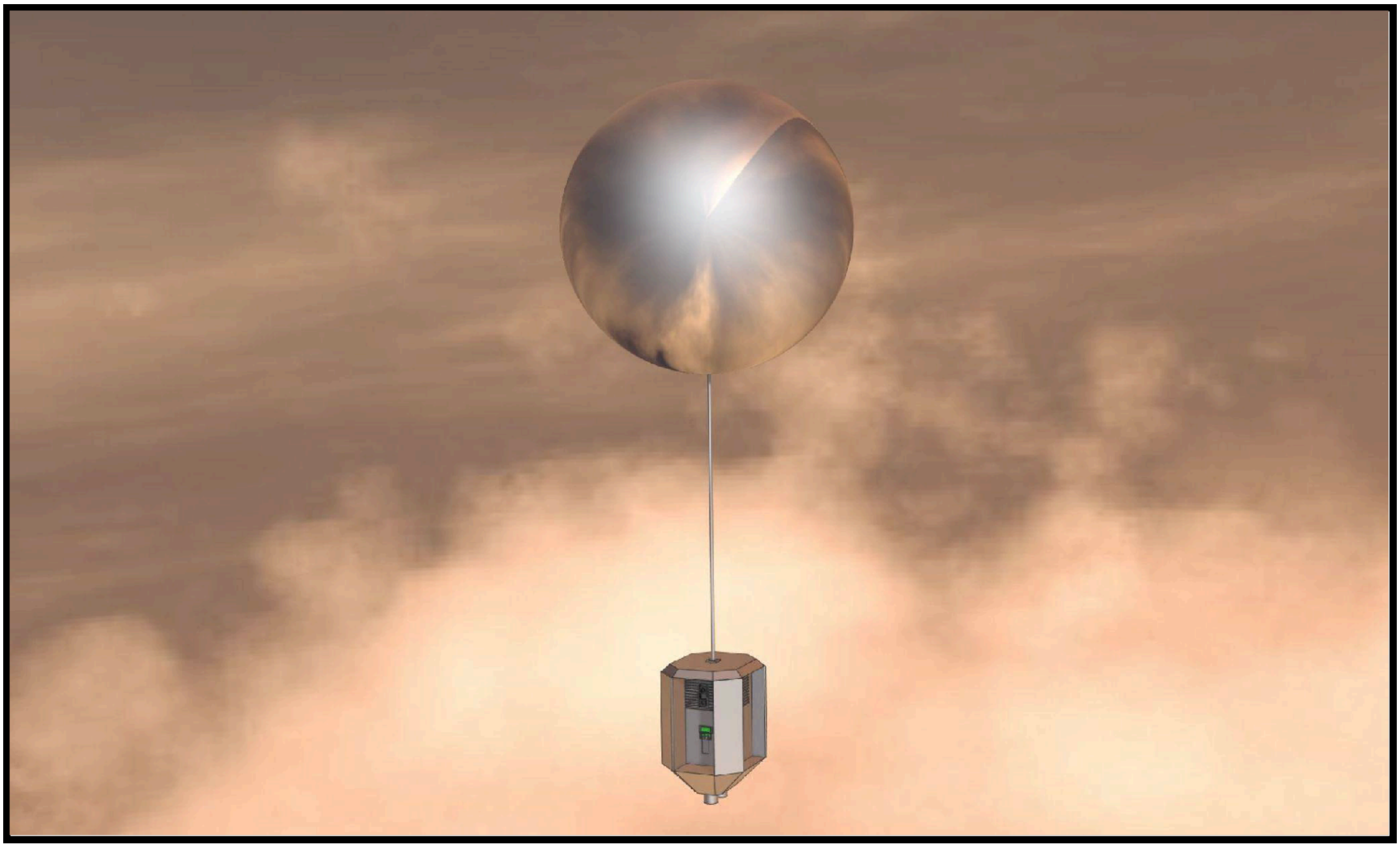
Venus Environmental Surveyor and Particle Analysis Aircraft (VESPAA)



Preliminary Design Review

<u>Team 8</u>

April 19, 2021

Table of Contents

1. Introduction and Summary **4**

1.1 **Team Introduction** **4**

1.2 **Mission Overview** **7**

1.2.1 Mission Statement 7

1.2.2 Mission Requirement 7

1.2.3 Mission Success Criteria 8

1.2.4 Concept of Operations 9

1.3 **Descent Maneuver and Vehicle Design Summary** **10**

1.4 **Payload and Science Instrumentation Summary** **14**

2. Evolution of Project **17**

2.1 Evolution of Mission Experiment Plan 17

2.2 Evolution of Descent Maneuver and Vehicle Design 17

2.3 Evolution of Payload and Science Instrumentation 18

3.1 Selection, Design, and Verification **20**

3.1.1 **System Overview** **20**

3.1.2 Subsystem Overview 23

3.1.3 Dimensioned CAD Drawing of Entire Assembly 24

3.1.4 Manufacturing and Integration Plans 27

3.1.6 FMEA and Risk Mitigation 30

3.1.7 Performance Characteristics and Predictions 35

3.1.8 Confidence and Maturity of Design 36

3.3 Payload Integration **38**

4. Payload Design and Science Instrumentation **47**

4.1 **Selection, Design, and Verification** **47**

4.1.1 System Overview 47

4.1.2. Subsystem Overview 49

4.1.3 Manufacturing Plan 56

4.1.4 Verification and Validation Plan 57

4.1.5 FMEA and Risk Mitigation 59

4.1.6 Performance Characteristics 65

4.2 **Science Value** **67**

4.2.1 Science Payload Objectives 67

4.2.2 Creativity/Originality and Significance 72

4.2.3 Payload Success Criteria 72

4.2.4 Experimental Logic, Approach, and Method of Investigation 74

4.2.5 Testing and Calibration Measurements 79
4.2.6 Precision of Instrumentation, Repeatability of Measurement, and Recovery System 81
4.2.7 Expected Data & Analysis 83

5. Safety **89**

5.1 **Personnel Safety** **89**
5.1.1 Safety Officer 89
5.1.2 List of Personnel Hazards 90

5.2 **Vehicle/Payload Safety** **92**
5.2.1 Environmental Hazards & Analysis 92
5.2.2 Hazard Mitigation 93

6. Activity Plan **95**

6.1 **Budget** **95**

6.2 **Schedule** **100**

6.3 **Outreach Summary** **103**

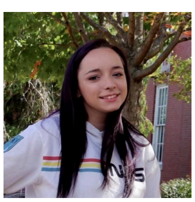
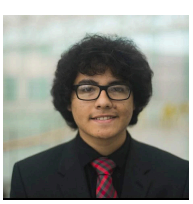
6.4 **Project Management** **104**

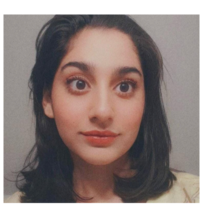
7. Conclusion **106**

References **108**

1. Introduction and Summary

1.1 Team Introduction

Team 8			
Name	**University**	**Location**	**Relative Experience**
 **Marco Thompson** Project Manager	Florida State College of Jacksonville / University of North Florida	Florida	Experience in public outreach through the Solar System Ambassador program and Planetary Society. Managed budgets and procurement working in e-commerce for a technology refurbishment company. Formed relationships with suppliers and provided customer service.
 **Matt Denet** Lead Engineer	Manhattan College	New York	CAD/FEA software experience: (NX, SolidWorks, Abaqus) Product and Mechanical Design Engineering - researching, modeling, 3D printing, and testing prototypes of various products; Research Project designing a prosthetic knee joint for transfemoral amputees. Programming/Coding software experience: (MATLAB, Arduino, Swift/XCode) Various coding, programming, and data collection projects; iOS app development
 **Juliette Gudknecht** Lead Scientist	Bloomsburg University	Pennsylvania	Senior Data Science and Physics major. Lots of experience in science research and data science coding. 2 years research on NASA kepler space telescope.
 **Jose Garcia**	Carnegie Mellon University	Pennsylvania	Internship with General Electric, worked on New Project Development for a new plane and presented to managers. Gantt charts, risk assessment. Treasurer for SHPE, CAD experience (Solidworks), 3D printing, Coding experience (python, C), ANSYS.

Deputy Project Manager			
 **Jacob Riek** Engineering	University of Central Florida	Florida	Aerospace and Mechanical Engineering, Design, Analysis, Controls, Robotics, CAD, CFD, FEA
 **Amelia Sharpe** Administration	University of Pennsylvania	Philadelphia	Computer Engineer skills to offer: Java Programming
 **Hee Ju Kim** Lead Administrator	University of Georgia	Georgia	Computer programming skills in Java and C++. Experience in database management using MySQL. Launched a web development project for a non profit. LaTeX documentation, MS Powerpoint. Organizational skills and customer service from working at a front desk.
 **Liying Wu** Administration	University of Florida	Florida	Proficient at excel, written communications. Graphic design experience, certified in MS PowerPoints.
 **Ayesha Kashif** Science	Hudson County Community College	New Jersey	Conducted team research on given topics. Beginner in programming languages Investigated sustainable information and conducted mathematical analysis

 **Elijah Weinstein** Engineering	Purdue University	Indiana	Senior in aerospace engineering. Experience with CAD, ANSYS, CEA, EES, MATLAB, Microsoft 365 Products. Mild experience with C, Python and Labview
 **Mark Farag** Engineering	Union County College	New Jersey	Experience in CAD, Inventory, MATLAB.
 **Harshil Jain** Engineering	Michigan State University	East Lansing	Mechanical engineering
 **Carter Fahey** Science Safety Officer	Boston University	Boston	Communication and public outreach skills from museum volunteer work and customer service jobs. Proposal/planning experience through NPWEE. Research experience with NASA GRC. Holds leadership/planning/outreach role in service organization.

1.2 Mission Overview

1.2.1 Mission Statement

The Venus Environmental Surveyor and Particle Analysis Aircraft (VESPAA)'s goals are to study the Venusian atmospheric aerosols and analyze its composition, create a detailed map and survey of the planet's environmental features, and listen for any seismic activities that may be occurring. These goals create insight into the processes that formed Venus' unique and complex planetary conditions, to understand Venus' past and current climate, future habitability, and current possible biological activities.

VESPAA will sample the atmosphere, conduct its environmental survey, and record infrasound data using a suite of proven heritage level instrumentation including spectrometers, thermal imaging, microphones, and cameras. The mission shall perform this for up to 30 days as it traverses the atmosphere within varying altitudes. This concept would provide enhanced data with higher detail than previous missions, as many of the experiments on the vehicle are only capable of being collected in situ. The collected data will be used to answer the many questions about climate change, how those processes occur within Earth's atmosphere, and the effect it has on the biological and geological environment. If life were to be discovered within Venus' atmosphere this would bring a deeper understanding of how life can evolve in extreme environments and the natural systems that can cause life to form.

1.2.2 Mission Requirement

- The mass of the VESPAA mission shall have a mass up to 175 kg (385.81lbs),
    - Currently under the mass limit at 111.11kg
- The volume of the VESPAA mission shall have a volume within the dimensions 60cm x 70cm x 90cm, since the spacecraft will be attached to the primary orbiter that will support a limited mass.
    - All constraints are met and have been appropriately configured
- The budget of the VESPAA mission shall remain $250M or less
    - The mission maintains this with cost that are < $21M
- the VESPAA mission spacecraft shall enter and remain in the Venusian Cloud Tops at an altitude of ~50 to 70km above the surface of Venus, in order to collect data about the atmosphere.
- the VESPAA mission spacecraft shall communicate directly to the orbiting spacecraft, which will relay the communications to Earth.
    - The vehicle will carry two transmitters to ensure transmission clarity and speed.
- the VESPAA mission shall be able to withstand environmental hazards present in the Venusian atmosphere such as weather patterns, atmospheric conditions (after arrival), or solar winds, radiation, etc.

    - The vehicle is coated to prevent corrosion and has minimal external moving parts.
- All personnel shall wear appropriate PPE (Personal Protective Equipment) when working near dangerous machinery during the production of the VESPAA mission.
- Verification testing shall be conducted starting from development until before launch, under conditions simulating the destination in order to ensure that the project will operate as intended.

1.2.3 Mission Success Criteria

For the mission to be considered successful, the following criteria must be held:

- Successfully enter the Venusian atmosphere and achieve a power safe state
- Travel in the Venusian atmosphere at a range of altitudes between 50km to 75km
    - Demonstrate altitude and translation control within the atmosphere
    - Utilizing a hybrid helium technique, the vehicle should be able to demonstrate altitude control; if not the vehicle with be able to conduct research at the fixed altitude
- Take thermal images of the clouds and surface at intervals of 10 km to observe atmospheric, environmental, and geological features.
    - Imaging data between 9-12 μm would be sufficient to collect data needed to detect geological features and record cloud temperature data.
- Utilize spectrometers to identity the chemistry and composition of atmospheric aerosols in each cloud layer, with data points for every 10 km
    - The composition of aerosols can be analyzed by spectrometers, and nephelometers visually by recording data generally ranging from 0.3-6 μm in resolution. This would be sufficient to catalogue many of the particles the vehicle would come in contact with.
- Record 100 hours + of sound waves with microphone, observing for seismic activities
- Remain airborne in higher altitudes (75km) to lower altitudes (50km) for around 20-30 days, and complete 6 revolutions of the planet.
    - The vehicle will need to discharge its non-replaceable power slowly and run certain instruments selectively to complete the required duration. The backup power supply can only run the vehicle and one of the instruments at a time.

1.2.4 Concept of Operations

Operations will begin once the vehicle has successfully completed its EDL maneuver and communications are established with the orbiter. The vehicle will conduct an altitude adjustment to 65km above the surface within the middle cloud layer. Once there the vehicle will test its scientific equipment by collecting a sample of the atmosphere using its mass spectrometers and nephelometer, turn on its thermal imager and microphone. After the instruments have been validated the vehicle will travel along its flight plan adjusting its altitude between 75km - 50km to sample the distinct cloud layers of Venus's atmosphere. This will allow for the analysis and comparison of aerosols of each layer. Also the thermal imaging systems shall survey and map the ground features and cloud conditions. The microphone aboard this vehicle will be used to observe and record any seismic activities. The vehicle will continue this flight pattern and data collection until it has used all of its available power which is estimated for a duration of 30 days and completing 6 revolutions of the planet. After the power is exhausted the craft will enter the lower atmosphere where it will no longer be able to send communications back to the orbiter, signaling the mission end.

Concept of Operations Graphic:

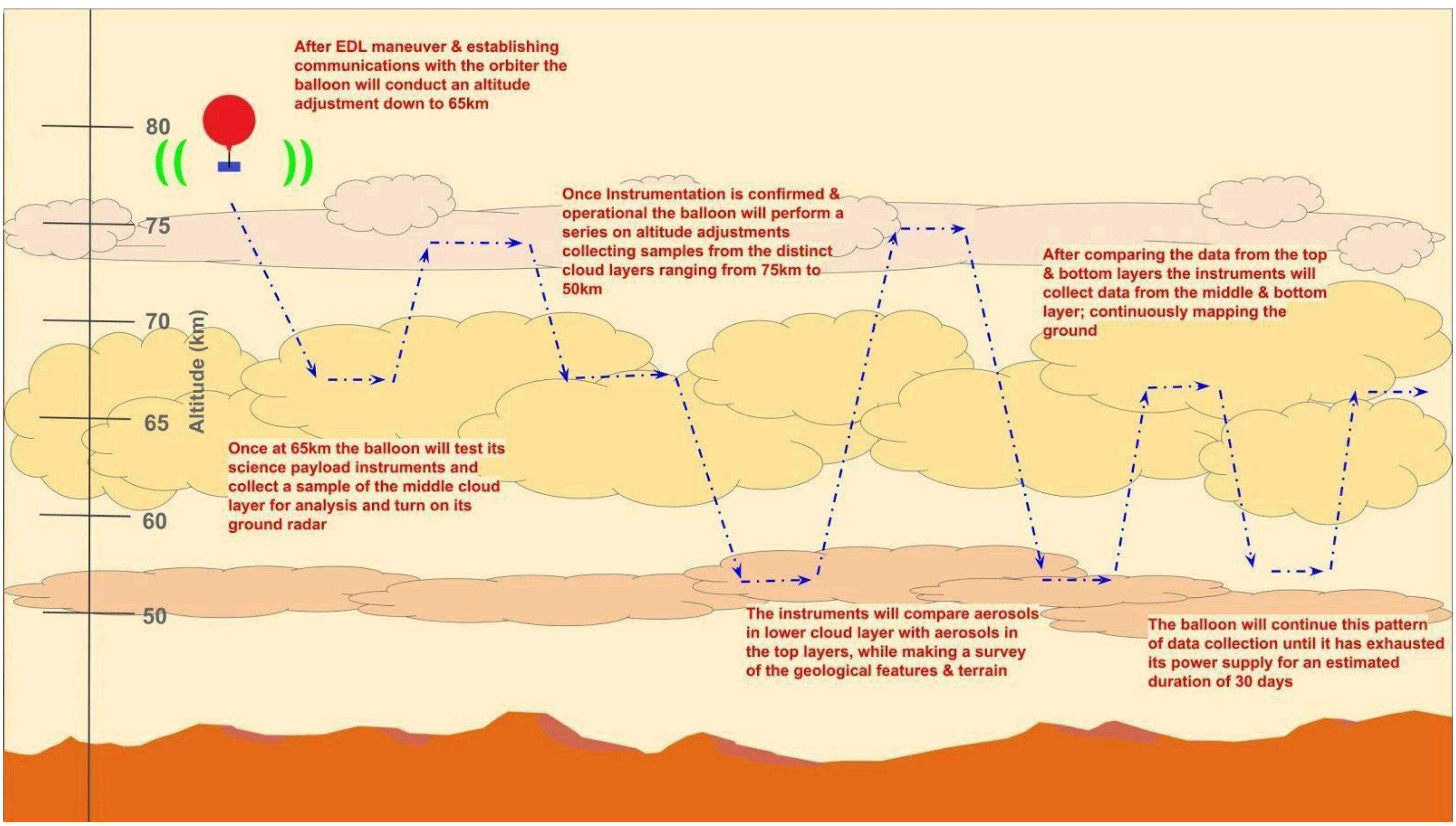


Figure 1.1: Concept of Operations

1.2.5 Major Milestone Schedule

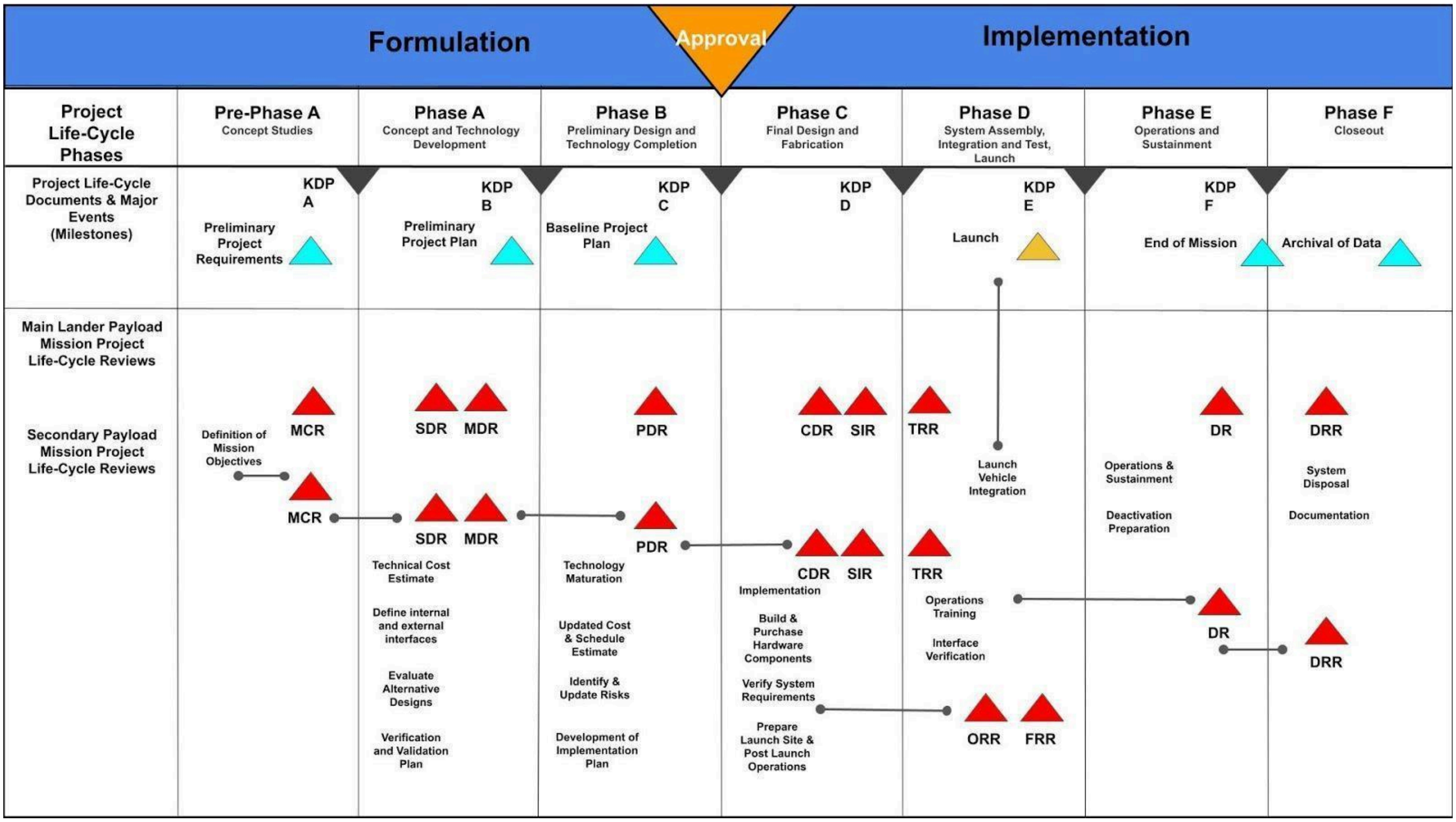


Figure 1.2: Milestone Schedule

1.3 Descent Maneuver and Vehicle Design Summary

- The entry vehicle will detach from the orbiter after performing an aerobraking maneuver to allow a safe EDL Maneuver
- The entry vehicle will enter Venus' atmosphere at a 45 degree angle sufficiently slowing the craft to 70m/s before deploying the drogue chute
- Once the craft has slowed to 35m/s at an altitude of 140km above the surface it will jettison the heat shield and deploy the main and secondary payload
- The secondary payload will deploy a secondary chute and begin inflation of its balloon using an onboard inflation system
    - This difference in relative velocities will allow it to separate from the main payload safely without added propulsion
- Once the balloon is fully inflated it will establish a comm link with the orbiter and move toward its desired altitude

- After communications are verified the vehicle will begin testing its scientific instrumentation and proceed to start on its science objectives

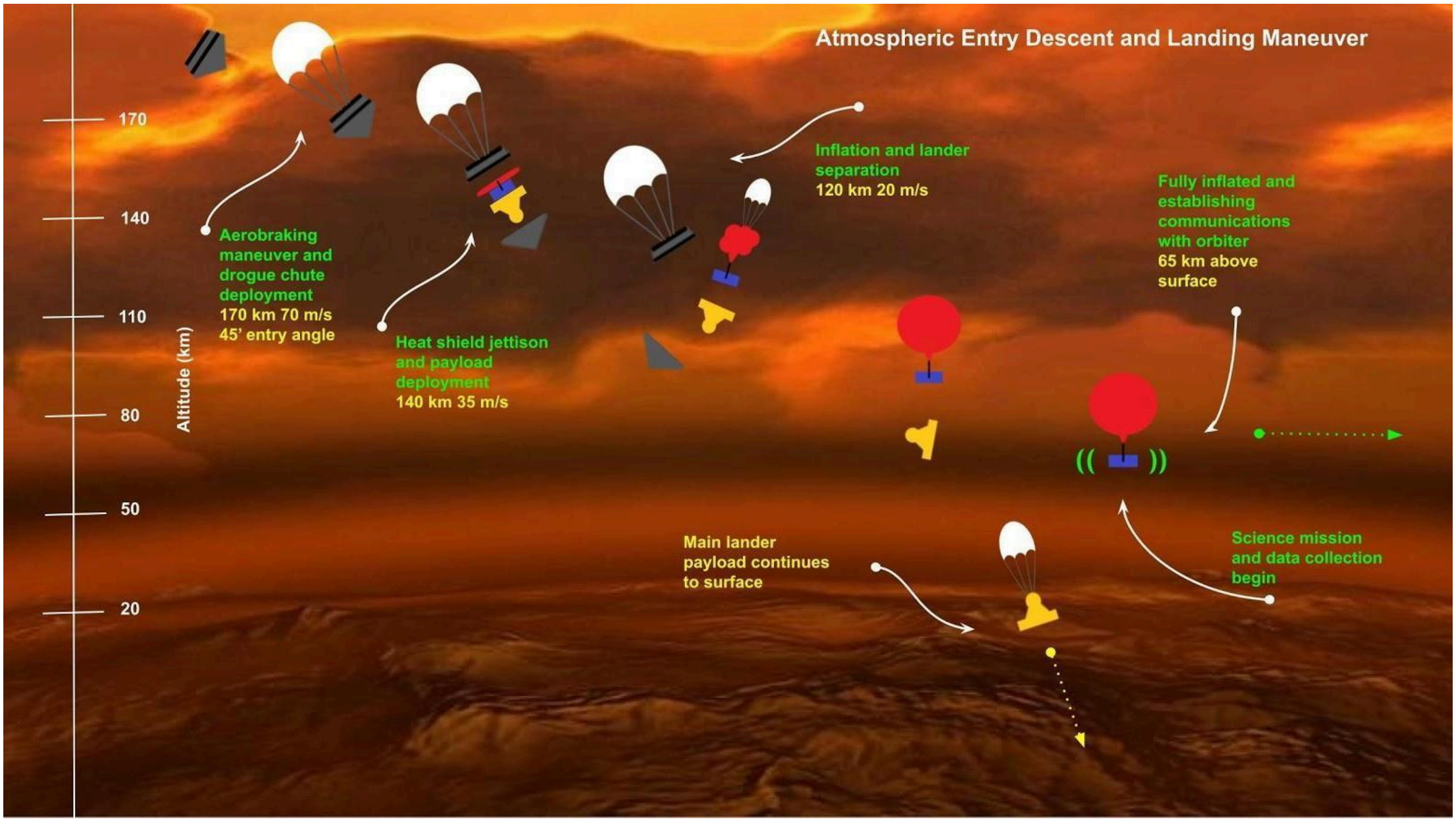


Figure 1.3: Entry Descent and Landing Graphic

The current CAD model consists of the vehicle body, cable, balloon, and payload models. The body contains all of the scientific equipment needed to collect data of the Venusian atmosphere.The present CAD model is 63.89 kilograms under the mass constraint outlined in the *Venus Atmospheric Strategic Science Investigation* document. The material selection is based on the conditions that will be subjected to by the harsh atmospheric conditions. Aluminum 2024 (Alloy) is used to cope with high strength-to-weight ratios and will be used to create the main body of the vehicle. Carbon steel is highly resistant in tension and compression. Carbon steel will also be used for the cable holding the balloon in place. Polytetrafluoroethylene (teflon) is highly resistant to Venus' atmosphere, and will be used for the outer balloon part of the vehicle.

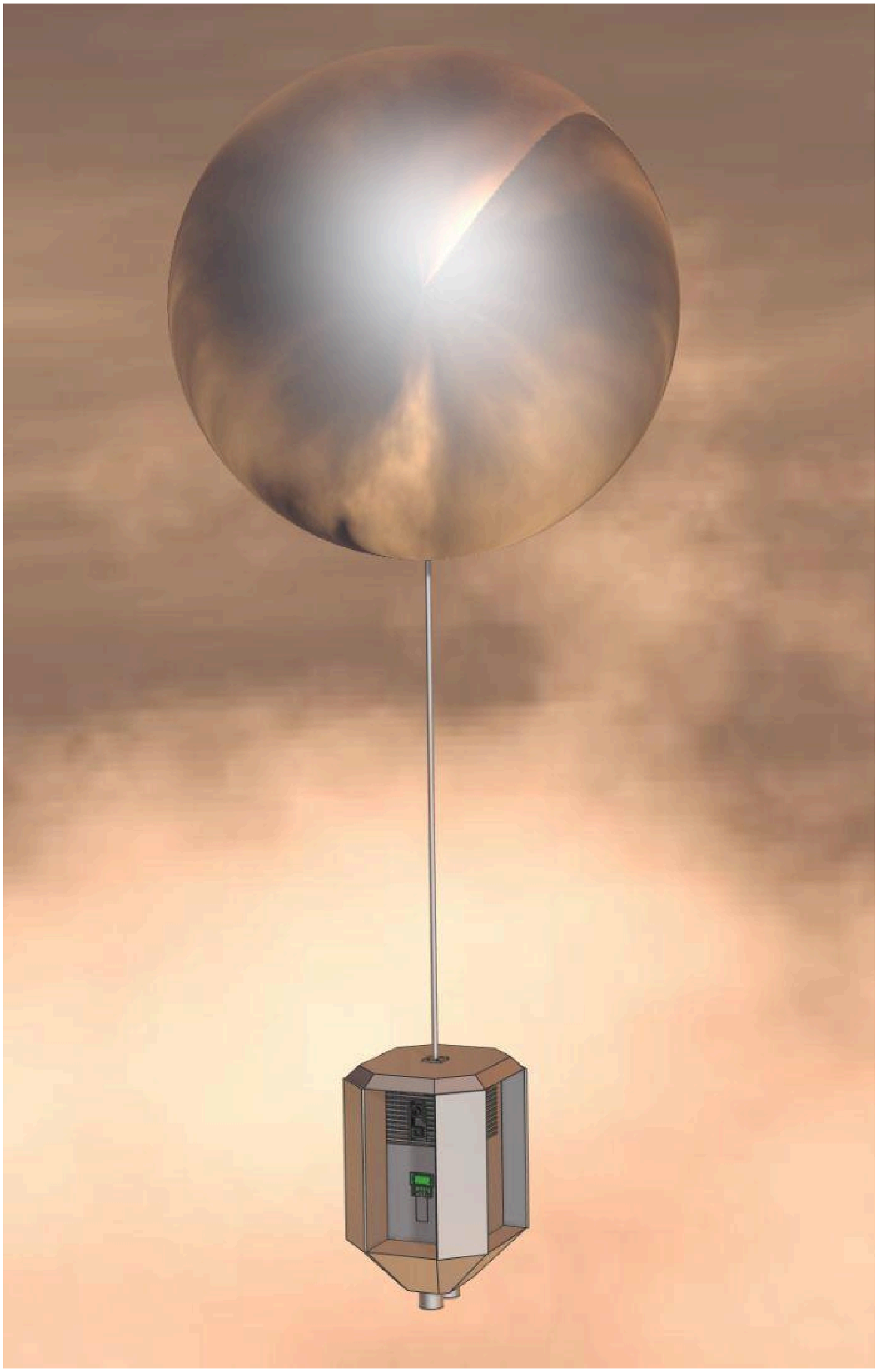


Figure 1.4: Vehicle Concept in Venus Atmosphere

Model	Material	Quantity	Mass [kg]	Volume [cm^3]
Body	**Aluminum 2024 (Alloy)**	1	28.50	64999.94
Cable	**Carbon Steel**	1	0.55	70.62
Balloon (undeployed)	**Polytetrafluoroethylene (Teflon)**	1	53.00	24089.14
Balloon (deployed)	**Polytetrafluoroethylene (Teflon)**	1	53.00	523598.64

Total Mass	Total Volume Undeployed	Total Volume Deployed
111.11 kg	89323.59 cm^3	588833.25 cm^3

1.4 Payload and Science Instrumentation Summary

The vehicle's prime objectives are to analyze Venus' atmosphere and create a detailed map of the environment over the terrain it will traverse. In order to meet these goals the craft will need to be outfitted with several instruments that can collect and analyze aerosols from the cloud layers on Venus and survey the environmental and geological features, while also recording ambient sound to obtain evidence of seismic activity. The suite of scientific instruments and vehicle payloads include:

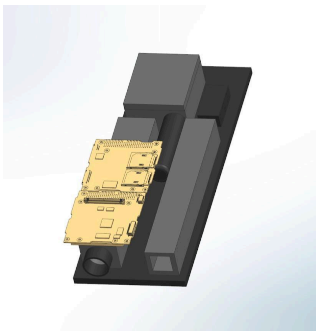
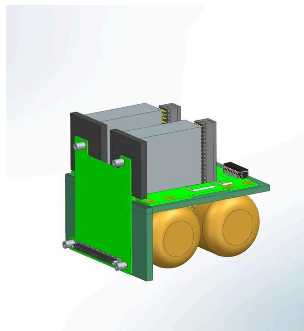
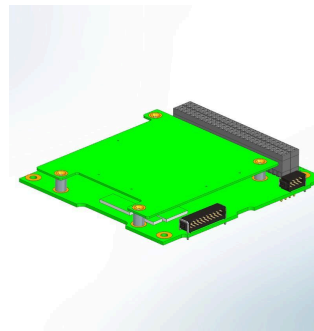
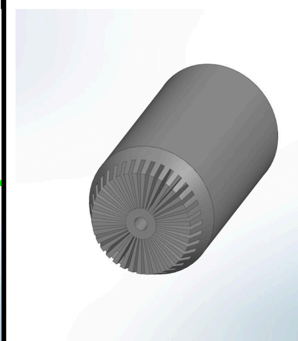
				
HyTI Hyperspectral Thermal Imager	SPICAV Spectrometry Instrument	Nephex Nephelometer Instrument	ISIS S-Band Antenna & Transmitter	4006ER Omni Directional Microphone
Spectral resolution: 8-10.7 µm Power supply: 90Wh Battery Computer: iX5-100 Communications: S-Band Transmitter w/ antenna array	Ultraviolet channel (SUV) 118–320 nm, resolution 1.5 nm Infrared channel (SIR) 0.7–1.7 µm, resolution 0.5–1.2 nm SOIR Instrument range λ=2.2–4.3 µm, spectral resolution $\lambda/\Delta\lambda$>15,000	Particle size range 0.1 to 50 µm	Frequency: 2200-2290 MHz	Frequency range: ±2 dB10 Hz - 20 kHz
Cryogenically-cooled (BIRD FPA)	Temperature range: -40°C to 70°C	Temperature range: 0°C to 50°C	Temperature range: -40°C to 70°C	Temperature range: -40°C to 45°C (-40°F to 113°F)
Mass: 12kg	Mass: 13.05kg	Mass: 1.7kg	Mass: 132g	Mass: 114g

Figure 1.5: Scientific Payload

- HyTI (Hyperspectral Thermal Imager) [k]
    - “a 6U CubeSat equipped with a TIR hyperspectral imager (HSI) for terrestrial science applications. This instrument will also measure the 6 micron molecular water feature, time-of-day variations in the temperature of the surface at high spatial and time resolution for thermophysical studies.”(NASA Hyperspectral Thermal Imager (HyTI) Mission)[k]
    - Thermal Imaging will provide details about geological features such as surface temperatures and active volcanism. Also this instrument will provide data on the cloud and weather patterns in the Venusian Environment.

- (SPICAV) The Spectroscopy for Investigation of Characteristics of the Atmosphere of Venus [r,s] is a suite of three spectrometers in the UV and IR range with a total mass of 13.9 kg.
    - A UV spectrometer (118–320 nm, resolution 1.5 nm) It is dedicated to nadir viewing, limb viewing and vertical profiling by stellar and solar occultation.
        - The UV sensor will measure the vertical profiles of CO_2, temperature, SO_2, SO, clouds and aerosols. The density/temperature profiles obtained with SPICAV will constrain and aid in the development of dynamical atmospheric models, from cloud top (~60 km) to 160 km in the atmosphere. It will support the mission by capturing and observing the upper atmosphere, through the emissions of CO,CO^+ AND CO_2^+
    - The SPICAV VIS-IR sensor (0.7–1.7 μm, resolution 0.5–1.2 nm) employs a pioneering technology: an acousto-optical tunable filter (AOTF).It will observe the thermal emissions peering through the clouds.
        - In solar occultation mode this channel will study the vertical structure of H_2O, CO_2, and aerosols.
    - The SOIR spectrometer is a new solar occultation IR spectrometer in the range λ=2.2–4.3 μm, with a spectral resolution $\lambda/\Delta\lambda$>15,000.
        - The main objective will be to measure HDO and H_2O in solar occultation, in order to characterize the escape of D atoms from the upper atmosphere and give more insight about the evolution of water on Venus.

- The Nephelometer (Nephex) [l,m] instrument will measure the presence of clouds and return data on the properties of the Venusian clouds. The instrument will provide some guides as to the global variability of the cloud structure; the instrument will monitor optical qualities of windows and temperatures of critical components, and operate at varying altitudes.

- The ISIS High Data-rate S-band Transmitter and S-band Patch Antenna [f,g] are compact and low-mass solutions that are suitable for frequency ranges within 2200-2290 MHz

(S-Band). The transmitter is flexible, and can implement CCSDS as data link layer protocol, which allows for in-flight configuration of data-rate, modulation, frequency, and RF output.

- DPA 4006ER Omnidirectional Microphone [a] will help gain a better insight into the soundscape. The DPA 4006ER will record the entry and descent of the vehicle. Also will be used to allow engineers and scientists to record and sound related to seismic activities by collecting data in the infrasound that is scattered into the atmosphere.

The payload will adhere to an operations sequence that will budget the data collected by each instrument. Many of the devices need light to operate and will power down on the night side of the planet. Each device will run by the assigned time to maximize potential data collected as well as coincide with peak transmission times. The vehicle does however have a larger power budget and should be capable of collecting data until the projected mission end

2. Evolution of Project

2.1 Evolution of Mission Experiment Plan

When forming the VESPAA mission and experiment plan, there was not much change along the way. The science objectives were not changed, but instruments were changed a little, and it was a little harder to get information on them. One change that was made included removing the Mastcam Z from the instruments list. Therefore, the 3D Image data was no longer needed. Also, the (VIRS)IR Radar Imager was changed to the (HyTI)Thermal Imager with a redundant backup system. These were exchanged due to size constraints, so now it is more compact with no outside moving parts. The data will now be received in the 6-12nm wavelength vs. .7nm-11nm. Another thing that was changed was the inflation system was changed from disposable tank system to onboard reusable system. This reduces moving parts on the entry system and solves the ability to navigate to different altitudes. These changes showed that the mission instruments and science evolved and grew to fit the mission.

2.2 Evolution of Descent Maneuver and Vehicle Design

The vehicle and payload design, along with the descent maneuver changed drastically over time. The vehicle design is an ongoing process, currently on its third iteration. With research, development, and planned testing, the design will continue to improve. The descent maneuver has stayed relatively constant, with some minor, yet important, improvements.

The first iteration of the vehicle design was simple. It consisted of the vehicle's body, which was connected to the balloon inflation system with use of a cable. While this iteration was just the prototype, it did need much improvement. The first iteration was the first step in designing the maximum volume and weight allowed for the mission, but there were no specific tools or instruments implemented.

The improvements into the second iteration were the most drastic. A tubing system was added into the cable to allow inflation and deflation, which will be discussed further in the evolution of the descent maneuver. Each instrument was also meticulously implemented to allow for a balanced design. The body was also redesigned to be more aerodynamic to reduce drag and stress on the vehicle. An energy system was also designed to implement solar panels throughout the vehicle.

The improvements into the third iteration were minor, however, vital for the completion of the design. The structure as a whole stayed the same, however, heat transfer analysis was done in order to make sure the internal systems were at a desired temperature. A ventilation and fan system were added and will be tested to make sure these systems operate according to plan.
The descent maneuver has stayed rather constant with some improvements. In the mission goals, the plan was to change altitudes to test different layers of the atmosphere. This was an

engineering problem that needed to be taken care of. With research, a plan to use some internal heat and atmospheric heat to heat the helium in the balloon was implemented. This heating and cooling will respectively increase or decrease the density of the helium. This is possible with the balloon at a constant volume. With this in mind, the balloon structure was made to be a stronger and sturdier frame. This system also meant that the helium tanks would no longer be jettisoned. The design and maneuver are ongoing processes. With new research and testing, they will improve to conform with the mission goals. As of now, the baseline design and maneuver are complete, however, small improvements will definitely be needed.

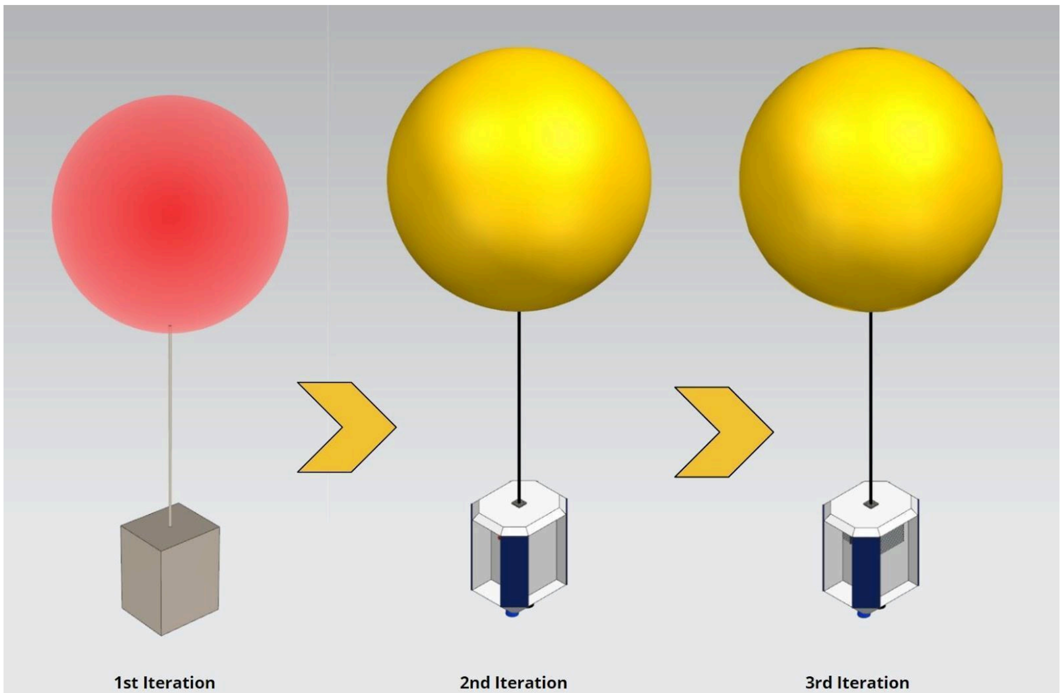


Figure 2.1: Design Iterations

2.3 Evolution of Payload and Science Instrumentation

VESPAA includes various payload and science instruments in order to develop a successful high altitude exploration vehicle. Several potential instruments were selected at first, but after much research and consideration, the final science instruments were selected to assist the subsystems of VESPAA's design.

The high energy Eagle Pitcher 60Ah Space Cell Battery [c] will connect all the instruments and generate energy for all the equipment in the mission. This lithium-ion space battery is the representation of the power system because it is applicable in the Venus atmospheric pressure and temperature, and also contains many years of operation. In order to process and store the data from Venus, science instruments such as the 4006ER Omni Microphone, Nephelometer, Spectrometer, and Hyperspectral Thermal Imager will be utilized.

These instruments will investigate and collect the linear frequency from in or outside the earth, microphsycia data of the clouds, ultraviolet and infrared radiation, and possess a camera capable of acquiring data well beyond the spectral range of the human eye. The information from these instruments will then be sent to the S-Band Antenna and Transmitter that will allow communication to the earth. These instruments used from communication will allow integration on any CubeSat platform directly and in-flight configuration of data-rate, modulation scheme, frequency, and RF output power.

3. Descent Maneuver and Vehicle Design

3.1 Selection, Design, and Verification

3.1.1 System Overview

The entry system consists of the lander and balloon system. In the lander system, an aeroshell protects the inside elements from the harsh atmosphere i.e., the aerodynamic force and high temperature and pressure. The aeroshell consists of the backshell and the heat shield. It is used to significantly decelerate the vehicle with the friction of the atmosphere. The heat shield protects the inner systems from destruction. When the vehicle is at the appropriate velocity, the drogue parachute is deployed and the aeroshell is jettisoned. This process separates the payload into two parts: the balloon system and the lander system. The lander system continues its descent, while the balloon system starts its helium inflation. It is important for the balloon system to maintain an aerodynamic pressure within tolerable limits during the deployment and inflation process.

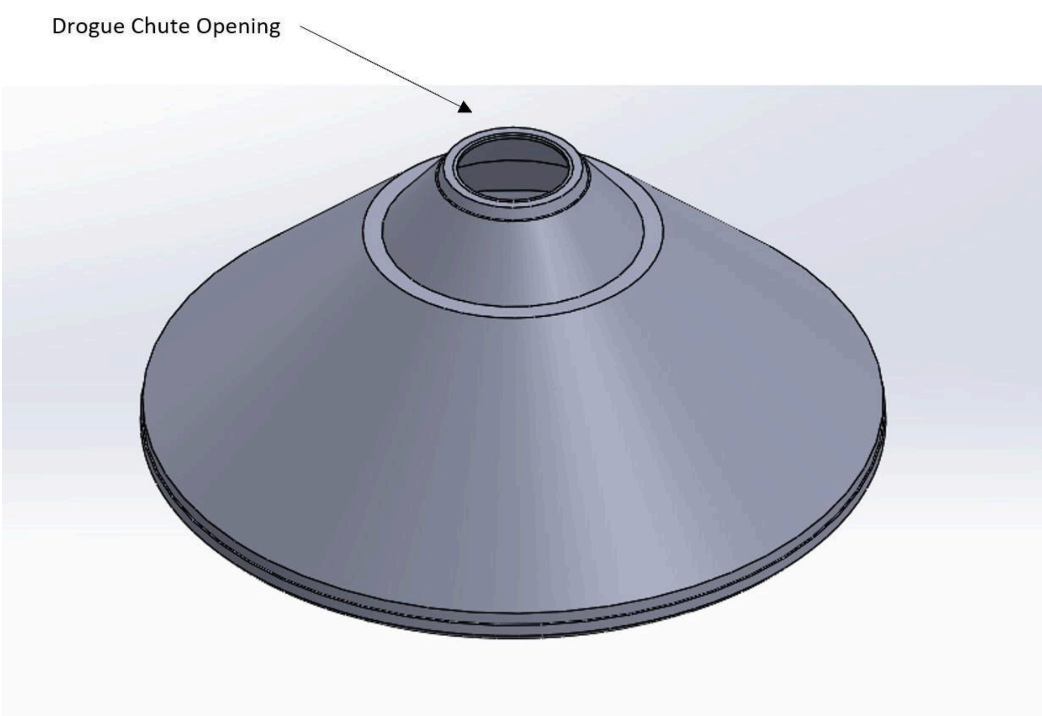


Figure 3.1: Isometric view of Aeroshell

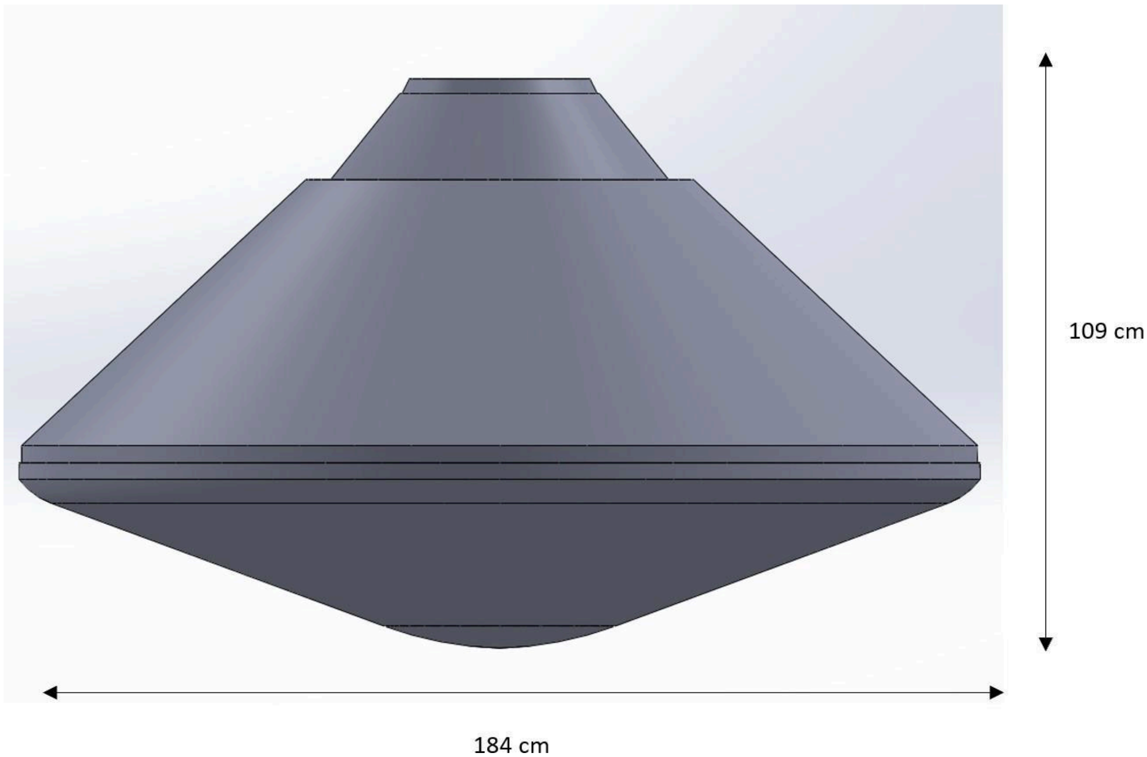


Figure 3.2: Side View of Aeroshell

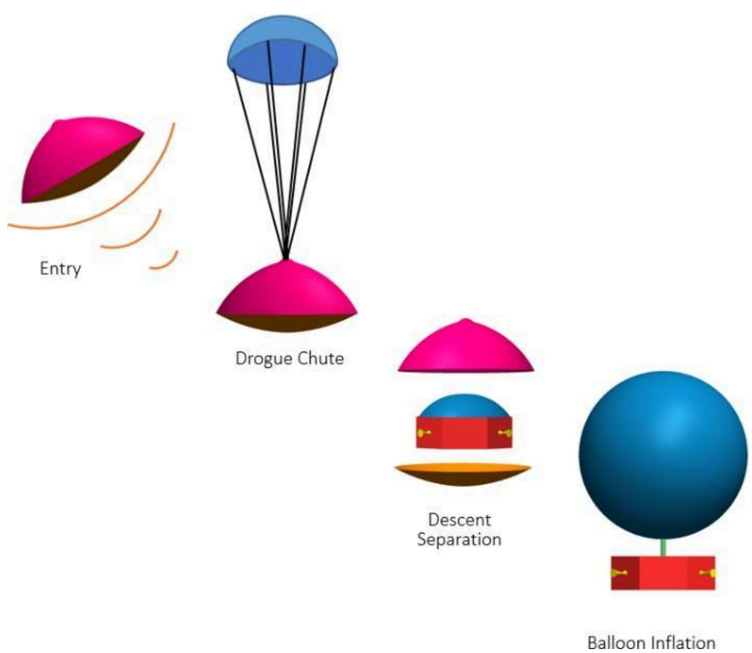


Figure 3.3: Entry and Descent Mockup Procedure

The inflation system valves open to allow the flow of the helium gas from the onboard helium tanks into the inside of the balloon through a flexible pipe. This process will take up to 5 minutes to be complete. At this point, the balloon will be fully buoyant and will rise to the equilibrium attitude of 70km. VESPAA will begin its science operations phase. Meanwhile, the lander will touch the surface after one hour.

The vehicle contains a balloon, firing box, and lander. The balloon will be packed under the aeroshell. It is expected that a tether connecting the top of the lander to the bottom of the balloon inflation system will be used to exert a transient force. This will allow the lander to rotate to its correct orientation. The rope will cut the pyrotechnics that will make the balloon parachute extract the force to rotate the lander. Once the cutter fires, the balloon and lander separate, and the lander parachute deploys.

The pyrotechnics explode to activate the jettisoning of the aeroshell. After the vehicle reaches the correct altitude at 140km, the microcontroller of the vehicle will open a valve that will inflate the balloon from the helium storage tanks..The balloon will deploy from a folded position. Once the tanks fill the balloon, a sensor will give feedback to the microcontroller and it will signal to begin testing and regulating pressures inside the balloon system

The balloon structure contains two main components: the balloon, and gondola. The balloon is made of a fabric-based laminate material and metal end fitting, such as titanium, aluminum, and composite materials. The balloon materials are high strength metals that are resistant to the sulfuric acid found in Venusian atmosphere.

The balloon is made up of three layers of different material. The outer layer is a Teflon film that is 25-μm thick, which resists the acid in the atmosphere. The Teflon is metalized with aluminum to provide the high reflective surface that will minimize the solar heating of the vehicle. The middle layer is made of metalized Mylar film that is 25-μm thick, which is selected to retain the helium gas. The Mylar is bonded to Vectran fabric to provide the high strength to the internal pressure. The inner layer is made of an aliphatic urethane coating to provide a good surface to bond the internal gore-to-gore structural tape.

- Balloon buoyancy is calculated using the Archimedes equation: $B=V \times \rho_{air}$, (B = net buoyancy, V = volume, and ρ_{air}= density of air). For a balloon to float, the density of gas must be less than the density of the desired atmospheric layer. To do this, the balloon is filled with a light gas like helium. Another option is to heat up the air, which causes a rise similar to a hot air balloon. <u>Both methods can be used together, which is called a Rozier balloon.</u>

3.1.2 Subsystem Overview

In section 3.1.1, it was explained how the vehicle uses a Balloon and Inflation system to successfully navigate the vehicle to a safe altitude as intended. This is instigated by our descent into the Venusian atmosphere, where it will continue on its controlled freefall until it reaches a certain velocity. Which will be determined by instruments onboard the vehicle.

- Once this threshold is reached, a small explosive will release the drogue chute to increase drag and decrease velocity. This is a necessary step as a high velocity would add uncertainty and unnecessary risk to the inflation system.
- Once at a decreased velocity, the next step is to determine the appropriate altitude that the aeroshell will split. The aeroshell is necessary within this system to protect the vehicle from the harsh entry of the Venusian atmosphere, and the predetermined altitude and velocity, the aeroshell will split.
- Directly after the split, the inflation process will begin. Due to the many uncertainties of the Venusian atmosphere (i.e. wind speeds) the vehicle may not be at the correct altitude. To combat this, a subsystem will need to be implemented to correct the altitude and adjust if the vehicle drifts to different altitudes. This subsystem is of utmost importance since the altitude in which the vehicle resides will affect the data from the scientific instruments and possibly damage the vehicle due to the high pressure/temperature of lower altitudes.
- The design team discussed using a Rozier Balloon in order to have the most effective and efficient method of maintaining a certain altitude for any length of time within our operating window. In this system, only one balloon will be used to decrease the overall complexity of the system. However, this would increase the risk of balloon leakage and/or failure of this subsystem. This tradeoff will be mitigated by increasing research and development of the most efficient Balloon system to keep the vehicle afloat. Section 3.1.8, goes more in depth as to how this system will evolve and change with the simulation research.

3.1.3 Dimensioned CAD Drawing of Entire Assembly

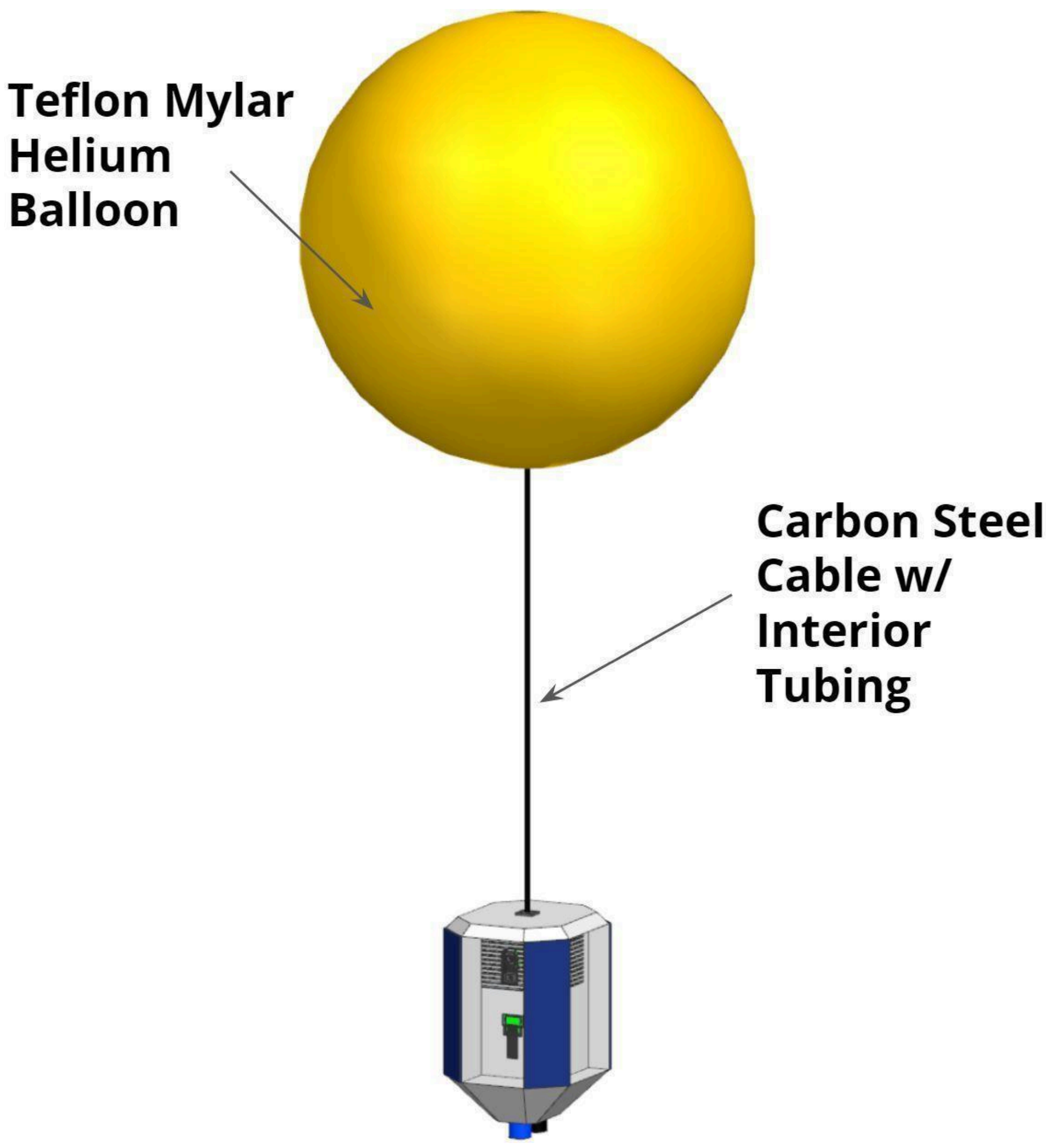


Figure 3.4: Isometric View of Payload

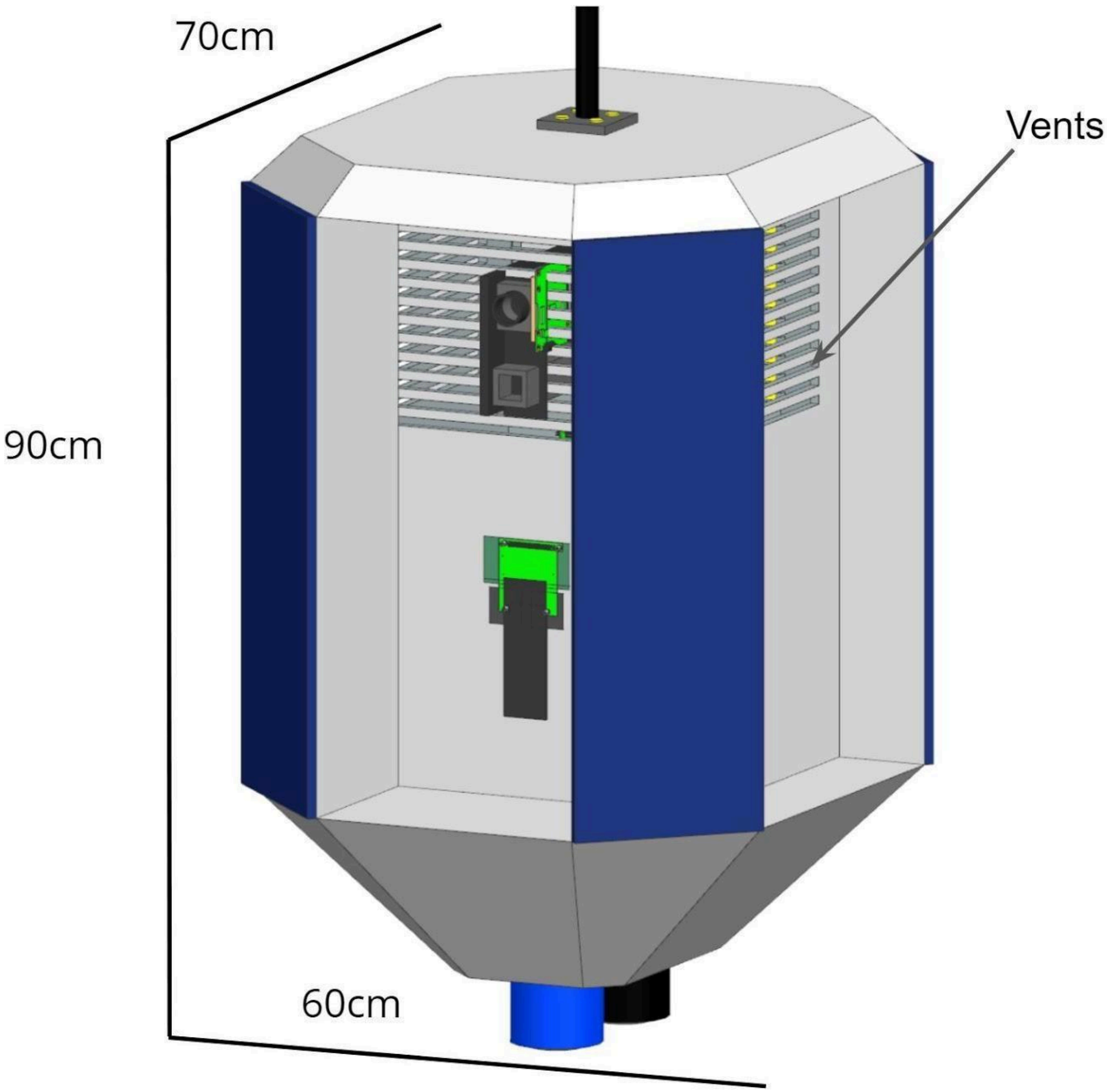


Figure 3.5: Isometric View of Payload with Dimensions

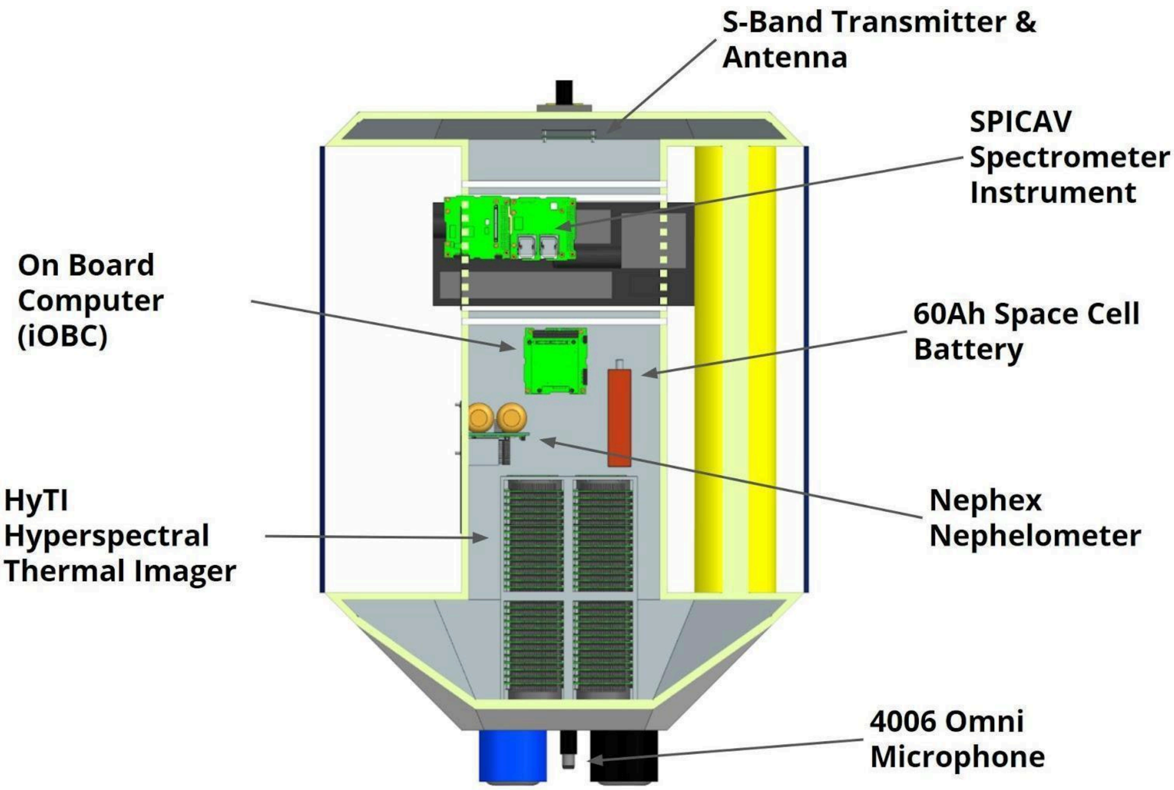


Figure 3.6: View of Payload Interior

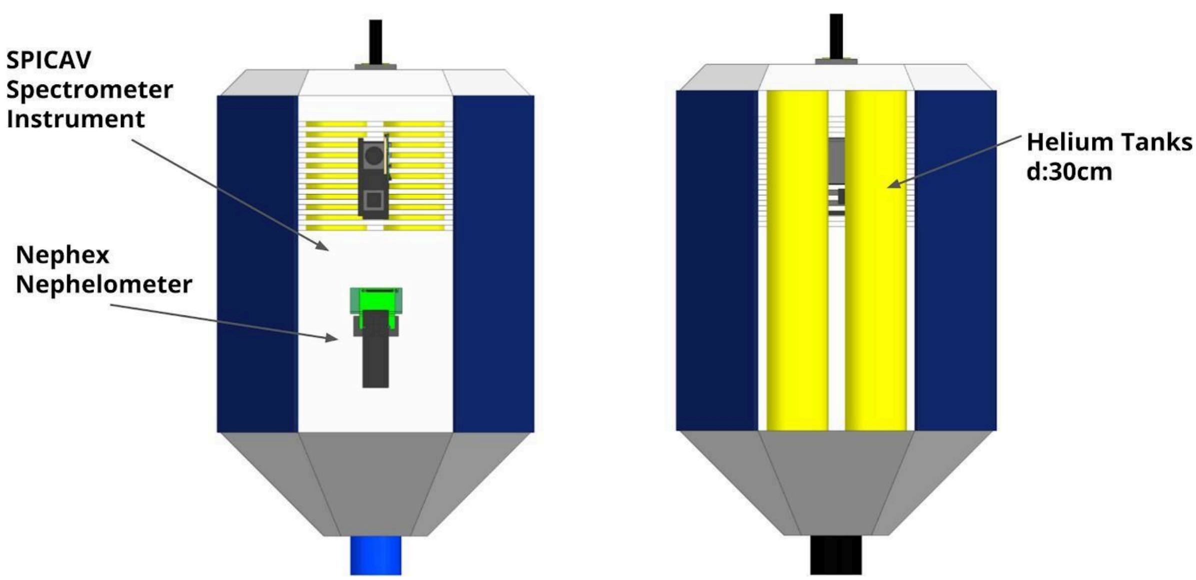


Figure 3.7: Two Side Views of Payload

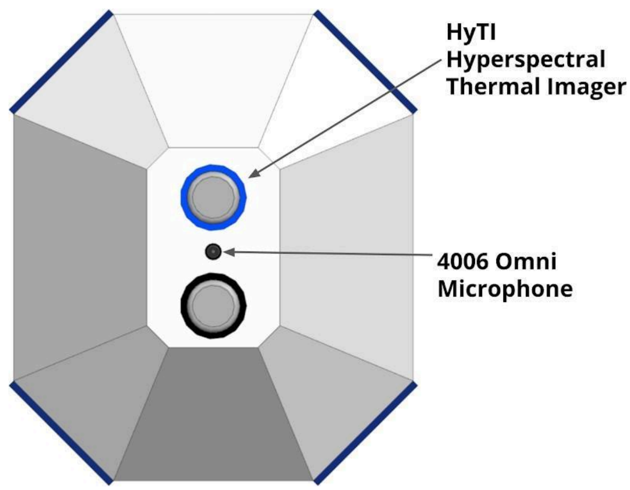


Figure 3.8: Bottom View of Payload

3.1.4 Manufacturing and Integration Plans

Our team's plan to manufacture and test the Vehicle will take one year. The engineering personnel consists of six members. The Vehicle design consists of the payload body and the balloon system. The engineering personnel are split into Sub-teams to manufacture and test each of the three components.

- The payload body is made of Aluminum, which is a light, yet sturdy, material. Aluminum is also a good heat conductor, so a multi-layer insulation material will be needed in order to maintain equilibrium for the internal systems. The inside of the vehicle will also need to implement a cooling system for the internal systems and electronics.
- The balloon will be made of a durable Teflon material, which will allow for inflation, but ensure the balloon will not be damaged by anything that may be in the atmosphere.
- The balloon will be attached to the vehicle body with a Carbon Steel Cable. Carbon Steel is a pliable material, which will allow bending and flexibility. This will reduce stress on the cable, while also keeping the body steady. Lastly, the aeroshell will be made of aluminum with a heat shield for entry and descent.

Each component will take two months to manufacture, which leaves for six months of testing. Each component will first go through rigorous testing individually in a clean room and also through finite element analysis. The design will then be assembled and tested in the clean room and the Venusian atmosphere mock room.

3.1.5 Verification and Validation Plans

In order to verify that the requirements of the overall mission are met, several necessary steps are to be taken before launch. To effectively verify that each component, subsystem, or part meets its intended requirements, testing will be conducted in simulated environments. In the case for the scientific measurements, they will be tested individually and as a collective whole in a simulated environment designed to mimic the upper Venusian atmosphere. If any changes to the vehicle design are required to protect the instruments, they will be made in the development stage.

For the inflation subsystem, analysis would be performed to determine if the subsystem would be able to deploy under certain conditions and successfully release the vehicle. Since the altitude in which the vehicle would be released has similar conditions to Earth's atmosphere, testing of the inflation subsystem could be done on Earth. In these tests, its success will be determined if the vehicle is released in the predetermined conditions of altitude and velocity, with allowable uncertainties.

For the vehicle, the overall goal is to prolong the lifespan of the inflation system. In such a case, various tests would need to be implemented on the balloon/inflation system. A Venusian atmosphere would need to be replicated to test how long the vehicle would be able to stay afloat. Its performance under high wind conditions will also be tested to determine the effectiveness of the altitude adjustment.

In the same testing area, the scientific measurements of the onboard instruments will also be tested. Since the testing area is replicated, tests can be conducted to determine how accurate the scientific measurements are to the predetermined conditions. For example, the temperature in the simulated environment would be known, and data from the vehicle would give a reading of the temperature. If the measured temperature is significantly different from the actual temperature and its uncertainties, then the onboard instrument is not up to par or the vehicle layout is somehow causing interference with the instrument.

After the verification of the system, validation testing will be required to determine if the overall system will complete the required goals of the mission. This will take place in a series of phases: analysis and testing. The analysis phase will take place before the prototype or assembled product is not yet available, therefore mathematical modeling and analytical techniques will be used to verify its validity in the mission. In the testing phase, the use of an end product will be used to determine the behavior in multiple conditions to measure its success in a simulated environment. In the case that either of these phases fail or do not meet the expectations of the stockholders, reengineering will be needed to correct any issues. However, in doing so, it is of utmost importance that these actions do not result in any new issues with any part that may hinder the performance of the product.

3.1.6 FMEA and Risk Mitigation

					1=Low 5=High	1=Low 5=High		1=Low 5=High	1=Low 5=High	
Item Number	Functions	Failure Mode	Cause(s)	Effect(s)	Severity	Probability	Detection	Ease of Detection	Risk Level	Recommended Action(s)
RP-1	Materials and Systems	High temperatures	Temperature is high during entry and when at low altitude.	Melted or otherwise damaged hardware. Thermal expansion/contraction of materials as they heat up and cool down.	3	4	Radio Communication of Instrument Data	5	4	Mitigate Risk by using material requirements for high temperatures to survive the entry and descent phase.
RP-2	Aerospace and Propulsion	Failed entry and descent	Caused by a variety of factors like parachute failure, high temperatures, aeroshell jettison failure, etc.	The vehicle will be unable to perform mission function.	5	3	Radio Communication of Instrument Data	3	5	Research Risk to determine failure modes of a failed entry and descent maneuver.
RP-3	Mechanical and Design	Balloon deployment failure	Actuation failure, packed incorrectly and gets caught,	The vehicle will be unable to perform mission function.	5	2	Radio Communication of Instrument Data	2	4	Use extensive testing on materials and components before launch to determine system reliability.
RP-4	Materials and Systems	Total loss of communication	Damaged radio communication antenna.	The vehicle will be unable to perform mission function.	4	2	Permanent Loss of Communication	5	3	Mitigate Risk by protecting components from impacts and provide redundant hardware.
RP-5	Admin	Over budget	Caused by a variety of factors like material lead times, COVID-19 impacts, unplanned issues,	Potential schedule delay if need to request additional funds for the project.	1	3	Budget Analysis	4	1	Accept Risk by allocating additional funds from the budget for unplanned risks.

			component availability, etc.							
RP-6	Aerospace and Propulsion	Failed orbital insertion	Caused by failure to perform the correct maneuver to enter the orbit of Venus.	Redundancy built into vehicles to perform the same task. Otherwise, the vehicle will be unable to perform mission function.	1	2	Radio Communication of Instrument Data	4	1	Mitigate Risk by monitoring the orbit of the vehicle and using thrusters to adjust course to enter Venus' atmosphere at the correct speed and location. If entry fails, circle the planet for gravity assist and repeat.
RP-7	Aerospace and Propulsion	Solar Radiation	Radiation is high while the vehicle is not protected by an atmosphere.	Melted or otherwise damaged hardware. Corrosion of materials as they remain exposed to radiation.	4	3	Radio Communication of Instrument Data	4	4	Research Risk to determine failure modes of solar radiation and estimate lifetime of hardware based on exposure to solar radiation.
RP-8	Admin	Delayed schedule	Caused by a variety of factors like material lead times, COVID-19 impacts, unplanned issues, component availability, etc.	Delay launch of vehicle, potential to accrue fees associated with delaying the schedule like employing workers for longer than planned, paying launch lot fees, etc.	2	4	Schedule Analysis	2	3	Watch Risk by monitoring schedule and planning additional time into schedule to account for unplanned delays due to outside factors.
RP-9	Aerospace and Propulsion	Space debris	Roaming debris is everywhere in space.	Space debris can impact the vehicle and cause temporary or permanent damage that could result in system failure.	2	3	Camera	1	2	Research Risk to determine how space debris can impact the mission and estimate likelihood of occurrence.
RP-10	Mechanical and Design	Over mass constraint	Final assembly of the vehicle is	Re-working materials will have a cost and	3	2	Inspection	4	2	Watch Risk by monitoring total vehicle weight and setting maximum

			too heavy for the given weight constraint.	time impact on the project.						weight requirements for different functional areas of the orbiter.
RP-11	Mechanical and Design	Over Volume Constraint in stowed configuration	Stowed configuration of the vehicle is too large for the given volume constraint.	Re-working materials will have a cost and time impact on the project.	2	2	Inspection	3	1	Watch Risk by monitoring stored vehicle volume and setting maximum volume requirements for different functional areas of the orbiter. Utilize folding techniques to reduce the overall footprint of the vehicle while stowed.
RP-12	Admin	COVID-19 impacts	Global pandemic spread by germs.	Cost and schedule impacts, personnel health impacts.	2	5	COVID-19 Testing	3	4	Accept Risk by planning for additional cost and time delays due to COVID-19.
RP-13	Admin	Unplanned Risks	Risk caused by unpredictable outside factors.	Primarily impact cost and time but could affect any aspect of the project.	3	5	N/A	1	5	Accept Risk by planning for additional cost and time delays due to unplanned impacts due to outside factors.

Project Risk Management Matrix

Probability					
5		RP-12-COVID-19 Impacts	RP-13-Unplanned Risks		
4		RP-8-Delayed Schedule	RP-1-High Temperatures		
3	RP-5-Over Budget	RP-9-Space Debris		RP-7-Solar Radiation	RP-2-Failed Entry and Descent
2	RP-6-Failed Orbital Insertion	RP-11-Over Volume Constraint	RP-10-Over Mass Constraint	RP-4-Total Loss of Communication	RP-3-Balloon Deployment Failure
1					
	1	**2**	**3**	**4**	**5**
	Severity				

Descent Maneuver and Vehicle Design

Probability	**Severity**	**Approach**	**Item Number**	**Risk Description**	**Risk Area**	**Risk Plan**
4	3	Mitigate	RP-1	High temperatures	Materials/Systems	Mitigate Risk by using material requirements for high temperatures to survive the entry and descent phase. Aeroshell and heat shield should be used for entry and rated for ultra-high temperatures.
3	5	Research	RP-2	Failed entry and descent	Aerospace/Propulsion	Research Risk to determine failure modes

2	5	Mitigate	RP-3	Balloon deployment failure	Mechanical/Design	Use extensive testing on materials and components before launch to determine system reliability.
2	4	Mitigate	RP-4	Total loss of communicati o n	Materials/Systems	Mitigate Risk by protecting components from impacts and provide redundancy.
3	1	Accept	RP-5	Over budget	Admin	Accept Risk by allocating additional funds from the budget for unplanned risks.
2	1	Mitigate	RP-6	Failed orbital insertion	Aerospace/Propulsion	Mitigate Risk by monitoring the orbit of the vehicle and using thrusters to adjust course to enter Venus' atmosphere at the correct speed and location. If entry fails, circle the planet for gravity assist and repeat.
3	4	Research	RP-7	Solar Radiation	Aerospace/Propulsion	Research Risk to determine failure modes of solar radiation and estimate lifetime of hardware based on exposure to solar radiation.
4	2	Watch	RP-8	Delayed schedule	Admin	Watch Risk by monitoring schedule and planning additional time into the schedule to account for unplanned delays due to outside factors.
3	2	Research	RP-9	Space debris	Aerospace/Propulsion	Research Risk to determine how space debris can impact the mission and estimate likelihood of occurrence.
2	3	Watch	RP-10	Over mass constraint	Mechanical/Design	Watch Risk by monitoring total vehicle weight and setting maximum weight requirements for different functional areas of the orbiter.
2	2	Watch	RP-11	Over Volume Constraint in stowed configuration	Mechanical/Design	Watch Risk by monitoring stored vehicle volume and setting maximum volume requirements for different functional areas of the orbiter. Utilize folding techniques to reduce the overall footprint of the vehicle while stowed.
5	2	Accept	RP-12	COVID-19 impacts	Admin	Accept Risk by planning for additional cost and time delays due to COVID-19.

5	3	Accept	RP-13	Unplanned Risks	Admin	Accept Risk by planning for additional cost and time delays due to unplanned impacts due to outside factors.

3.1.7 Performance Characteristics and Predictions

The atmosphere of Venus is mainly composed of carbon dioxide and sulfur dioxide. These compounds can be corrosive and potentially hazardous to vehicles that are not suited for the environment. The average wind speed at the equator is 200kph in the cloud layers. So the vehicle design has been reinforced to deal with these extreme conditions.

- VESPAA is a secondary payload to a Venus lander and the EDL maneuver course has been planned to enter into an insertion at the equator region.
  - This region was chosen as it will provide maximum range for the balloon and orbiter system.
  - The vehicle will enter the Venusian Atmosphere September 29th of 2023, however because of the day night cycles on Venus and high surface temperatures, the seasons do not fluctuate, allowing for predictable and testable weather conditions across a range of altitudes.
- VESPAA also seeks to innovate by demonstrating controlled flight by controlling which altitudes the vehicle chooses to fly at. This as discussed earlier in the Rozier Balloon concept, would allow the helium to be heated to change the buoyancy of the vehicle. If proved successful this would allow researchers to gather data from within each separate cloud layer on Venus.
  - Helium will be heated in correspondence with the Ideal Gas Law, $PV=nRT$, and utilizing Archimedes principle, the craft will be able to calculate the appropriate density to heat the Helium to, by recording the barometric pressures and relaying that back to the control system.
  - Altitude will be recorded by altimeters sensors that shall provide the craft with the necessary data to make accurate adjustments.
  - The vehicle shall also have governors to automatically correct altitudes if the craft drops below 50km in altitude.
- The temperature on Venus ranges between -76 °C and 75 °C (day and night) which will only require minimal regulation and control for the payload and subsystems. The vehicle has no outside moving parts that need to be protected from the elements or maintenance during its flight duration.
  - Thermal sensors inside the craft will deliver feedback to the control systems that regulate the internal temperatures. These systems will also provide data for temperature measurements as well.
- VESPAA's system is powered by a 60Ah satellite battery and a 90Wh backup supply. It will budget its power to its components in order to conserve power during no-operational modes. This amount of power is needed to maintain the system components and regulators that monitor the vehicle's altitude and temperature.
  - The vehicle needs no additional power sources for the mission. Each device draws

less than the required amount of energy needed to operate each of these systems, with reserve for emergency management.

VESPAA's design is anticipated to perform nominally because our system requirements ensure the equipment can operate at the extreme environmental conditions faced while in the atmosphere of venus. This platform provides a low risk architecture that is able to reliably perform as intended, while also providing a large amount of scientific return.

3.1.8 Confidence and Maturity of Design

The Venusian Payload systems and instrumentation has evolved to meet the criteria of the mission. Specific materials were chosen, in order to combat the extreme conditions, i.e. temperature and pressure. The aeroshell, payload, and inflation system were made of materials specific to their goals. Simulations and testing will be necessary to project the effectiveness in the Venusian atmosphere.

The Venusian Payload has matured and been revised. The initial design was slimmed out and made more aerodynamic and balanced to combat the high winds. The cable, which attaches the balloon to the vehicle body was also shortened to reduce rapid movement in the high winds. Simulations and testing, such as finite element analysis, will be necessary to verify the durability and quality of the materials and design structure. Testing will be done in a clean room and also in a room designed to mimic the Venusian atmosphere. After the testing, some upgrades and changes may be necessary.

3.2 Recovery/Redundancy System

VESPAA is capable of performing in one of the most demanding environments. Due to the nature of secondary mission architecture and its constraints, the VESPAA mission is limited in its scope to create a system with a backup power supply and communications array. As well as ensuring all sequences can be performed in order to inflate the balloon and keep it at the desired altitudes.

- The VESPAA vehicle will be facing an environment that has highly corrosive elements, therefore protective measures were designed to mitigate failures and the need for repair. The mylar and teflon coatings on the balloon are designed to handle the SO_2 and SO_3 rich atmosphere. The internal vectran fabric will keep the pressure constant while allowing for flexibility. The air in the balloon will be monitored and regulated by the computers on board.
- The VESPAA vehicle is also designed to withstand the harsh climate. Utilizing a teflon coated aluminum housing, which is light and stable. The inside should be pressurized to keep components working optimally. Active cooling, internal heat sinks and thermal

modules regulate the temperature as the craft travels from day to night sides of the planet. Each sensor will have a redundant backup for proper calibration and to record any off-nominal behaviors.

- Some of the instruments on the scientific payload include their own power supply, and one carries its own computer processor, storage array, and S-band transmitter. This instrument shall be utilized as a backup so it can provide direct power to all systems of the craft, it can process and store data, and communicate with the orbiter.
- There are four science instruments, one of which has three spectral cameras. In case something were to happen to one, another could take similar measurements. And due to the many science instruments on-board, each one individually can provide robust amounts of data, even if the others stopped or could not operate.

Although VESPAA is not capable of providing a fully redundant system, it will have adequate opportunities to succeed even if handicapped. This system is designed to meet the challenges and extreme conditions it will be exposed to. By providing reinforced shielding on the balloon and vehicle, and by having redundant power and communication systems available, the VESPAA mission is able to operate confidently.

3.3 Payload Integration

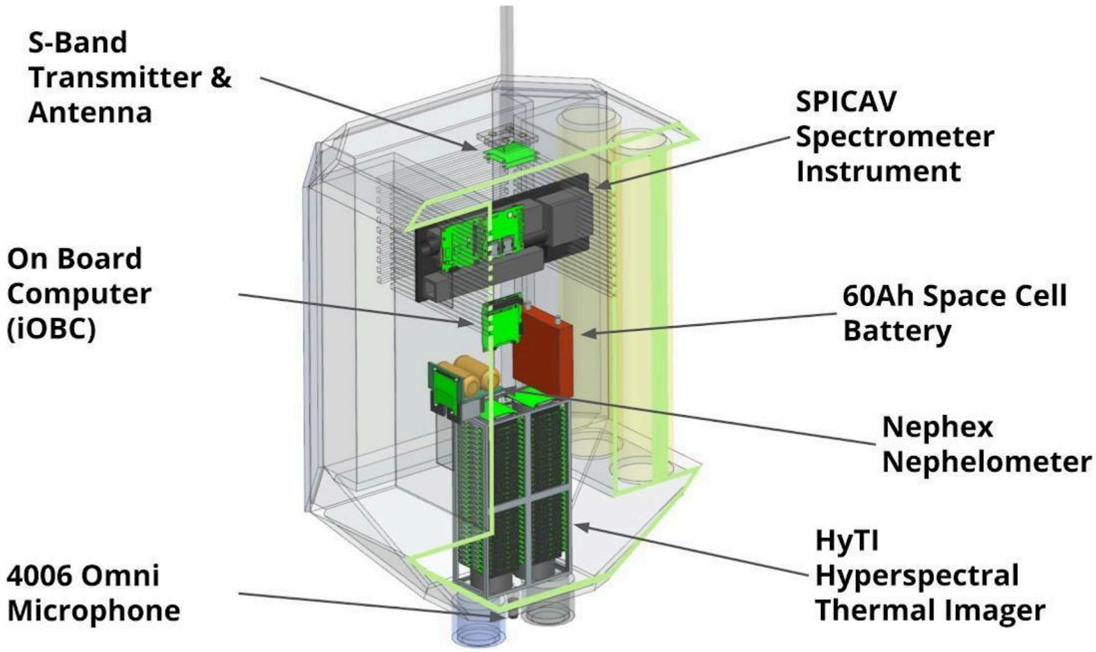


Figure 3.9: Interior View of Vehicle Payload

The Payload integration for the concept design is fairly straightforward. Each device conforms to the dimensional requirements and leaves adequate space for mounting each instrument securely in the vehicle's chassis. Everything is connected to the primary computer, the ISIS On Board Computer IOBC [e], which processes information that is sent to Earth via an orbiter using its S-band transmitters and antennae. The Eagle Pitcher 60Ah battery will be mounted on the interior of the craft and connected to all instruments and hardware as well. This battery and the batteries on the HyTI instrument will provide power to perform VESPAA's duties for the lifetime of the mission.

- The housing which will be made from aluminum will provide shielding from the harsh conditions of Venus' atmosphere.
- Since all of the instruments only utilize internal moving parts, all of the payloads can remain mounted inside the vehicle interior.
- These instruments are connected using reliable and flight ready cables and connectors which will provide constant power and quick data transmission and storage.
- Most of the payload has been designed to be mountable and highly integratable.

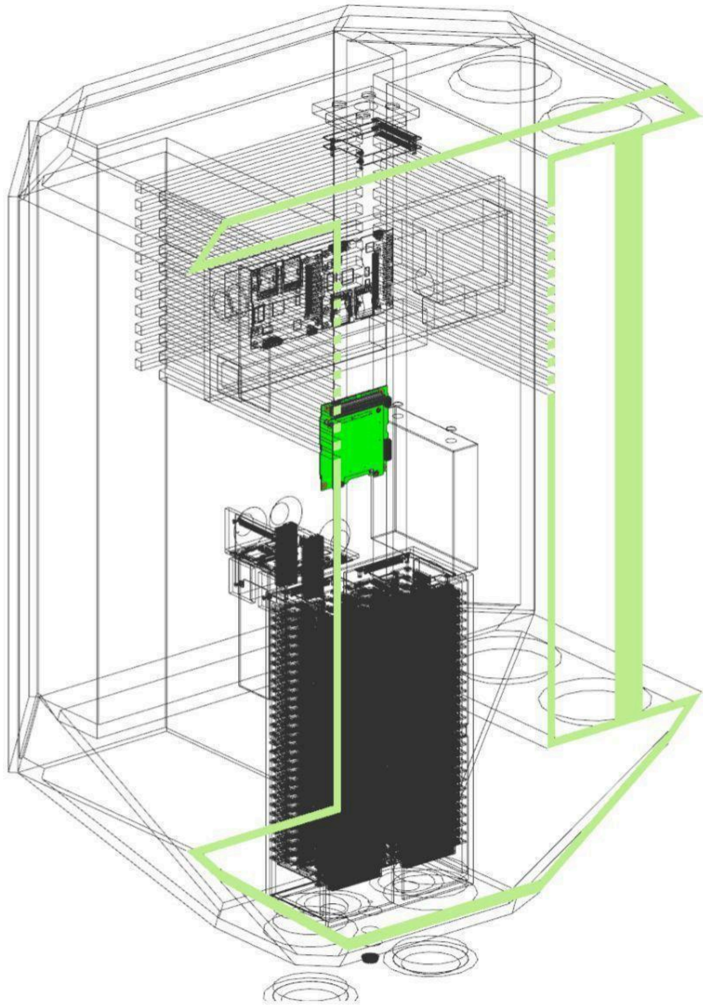


Figure 3.10: The ISIS On Board computer (IOBC) (highlighted)

The ISIS On Board computer (IOBC) is a heritage grade cubestat computer with an ARM9 400MHz processor. The computer features the ability to store data up to 32GB on an SD Card drive. This computer will do the majority of the data processing with secondary tasks being performed by the HyTI's iX5-100 computer. The IOBC is connected to all subsystems, controllers, and sensors. Its programming schedule prioritizes data collection, thermal regulation, altitude control and transmission to the orbiter. The two systems work together and each have their own power supply. Some advantages of the systems include:

- On-board telemetry: voltages, power-controller, and real time clock
- High reliability data storage and fail safe filesystem
- Flexible daughterboard architecture
- Robust design

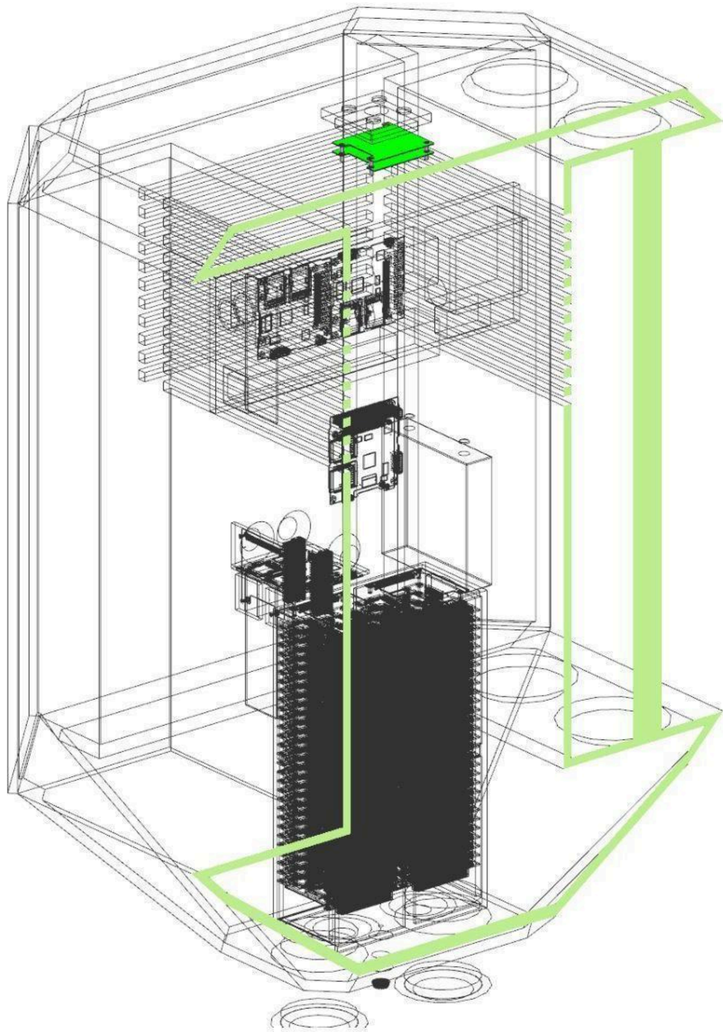


Figure 3.11: ISIS S-Band Patch Antenna and Transmitter (highlighted)

S-Band patch antenna is suitable for any cubesat platform and directly compatible with the ISIS S-band transmitter and transceiver products as well as ISIS standard CubeSat structures. The antenna is designed to fit on 1 U face. It’s also compatible with ISIS S-band radio products. The S-Band patch antenna designed for S-band communications on nanosatellites and CubeSats. The antenna frequency range is 2200 to 2290 MHZ and its mass is 250 grams with internal storage up to 32 GB. The small volume, light mass and high effective frequency range for the
S-Band patch antenna makes it the best choice to use on Venus mission. The antenna will be connected with the 60AH Space cell battery and the ISIS On Board computer (IOBC) . It shall transmit up to 500mpbs of data to the orbiter which shall send the information back to Earth.

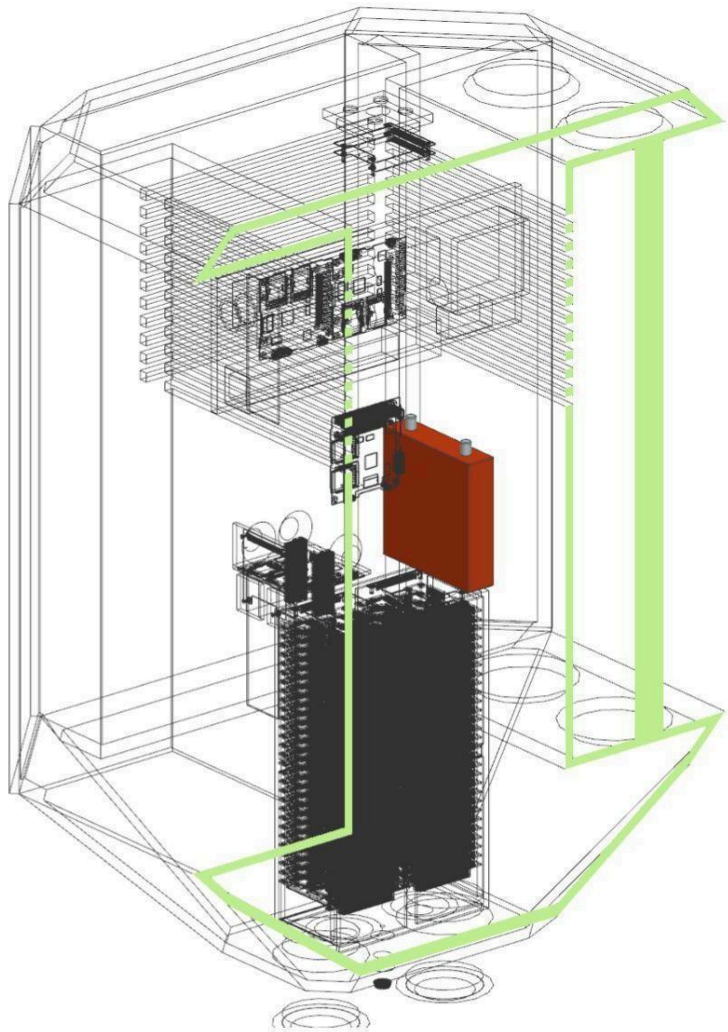


Figure 3.12: Eagle Picher 60Ah Space Cell Battery (highlighted)

The lithium-ion space cell battery contains high energy that will help in the mission. The 60Ah Space Cell Battery can operate in Venus' atmospheric pressure and temperature. It's operating temperature -4 to 104 F and storage temperature at -40 to 104 F. It has a long life: over 40,000 low-earth orbit cycles at 40% depth of discharge (DOD) over 10 years of operation which is the ideal batteries for space missions.

- It will generate the primary source of energy for most of the equipment in the mission and is connected to all of VESPAA's, payload and hardware.

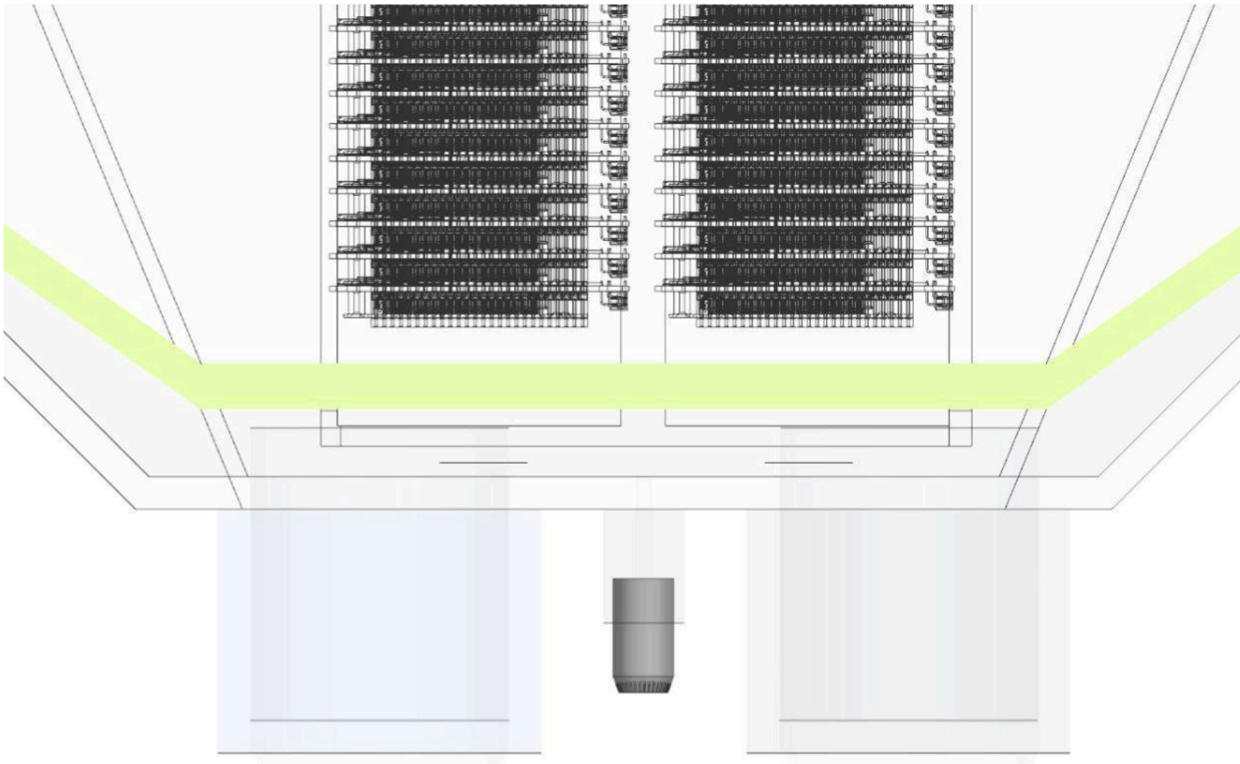


Figure 3.13: DPA Microphones 4006EROmni has sensitivity at all angles

The 4006ER Omni Mic offers total transparency in any recording situation in or outside the earth. It picks up incredible details and depth of sound. The high-frequency characteristics across a wide range of instruments is impressive. It records natural sound, has high sensitivity, with low noise-floor and linear frequency response from 10 to 20 KHZ. The 4006ER Mic will record the sound of the atmosphere of Venus and send it to the earth with high quality.

- The mic will connect with the S-Band patch antenna to send the records and will get its electricity from the 60Ah Space Cell Battery. The 60 Ah battery supplies sustainable energy to the microphone for the duration of the mission. The ISIS On Board computer (IOBC) will process and store data for transmission.

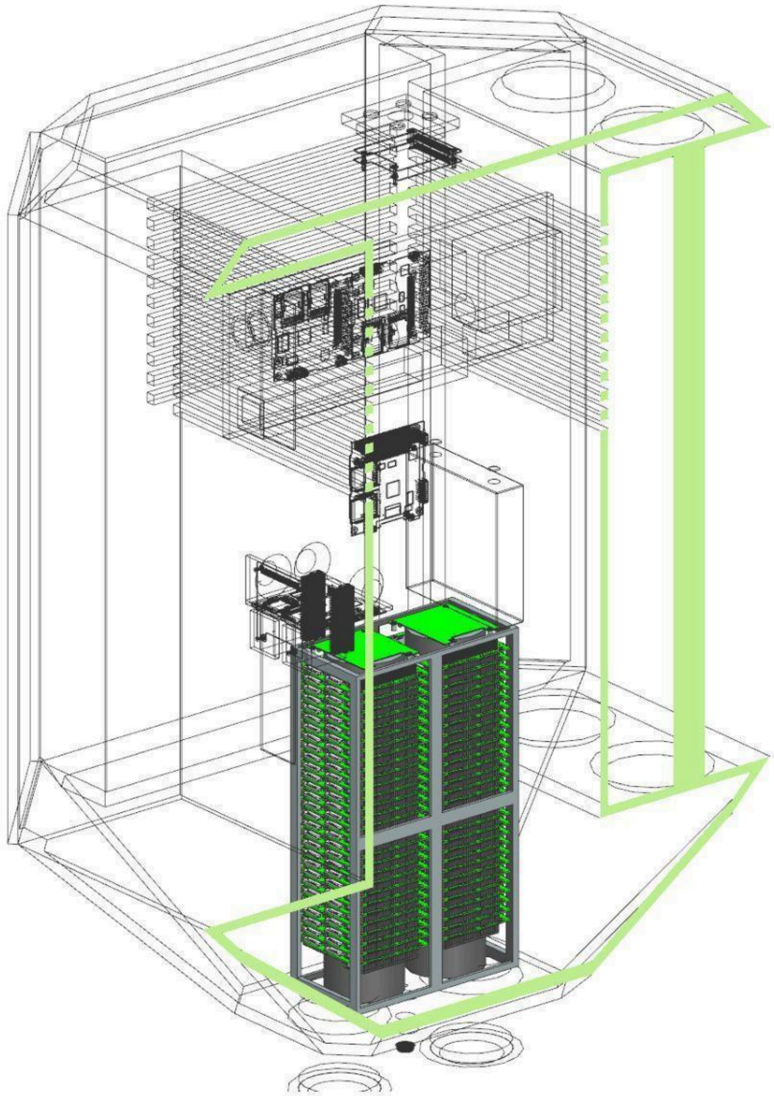


Figure 3.14: Hyperspectral thermal imager (HyTI) Cubesat (Dimensions 10 x 34 x 22.6 cm)

The hyperspectral thermal imager (HYTI), a 6u CubeSat equipped with a tir hyperspectral imager (hsi) for terrestrial science applications the same instrument is ideally suited for surface science when modified for wavelengths that include the Christiansen feature, allowing for surface resource characterization and utilization. This instrument will also measure the 6-micron molecular water feature, time-of-day variations in the temperature of the Venus surface at high spatial and time resolution for thermophysical studies.

- The HyTI Cubesat features its own 90Wh power source and computer. It can be utilized by other instruments during the mission.
- The HyTI Cubesat also contains its own ISIS S-band Transmitter that can transmit data to the orbiter that the instruments collect

In the following CAD design, it shows the location of the microphone and the Hyperspectral thermal imager in the vehicle. The would be on the bottom of the vehicle and connect with the primary computer (IOBC), but run is self reliant, however it will also connect to the S-Band Antenna and Transmitter and 60Ah Space Cell Battery to utilize their features and energy if needed .This connection also allows the the HyTI instrument to share its 90Wh rechargeable power supply with the other instruments and utilize its S-band transmitter.

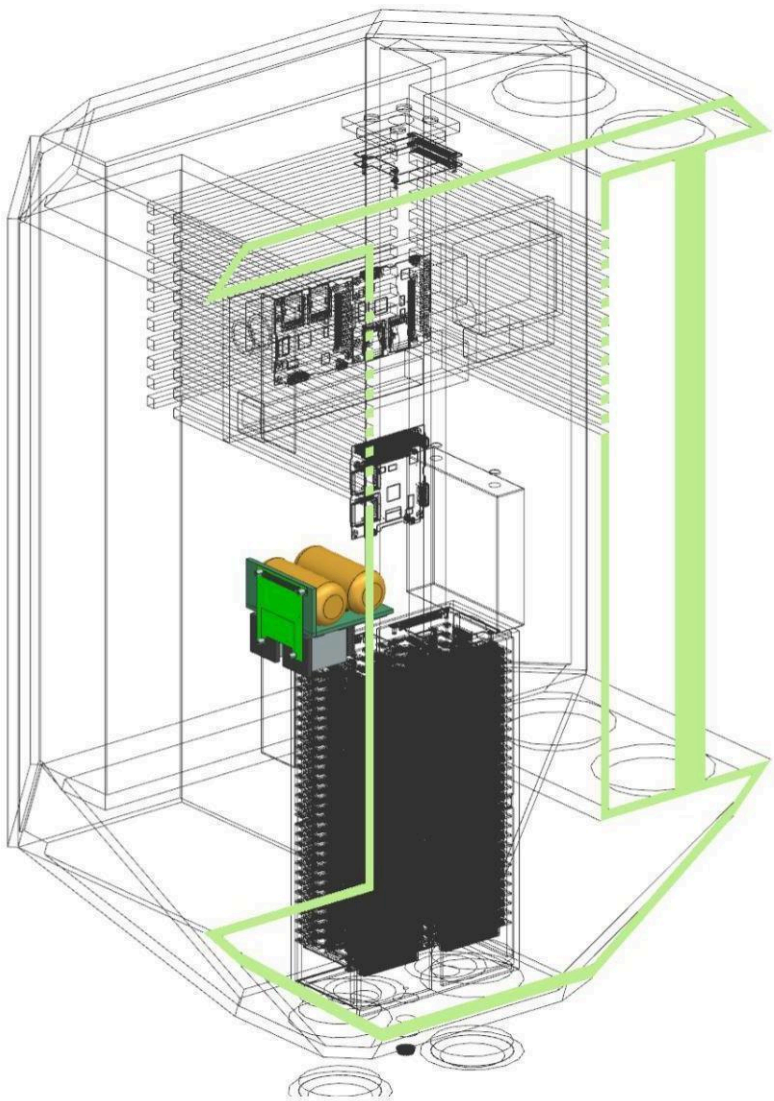


Figure 3.15: Nephex Nephelometer (dimensions 10 x 10 x 10 cm)

The Nephelometer Experiment characterizes the makeup of planetary clouds. Current cloud measurements, based on satellite imaging, provide low resolution data about the edges of cloud layers. Nephelometry yields microphysical data about particle size, shape, and concentration from a cloud's interior. Nephex design improves on the Galileo nephelometer with much lower size, weight and power. The smaller form factor allows Nephex to fly on more opportunities in threshold environments and planetary atmospheres.

The Nephelometer will measure the concentration of suspended particulates in a gas colloid of Venus' atmosphere and send it to the IOBC for processing and storage. "Roughly 1.7kg in mass, operates at 5.3W, and is contained in a 10cm cube, is roughly 1/40 of the volume of the Galileo nephelometer." (*Nephex*)[m]

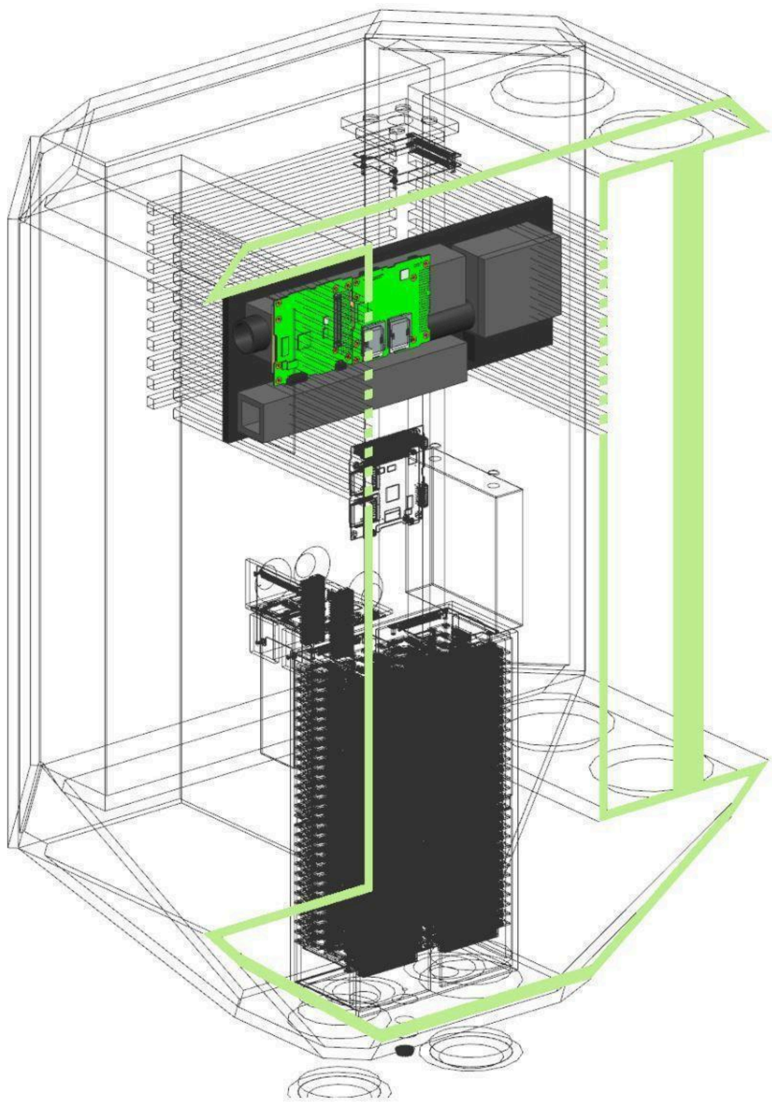


Figure 3.16: Spectrometer (SPICAV) (dimensions 50 x 15 x 10 cm)

SPICAV is an imaging spectrometer for ultraviolet and infrared radiation. SPICAV is derived from the SPICAM instrument flown on Mars Express, which was equipped with two channels, one for ultraviolet wavelengths and one for infrared. SPICAV retains these channels, SPICAV-UV (SUV) for ultraviolet and SPICAV-IR for infrared and adds an additional channel (SOIR, Solar Occultation at Infrared), to observe the Sun through Venus's atmosphere at longer infrared wavelengths (2.3 µm - 4.2 µm).

The Microphone, Nephelometer, Hyperspectral Thermal Imager and the SPICAV instrument will get their specific information and then send the data to the ISIS On Board computer (IOBC), which will process and store the information. The S-Band Antenna and Transmitter will transmit the data and send it back to the orbiter. Each one of these instruments shall assist in obtaining more information about Venus' atmosphere. At the end of the projects, the science team shall receive Venus atmospheric and geological sound, Thermal imaging, and aerosol data from the atmosphere.

4. Payload Design and Science Instrumentation

4.1 Selection, Design, and Verification

4.1.1 System Overview

Like mentioned in 3.1, VESPAA is equipped with two computers, which control the vehicle's main systems and subsystems. The N^2 Chart (below) describes the development of subsystem interfaces and highlights the input and output dependency assumptions and requirements. Data is collected from the various systems and are processed by the computers which will then tell the craft to perform the appropriate function. Each subsystem is maintained and monitored by various sensors and modules that ensure optimal performance. Below are the interactions of the payload subsystems.

- Thermal sensors will relay data to the computer about the vehicle's and its instruments operation temperature. These sensors will also notify the computer to regulate the instrument's temperatures (if necessary). This information collected is also stored and transmitted.
- Accelerometers on the vehicle will also provide data to the computer about its trajectory and heading.
- Altimeters will notify the computers of the vehicle's altitude and will provide the data necessary to perform altitude adjustments.
- The vehicle payload will receive its data and have it processed and stored by two computers onboard.
- Data that is collected will be transmitted to the orbiter via the vehicle's S-Band communications system.
- The battery system provides the necessary energy for the instrument as well as the backup supply that the HyTI instrument also carries. This power system is connected to all of the vehicle's components.

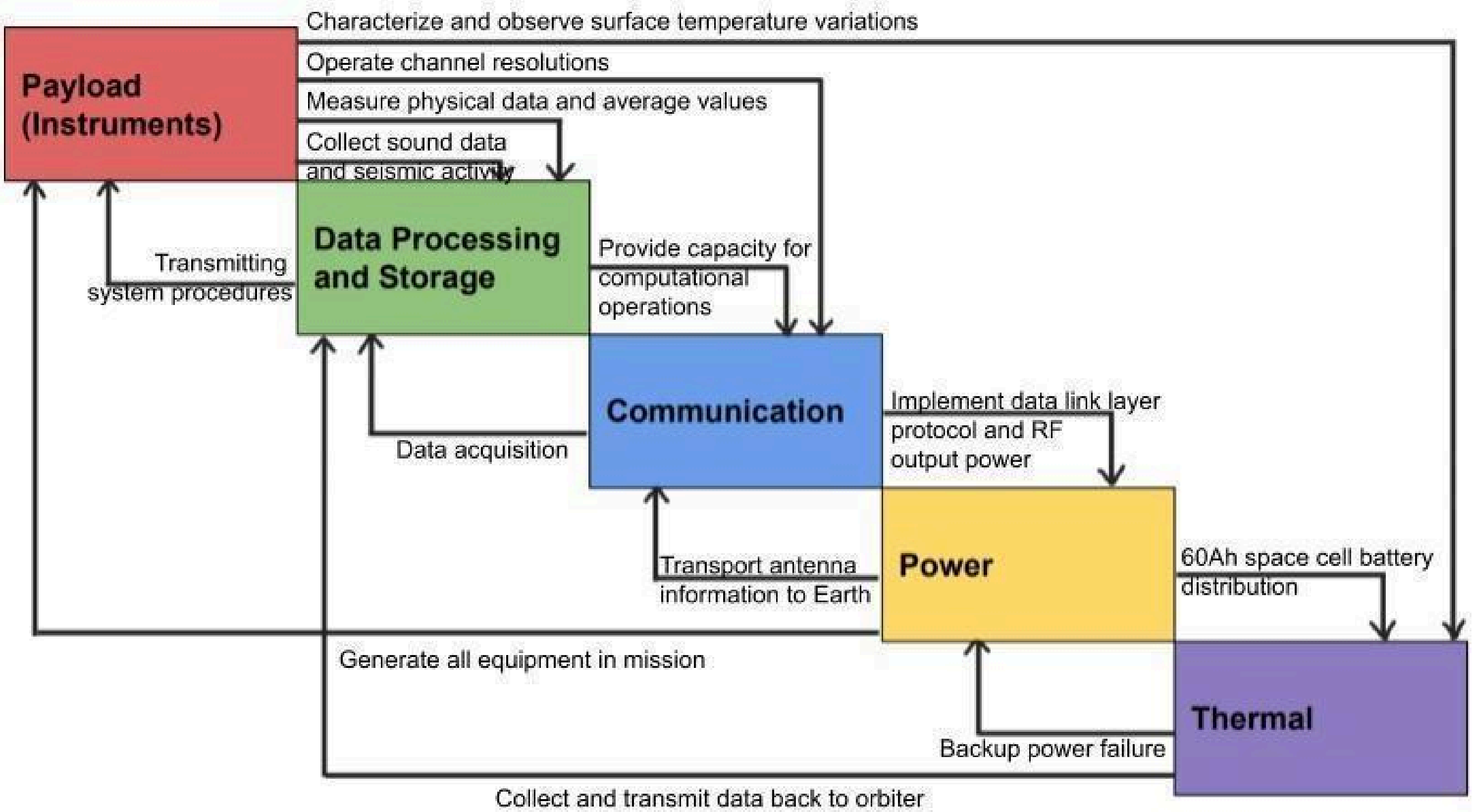


Figure 4.1: Mission Concept N^2 Chart (note: thermal refers to HyTI backup system)

4.1.2. Subsystem Overview

The subsystem in the mission concept design consists of a suite of data gathering instruments, a power system, a communications system, data processing and storage. This system is connected and mounted inside the vehicle as outlined in 3.3.

Data Collection

- **Microphone**
    - The 4006ER Omni Mic offers total transparency in any recording situation. It picks up incredible detail and depth of sound. The definition of its high-frequency characteristics across a wide range of instruments is impressive. It offers natural sound, high sensitivity, low noise-floor and linear frequency response from 10 to 20 kHz (±2 dB). NASA's Mars 2020 Rover took off on July 30, 2020 for a seven-month journey to the mysterious Red Planet. It touched down successfully on February 18, 2021 with a DPA 4006ER Omnidirectional, an MMA-A Digital Audio Interface and an MMP-G Modular Active Cable in tow. [a]

Parameter	**Value**	**Unit**
Operation temperature	-40 to 45	°C
Principal of operation	Pressure	-
Frequency range	20-20,000	Hz
Cable drive capacity	100	m
Voltage supply	48	V
Current consumption	3.5	mA
Power supply	.168	W
Mass	114	g
Microphone diameter	16-19	mm
Capsule diameter	16	mm
Microphone length	35	mm

- **Nephelometer**
    - The principle of operation for the Nephex nephelometer is standard configuration integrating nephelometry. This instrument measures the particle backscattering extinction coefficient of light (bscat) by aerosols. This measurement is accomplished by performing a geometrical integration of light scattered within a sample volume illuminated with a diffuse light source oriented orthogonally to the detector. This technique provides a direct measurement of the bscat of an aerosol sample independent of the physical and chemical composition. [l,m]

Parameter	**Value**	**Unit**
Operation temperature	0 to 50	°C
Range	0 to > 1	km
wavelength	530	nm
Sample volume	.44	L
Mass	1.7	kg
Dimensions	10 x 10 x 10	cm
Power requirements	5.3	W

- **SPICAV**
    - Spectroscopy for the investigation of the characteristics of the atmosphere of Venus (SPICAV) is a suite of three spectrometers in the UV and IR range with a total mass of 13.9 kg flying on the Venus Express (VEX) orbiter, dedicated to the study of the atmosphere of Venus from ground level to the outermost hydrogen corona at more than 40,000 km. [r,s]

Parameter	**Value**	**Unit**
Power consumption	17.6, 26.4, 51.4	W
DPU dimensions	161 x 142 x 70	mm
SU dimensions	504 x 400 x 350	mm
Data rates	9, 34, 66	kbits/s
DPU mass	13.05	kg

SU mass	.865	kg
Spectral band UV	.55	nm/pix
Spectral band IR	.8	nm/pix
Spectral band SOIR	.32	cm^-1

- **Hyperspectral Thermal Imager**
  - "The HSI on-board HyTI is based on the Fabry-Perot Interferometer principle with a "no moving parts" design, ideal for spaceflight missions... it will provide 64 spectral channels of hyperspectral data between 6-11 microns. The instrument detector is a JPL BIRD TIR Focal Plane Array (FPA). BIRD imagers have high uniformity, low cost, low noise, and higher operating temperatures than previously flown TIR FPAs."(v)

Parameter	**Value**	**Unit**
Spectral range	8-10.7	µm
Spectral Resolution	13	cm^-1
Bandcount	64	
Spatial resolution	10-40	m
Dimensions	100.0 x 340.5.0 x 226.3	mm
Swath width	2-15	km
Frame rate	160	Hz
Mass	12	kg
Power consumption	~30	W

Power

- **Battery Cell**
  - The 60Ah space cell battery is a high energy long-cycle life and low maintenance lithium-ion cell for demanding applications. The cell has historic uses on law landers and various earth and exploratory satellites.[c]

Parameter	**Value**	**Unit**
Operational temperature	-20 to 40	°C
Storage temperature	-40 to 40	°C
Specific energy	160	Wh/kg
Nominal voltage	3.6	V
Voltage range	3.0-4.1	V
Cell weight	1.6	kg
Dimensions without spokes	141.3 x 137.7 x 34	mm
Dimensions with spokes	155.1 x 137.7 x 34	mm
Shell material	Stainless steel	-

Communications

- **S-Band Patch Antenna**
  - The ISIS S-band patch antenna is a compact, low mass solution suitable for the 2200-2290 MHz S-band frequency range. This antenna is suitable for integration on any CubeSat platform and directly compatible with the ISIS S-band transmitter and transceiver products as well as ISIS standard CubeSat structures.[f]

Parameter	**Value**	**Unit**
Operational Temperature	-20 to 50	°C
Frequency Range	2200-2290	MHz
Half power beam width	100	°
Return loss	>13	dB
Bandwidth	>100	MHz
Power consumption	2	W
Mass	<50	g
Diameter	80	mm
Height (Without connector)	5.0	mm
Connector height	8.8	mm

- **S-Band Transmitter**
  - The ISIS High Data-rate S-band Transmitter is a CubeSat compatible transmitter designed to meet the needs of high data-rate downlinks of up to 4.3 Mbps (usable information bit-rate at CCSDS TM Transfer Frame level). The transmitter can be used for both TT&C or Payload Data downlinks. The S-band transmitter is flexible, implementing CCSDS as data link layer protocol and allowing in-flight configuration of data-rate, modulation scheme, frequency, and RF output power.[g]

Parameter	Value	Unit
Operational temperature	-40 to 70	°C
Frequency range	2200-2290	MHz
Frequency step size	1	kHz
Frequency stabilizer	+/- 10	ppm
RF output power	27-33	dBm
Transmitted data rate	10	Mbit/s
Useful information bitrate	4.3	Mbit/s
Supported symbol rates	0.625, 1.25, 2.5, 5	Msym/s
Power consumption	13	W
DC voltage supply	7-20	V
Dimensions	98.8 x 93.3 x 14.5	mm
Mass	132	g

Data Processing

- **iX5100 SpaceCloud**
  - "The iX5100 uses computer modules from the Unibap e20xx / e21xx series with support for GPU and one or more neuron network accelerators. Fully equipped, the iX5100 has the capacity for several trillion computational operations per second (TOPS)."[k]

Parameter	Value	Unit
Operational temperature	-40 to 70 (15 W TDP SOC)	°C
Intelligent Processing Core	Unibap Qseven e20xx/e21xx compute modules	
RAM	2 GB DDR3 ECC (CPU/GPU), 0.5 GB DDR3 ECC (FPGA) ECC on Flight Models	GB

Storage	Up to 240 GB M.2 Solid State Drive (SSD) SLC type 64 GB eMMC / Micro-SD card	GB
Display output for development	HDMI output, max 4K HD	
Ethernet, GigaLAN	1	RJ-45
USB	2 × USB v2.0 1 x USB v2.0 (ext. connector) 1 × USB v3.0 (ext. connector)	USB
Serial Communication	5x RS232/422 (Isolated)	Serial
Power consumption	10-30 W (Depending on processing and storage selection and use)	W
DC voltage supply	12VDC	V
Dimensions	96 × 95 × 50	mm
Mass	200 (included on HyTI)	g

- **The ISIS On Board computer (IOBC)**
    - “Its pluggable daughter board offers additional flexibility and customizability by providing a wide range of extra interfaces for payloads, sensors or actuators in a compact form factor.” [e]

Parameter	**Value**	**Unit**
Operational temperature	-25 to 65	°C
Processing Core	400MHz 32-bit ARM9 processor	MHz
RAM	64MB SDRAM	MB
Storage	2 x 2GB high reliability SD cards for fail safe data storage (up to 32 GB on request) or 2x any size standard SD cards 512kb FRAM 1MB NOR Flash	GB
Master or slave mode	SPI master mode up to 8 slave	
Ethernet, GigaLAN	None	RJ-45

USB	Adapter board (including debugging UART to USB conversion) + USB cable	USB
Serial Communication	2x UART (RS232 + RS232 / RS485 / RS422)	Serial
Power consumption	40W average (Depending on processing and storage selection and use)	W
DC voltage supply	3.3VDC	V
Dimensions	96 x 90 x 12.4	mm
Mass	200g	g

4.1.3 Manufacturing Plan

The VESPAA architecture provides a low cost solution with a high return because it is able to leverage the availability of flight ready hardware in the aerospace market. This allows mission designers to acquire many of the parts they need quickly for rapid testing and integration. COTS products give missions the ability to assemble all of the components needed to build the vehicle and its instruments.

- The timeline for the manufacturing process for the vehicle's science instrumentation is less than six months. They can be assembled independent of vehicle design, as most parts will arrive ready for integration and testing.
- The HyTI which is ready for purchase "as is" can also be assembled from standard 6U cubesat frames, with component parts from heritage suppliers like ISIS and Eaglepitcher. The lead time on many of these parts is 12 weeks which will allow for adequate time to prepare the body of the vehicle for integration. The camera and thermal cooling systems are also available through reliable suppliers
- VESPAA's microphone is the 4006ER Omni, which is a commercial class microphone that has flown on the Mars Perseverance mission. This device is easily configurable, portable, and affordable. This solution offers a high quality device without the need for assembly, the device can be integrated immediately.
- To assemble the Nephlex instrument it will require 1550 nm and a 785 nm Matchbox series laser, from Integrated Optics, another commercial supplier. This instrument also utilizes the readily available beagle box controller and a set of 18650 batteries.

This design that NASA/Ames Research Center created is already at a TRL4 level

- The SPICAV instrument is not readily available off of the shelf and would need to be manufactured or purchased. However the design has flown twice and is most likely available to procure. The instrument itself is lightweight, consisting of telescope tubes, mirrors and detectors. However it likely has a long lead time and the also most expensive instrument on the vehicle.

All of the science instrumentation will need additional housing, mounting, and securing onto the main frame. These instruments will be connected to the vehicle's main computer housed inside the vehicle. None of the connections on the instruments are proprietary, and are easily available as well. As the Commercial space market is booming with innovation and reliable suppliers, this trend makes spaceflight missions like the VESPAA vehicle more affordable and attainable for potential customers.

4.1.4 Verification and Validation Plan

The product verification process is the first of the verification and validation processes conducted on an end product. As used in the context of the systems engineering common technical processes, a product is one provided by either the Product Implementation Process or the Product Integration Process in a form suitable for meeting applicable life cycle phase success criteria. The main testing and verification happens at the realized end product or realized product. Verification testing relates back to the approved requirements set and can be performed at different stages in the product life cycle.

The approved specifications, drawings, parts lists, and other configuration documentation establish the configuration baseline of that product, which may have to be modified at a later time. Without a verified baseline and appropriate configuration controls, later modifications could be costly or cause major performance problems.

- We will verify the balloon and the payload body by testing in a confined atmosphere. The approved specifications, drawings, parts lists, and other configuration documentation establish the configuration baseline of the system, which may have to be modified at a later time. Without a verified baseline and appropriate configuration controls, later modifications could be costly or cause major performance problems. The cooling systems for the internal systems will be tested under stimulated environments.

The next step after verification is validation. Product verification proves that an end product (whether built, coded, bought, or reused) for any element within the system structure conforms to its requirements or specifications. Such specifications and other design description documentation establish the configuration baseline of that product, which may have to be modified at a later time. Without a verified baseline and appropriate configuration controls, such later modifications could be costly or cause major performance problems.

- Validation testing is conducted under realistic conditions (or simulated conditions) on end products for the purpose of determining the effectiveness and suitability of the product for use in mission operations by typical users.

4.1.5 FMEA and Risk Mitigation

					1=Low 5=High	1=Low 5=High		1=Low 5=High	1=Low 5=High	
Item Number	**Functions**	**Failure Mode**	**Cause(s)**	**Effect(s)**	**Severity**	**Probability**	**Detection**	**Ease of Detection**	**Risk Level**	**Recommended Action(s)**
RP-1	Materials and Systems	High temperatures	Temperature is high during entry and when at low altitude.	Melted or otherwise damaged hardware. Thermal expansion/ contraction of materials as they heat up and cool down.	3	4	Radio Communication of Instrument Data	5	4	Mitigate Risk by using material requirements for high temperatures to survive the entry and descent phase.
RP-2	Aerospace and Propulsion	Separation failure of aeroshell	Failure of pyro to actuate and remove aeroshell.	The vehicle will be unable to perform mission function.	5	2	Radio Communication of Instrument Data	3	4	Mitigate Risk by using legacy hardware and performing several functional tests under a simulated environment
RP-3	Mechanical and Design	Balloon Inflation System Failure	Damaged balloon deployment system, balloon potentially caught on something while in packed configuration.	The vehicle will be unable to perform mission function.	5	3	Radio Communication of Instrument Data	2	5	Use extensive testing on materials and components before launch to determine system reliability.
			Damaged							

RP-4	Materials and Systems	Damaged Satellite Antenna	radio communication antenna by impact, temperature, or	The vehicle will be unable to perform mission function.	4	1	Permanent Loss of Communication	5	3	Mitigate Risk by protecting components from impacts and provide redundancy.

			radiation.							
RP-5	Admin	Over budget	Caused by a variety of factors like material lead times, COVID-19 impacts, unplanned issues, component availability, etc.	Potential schedule delay if need to request additional funds for the project.	1	3	Budget Analysis	4	1	Accept Risk by allocating additional funds from the budget for unplanned risks.
RP-6	Materials and Systems	Damage to Cameras	Damaged camera by impact, temperature, or radiation.	The vehicle will be unable to perform mission function.	4	2	Radio Communication of Instrument Data	4	3	Mitigate Risk by monitoring the orbit of the vehicle and using thrusters to adjust course to enter Venus' atmosphere at the correct speed and location. If entry fails, circle the planet for gravity assist and repeat.
RP-7	Aerospace and Propulsion	Solar Radiation	Radiation is high while the vehicle is not protected by an atmosphere.	Melted or otherwise damaged hardware. Corrosion of materials as they remain exposed to radiation.	4	4	Radio Communication of Instrument Data	4	5	Research Risk to determine failure modes of solar radiation and estimate lifetime of hardware based on exposure to solar radiation.

RP-8	Admin	Delayed schedule	Caused by a variety of factors like material lead times, COVID-19 impacts, unplanned issues, component availability, etc.	Delay launch of vehicle, potential to accrue fees associated with delaying the schedule like employing workers for longer than planned, paying launch lot fees, etc.	2	4	Schedule Analysis	2	3	Watch Risk my monitoring schedule and planning additional time into the schedule to account for unplanned delays due to outside factors.
RP-9	Aerospace and Propulsion	Atmospheric Debris	Roaming debris is potentially in the atmosphere.	Roaming debris can impact the vehicle and cause temporary or permanent damage that could result in system failure.	2	3	Camera	1	2	Research Risk to determine how atmospheric debris can impact the mission and estimate likelihood of occurrence.
RP-10	Mechanical and Design	Over mass constraint	Final assembly of the vehicle is too heavy for the given weight constraint.	Re-working materials will have a cost and time impact on the project	3	2	Inspection	4	2	Watch Risk by monitoring total vehicle weight and setting maximum weight requirements for different functional areas of the orbiter.

RP-11	Mechanical and Design	Over Volume Constraint in stowed configuration	Stowed configuration of the vehicle is too large for the given volume constraint.	Re-working materials will have a cost and time impact on the project	2	2	Inspection	3	1	Watch Risk by monitoring stored vehicle volume and setting maximum volume requirements for different functional areas of the orbiter. Utilize folding techniques to reduce the overall footprint of the vehicle while stowed.
RP-12	Admin	COVID-19 impacts	Global pandemic spread by germs.	Cost and schedule impacts, personnel health impacts.	2	5	COVID-19 Testing	3	4	Accept Risk by planning for additional cost and time delays due to COVID-19.
RP-13	Admin	Unplanned Risks	Risk caused by unpredictable outside factors.	Primarily impact cost and time but could affect any aspect of the project.	3	5	N/A	1	5	Accept Risk by planning for additional cost and time delays due to unplanned impacts due to outside factors.
RP-14	Materials and Systems	Damaged Temperature Sensors	Damaged sensor by impact, temperature, or radiation.	The vehicle will be unable to perform mission function.	2	1	Radio Communication of Instrument Data	4	1	Mitigate Risk by protecting components from impacts and provide redundancy.
RP-15	Materials and Systems	Damaged Pressure Sensors	Damaged sensor by impact, temperature, or radiation.	The vehicle will be unable to perform mission function.	3	1	Radio Communication of Instrument Data	4	1	Mitigate Risk by protecting components from impacts and provide redundancy.

RP-16	Materials and Systems	Damaged Atmos p heric Composition Sensors	Damaged sensor by impact, temperature, or radiation.	The vehicle will be unable to perform mission function.	5	1	Radio Communication of Instrument Data	4	3	Mitigate Risk by protecting component from impacts and provide

		Project Risk Management Matrix				
P ro b a bi lit y	**5**		RP-12-COVID -19 Impacts	RP-13-Unplanned Risks		
	4		RP-8-Delayed Schedule		RP-7-Solar Radiation	
	3	RP-5-Over Budget	RP-9-Atmospheric Debris	RP-1-High Temperatures		RP-3-Balloon Inflation System Failure
	2		RP-11-Over Volume Constraint	RP-10-Over Mass Constraint	RP-6-Damage d Camera	RP-2-Separation Failure of Aeroshell
	1		RP-14-Damaged Temperature Sensors	RP-15-Damaged Pressure Sensors	RP-4-Damage d Satellite Antenna	RP-16-Damaged Atmospheric Composition Sensors
		1	**2**	**3**	**4**	**5**
		Severity				

Payload Design and Science Instrumentation

Probability	**Severity**	**Approach**	**Item Number**	**Risk Description**	**Risk Area**	**Risk Plan**
3	3	Mitigate	RP-1	High temperatures	Materials/Systems	Mitigate Risk by using material requirements for high temperatures to survive the entry and descent phase. Aeroshell and heat shield should be used for entry and rated for ultra-high temperatures.

	2	5	Mitigate	RP-2	Separation failure of aeroshell	Aerospace/Propulsion	Mitigate Risk by using legacy hardware and performing several functional tests under a simulated environment	
	3	5	Mitigate	RP-3	Balloon Inflation System Failure	Mechanical/Design	Mitigate Risk by using legacy hardware and performing several functional tests under a simulated environment	
	1	4	Mitigate	RP-4	Damaged Satellite Antenna	Materials/Systems	Mitigate Risk by protecting components from impacts and provide redundant hardware.	
	3	1	Accept	RP-5	Over Budget	Admin	Accept Risk by allocating additional funds from the budget for unplanned risks.	
	2	4	Mitigate	RP-6	Damage to Cameras	Materials/Systems	Mitigate Risk by protecting components from impacts and provide redundancy.	
	4	4	Research	RP-7	Solar Radiation	Aerospace/Propulsion	Research Risk to determine failure modes of solar radiation and estimate lifetime of hardware based on exposure to solar radiation.	
	4	2	Watch	RP-8	Delayed schedule	Admin	Watch Risk my monitoring schedule and planning additional time into the schedule to account for unplanned delays due to outside factors.	
	3	2	Research	RP-9	Atmospheric Debris	Aerospace/Propulsion	Research Risk to determine how atmospheric debris can impact the mission and estimate likelihood of occurrence.	
	2	3	Watch	RP-10	Over mass constraint	Mechanical/Design	Watch Risk by monitoring total vehicle weight and setting maximum weight requirements for different functional areas of the orbiter.	
	2	2	Watch	RP-11	Over Volume Constraint in stowed configuration	Mechanical/Design	Watch Risk by monitoring stored vehicle volume and setting maximum volume requirements for different functional areas of the orbiter. Utilize folding techniques to reduce the overall footprint of the vehicle while stowed.	

5	2	Accept	RP-12	COVID-19 impacts	Admin	Accept Risk by planning for additional cost and time delays due to COVID-19.
5	3	Accept	RP-13	Unplanned Risks	Admin	Accept Risk by planning for additional cost and time delays due to unplanned impacts due to outside factors.
1	2	Mitigate	RP-14	Damaged Temperature Sensors	Materials/Systems	Mitigate Risk by protecting components from impacts and provide redundancy.
1	3	Mitigate	RP-15	Damaged Pressure Sensors	Materials/Systems	Mitigate Risk by protecting components from impacts and provide redundancy.
1	5	Mitigate	RP-16	Damaged Atmospheric Composition Sensors	Materials/Systems	Mitigate Risk by protecting components from impacts and provide redundancy.

4.1.6 Performance Characteristics

The payload will be exposed to the venus atmosphere between altitudes of 140 km and 50 km, typically operating between 50 km and 75 km. The payloads components will need to be able to operate under the condition associated with these altitudes. This means the payload will have to operate at temperatures between -76 °C and 75 °C, pressures from 0.005 Bar to 1.08 Bar. The payload must also survive brief exposure to extremely cold temperatures as low as -112 °C. Moreover, the payload will have to survive the composition of venus' atmosphere which will include carbon dioxide, sulfuric acid, sulfur dioxide, water vapor, carbon monoxide, monatomic oxygen and sulfur tetroxide.

All instruments will need some form of protection from sulfuric acid that shall be provided by the vehicle's exterior.

S-Band Antenna

- Operation temperature -20 °C to 50 °C
  - Thermal system will be required to meet this requirement
  - Both heating and cooling will be required
- Pressure should not affect his instrument

S-Band Transmitter

- Operation temperature -40 °C to 60/40 °C
    - Thermal system will be required to meet this requirement

    - Both heating and cooling will be required
- Pressure should not affect his instrument

60Ah Space cell battery
- Operation temperature -20 °C to 70 °C
    - Thermal system will be required to meet this requirement
    - Both heating and cooling will be required
- Pressure should not affect his instrument
- Stainless steel case will not react with sulfuric acid
    - If stainless steel has water on it sulfuric acid will damage the steel
    - Condensation could occur from water vapor in atmosphere

Microphone
- Operation temperature -40 °C to 45 °C
    - Thermal system will be required to meet this requirement
    - Both heating and cooling will be required
- Pressure should not affect his instrument
    - Pressure does affect this but can be calibrated internally

Nephelometer
- Operation temperature 0 °C to 50 °C
    - Thermal system will be required to meet this requirement
    - Both heating and cooling will be required
- Pressure should not affect his instrument

Spectrometer
- Internal temperature control
- Pressure should not affect his instrument

Hyperspectral Thermal Imager
- Operation temperature 5 °C to 40 °C
    - Internal temperature stabilizer
- Pressure should not affect his instrament

4.2 Science Value

4.2.1 Science Payload Objectives

The VESPAA (Venus Environmental Surveyor and Particle Analysis Aircraft) shall study the Venusian cloud layers with various scientific payloads that shall sample aerosols from the atmosphere and record the vertical profiles of CO2 SO2, SO, H2O and observe the emissions of CO, CO+, and CO2+, which shall give researchers valuable data used to better understand and measure the dynamic deep atmosphere. The vehicle shall also take IR Images of the surface within observation bands ranging 8-10.7 µm that shall allow for detailed weather, terrain, and feature mapping, while also obtaining significant coverage of the planet's hemispheres. Also that data shall give researchers more insight into weather patterns and other related phenomenon.The VESPAA vehicle shall include microphones onboard to observe seismic activities via infrasound signals that are recordable thousands of kilometers away from volcanic and seismic epicenters. This mission shall also collect in-situ measurements of the atmospheric pressures between 0.01 bar and ~1 bar to study the composition of gases within each cloud layer. Data shall then be transmitted to the orbiter up to 500mbps through S-band 2200-2290 MHz frequency communication antennas and then relayed back to the Earth network. The VESPAA vehicle shall have more than enough battery power to operate scientifically robust systems and maintain operational altitudes and communications, all while maintaining a safe and energy rich design.

- Venus offers a unique set of challenges and poses many questions about its formation and how its climate behaves. Many see it as an opportunity to better understand exoplanets and climate change on Earth. “Venus is covered by a thick global cloud layer, between altitudes of 48 to 70 km. This cloud layer is divided into three regions, characterized by variations in the distribution of cloud particles . The upper cloud (~60 to 70 km) absorbs most of the UV flux coming from the Sun. A planet-wide deep convective layer is localized in the middle cloud (~50 to 60 km) and lower cloud layers (~45 to 50 km). The energy absorbed below the clouds cannot escape past the cloud base through radiative processes, due to cloud and CO2 optical thickness. This results in the destabilization of the lower and middle cloud layers, with strong convection that transports energy from the cloud base to ~60 km.” (*Seismology on Venus with infrasound observations from balloon and orbit*) [h]
- Additionally given the similarities Venus once shared with Earth's current climate many have hypothesized that life could have existed on the surface and could still be inhabiting within the cloud layer through evolutionary processes.
    - ”Life may have been both present and abundant at least until its oceans were lost. Just as the ocean/fluvial environment may have left signs within the planets geology and composition that new missions could identify (e.g.higher resolution

radar imaging, direct imaging near the surface, chemical and mineralogical analysis)"(*The Venus Life Equation*) [t]

- After EDL and the inflation maneuver the computer will run a diagnostic check on all power systems and component sub-systems. Error-correcting based on values and inputs received based on telemetry data. Once the system is complete and running it shall establish communications link with the orbiter using the S-Band frequency and confirm operational status to mission control. The vehicle will maintain an altitude of 65km above the surface while in communications standby mode. After the connection is established the VESPAA vehicle will begin to test and calibrate its instruments, sampling the 65km layer first before moving into its mission life cycle.
- VESPAA is currently developing methods for controlling and maintaining altitudes within the Venus atmosphere, using the Rozier method discussed earlier. The concepts shall improve upon methods that have no controllable features. Based on the criteria the vehicle will need to maintain altitude control between 50km - 75km and be responsibly capable of doing this autonomously. This shall also be applied to prevent altitude loss due to cooler temperatures on the night side of the planet. Atmospheric dynamic models based on the data collected by the Vega Balloon have been used in simulations to demonstrate flight within the 50km - 75km region. "Flights at both altitudes demonstrated a net energy gain. What is interesting to note about the results is that the average energy gathered per cycle was larger at the 60km altitude, but the total energy gain in the system was larger for the flight at 55 km." Figure 4.2.(*Future of Venus Research and Exploration.*) [d]

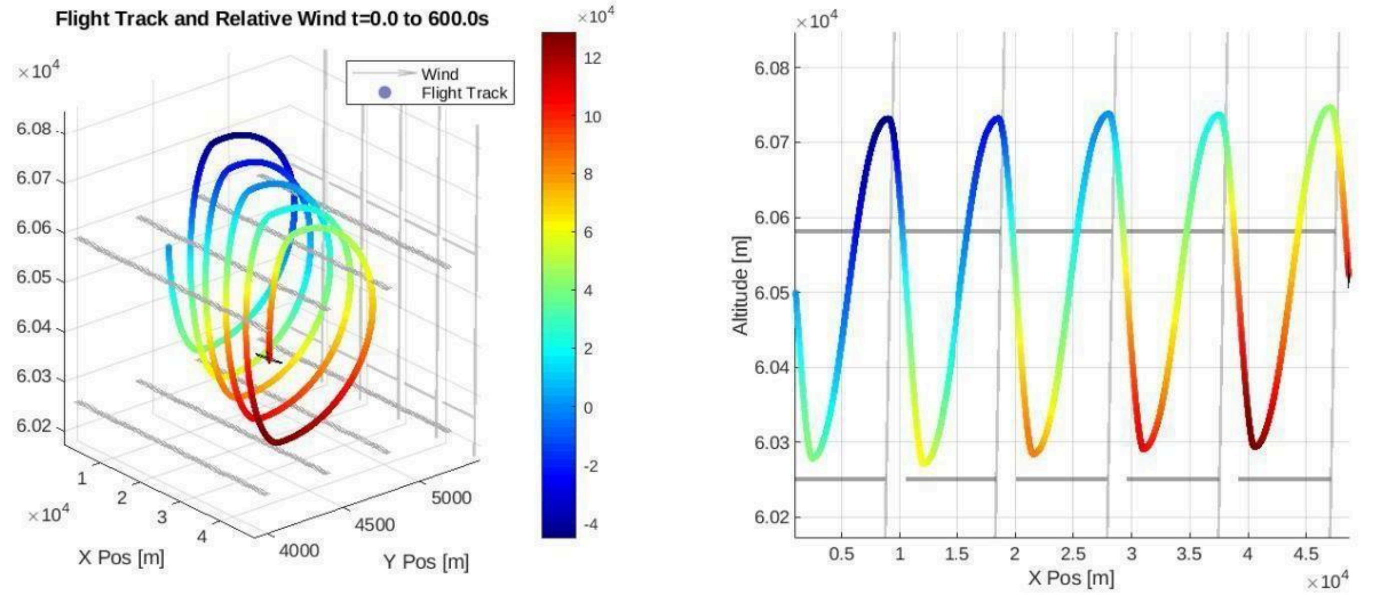


Figure 2: Results from a flight through the high fidelity model using the relative version of the dynamic soaring algorithm. The flight was conducted around 60 km in altitude over 600 seconds and shows relative energy gain as the color of the flight path.

Figure 4.2: Aerodynamic model shows net altitude gain [d]

- This research would suggest that traditional methods for controlled flight are capable within the desired range of VESPAA's design. And if this data is accurate then the performance of the VESPAA vehicle shall be more predictable and more reliable.

- the VESPAA vehicle's design shall be able to survey much of the Venus terrain in its short life-span with its thermal imager on the HyTI, covering around 200 square km per hour. According to a white paper by Siddharth Krishnamoorthy, "The trajectory of a balloon within the cloud layers may be investigated with general circulation models (GCMs). According to the IPSL Venus GCM, for example, a balloon launched in the equatorial region may have large latitudinal variations, up to 60° of latitude, over a timescale of tens of Earth days." [h]
    - This area of coverage shall provide researchers with higher resolution images of Venus' atmospheric and terrain features than that of the Magellan and Venus Express missions.If the craft is able to travel 60° latitudinally toward the polar region of Venus over the course of ~10 days, then a large kilometer area of resolution every five minutes shall be adequate enough to make a detailed map of the hemisphere in which the craft is travelling in.
- The current mission concept objective is to collect aerosols from within the different layers of clouds Venus has. As it traverses the various layers the data the mission shall collect and effectively compare the samples of the atmospheric compounds by taking samples at different altitudes. "Recent modelling (Way M. J., et al., 2016) has shown it is

theoretically possible that ancient Venus may have been capable of retaining oceans of liquid water near the surface, with a climate extremely similar to Earths." (*Space Physics at Venus:Exploring atmospheric dynamics, escape, and evolution*) [u] Venus provides a great opportunity to study dynamic systems like Earth's and gives insight into the forces that shaped Venus'past.

  - The VESPAA mission shall fly on a path in the atmosphere collecting data between the altitudes of 50km -70km and 65km above the surface. The (SPICAV) Instrument shall be able to record several sets of data in the visible, ultraviolet, infrared, and long-wave infrared of the atmosphere's composition of particles. The instrument has several operational modes that allow it to exclude observations, but requires a stable and specific attitude.

- The surface of Venus and its features are shaped by unknown forces, many prevailing theories suggest that there is active volcanism. "Carrying out a seismic investigation at Venus could provide critical and presently unavailable information regarding the planet's current levels of tectonic and volcanic activity, the spatial and temporal distribution of that activity, possibly the contemporary impact flux there, and even information about the planet's interior itself." [h]
  - The VESPAA mission design shall include microphones that will be used to record seismic and tectonic activities in the 20 Hz - 20 kHz range. This measurement can be run during any period of the VESPAA mission's flight path as these measurements can be recorded well within the vehicle's flight plan.
  - "On Earth, a typical VEI 4 (VEI: Volcanic Explosivity Index) eruption may produce precursory and co-eruptive seismicity recordable at local distances (<50 km), co-eruptive seismicity recordable to regional distances (to ~250 km), and infrasound signals recordable for several thousand kilometers from the source, depending upon stratospheric wind direction and site noise conditions" [h]
- The mission shall operate for ~30 days based on the trajectory models defined in the *NASA JPL 2009 Venus Flagship Mission Study* [j]. That if travelling in the cloud layer above 50km of the surface the natural currents would take an unaided aircraft eventually toward the poles over the course of about ~30 days. This duration could increase if models that show controlled flight may be possible are correct, then later designs could potentially last much longer and conduct more research.
  - "The balloons are expected to drift poleward due to the prevailing winds and end up in the polar vortex by the end of the 30-day mission. This will provide substantial latitudinal coverage for the balloon science investigations "*(NASA, JPL. (2009) Venus Flagship Mission Study)*[j]
- All of the data will be transmitted back to the orbiter that is able to receive several different radio bands. The VESPAA mission will transmit up to 500mbps through S-band 2200-2290 MHz frequency to the orbiter several hours every orbit. This frequency was chosen by the VESPAA mission team as it is capable of transmitting through the thick

Venusian atmosphere and maintaining a stable and uninterrupted signal. “The average data rate for the balloon-orbiter link is over 500 b/s, when the orbiter range is less than 30,000 km and the elevation angle is more than 20° periods and possible periods of data transmission during the 30-day balloon mission. Proper conditions for the 500 b/s data rate exist for several hours on practically every orbit.” [j]

- The vehicle will be outfitted with a S-band transmitter and antennae that shall provide reliable and stable connection. The ISIS High Data-rate S-band Transmitter and S-band Patch currently selected also features a data link layer protocol, which allows for in-flight configuration of data-rate, modulation, frequency, and RF output.
- “S-Band was chosen because it was successfully used by the Pioneer-Venus probes and the Venera/VEGA landers and because it offers small atmospheric losses through the thick Venusian atmosphere.” [j]

Researchers have limited models and many unanswered questions about Venus such as: How long has the climate been in its current extreme state, and what forces cause this phenomenon? By examining the compositions of the elements CO, CO+, CO2, SO, SO2, & H2O in the different cloud layers researchers shall gain further insight into Venus’ evolution. Radar images of the features of the surface and concentrations of particles in the cloud layers shall assist teams who are modeling these dynamic conditions and by creating a more detailed map of weather, terrain, and other features on the surface using 25 IR observation channels between 8-10.7 ųm. The VESPAA mission will also listen for tectonic, volcanic, and seismic activity that is likely to be happening on the surface using several microphones. These experiments shall be conducted for around 30 days as the natural vortex will cause the craft to head toward the poles several degrees in latitude gain every day. Additionally, communications will be maintained and transmitted at over 500 b/s via orbiter-balloon link which is then transmitted back to the network. Controlled flight could potentially extend the mission but further research is needed.

4.2.2 Creativity/Originality and Significance

While following the principles of physics to ensure a well functioning balloon, the VESPAA mission sought to create a unique mission which prioritized innovation. The following are the goals for our mission:

- To study aerosols and cloud composition within the different cloud layers on Venus
- To use radar to take pictures of the surface features it passes over
- To use recorded sound to study volcanoes and seismic activity.

The information gathered from the VESPAA mission is significant due to the lack of in-situ measurements taken on Venus. Its unique and dynamic atmosphere allows researchers to better understand many unanswered questions about planet formations. The VESPAA mission seeks to gather this data and utilize its discoveries to create better models and data sets for Venus' unique features.

4.2.3 Payload Success Criteria

Type	**Criterion**	**Instrumentation**	**Baseline**	**Threshold**	**Success**
Atmospheric composition	Compare compositions of aerosols (CO_2 SO_2, SO, H_2O, CO, CO^+, and CO_2^+) of the atmosphere at various altitudes.	SPICAV (spectrometer) - measures in the UV and IR spectrum; Nephelometer	data entry every 100km through the atmosphere	same as baseline	same as baseline
	collect in-situ measurements of the atmospheric pressures between 0.01 bar and ~1 bar	Nephelometer	data entry every 100km through the atmosphere	same as baseline	same as baseline
Imaging	IR Images of the surface within observation bands ranging 6µm - 12µm	HyTI (Hyperspectral Thermal Imager)	Capture images at intervals of 100km through the atmosphere	same as baseline	same as baseline
Seismic data	observe seismic activities via infrasound signals that are recordable thousands of kilometers away from volcanic and seismic epicenters	4006ER Omni (microphone) “It offers natural sound, high sensitivity, low noise-floor and linear frequency response from 10 Hz to 20 kHz (±2 dB).”	100(+) hours	same as baseline	same as baseline

*Data transmission	Transmit data to orbiter	ISIS S-band patch antenna and transmitter	up to 500mbps through S-band 2200-2290 MHz frequency	10MB of data sent	500MB of data sent
	Orbiter data relayed to Earth	ISIS S-band patch antenna and transmitter			
*Flight	Remain airborne at designated altitudes for at least 30 days	60Ah Space Cell Battery	30 days	Same as baseline	Same as baseline

* = satisfy mission requirements, but may not directly meet the mission objectives

Figure 4.3: Criteria Chart

Categories of criteria for success of the instrumentation include atmospheric composition, imaging of Venusian surface, seismic/sound data, data transmitted to orbiter and relayed to earth, and duration of flight.

- The atmospheric data the team expects to collect from this mission will give a better understanding of how, why, and for how long the extreme conditions have persisted on Venus. A study of aerosol composition in the atmosphere may reveal past conditions on Venus, including possible retention of liquid water on the surface in the past.
- Obtaining further infrared images of the surface of Venus from various altitudes will further our current understanding of the terrain and assist in mapping a more complete model of Venus.
- Sound data collected during this mission will give researchers a better understanding of current seismic activities that may reveal ongoing processes in the formation of Venusian terrain and interior, possibly extending to the formation of the planet—and our solar system.

All of this information combined shall give a better understanding of the Venusian atmosphere and surface, which may aid in simulating similar conditions here on Earth. Researchers may then be able to conduct further testing on different materials under these conditions in order to study how current instruments may be modified/constructed to be more suitable and sustainable for future long-term missions. As Earth's own atmosphere and climate continue to shift, it may be possible to observe similar (or dissimilar) effects due to changes occurring in the Venusian atmosphere.

4.2.4 Experimental Logic, Approach, and Method of Investigation

The VESPAA vehicle is tasked with collecting and transmitting data from the various instruments it shall carry. Each of the instruments will collect different data sets from the Venusian environment, store the data, and then transmit the data to the orbiter which shall then relay the data back to researchers on Earth. The methods for collecting the data shall vary from instrument to instrument and shall also vary in transmission duration. Much of this data can be stored on a solid state drive and queued for optimal transmission opportunities and more efficient energy usage. In addition, each of the instruments systems has an automated schedule that creates a backup of its last data set in case of a failure that may occur. This schedule was also designed to maximize the science potential while mitigating risks to the vehicle and its mission's goals. Each instrument will record its data for the selected duration (some operating simultaneously) until the procedure is completed. The data will then be cached and processed, and organized until transmission is verified and the cycle will then continue to repeat for the duration of the mission.

- The two computers, the main ISIS On Board computer (IOBC) and the HyTI instrument processor iX5-100 and storage array, will track time of measurements and organize stored data based on the type and timing of recordings. In conjunction with on-board altimeters, thermometers, and pressure sensors, this data recorded will be transmitted with the other data sets and shall run during the majority of mission life, as these sensors will also provide valuable feedback to the vehicles controllers to regulate thermal and altitude control. There are many flight ready heritage hardware choices available that are capable of handling the atmosphere on Venus. These processors are connected to and control all of the vehicle's functions and its scientific payloads.
    - "Onboard the HyTI satellite, the iX5-100 solution processes approximately 464 megabits per second (Mbps) of real-time data from the spectral thermal sensor and has up to 240 GB of non-volatile data storage." (NASA Hyperspectral Thermal Imager (HyTI) Mission)[k]
    - "The iX5100 offers interfaces for sensor readout and payload telemetry downlink/telecommand in combination with high speed local SSD storage in one package. iX5100 has been integrated with S- and X-band radios." [k]

Infrasound recordings of the Venusian atmosphere shall give researchers more insight into the seismic and geological activities that are occurring on Venus' surface. Recording sound via microphone was demonstrated in the early Venus missions, and proved to capture high quality audio data. The array of microphones on the VESPAA vehicle will be arranged on the vehicle's bottom on the exterior of the craft. Protected by a special casing that is designed to operate in extreme environments. The crafts objective is to obtain and transmit 100 + hours of sound data from recording the ambient sound on Venus."Observations on Earth have revealed that seismic activity produces a host of acoustic and gravity waves in the atmosphere.” [h]

- The microphone will record data when other equipment is in standby mode and not performing functions that would create any acoustic disturbances.
- Each data set will be paired with its corresponding altitude and speed for more accurate modelling of the position
- The microphone will record for 1 hour intervals which will allow it to sample around 200 square kilometers every hour based on the average wind speed of the Venusian atmosphere (200kph)
- The data will be stored and processed, then transmitted during optimal transmission periods

Many geological and terrain features of Venus remain relatively unknown including data about precipitation, cloud behavior, and if there is active volcanism. Thermal imaging can provide researchers with valuable data that can be used to determine if there is active geology on the surface and model weather patterns of the distinct cloud layers. The mission’s objective is to take imaging data sets every 15km or every 5 min during scheduled operating times.

- The Hyperspectral Thermal Imager (HyTI) cubesat instrument has a thermal imaging camera that offers channels between 8-10.7 µm and is cryogenically-cooled (BIRD FPA). It also contains its own iX5-100 computer, s-band transmitter, 90Wh of batteries. Making the instrument self reliant and can operate independently.
- “The mission will use a spatially modulated interferometric imaging technique to produce spectro-radiometrically calibrated image cubes, with 25 channels between 8-10.7 ųm, at 13 cm-1 resolution), at a ground sample distance of ~60 m.”[k]
- The Imager will be facing downward on the bottom of VESPAA’s design vehicle. Images will be taken in 5 min intervals for 8 hours everyday during its scheduled operating times
- The data will be stored and processed, then transmitted during optimal transmission periods

The composition of the atmosphere on Venus is mainly made up of CO, CO+, CO2, SO, SO2, & H2O. But due to the extreme greenhouse effect Venus experiences much of those particles stay suspended in the varying cloud layers. Although there are some analyses of the composition of the Venus atmosphere via previous missions, the exact compositions of the atmosphere’s concentrates are unknown. The VESPAA mission would include several imaging spectrometers with two channels that shall analyze the aerosol content within the varying altitudes of Venus’ atmosphere at intervals of 100km while operating during the daytime.

- Utilizing the already proven Spectroscopy for Investigation of Characteristics of the Atmosphere of Venus (SPICAV) instrument which includes 3 separate spectrometers. The mission can collect multiple data sets using UV, IR, and SOIR techniques to create data cubes for transmission.

- The Ultraviolet channel (SUV) is based around a holographic diffraction grating which collects light onto a holographic mirror at the entrance and directs it to a CCD detector block. The CCD camera equipped with an image intensifier records the data.
    - “The usable spectral band is 118 to 320 nm, chosen so as to offer good resolution (~1 nm) for stellar observations and to cover the CO 2 and O 3 bands. The lower wavelength was selected to be just below the Lyman α wavelength and the upper wavelength was chosen to reject visible light.” [s]
- The Infrared channel (SIR) is based around a scanning acousto-optical tunable filter (AOTF) which collects light from the sun and directs it into a telescope with a collimation lens. This light is directed into a Hybrid Si/InGaAs PIN photodiode detection block.
    - “The two output beams from the AOTF are collimated by another lens and detected by two hybrid silicon/indium gallium arsenide PIN photodiodes.” [s]
- The Solar Occultation in the Infrared SOIR Instrument is a compact high resolution spectrometer, combined with a TeO_2 Acousto-Optic Tunable Filter (AOTF). The instrument collects light and is then refracted into selectable wavelengths, which are reflected onto the detector which sends the data to be stored and processed.
    - “The detector system is a modified SOFRADIR Integrated Detector Dewar Cooler Assembly, sensitive to radiation in the 1.7 to 4.3 µm spectral region, consisting of a two-dimensional array of photovoltaic HgCdTe pixels (320 columns x 256 rows) cooled by a Stirling type cooler (RICOR) to about 88 K.”[s]

- The SPICAV Instrument will be mounted to the side of the vehicle, giving the instruments optimal light and solar occultation gathering opportunities.
- The instruments can run simultaneously but would consume power more rapidly. Also many of the instruments are limited to making observations during the day time side of Venus.
- The data collected will be stored and processed, then transmitted during optimal transmission periods

Like mentioned above, the composition of the atmosphere is unknown and is in need of further investigations. The VESPAA mission also includes a nephelometer, designed to measure and study the vapor and gasses in Venus’ atmosphere. A nephelometer would provide in-situ measurements and take accurate particle analysis of what makes up the varying cloud layers. The mission goal is to take nephelometry measurements every 100km during its scheduled operations.

- “Nephelometry yields microphysical data about particle size, shape, and concentration from a cloud’s interior. Nephex design improves on the Galileo nephelometer with much lower size, weight and power. The smaller form factor allows Nephex to fly on more opportunities in threshold environments and planetary atmospheres.” [l]
- The Nephex instrument improves on the Galileo instrument design, and is already a TRL4 design. Its compact design allows it to be mounted underneath the SPICAV unit on the side of the vehicle
- The Nephex instrument shall collect gas into an inlet port and then use two lasers to backscatter particle measurements onto two photodiodes with bandpass filters to collect the data. This data is stored locally on a SD card before being processed for transmission.
    - “The nephelometer is sensitive enough to apply dynamic light scattering principles to the backscattered light, allowing for a calculation of particle sizes. This method would be especially interesting and precise for a planet like Venus, where hazes are known to form layers with distinct, multimodal particle sizes”(Nephex: Nephelometer for Measuring Cloud Particle Size and Density in Planetary Atmospheres.)[m]
- The data collected will be stored and processed, then transmitted during optimal transmission periods

Due to the orbit period of the orbiter visibility can only be maintained for several hours at a time. Because of this limitation there shall be a schedule in which transmissions will take priority over other experiments. Since the craft has two computers with s-band transmitters, the uplink rate could potentially transmit double the amount of data per sec. And, based on a study conducted by the *Venus Flagship Mission Study* (Figure 4.4), the amount of time a balloon orbiter would have to transmit shall allow the VESPAA vehicle to transmit up to a significant amount of data back to researchers. In addition, with the ability to maneuver and adjust altitudes, the possibility for transmission rates increase as well.

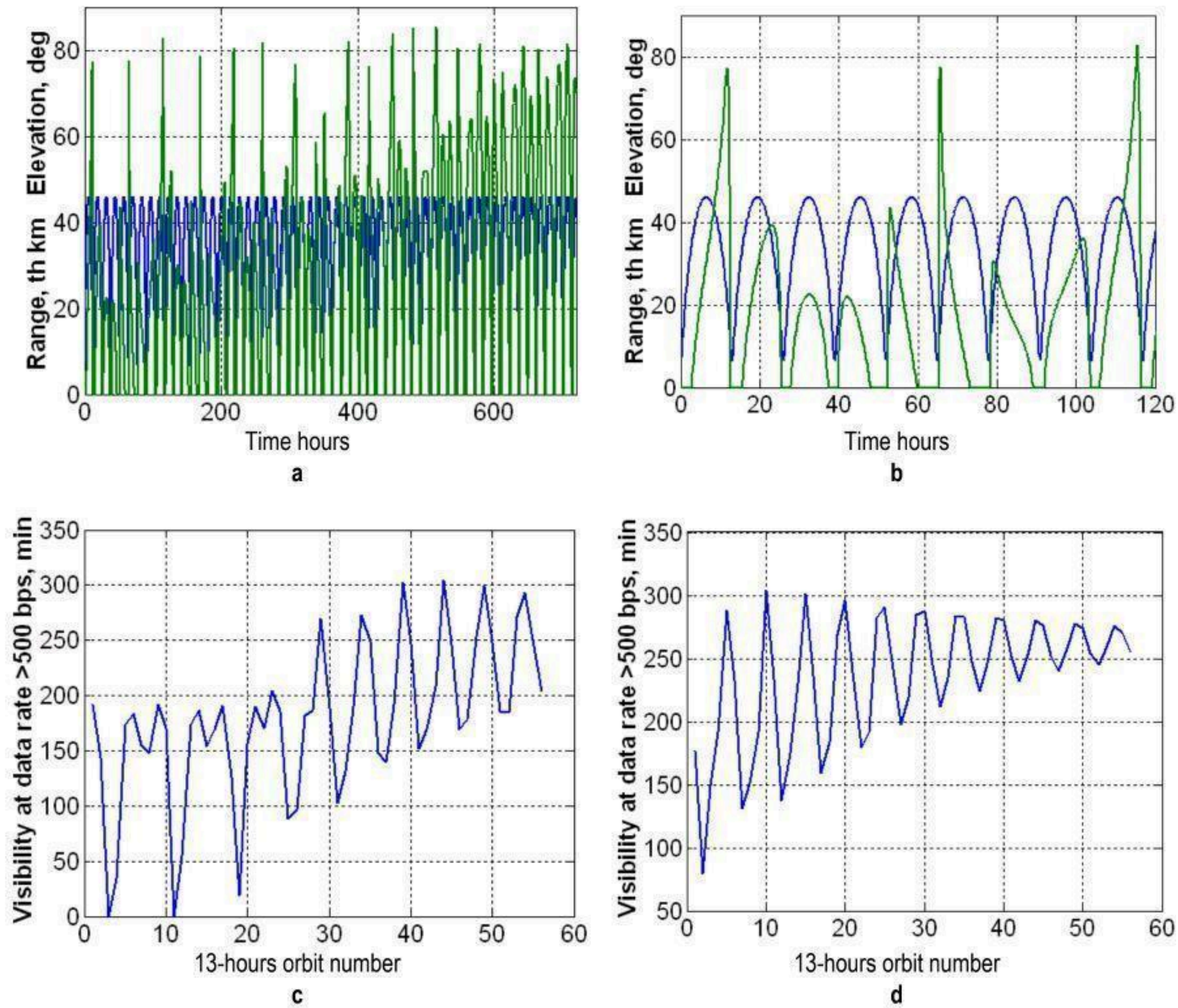


Figure 4.20: Balloon-orbiter visibility periods (a, b) and possible periods of data transmission (c, d) during 30-days balloon mission. a, b: orbiter range (blue) and elevation angle (green), balloon insertion at -25°; a: during the whole 30-days mission; b: during the first five days; c: balloon insertion at -25°; d: balloon insertion at -47°.

Figure 4.4: Peak Transmission Times (NASA, JPL. (2009) Venus Flagship Mission Study)[j]

During the mission lifetime these instruments will provide valuable data for researchers to study and analyze. The nature of this mission concept allows the vehicle to collect several sets of data passively and without very many moving parts. The mission vehicle if improved upon could last longer and potentially return more data if altitude control proves successful. However, the objectives and goals of this mission can still be achieved without that element, and has been designed to achieve multiple scientific returns. Venus provides a largely unexplored neighbor that gives researchers the opportunity to answer the many unknowns about Earth and how other planets form.

4.2.5 Testing and Calibration Measurements

The Preliminary testing includes calibration techniques and ensuring all instruments are ready for collection. The controls will be taken on Earth for each of the instruments, by testing varying composition of aerosols and gases in the different found in the cloud layers on Venus on laboratory analog instruments on Earth. This research shall ensure that the measurements and data collected are within the expected ranges.

The DPA 4006ER Omnidirectional Microphone which will record acoustic sound from Venus.

- This device is calibrated by the manufacturer, and is designed to record high quality sound in extreme environments
- The instrument will perform its test by transmitting 1sec of audio to the orbiter
- A control device will be maintained, which can be used to troubleshoot issues if they arise
- "Atmospheric propagation may induce additional dispersion terms to the acoustic waveforms that would have to be corrected in order to recover the wave dispersion at the surface." [h]

The HyTI (Hyperspectral Thermal Imager) a 6U CubeSat equipped with a TIR hyperspectral imager (HSI) for terrestrial science applications.

- This instrument will be calibrated by the manufacturer if purchased from the manufacturer.
- This device can be assembled and integrated with plug-and-play connectivity to compatible components.
- Data sets that have been taken by other missions with this instrument will be used for additional control data
- This instrument will test its system by running a system check on its on-board computer and establish a data link using the instrument's S-band transmitter. Once established an uplink the TIR will transmit a single image to the orbiter for confirmation.

The Nephelometer Experiment (NephEx) designed to take measurements of Venus' atmosphere.

- "The balloon-ready instrument will consist of two COTS lasers, and an in-house designed circuit board for detecting scattered light and confirming proper laser operation." [l]
- This technology is being development by NASA Ames and will have calibration methods available to obtain
- The vehicle shall test its system by transmitting a single data set from the cloud layer back to the orbiter
- A control device will be maintained on earth, which can be used to troubleshoot problems if they occur.

(SPICAV) The Spectroscopy for Investigation of Characteristics of the Atmosphere of Venus is a suite of three spectrometers in the UV and IR range.

- The vehicle shall test its system by transmitting a single data set from each instrument to the orbiter relay system
- A control device will be maintained on earth, which can be used to troubleshoot problems if they occur.
- The SPICAV-UV spectrometer (118–320 nm, resolution 1.5 nm)
  - Calibration of the UV spectrophotometer including control of absorbance using potassium dichromate solution, resolution power using toluene in hexane, limit of stray light and wavelength accuracy. Ensure that the connections of the spectrometer are proper.
  - Measurements are limited by daylight and will not be able to be performed on the night time side of the planet.
- The SPICAV VIS-IR sensor (0.7–1.7 μm, resolution 0.5–1.2 nm) employs a pioneering technology: an acousto-optical tunable filter (AOTF). H_2O, CO_2, and aerosols.
  - Measurements are limited by daylight and will not be able to be performed on the night time side of the planet
- The SOIR spectrometer is a new solar occultation IR spectrometer in the range λ=2.2–4.3 μm, with a spectral resolution $\lambda/\Delta\lambda > 15{,}000$
  - Thermal and dark current is measured and subtracted onboard
  - Detector nonlinearity correction: the detector response to incident light is not linear over the complete dynamic range of the well capacity. For low signals, a nonlinearity correc-tion has to be applied.
  - Bad pixel and pixel-to-pixel variability correction: the properties, i.e., the gain of each pixel differs slightly. Moreover, some (bins of) pixels show unpredictable or systematically wrong behavior. Their values are removed and replaced by values of adjacent pixels or bins.
  - Sensitivity correction takes into account the non constant overall instrument sensitivity as a function of wavelength.
  - AOTF frequency-to-wavenumber calibration,also called tuning relation (see Subsection 5.D): establishing an AOTF tuning relationship between the applied RF and the selected wavenumber domain and bandpass curve.
  - Spectral calibration, which transforms pixel number into wavenumber and evaluates the calibration error Signal-to-noise ratio.
  - Division by a reference solar spectrum: ideally the reference spectrum that is taken outside the at-mosphere would be measured with an identical rela-tive slit position with respect to the solar disk. Attitude drift of the spacecraft makes the slit float. However, it results in a gradual linear change of the intensity.
  - Measurements are limited by daylight and a consistent line of sight with the sun. Experiments will not be able to be performed on the night time side of the planet

Most of the instruments on the VESPAA vehicle have little to no moving parts. This allows for better reliability and reduces the need for error correction. Many of these instruments can be calibrated before launch and will likely keep their calibration when they arrive at Venus. The Instruments will perform and validate these tests before moving into the science mission phase. This will allow any and all troubleshooting to occur before the operations phase can begin, minimizing later risks.

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

SPICAV

- SPICAV is a spectrometer equipped with three channels: SPICAV-UV (SUV) for ultraviolet wavelengths, SPICAV-IR (SIR) for infrared wavelengths, and SOIR, measuring solar occultation in the infrared. SPICAV measures for extended periods, eliminating the need to average multiple readings. Data is analyzed over time. The system is calibrated after launch to ensure data accuracy, as the launch may cause calibration changes. This instrument can continue to operate even when one or multiple channels fail, allowing data to continue being collected.
    - Precision values:
        - Channel Resolutions:
            - SUV (ultraviolet): 0.8nm
            - SIR (infrared): 0.5 - 1nm
            - SOIR (solar occultation in the infrared): 0.2 - 0.5cm -1

HyTI

- The Hyperspectral Thermal Imager (HyTI) instrument is a hyperspectral imager developed for terrestrial data collection. After modifications to certain wavelengths, the imager will allow resource characterization and observations of surface temperature variations. Multiple data sets will be captured during the mission, allowing comparison of data across a range of times. HyTI carries a backup battery in case of power failure, allowing it to continue collecting and transmitting data back to the orbiter. It also features an on-board computer, allowing data to be processed independently.
    - Precision values:
        - Spectral Resolution: 13 cm−1
        - Bandcount: 64
        - Spatial Resolution: 10 m (at 50 km) and 40 m (at 200 km)
        - Frame Rate: 160 Hz

Nephelometer

- The Nephelometer will collect data on particle shape, size, and concentration in Venus's cloud layer to characterize cloud makeup. The instrument will make multiple measurements at different altitudes, and is capable of taking both instantaneous measurements and average values over specified periods ranging from a few seconds to a few minutes. It can store data internally before transmitting data to the orbiter, allowing time to troubleshoot transmission issues if necessary.
  - Precision values:
    - Range: 0 - >1Km^-1
    - Lower range: <0.001km^-1 when using 30 second averages

4006ER Microphone

- The mission's 4006ER Microphone will collect sound data allowing the team to record seismic activity from the surface. The microphone takes data over extended periods, which will be analyzed to determine when seismic activity occurs. The microphone does not rely on the mission's other instruments, so if others fail, data can still be collected.
  - Precision value:
    - 10 to 20 kHz (±2 dB).

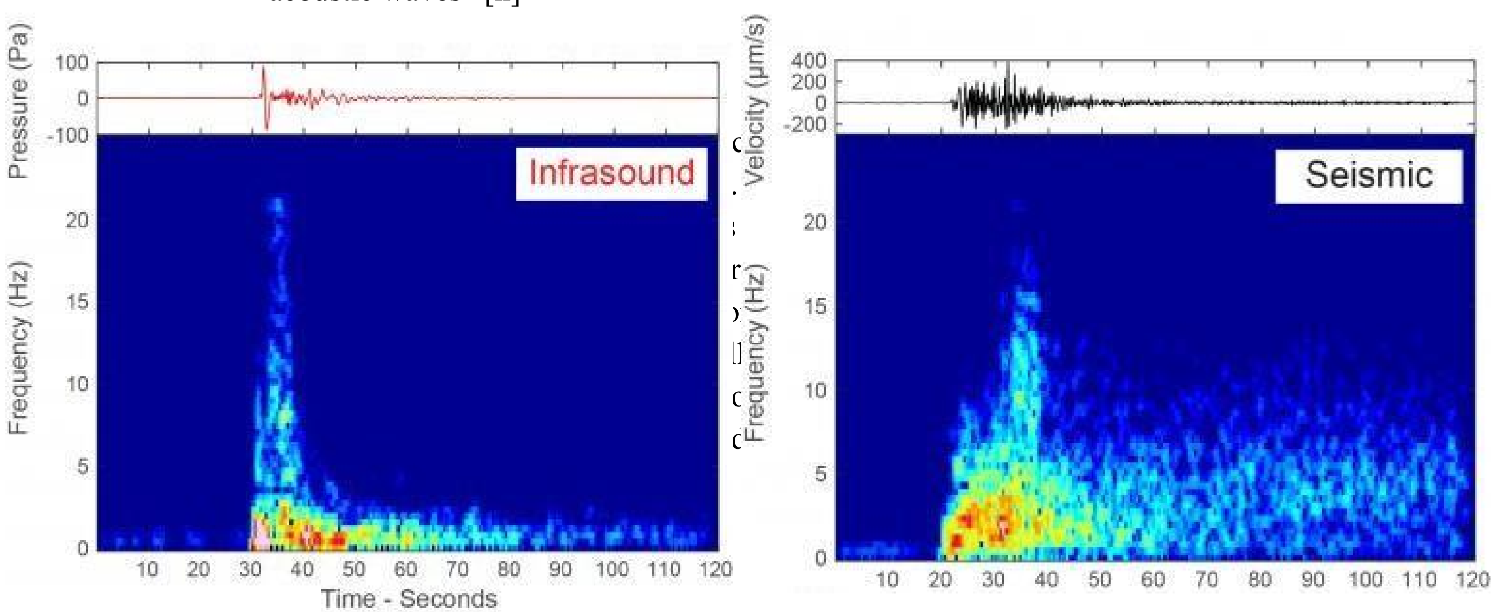
In the event that one (or more) of the instruments fails, the vehicle shall be able to continue to perform its other tasks. In Addition, the HyTI instrument has an additional S-band transmitter that can be used by other instruments as a backup to communicate with the orbiter. Also the vehicle is designed to store data on storage drives and then transmit that data during optimal transmission times. Because of this the data is immediately processed and stored. Furthermore the HyTI instrument provides a source of backup energy through its battery power system to the other components of the vehicle in case of low power.

4.2.7 Expected Data & Analysis

VESPAA's payload features several scientific instruments that will return unique data sets to researchers on Earth. Each instrument is selected to fulfill research about Venus' features that have yet to be answered. If each instrument performs as expected then the VESPAA mission would provide a significant amount of data that shall be useful for later modelling and understanding Venus.

The DPA 4006ER Omnidirectional Microphone will be used to record infrasound data to listen for signs of active volcanism and other geological activity.

- "Acoustic waves arrive first in the atmosphere above the source area. The dissipation of these waves in the upper atmosphere creates a local temperature increase. Further from the source, gravity waves generated at the epicenter reach the upper atmosphere. Finally, seismic waves propagate around the planet and generate upward-propagating acoustic waves" [h]



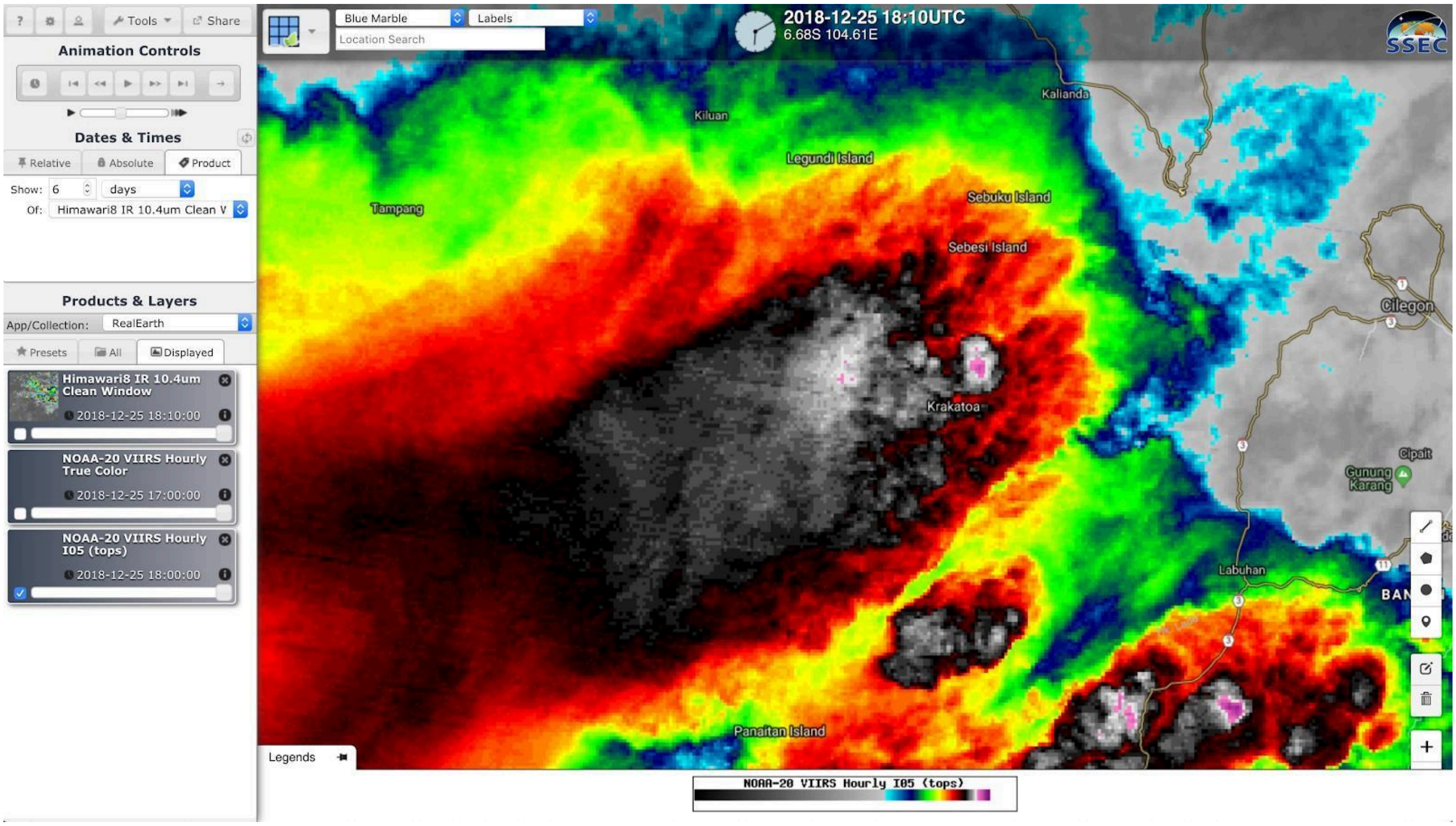
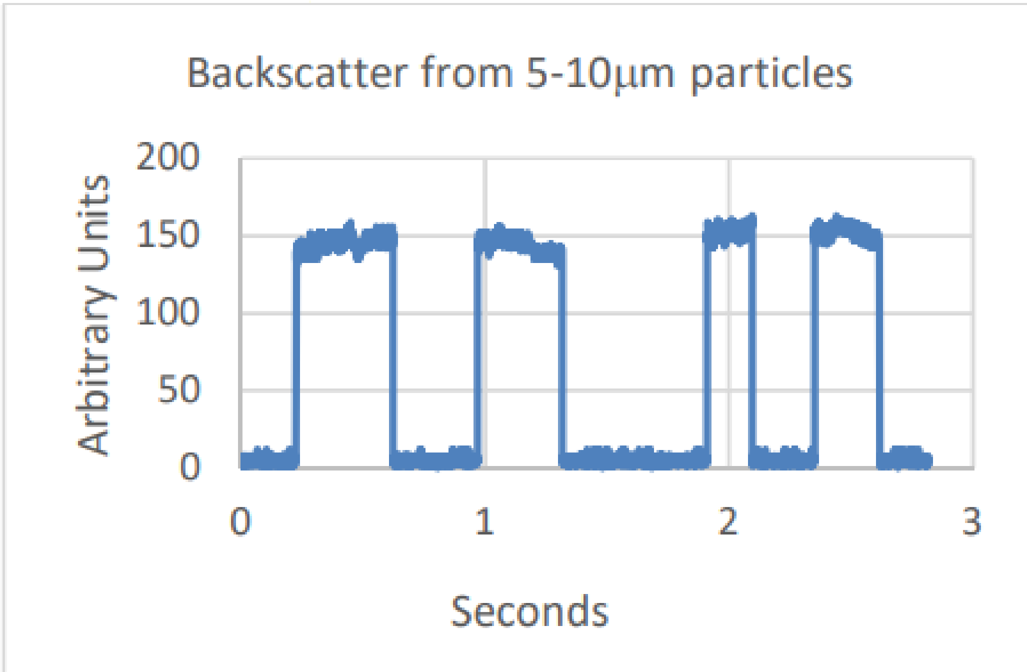


Figure 4.6: Thermal Spectral Band 10.4nm Eruption of Anak Krakatau (University of Wisconsin-Madison Space Science and Engineering Center)[o]

- With the range of spectral bands that the HyTI instrument has. Researchers will be able to collect cloud and emission temperature data. But also ground temperature data as well.

The Nephelometer Experiment (NephEx) will study the particle size and composition of the cloud layers. Below is a test from the Neplex instrument that measured the particulate of chalk during testing.



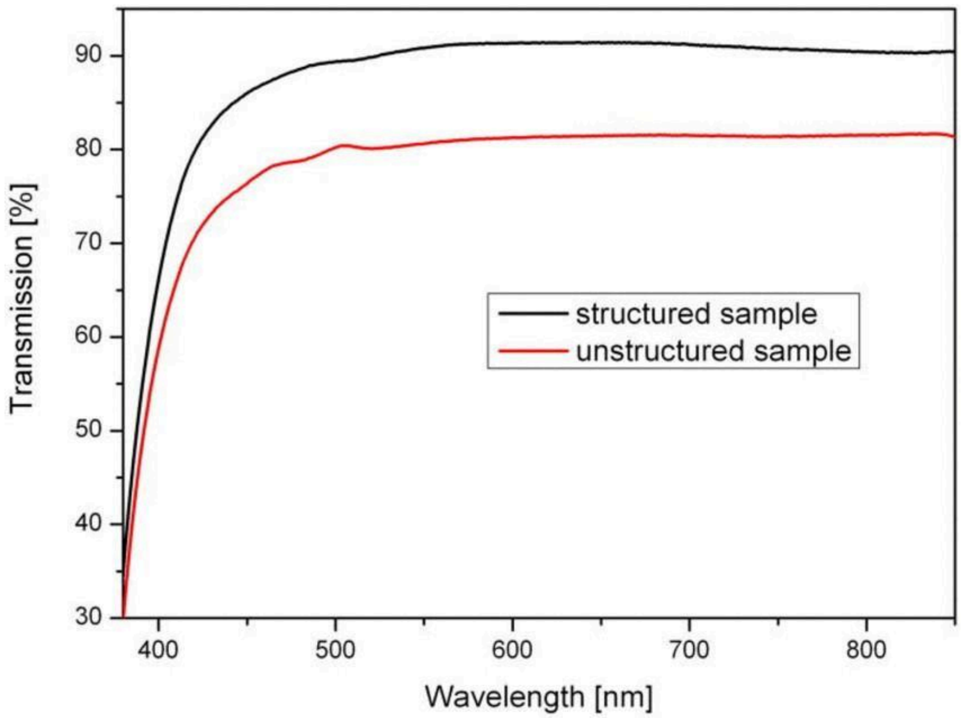
Data showing backscattered 785nm light from chalk particles (size range 5-10µm.) Maxima indicate the presence of particles. Minima show the range of ambient noise in the lab environment.

Figure 4.7:(Nephex: Nephelometer for Measuring Cloud Particle Size and Density in Planetary Atmospheres.)[m]

- Balloon Nephelometer Measurement Requirements:[j]
  - Frequency of measurement Every 30 minutes
  - Range of measurement Particle size range 0.1 to 50 µm
  - Sensitivity Polarizing nephelometer can do composition
  - Accuracy Size and number densities to ±10%. Aerosol constituents to ±15%.
  - Constraints Operates in H_2SO_4/H_2O aerosol environment
- "More lab-based sampling shall be performed on different sized particles within the 0.1m – 10m range. Optics to better align the backscatter with the sensor photodiode, and to filter out noise will be explored." [m]

(SPICAV) The Spectroscopy for Investigation of Characteristics of the Atmosphere of Venus is a suite of three spectrometers in the UV and IR range. These instruments will be used to analyze the composition and identify the compounds that are located in the cloud layers.

- "Number of spectra per mission: He = 15, other noble gases = 75, CO = 75, sulfur compounds = 200 including two 3 hour campaigns with a spectrum acquired every 20 minutes" (Venus Flagship Mission p 4-11)
- A UV spectrometer (118–320 nm, resolution 1.5 nm)



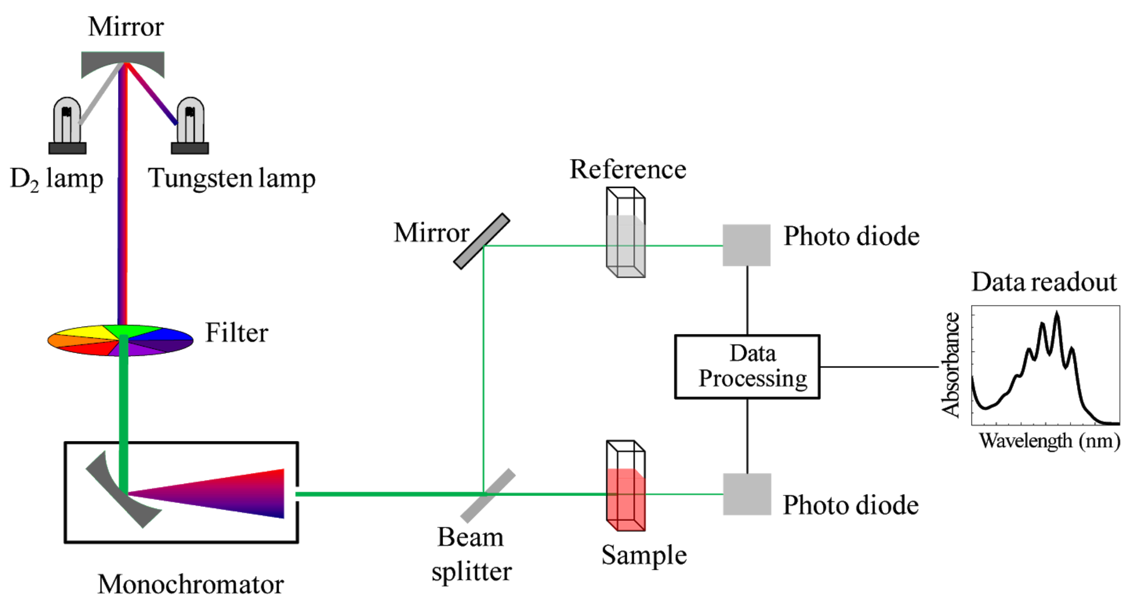


Figure 4.8: (above), examples of an expected data set. Figure 4.9: (below) example of the collection method for data samples [s]

- The SPICAV VIS-IR sensor (0.7–1.7 µm, resolution 0.5–1.2 nm) employs a pioneering technology: an acousto-optical tunable filter (AOTF). H2O, CO2, and aerosols.

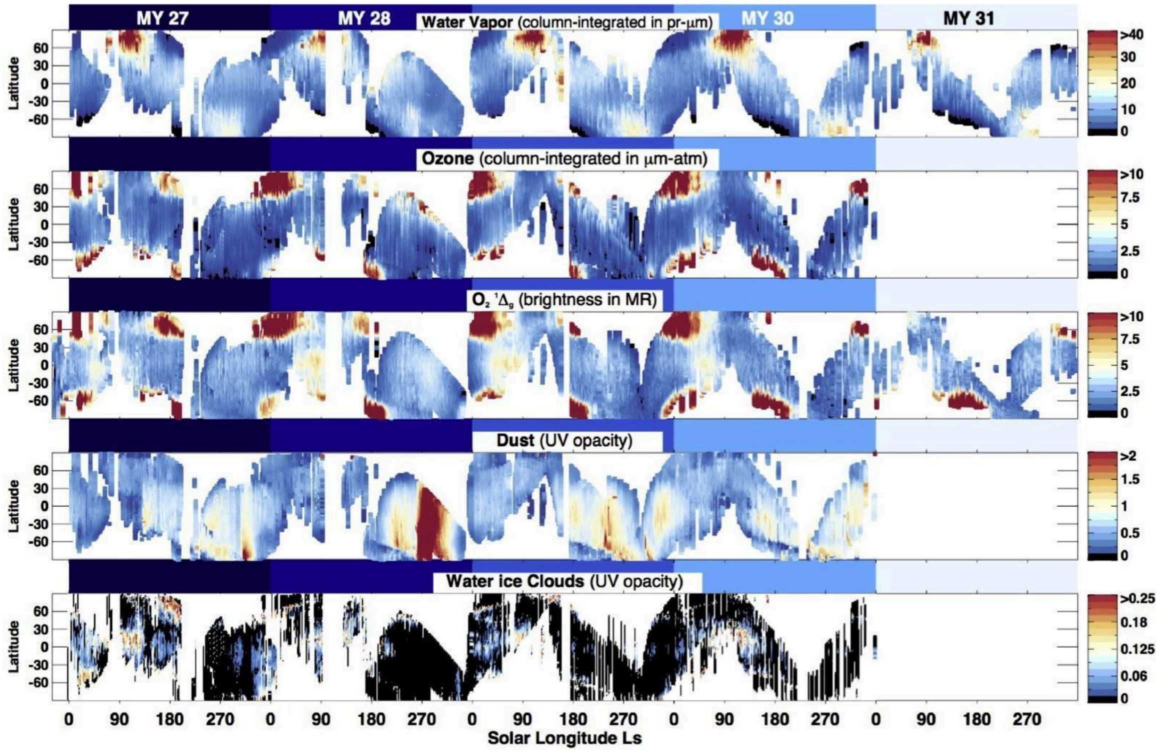
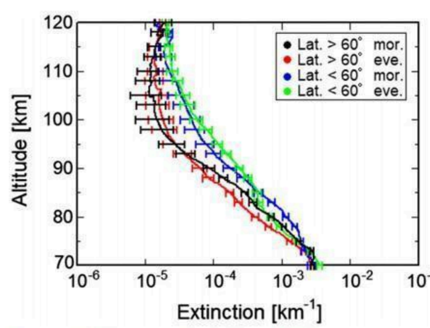
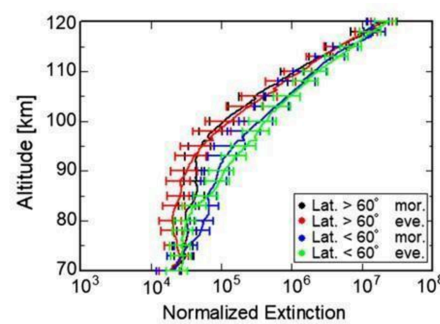


Figure 4.9: Atmospheric composition samples from Venus Express Mission [s]

- The SOIR spectrometer is a new solar occultation IR spectrometer in the range λ=2.2–4.3 µm, with a spectral resolution λ/Δλ>15,000.



Average extinction coefficient profiles for morning high-latitude (latitude > 60°, black line), evening high-latitude (latitude > 60°, red line), morning low-latitude (latitude < 60°, blue line), and evening low-latitude (latitude < 60°, green line) observations. The average of the variability is 21.5% for the morning high-latitude observations



Average of all normalized extinction coefficients for morning high-latitude (latitude > 60°, black line), evening high-latitude (latitude > 60°, red line), morning low-latitude (latitude < 60°, blue line), and evening low-latitude (latitude < 60°, green line) observations. The average of the variability is 34.3% for the morning high-latitude observations

Figure 4.10: Data gathered from SOIR on Venus Express Mission (An uppermost haze layer above 100 km found over Venus by the SOIR instrument onboard Venus Express)[n]

The ISIS High Data-rate S-band Transmitter and S-band Patch Antenna are compact and low-mass solutions that are suitable for frequency ranges within 2200-2290 MHz (S-Band). The transmitter is flexible, and can implement CCSDS as data link layer protocol, which allows for in-flight configuration of data-rate, modulation, frequency, and RF output.

- The data will be relayed to the orbiter and transmitted back to Earth.
- The two onboard computers will perform and correct all errors in the data before transmission.

Through the use of these instruments, the mission will be able to gather new critical information, which will lead to new studies and investigations into understanding the atmosphere and the geological activity on Venus. The thermal imaging spectrometer provides researchers with a deeper understanding of the volcanic activity on Venus and these measurements will help researchers understand the overall internal structure and the seismicity and heat flow of Venus, which shall improve current and future understanding about the volcanic and tectonic activity on Venus through observing the thermal emissions.

Furthermore, the imaging spectroscopy will help track variations in SO_2 and SO within the cloud activity. The sensors and the system of electronics which will be able to operate at a higher temperature will provide measurements which will be capable of gathering data through the atmosphere as well as the surface. The measurements in the atmospheric and surface level will be focusing on understanding the surface and geochemistry of Venus. These observations in the upper cloud layer will further the studying of the characterization of Venus's geochemistry. The data will bring new concepts and ideas into the scientific community which will lead to new studies and advance known research of the ground based and atmospheric structure of the planet Venus.

5. Safety

5.1 Personnel Safety

5.1.1 Safety Officer

Mission Concept Safety Officer
Carter Fahey - Science Team

The VESPAA mission concept team elected their safety officer who was both qualified and interested in maintaining safety protocols and identifying risks. As a member of the Science Team the Safety Officer offers cross-disciplinary support to the Engineering and manufacturing teams. The Safety Officer's main duties are ensuring that adequate training and handling standards are met. They will also certify that each individual that is included in the manufacturing, construction, transportation, etc of the VESPAA vehicle design is capable of adhering to proper procedures and safety etiquette.

- The Safety Officer, a member of the science team, has expertise in and has done extensive research on the environment and provided detailed analysis of the atmosphere in which the VESPAA mission will be operating. Which provided beneficial data to designers and engineers to help improve the VESPAA mission's design.

    Finding:
    - Lightning is also produced within the clouds
    - The atmosphere is nearly as thick as liquid water because its surface pressure is extremely high — 93 times the pressure of Earth's atmosphere.
    - There is no water on Venus and only small, trace amounts of water in its atmosphere.
    - There are extremely high winds (360 km/hour at the very top - this is hurricane force) at the cloud-top level which could damage the craft, winds decrease closer to the surface
    - Venus' surface is at 393°C. hotter than the planet Mercury
- The Safety Officer oversees all OSHA standards and guidelines are met and conducts training for all personnel.
- The Safety Officer will perform all final checks on equipment handling and maneuvering; needing to be present during much of the manufacturing, assembly, testing, and integration processes.
- The Safety Officer signs off on any and all required safety checkpoints, validating licensing and certifications.

- The Safety Officer monitors and records all incidents that occur during development.

The Safety Officer is a vital role in the mission's overall success. By providing safety standards and guidelines, all of our team can remain safe and productive while also providing critical design feedback to engineers and scientists. The Safety Officer shall do everything in their power and expertise to ensure the safety of the team and others that may be involved with the VESPAA mission.

5.1.2 List of Personnel Hazards

Although VESPAA is not an extremely large vehicle, the possibility for accidents and injury still exists. The craft weighing up to 175kg (385.81lbs) can cause significant damage to property and individuals if unchecked. Many of the Hazards and their mitigations have been identified by the whole mission concept team and then reported to the Safety Officer who will ensure adequate mitigations are maintained during development.

Many of the potential hazards are identified as but not limited to:

- Potential exposure to toxic chemicals and materials that could damage health
- Potential fall of equipment or inadequate lighting when working underneath spacecraft or in tight spaces, leads to injuries / Short-term impact noise, damages hearing
- Electric shock from electronics and other equipment
- Heavy equipment causing harm to personnel
- Improper mounting and transportation of instruments and vehicles
- Overpressurized balloon explosion
- Cables snapping and weight falling during testing
- Miscellaneous fires from faulty components and overloading
- When in simulation and in manufacturing, the clean room may be contaminated with outside particles.

Most of these hazards can be mitigated and will be discussed further in 5.1.3 below. It was important for the team to come up with these hazards together. Having the advantage of each member's specialization that covers many more possible scenarios that could pose threats to members and the VESPAA vehicle. This allows the team to be more comprehensive and more aware of the dangers and risks involved.

5.1.3 Hazard Mitigation

Many of these techniques and strategies address the situations posed above and more. This list of mitigation practices will be applied accordingly and it will ensure that should any situation arise; the team and its Safety Officer will be able to handle and quickly respond to the incident.

- Manufacturing
  - Adequate supply of PPE and clean suits for personnel, Material Safety Data Sheets (MSDS) on all hazardous materials
  - Mandatory health insurance, access to employees' private medical and insurance records
  - Reducing noise at the source by adjusting reciprocating equipment or adding mufflers
  - Adequate supply of ocular protection
  - Isolated storage of chemicals, proper handling of gases, correct disposal/storage of lithium batteries
  - Safety training at the different levels to ensure that all personnel understand proper handling of equipment and materials and how to report mishaps
  - In the case of contamination, proper decontamination techniques are to be administered as soon as possible.
- Surveillance
  - Accident and injury statistics should be routinely reviewed and analyzed to identify trends and the causes or loci of various types of injuries and equipment damage.
- Direct observation and measurement
  - Safety committees composed of workers, management, and, occasionally, professional consultants should periodically observe maintenance operations to identify unsafe equipment or practices.
- Analytical evaluation
  - Maintenance tasks that are amenable to analytical evaluation, e.g., manual lifting, should periodically be subjected to the appropriate calculations.
- Critical incident reporting
  - A mechanism should be put into place to allow workers anonymously to report unsafe equipment or activities that resulted, or nearly resulted, in injury or equipment damage.
- Passive surveillance
  - Monitoring and analyzing accident and injury records to identify patterns of recurring incidents

Although it is impossible to mitigate all possible hazards that may occur during manufacturing and testing, the team shall be prepared and highly trained in all aspects of how to build and operate the design safely. These standards not only protect the personnel involved, but also the public and property.

5.2 Vehicle/Payload Safety

5.2.1 Environmental Hazards & Analysis

Venus has been described as the most dangerous planet in the solar system. Venus' atmosphere is acidic and thick. Its clouds, which hide the surface from view, contain concentrated sulfuric acid and strong enough to dissolve most metals used to make spacecraft. Because of this the VESPAA mission's team has invested a significant portion of the design to being resistant to those elements. However, that is not the only environmental hazard that Venus features. In addition there are environmental factors on Earth and in transit from planet to planet.

Many of the potential hazards are identified as but not limited to:

Atmosphere and Systems:

- Volatile compounds and sulfuric acid rich atmosphere on Venus.
- Sulfuric acid reacts with the vehicle or instruments materials. The sulfuric acid in Venus' atmosphere might react with the instruments and damage them.
- 200-300kph winds.
- Pressures on the atmosphere of 75-100 atm
- Atmospheric temperatures ranging from -76 to 75 C both min and max are outside the operational temperatures of some instruments.
- Loss of communication with spacecraft.
- Atmospheric bursts of lightning (could damage electrical systems)
- Micrometeorites (could damage vehicle or systems)
- Unexpected change in temperature; higher than expected temperatures on Venus at the layer that the vehicle moves on, might cause damage to the instruments inside the vehicle. it might damage the antena and lose the connection with the vehicle.
- The ambient light on Venus is highly reflected and might make it difficult to detect and capture surface images.
- Damage in lithium-ion cell battery. By using the lithium ion battery for a long time without any free time, that might cause damage to the battery and leaking the lithium inside the vehicle.
- Signal transfer from VESPAA to the orbiter before it's relayed back to Earth, the data may become corrupted or lost during this process.

- System failure from unintentional pollution or contamination from the Venusian atmosphere.
- The materials of VESPAA vehicle may react with certain compounds in the atmosphere, contaminating the data collected by the instruments.

Pre-launch
- Mild hazardous weather conditions when launching, such as lightning / precipitation static.
- Improper placement of worksite that could lead to gas leaks and chemical spills
- Environmental pollution caused by the manufacturing efforts.

Because Venus has so many uncertain and unknown characteristics the team has compiled a list of mitigation strategies for dealing with many of the hazards. These strategies shall ensure the craft and vehicle can operate and pursue its intended mission.

5.2.2 Hazard Mitigation

The VESPAA mission's team has developed a well thought out plan to mitigate and reduce the hazards described in 5.2.1. These techniques will be utilized proactively, as maintenance of the vehicle is impossible once it reaches its destination. As the team identified these hazards they proposed and implemented these techniques.

Atmospheric and Systems Hazard Mitigation:
- Teflon coated surfaces on the vehicle and balloon to prevent corrosion and damage from sulfuric acid and other volatile compounds
    - All of the surfaces have been tested to not interact with the atmosphere, potentially disrupting any observations
    - Ensuring all clean room standards are maintained and accurate logs kept.
- Research and test materials to be used during the mission
    - Does it emit or produce certain substances/signals that may be logged as Venusian but actually being a product of the mission itself?
        - If so, those can be recorded and eliminated when the data is analyzed
- The double bonded Teflon, mylar, and vectran fabric will create a surface that can absorb small projectiles, while the gondola is suspended the aluminum exterior could absorb impacts from small projectiles as well.
- Simple gondola design that produces little asymmetrical drag and can operate in a variety of positions.
- Insulation to limit the temperature change of helium and keep pressure at desired levels
- Introduce a finite element analysis to maximize the allowable stress and strain on the cable to reduce stress and strain

- Proper insulation and ventilation to assist with thermal control and pressure regulation
- Active thermal and cooling systems to regulate instrument temperatures
- All instruments shall have rubber shielding around mounting hardware in case of electrical shock
- Loss of communication with spacecraft would result in total mission loss
- Have a backup device and frequent monitoring of incoming signals.
  - Can the device be troubleshooted/rebooted from Earth?
    - If not, can a backup replace the current one and continue the signal transfer
  - Program in a periodic signal from the mission that confirms that all devices are working properly
- To prevent battery overload, the system will utilize a schedule of operations for the instruments that only operate a select few instruments at a given time.
- Ambient light has been mitigated on several instruments by including light shrouds around their optical viewports, reducing oversaturation as well.

Pre-launch

- Launch window may need to be extended as necessary to allow for favorable weather
- Isolate facilities so that it is not close to human or animals residences
- Coincide with EPA and determine any risks or problems that have risen. extensive research will be conducted to conceive the best way to manufacture parts quickly, efficiently, and with minimal risk to the environment.

Ensuring that the vehicle reaches its destination and can perform its mission objectives is the top priority for the VESPAA mission's team. By identifying these hazards and implementing smart techniques to protect the concept design from these potential hazards, the team can ensure a reliable design that will perform as planned.

6. Activity Plan

6.1 Budget

	Total Salaries $ $ 3,040,000.00
	Total ERE $ $ 848,464.00
	Total Travel Costs $ 12,985.40
	Total Outsourced Manufacturing Cost $ $ 6,284,901.94
	Total In-House Manufacturing Cost $ $ 1,300,000.00
	Total Equipment Cost $ $ 1,582,136.00
	In-House Manufacturing Margin $ $ 1,441,068.00
	Total Direct Costs $ $ 4,182,136.00
	Total MTDC $ $ 2,600,000.00
	Total F&A $ $ 1,213,635.13
	Total Cost Margin $ $ 4,716,957.14
	Total Projected Cost $ 15,723,190.47

Total Project Cost
$\underline{\text{ \$ 20,440,147.62}}$

Budget Summary

The VESPAA mission's budget provides a low cost high scientific return plan. A 4 year mission that's total costs are well within the allotted $250M budget. The project can be assembled quickly allowing for a quick turnaround time and rapid integration. VESPAA utilizes Flight Ready hardware from leading distributors that meet the scientific requirements and design specifications outlined. The hardware is inexpensive and reliable, scalable as the concept's requirements change. Many costs accounted for in the budget are projected costs anticipated for the finalized concept. The schedule range starts early in 2021 and finalizes 2024 with a launch selected on June 9th of 2023 since this is an optimal time for a venus transfer as it is during its 584 days periapsis. Also an *additional 30% margin in addition to the margins added for manufacturing (~50%) and facilities and administrative costs (~10%)* have all been factored in.

Total Project Cost(1)
$ 20,440,147.62

Total Cost Margin
$ 4,716,957.14

- The main site for operations would be in Orlando, FL.in a 20,400 sq/ft industrial warehouse (2), for a 4 year lease $ 195,534.00 a year after taxes (3) . This facility has 6 loading docks, a power supply (Amps: 200-400 Volts: 220-440 Phase: 3) a sprinkler system, and is constructed out of masonry. It's location is 61.9 miles (~79min) to Port Canaveral. This facility is also ideal as it can be quickly set up and its large inside features allow it to provide adequate room to assemble all devices on site and would reduce the need for additional travel.
    - The Manufacturing facility cost also includes a first year investment of ~$100k in addition to the first year's rent to build out the warehouse for mission concept assembly, including servers, PPE, rentals, storage, etc. This figure is estimated based on the pricing available from local suppliers and vendors, this figure leaves margin for unforeseen cost that may occur during this build out phase
    - (4) Materials and Supplies are also based on the competitive market prices for raw materials and bulk supplies. These items can be acquired through many vendors and have similar price points. The budget for materials and supplies will also include $100k after the initial year investment for each subsequent year until closeout. This figure estimates

any need to repair or replace equipment and other supplies that would be needed for the facilities to maintain operations on schedule.

Total Manufacturing Facility Cost
$ 882,136.00
Materials and Supplies Cost
$ 1,300,000.00

- The budget accounts for an additional testing facility, also with an additional $100k for facility build out, that can be acquired in the Orlando area. This facility would be used to simulate the Venusian atmosphere and other effects which would be needed for 3 years leading up to launch. This facility would incur similar cost to the main facility, but is estimated to be less without the needed larger heavy equipment.

Total Test Facility Cost
$ 700,000.00

- Many commercial partners produce Heritage and Flight Ready hardware that is easily available and affordable. Many of VESPAA's designs will leverage the quality and experience of these technologies and allow for rapid development times, and lower overall cost. The majority of the cost will be paid in the first year to allow for any and all lead times. Each subsequent mission year until the final year will receive an additional $100k for additional development and equipment, with an additional $100k for the second year to support any design iterations that may be necessary.
    - Instruments are flight ready and meet industry standards
    - Meet or exceed desired scientific specifications and capabilities
    - Are designed to handle environmental factors operating in a variety of ranges
    - Standard connectivity integrations

Total Science Instrumentation Cost
$ 1,982,924.70

- The COTS components hardware can also be procured by reliable suppliers and provide an extremely affordable option that has low lead times and consistent availability. Specifications and hardware guidelines meet or exceed requirements summarized by the engineering teams. Vehicle Design and inflation outline and bill of Bill of Materials. Each subsequent mission year until the final year will receive an additional $100k, also, for additional development and equipment.

- Many parts use a standard interface USB ,1Gb RJ-45 PoE, RS-232 etc.
- TRL and Heritage flown components
- Scalable and Highly configurable.
- Cross platform compatibility

Total COTS Components Cost
$ 4,301,977.24

- Each member of the Science, Engineering, and Administration teams is paid $80k with fringe benefits for full time staff. During certain phases of the design, some teams will operate at half capacity when certain tasks will no longer involve them. Each member will be on contract for the ~4 years needed to complete the mission. Personnel will review and design VESPAA as well as operate and manage the vehicle. This timeframe also accounts for key decision points and necessary reviews that are expected.
  - Launch day travel accommodations have been estimated for 5 days and 4 nights,surrounding launch date.(5) Plus additional per diem costs and mileage.
    - 13 rooms, 13 vehicles, 10 flights

Total Personnel
$ 3,888,464.00
Total Travel Cost
$ 12,985.40

As outlined in this summary this mission is a low-cost mission design concept and can have significant impacts on the ongoing research on Venus and it's dynamic systems. With this budget There could potentially be several multiple crafts built for this mission given the initial budget cap. By utilizing cost-saving suppliers the mission is affordable and scalable, with a quick turnaround time. This solution also offers optional configurations and allows full quality assurance.The mission design is robust and state of the art, as well as reliable, durable, and fully integrated.

Year	2021 Total	2022 Total	2023 Total	2024 Total	Cumulative Total
PERSONNEL					
Science Team	$ 240,000.00	$ 120,000.00	$ 240,000.00	$ 120,000.00	**$ 720,000.00**
Engineering Team	$ 240,000.00	$ 480,000.00	$ 480,000.00	$ -	**$ 1,200,000.00**
Administrative Team	$ 320,000.00	$ 320,000.00	$ 320,000.00	$ 160,000.00	**$ 1,120,000.00**
Total Salaries	$ 800,000.00	$ 920,000.00	$ 1,040,000.00	$ 280,000.00	**$ 3,040,000.00**
Total ERE	$ 223,280.00	$ 256,772.00	$ 290,264.00	$ 78,148.00	**$ 848,464.00**
TOTAL PERSONNEL	$ 1,023,280.00	$ 1,176,772.00	$ 1,330,264.00	$ 358,148.00	**$ 3,888,464.00**
TRAVEL					
Total Flights Cost	$ -	$ -	$ -	$ 992.00	**$ 992.00**
Total Hotel Cost	$ -	$ -	$ -	$ 6,708.00	**$ 6,708.00**
Total Transportation Cost	$ -	$ -	$ -	$ 1,131.90	**$ 1,131.90**
Total Per Diem Cost	$ -	$ -	$ -	$ 4,153.50	**$ 4,153.50**
Total Travel Costs	$ -	$ -	$ -	$ 12,985.40	**$ 12,985.40**
OTHER DIRECT COSTS					
Total Outsourced Manufacturing Cost	$ 5,584,901.94	$ 300,000.00	$ 200,000.00	$ 200,000.00	**$ 6,284,901.94**
|> Science Instrumentation	$ 1,582,924.70	$ 200,000.00	$ 100,000.00	$ 100,000.00	**$ 1,982,924.70**
|> Other COTS Components	$ 4,001,977.24	$ 100,000.00	$ 100,000.00	$ 100,000.00	**$ 4,301,977.24**
Total In-House Manufacturing Cost	$ 1,000,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	**$ 1,300,000.00**
|> Materials and Supplies	$ 1,000,000.00	$ 100,000.00	$ 100,000.00	$ 100,000.00	**$ 1,300,000.00**
Total Equipment Cost	$ 295,534.00	$ 495,534.00	$ 395,534.00	$ 395,534.00	**$ 1,582,136.00**
|> Manufacturing Facility Cost	$ 295,534.00	$ 195,534.00	$ 195,534.00	$ 195,534.00	**$ 882,136.00**
|> Test Facility Cost	$ -	$ 300,000.00	$ 200,000.00	$ 200,000.00	**$ 700,000.00**
In-House Manufacturing Margin	$ 647,767.00	$ 297,767.00	$ 247,767.00	$ 247,767.00	**$ 1,441,068.00**
Total Direct Costs	$ 8,551,482.94	$ 2,370,073.00	$ 2,273,565.00	$ 1,314,434.40	**$ 4,182,136.00**
Total MTDC	$ 8,108,181.94	$ 1,626,772.00	$ 1,680,264.00	$ 721,133.40	**$ 2,600,000.00**
FINAL COST CALCULATIONS					
Total F&A	$ 810,818.19	$ 162,677.20	$ 168,026.40	$ 72,113.34	**$ 1,213,635.13**
Total Projected Cost	$ 9,362,301.13	$ 2,532,750.20	$ 2,441,591.40	$ 1,386,547.74	**$ 15,723,190.47**
Total Cost Margin	$ 2,808,690.34	$ 759,825.06	$ 732,477.42	$ 415,964.32	**$ 4,716,957.14**
Total Project Cost	$ 12,170,991.47	$ 3,292,575.26	$ 3,174,068.82	$ 1,802,512.06	**$ 20,440,147.62**

6.2 Schedule

Phase	Tasks	Start	End	2021	2022	2023	2024
	Phase A	**1/1/2021**	**5/7/2021**				
	Phase B	**5/10/2021**	**10/29/2021**				
	Phase C	**11/1/2021**	**1/3/2023**				
	Phase D	**1/6/2023**	**6/9/2023**				
	Phase E	**11/1/2023**	**1/11/2024**				
	Phase F	**1/14/2024**	**5/30/2024**				
A	Mission Concept and Design	**1/1/2021**					
	MDR (Mission Definition Review)		5/7/2021				
B	Technology Development	5/10/2021					
	Engineering prototyping						
	Risk-mitigation activities						
	PDR (Preliminary Design Review)		10/29/2021				
C	CDR for each hardware/product before production	11/1/2021					
	Build & Purchase Hardware Components						
	Verify System Requirements						
	Identify and update risks						
	Prepare Launch Site & Post Launch Operations						
	Safety Review		1/3/2023				
D	System and parts integration	1/6/2023					
	System functional and physical configuration audits						
	Interface Verification						
	Safety Review						
	Key personnel arrival at Cape Canaveral						
	Launch	**6/9/2023**	**6/9/2023**				
E	PLAR (Post-Launch Assessment Review)	7/1/2023					
	Operations & Sustainment						
	DR (Decommissioning Review)						
	Develop final mission report		1/11/2024				
F	Dispose of the system and supporting processes	1/14/2024					
	DRR (Disposal Readiness Review)						
	Archival of data / document						
	Baseline mission final report		**5/30/2024**				

- Mission Schedule begins on Jan 1st 2021, and is currently underway. Having completed the milestone Mission Definition Review by May 7th and completing Phase A of the concept mission.
- Phase B begins May of 2021 working on the technology developments, engineering prototyping, and risk management activities. The design should be ready for its PDR by the end of October of 2021.
- Once approved the team will enter its Phase C part of the schedule. This period between November 2021 and January 2023 allows for building and purchasing of the hardware components and ensures effective testing and design review. This period will also be used to verify system requirements, identify and update risks and prepare for Safety Review.
- Phase D will begin on January 6th of 2023 and will include further testing and verification for flight reviews. The system will become integrated onto the main mission, functionality audits will be performed. Phase D will be concluded with the expected Launch Date set for June 9th 2023

- The mission architecture is contained as a secondary payload on a primary mission. The launch vehicle will be provided as well as the entry vehicle, both of which are able to produce/withstand the delta-v from launch and arrival. The trajectory selected was based on these parameters and other factors, such as the estimated manufacturing and testing periods, reviews, etc.

Name	Size	Earth Departure	Destination Arrival	Duration (days)	C3 (km2/s2)	Abs DLA (degs)	Injection DV (km/s)	Post-injection DV (km/s)	Total DV (km/s)
Venus	12104 km	Nov-29-2022	Feb-20-2024	448	7.3	14	3.55	0.39	3.95
Venus	12104 km	May-26-2024	Sep-02-2025	464	6.6	15	3.52	0.44	3.97
Venus	12104 km	Jun-09-2023	Oct-15-2023	128	11.2	8	3.73	0.37	4.1
Venus	12104 km	Dec-04-2024	May-29-2025	176	11.6	3	3.74	0.43	4.17
Venus	12104 km	Dec-20-2024	May-29-2025	160	12.9	3	3.8	0.42	4.22
Venus	12104 km	Jun-09-2023	Sep-29-2023	112	12.6	8	3.78	0.53	4.31
Venus	12104 km	Jun-27-2024	Sep-02-2025	432	6.2	31	3.5	0.85	4.35
Venus	12104 km	Jun-27-2024	Aug-17-2025	416	16.4	16	3.95	0.49	4.44
Venus	12104 km	Dec-15-2022	Jan-19-2024	400	18.1	9	4.02	0.43	4.45
Venus	12104 km	Jul-13-2024	Aug-17-2025	400	10.4	17	3.69	0.86	4.55
Venus	12104 km	Dec-31-2022	Jan-19-2024	384	16.7	13	3.96	0.84	4.8
Venus	12104 km	Jun-25-2023	Sep-29-2023	96	22.5	12	4.21	0.62	4.83
Venus	12104 km	Jul-29-2024	Aug-17-2025	384	12.3	15	3.77	1.39	5.16
Venus	12104 km	Jun-25-2023	Sep-13-2023	80	26	11	4.35	1.56	5.9

Based on data calculated with (https://trajbrowser.arc.nasa.gov/)

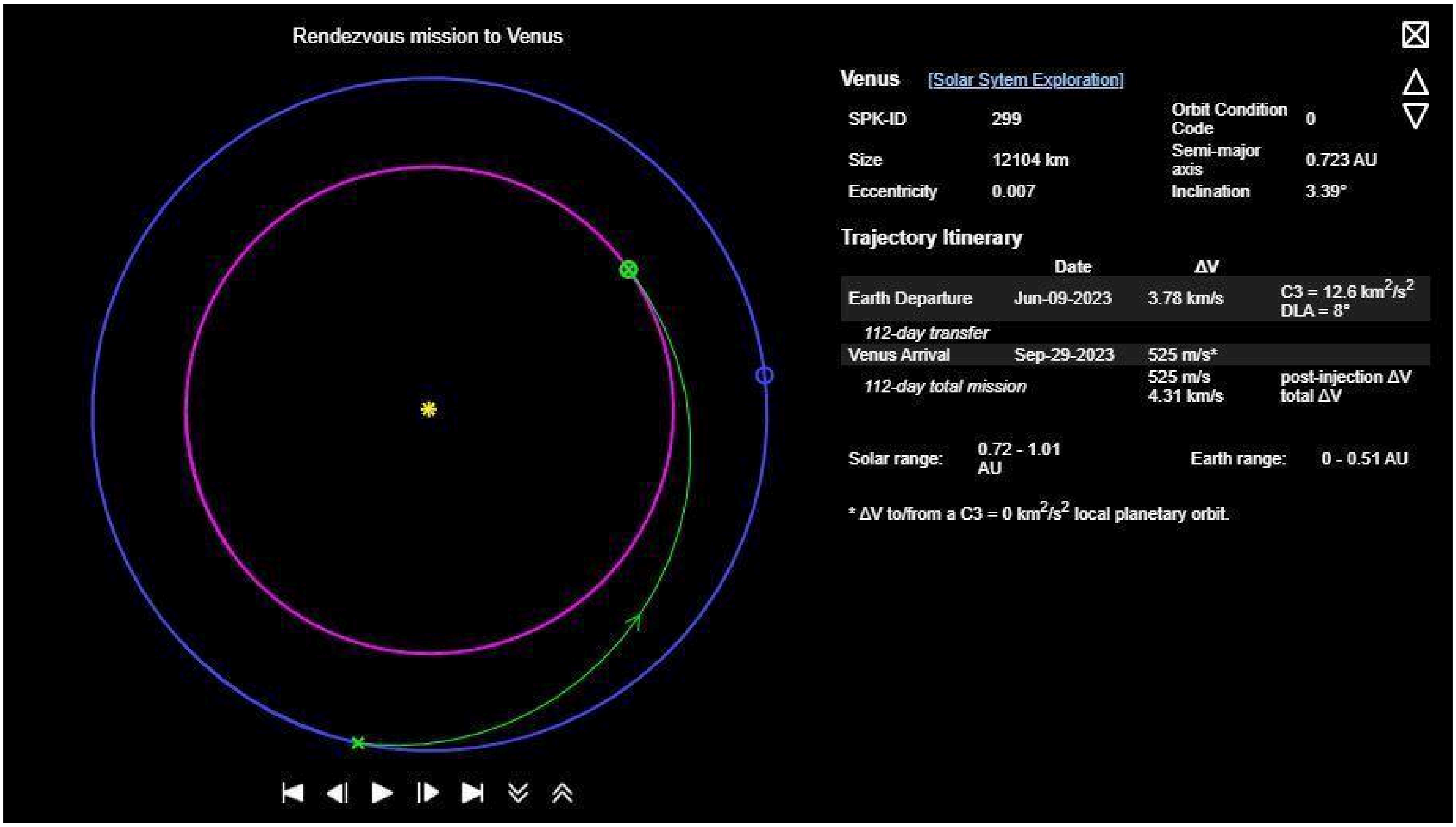


Figure 5.1: Orbital Transfer Maneuver

- Operational Phase E mission begins on September 29th, 2023 and will last an estimated one month to collect data necessary to be considered successful. VESPAA design is not currently intending on extending its mission life and will develop its final mission report.
- Phase F ends on March 30th 2024 after all closeout documentation has been updated and submitted. The data will be archived and documented, completing the disposal and final mission reports.

6.3 Outreach Summary

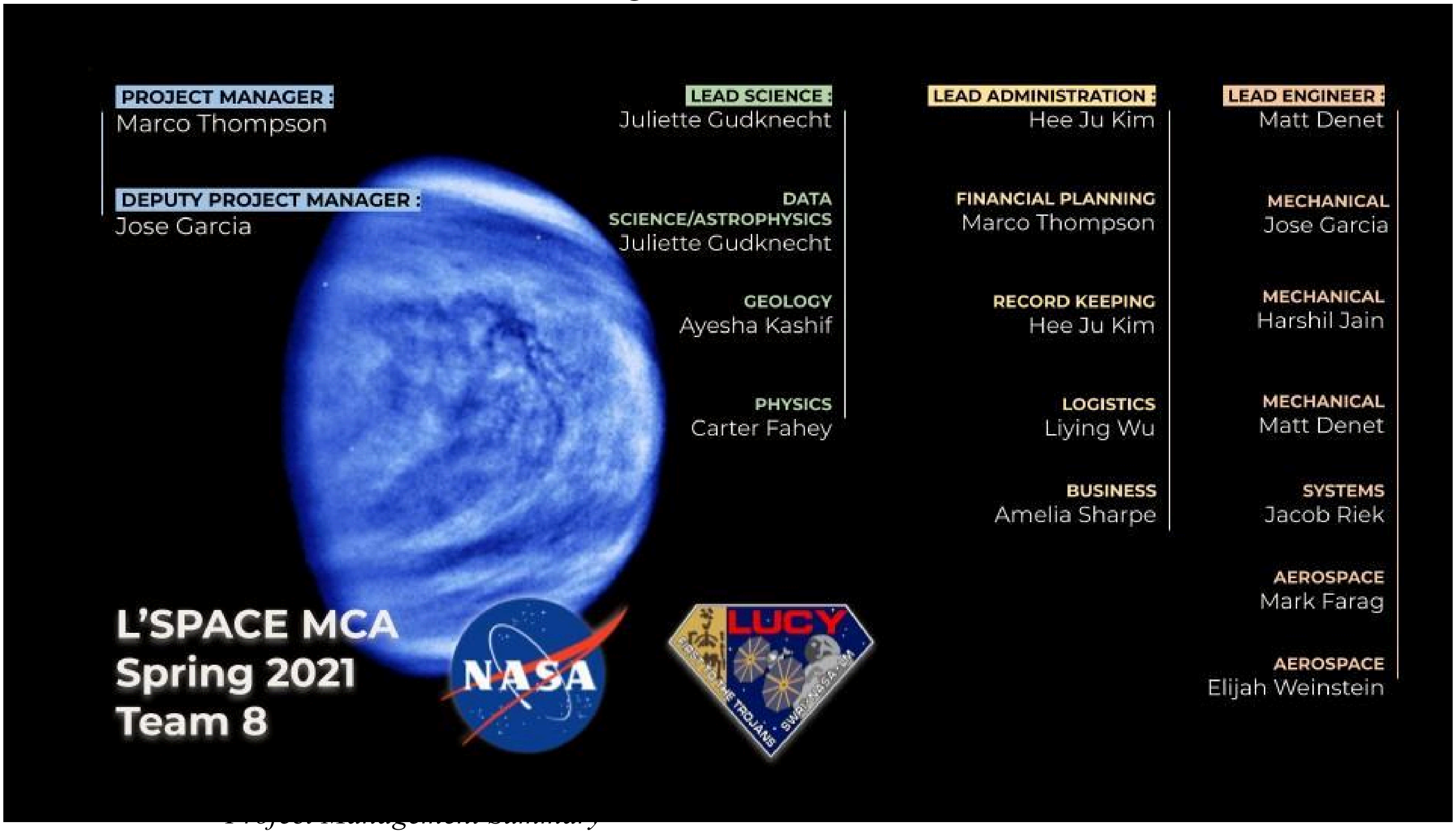
Every year, a significant part of our funding is allocated towards public outreach to maintain and encourage STEM engagement. This year, we aim to target younger children in the most underprivileged areas in an effort to reach every last child. We also aim to increase diversity and create a more inclusive STEM space. Our mission is to:

- Recruit and train a team of STEM educators; Mathematicians, Computer Scientists, Chemists and more.
- Liaison with K-12 schools and local communities in these underprivileged areas to create a sequenced schedule for the year. Our team of skilled educators will be divided and sent out to lead workshops and hold seminars periodically over the year.
- Add participating students and educators to our NASA database to build a stronger relationship with our community.

By doing so, we are allowing our future generations to rise up to not only pursue their dreams in STEM but also affording equal opportunities for people across the country.

6.4 Project Management

Organizational Chart



Team 8 has a group strong attitude that derives from the talented members that make up the team. Each member brings their technical expertise to ensuring the reliable development of the VESPAA mission. The team consists of a set of sub-teams that openly communicate between channels and encourage help for tasks on other teams.

- The Project Management goal is to ensure maximum cooperation and communication through engagement and independence. All roles were decided by the group after they were applied for, allowing for active participation in the process. All members are contributing to the success of the mission. All teams and individuals are able to self manage their assigned tasks and are accountable for any and all task deadlines, while being mindful of other pending tasks.
- The Engineering Team is the largest and has the most diverse range of specialists. This team is broken down into further sub-teams such as Mechanical and

Aerospace teams. Their tasks and research are assigned via these sub teams allowing those teams ability to work separately and independently. The Engineering Team is responsible for building the design and ensuring hardware fits within the desired constraints.

- The Science Team has three departments that it specializes in, each scientist being the expert of those departments. Tasks are also assigned based on department assisting other departments when available. The Science Team's research guides the requirements and limitations of the VESPAA mission.
- The Administration Team has four sectors that it oversees for the VESPAA mission. This includes financial planning, record keeping, logistics, and business. Each administrator is assigned tasks relevant to their sector and assists with general duties. The Administration Team's role is to provide organization and structure for the VESPAA mission and the teams required deadlines.

A communication is given daily to inform the team of any notifications and events, or any updates needed for completing goals. A weekly meeting is open but not required for all to attend, as the events are summarized later. Sub teams also have meetings for the tasks and projects, but all are open to join and encouraged to help inter-team communications. Team 8 has performed well and delivered quality products in the past and will consistently continue to do so in the future. Team 8 is hardware tested and flight ready.

7. Conclusion

Ultimately the VESPAA mission will provide researchers critical data about the Venusian environment and provide affordable and reliable architecture for similar missions in the future.

This platform is simple in design and can be assembled quickly for rapid delivery. The modular design allows for the integration of various science instruments that fit in the cubesat format. The vehicle can return data from various altitudes within Venus' atmosphere by controlling the temperature of the helium inside the balloon and helium tanks, similar to a Rozièr balloon. The vehicle will sample data utilizing a variety of different scientific instruments that record unique data sets and relay the information back to the orbiter, which will transmit the data back to *the Network.* The mission should last up to 30 days completing at least 6 revolutions around the planet carried by the persistent vortex in Venus' atmosphere. This shall be plenty of time to collect a significant amount of data that spans a large swaths of Venus' environments.

The mission life could possibly be extended, however, further development of solar cells and controlled flight technology would need to be researched. If more time and testing allowed the VESPAA mission's team would conduct research into a lifting body blimp design in order to traverse altitudes more rapidly, while also providing more stability allowing for more sophisticated technologies like Synthetic Aperture Radar (SAR). These design iterations are within the budget and size constraints, and could also be manufactured and tested quickly as much of the research collected confirms these concepts. Development is still an open possibility.

Once the PDR is approved the team would immediately begin purchasing equipment and making arrangements to rent any facilities or equipment. The team will also begin working on the hardware's Critical Design Review, including a review that ensures all of the equipment meets the technical, performance, cost, schedule, etc. requirements. This review will be conducted during our manufacturing phase to establish a baseline and ensure all criteria are met. The CDR will also update the risk assessments made within this document, in addition to another Cost Analysis, Technical Readiness Review, etc. The mission should move through these phases as much of the hardware is already flight proven, reliable, and readily available.

The Venus Environmental Surveyor and Particle Analysis Aircraft (VESPAA) mission shall provide data that will enhance the understanding of complex weather patterns and extreme environments on planets and other planetary bodies as well as better understanding the history of Venus. Studying this data shall give insights into how to potentially model climate change and what effects result from it. This mission also has the capability to discover life, if present, within the atmosphere. With the amount of data collected from just one of the VESPAA mission designs, researchers shall be able to answer many of these long sought after questions, and have more than enough data to create better models of Venus' environment for potential future missions.

The VESPA mission is the culmination of the dedication of the designing team. With careful planning and effective research the mission concept excels at demonstrating capability but also teamwork and dedication. The talent and skill of all the members provides the heart and soul of this project, all included in the process; the best of the best. Through hardship to the stars - *Ad astra per aspera.*

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Internal documents created by Team 8
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