise.

F&A %	10%	10%	10%	10%	10%	10%					
Manufacturing Margin	50%	50%	50%	50%	50%	50%					
Total Cost Margin	30%	30%	30%	30%	30%	30%					
ERE - Staff	28%	28%	28%	28%	28%	28%					

Name	Location	Airport	Flight Cost (Round Trip)	Flight Number			
Sandibell Vega	New York	JFK	$97.00	B6 1584		Information Sources:	Expedia
Andy Zhou	New York	JFK	$97.00	B6 1584			Budget Car Rental
Alexander Diepp	Orlando, FL	-	$0.00	-			
Rajaa Elhassan	New York	JFK	$97.00	B6 1584			
Matthew Swanso	Morgantown WV	PIT	$139.00	NK 2652			
Sanja Kirova	Boston MA	BOS	$30.00	F9 1238			
Luis Rivera	Utuado, Puerto F	SJU	$101.00	NK 1263			
Alex Xu	New York	JFK	$97.00	B6 1584			
Melany Evangelis	Fairfax VA	DCA	$97.00	B6 2224			
Nimra Shakoor	Ithaca NY	ITH	$174.00	AA 5638			
Jennifer Barkley	Fayetteville, NC	FAY	$204.00	AA 5470			
Alberto Leon	Woodland Park,	EWR	$44.00	F9 1259			
Robert Minor	Chester, WV	PIT	$139.00	NK 2652			
	Multiplier	**200%**	$1,316.00	<- Subtotal			
		Total	$2,632.00				

Hotel Info			
Name	Country Inn & Suites by Radisson, Port Canaveral, FL		
Rate (per night)	$131	Single Room/Suite, King Bed	
Nights	4		
Rooms	13		
Total	**$6,812**		

Meals		Days	Subtotal
Per Diem	$71	4	$284
Reduced	$53	2	$107
People	13		
		Total:	$5,077

Car Rental				
Length	6 Days			
Company	Budget Car Rental			
Vehicle	Compact			
Number	10			
Price/Vehicle	$158.36	COVID-19 Price Adjustment:		100%
Total	$3,167.20			

Testing Costs							
Item	Price	Quantity (If Applicable)	Cost	Source	Attention	Factor	3
H2SO4 (2.5 L)	$97.00	400	$38,800.00	https://www.grainger.com/product/L		**Total:**	**$74,141,427.48**
HF (2.5 L)	$70.00	400	$28,000.00	https://www.grainger.com/product/9			
HCl	$20.34	400	$8,136.00	https://www.grainger.com/search/lal			
Wind Tunnel - General Occupancy (Hours)	$650.00	600	$390,000.00	https://www.aa.washington.edu/AER			
Wind Tunnel - Electronic Pressure Scanning (Per Test	$2,500.00	100	$250,000.00	https://www.aa.washington.edu/AER			
Wind Tunnel - Internal Forces (Per Test)	$2,500.00	100	$250,000.00	https://www.aa.washington.edu/AER			
Wind Tunnel - High Pressure Air Supply (Per Test)	$2,500.00	100	$250,000.00	https://www.aa.washington.edu/AER		(Wind Tunnel Subtotal):	$1,277,600.00
Wind Tunnel Pre-Test Hourly Consultation (Per Test)	$125.00	200	$25,000.00	https://www.aa.washington.edu/AER			
Wind Tunnel Trip Dots (Ft)	$17.00	800	$13,600.00	https://www.aa.washington.edu/AER			
Wind Tunnel Formal Test Report	$330.00	300	$99,000.00	https://www.aa.washington.edu/AER			
Tension Testing Machine	$2,845.25	2	$5,690.50	https://www.abqindustrial.net/store/			
Thermal-Vacuum Testing (20' diameter, 100m) (estir	$5,000.00	200	$1,000,000.00	https://www.nasa.gov/centers/johns			
Vibration Testing for Payload (estimate)	$3,000.00	100	$300,000.00				
Validation Testing and Data collection	$403,916.25	1	$403,916.25	https://www.nasa.gov/sites/default/f			
General Shipping for Testing	$200,000.00	1	$200,000.00	https://westerncontainersales.com/s			
Plasma ArcJet	$1,000.00	800	$800,000.00	https://www.nasa.gov/centers/ames/			
Structural Shock Testing	$800.00	600	$480,000.00	https://www.nts.com/services/testin			
PCB Electronics Testing	$40,000.00	70	$2,800,000.00	https://www.fictiv.com/articles/crash			
Drop Testing	$200.00	200	$40,000.00	https://www.itc.mb.ca/wp-content/u			
Impact Testing	$130.00	100	$13,000.00	https://www.itc.mb.ca/wp-content/u			
Coating Testing	$150.00	100	$15,000.00	https://www.itc.mb.ca/wp-content/u			
UV Exposure Testing	$5.00	800	$4,000.00	https://www.itc.mb.ca/wp-content/u			

Manufacturing and Assembly Costs (Refer to "Parts List" Spreadsheet)								
Item	**Unit Price**	**Quantity**	**Cost**	**Source**	**Need Attention?**		**Factor**	**3**
Sewing/lasermelting	$125.00	200	$25,000.00				**Total:**	**$26,430,053.00**
Welding; form-pressed;	$125.00	400	$50,000.00	Advance Manufa				
Welding of structure; po	$125.00	400	$50,000.00	Advance Manufa				
Additional Manufacturir	$1,000,000.00	1	$1,000,000.00					
Employee/Worker Insura	$600.00	468	$280,800.00	$600/month/per				
PPE (COVID-19 Related a	$2,500.00	36	$90,000.00	$2500/month. As				
PCB Manufacturing	$25.00	1000	$25,000.00	https://pcbshopp				
Soldering	$2.00	1000	$2,000.00	https://pcbshopp				
PCB and General Electro	$44.00	1000	$44,000.00	https://pcbshopp				
Aluminum friction weldi	$125.00	400	$50,000.00	Advance Manufa				
Aluminum Form-Pressin	$125.00	400	$50,000.00	Advance Manufa				
Aluminum form-pressing	$125.00	400	$50,000.00	Advance Manufa				
Aluminum precision cutt	$100.00	600	$60,000.00	https://www.the				
Aluminum precision mill	$80.00	600	$48,000.00	https://prototecl				
Aluminum precision lath	$3,000.00	24	$72,000.00	Lathe Rental fror				
Titanium precision millir	$60.00	1000	$60,000.00	https://www.cre				
Titanium precision cuttir	$45.00	800	$36,000.00	https://www.rad				
Titanium precision lathir	$45.00	800	$36,000.00	https://www.rad				
Titanium precision drillir	$45.00	800	$36,000.00					
Aluminum precision drill	$100.00	600	$60,000.00					
Deburring tool	$1,868.13	10	$18,681.30	https://www.ms				
Linear Explosive Charge	$30.00	800	$24,000.00	https://www.bls.				
Balloon Sewing	$125.00	200	$25,000.00					
Parachute sewing	$125.00	200	$25,000.00					
Balloon Manufacturing	$125.00	200	$25,000.00					
Heresite coating	$55.00	1000	$55,000.00	https://rahnindu				
Software Development /	$30.00	800	$24,000.00					
ANSYS CAD and Analysis Software	$10,000.00	20	$200,000.00					
Computer Simulation	$0.12	819200	$98,304.00	https://www.sab				
General Data Analysis software	$860.00	27	$23,220.00	https://www.ma				

Materials (For Full Details refer to "Parts List" spreadsheet)

Part	Unit Price	Quantity	Cost	Source	Need Attention?			
							Factor	3
Titanium (Grade 5) sheets	$300.24	20	$6,004.80	https://www.cali			**Total:**	$2,425,444.15
Titanium (Grade 5) Rods	$106.62	20	$2,132.40	https://www.cali				
Helium	$422.60	4	$1,690.40	https://www.gra				
Aluminium 6061 sheets (43 :	$662.02	4	$2,648.08	https://store.buy				
Aluminium 6061 sheets (56 :	$413.45	2	$826.90	https://store.buy				
Teflon cloth matrix	$66.99	2	$133.98	https://www.am				
Al2O3 Balloon and Solar Coa	$225.00	6	$1,350.00	https://materion				
PTFE coating	$50.00	24	$1,200.00	-				
Titanium metal matrix comp	$11,000.00	30	$330,000.00	AAE American				
Tantalum	$1,178.60	300	$353,580.00	https://www.mc				
Mylar	$184.00	2	$368.00	https://www.gra				
Aluminium Reflective Coatin	$56.00	2	$112.00	https://www.hor				
Cable Covering	$500.00	1	$500.00	https://www.gor				
Ammonia coolant	$33.50	4	$134.00	https://www.gra				
Argon gas	$215.00	10	$2,150.00	-				
Protective braids for cable c	$500.00	2	$1,000.00	https://www.gor				
			$0.00					
AZ-93 Thermal Coating	$2,500.00	1	$2,500.00					
General Mechanical Compor	$21,663.87	1	$21,663.87	https://www.nas				
316 steel pipes, PEX pipes, fi	$1,000.00	1	$1,000.00	https://www.gra				
Kapton Tape	$125.00	2	$250.00	https://www.kap				
Heresite	$100.00	1	$100.00	https://www.her				
Copper	$50.00	1	$50.00					
Linear Explosive Charge	$4,034.00	1	$4,034.00	https://www.eba				
Liquid Helium Dewar	$900.00	1	$900.00	https://www.mc				
Thermablok thermal Insulation	$300.00	16	$4,800.00	https://testsite.t				
Aerogel solid material	$450.00	8	$3,600.00	http://www.buya				
Heat-resistant gasket material (Chassis A)	$135.00	3	$405.00	https://mtigaske				
Heat-resistant gasket material (Chassis B)	$226.00	3	$678.00	https://www.mc				
Copper	$56.65	3	$169.95	https://www.mc				
Pyrogel	$300.00	25	$7,500.00	https://www.the				
Parachute material	$13,000.00	2	$26,000.00	https://www.avi				
Teflon cloth matrix	$155.00	200	$31,000.00	https://standartp				

Commercial Off-The-Shelf Parts

Item	Price	Quantity	Cost	Source	Need Attention?		Factor	3
C/TT-505 UHF Command/Telemetry Transceiver	$21,000.00	2	$42,000.00	https://www.l3h			**Total:**	**$12,690,946.57**
Temp-Sensor Cable 25' for C-110S, C-440S, C-100,	$31.00	100	$3,100.00	https://www.avi				
Humidity tempeature sensor	$29.50	4	$118.00	https://www.goo				
"194-104QBR-G01 Honeywell - Thermistor"	$14.94	2	$29.88	194-104QBR-G01				
Solar panels & arrays	$400.00	8	$3,200.00	http://www.spec				
Lithium-Ion batteries	$800.00	6	$4,800.00	https://www.ene				
Sulfuric acid filter	$50.00	4	$200.00	SupplyHouse				
Sulfuric acid vapor neutralizer (2 L)	$188.00	2	$376.00	Grainger				
316 steel pipes, fittings, etc.	$1,000.00	2	$2,000.00	https://www.gra				
Kevlar Rope	$43.20	2	$86.40	https://www.usr				
0.05 micron UPE filter	$50.00	20	$1,000.00	https://www.ent				
0.1-1 micron UPE filters	$50.00	20	$1,000.00	https://www.cob				
1-4 micron UPE filters	$40.00	20	$800.00	https://www.cob				
1/125 hp HP Diaphragm Compressor Pump	$220.00	1	$220.00	https://www.gra				
Diaphragm pump	$300.00	1	$300.00	https://www.gra				
0.5 Gallon tank	$40.00	1	$40.00	https://www.via				
Electronic Control Valves	$104.29	6	$625.74	https://www.mc				
PICA Tiles	$5,408.73	12	$64,904.78	https://fibermat				
Mechanical Seals	$27.00	10	$270.00	https://www.mc				
Data Logger	$1,357.00	1	$1,357.00	https://www.ni.c				
High Voltage Cable	$100.00	1	$100.00	https://global-se				
Low Voltage Cable	$12.89	1	$12.89	https://www.ces				
Accelerometer	$30.00	1	$30.00	https://www.nas				
Gyroscope	$30.00	1	$30.00	https://www.nas				
Surface Thermocouples	$470.00	12	$5,640.00	https://www.goo				
Radar Sensor	$16,983.53	1	$16,983.53	https://www.nas				
Methane Sensor	$7,385.54	1	$7,385.54	https://www.nas				
Oxygen Sensor	$7,385.54	1	$7,385.54	https://www.nas				
Particle sensor	$2,581.64	1	$2,581.64	https://www.nas				
Pyroelectric detector	$2,581.64	1	$2,581.64	https://www.nas				
Magnetic current detector	$2,581.64	1	$2,581.64	https://www.nas				
MEMS Air Flow Sensor	$5,741.82	1	$5,741.82	https://www.nas				
Check Valve - Flow Sensor	$2,581.64	1	$2,581.64	https://www.nas				
Ambient Light Sensor	$1,709.32	1	$1,709.32	https://www.nas				
Fiber Optic Cables	$100.00	30	$3,000.00		Assuming needs 30m of cabling			
Valve controller	$1,428.00	1	$1,428.00	https://www.sie				
Check Valve (Resistant to cold temps ~4 K)	$2,018.89	1	$2,018.89	https://www.nas				
SLA 561V (ablator for backshell)	$14,187.74	1	$14,187.74	https://www.loc				
Ty-Rap Cable Ties (steel/heat/chemical resistant zip ties for cable management)	$130.00	18	$2,340.00	https://www.abb				
Parachute controller (electronics)	$927.98	2	$1,855.97	https://www.nas				
Aeroshell controller (electronics)	$927.98	2	$1,855.97	https://www.nas				
Cooling controller (electronics)	$927.98	2	$1,855.97	https://www.nas				
Low Gain Antenna	$2,500.00	4	$10,000.00		Source			
High Gain Antenna	$2,500.00	4	$10,000.00		Source			
Cost of Material Adjust for Venus Atmosphere	$2,000,000.00	2	$4,000,000.00					

Instruments (For Full Details refer to "Parts List" spreadsheet)								
Item	**Price**	**Quantity**	**Cost**	**Source**	**Need Attention?**	**Note**	**Factor**	**3**
HIPWAC	$25,000.00	2	$50,000.00	https://kups.ub.u		See HIPWAC	**Total:**	**$6,753,399.00**
Polarimeter	$1,133.00	1	$1,133.00	https://www.fish				
Mass Spectrometer (estimate)	$100,000.00	2	$200,000.00	https://www.the				
Other Instruments (placeholder estimate)	$2,000,000.00	1	$2,000,000.00					

Item	Qt.	Price	Cost	Source	
Gas Laser	1	120	120	FARO technolo	https://omtechlaser.com/products/40w-co2-laser-tube-usb-3020-40?variant=31899651080257&currency=USD&utm_medium=product_sync&utm_source=googl
optical attenuat	1	30	30	Thorlabs	https://www.thorlabs.com/thorproduct.cfm?partnumber=FA10T-APC
flip mirror	2	227	454		https://www.bhphotovideo.com/c/product/1540132-REG/alpine_astronomical_bfm_ii_baader_flipmirror_ii_star.html/?ap=y&ap=y&smp=y&smp=y&lsft=BI%3A51
spectrum analy	1	4102	4102	Textronics	https://www.valuetronics.com/product/rsa306b-tektronix-spectrum-analyzer-new?gclid=CjwKCAiAg8OBBhA8EiwAlKw3kk-U67NvF2bHHeQSIizWCjdAKa5ReXY
beam splitter (p	1	400	400	Thorlabs	https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=7657
dichroic mirror	1	300	300	Thorlabs	https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=3313
mirror	1	400	400	Thorlabs	https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=6835
IR mixer detect	1	4449	4449	Thorlabs	https://www.thorlabs.com/thorproduct.cfm?partnumber=PDA10JT
optical CCD gu	1	5026	5026	Thorlabs	https://www.thorlabs.com/thorproduct.cfm?partnumber=340UV-GE&gclid=CjwKCAiAg8OBBhA8EiwAlKw3ko6cvZph_Y5ZRNCaxqOm2MrbNTpmiA0B3OzwPD_
chopper systen	1	1294	1294	Thorlabs	https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=287
chopper wheel	2	100	200	Thorlabs	https://www.thorlabs.com/newgrouppage9.cfm?objectgroup_id=287
Acousto - optica	1	6000	6000	estimate	
		Total	22775		

Outreach							
Item	**Budget**	**Quant**	**Cost**	**Source**			
Team Member Lodging (	$135.00	40	$5,400.00	https://www.gsa		**Total**	**$103,240.00**
Meals (Per Day)	$71.00	40	$2,840.00				
Transportation	$5,000.00	1	$5,000.00				
Social Media Manager	$80,000.00	1	$80,000.00				
Merchandise	$10,000.00	1	$10,000.00				

The budget was calculated by creating different sections using the tabs of the budget spreadsheet and compiling them into a budget estimate. The budget was broken down into operations cost and development cost. Operations includes team salary, travel, lodging, meals, and outreach program. Development costs include testing, manufacturing, materials, commercial off-the-shelf (COTS), and instruments. For each category, the ability to produce and test 3 prototypes was factored in. The total budget (including margins) was **$233,952,374.70.**

Operations:

1. Salary
    a. There are 13 team members divided into the Science team, the Engineering team, and the Business Administration team. All team members work full time in the first two years to support mission development. In the third year, only one member of the Engineering team and one member of the Business Administration team work full time for post-launch support.
2. Outreach
    a. A total of $103,240.00 is reserved for outreach efforts. This includes lodging, meals, and transportation costs for team members to use for outreach at schools as well as a salary for an outreach director / social media manager.
3. Travel Costs (Launch)
    a. This budget accounts for the cost of airline tickets, 4 nights at the Country Inn & Suites by Radisson (Port Canaveral, FL), and meals for all 13 team members. Also included is car rental fees for 10 compact cars.

Development:

1. Manufacturing
    a. Includes outsourced manufacturing and facility costs for mission development. Examples include welding, 3D printing, cutting, form-pressing, sewing, laser melting, and assembly.
        i. The chassis of both payload and vehicles will require cutting, form-pressing, welding, and assembly.
        ii. The super-pressure helium balloon will require advanced sewing and possibly laser melting to form the correct balloon geometry.
        iii. The low voltage and power circuits will require advanced soldering, testing, and assembly.
2. Testing
    a. Includes cost of using external facilities or purchasing testing equipment. This includes materials for chemical tests, stress test machines, wind tunnel fees, and thermal-vacuum testing fees.
        i. These tests must show that:
            1. The balloon can maintain the desired altitude at simulated conditions for a minimum of 20 days.
            2. All of the materials are resistant to corrosion, especially from sulfuric acid, hydrofluoric acid, and hydrochloric acid.
            3. The filtration and temperature-controlling systems can maintain constant conditions.
            4. The payload and vehicle can move predictably in hurricane-speed winds.
            5. The electrical circuits can operate in Venus-like conditions with the flux found in the 50-70 km altitude layer of atmosphere.
3. Materials
    a. Includes cost of raw materials. A complete list can be found on the spreadsheet.The $250 million NASA grant would enable the development and

operation of this atmospheric mission to Venus. To determine the expected cost, historic mission expenses were analyzed, namely the Vega balloons and MRO. The expenses listed below are not all-inclusive, so generous margins were utilized.

b. There are significant cost items on and off the vehicle and payload that are vital to success. This section will expand on these costs and provide supporting information on these items. These items are not required for each prototype but complete the picture of expenses over the entire mission period.
   i. Vehicle
      1. The vehicle will be the main mode of transportation of the payload on Venus.
      2. Altitude and Orbit Control System
         a. In order to maintain the desired altitude, a helium-filled super pressure balloon design was chosen. This balloon is designed to fly with a positive internal pressure at all times and can carry a 175kg load. The materials for this balloon include Mylar (inner layer), teflon film (for anti-corrosion protection), and Technora (sewing and tendon shaping fiber as an alternative to Kevlar).
      3. Chassis
         a. The vehicle chassis is made of aluminum sheets PTFE hard coat anodized in order to withstand harsh conditions. The chassis will be form pressed to fit certain components and laser cut and welded to provide structural support.
      4. Power
         a. Extending solar arrays on two sides of the vehicle will provide enough power for all of the electronics. The solar arrays will be prepared for harsh Venus conditions with Al_2O_3 coating. In addition, a lithium ion battery will be included in an airtight and controlled environment enclosure to provide power during night-time travel.
         b. All circuits, wires, and cables will be enclosed in or covered with corrosion and heat resistant materials.
   ii. Payload
      1. The payload contains all of the experiments on Venus.
      2. Chassis
         a. The payload chassis is made of titanium sheets. The titanium sheets will be form pressed to fit various parts of the scientific instruments which require temperature and pressure control.
         b. Various openings for instrument exposure will be made and sealed using a series of compressed o-rings (included in miscellaneous hardware).

4. Science Instrumentation
   a. Cost for science instrumentation (some are off-the-shelf), and the cost associated with adapting those instruments for mission-related use on Venus. To account for this, instrument costs were doubled.
5. COTS
   a. Includes cost for commercial-off-the-shelf components, and all costs associated with adapting those instruments for use on Venus.

6.2 Schedule

Table 14

Full Team Schedule

Start	Phase
01/12/2021	**Pre-Phase A: Conceptual Study**
02/08/2021	**Phase A: Preliminary Analysis** ● 02/08/21–02/15/21—Milestone 1: Proposal & Summary
02/16/2021	**Phase B: Definition** ● 02/16/21–02/22/21—Milestone 2: Activity Plan ● 02/23/21–03/14/21—Milestone 3: Descent Maneuver & Vehicle Design, Payload Design & Science Instrumentation ● 03/15/21–03/21/21—Milestone 4: Safety ● 03/22/21–04/07/21—Milestone 5: Preliminary Design Review ● 04/08/21–04/16/21—Milestone 6: Video Presentation
04/20/2021	**Phase C/D: Design & Development** ● 04/20/21–08/02/21—Critical Design Review ● 08/05/21–09/01/21—Order Parts ● 08/15/21–12/10/21—Manufacturing ● 10/15/21–01/29/22—Test Readiness Review
02/02/22	**Phase E: Operations** ● 02/02/22–06/15/22—Testing ● 02/02/22–06/15/22—Outreach Initiatives ● 07/01/22–09/15/22—Assembly, Test, & Launch Operations ● 09/01/22–10/01/22—Ship Parts for Launch
10/28/2022	**Mission End** ● 11/19/22–11/26/22—Team Arrival & Launch Preparations ● 11/29/22—Launch ● 02/20/24–03/20/24—Arrival to Venus & Data Collection ● 03/25/24–07/01/25—Data Analysis

6.3 Outreach Summary

The team has devised two ways to maximize outreach with the general public. Firstly, they will create social media accounts dedicated to the mission launch. With an Instagram account, the first post will be detailing the team's mission concept and the significance of completing this mission. The team would like for NASA's instagram account to post about their account on their page as well, as their 65 million followers could give great publicity to the launch. After that, a post will be devoted to each team member and their role in this launch. Once the intros are completed, pictures about Venus along with facts detailing how Venus functions will continue to be posted in efforts to show how fascinating learning about one of Earth's sister planets is. The final week before launch will be dedicated to posting all the different steps that had to be completed in order to have a fully functional and successful launch, with each day being a new step.

The team also wants to interact with surrounding schools and universities. Select members will meet with several schools, ranging from middle school all the way to university. The priority is to expose all the different grade levels to the mission and aerospace/physics. For 6th to 8th graders, an assembly can be held teaching about NASA and the career of physics/aerospace along with the launch and goal and answer any questions they have about it. The group will finish off the assembly by giving a few lucky students (<50 across all middle schools) the chance to come down and watch the launch (accompanied by a parent/guardian).

The same will occur with high school students, but rather having an assembly, the team will simply visit students during their STEM classes. The main focus will be speaking on aerospace and hopefully exposing it to any potentially bright students who just haven't had the chance to learn about aerospace engineering and physics in general. Once again, they will offer them limited invites to the launch (<100 across all high schools). The team also collectively decided to offer only the high school students a field trip to visit their lab on a later date.

To decide who will be invited to bring to the launch, they will allow all the students who would like to attend to write their names down and simply choose the winners at random by using a generator website to be as fair as possible. All the winners will have their expenses paid and will be given special access with the launch and even memorabilia after, to ensure they do have a memorable and overall enjoyable time at the launchsite.

Finally, for college students, once again focusing on students in the STEM fields, the team will invite all Florida universities' STEM students to come down to the launch, demonstrating to them what fellow college students have been able to accomplish with this launch and meet with experts and learn more about the program. The team still wishes for the rest of the nation and other countries to be a part of the launch as well, which is why they will be livestreaming the launch globally. Once the launch is completed however, the team still wants the public to be a part of their mission, and propose an experiment that requires their assistance. Since their launch deals with using a weather balloon to monitor the atmospheric health of Venus, it'd seem right to have communities around the nation monitor their atmospheric health too. The atmosphere of Earth is what supports life and is needed for the water cycle and the weather. With places like California, which had massive wildfires occur in 2020 with major levels of CO_2, would be a great example to see how the health of their atmosphere is as of now. Gathering all the atmospheric data around the US and then comparing it to Venus's can show some drastic results and how humans are able to live on Earth in comparison to Venus.

6.4 Program Management Approach

To form the team organization, a list of the available positions was posted, and team members were encouraged to fill their names into the box next to the title that was wished to be held, or the sub team the member was interested in being a part of. The group decided that each person was to select two positions: a first choice, and a back up plan. For the positions that only required one person, if multiple people wished to have that position, each individual was allowed to state what would be brought to that position. The team then allowed the group to ask questions and interview potential candidates. Once speeches and interviews were concluded, there was an anonymous voting system to allow team members to vote on the candidate of choice for the role.

The team leads are empowered to lead the respective teams in the manner that is desired. Creativity and multiple opinions and ideas are encouraged to be brought to the table. The team's overall view is that healthy opposition drives innovation. This has been a great approach and produced on-time results. On the occasion issues do arise, team leaders are encouraged to facilitate conversations with the members on the team to reach a mutual decision that suits the big picture. The leadership team has a solid view that the group is dedicated to the project and the team.

The team works in multiple modes, from a total team effort, a sub-team effort, and an individual effort. Tasks are broken up among sub-teams and then assigned to a team member within that sub-team. The individual is given clear and concise expectations for their work. Individuals have the support and backing of the team to be able to work and bring ideas to the team with confidence. The team operates in a servant-style manner, offering assistance to fellow team members at every turn. This empowering approach allows individuals to operate at full potential, and drives engagement and project excitement.

The team has a fair amount of pride in the great communication shared among members. With the help of Discord, Zoom, Trello, Google Drive and e-mail, the team is in constant communication both inter-departmental and as a whole. A Gantt chart is the team's road map. The chart dictates the what and when of the tasks. Generally, tasks are selected by what the team member wishes to work on. The team leads will assign and distribute tasks as necessary should anything that may hinder progress arise.

Figure 42

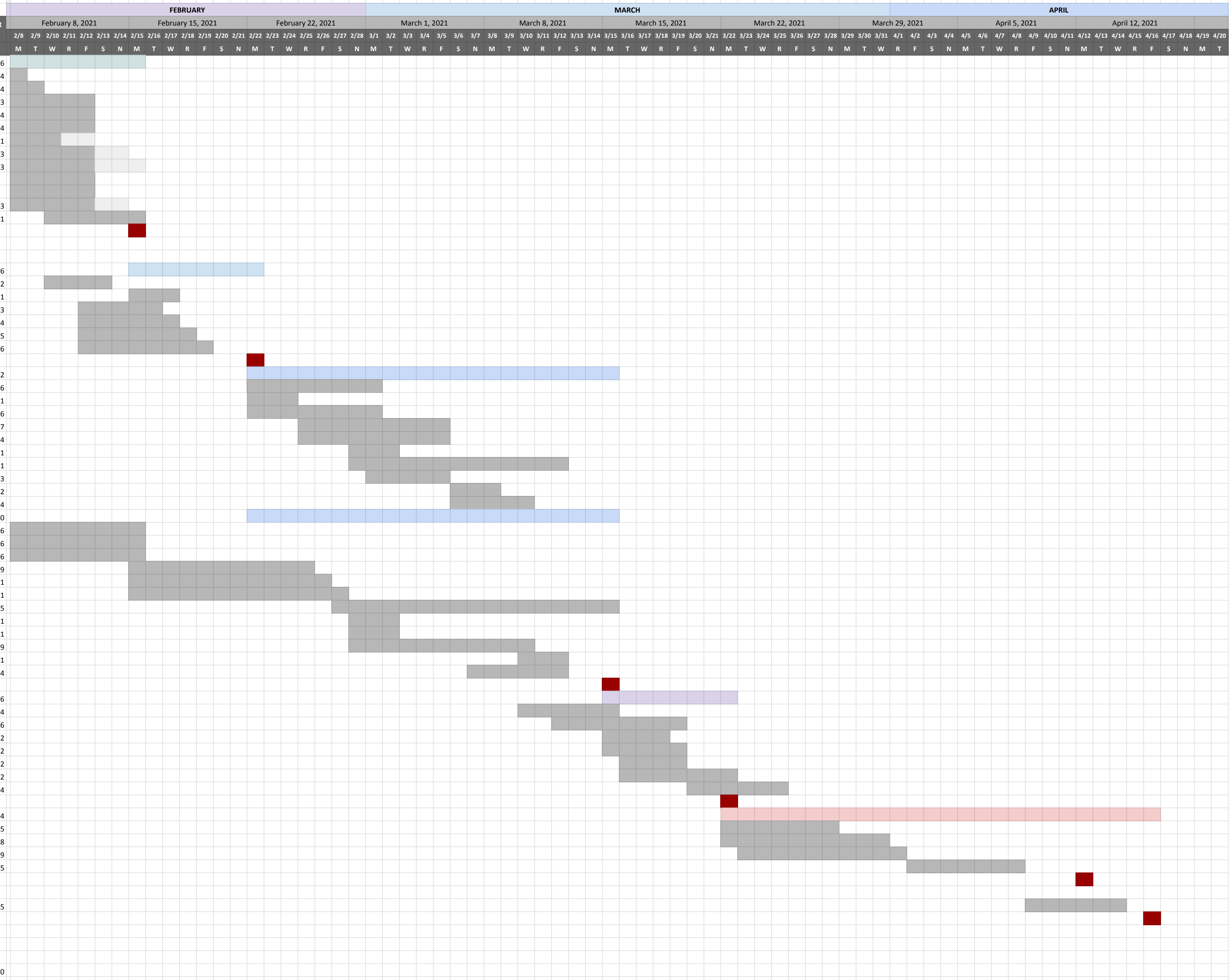
Team Structure

Table 15

Gantt Chart

Sky Walkers
Team #16
Members: Robert Minor, Matt Swanson, Jennifer Barkley, Nimra Shakoor, Sanja Kirova, Rajaa Elhassan, Alexander Dieppa, Alberto Leon, Sandibell Vega, Luis Rivera Gabriel, Alex Xu, Andy Zhou, Melany Evangelista

DELIVERABLE	TASK	DRI	PROGRESS	START	END	DAYS	MARGIN
	Conceptualize - Section 1		92	2/8	2/15	6	0.6
Schedule	Create Gantt Chart	All		2/3	2/8	4	0.4
Discussion	Research Venus atmosphere	All		2/4	2/9	4	0.4
Section 1.1	Define the experiment scope and purpose of research/rev	Matt, Alex		2/5	2/9	3	0.3
Section 1.2	Compose the mission overview	Alex		2/5	2/10	4	0.4
Section 1.1	Write team introductions	Matt		2/5	2/10	4	0.4
Section 1.2.3	Outline Criteria and Constraints for vehicle and payload	Andy, Sa	100	2/8	2/10	1	0.1
Section 1	Conceptualize vehicle design and write summary	Alex D, I	100	2/8	2/12	3	0.3
Section 1.2.4	Outline and draft Concept of Operations	Sanja	100	2/8	2/12	3	0.3
Section 1.2.5	Create major milestones schedule	Alberto					
Section 1.4	*Payload and Science Instrumentation Summary*	*Science*					
Section 1	Draft Payload and Science Instrumentation Summary	Andy	80	2/8	2/12	3	0.3
Section 1	Determine and produce graphic for the descent maneuve	Alex D, A	80	2/10	2/12	1	0.1
	Submit Drafted Section 1 of PDR		☑		2/15		
	System Requirements Review						
	Mission Definition Review						
	Define - Section 6		72.14285714	2/15	2/22	6	0.6
Section 6.1	Research materials and component costs	Alex X		2/10	2/13	2	0.2
Section 6	Compile expected parts list (BOM)	All	72.14285714	2/15	2/17	1	0.1
Section 6.1	Organize budget	Alex X		2/12	2/16	3	0.3
Section 6.2	Organize schedule	Nimra		2/12	2/17	4	0.4
Section 6.3	Write outreach summary	Alberto		2/12	2/18	5	0.5
Section 6.4	Form program management approach	Robert		2/12	2/19	6	0.6
	Submit Drafted Section 6 of PDR		☑		2/22		
	Design - Sections 3&4DEW			2/22	3/15	20	2
Section 3	Complete entire CAD assembly of vehicle	Alex D, Andy		2/22	3/1	6	0.6
Section 4	Define payload success criteria	Sandibell, Sanja		2/22	2/24	1	0.1
Section 4	Complete entire CAD assembly of payload	Andy, Sanja		2/22	3/1	6	0.6
Section 4	Draft Manufacturing Plan for vehicle	Sanja		2/25	3/5	7	0.7
Section 3	Draft Manufacturing and Integration Plans for payload	Melany, Sandibell		2/28	3/5	4	0.4
Section 3	Generate Performance Characteristics and Predictions for	Alex D, Andy		2/28	3/2	1	0.1
Section 3	Perform FMEA and write Risk Mitigation	Melany		2/28	3/12	11	1.1
Section 3	Integrate the payload and vehicle (CAD)	Alex D		3/1	3/5	3	0.3
Section 4	Provide System Overviews	All		3/5	3/8	2	0.2
Section 4	Generate Performance Characteristics of payload			3/5	3/10	4	0.4
	Development - Sections 3&4						0
Section 4	Determine Science Payload Objectives	Robert		2/8	2/15	6	0.6
Section 4	Determine Creativity/Originality and Significance	Luis, Jennifer		2/8	2/15	6	0.6
Section 4	Determine Payload Success Criteria	Robert, Jennifer		2/8	2/15	6	0.6
Section 4	Test Experimental Logic, Approach, and Determine Methc	Rajaa		2/15	2/25	9	0.9
Section 4	Testing of Design and Calibration Measurements	Luis, Robert		2/15	2/26	10	1
Section 4	Determine Precision of Instrumentation, Repeatability of I	Rajaa, Jennifer		2/15	2/27	11	1.1
Section 4	Gather Expected Data & Perform Analysis	All		2/27	3/15	15	1.5
Section 4	Draft Verification and Validation Plan for vehicle	Melany, Andy, Sandib		2/28	3/2	1	0.1
Section 3	Draft Verification and Validation Plan for payload	Sandibell, Andy		2/28	3/2	1	0.1
Section 3	Design Recover/Redundancy System for vehicle	Alex D, Melany		2/28	3/10	9	0.9
Section 3	Provide system overview and maturity of design	Alex, Andy		3/10	3/12	1	0.1
Section 5	Perform hazard research/analysis	Alberto		3/7	3/12	4	0.4
	Submit Drafted Sections 3 and 4 of PDR		☐		3/15		
	Analysis - Section 5			3/15	3/22	6	0.6
Section 5.1	Review personell safety	Alberto		3/10	3/15	4	0.4
Section 5.1	Review vehicle/payload safety	Alberto		3/12	3/19	6	0.6
Section 5	Define Environmental Hazards - Vehicle Safety	Andy, Sanja		3/15	3/18	2	0.2
Section 5	Define Environmental Hazards - Payload Safety	Melany		3/15	3/18	2	0.2
Section 5	Propose Hazard Mitigation methods - Vehicle Safety	Alex D		3/16	3/19	2	0.2
Section 5	Propose Hazard Mitigation methods - Payload Safety	Sandibell		3/16	3/19	2	0.2
Section 5.2	Write experiment development process review	Nimra, Matt		3/20	3/25	4	0.4
	Submit Drafted Section 5 of PDR		☐				
	Communication - Section 2 and Presentation			3/22	4/16	24	2.4
Section 2.1	Evaluate evolution of mission experiment plan	Nimra		3/22	3/28	5	0.5
Section 2.1	Write conclusion	Matt		3/22	3/31	8	0.8
PDR	Finalize and compile bibliography and Materials Data Shee	All		3/22	4/1	9	0.9
PDR	Review (and revise) the PDR	All		4/2	4/8	5	0.5
PDR	Final PDR Report		☐				
	Preliminary Design Review						
Presentation	Create visual aid and script for Video Presentation	All		4/8	4/14	5	0.5
	Video Presentation		☐				
	Critical Design Review						
	System Integration Review						
	Operations Readiness Review						
	Primary Mission						0
	Extended Mission						0



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7 Conclusion

7.1 Mission Statement

This proposed mission would be a turning point in the understanding of the atmosphere of Venus, especially the range of the atmosphere that closely mirrors habitable Earth conditions. The mission would accomplish an investigation into phosphine gas and attempt to triangulate areas of abundance as a key indicator of origin. Additionally, this mission would collect data on various biomarkers and compounds of interest throughout the atmosphere and correlate these with geographical location. The mission would yield a topographical map of the atmosphere indicating varying concentrations of compounds in the atmosphere. This data could be used to coordinate future missions as well as confirm hypotheses about the history of Venus.

7.2 Vehicle Overview

The vehicle’s chassis was designed with ability to withstand compression, sulfuric acid resistance, ability to be airtight, and radiation resistance. Additionally, the vehicle will house various control systems such as an altitude control system (AOC). The primary mechanism of the altitude control system is its ability to maintain neutral buoyancy in the target altitude range. The AOC system will achieve this through use of a superpressure teflon cloth matrix balloon filled with helium and a parachute. As well as altitude control, the vehicle is also designed to have a passive thermal control system to maintain a functional temperature in the vehicle. The power and communications systems were also carefully designed with backup systems in place to prevent any failure modes in these systems.

7.3 Payload Overview

The payload mainly consists of four instruments as well as other control and communications systems. The first instrument in the payload is a modified version of the Mars Color Imager, MARCI. This device will be used to produce a global weather map of Venus as well as detect variations in ozone, dust clouds, and other gasses in Venus' atmosphere. The next instrument is an ion and neutral mass spectrometer, which will be exposed to the Venusian atmosphere in order to identify molecules in the atmosphere. This instrument will be similar to the Cassini Spacecraft's Ion and Neutral Mass Spectrometer and the Huygens' Gas Chromatograph Mass Spectrometer in design development, specifically referencing a CubeSAT design to develop a smaller and more suitable instrument. Another instrument used is a modified Heterodyne Instrument for Planetary Wind and Composition (HIPWAC) which would be used to measure the flow of winds and to detect various gasses in the Venusian atmosphere. The final instrument to be used in the payload is a Polarimeter, which will use optics to measure the direction and extent of the polarization of light reflected from their targets. Additionally, the payload will house various sensors for control systems such as an accelerometer, pyroelectric detector, and temperature sensors.

7.4 Future Plans

The next milestones the team would work towards after the approval of the PDR would be the development of prototypes for the Critical Design Review (CDR) as well as refining design decisions through testing and simulation. At the current stage of mission development, design selections were made through extensive research and discussion. However, through future testing, the team will likely change aspects of the design to overcome unforeseen challenges. This CDR development stage will be vital to the mission’s success and the team has several tentative plans for this stage.

Possibly the largest milestone for the next stage would be refining details of the design in the PDR to the fullest extent. This would entail researching and testing hardware development as well as finalizing manufacturing processes in order to achieve drawings and schematics of the vehicle and payload that follow professional standards as well as having the precision and detail necessary for a design at this stage. One important milestone would be compiling a final parts list after extensive prototypes, simulation, and analysis result in a final design. Additionally, after this testing process, the team would revisit any FMEA and Risk Mitigation Chart with newfound knowledge of unforeseen failure modes that arose during testing. Another milestone at this stage would be initial software development and plans for software implementation, as well as finalized electronics for the entire system. Lastly, another significant milestone would be development of instruments and instrument prototypes as remarkable adjustments are required to ensure the instruments can fulfill their purpose on Venus.

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