Balloon Reconnaissance Atmospheric Venus Exploration
2020-2023 Preliminary Design Review

NASA Lucy Student Pipeline Accelerator and Mission Concept Academy

Team 23 - Z3NITH

Table of Contents

1. Introduction and Summary

1.1 Team Introduction

Stefanie Thompson
Project Manager

Stefanie Thompson - Stefanie Thompson attends the University of Texas at Austin in Austin, Texas. She has experience in circuit analysis and embedded systems design through her studies. She is a CAD certified user and through her experience with the Texas Rocket Engineering Lab, she has strengths in rocket electronics hardware and software simulation. Stefanie will be serving as the Project Manager on the team.

Alejandro Pasillas
Lead Administrator

Alejandro Pasillas - Alejandro Pasillas attends the University of Texas at Dallas in Richardson, Texas, and is pursuing his bachelor's in Mechanical Engineering. He has experience working in a team environment through various academic and industrial projects. He has an interest in robotics and its application to space and aeronautics. His technical skills include; SolidWorks, Matlab/Simulink, Ansys, C/C++, R, and Universal Robotics programming. In his free time, he enjoys learning about web programming and working on personal projects related to engineering. He will serve as the business administration team lead.

Amine Sakrout
Lead Engineer

Amine Sakrout - Amine Sakrout attends Texas A&M University in College Station, Texas but is at home in Richardson, Texas. His strengths are Python, Java, AutoDesk Inventor, AutoCAD, and robotics. Amine will be serving as the engineering team lead on the team.

Grant Alumbaugh
Aerospace Engineer

Grant Alumbaugh - Grant Alumbaugh attends the University of Alabama in Tuscaloosa, Alabama. His educational background lies in the math and physics fields. His technical background is in CAD and coding. Grant is serving as the aerospace engineer on the team.

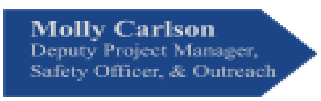
Alyssa Vellucci
System Engineer & Material Scientist

Alyssa Vellucci - Alyssa Vellucci attends the University of Texas at Dallas in Richardson, Texas. Her coursework has gained her applied mechanical knowledge and she has experience in robotic design, automation, system control, 3D printing, CAD, circuit design, and material science. She also has project management experience through industry internships. Alyssa is serving as the systems engineer and material scientist on the team.

Ethan Henderson - Ethan attends the University of Oklahoma in Norman, Oklahoma. His technical skills include CAD, Matlab, and an LSS Fundamentals certification. Ethan is serving as a mechanical engineer on the team.

Kaden Walworth - Kaden Walworth attends the University of Alabama in Tuscaloosa, Alabama. He has experience in coding and CAD. His educational background lies in math and physics. Kaden is serving as a mechanical engineer and logistics manager on the team.

Jawad Hamza - Jawad Hamza attends the University of Texas at Austin in Austin, Texas. His educational background and interests are in computer science and mathematics using Python, Java, and machine learning. He was a three-time state winner across Texas spanning various competitions regarding information technology and security, proving his ability to understand and apply technical skills effectively for a project. He also was involved in STEM outreach for high school students and competed in multiple hackathons. Jawad is serving as the science lead on the team.



Molly Carlson - Molly Carlson attends Wichita State University in Wichita, Kansas. Her experience as a Stanford University Innovation Fellow has gained her a design thinking certification and a background in project management and interdisciplinary collaboration. She has experience in MatLab, Python, LabVIEW, and 3D printing. Molly is serving as the deputy project manager, outreach administrator, and safety officer on the team.

1.2 Mission Overview

1.2.1 Mission Statement

The BRAVE (Balloon Reconnaissance Atmospheric Venus Exploration) lander is a secondary airborne vehicle to a lander orbiter mission to Venus that specifically focuses on investigating and collecting data on signs of life and sustainability within the Venusian atmosphere and informing future missions. The purpose of this focus lies in the lack of clear and complete data on the diverse planetary conditions of Venus. Thus, this mission attempts to solve this through surveying and assessing the atmosphere's internal chemistry, interactions between both solar and thermal radiation fields, temperature, pressure, wind velocities, and solar heating rate through panoramic images captured by a spectroradiometer including the presence of life-sustaining substances (water, carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur) to identify regions which promote sustainability and provide detailed insights for computational modeling and designing of future missions.

1.2.2 Mission Requirements

1.2.2.1 Logistics

- All components, including payload instrumentation, power, structure, communications, and subsystems shall weigh no more than 175 kg.
- The stowed configuration when attached to the primary orbiter shall be no bigger than 60 cm x 70 cm x 90 cm.
- All components shall cost no more than $250 million.
- To prevent false positives when identifying forms of life in the cloud tops, all components shall be thoroughly sterilized to prevent cross-contamination from the lander to the atmosphere.

1.2.2.2 Orbit Maneuver

- The main payload shall escape Earth's orbit (29,785.15968 m/s) into an elliptical orbit (25,540.41751 m/s) by performing a Hohmann transfer through increasing its velocity by 253.07879 m/s. It then shall escape elliptical orbit into Venus's orbit (35,020.99797 m/s) with a velocity increase of 5480.58046 m/s.

1.2.2.3 Parachute

- The parachute shall resist degradation from the masses of sulfuric acid throughout the atmosphere during entry.
- The parachute shall not tear when connected to the lander caused by acceleration during entry.

1.2.2.4 Balloon

- The balloon shall aerially deploy and inflate after the parachute is detached.
- The balloon shall carry a 122.1 kg gondola including all components and subsystems.
- The balloon shall resist shifts in vertical wind velocities and solar heating which would otherwise remove it from the desired range of 52 to 62 km.
- The balloon shall circumnavigate the cloud tops from altitudes between 52 and 62 km based on pre-commanded flight profiles during both day and night.
- The balloon shall resist envelope degradation from sulfuric acid aerosols in the cloud tops.

1.2.3 Mission Success Criteria

- Safely land and stay in orbit at a constant velocity in the Venusian cloud tops at an altitude range of 50 to 62 km for all measurements.
- Capture multispectral images with Panoramic Cameras once 52 to 62 km above the surface and at every 1 hour interval to assess spatial variability of C, H, N, O, P, S, and H_2O compositions.
- The magnetometer will measure with a 32 Hz sampling rate.
- Barometric pressure sensors will detect any seismic signals for signs of past and present activity in infrasound frequencies over a range of 0.01 - 80 Hz and noise floor < 0.001 Pa.
- Gather and identify data on traces of organic objects, including photosynthetic pigments, to assess photosynthetic activity in the atmosphere through fluorescent and dark-field images of cloud droplets at a spatial resolution < 0.5 µm at 265, 370, 470, and 530 µm to compare concentrations of biosignatures during the day and night.
- The nephelometer measures particle size with a resolution of 0.1 µm and refractive index to a resolution of < 0.02 µm.
- The nephelometer measures the intensity and polarization of scattered light to an accuracy of 1% at every 1 hour interval to assess spatial variability.
- The visible imager takes images of the balloon and atmosphere 24 hours on Earth.
- UHF-T will send all images and measurements to Earth after the hourly image capture and measurements are complete with an accuracy of ≥ 95%. If not possible, data transmission and collection will halt until an accuracy of ≥ 95% is met.

1.2.4 Concept of Operations (COO)

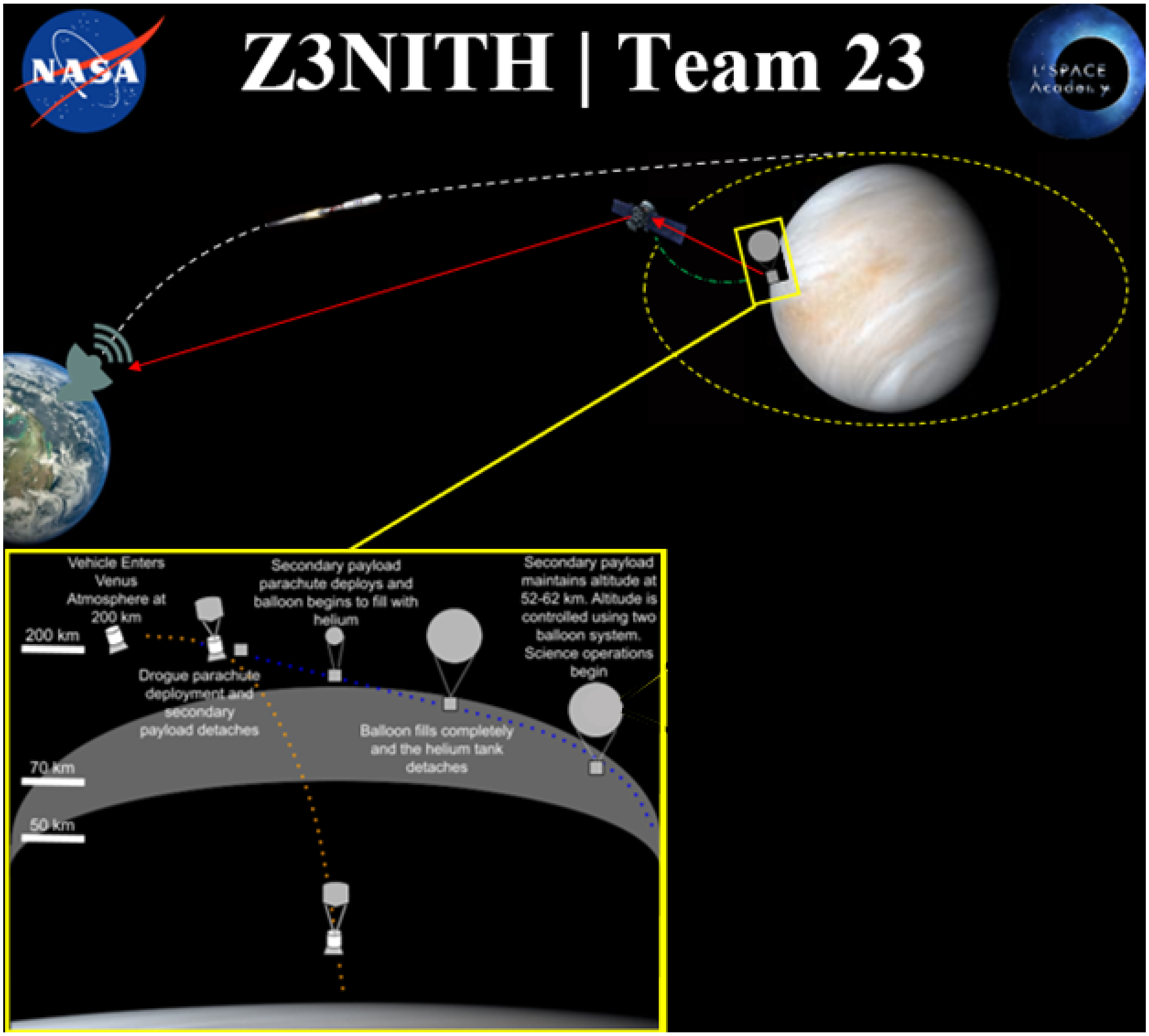


Fig. 1. The Concept of Operations graphic illustrates a top-level graphical overview of the missions objectives from launch to beginning of science operations.

BRAVE will enter the Venusian atmosphere at 140 km. The drogue parachute will deploy and the payload will detach to reach the Venusian surface. The secondary payload will deploy a balloon to maintain the structure between 52 to 62 km above the surface, where the payload will begin to take multispectral images and measure pressure, wind velocities, and atmospheric concentrations of isotopic ratios of oxygen, water, carbon dioxide, sulfur dioxide, and sulfur trioxide. The probe will contextualize these measurements to collect data regarding biosignatures with respect to altitude.

1.2.5 Major Milestones Schedule

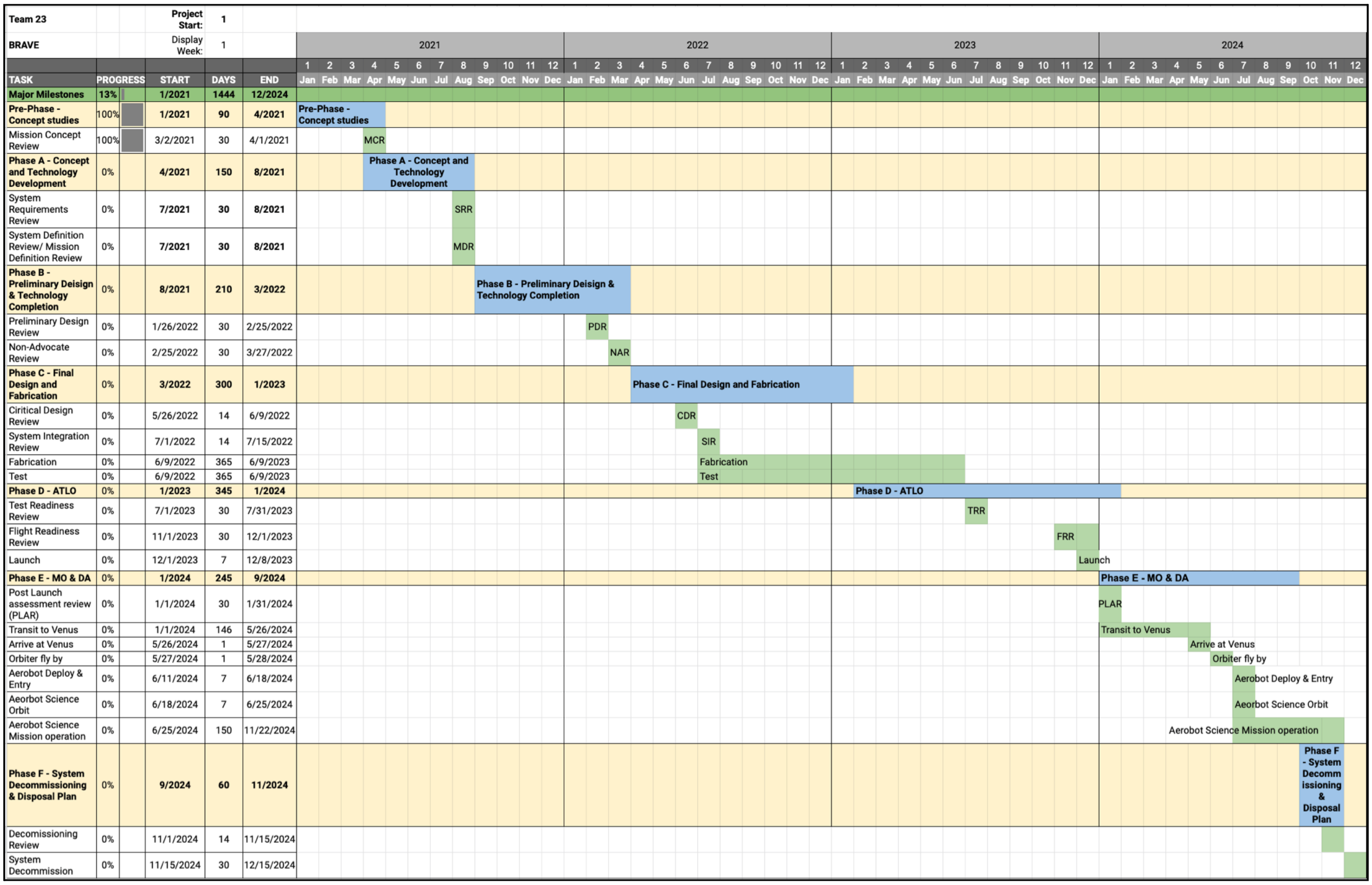


Fig. 2. The schedule illustrated above spans through all of the mission phases and the major milestones in between.

The mission timeline is scheduled for 4 years or 48 months. The Schedule details the major milestones throughout the pre-phase and phase A- F. The schedule includes the start date and the end date for each major milestone. A progress bar indicated how far along that task is relative to its start and end date. The blue bars represent the phase of the mission and the green bars represent the tasks within that phase.

1.3 Descent Maneuver and Lander Systems

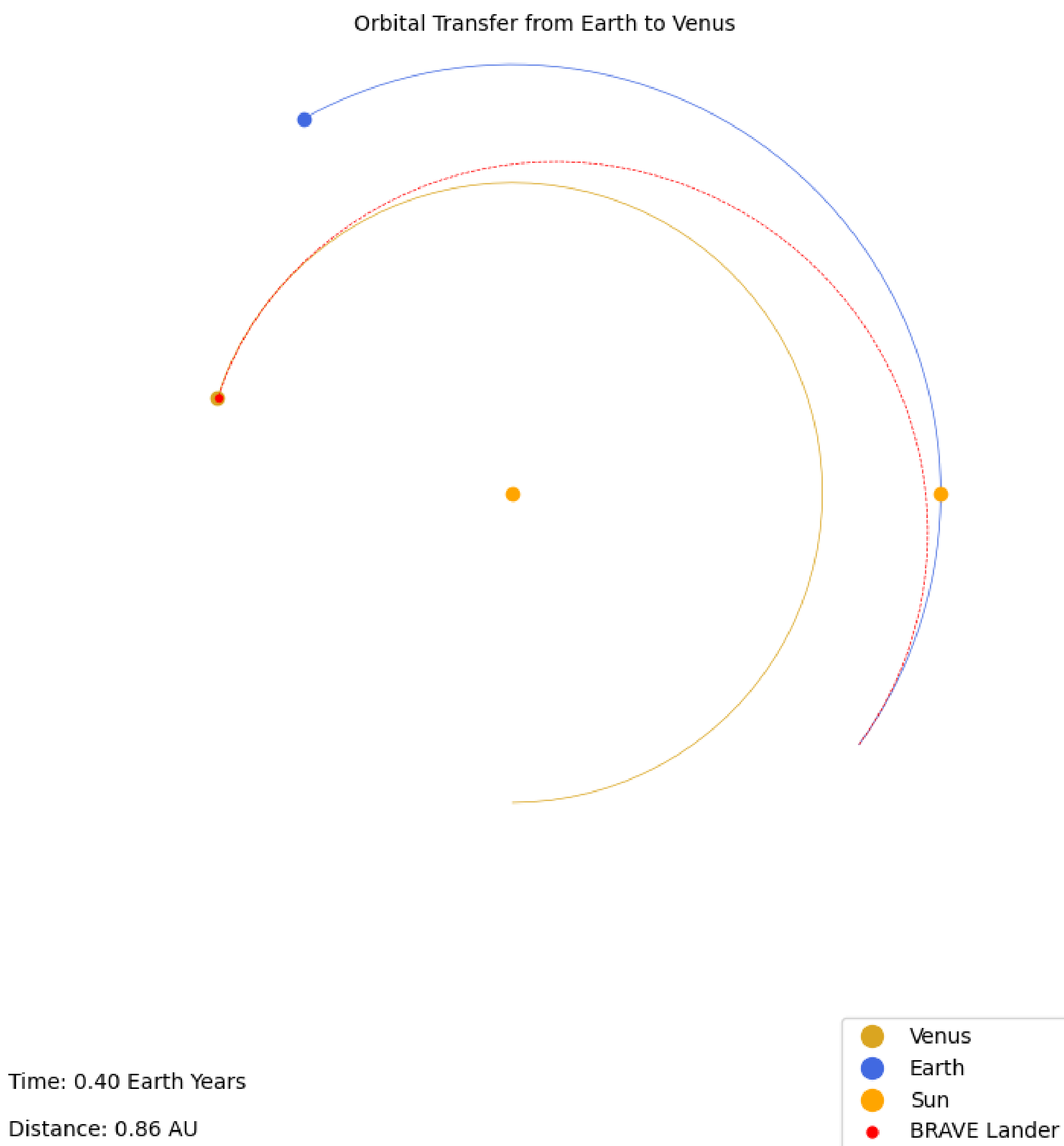


Fig. 3. Trajectory of the orbital transfer including the orbital trajectories of Venus, Earth, and the BRAVE lander. To denote the aphelion of Earth, an extra marker of the Sun was placed on its trajectory.

1.3.1 Entry, Descent, and Landing (EDL)

Depicted above is the trajectory of the BRAVE mission orbital transfer (including that of the main mission). To escape the elliptical orbit into Venus's orbit (35.02099797 km/s), the vehicle will increase its velocity by 5.48058046 km/s. The total distance covered during the transfer is 128,654,168.802 km, or 0.86 AU, over 0.40 Earth years. Once 140 km above the surface, the BRAVE lander is detached from the main payload. As the BRAVE lander comes closer to a heat load, that is above the operational limit of all components, it deploys a parachute to decelerate. Once it decelerates until a velocity where the balloon will not tear, a super-pressure balloon is deployed until an altitude of 56 km above the surface is met, beginning the scientific investigation.

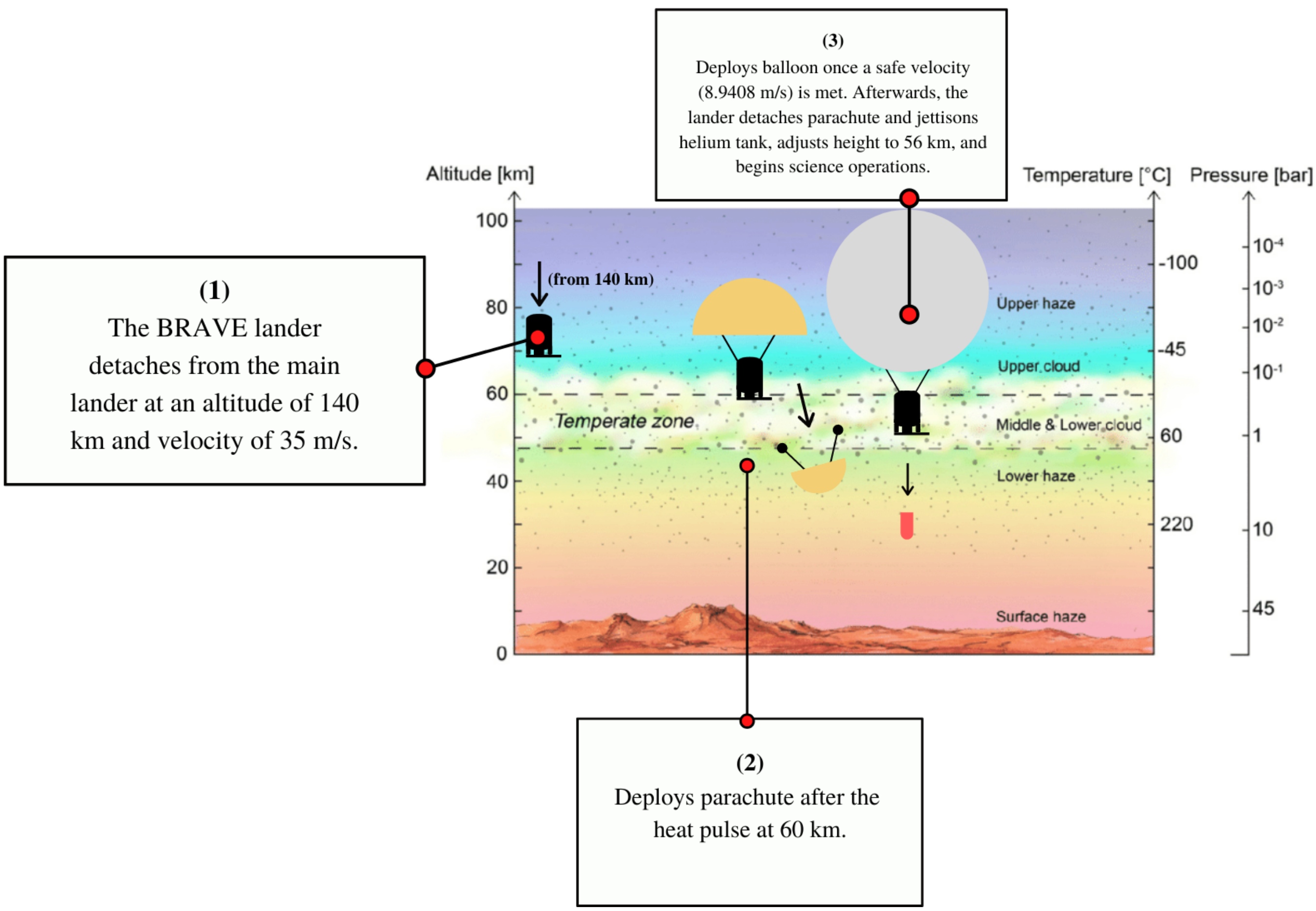


Fig. 4. Overview of EDL sequence (figure modified from (Seager et al. 2021)).

1.3.2 Systems

To maintain the payload's altitude, the balloon uses a dual-chamber system to control buoyancy where helium is transferred from the outer to the inner chamber to lower altitude and vice versa. Displayed below is the entire BRAVE assembly:

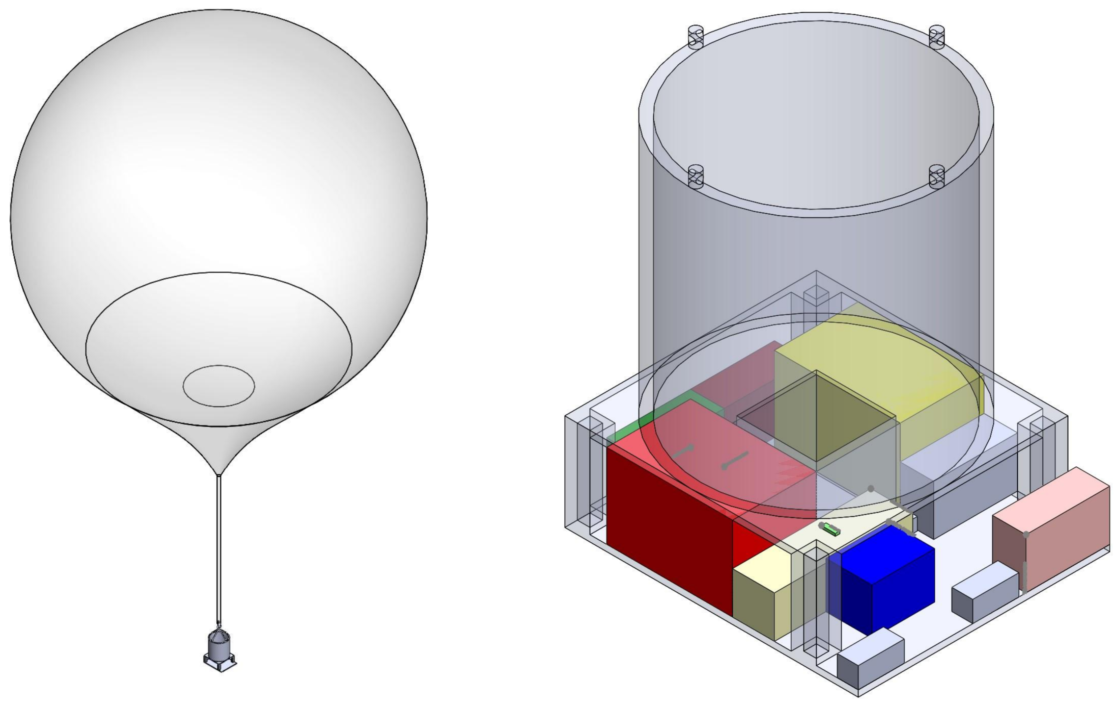


Fig. 5. Models including all systems and components.

Displayed below is the mass for each component on the BRAVE mission:

Component	Mass
Instruments	34.916 kg
Gondola	35.458 kg
Solar Arrays	3.52 kg total
Helium	24.6035 kg
Helium Tank	7.7 kg
Parachute	12.4568628981 kg
Balloon System	51.7803215 kg
Radiators	2 kg total
Backup Batteries (2 x 10 Ah)	2 kg total
Total Mass	174.434684398 kg

Fig. 6. Mass components of BRAVE mission

1.4 Payload and Science Instrumentation Summary

<u>Panoramic Cameras (Pancam) (0.54 kg, 5cm x 5cm x 11cm)</u>

Pancam is a set of two cameras that will capture high-resolution, multi-wavelength 3-D panoramic pictures of the atmosphere surrounding the vehicle. The Pancam Mast Assembly enables the cameras to rotate 360° while the camera bar provides them with a 180° range of elevation. Each camera uses its filter wheel to take multispectral images to assess the composition and properties of the atmosphere.

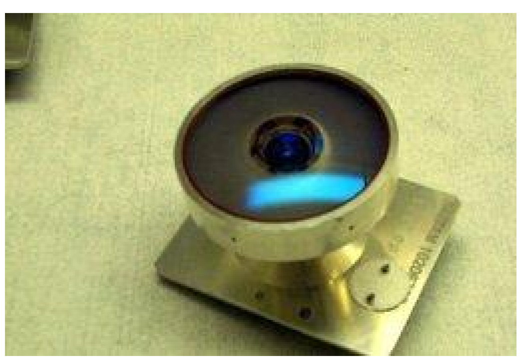


Fig. 7. Pancam len
Image credit: Arizona State University

Aerosol Mass Spectrometer (AMS) (7 kg, 30cm x 20cm x 20cm)

AMS will measure the composition of life-sustaining elements (C, H, N, O, P, S) in the atmosphere on a smaller scale than Pancam.

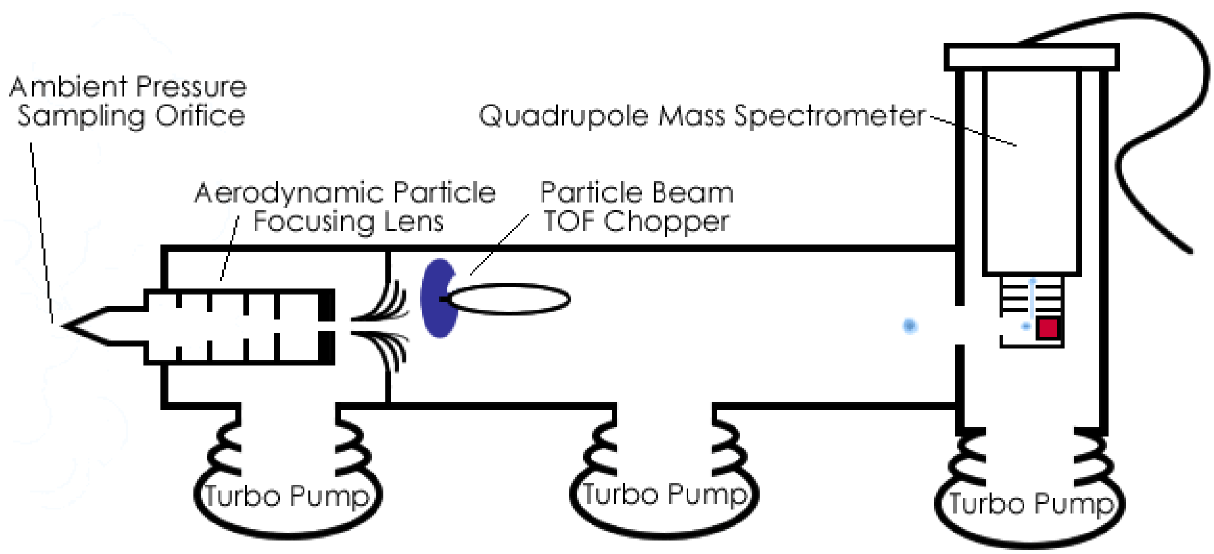


Fig. 8. Example AMS
Image credit: Matt Thyson (Lexington, Massachusetts)

Nephelometer (Neph) (4 kg, 30cm x 20cm x 20cm)

Neph will assess incoming cloud droplets and aerosols by measuring the light scattered from them to determine shape, size, and refractive index on a smaller scale than the pancam.

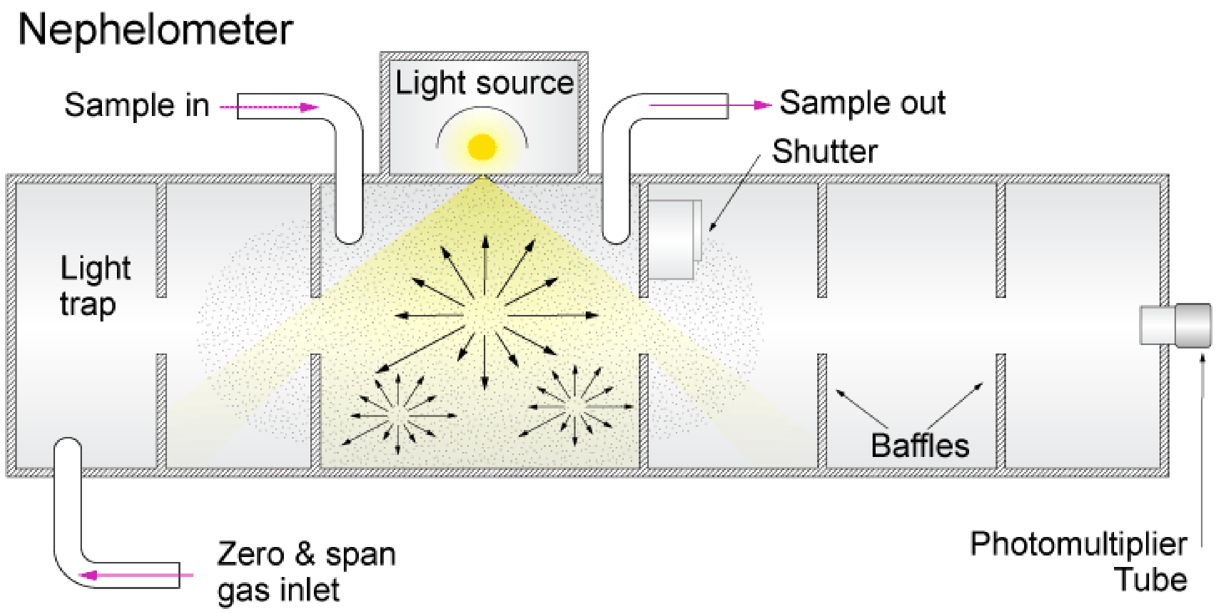


Fig. 9. Example nephelometer.
Image credit: Queensland Government

Barometric Pressure Sensor (BPS) (1 kg, 20cm x 12cm x 8cm)

BPS will detect any infrasound to measure seismicity for identifying quakes for evidence of past and present tectonic and volcanic activity.

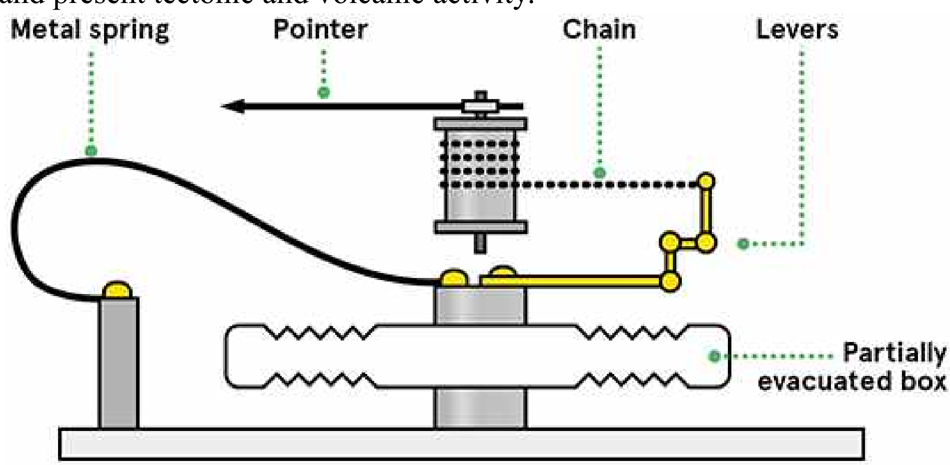


Fig. 10. Design of a barometric pressure sensor
Image credit: Avnet Abacus

Temperature Sensor (TS) (0.75 kg, 20cm x 12cm x 8cm)

Coupled with BPS, TS will assess the convective stability of the atmosphere and provide context for other measurements taken during the mission, including solar flux and thermal radiation.

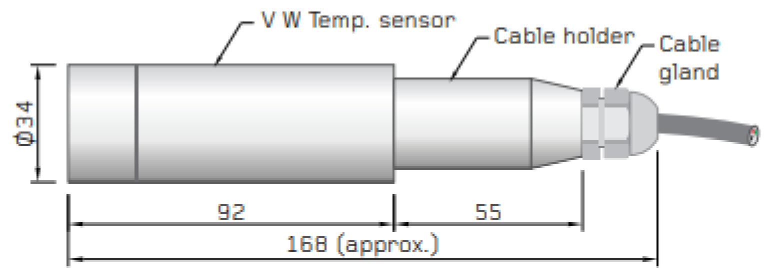


Fig 11. Design of a temperature sensor
Image credit: Encardio rite

Radiometer (Rad) (1 kg, 20cm x 12cm x 8cm)

Rad will measure upward and downward solar fluxes as a function of the altitude to assess the effects of radiation on Venusian cloud-level dynamics.

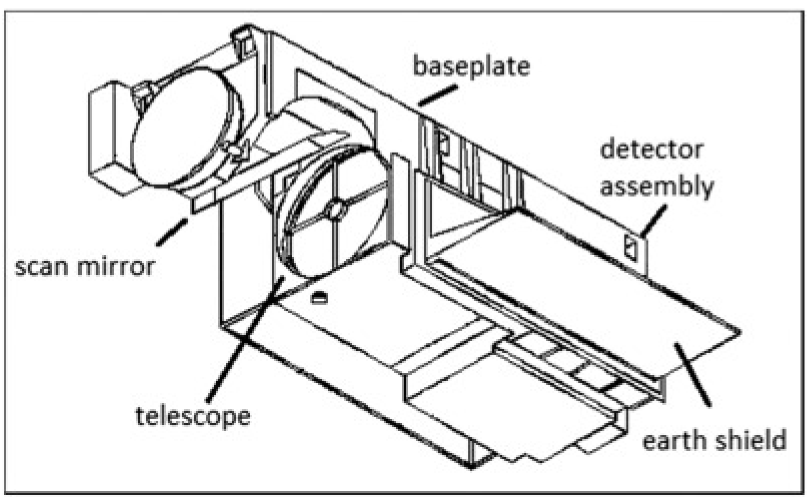


Fig 12. Design of a radiometer
Image credits: X. Xiong

3-D Anemometer (3DA) (1 kg, 20cm x 12cm x 8cm)

3DA will measure wind velocity and turbulence relative to vertical changes due to buoyancy changes from vertical winds. Additionally, it will improve sensitivity to turbulence and atmospheric waves.

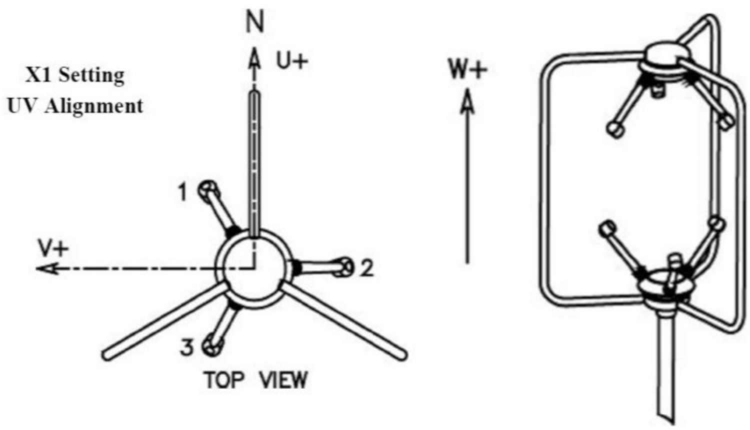


Fig. 13. Design of a 3D anemometer
Image credit: Francisco Javier García Ramos

Fluorimetric Microscope (FM) (5 kg, 10 cm x 10 cm x 33cm)

FM will analyze incoming cloud droplets for traces of biosignatures associated with past or present life, including photosynthetic activity, using fluorescence and dark-field images of cloud droplets.

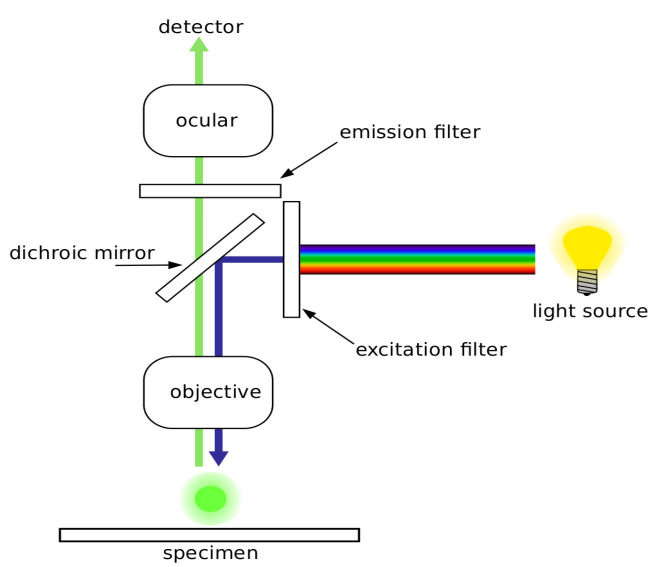


Fig. 14. Design of a fluorimetric microscope

Image credit: Henry Mühlpford

Sun sensor (SS) (10 kg, 33mm x 11mm x 6mm)

SS is a SSOC-D60 2-axis digital sun sensor which detects the location of the sun with respect to the BRAVE lander to measure the effects of the sun's position on sustainability in various areas across Venus. Additionally, the location of the sun will be important to reposition the BRAVE lander if necessary as it is solar-powered.

Fig.15. SSOC-D60 2-axis digital sun sensor

Image credit: CubeSatShop

Visible Imager (VI) (3 kg, 15cm x 11cm x 11cm)

To support the outreach of this mission and involve the greater community, VI will take images of the balloon and atmosphere.

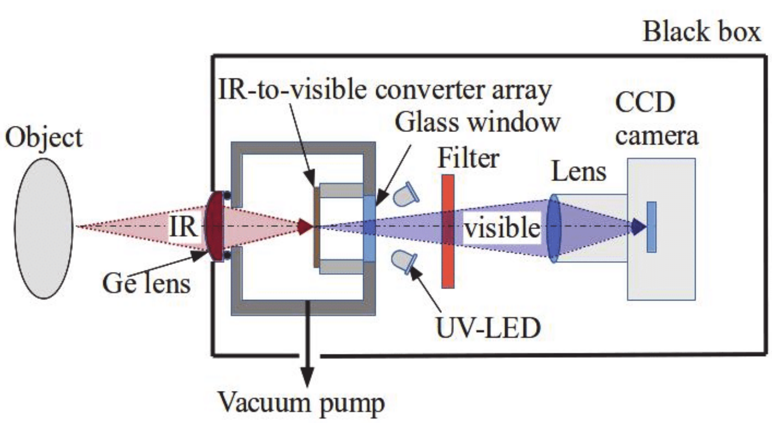


Fig.16. Design of a visible imager

Image credits: Takashiro Tsukamoto

Magnetometer (Mag) (0.5 kg, 4cm x 3cm x 3cm)

Mag will be used to delineate the magnetic field's strength and topology to show evidence of a current or past magnetic field and evidence of a current or past plate tectonic system.

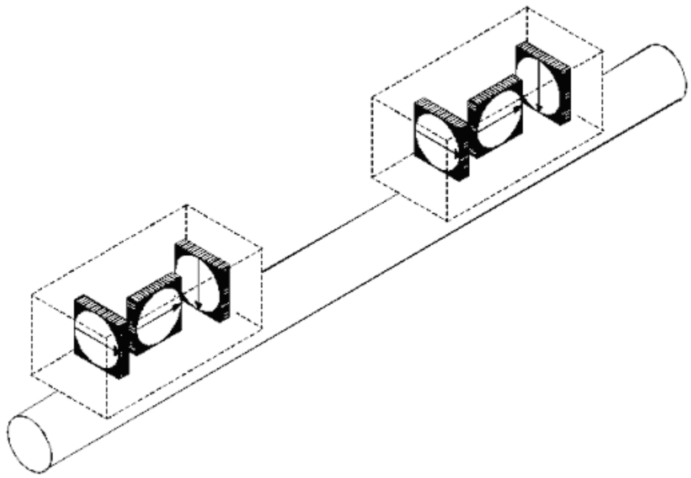


Fig. 17. Design of a magnetometer

Image credits: André Balogh's

Ultra-High Frequency Transceiver (UHF-T) (0.376 kg, 1.22 mm^3 x 1.22 mm^3 x 1.22 mm^3)

Based off of the EnduroSat UHF Transceiver II, four Ultra-High Frequency Transceivers, each weighing 0.094 kg, will send the images and measurements the BRAVE lander takes back to Earth in the ranges of 400 - 403 mHz or 430 - 440 mHz.

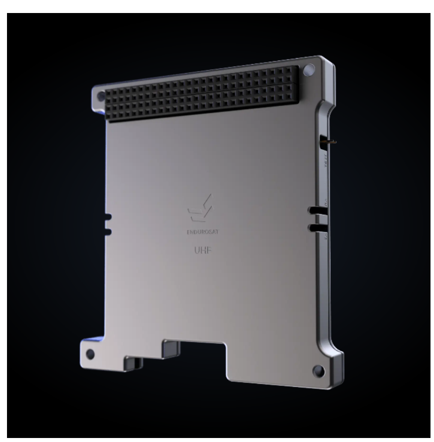


Fig. 18. EnduroSat UHF-Transceiver II

Image credit: EnduroSat

Inertial Measurement Unit (IMU)) (0.75 kg, 9 cm x 9 cm x 9 cm)

To gather data for updating current atmospheric models, weather parameters must be correlated to altitude. Additionally, the balloon must be supervised such that it does not exit the altitude range of 52 to 62 km. Thus, an LN-200S IMU shall be integrated to report altitudes of the payload for trajectory reconstruction and its measurements.

Fig. 19. LN-200S

Image credit: Northrop Grumman

2. Evolution of Project

2.1 Evolution of Mission Experiment Plan

The BRAVE mission was initially considered to be a year-long stationary mission for observing the behavior of the Venusian atmosphere over a duration of time. However, the overweighting benefits of a scouting mission quickly became clear due to the alarmingly incomplete models on the diverse planetary conditions of Earth-like planets. Thus, the new primary objective became the collection of data on the Venusian atmosphere with an emphasis on its full characterization, leading to the design of the flight operations discussed in Section **4.2.4** to cover an array of altitudes, latitudes, and their respective measurements in the cloud tops over a 60-day time period (one diurnal cycle on Venus).

2.2 Evolution of Descent Maneuver and Vehicle Design

Initially, the lander's aeroshell was designed as a two-layer hexagon to store the science instruments. This model, Fig. 5, had inadequate space to store the science instruments and was therefore unfit for the mission.

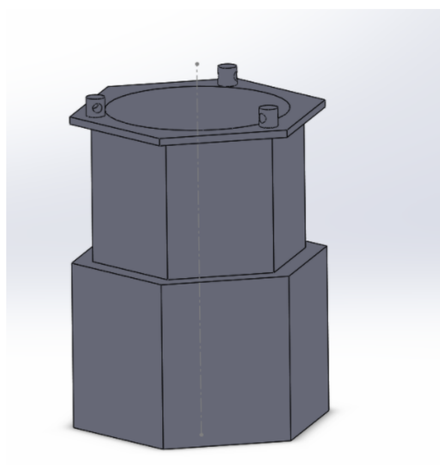
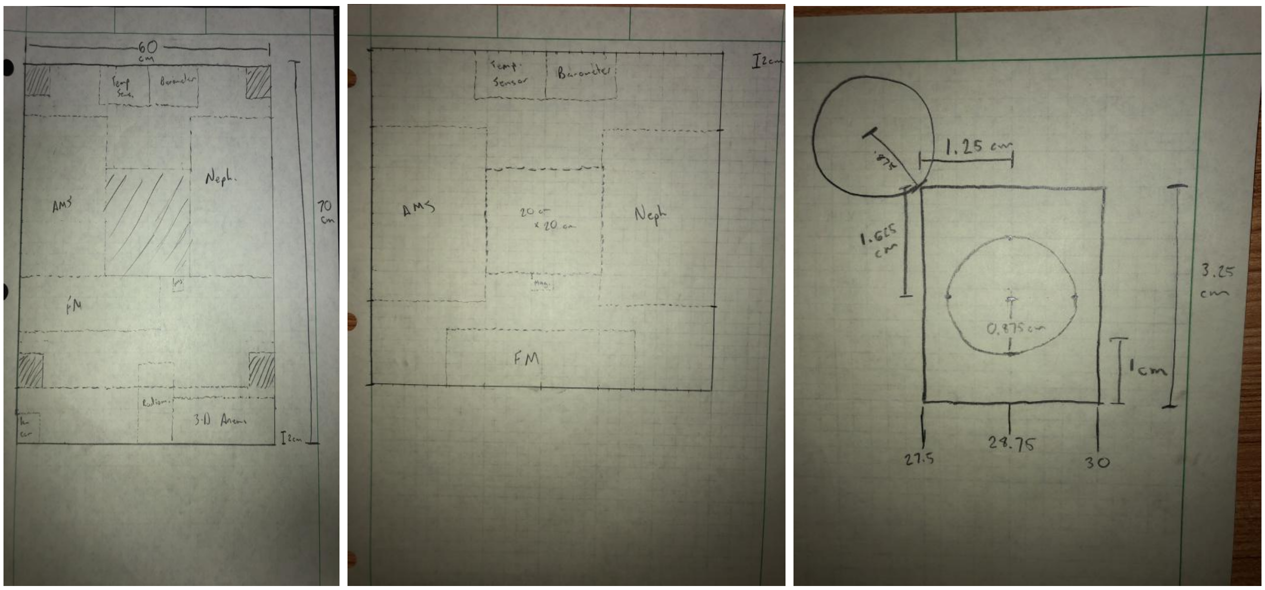


Fig. 20. Original BRAVE aeroshell design

Alternatives to the balloon were also discussed in the early stages of the mission development. Gliders were the first iteration but were not selected due to the weight and size. Rockets were in the second iteration but were also discarded due to weight, size, and fuel requirements. The balloon was the least expensive and lightest option.



Figs. 21-23. Sketch of Science Payload Integration With Gondola

2.3 Evolution of Payload and Science Instrumentation

To power the payload, a Multi-Mission Radioisotope Thermoelectric Generator (MMRTG) was initially considered against solar panels by weighing costs and efficiency within the scope of the mission. Ultimately, because the mission shall be relatively short-term (60 days), an MMRTG costs \$108M for production and deployment (43.2% of the total mission budget), and solar panels have heritage from past Venus probe missions including Magellan, powering the payload using solar arrays seemed to be the best option.

To provide a clear estimate of the lander's altitude for better control, especially for emergency operations, and to correlate atmospheric measurements with various areas in the cloud tops, an Inertial Measurement Unit (IMU) was later added to the payload.

While the design has remained similar throughout the entire process, different methods of descent were considered before the neoprene helium balloon was chosen to be the most cost-effective and lightest material. Among the options were gliders and rockets, but both were found to be expensive to manufacture and bulky.

3. Descent Maneuver and Vehicle Design

3.1 Selection, Design, and Verification

3.1.1 System Overview

After detachment from the orbiter, the vehicle, together with the main lander, will begin entry into the atmosphere. The lander will deploy a parachute with a 2.5 m diameter, slowing them to 35 m/s. Once this velocity is reached, the lander will detach and begin its descent. The vehicle will deploy another parachute, slowing it to 8.9408 $\frac{m}{s}$, when it will reach 60 km above Venus. Here, the parachute will detach, deploying the balloons, and inflating them.

The balloons are attached to the top of the vehicle system by four cables. The balloon system consists of a zero-pressure balloon, filled with helium, a super-pressure balloon, filled with pressurized helium, and a pump to transfer helium between the zero-pressure and super-pressure balloons. This system is similar to a helium tank used to fill party balloons; when the pressurized helium is moved to the zero-pressure balloon, it becomes less dense than the surrounding atmosphere and provides lift.

The vehicle system consists of a gondola that houses the helium tanks used to inflate the balloons as well as all science components. Science components are housed underneath the cylinder which holds the tanks and balloons. The vehicle system will be constructed out of carbon fiber due to its low weight and corrosion resistance.

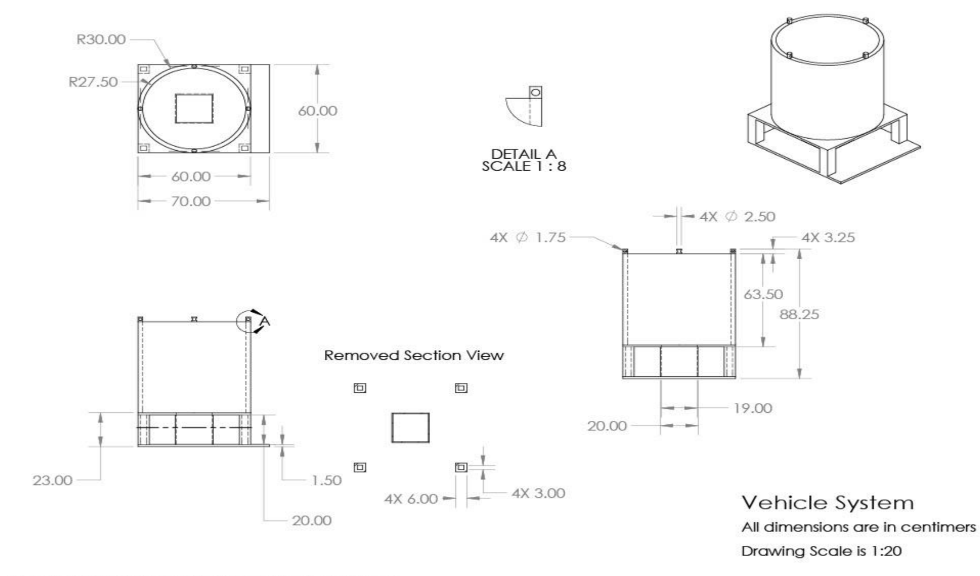


Fig. 24. Dimensioned Drawing of Vehicle System

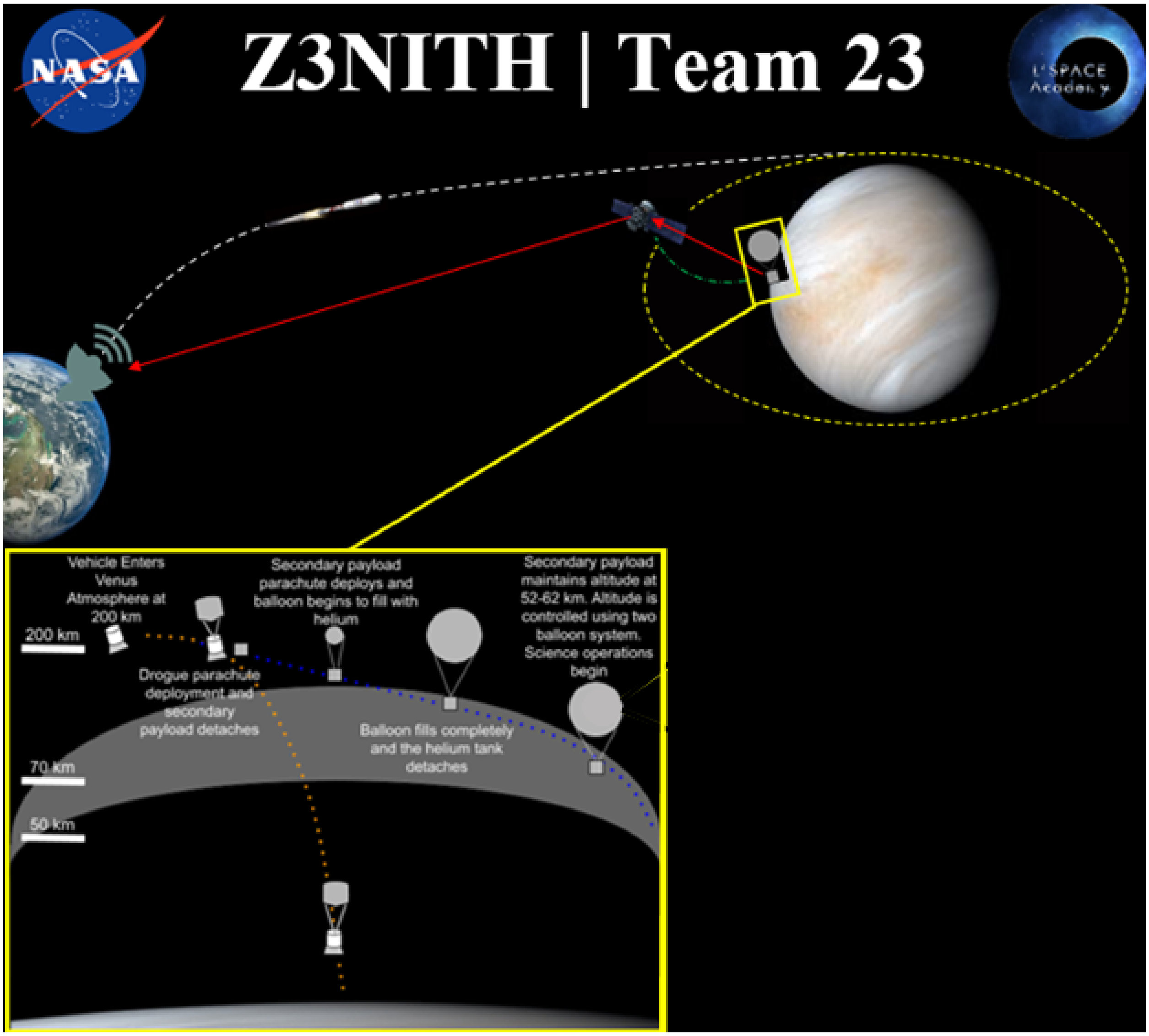


Fig. 25. Concept of Operations

3.1.2 Subsystem Overview

The balloon design consists of one zero-pressure balloon, and a super-pressure balloon inside it. The zero-pressure balloon is made of neoprene coated outside in Teflon to provide resistance to the sulfuric acid in Venus's atmosphere and inside in aluminum to reflect the sun and prevent overheating. The super pressure balloon will be made of vectran fabric due to its high tensile strength, with an inner coating of polyurethane to prevent leaking. The super-pressure balloon is connected to the zero-pressure balloon via a pump, which is used to transfer pressurized helium to the zero-pressure balloon and provide lift. The mechanism which detaches the parachute when the vehicle reaches a velocity of 15 m/s will also release the balloons and trigger the onboard helium tanks to inflate them.

3.1.3 Dimensioned CAD Drawing of Entire Assembly

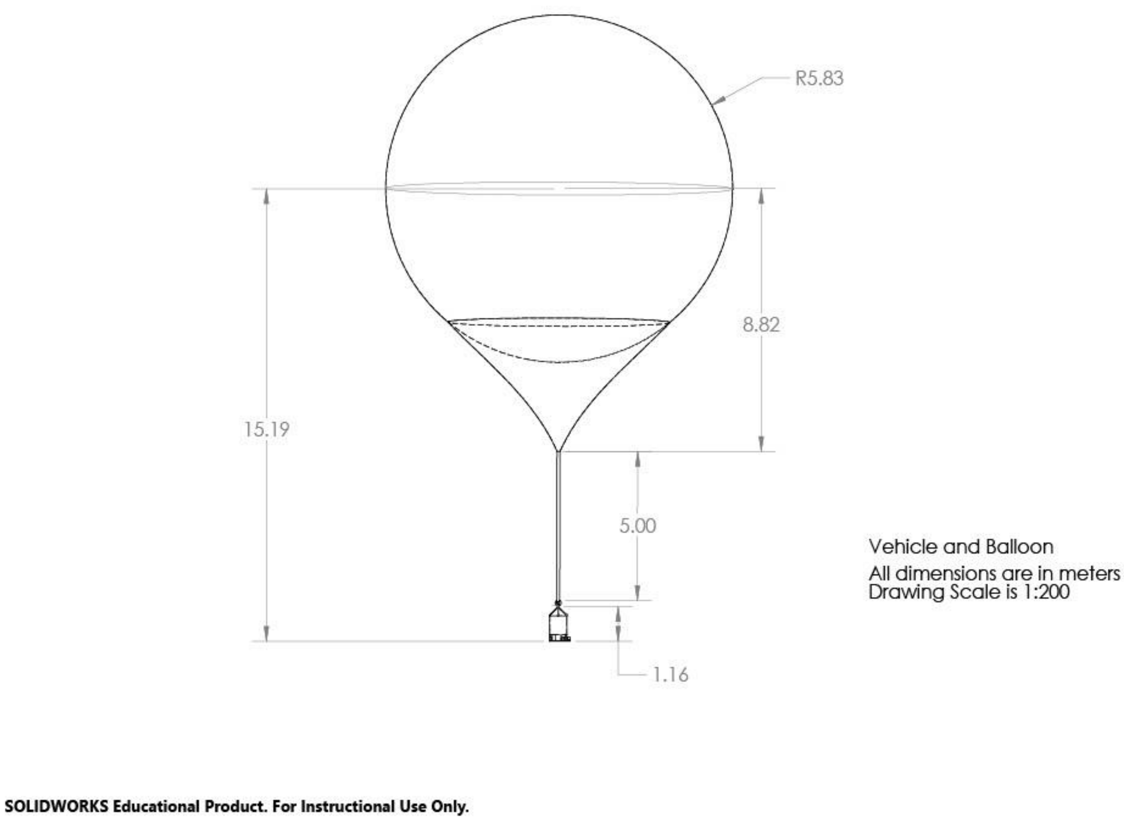


Fig. 26. Balloon and Gondola Assembly

3.1.4 Manufacturing and Integration Plans

Our balloon will be manufactured by Loon, a company that specializes in creating balloons. Our parachute will be manufactured by Nivitex. We will 3D print the gondola from carbon fiber using a 400 SERIES WORKBENCH XTREME 3D PLATFORM which is capable of printing a 1 X 1.5 X .7 m object. Printing the gongola should be possible as it can be, at most, .9 X .7 X .6 m. The parachute will be exposed to the atmosphere as soon as the gondola detaches from the lander which removes the need for special mechanisms to be attached to it. The balloon will be attached to a helium tank. The balloon will begin to fill as soon as the gondola detaches from the lander. The balloon is a two balloon system and will have a pump going between the two balloons so helium can be transferred between them. Using the measurement of each instrument and the measurements of the gondola, we were able to confirm we have enough room for each component. We will build the whole assembly during years 2 and 3. Once we have all components, it should take no more than a month to construct the entire assembly.

3.1.5 Verification and Validation Plans

Verification Tasks

- Balloon Helium Output
    - Test helium outputted using a helium gas test gauge
    - Calculate necessary helium output using balloon size, vehicle weight, and gravity and atmospheric pressure on Venus
        - If real output is greater than necessary output, continue
        - Else, disassemble the pump and find the issue. Repeat testing until pressure output reaches what is required.
- Instrument Operation Status
    - Test instruments by having them determine what quantity they were made for measuring on Earth in a test location.
        - If the instruments mounted on the vehicle show the right quantities found by other, more reliable instruments testing the same room, continue
        - Else, find what instruments are displaying incorrect information and fix or replace the instrument. Repeat this process until all instruments display the correct information.

- Balloon Functionality

- Test balloon by dropping from a height of 50km with mass similar to what the vehicle will weigh
  - If balloon opens and softens the landing to expected speed, continue
  - Else, reassess equations used to calculate what pressure would be needed to slow the balloon's fall. Test if pressure outputted while falling matches what needs to be released. Repeat this test until balloon hits the ground at expected velocity

- Balloon Mounts
  - Inspect balloon mounts before and after dropping from a height of 50km by using magnetic particle inspection
    - If balloon mounts/connectors pass inspection, continue
    - Else, replace mounts. Repeat this process until the balloon mounts pass inspection.

- Vehicle Shell Check
  - Inspect vehicle before and after dropping from a height of 50km by using magnetic particle inspection
    - If vehicle passes inspection, continue,
    - Else, replace the plate where cracks are found or weld cracks shut. Repeat 50km drop test until vehicle passes inspection

Validation Tasks

- Balloon Helium Output
  - Test helium output in a simulated environment with a range from -110°C to 110°C at 0.00002 bar to 2.03 bar, simulating a range of 100km above Venus's surface to 45km above Venus's surface
    - If real output is greater than necessary output, continue
    - Else, disassemble the pump and find the issue. Repeat testing until pressure output reaches what is required
- Ballon Strength
  - Test balloon tensile strength by fully filling and releasing balloon with helium in a test environment with temperatures at a range from -110°C to 110°C at 0.00002 bar to 2.03 bar
  - Inspect balloon to ensure there are no leaks, tears, or other issues
    - If balloon passes inspection, continue
    - Else, replace balloon and redo calculations to determine where the issue comes from. Repeat test and inspection until there are no rips or leaks

- Instrument Operations Status

        - Test instruments by having them determine what quantity they were made for measuring in a test environment with temperatures at a range from -10°C to 45°C at 0.00002 bar to 2.03 bar
            - If the instruments mounted on the vehicle show the right quantities found by other, more reliable instruments testing the same room, continue
            - Else, find what instruments are displaying incorrect information and fix or replace the instrument. Repeat this process until all instruments display the correct information
- Vehicle Shell Check
        - Inspect vehicle for cracks or deformities after other results in a test environment with temperatures at a range from -110°C to 110°C at 0.00002 bar to 2.03 bar have been completed
            - If vehicle passes inspection, continue
            - Else, replace the plate where cracks are found or weld cracks shut and change/strengthen the shell. Place back in test environment and retest until material no longer deforms
- Communications Check
        - Test whether information is being collected and relayed properly by the UHF antenna in a test environment with temperatures at a range from -110°C to 110°C at 0.00002 bar to 2.03 bar
            - If information is properly relayed, continue
            - Else, replace antenna and search for issue. Repeat test until information is properly relayed

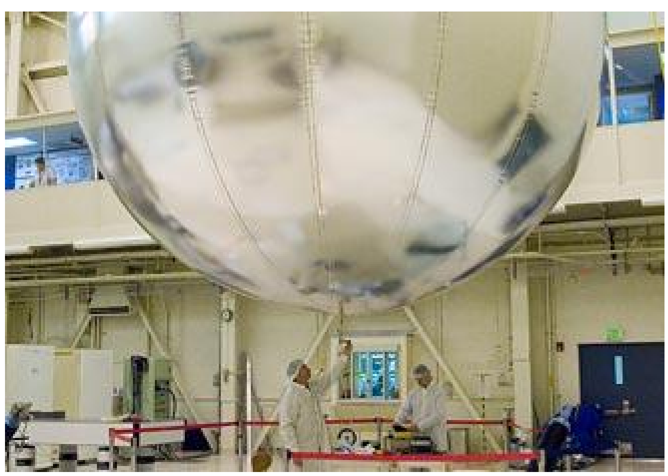


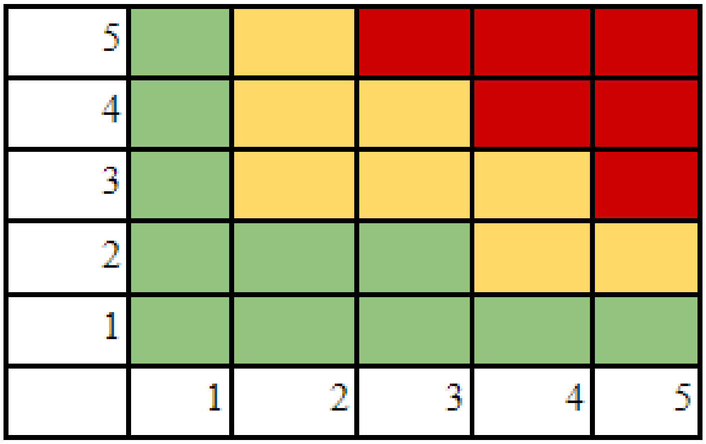
Fig. 27. Prototype Venus Balloon in JPL Cleanroom
Image credit: NASA/JPL-Caltech

3.1.6 Failure and Risk Mitigation

Risk mitigation and failure analysis are crucial parts of the BRAVE mission. A failure mode and effect analysis (FMEA) identifies risks and failure modes of the missions and actions that are used to mitigate said risks and failure modes of the descent and lander design. The FMEA is based on occurrence, severity, and mitigation. The “take action” section identifies what measures have been taken to mitigate the risk. The risk analysis chart assesses potential risks based on the likelihood and consequence of said risk. The consequences of the risks were analyzed off technical risks, scheduling risks, and cost risks. Each risk is monitored and updated by the sub-team leads and safety officer. High risks are monitored bimonthly, medium risks are monitored monthly, and low risks are monitored every 2 months.

ID	Summary	Occurrence	Severity	Trend	Approach	Risk Statement	Status
1	lander parachute not deployed	1	4	→	M	Lander parachute does not inflate	LOW
2	lander doesn't detach	1	4	→	M	Lander and vehicle stay together and the lander does not continue to the surface of Venus	LOW
3	vehicle parachute not deployed	2	4	↑	M	Failure of parachute inflation mechanism	LOW
4	vehicle parachute not detach	2	4	↑	M	Failure of parachute removal mechanism	LOW
5	balloon not inflated	3	4	↓	M	Helium tanks failure to inflate balloon	MED
6	balloon inflated partially	3	3	↓	M	Balloon over filled with helium	MED
7	balloon over inflated	2	3	↓	M	Balloon under filled with helium	LOW
8	balloon bursts	2	3	↓	M	Total corrosion of balloon and causes the balloon to no longer support vehicle	MED
9	cables attaching balloons break	3	4	NEW	M	Cables attaching to the balloon break	MED
10	balloon leaks	3	3	↓	M	Partial corrosion of balloon and causes the balloon to lose helium at the same rate helium is put into the balloon	MED
11	vehicle loses connection to earth	3	5	↑	R	Vehicle can no longer send data collected back to headquarters	HIGH
12	Shell deformation during entry or descent	3	1	→	W	Shell is no longer in original shape, instrument protection could be compromised	LOW
13	Balloon latch mechanism connecting breaks	2	4	→	M	Balloon latch connecting balloons to vehicle break causing the vehicle to not be attached to balloons	MED

Fig. 28. Risk Mitigation Chart for vehicle design and descent



Legend		
Criticality	**L x C Trend**	**Approach**
High	↓ Decreasing (Improving)	M - Mitigate
Medium	↑ Increasing (Worsening)	W- Watch
Low	→ Unchanged	A - Approach
	NEW	R - Research

Fig. 29. Risk Matrix

Likelihood	
Level (1-5)	**Probability**
5	Near certain to occur
4	Highly likely to occur
3	May occur
2	Unlikely to occur
1	Not likely

Fig. 30. Likelihood Scale

Consequences			
Level	Impact		
	Tehnical	Schedule	Cost
5	Death or major injury, loss to client or personnel, major systems, or vehicle during mission	Launch window will be missed	Cost overrun 50% of allotted budget
4	Severe injury or illness, minor loss to personnel or client, major systems, or vehicle during mission	Schedule impact causing launch date to be missed	Cost overrun 50% to 15% of allotted budget
3	Mild injury or illness, mild loss to personnel or client, minor systems, or vehicle during mission	Schedule impact greater than 1 week, no impact on launch window	Cost overrun 15% to 5% of allotted budget
2	Minor injury or illness, minor loss to personnel or client, minor systems, or vehicle during mission	Schedule impact > 1 week, no impact on launch window	Cost overrun 5% to 2% of allotted budget
1	No injury or illness, no impact to personnel or client, systems, or vehicle during mission	No effect to schedule	Cost overrun less than 2% of allotted budget

Fig. 31. Consequence Scale

Function Failure Modes and Effects Analysis															
Mission: Balloon Reconnaissance Atmospheric Venus Exploration															
System: Balloon System											**Action Results**				
Subsystem/ Component Name	**Potential Failure Modes**	**Potential Causes of Failure**	**Occurrence (1-5)**	**Potential Effects of Failure**	**Severity (1-5)**	**Mitigating Factors**	**Mitigation (1-5)**	**RPN**	**Recommended Actions**	**Department/ Individual Responsible & Completion Date**	**Actions Taken**	**Occurrence (1-5)**	**Severity (1-5)**	**Mitigation (1-5)**	**RPN**
Zero-Pressure Balloon	Failed to inflate	Pump malfunction	3	Balloon does not hold weight of gondola, gondola does not maintain proper altitude	4	Pre-flight checks	2	24	Inflation testing	Engineering Date Completed: May 5, 2023	Inflation testing	3	4	2	24
	Over inflated	Pump misreading pressure in balloon	2	Balloon pops, balloon no longer supports gondola, gondola fails to maintain proper altitude	3	Pre-flight checks	2	12	Inflation testing	Engineering Date Completed: May 5, 2023	Inflation testing	2	3	2	12
	Inflated partially	Pump misreading pressure in balloon	3	Balloon unable to hold gondola at proper altitude	3	Pre-flight checks	2	18	Inflation testing	Engineering Date Completed: May 5, 2023	Inflation testing	3	3	2	18
	Leaks	Tear in material due to venusian atmosphere	3	Balloon slowly looses pressure, gondola does not maintain proper altitude	3	Tensile strength tests on material	3	27	Further strength testing	Engineering Date Completed: May 5, 2023	Further strength testing	3	3	3	27
	Pops	Over inflation due to pump malfunction, tear in material due to venusian atmosphere	2	Balloon causes gondola to not maintain proper altitude	4	Tensile strength tests on material in venus like atmosphere	3	24	Further strength testing	Engineering Date Completed: May 5, 2023	Further strength testing	2	4	3	24
						Coating in aluminum and Teflon	2	16	Stress test coating	Engineering Date Completed: May 5, 2023	Stress test coating	2	4	2	16
	Incorrect size, smaller	Manufacturing error	2	Balloon inflation causes balloon to pop	2	Correct dimensions delivered to manufacture	1	4	Double check design	Manufacture & Engineering Date Completed: July 14, 2022	Double check design	2	2	1	4
	Incorrect size, larger	Manufacturing error	3	Balloon inflation causes balloon to pop super-pressure balloon,	3	Correct dimensions delivered to manufacture	1	9	Double check design	Manufacture & Engineering Date Completed: July 14, 2022	Double check design	3	3	1	9

				balloon does not inflate fully											
Super-Pressure Balloon	Failed to inflate	Pump malfunction	3	Balloon does not hold weight of gondola, gondola does not maintain proper altitude	4	Pre-flight checks	2	24	Inflation testing	Engineering Date Completed: May 5, 2023	Inflation testing	3	4	2	24
	Over inflated	Pump misreading pressure in balloon	2	Balloon pops, balloon no longer supports gondola, gondola fails to maintain proper altitude	3	Pre-flight checks	2	12	Inflation testing	Engineering Date Completed: May 5, 2023	Inflation testing	2	3	2	12
	Inflated partially	Pump misreading pressure in balloon	3	Balloon unable to hold gondola at proper altitude	3	Pre-flight checks	3	27	Inflation testing	Engineering Date Completed: May 5, 2023	Inflation testing	3	3	3	27
	Leaks	Tear in material due to venusian atmosphere	3	Balloon slowly loses pressure, gondola does not maintain proper altitude	3	Shielding using polyurethane	2	18	Strength test polyurethane coating	Engineering Date Completed: May 2, 2023	Strength test coating	3	3	2	18
	Pops	Over inflation due to pump malfunction, tear in material due to venusian atmosphere	2	Balloon causes gondola to not maintain proper altitude	4	Tensile strength tests and testing of material in venusian atmosphere like conditions	3	24	Strength test material	Engineering Date Completed: May 5, 2023	Strength test material	2	4	3	24
	Incorrect size, smaller	Manufacturing error	3	Balloon inflation causes balloon to pop, zero pressure balloon does not fit inside	3	Correct dimensions delivered to manufacture	1	9	Double check design	Manufacture & Engineering Date Completed: July 14, 2022	Double check design	3	3	1	9
	Incorrect size, larger	Manufacturing error	2	Balloon not fully inflated, does not support gondola	2	Correct dimensions delivered to manufacture	1	4	Double check design	Manufacture & Engineering Date Completed: July 14, 2022	Double check design	2	2	1	4
Balloon Pump	Failed to inflate balloons	Incorrect Pressure reading	3	Balloons cannot support gondola, gondola unable to maintain proper altitude	4	Pre-flight checks	2	24	Inflation testing	Engineering Date Completed: August 5, 2023	Inflation testing	3	4	2	24

	Leaks	Seal failure or corrosion	4	Balloons slowly loses pressure, gondola unable to maintain proper altitude	3	Test pump under vesuvian atmospheric like conditions	3	36	Weather testing	Engineering Date Completed: August 5, 2023	Weather testing	4	3	3	36
						Tensile strength test	3	36	Further strength testing	Engineering Date Completed: August 5, 2023	Further strength testing			3	36
Balloon Cables	Breakage	Corrosion in venusian atmosphere	2	Balloons disconnect from gondola, gondola unable to maintain proper altitude	4	Tensile strength test in venusian atmospheric like conditions	4	32	Further strength testing	Engineering Date Completed: August 5, 2023	Further strength testing	2	4	4	32
	Incorrect Length	Manufacturing error	3	Balloons too close or too far from gondola	3	Correct dimensions delivered to manufacture	1	9	Double check design	Engineering Date Completed: July 14, 2022	Double check design	3	3	1	9

Fig. 32. FMEA chart of balloon system

Mission: Balloon Reconnaissance Atmospheric Venus Exploration															
System: Gondola Vehicle											**Action Results**				
Subsystem/ Component Name	**Potential Failure Modes**	**Potential Causes of Failure**	**Occurrence (1-5)**	**Potential Effects of Failure**	**Severity (1-5)**	**Mitigating Factors**	**Mitigation (1-5)**	**RPN**	**Recommended Actions**	**Department/ Individual Responsible & Completion Date**	**Actions Taken**	**Occurrence (1-5)**	**Severity (1-5)**	**Mitigation (1-5)**	**RPN**
Parachute	Does not deploy	Latch failure	2	Parachute does not slow gondola, balloons unable to inflate quickly enough, failure of gondola to maintain proper altitude	4	Pre-flight check	2	16	Pre-flight check	Engineering	Pre-flight check Date Completed: October 5, 2023	2	4	2	16
	Tear in material	Toxic conditions of Venusian atmosphere, unsturdy material	3	Parachute unable to fully slow gondola down to necessary velocity, balloons unable to fully inflate	3	Tensile strength test in venusian atmospheric like conditions	3	27	Further strength and weather testing of material	Engineering	Further strength and weather testing of material Date Completed: October 5, 2023	3	3	3	27
	Does not detach	Latch failure, balloon failure	2	Balloons unable to inflate, gondola unable to maintain proper altitude	4	Pre-flight check	2	16	Pre-flight check	Engineering	Pre-flight check Date Completed: October 5, 2023	2	4	2	16
Shell	Deforms	Velocity of entry and descent, debris in atmosphere. toxic atmosphere conditions	3	Instrumentation deformation or breakage	1	Strength testing, Pre-flight checks, test carbon fiber under venusian atmospheric like conditions	4	12	Further strength and weather testing of material	Engineering	Further strength and weather testing of material Date Completed: October 5, 2023	3	1	4	12
	Breakage and loss	Toxic conditions of Venusian atmosphere, entry and descent velocity, debris in atmosphere	3	Instruments exposed to atmosphere	3	Strength testing, Pre-flight checks, test carbon fiber under venusian atmospheric like conditions	4	36	Further strength and weather testing of material	Engineering	Further strength and weather testing of material Date Completed: October 5, 2023	3	3	4	36

Gondola	Incorrect size, smaller	Manufacturing error	2	Instruments unable to fit	4	Correct dimensions delivered to manufacture	1	8	Double check design	Manufacture & Engineering	Double check design Date Completed: July 14, 2022	2	4	1	8
	Incorrect size, larger	Manufacturing error	2	Gondola is overweight, balloons cannot stabilize at proper altitude	4	Correct dimensions delivered to manufacture	1	8	Double check design	Manufacture & Engineering	Double check design Date Completed: July 14, 2022	2	4	1	8
	Connection to Earth lost	Toxic conditions in atmosphere, mechanism corrosion, mechanism breakage, weather in atmosphere	3	Failure to complete science requirements	5	Prioritize communication system by placing it most central in the gondola	3	45	Double check assembly and design	Engineering	Double check design Date Completed: July 14, 2022	3	5	3	45
						pre-flight checks	3	45	Pre-flight check	Engineering	Pre-flight check Date Completed: October 5, 2023			3	45
						daily check-ins during mission	3	45	Pre-flight check	Engineering	Pre-flight check Date Completed: October 5, 2023			3	45

Fig. 33. FMEA chart of gondola vehicle

Mission: Balloon Reconnaissance Atmospheric Venus Exploration																
System: Lander Vehicle											**Action Results**					
Subsystem/ Component Name	**Potential Failure Modes**	**Potential Causes of Failure**	**Occurrence (1-5)**	**Potential Effects of Failure**	**Severity (1-5)**	**Mitigating Factors**	**Mitigation (1-5)**	**RPN**	**Recommended Actions**	**Department/ Individual Responsible & Completion Date**	**Actions Taken**	**Occurrence (1-5)**	**Severity (1-5)**	**Mitigation (1-5)**	**RPN**
Lander	Failure to detach from gondola	Latch malfunction	1	Gondola unable to stay in atmosphere	4	Pre-flight checks	2	8	Pre-flight testing	Engineering	Pre-flight testing Date Completed: December 5, 2023	1	4	2	8
Lander Parachute	Failed to deploy	Latch malfunction	1	Lander and gondola unable to slow descent towards surface, gondola unable to stay in atmosphere	4	Pre-flight checks	2	8	Pre-flight testing	Engineering	Pre-flight testing Date Completed: December 5, 2023	1	4	2	8
	Tear in material	Toxic conditions of venusian atmosphere, unsturdy material	3	Lander and gondola unable to fully slow descent towards surface, failure of lander to release gondola at proper altitude	3	Test material under venusian like conditions, stress test material	3	27	Further strength and weather testing	Engineering	Pre-flight testing Date Completed: December 5, 2023	3	3	3	27

Fig. 34. FMEA chart of lander vehicle

Risk Priority Number (RPN)	
Number	**Status**
125-75	HIGH
74-45	MED
45-20	MED
19-10	LOW
9-1	LOW

Fig. 35. Risk Priority Number Scale

Mitigation Scale	
Level	Effect
5	Unable to mitigate
4	5% to 35% Probability the mitigation will be effective
3	35% to 65% Probability the mitigation will be effective
2	65% to 98% Probability the mitigation will be effective
1	>99% Probability the mitigation will be effective

Fig. 36. Mitigation Scale

3.1.7 Performance Characteristics and Predictions

3.1.7.1 Environment

BRAVE was designed to maximize performance while minimizing the risks posed by environmental hazards. BRAVE's teflon-coated balloon and carbon fiber gondola are highly resistant to corrosion from the sulfuric acid that is present in Venus's atmosphere. Venus's cloud layer has similar atmospheric conditions to Earth's atmosphere, so temperature and pressure will not be a concern. BRAVE's atmospheric probe will likely be subjected to high winds both during its descent and as it is collecting data, but BRAVE's two-balloon system will be able to dynamically adjust the height of the probe should it be pushed too high or too low. BRAVE's target launch date of December 1 means that it will arrive at Venus between late May and early June. However, Venus has no seasonal cycles, so there should be no seasonal weather conditions of concern. Overall, BRAVE should perform as expected on its mission.

3.1.7.2 EDL

To test and gain a rough estimate of the BRAVE lander under atmospheric pressure, density, and temperature within the altitude range of maximum deceleration and heat load, the EDL sequence until parachute deployment was simulated based on the Venus International Reference Atmosphere (VIRA) and curated Venus parameters by Goddard Space Flight Center. VIRA was used as it is the global standard for modeling the Venusian atmosphere based on Pioneer Venus and Venera Probe data.

Nomenclature	
Property and Units	**Symbol**
Atmospheric Density ($\frac{kg}{m^3}$)	ρ, where ρ_0 is at 0 *km*
Altitude (*km*)	z
Scale Height (*km*)	H, which is defined for 0 *km*
Gravity ($\frac{m}{s^{-2}}$)	g
Gravitational Parameter ($\frac{km^3}{s^2}$)	μ
Velocity ($\frac{m}{s}$)	v
Ballistic Coefficient ($\frac{kg}{m^2}$)	β
Mass (*kg*)	M
Cross-Sectional Area (m^2)	A
Drag (*N*)	D, which is opposite to the velocity vector
Drag Coefficient	C_D
Euler's Number	e

Fig. 37. Nomenclature Chart

The following formulae modeled the Venusian atmosphere through the properties of density and gravity:

$$\rho = \rho_0 e^{\frac{-z}{H}}$$

$$g = \frac{\mu}{(r+z)^2}$$

Displayed below are each property's respective gradients for each altitude. The red-dashed lines denote the range of science operations:

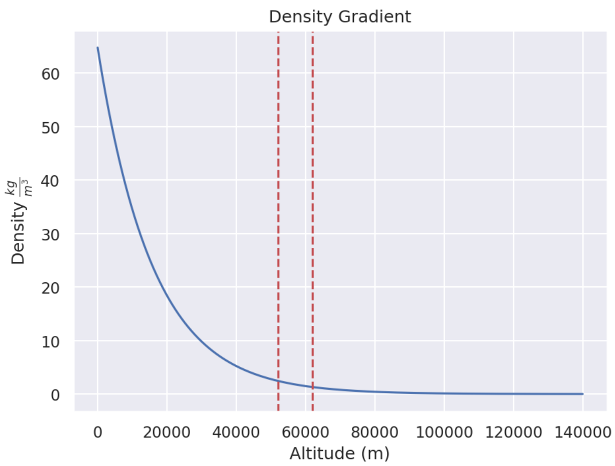


Fig. 38. Density Gradient

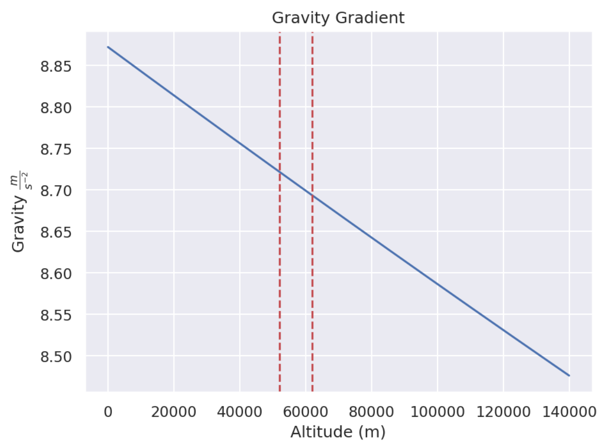


Fig. 39. Gravity Gradient

$D$is given by the following:

$$D = \frac{\frac{1}{2}\rho v^2}{\beta}$$

$\beta$is given by the following:

$$\beta = \frac{M}{C_D A}$$

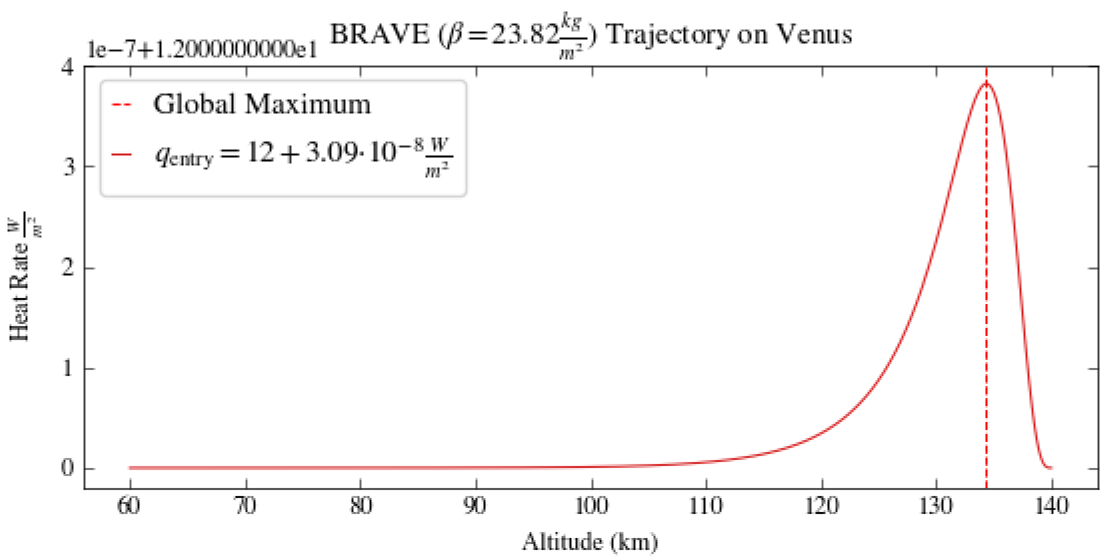
where $\beta_{lander} = 24.09\ \frac{kg}{m^2}$, $M = 174.434684398\ kg$, and $A = 7.24\ m^2$.

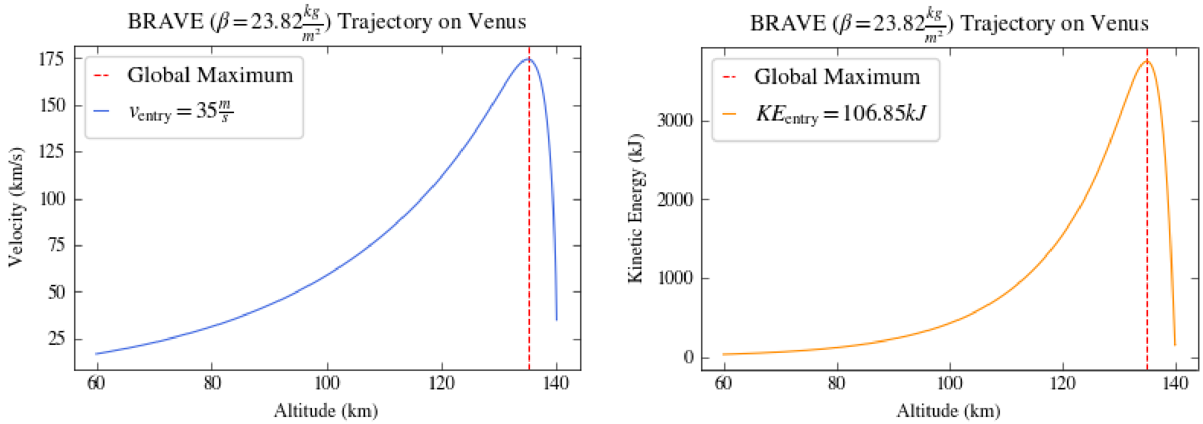
A was calculated by adding both the cylindrical tube and rectangular tube portions. Because C_D is usually determined experimentally, for the sake of estimation, it was considered to be 1 based on the BRAVE lander's largely cylindrical shape as past research and tests on the drag coefficient have determined it, on average, to be approximately 1 [Heddleson et al., 1957; Brusch et al., 2003].

The initial conditions of the BRAVE lander were at an altitude of 140 km above the surface at a downward velocity of 35$\frac{m}{s}$. The lander was determined to achieve an instantaneous downward velocity of 16.79 $\frac{m}{s}$at the nominal altitude of 60 km before deploying the parachute. The entire sequence takes 1764.7 seconds, which is around a half-hour. The parachute is deployed to reach a safe landing speed of 8.9408 $\frac{m}{s}$ (20$\frac{mi}{hr}$) or less. The following formulae was derived from an analysis of the approximate stagnation point radiative heat rate for the Pioneer-Venus landers during entry [Tauber et al. 2012]. It was used to calculate the heat load ($\frac{W}{m^2}$) during EDL for the BRAVE lander for certain velocities and atmospheric densities; all variables use the MKS (meter, kilogram, second) system:

$$q = 2.195 \times 10^{-22} v^{7.9} \rho^{1.2} r^{0.49} \quad \frac{W}{m^2}$$

The following are all the trajectories of radiative heating rate, velocity, and kinetic energy, respectively:





Figs. 40-42. BRAVE trajectory of radiative heating rate, velocity, and kinetic energy.

EDL Statistics	
Property and Units	**Value**
Maximum Velocity ($\frac{m}{s}$)	175.08
Maximum Heat Rate ($\frac{W}{m^2}$)	16.97
Maximum Kinetic Energy (kJ)	3780.86
Altitude of Maximum Heating Rate (km)	134.32
Altitude of Maximum Velocity and Kinetic Energy (km)	134.96
Initial Velocity ($\frac{m}{s}$)	35
Final Velocity ($\frac{m}{s}$)	16.79
Initial Altitude (km)	140
Final Altitude (km)	60
Initial Kinetic Energy (kJ)	105.849
Final Kinetic Energy (kJ)	24.59
Elapsed Time (s)	1754.9

Fig. 43. EDL Statistics Chart

3.1.8 Confidence and Maturity of Design

The BRAVE vehicle has experienced numerous iterations and analyses. Conditions to which it will be exposed have been found, and its design tweaked to provide the best, most cost-effective vehicle possible, while still providing invaluable data concerning conditions on Venus. The vehicle will undergo rigorous testing before beginning its mission.

Initially, several vehicle types were considered, a balloon, a glider, or a rocket. The glider presented the advantage of maneuverability and would be able to be flown to any coordinate point above Venus. However, due to the very high cost and weight, it was not proven to be feasible, and a balloon vehicle was chosen. A balloon-powered vehicle could be a simple balloon, calibrated to float above Venus at a fixed altitude, or a variable-altitude balloon. The variable-altitude balloon was chosen, as it gave the advantage of taking valuable science from different points in the Venusian atmosphere, between 52 and 62 kilometers above the surface. The balloon design chosen contained a super-pressure balloon held inside a zero-pressure balloon. After being decided, this design did not change.

The gondola, which was to hang from the balloon and carry all science components went through a redesign. Initially, the gondola was to be two hollow cylinders of different diameters with hexagonal cross-sections stacked (Figure 5). This design presented the problem of holding all science components in the same chamber as helium tanks necessary for primary inflation of the balloons. The redesigned gondola had a cylindrical chamber for the helium tanks and balloons and a platform underneath for science components (Figure 7). This allowed for the components to have access to the atmosphere, which was necessary for many components, especially the panoramic cameras. Science components did not change after initially being chosen.

To determine the appropriate entry profile of the vehicle, calculations were performed, keeping in mind the relative fragility of the balloon. Determination of balloon construction and the material was heavily informed by previous studies, especially with regards to buoyancy in relation to volume and material [Hall et. al, 2019].

The vehicle will undergo rigorous testing before the mission to determine the integrity of its design. Planned tests include repeated tests of the helium pump, tests of all instruments in an earth environment, a drop test of the system to ensure safe inflation of the balloon and structural integrity of all mechanical components, and magnetic particle inspection of mechanical components after testing. Predetermined results will conclude success or failure after these tests, which could lead to alterations of design.

Failure and risk mitigation has been performed for the mission using failure mode and effect analysis. Risks have been outlined, categorized by severity and likelihood. All precautions will be taken with the mission, but it is impossible to completely ensure success. Still, there is high confidence in the design of the BRAVE vehicle and the success of the mission.

3.2 Recovery/Redundancy System

Connection to Earth is the most vital system/tool:

- Panoramic Cameras - 2 cameras able to see 180°. If one is disabled, the vehicle must rotate to see.
- Double every sensor except panoramic cameras.
- 4 UHF transceivers to ensure constant connection to Earth.

Having a backup balloon is vital to the success of the mission. A secondary identical balloon is recommended with a separate release system to ensure mission success should the primary balloon fail. This emergency balloon system will act as an independent system to the main balloon, to account for failures in the primary balloon, latch release system, gas fill release, and/or sensors.

Extra shielding on the instruments can ensure that should the system experience significant turbulence, the sensitive instruments will be protected and able to function as normal. Backup instrumentation could also be a suggestion should the budget allow

3.3 Payload Integration

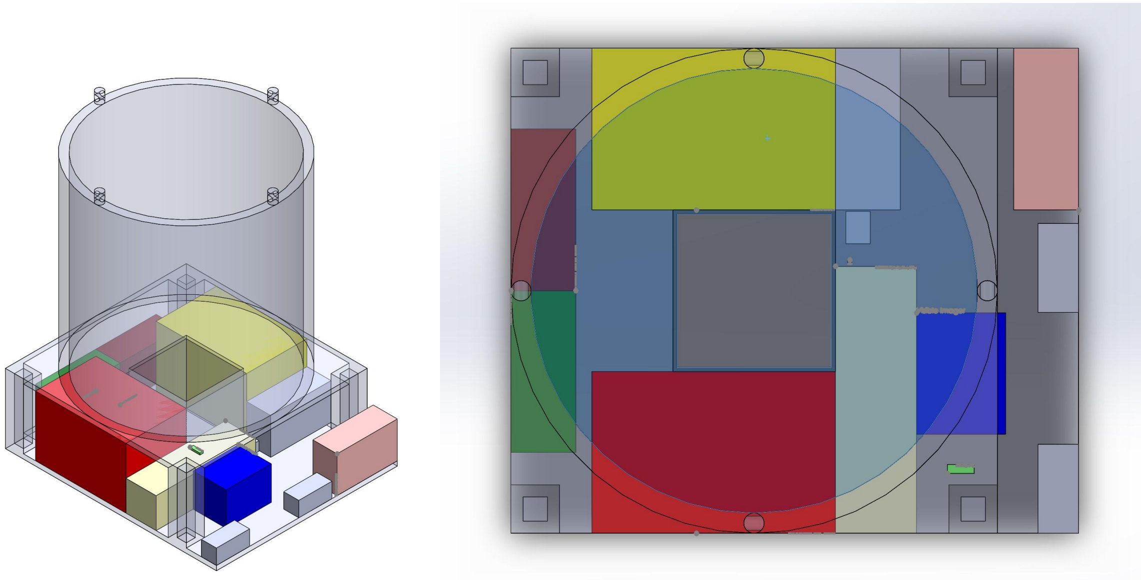
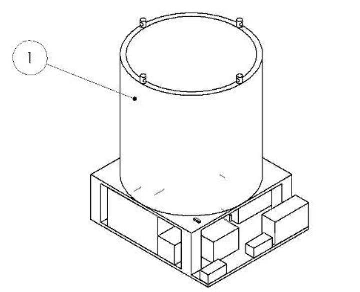


Fig. 44. Science Components Integrated into Vehicle System

ITEM NO.	PART NUMBER	QTY.
1	Gondola	1
2	3D Anemometer	1
3	Radiometer	1
4	Temperature Sensor	1
5	Barometric Pressure Sensor	1
6	Fluorimetric Microscope	1
7	AMS	1
8	Nephelometer	1
9	Magnetometer	1
10	Ultra High Frequency Transceiver	1
11	Sun Sensor	1
12	Visible Imager	1
13	Pancam	2



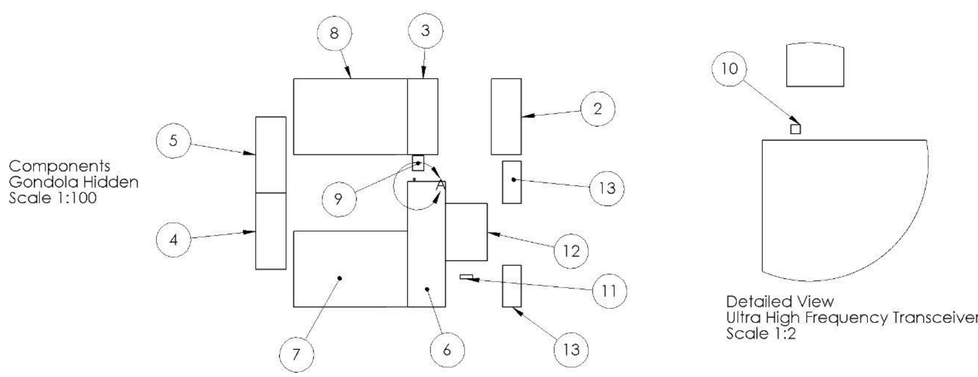


Fig. 45. Science Components in System, Labeled

All instrumentation will be placed at the bottom of the vehicle and will be connected by a multi-interface card. The network interface controller allows for interoperability while reducing non-recurring engineering, therefore reducing the risk of misinterpretation across receiving systems. Components are connected at nodes and cross-communication is time-triggered through a pre-programmed algorithm as a safety precaution and ability to detect communication failure. Components are attached according to heat dissipation with sufficient spacing in place to prevent overheating and potential frying of the controller. The layout also allows instruments such as the radiometer and sun sensor access to the sun, which is necessary for the instruments to operate. Other instruments such as the nephelometer and aerosol mass spectrometer have access to the air.

4. Payload Design and Science Instrumentation

4.1 Selection, Design, and Verification

4.1.1 System Overview

Atmospheric Unit (Instruments)		Gathers telemetry	Provide raw measurement data	Instruments generate heat	
Sets locations for all measurements	**Altitude Control (Balloon-in-a-Balloon)**				
Measurement procedures	Set altitudes at commanded profiles	**Command & Data Handling**	Transmission commands	Processor generates heat	
			Communications	Transceivers generate heat	
Regulate temperatures for instruments		Regulate temperatures for processor and board	Regulate temperatures for transceivers	**Thermal**	Regulate solar panel and battery temperatures

Power instruments (54.1 W)		Power processor and board (>1W for chip, ~3W for board peripherals)	Power 4 UHF transceivers (5.6 W total)	Power radiator	**Power**

Fig. 46. System overview flow chart

The above N^2 matrix shows the functional interactions between all subsystems necessary for mission operations. The arrows represent a relationship between two systems and are accompanied by a description of their connection.

4.1.2 Subsystem Overview

4.1.2.1 Atmospheric Unit

The atmospheric unit consists of a suite of instruments to measure atmospheric parameters, including an aerosol mass spectrometer and nephelometer to assess the chemical composition and cloud droplet deposition, panoramic cameras to gain a 360° spectral view of the atmosphere, a radiometer to measure solar rays in the cloud tops, a temperature sensor, a pressure sensor, and a 3-D anemometer to measure vertical wind speeds.

4.1.2.2 Altitude Control

A balloon-in-a-balloon design is used where a helium zero-pressure balloon is the outer chamber with a pressure approximately equal to the atmosphere and a super-pressure balloon of constant volume and higher pressure is the inner chamber. Helium pumps from the outer chamber to the inner chamber to lower buoyancy and thus altitude, and vice versa for raising altitude. The system is entirely closed to prevent sulfuric acid aerosols from entering any chamber.

4.1.2.3 Command and Data Handling

To allow commands for the lander to be guided, navigated, and controlled especially in the case of an emergency, the gondola uses an ARM Cortex-M4 processor with operations scheduled in advance for autonomy during the mission. Data is packetized and transmitted to the main lander and Earth through the NASA Deep Space Network. The data storage rate is 2000 mbits, with a housekeeping data rate of 2 kbps, a maximum storage playback rate of 30000 kbps, and 2 Gbits of total data storage.

4.1.2.4 Communications

The payload includes four ultra-high-frequency transceivers to ensure constant communication with the main lander and Earth. They are manufactured by EnduroSat, a vendor with a high heritage for providing communication modules for NASA missions. The transceivers have a frequency range of 400 - 403 MHz or 430 - 440 MHz and a sensitivity of up to -121 dBm.

4.1.2.5 Thermal

To minimize heat to the payload, a thermal radiator is mounted by the house of instruments at the bottom. To maximize solar ray reflection for minimizing heat to the payload, the radiator is painted white.

4.1.2.6 Power

The lander relies on a static mounted solar array consisting of six panels.

4.1.3 Manufacturing Plan

Each of our scientific instruments will be Commercial-Off-The-Shelf instruments. Our balloon will also be Commercial Off-The-Shelf. We will manufacture the gondola in-house ourselves. We will use our 3D printer, 400 SERIES WORKBENCH XTREME 3D PLATFORM, to print our gondola, which will be made from carbon fiber. We will contact the companies about the components to find out how long it will take to get each component, allowing us to plan. We will make sure we get each component with adequate time to finish the project.

4.1.4 Verification and Validation Plan

The Pancam's Mast Assembly allows the camera to sweep a full 360 degrees to obtain a panoramic view. The verification plan entails testing this panoramic ability of the camera. The Pancam will be allowed to make a full sweep image capture by swinging up and down 180 degrees on the PMA. If the picture fails to be taken (i.e. there is no image data, the image data is corrupted or unreadable, etc.) then troubleshooting will occur to find the cause of the issue. The Pancam also has multiple image filters to allow for multispectral imaging capabilities. Images will be taken for each filter on the Pancam's filter wheel to test the efficacy of the filters.

The Aerosol Mass Spectrometer will be tested in environments where C, H, N, O, P, and S elements are present to test the efficacy of measurement of this instrument.

The nephelometer will be tested in an environment with a known concentration of elements suspended in a gas cloud to test its ability to measure the shape, size, refractive index, and concentration of the element.

The barometric pressure sensor will be tested in environments of low and high pressures to ensure it can measure properly in any situation.

The temperature sensor will be tested in hot and cold environments to ensure it can measure properly in any situation.

The radiometer will be subjected to electromagnetic radiation of a known amount to ensure its measurements are accurate.

The 3D anemometer will be tested with wind speeds of varying directions to ensure it can measure turbulence with accuracy.

The sun sensor will be tested in the presence of the sun and not in the presence of the sun to verify that the sensor can detect the sunlight appropriately. It will also be tested at different angles relative to the sun to ensure that the sun sensor can properly measure the angle of the sun.

The visible imager will be verified by taking images and ensuring the image file is sufficient (i.e. not corrupted, contains all image data, not a black screen, etc.)

The magnetometer will be verified by being tested in the presence of magnets of varying strength to ensure proper measurements by the instrument.

The ultra-high frequency transceiver will be verified to ensure it can transmit and receive data properly and that its firmware is up-to-date.

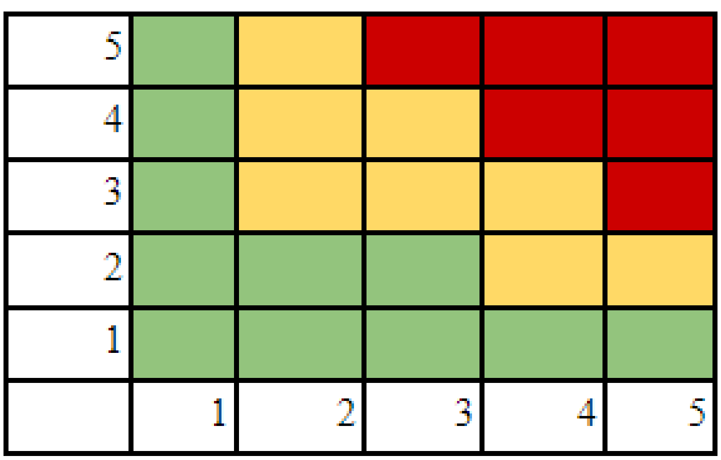
The inertial measurement unit will be tested at varying orientations to verify it can measure the body's specific force, angular rate, and orientation in different scenarios.

4.1.5 FMEA and Risk Mitigation

Further risk mitigation and FMEA were developed for the scientific instruments and payload of BRAVE. The FMEA is based on occurrence, severity, and mitigation. The risk analysis chart is based on the likelihood and consequence of the risks. The consequences of the risks were analyzed off technical risks, scheduling risks, and cost risks. Each risk is monitored and updated by the sub-team leads and safety officer. High risks are monitored bimonthly, medium risks are monitored monthly, and low risks are monitored every 2 months.

ID	Summary	Occurrence	Severity	Trend	Approach	Risk Statement	Status
1	Scientific instrument failure	5	2	→	M	Instruments fail to collect data	MED
2	Panoramic camera failure	5	3	↓	M	One or both of panoramic cameras fail to function	HIGH
3	Data scrambled on way back to earth	4	1	↓	R	Data is not properly transmitted to Earth	LOW
4	Atmospheric weather causes power loss	4	5	→	A	Vehicle loses power due to unforeseen atmospheric conditions	HIGH
5	Instruments damaged during entry or descent	3	2	↓	M	Instruments nonfunctional or partial functional after entry or descent	LOW
6	Delay in communication time	5	1	↓	A	Receiving and transmission requires more time than initially determined	LOW

Fig. 47. Risk Mitigation Chart



Legend		
Criticality	L x C Trend	Approach
High	↓ Decreasing (Improving)	M - Mitigate
Medium	↑ Increasing (Worsening)	W- Watch
Low	→ Unchanged	A - Approach
	NEW	R - Research

Fig 48. Risk Matrix

Likelihood	
Level (1-5)	**Probability**
5	Near certain to occur
4	Highly likely to occur
3	May occur
2	Unlikely to occur
1	Not likely

Fig. 49. Likelihood scale

Consequences			
Level	Impact		
	Tehnical	Schedule	Cost
5	Death or major injury, loss to client or personnel, major systems, or vehicle during mission	Launch window will be missed	Cost overrun 50% of allotted budget
4	Severe injury or illness, minor loss to personnel or client, major systems, or vehicle during mission	Schedule impact causing launch date to be missed	Cost overrun 50% to 15% of allotted budget
3	Mild injury or illness, mild loss to personnel or client, minor systems, or vehicle during mission	Schedule impact greater than 1 week, no impact on launch window	Cost overrun 15% to 5% of allotted budget
2	Minor injury or illness, minor loss to personnel or client, minor systems, or vehicle during mission	Schedule impact > 1 week, no impact on launch window	Cost overrun 5% to 2% of allotted budget
1	No injury or illness, no impact to personnel or client, systems, or vehicle during mission	No effect to schedule	Cost overrun less than 2% of allotted budget

Fig. 50. Consequence scale

Function Failure Modes and Effects Analysis																
Mission: Balloon Reconnaissance Atmospheric Venus Exploration																
System: Scientific Instruments payload												Action Results				
Subsystem/ Component Name	Functions	Potential Failure Modes	Potential Causes of Failure	Occurrence (1-5)	Potential Effects of Failure	Severity (1-5)	Mitigating Factors	Mitigation (1-5)	RPN	Recommended Actions	Department/ Individual Responsible & Completion Date	Actions Taken	Occurrence (1-5)	Severity (1-5)	Mitigation (1-5)	RPN
Pancam 1	Panoramic multispectral images to asses composition and properties of atmosphere	Pancam 1 instrumentation failure	Exposure to toxic atmosphere	5	Unable to take full 360° multispectral images	3	Second Pancam installed	2	30	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	5	3	2	30
		Instrumentation failure of both fancams	Exposure to toxic atmosphere	3	Unable to take multispectral images	4	Non-exposed parts coated in corrosion resistant material	3	36	Pre-flight checks of coating	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	4	3	36
Pancam 2	Panoramic multispectral images to asses composition and properties of atmosphere	Pancam 2 instrumentation failure	Exposure to toxic atmosphere	5	Unable to take full 360° multispectral images	3	Second Pancam installed	2	30	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	5	3	2	30
AMS	Measure composition of carbon, hydrogen, nitrogen, oxygen, phosphorus, sulfur	AMS instrument failure	Exposure to toxic atmosphere	3	AMS unable to take measurements of carbon, hydrogen, nitrogen, oxygen, phosphorus, sulfur	3	Second AMS installed	3	27	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	3	3	27
		AMS failure to find life-sustaining elements	Life-sustaining elements no longer in venusian atmosphere	3	Change of mission objectives	5	Unable to mitigate	5	75	Unable to take action	Monitored by science	Unable to take action	3	5	5	75
Neph	Measure light scattered from cloud droplets and aerosols to determine shape, size, and	Neph instrumentation failure	Exposure to toxic atmosphere	3	Neph unable to take light measurements	3	Second Neph installed	3	27	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	3	3	27

	refractive index															
BPS	Detect infrasound to measure seismicity	BPS instrumentation failure	Exposure to toxic atmosphere	2	BPS unable to detect infrasound and unable to measure seismicity	4	Second BPS installed	3	24	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	2	4	3	24
TS	Assess convective stability of atmosphere	TS instrumentation failure	Exposure to toxic atmosphere	2	TS unable to access convective stability	4	Second TS installed	3	24	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	2	4	3	24
Rad	Measure upward and downward solar fluxes as a function of altitude	Rad instrumentation failure	Exposure to toxic atmosphere	3	Rad unable to measure solar fluxes	3	Second Rad installed	3	27	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	3	3	27
3DA	Measure wind velocity and turbulence	3DA instrumentation failure	Exposure to toxic atmosphere	2	3DA unable to measure wind velocity a turbulence	4	Second 3DA installed	3	24	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	2	4	3	24
FM	Analyze cloud droplets for traces of biosignatures associated with past or present life	FM instrumentation failure	Exposure to toxic atmosphere	3	FM unable to analyze cloud droplets for biosignatures	4	Second FM installed	3	36	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	4	3	36
		FM unable to find biosignatures	Biosignatures no longer in venusian atmosphere	3	Change of mission objectives	5	Unable to mitigate	5	75	Unable to take action	Monitored by Science	Unable to take action	3	5	5	75
SS	Measure effects of sun's position on sustainability of Venus	SS instrumentation failure	Exposure to toxic atmosphere	2	SS unable to measure sun position	5	Second SS installed	3	30	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	2	5	3	30
VI	Take images of balloon and atmosphere	VI instrumentation failure	Exposure to toxic atmosphere	3	VI unable to take images	2	Second VI installed	2	12	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	2	2	12
Mag	Delineate magnetic field strength and topology	Mag instrumentation failure	Exposure to toxic atmosphere	3	Mag unable to delineate magnetic field strength	3	Second Mag installed	3	27	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	3	3	27

					and topology											
UHF-T	Send images and measurements from vehicle to Earth	UHF-T instrumentation failure	Exposure to toxic atmosphere	3	UHF-T unable to send images and measurements to Earth	5	UHF-T located centrally of gondola	3	45	Pre-flight checks of location	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	5	3	45
							Four UHF-T installed	2	30	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation			2	30
IMU	Estimates altitude of vehicle	IMU instrumentation failure	Exposure to toxic atmosphere	3	IMU unable to estimate altitude	4	Second IMU installed	3	36	Pre-flight checks of installation	Engineering Date completed: October 1, 2023	Pre-flight checks of installation	3	4	3	36
Thermal Radiator	Minimize heat to payload	Thermal Radiator failure to expel heat	Design malfunction	2	Overheating of scientific instrument payload, instrumentation failure	4	Pre-flight checks	3	24	Thermal testing pre-flight	Science Date completed: September 1, 2023	Thermal testing pre-flight	2	4	3	24
			Exposure to toxic atmosphere	3	Overheating of scientific instrument payload, instrumentation failure	4	Painted white	2	24	Thermal testing pre-flight	Science Date completed: September 1, 2023	Thermal testing pre-flight	3	4	2	24
Solar Rays	Power source of BRAVE	Failure of solar rays to intake sunlight and convert to energy	Design malfunction	2	BRAVE rendered powerless and unable to function	5	Two backup 300 Ah Li-ion batteries	2	20	Testing of solar rays and backup batteries pre-flight	Science Date completed: September 1, 2023	Testing of solar rays and backup batteries pre-flight	2	5	2	20
			Exposure to toxic atmosphere	3	BRAVE rendered powerless and unable to function	5	Two backup 300 Ah Li-ion batteries	2	30	Testing of solar rays and backup batteries pre-flight	Science Date completed: September 1, 2023	Testing of solar rays and backup batteries pre-flight	3	5	2	30

Fig. 51. FMEA chart of Scientific Instrument Payload

Risk Priority Number (RPN)	
Number	**Status**
125-75	HIGH
74-45	MED
45-20	MED
19-10	LOW
9-1	LOW

Fig. 52. Risk Priority Number Scale

Mitigation Scale	
Level	**Effect**
5	Unable to mitigate
4	5% to 35% Probability the mitigation will be effective
3	35% to 65% Probability the mitigation will be effective
2	65% to 98% Probability the mitigation will be effective
1	>99% Probability the mitigation will be effective

Fig. 53. Mitigation Scale

4.1.6 Performance Characteristics

The tolerances of BRAVE and its payload must be sufficient to minimize risk to hardware failure during the mission. The failure of any piece of equipment could jeopardize the mission. Each component in the payload must be tested thoroughly to ensure it can withstand the conditions of Venus's atmosphere as well as the changes in pressure, acceleration, and vibrations during the mission. The Pancam has been used on the Mars Exploration Rover (MER) project and was thoroughly tested to withstand those conditions per the Pancam Calibration Plan. This camera was field-tested in the Atacama Desert and Iceland to ensure that the instrument can perform in fairly extreme conditions. Due to Venus' atmosphere and the sensitive nature of the Pancam's lens, a housing is required for this instrument to prevent damage to the camera array.

The aerosol mass spectrometer and nephelometer have been used in similar endeavours such as the NASA Airborne Science program, and have been mounted on aircraft that reach elevations of 42,000 ft. in Earth's atmosphere. Since Venus's atmosphere is fairly similar to Earth's atmosphere in terms of temperature and pressure, these instruments will be suited for the mission.

Any instrument that does not require direct contact to the atmosphere such as the radiometer, sun sensor, magnetometer, ultra-high frequency transmitter, and the inertial measurement unit will be housed to proactively protect the instruments from potential damage during the mission.

4.2 Science Value

4.2.1 Science Payload Objectives

The scientific goal of the BRAVE mission is to scout the Venusian atmosphere for signs of life and sustainability to address the lack of incomplete information on its diverse planetary conditions. This will be achieved through assessing the chemical composition of the cloud tops, interactions between both solar and thermal radiation fields, temperature, pressure, wind velocities, and solar heating rate with respect to the altitudes at which the lander takes measurements with the atmospheric suite.

Venus is of significant interest to the understanding of habitability on extraterrestrial planets due to its size and orbit being a unique and insightful comparison for the history of evolution on Earth and Earth-size planets. Past models of the planet prove this by highlighting a loss of substantial amounts of water during its history shown in its atmospheric D/H ratio, with some studies going as far as to provide evidence for ice crystals formed at the cloud tops, the current existence of water vapor, and past oceans spanning several billion years [Taylor et al., 2018; Bottem et al., 1965]. It is theorized by many that the past habitability of Venus diminished to its current state due to rampant climate change from an intense runaway greenhouse effect [Pollack, 1971; Pollack et al., 1980; Bullock and Grinspoon, 2001; Ingersoll, 1969; Kasting, 1988]. If there is or once was water in the cloud tops, when considering the prerequisites for photosynthesis: water, carbon dioxide, and sunlight, as well as evidence for the existence of these factors, a past or even current presence of indigenous biology housed in the clouds, seems possible, especially with the presence of microbes in the atmosphere of Earth [Morowitz and Sagan 1967, Delort and Amato, 2017]. When considering this current knowledge on the planet, Venus was likely as habitable as modern Earth. Since Venus is the most accessible instance of an end-state habitable Earth-size planet, studying its entire past up to its current state would provide rich data of the network of interactions and steps required to create and maintain habitable worlds. It can also extend to inform us on the evolution of the solar system in relation to Earth, including the origin of the Earth's volatiles, the formation of Earth's water, and the storage of Earth's water as a result of tectonics. Moreover, studying the effects of climate change on Venus will provide us information on possibly treating and preventing it on Earth.

To fulfill the mission's scientific goal of scouting the Venusian atmosphere for signs of life and sustainability, the payload must complete the following objectives:

4.2.1.1 Determine the chemical composition of the cloud tops through measuring isotopic ratios of elements, including carbon, hydrogen, oxygen, phosphorus, sulfur, and noble gases to trace oceanic and atmospheric history, signs of sustainability, and reservoirs of volatiles.

4.2.1.2 Provide local atmospheric context through 360° stereo panoramic imagery and an inertial measurement unit to correlate all measurements with position in the atmosphere.

4.2.1.3 Trace tectonic history by characterizing the interplanetary magnetic field, residual crustal magnetic field, and included magnetic field.

4.2.2 Creativity/Originality and Significance

Venus has remained largely unexplored compared to celestial bodies like Mars or the moon, which only distances humanity further from the opportunity of studying an end-state Earth-size planet which was most likely once habitable. To understand all planetary environments which could support life and yield detectable biosignatures, models with maximized detail and completion are a must.

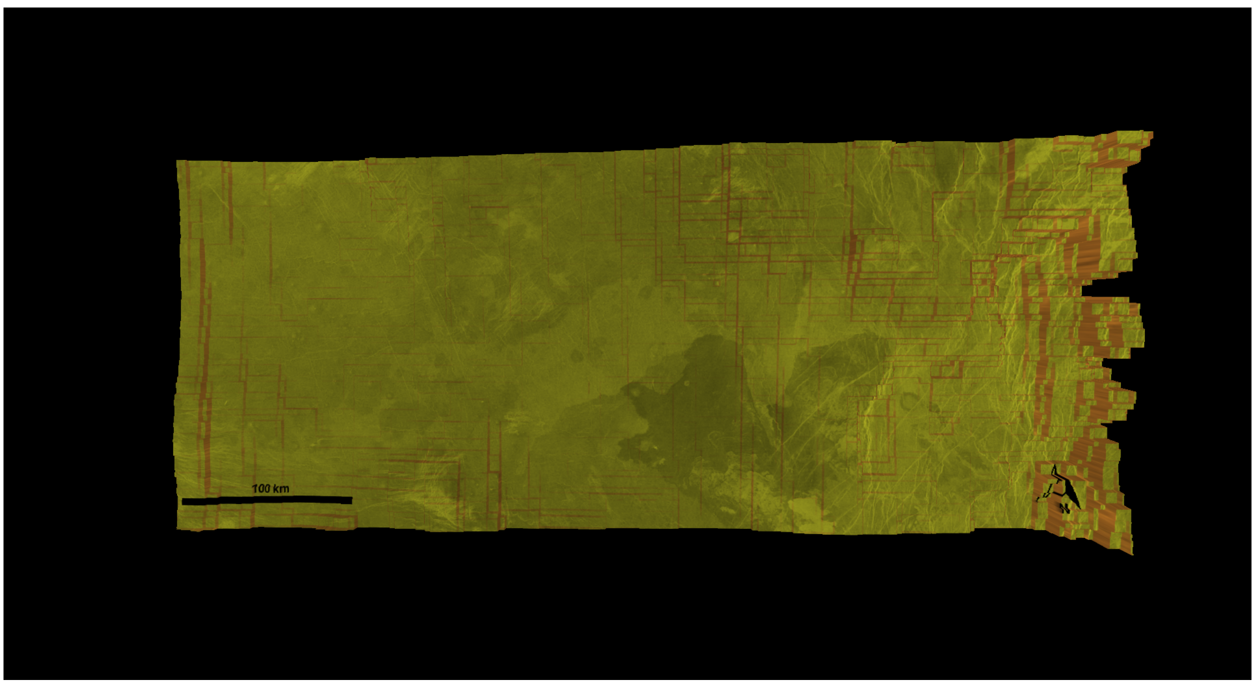
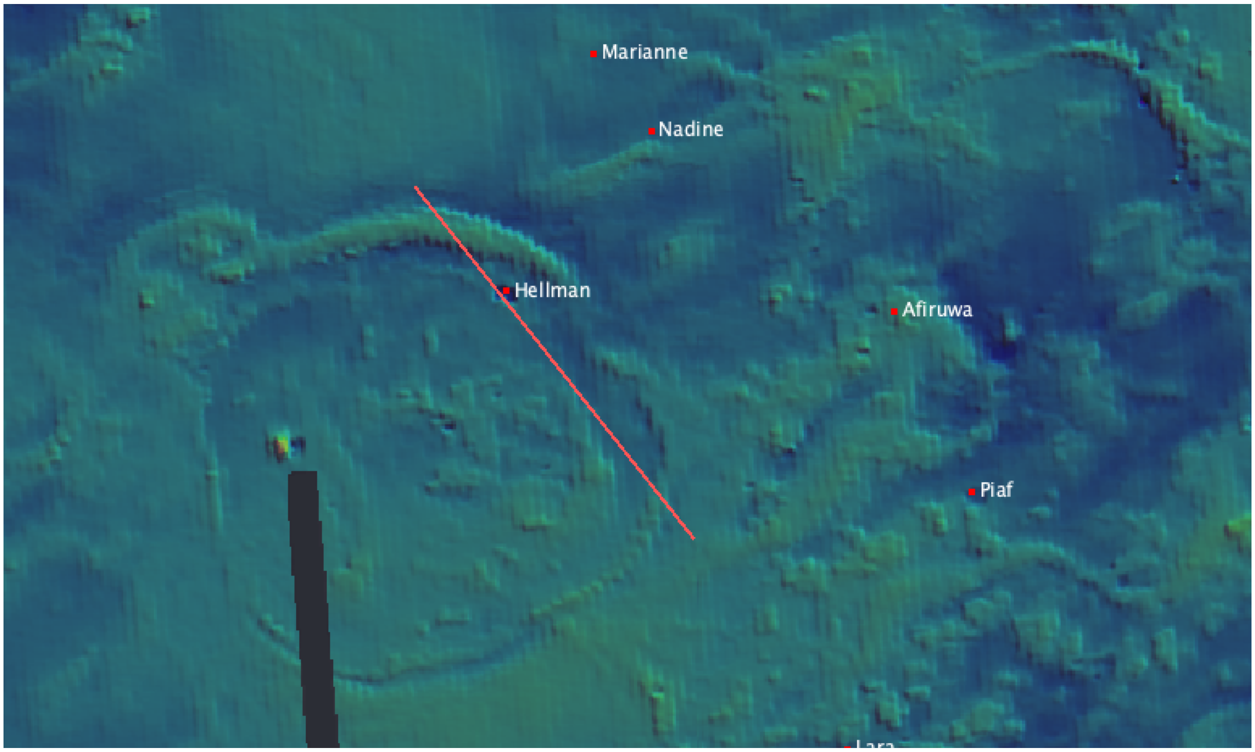
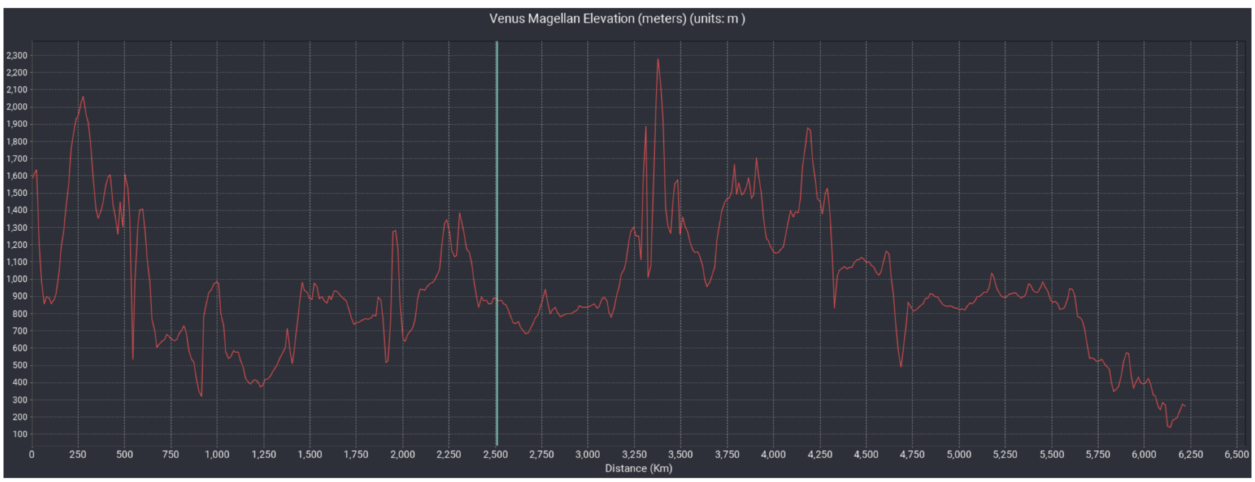


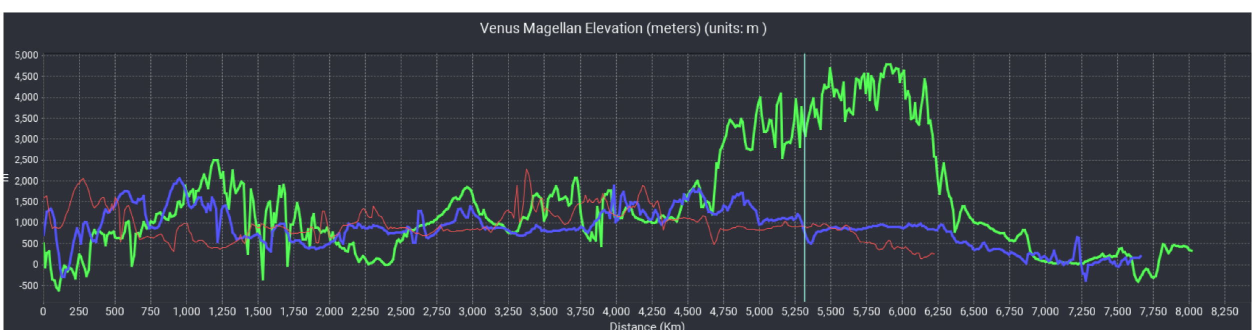
Fig. 54. Elevation map of an area within Ovda Regio at 5°N, 75°W.

Depicted above is Ovda Regio, the landing site for the BRAVE mission. Although the coverage of the area will be largely dynamic, Z3nith chose this site for initial measurements specifically because of its uniquely high elevation. This causes tremendous gravitational waves which reach into the upper atmosphere and affect wind velocities, of which are great important to understanding the uniqueness of the planet and the effect of these disturbed wind patterns on its sustainability both in its past and present. Additionally, the high elevation in this region minimizes the effects of the atmosphere by increasing the upwelling radiation by increasing the amount of downwelling radiation reaching the surface which is reflected. Moreover, the amount of upwelling radiation dissipates due to the detectors is decreased.and hence increasing the upwelling radiation. [Amato et. al, 2020; Moroz, 2002; Knicely & Herrick, 2019].

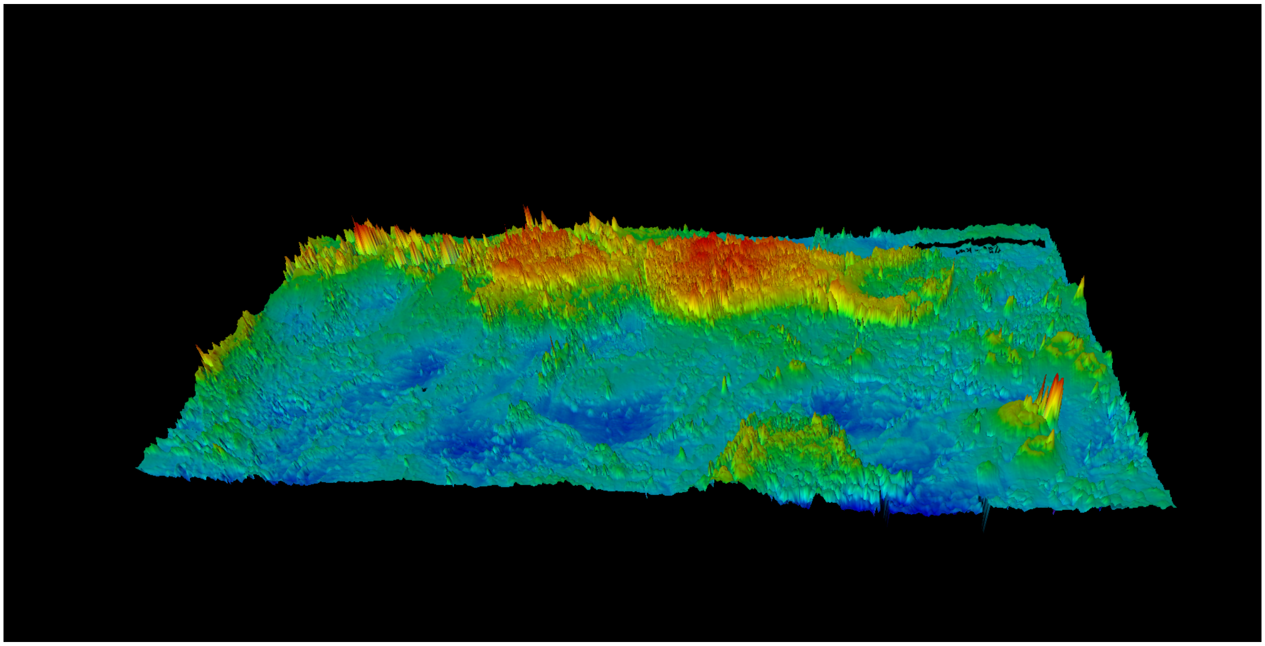
Below are various further representations of Ovda Regio in regions outside of the landing site:







	Profile Line	Value	Distance	Latitude	Longitude	Color	Remove
	Profile 1 (10°N, 49.875°E) (10°N, ..	901.706 m	5,318.55 km	10	101.085		
	Profile 2 (10°N, 43.375°E) (10.125.	774.464 m	5,318.55 km	10.086	94.576		
	Profile 3 (47.125°N, 80.625°E) (-2..	3,085.565 m	5,318.55 km	-3.25	81.951		



Figs. 55 - 58. Various captures of Ovda Regio including elevation of mountainous regions

4.2.3 Payload Success Criteria

The main criteria for payload success are the identification of biosignatures in Venus' atmosphere. The two panoramic cameras will capture multispectral images at one-hour intervals at 180° a part. The magnetometer will measure the magnetic field of Venus using a 32 Hz sampling range. The barometric pressure sensors will detect any seismic signals for signs of past and present activity in infrasound frequencies over a range of 0.01 - 80 Hz and noise floor < 0.001 Pa. The nephelometer will measure particle size with a resolution of 0.1 μm and refractive index to a resolution of < 0.02 μm and the intensity and polarization of scattered light to an accuracy of 1% at every 1-hour interval to assess spatial variability. The visible imager will take images of the balloon and atmosphere every hour. The UHF-T will send all images and measurements to Earth after the hourly image capture and measurements are complete with an accuracy of ≥ 95%. If not possible, data transmission and collection will halt until an accuracy of ≥ 95% is met. Each instrument must be functioning properly and accurately to reach the ≥ 95% threshold. The data collected will identify biosignatures in Venus' atmosphere to improve the accuracy of the planetary model and identify potential zones for further investigation by future missions.

4.2.4 Experimental Logic, Approach, and Method of Investigation

The lander will circumnavigate the atmosphere every five days by being carried by its super-rotating winds from altitudes of 52km to 62km, a range which houses a majority of the Venusian cloud layer which is of high interest for investigating sulfuric acids, winds, cloud aerosols, and solar heating. The lander will use an aerosol mass spectrometer, nephelometer, and 360° multispectral images with two panoramic cameras to measure the D/H ratio, isotopic ratios of oxygen, water, carbon dioxide, sulfur dioxide, and sulfur trioxide in the cloud tops in both liquid and gaseous phases at least 5 times over varying altitudes. The nephelometer must measure with a resolution of 0.1 μm and refractive index to a resolution of < 0.02 μm. The aerosol mass spectrometer, nephelometer, and anemometer will describe the atmospheric circulation and vertical wind velocities in correlation to cloud composition. The fluorimetric microscope will gather samples of cloud droplets at varying altitudes to identify data on traces of organic objects, including photosynthetic pigments, to assess photosynthetic activity in the atmosphere through fluorescent and dark-field images of cloud droplets at a spatial resolution <0.5 μm at 265, 370, 470, and 530 μm to compare concentrations of biosignatures during the day and night. The lander will contextualize measurements using the inertial measurement unit to provide data on temperature, pressure, vertical wind velocity, chemical composition, and biosignatures with respect to altitude to improve the accuracy of future planetary models. After collecting and contextualizing the data, it will be sent back to Earth through the Deep Space Network. Communication between the land and Earth will be completed at least once a day for 60 minutes.

4.2.5 Testing and Calibration Measurements

4.2.5.1 Imaging

Imagers, which include the panoramic cameras and radiometer, are calibrated by targets containing red, green, blue, and yellow corners once in the atmosphere, thus serving as the control variable. Once the colors appear as they should through each of the imagers, the calibration will be complete.

4.2.5.2 Meteorology

Meteorological measurements (i.e. those of the temperature sensor, pressure sensor, 3-D anemometer, and nephelometer) will be calibrated through comparison of in situ measurements with those from previous literature:

- The nephelometer will measure the scattering coefficients of dry CO_2 gas and compare these amounts with known values from previous research.
- The temperature sensor, pressure sensor, and 3-D Anemometer will measure temperature, pressure, and wind velocities, respectively, at 75° latitude and compare these values with the expected amounts from the Venus International Reference Atmosphere and other literature depending on the latitude of measurement [Ando et al., 2020].

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

To prevent data loss through communications failures each sub-systems is continuously saved on a backup system onboard if a restart is necessary.

Instrument	Precision
Aerosol Mass Spectrometer	$\pm$ 1%
Nephelometer	$\pm$ 10%
Radiometer	$\pm$0.1 K
Temperature sensor	$\pm 2 \circ C$
Pressure Sensor	0.008%
3D Anemometer	3%
Pancam	1%
UHF Transceiver II	$\pm 2.5\, ppm$
Visible Imager	1%
Inertial Measurement Unit	$150\, ppm$

Fig. 59. Instrument precision and repeatability table

All measurements will be repeated throughout the 60 days in each of the 12 circumnavigations to maximize accuracy. To reduce noise in the data, the measurement of each property shall be averaged across all 12 circumnavigations for a dataset with higher clarity for future models.

4.2.7 Expected Data & Analysis

4.2.7.1 Pancam

The two panoramic cameras are expected to capture 360° of the surrounding atmosphere and surface. Along with data from the other units, the pancam data will better characterize the regions.

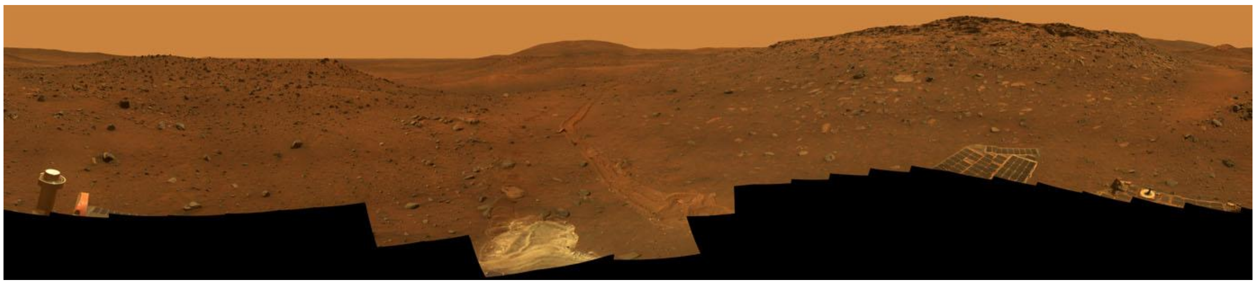


Fig. 60. Full-circle view from the panoramic camera on the Mars Exploration Rover Spirit displaying the terrain surrounding the location known as "Troy".
Image credit: NASA/JPL/Cornell

4.2.7.2 Aerosol Mass Spectrometer

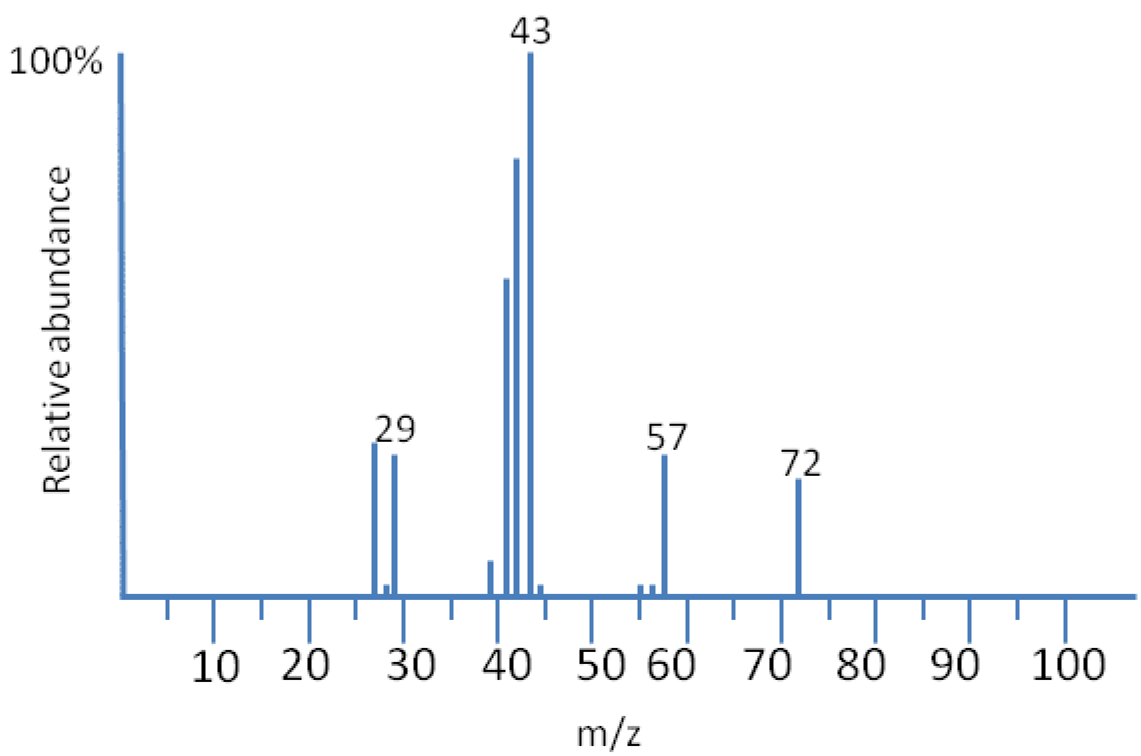


Fig. 61. Example data extracted from a spectrometer.

The aerosol mass spectrometer has the ability to create spectrographs that shall measure the relative composition of substances in the atmosphere. As cations enter the spectrometer, bonds will often be broken and create fragments with positive charges. Lines will be produced which will ultimately create a figure similar to the one above; a stick diagram representing fragmentation patterns. For the x-axis, $\frac{m}{z}$represents the relative mass of the charged cation, where $m$is mass and $z$is the charge. This will allow for the capture and analysis of many permutations of all interested substances of measurement, including water, carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur.

4.2.7.3 Sun Sensor

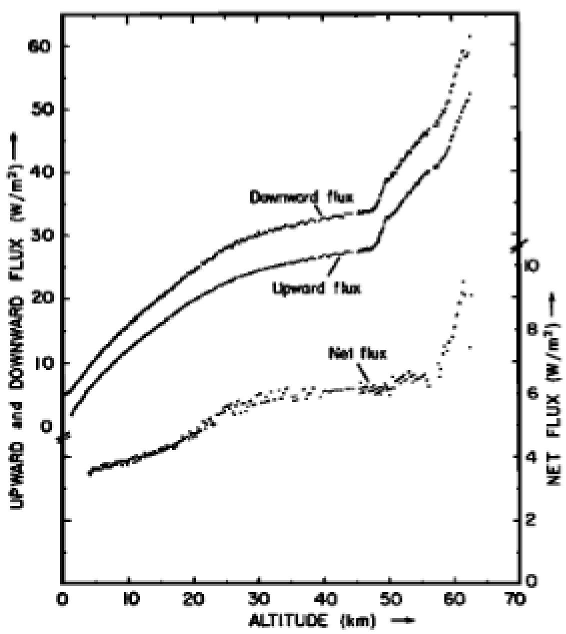
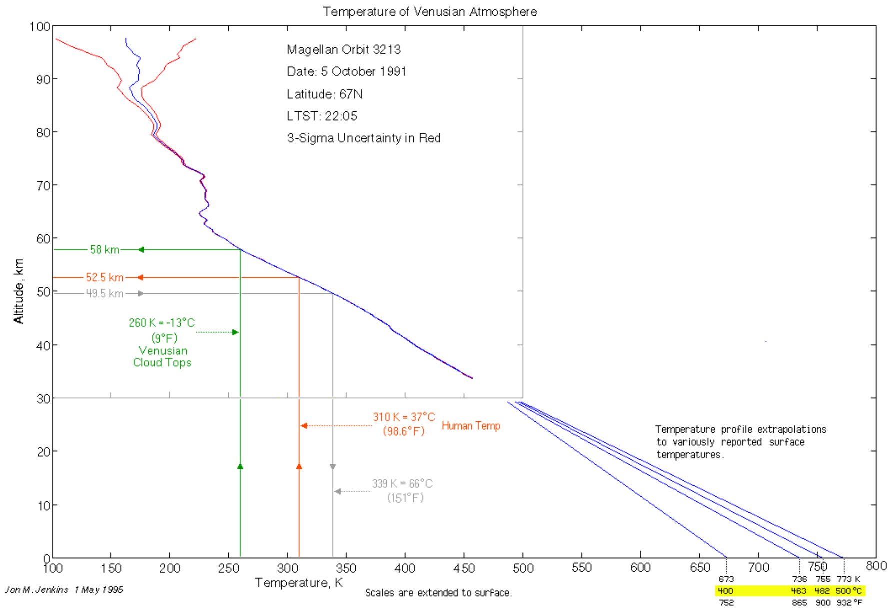
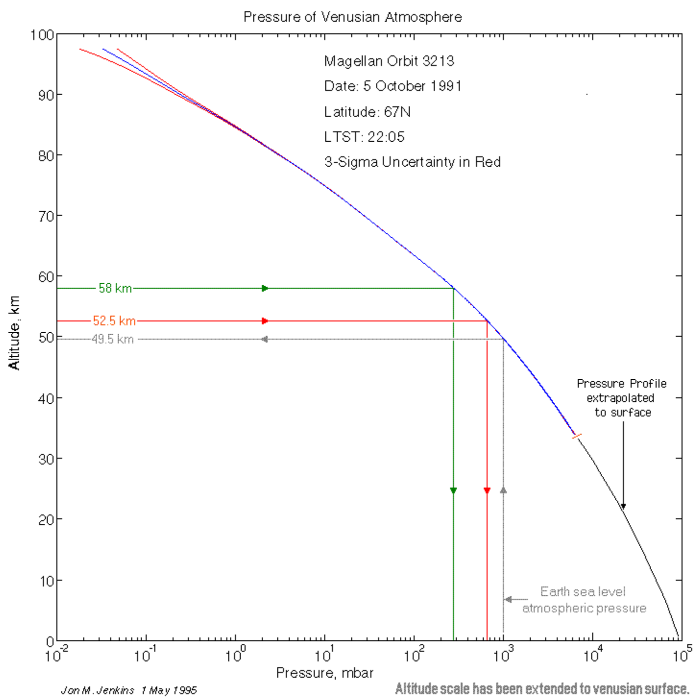


Fig. 62. Expected measurements from sun sensor

Depicted above are the expected measurements for the sun sensor to measure the downward and upward solar fluxes with respect to altitude and determine the net flux.

4.2.7.4 Meteorological Sensors





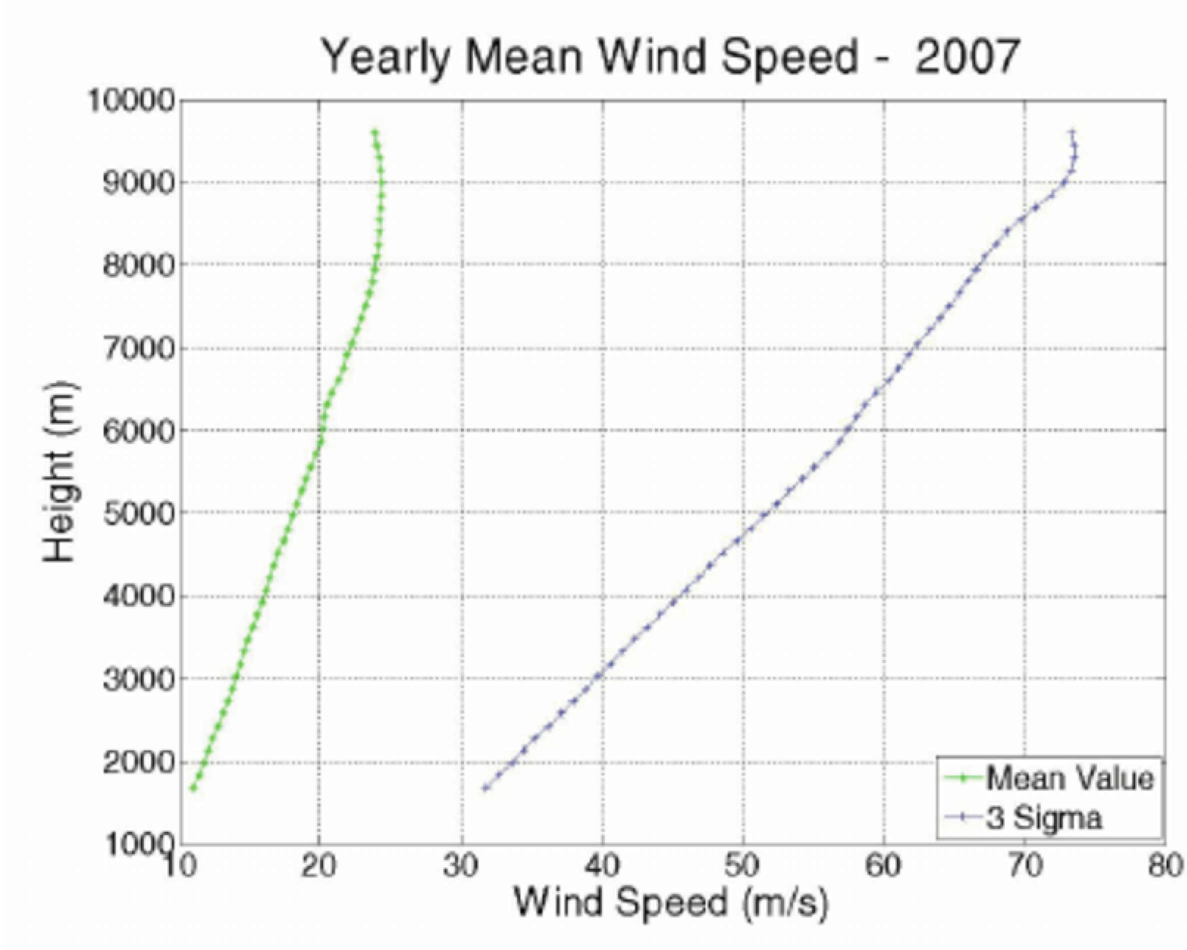


Fig. 63 - 65. Example meteorological data that shall be collected with the BRAVE lander.

Displayed above are models of temperature, pressure, and wind velocities respectively. The first two are models of the Venusian atmosphere itself. The novel data will be interpreted by attempts to find statistical relationships across all three properties and will section different ranges of altitudes as appropriate if weather conditions are extremely distinct.

5. Safety

5.1 Personnel Safety

5.1.1 Safety Officer

The safety officer for BRAVE is Molly Carlson. The responsibilities of the safety officer are the following: reviewing and approving all safety plans within the team and subcontractors, monthly safety checks of lab and manufacturing facilities, monthly meetings with the Project Manager, Deputy Project Manager, and subteam leads to review continuing safety concerns and assess any new safety concerns, and lead the team in emergency protocol training at the beginning of the mission and biannually throughout the duration of the mission. Every team member will complete safety training prior to mission start including fire, equipment, environmental, and cyber safety. Specific facility and lab safety protocols and policies were viewed before the selection of said lab or facility to ensure the location did not have existing critical safety concerns. Adequate funding for proper protective gear was allocated in the budget at the beginning of the planning stages to assure team safety.

5.1.2 List of Personnel Hazards

Reference	Personnel Hazard	Cause of Hazard	Effect of Hazard
1.1	Corrosive or toxic material	Not wearing PPE	Damage to skin, eyes, or lungs
2.1	Pyrotechnics triggering	Electrical malfunction	Bodily damage from explosion, potentially lethal
3.1	Heavy machinery	Machinery fails or is used incorrectly	Bodily damage from failing equipment or machine
4.1	Electricity	Not wearing correct PPE	Electrical shock, potentially lethal
5.1	Fire	Incorrect storage of material, electrical fire	Severe burning, potentially lethal
6.1	Noise	Loud machinery, not wearing PPE	Acoustic trauma

Fig. 66. Personnel hazards table

5.1.3 Hazard Mitigation

Reference 1.1: Personnel must wear personal protective equipment (PPE) to prevent any damage to the skin from corrosive or toxic chemicals. PPE will be required if working with corrosive or toxic chemicals. A safety officer will routinely survey the area for compliance. Finally, Material Safety Data Sheets (MSDS) will be readily available for all chemicals in the facility.

Reference 2.1: Pyrotechnic charges will have labels warning personnel. All personnel must have a thorough understanding of the potential hazard and what to do if a charge were to deploy.

Reference 3.1: If heavy machinery is utilized such as a crane or forklift, personnel must wear hard hats and take precautionary measures while operating the machinery and while working alongside the machinery.

Reference 4.1: To prevent electric shock insulated gloves and clothing must be utilized when working with high voltage equipment.

Reference 5.1: Personnel must have completed fire hazard training during the onboarding process. The facility must comply with local and federal fire regulations and safety policies.

Reference 6.1: To prevent personnel from experiencing acoustic trauma from loud machinery, the testing facility will have ear plug stations.

5.2 Vehicle/Payload Safety

5.2.1 Environmental Hazards

Reference	Vehicle Hazards	Cause of Hazard	Effect of Hazard
1.1	Chemical composition of atmosphere	Sulfur dioxide composition in atmosphere	Balloon tear
1.2	Chemical composition of atmosphere	Sulfur dioxide composition in atmosphere	Corrosion of metal
2.1	Wind speeds	Weather	Sudden change in course trajectory
3.1	Vertical displacement	Gravitational waves from mountainous terrain	Functional failure of balloon aerobot outside of flight boundaries
4.1	Instrument/ electronic interference	Weather / Solar Radiation	Loss in communication/data
5.1	Telemetry failure	Weather / Solar Radiation	Guidance system fails
6.1	Cloud formation	Solar panel failure due to weather conditions	Failed battery recharge
7.1	Fog	Murky environment at 50 ~ 60 km above surface	Failure of optical sensors

Fig. 67. Environmental hazards table

5.2.2 Hazard Mitigation

Reference 1.1: If the balloon should tear, a crash landing will occur. An acceptable velocity to minimize damages will be calculated on Earth prior to launch. Balloon is coated with teflon for sulfuric acid resistance.

Reference 1.2: Exposed metal will be coated in a corrosion-resistant material to resist atmospheric effects.

Reference 2.1: Propulsion methods with a continuous feedback loop to the ground station to make adjustments to the trajectory will be used to combat the effects of heavy winds.

Reference 3.1: Propulsion systems are in place to ensure the balloon stays within the flight boundaries.

Reference 4.1: To prevent against a loss of instrument communication, instruments will be shielded using aluminum or lead sheets.
Reference 5.1: If the guidance system should fail due to harsh weather, optical relays will be implemented. The distance between the transmitter, receiver, and size of optical terminal will be determined and balanced pre-launch. In addition, an algorithm that interprets noisy, garbled transmissions will be implemented
Reference 6.1: If the charging system fails due to cloud formation, then the system will enter a rest mode where power will only be used for thermal management.
Reference 7.1: The Pancam will be calibrated pre-launch with an accuracy of 7% and precision of 1% using preflight data in a murky environment similar to conditions on Venus.

6. Activity Plan

6.1. Budget

	Team 23 - BRAVE				
	# People on Team	FTE Year 1	FTE Year 2	FTE Year 3	FTE Year 4
Science Team:	3	1	1	1	1
Engineering Team:	3	1	1	1	1
Administrative Team:	3	1	1	1	1

NASA L'SPACE Mission Concept Academy Budget - Venus Atmospheric Strategic Science Investigation					
Year	**Yr 1 Total**	**Yr 2 Total**	**Yr 3 Total**	**Yr 4 Total**	**Cumulative Total**
PERSONNEL					
Science Team	$ 240,000.00	$ 240,000.00	$ 240,000.00	$240,000.00	**$960,000**
Engineering Team	$ 240,000.00	$ 240,000.00	$ 240,000.00	$240,000.00	**$960,000**
Administrative Team	$ 240,000.00	$ 240,000.00	$ 240,000.00	$240,000.00	**$960,000**
Total Salaries	$ 720,000.00	$ 720,000.00	$ 720,000.00	$ 720,000.00	**$2,880,000**
Total ERE	$ 200,952.00	$ 200,952.00	$ 200,952.00	$ 200,952.00	**$803,808**
TOTAL PERSONNEL	$ 920,952.00	$ 920,952.00	$ 920,952.00	$ 920,952.00	**$3,683,808**
TRAVEL					
Total Flights Cost	$ 3,316.00	$ 6,632.00	$ 3,316.00	$ 3,316.00	**$16,580**
Total Hotel Cost	$ 5,236.00	$ 10,472.00	$ 5,236.00	$ 5,236.00	**$26,180**
Total Transportation Cost	$ 652.54	$ 1,305.08	$ 652.54	$ 652.54	**$3,263**
Total Per Diem Cost	$ 3,514.50	$ 7,029.00	$ 3,514.50	$ 3,514.50	**$17,573**

OTHER DIRECT COSTS					
Total Outsourced Manufacturing Cost	$ -	$ 115,786,324	$ -	$ -	**$115,786,324**
|> Science Instrumentation	$ -	$ 99,766,324	$ -	$ -	**$99,766,324**
Fluorimetric Microscope		$ 4,000,000			
UHF Transceiver		$ 18,400			
sensors		$ 3,000,000			
Aerosol Mass Spectrometer and Nephelometer		$ 6,500,000			
Magnetometer		$ 6,900,000			
Visible Imager		$ 3,500,000			
Panoramic Cameras		$ 25,900,000			
Intertial Mass unit		$ 50,000			
Sun Sensor		$ 14,762			
|> Other COTS Components	$ -	$ 16,020,000	$ -	$ -	**$16,020,000**
Batteries - lithium-thionyl chloride		$ 15,840,000			
400 series workbench xtreme 3D platform		$ 100,000			
Solar panels		$ 80,000			
Total In-House Manufacturing Cost	$ -	$ 1,562,031	$ 1,562,031	$ -	**$3,124,062**
|> Materials and Supplies	$ -	$ 1,562,031	$ 1,562,031	$ -	**$3,124,062**
Helium tank		$ 315	$ 315		
Helium pump system		$ 695	$ 695		
Carbon Fiber Shell		$ 16,000	$ 16,000		
Parachute		$ 31	$ 31		
Balloon material		$ 82,000	$ 82,000		
Helicopter testing/rental		$ 1,414,000	$ 1,414,000		
Fabrication material		$ 50,000	$ 50,000		
Total Equipment Cost	$ -	$ 1,800,652	$ 1,800,652	$ -	**$3,601,304**
|> Manufacturing Facility Cost	$ -	$ 462,524	$ 462,524	$ -	**$925,048**
machinist labor (5 machinist)		$ 200,000	$ 200,000		
Aluminum (1000lb)		$ 500	$ 500		
Gold (10lb)		$ 205,460	$ 205,460		
Titanium (100lb)		$ 3,000	$ 3,000		
PPE		$ 1,494	$ 1,494		
Copper (500lb)		$ 2,070	$ 2,070		

other material		$ 50,000	$ 50,000		
|> Test Facility Cost	$ -	$ 1,338,128	$ 1,338,128	$ -	**$2,676,256**
Facility cost - 12 months		$ 538,128	$ 538,128		
Labor (10 workers)		$ 800,000	$ 800,000		
In-House Manufacturing Margin	$ -	$ 1,681,342	$ 1,681,342		**$3,362,683**

Total Direct Costs	$ 933,671	$ 121,776,739	$ 5,977,696	$ 933,671	**$9,849,429**
Total MTDC	$ 933,671	$ 119,075,761	$ 3,276,718	$ 933,671	**$6,248,125**
FINAL COST CALCULATIONS					
Total F&A	$ 93,367	$ 11,907,576	$ 327,672		**$12,328,615**
Total Projected Cost	$ 1,027,038	$ 133,684,315	$ 6,305,368	$ 933,671	**$141,950,392**
Total Cost Margin	$ 308,111	$ 40,105,294	$ 1,891,610		**$42,305,016**
Total Project Cost	$ 1,335,150	$ 173,789,609	$ 8,196,978		**$183,321,737**
F&A %	10%	10%	10%	10%	$0
Manufacturing Margin	50%	50%	50%	50%	$1
Total Cost Margin	30%	30%	30%	30%	$0
ERE - Staff	28%	28%	28%	28%	$0

Fig. 68. Budget diagram

The science, engineering, and business team shall have three employees per subteam which consist of science, engineering, and administrative throughout the mission's development. The total salary is based on a yearly earning of $80,000 per employee times the years employed. Associated travel costs are based on the federal per diem rates allowed for government employees and are calculated for a stay of five days, two days before launch, launch, and two days after launch. Other direct costs accounted for include science instrumentation, in-house manufacturing, facility cost, and other commercial off-the-shelf components necessary for the mission. Lastly, total project cost and total marginal cost are established providing the final cost of the mission.

Travel - $63,595.20

Flights: For each trip, every member will fly into the Melbourne International Airport in Melbourne, Florida. One team member will fly in from the Wichita Dwight D Eisenhower National Airport and the flight will cost $389. One member will fly in from Astin Aviation and the flight will cost $504. Four members will fly in from the Dallas Fort Worth International Airport and each flight will cost $313. Two members will fly in from the Birmingham-Shuttlesworth International Airport and each flight will cost $231. Two members will fly in from the Austin-Bergstrom International Airport and each of the flights will cost $198. (These are the prices for the flight to and from the testing center). Each flight will be through the Delta airline except for the Astin Aviation flight, which will be through American Airlines. The flights will cost $3,316 each round trip.

Hotel: The staff will stay at the Hyatt Place Titusville. It is 9.3 miles from the Kennedy Space Center. We will rent 11 rooms (one for each staff member) at $119 per night per room. The hotel rooms will cost $5,236 each trip.

Transportation: On each trip we will rent three Hyundai Elantra from the airport for the staff to use. These cost $40 per day per car. The Hyundai Elantra gets 32 miles per gallon in the city. The distance from the airport to the hotel is 40.7 miles and that trip will be made twice. The distance between the hotel and the Kennedy Space Center is 9.3 miles, and that trip will be made 6 times. The staff will be given a 5-mile radius for lunch and dinner. They will eat each meal 4 times while on this trip, meaning they will make the drive for each meal 8 times to take into account the drive there and the drive back. The total miles driven for each car will be 217.2 miles. This means each car will use 6.7875 gallons of gas. Gas costs $2.58 per gallon in Cape Canaveral, so the total cost for renting the cars and gas will be $652.54 each trip.

Per Diem: Employees are to be paid $71 each full day and $53.25 on travel days. The total cost will be $3,514.50.

Total Cost: The team will meet once in years 1, 3, and 4. In year 2 the team will meet twice. Since each trip costs $12,719.04 and we will make 5 trips, the total cost will be $63,595.20.

Science Instrumentation - $99,766,324.00

It would cost $49,883,162.00 to buy each instrument once, but we will buy two of each instrument for testing purposes and to make sure we have backups if necessary. This brings the total cost for scientific instruments to $99,766,324.00.

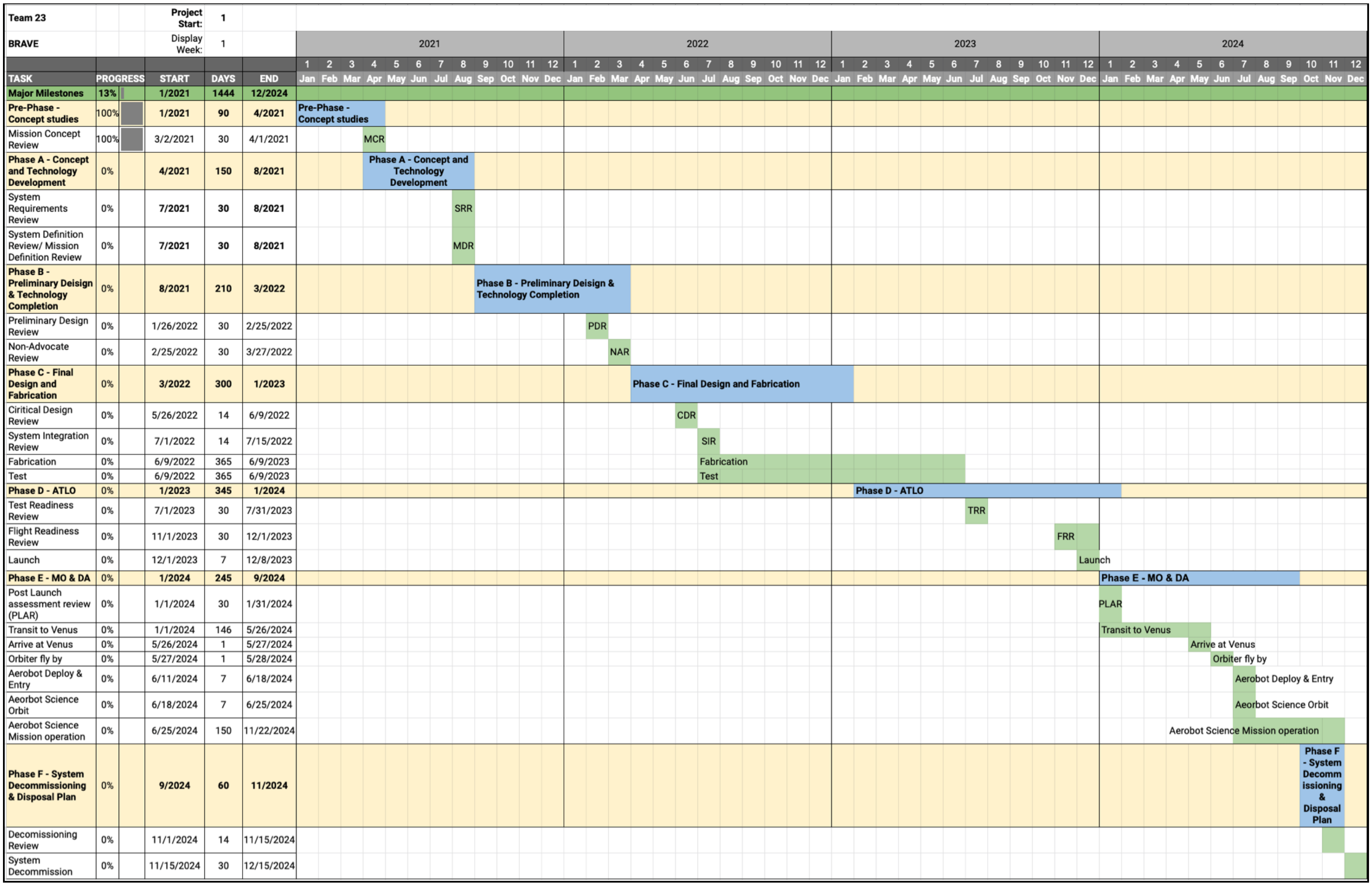
In-House Manufacturing Cost & Equipment Cost - $6,725,366.38

Helicopter Rental: cost $1,414,000. This will be used to test our project, allowing us to deploy our project at high altitudes.

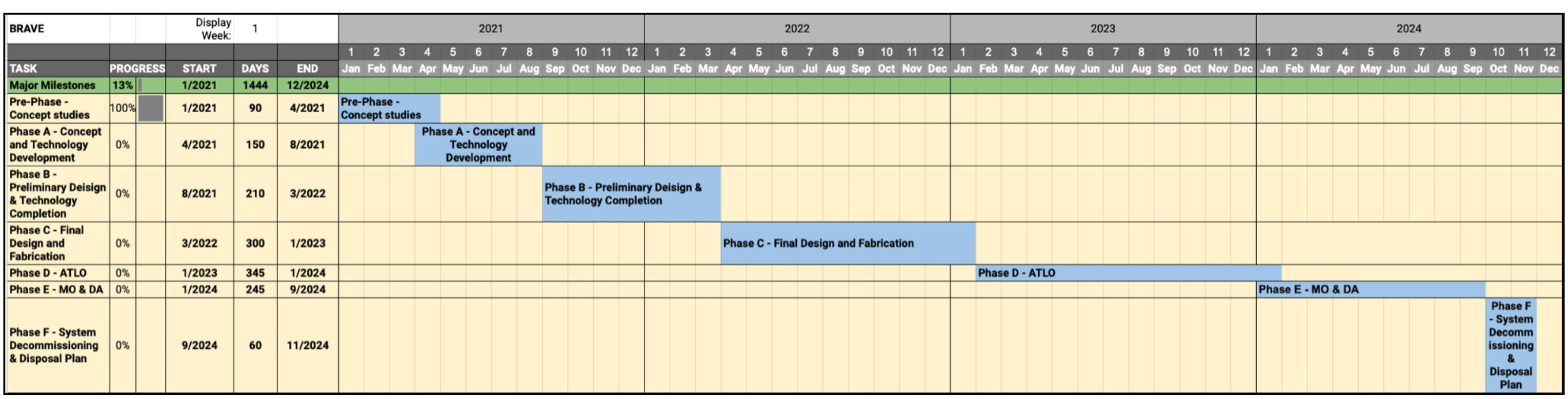
Testing Facility: total cost $2,676,256.00. We are going to rent our Moffett Federal Airfield as our testing facility. This will give us access to facilities such as wind tunnels to use to test our project. We will end up renting it out twice.

Total Cost: The total cost to buy all necessary materials plus the helicopter rental comes out to $3,362,683.19. However, we will end up fabricating our project a second time after the first one has been put through testing, we will need to buy everything twice. This brings the total cost to $6,725,366.38

6.2. Schedule



TASK	PROGRESS	START	DAYS	END
Team 23		Project Start: 1		
BRAVE		Display Week: 1		
Major Milestones	13%	1/2021	1444	12/2024
Pre-Phase - Concept studies	100%	1/2021	90	4/2021
Mission Concept Review	100%	3/2/2021	30	4/1/2021
Phase A - Concept and Technology Development	0%	4/2021	150	8/2021
System Requirements Review	0%	7/2021	30	8/2021
System Definition Review/ Mission Definition Review	0%	7/2021	30	8/2021
Phase B - Preliminary Deisign & Technology Completion	0%	8/2021	210	3/2022
Preliminary Design Review	0%	1/26/2022	30	2/25/2022
Non-Advocate Review	0%	2/25/2022	30	3/27/2022
Phase C - Final Design and Fabrication	0%	3/2022	300	1/2023
Ciritical Design Review	0%	5/26/2022	14	6/9/2022
System Integration Review	0%	7/1/2022	14	7/15/2022
Fabrication	0%	6/9/2022	365	6/9/2023
Test	0%	6/9/2022	365	6/9/2023
Phase D - ATLO	0%	1/2023	345	1/2024
Test Readiness Review	0%	7/1/2023	30	7/31/2023
Flight Readiness Review	0%	11/1/2023	30	12/1/2023
Launch	0%	12/1/2023	7	12/8/2023
Phase E - MO & DA	0%	1/2024	245	9/2024
Post Launch assessment review (PLAR)	0%	1/1/2024	30	1/31/2024
Transit to Venus	0%	1/1/2024	146	5/26/2024
Arrive at Venus	0%	5/26/2024	1	5/27/2024
Orbiter fly by	0%	5/27/2024	1	5/28/2024
Aerobot Deploy & Entry	0%	6/11/2024	7	6/18/2024
Aeorbot Science Orbit	0%	6/18/2024	7	6/25/2024
Aerobot Science Mission operation	0%	6/25/2024	150	11/22/2024
Phase F - System Decommissioning & Disposal Plan	0%	9/2024	60	11/2024
Decomissioning Review	0%	11/1/2024	14	11/15/2024
System Decommission	0%	11/15/2024	30	12/15/2024



TASK	PROGRESS	START	DAYS	END
BRAVE		Display Week: 1		
Major Milestones	13%	1/2021	1444	12/2024
Pre-Phase - Concept studies	100%	1/2021	90	4/2021
Phase A - Concept and Technology Development	0%	4/2021	150	8/2021
Phase B - Preliminary Deisign & Technology Completion	0%	8/2021	210	3/2022
Phase C - Final Design and Fabrication	0%	3/2022	300	1/2023
Phase D - ATLO	0%	1/2023	345	1/2024
Phase E - MO & DA	0%	1/2024	245	9/2024
Phase F - System Decommissioning & Disposal Plan	0%	9/2024	60	11/2024

Fig. 69. Schedule of BRAVE mission

6.3. Outreach Summary

One of the primary outreach goals is to encourage interest in the fields of science, technology, engineering, arts, and mathematics (STEAM). Social media outreach will include accounts on the following platforms: *Facebook, Twitter, Instagram, Snapchat*, and *Tik Tok* as well as a website. The website will feature images taken by the BRAVE lander of Venus' atmosphere and the lander itself. The website will also feature daily updates of Venus' atmospheric changes including pressure, temperature, wind velocity, and opacity. Graphs will also be displayed on the website showing the change in the measurements above throughout the mission.

While BRAVE as a mission focuses primarily on the science, technology, engineering, and mathematics (STEM) part of STEAM, the arts will have a special focus during outreach to United States-based schools to encourage cross-curricular work within the classroom. Z3nith will be providing curricular guideline ideas for educators and administrators on the BRAVE website, but creative changes are welcome. This curriculum will be easily adaptable for all education levels and a traditional school setting, remote learning, and a homeschool setting. Educators will be presented with the following questions: what did Venus used to look like? Did Venus once look like Earth? Why does Venus look the way it does now? Will Earth ever look like Venus? Why can humans not live on Venus? These open-ended questions will allow students to be involved in project-based and self-directed learning, regardless of education level. While ideas for each education level are given below, these questions are given as starting points for research and discussion and are meant to be open-ended.

Kindergarten through second grade (K-2) can participate in light research using apps on school devices, libraries, and other online resources. Articles will also be available on the BRAVE website. This will satisfy the science component of STEAM and students will gain research and reading skills. A class-wide writing assignment follows the research component, such as a class-wide discussion and Venn diagram comparing Earth and Venus to develop writing skills and communication skills. Venus or space-related math can be incorporated into the traditional curriculum such as "how many months will it take for the BRAVE lander to reach Venus" or "Count how many Venus planets there are drawn on the page".

Third through fifth grade (3-5) will be encouraged to add a larger math and science component by beginning to develop an understanding of climate changes on planets through deeper research. Individual or small group writing components with presentations are encouraged as well for grades 3-5.

Sixth through eighth grade (6-8) can develop scientific backing within their predictions of the questions presented above. Such as looking at specific chemical properties in Venus' atmosphere and what types of materials withstand Venus' toxicity. Group research and projects are encouraged at this level.

At the high school level (grades 9-12), even further research and deeper scientific understanding are encouraged. Students can develop hypotheses over the topography of Venus and the cause of the chemical composition of Venus' atmosphere. A deeper comparison of Earth and Venus can be done by grades 6-12. Grades 6-12 will be especially encouraged to answer the question "why can humans not live on Venus" and to have a discussion about climate change on Earth.

The technology component of STEAM can be satisfied through research on devices, using computer software to create a depiction of Venus, or by incorporating coding into the curriculum. To satisfy the engineering component of STEAM, groups of students will be encouraged to create their own Venus Atmospheric probe out of recycled materials. All grade levels will be able to participate in this activity, the range of complexity of the probe will differ between grades. To satisfy the art component of STEAM, students and groups can participate in the BRAVE Venusian Competition. This competition is centered around the question of what would a human have to look like to be able to survive on Venus. The material and reasoning can be presented in any form: film, 3D model or sculpture, drawing, computer rendering, etc. Teams will be asked to justify their design. As this competition is available for all educational levels, complexity within the justification of design will increase as the educational level increases (i.e. K-2 will be asked to write a small paragraph, 9-12 will be asked to give scientific reasoning (chemical properties, material specifications)) and more detailed designs will be encouraged as educational level increases as well. This project is open to all students, student groups, both within schools and outside of schools, and educators, both in a traditional school setting and remote learning. Students and educators can also participate in the BRAVE Mission Design activity. This activity is for students to design a mission patch for the BRAVE Mission. Creators can submit their patch designs to be featured on the BRAVE social media platforms.

At the University level, both undergraduate and graduate levels, students can apply to be a BRAVE Mission Ambassador and for BRAVE mission internships.

Fig. 70. Flyer for Venusian Competition

An example of a potential flyer to spread awareness to the general public about BRAVE and the BRAVE Venusian Competition.

6.4. Program Management Approach

Z3nith team members are split into 3 sub-teams with members assigned to one specific team while assisting other sub-teams as seen fit. Members are assigned weekly deliverables in coordination with the PDR deliverables requested. If there are no deliverables for the specific subteam, the subteam addresses the following week's. Team leads have adopted their subteam team structure as the project manager follows the scrum framework and encourages sprint planning. This allows the sub-teams to self-organize and work more efficiently. An early issue was the lack of team coherence due to lack of full team meetings which has been addressed by encouraging cross-functionality across the team and the implementation of subthreads so any team member can check on other sub-teams' status and progress.

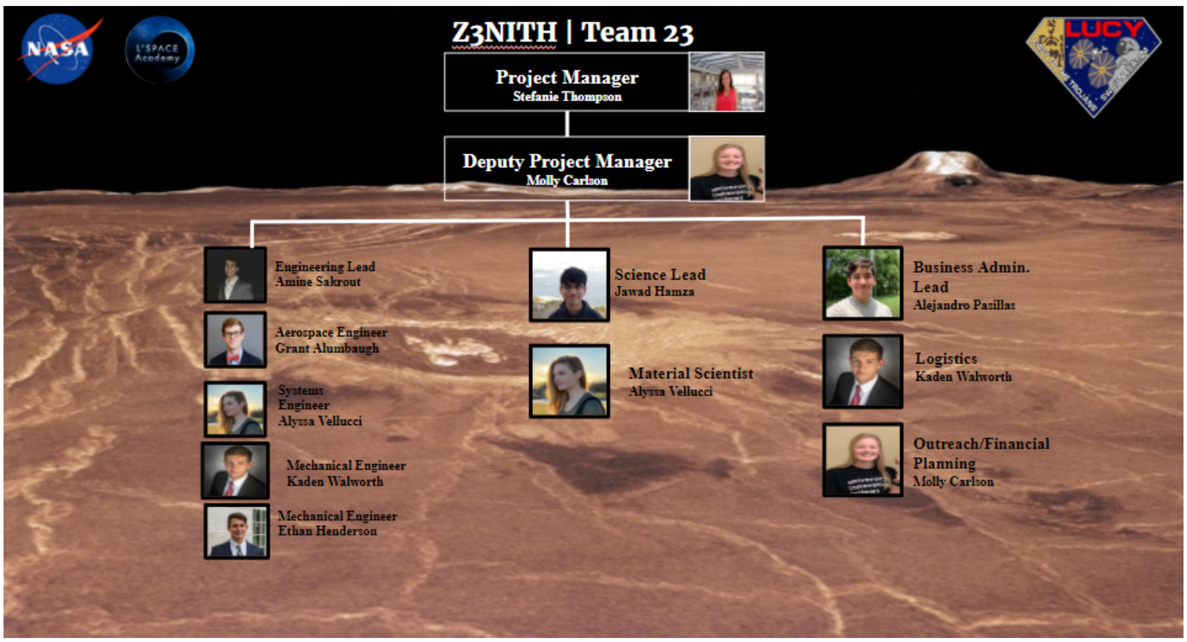


Fig. 71. Z3NITH team role diagram

7. Conclusion

This PDR introduces the next stage of space exploration by investigating and collecting data on signs of life and sustainability within the Venusian atmosphere. The BRAVE mission will survey and assess the atmosphere's internal chemistry, interactions between the solar and thermal radiation fields, temperature, pressure, wind velocities, and solar heating rate. These scientific discoveries will allude to Venus' diverse planetary conditions and provide insights into Venus' past conditions. Further missions can be designed off of BRAVE's scientific discoveries to continue to investigate Venus' past planetary conditions and her similarity to Earth.

The team will begin critical design review in March of 2022 and test readiness in July of 2023. Mission launch will occur on December 1, 2023, and the payload will arrive in the Venusian atmosphere in June 2024 after approximately 180 days of travel. The BRAVE lander will detach from the payload after reaching the proper altitude above the Venusian surface and the balloon will deploy getting the payload at the altitude. Observations and data collection of chemical properties of the atmosphere will then begin. The data collected will be transmitted back to Earth for computational modeling and further analysis by the scientific team.

The data collected by our mission is the key to unlocking Venus' past which will aid in the understanding of habitability on Earth-sized planets. This will not only lead to further missions but also a better understanding of Earth and the steps needed to maintain Earth's state of habitability. This mission represents the efforts of a team that not only wants to further scientific discovery and push the limits of exploration on a hostile planet but also to better our home planet Earth.

8. Acknowledgements and References

8.1 Acknowledgements

The Z3NITH team would like to thank everyone that aided in the writing of the BRAVE Preliminary Design Review. The team is extremely grateful for the guidance of support of our mentor, Miriam Youssef, for her consistent support and time invested into the team. The team would also like to thank Dann Garcia and Sheri Boonstra for the L'SPACE Mission Concept Academy and allowing our team to develop a Preliminary Design Review and to hear from some of NASA's top engineers and researchers

8.2 References

Aerospace Fabrication. Multilayer Insulation https://www.aerospacefab.com/product/mli/

Arizona State University. Welcome to Pancam Home! (n.d.). Retrieved from
http://pancam.sese.asu.edu/

Bottema, M., Plummer, W., Strong, J., and Zander, R. (1965), The composition of the Venus clouds and implications for model atmospheres, *J. Geophys. Res.*, 70(17), 4401– 4402, doi:10.1029/JZ070i017p04401.

Bruschi, G., Nishioka, T., Tsang, K., & Wang, R. (2003). A Comparison of Analytical Methods Drag Coefficient of a Cylinder. 1-34. Retrieved from https://sv.20file.org/up1/916_0.pdf.

Bullock Mark A., Grinspoon David H.,
The Recent Evolution of Climate on Venus,
Icarus, Volume 150, Issue 1, 2001,Pages 19-37,
ISSN 0019-1035, https://doi.org/10.1006/icar.2000.6570.
(https://www.sciencedirect.com/science/article/pii/S0019103500965709)

Chemical Resistance Chart. https://www.quickcutgasket.com/pdf/Chemical-Resistance-Chart.pdf

Constants and Expansions. PDF file. University of Texas.
https://www.ae.utexas.edu/courses/ase366k/constants.pdf

Costing Information Glass Reinforced Fibre. NIVITEX Fibreglass & Resins.
https://www.nivitex.com/glass-fibre-costing.html

Crisp, J.A., M. Adler, J.R. Matijevic, S.W. Squyres, R.E. Arvidson, and D.M. Kass (2003). Mars Exploration Rover mission.
https://agupubs.onlinelibrary.wiley.com/doi/full/10.1029/2002JE002038

Dunbar, B. (2007, August 27). Up, Up and Away -- To Venus. Retrieved from
https://www.nasa.gov/vision/universe/solarsystem/venus-20070827.html

Federal Aviation Administration. Returning from Space: Re-entry. Ch 4.1.7(10).
https://www.faa.gov/about/office_org/headquarters_offices/avs/offices/aam/cami/library/online_libraries/aerospace_medicine/tutorial/media/iii.4.1.7_returning_from_space.pdf

Fiberglass and Composite Material Design Guide. Performance Composites Inc.
https://www.performancecomposites.com/about-composites-technical-info/122-designing-with-fiberglass.html

Garner, R. (2015, July 17). Scientific Balloons FAQs. Retrieved from
https://www.nasa.gov/scientificballoons/faqs

Geoffrey Landis. "Low-Altitude Exploration of the Venus Atmosphere by Balloon," AIAA 2010-628. *48th AIAA Aerospace Sciences Meeting Including the New Horizons Forum and Aerospace Exposition*. January 2010.

Greaves, J.S., Richards, A.M.S., Bains, W. *et al.* Phosphine gas in the cloud decks of Venus. *Nat Astron* (2020). https://doi.org/10.1038/s41550-020-1174-4

Hall Jeffery L., Cameron Jonathan M., Pauken Michael T., Izraelevitz Jacob S., Dominguez, W Mitchell, Wehage Kristopher T. Altitude-Controlled Light Gas Balloons for Venus and Titan Exploration. AIAA AVIATION Forum, 2019. Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA., 91109, USA.
https://dartslab.jpl.nasa.gov/References/pdf/2019-BalloonTitanVeinus.pdf

Heddleson, C. F., Brown, D. L., & Cliffe, R. T. (1957). Summary of Drag Coefficients of Various Shaped Cylinders. *Engineering TID, 12*. Retrieved from
https://apps.dtic.mil/dtic/tr/fulltext/u2/a395503.pdf.

Hein, Andreas M et al. “A Precursor Balloon Mission for Venusian Astrobiology.” *Astrophysical journal. Letters* 903.2 (2020): n. pag. Web.

Hu, W. W., Campuzano-Jost, P., Palm, B. B., Day, D. A., Ortega, A. M., Hayes, P. L., Krechmer, J. E., Chen, Q., Kuwata, M., Liu, Y. J., de Sá, S. S., McKinney, K., Martin, S. T., Hu, M., Budisulistiorini, S. H., Riva, M., Surratt, J. D., St. Clair, J. M., Isaacman-Van Wertz, G., Yee, L. D., Goldstein, A. H., Carbone, S., Brito, J., Artaxo, P., de Gouw, J. A., Koss, A., Wisthaler, A., Mikoviny, T., Karl, T., Kaser, L., Jud, W., Hansel, A., Docherty, K. S., Alexander, M. L., Robinson, N. H., Coe, H., Allan, J. D., Canagaratna, M. R., Paulot, F., and Jimenez, J. L.: Characterization of a real-time tracer for isoprene epoxydiols-derived secondary organic aerosol (IEPOX-SOA) from aerosol mass spectrometer measurements, Atmos. Chem. Phys., 15, 11807–11833, https://doi.org/10.5194/acp-15-11807-2015, 2015.

Ingersoll, A. P. (1969). The Runaway Greenhouse: A History of Water on Venus, *Journal of Atmospheric Sciences*, *26*(6), 1191-1198. Retrieved Apr 19, 2021, from https://journals.ametsoc.org/view/journals/atsc/26/6/1520-0469_1969_026_1191_trgaho_2_0_co_2.xml

IMU-LN200. (n.d.). Novatel.
https://novatel.com/products/span-gnss-inertial-navigation-systems/span-imus/imu-ln200

Kasting James F.,
Runaway and moist greenhouse atmospheres and the evolution of Earth and Venus,
Icarus, Volume 74, Issue 3, 1988, Pages 472-494,
ISSN 0019-1035, https://doi.org/10.1016/0019-1035(88)90116-9.
(https://www.sciencedirect.com/science/article/pii/0019103588901169)

LN-200S Inertial Measurement Unit. Northrop Grumman.
https://www.northropgrumman.com/what-we-do/ln-200s-inertial-measurement-unit/

Maki, J. (2001). Pancam Calibration Plan. (pp. 5-52, Rep.). CA: JPL.

National Aeronautics and Space Administration. Standard for Performing a Failure Mode and Effects Analysis (FMEA) and Establishing a Critical Items List (CIL) (DRAFT). Flight Assurance Procedure 322-309
https://rsdo.gsfc.nasa.gov/documents/rapid-iii-documents/mar-reference/gsfc-fap-322-208-fmea-draft.pdf

Navarro, T., Schubert, G. & Lebonnois, S. Atmospheric mountain wave generation on Venus and its influence on the solid planet's rotation rate. *Nature Geosci* 11, 487–491 (2018). https://doi.org/10.1038/s41561-018-0157-x

Petrov, Leonid. Combined Observational Methods for Positional Awareness in the Solar System (COMPASS): Expanding the Space Service Volume Throughout Cislunar Space. June 28, 2019. 4th GSFC Planetary CubeSats Symposium. Goddard Space Flight Center. https://cubesats.gsfc.nasa.gov/symposiums/2019/presentations/Day2/EUBANKS.pdf

Pollackt James B., A nongrey calculation of the runaway greenhouse: Implications for Venus' past and present, Icarus, Volume 14, Issue 3, 1971, Pages 295-306, ISSN 0019-1035, https://doi.org/10.1016/0019-1035(71)90001-7.

Pollack, J. B., Toon, O. B., and Boese, R. (1980), Greenhouse models of Venus' High surface temperature, as constrained by Pioneer Venus measurements, *J. Geophys. Res.*, 85(A13), 8223–8231, doi:10.1029/JA085iA13p08223.

Sara Seager, Janusz J. Petkowski, Peter Gao, William Bains, Noelle C. Bryan, Sukrit Ranjan, and Jane Greaves.Astrobiology.ahead of printhttp://doi.org/10.1089/ast.2020.2244

Seiff A., Schofield J.T., Kliore A.J., Taylor F.W.,Limaye S.S.,Revercomb H.E.,Sromovsky L.A., Kerzhanovich V.V.,Moroz V.I.,Marov M.Ya.,
Models of the structure of the atmosphere of Venus from the surface to 100 kilometers altitude, Advances in Space Research, Volume 5, Issue 11, 1985, Pages 3-58, ISSN 0273-1177, https://doi.org/10.1016/0273-1177(85)90197-8.
(https://www.sciencedirect.com/science/article/pii/0273117785901978)

Space Math @ NASA. Exponential Functions and the Atmosphere. PDF file. National Aeronautics and Space Administration. https://spacemath.gsfc.nasa.gov/astrob/7Page15.pdf

Tauber Michael E., Palmer Grant E., Prabhu Dinesh. STAGNATION POINT RADIATIVE HEATING RELATIONS FOR VENUS ENTRY. ERC Corp., Huntsville, AL https://ntrs.nasa.gov/api/citations/20120001655/downloads/20120001655.pdf

Tomasko, M. G., Doose, L. R., Smith, P. H., and Odell, A. P. (1980), Measurements of the flux of sunlight in the atmosphere of Venus, *J. Geophys. Res.*, 85(A13), 8167– 8186, doi:10.1029/JA085iA13p08167.

Uin, J. (2016). Nephelometer Instrument Handbook. Brookhaven National Library, U.S.Department of Energy, Office of Science

United States of America, National Aeronautics and Space Administration. (n.d.). *Orion's Parachute System*.

Venus Fact Sheet. (n.d.). Retrieved from
https://nssdc.gsfc.nasa.gov/planetary/factsheet/venusfact.html

Venus Flagship Mission: VDRM Balloons. (n.d.). Retrieved from
https://vfm.jpl.nasa.gov/venusdesignreferencemission/vdrmballoons2/

Victor Vorontsov,
Designing of deployment sequence for braking and drift systems in atmosphere of Mars and Venus, Acta Astronautica, Volume 59, Issues 1–5, 2006, Pages 216-219,
ISSN 0094-5765, https://doi.org/10.1016/j.actaastro.2006.02.037.

Wagenknecht, B. (2009, March 30). *Inertial Measurement for planetary exploration:Accelerometers and Gyros*.
https://www.cs.cmu.edu/~sensing-sensors/S2009/student_lectures/20090330-bryan/20090330-inertial_navigation.pdf