Long-Term Analysis of Venus' Atmosphere through an *In-Situ* Research + Technical Demonstration Laboratory

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This Research is Dedicated to my Dad

“One Day the Flowers will Grow Again...”

_Tao Hua Yuan

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I have taken quite a journey from where I once was to where I am now. To everyone that was involved in the manifestation of this thesis, I truly appreciate the role that each individual played

To my parents, thank you for allowing my mind to wander, distant as it may be

To Lisa, thank you for being who You are

To my friends John + Dalton, thank you for being my most consistent critics

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ABSTRACT

At the core of our anthropocentric society is the ability to unveil the answers to questions that no one had thought to ask. The impending space age is no different, as the future of civilization will inevitably reach further into the field of stars. Information about the universe outside of our solar system is sparse, especially regarding the atmospheric characteristics of our future: Exoplanets. Venus presents an opportunity to educate ourselves about the intricate processes that are foreign to planets in Earth's immediate vicinity. Designing an *In-Situ* Research and Technical Demonstration Platform could enable humanity to unlock the secrets that Venus' Atmosphere protects. This research is one such attempt at developing an architecture that takes advantage of Venus' unique atmospheric conditions. An answer to humanity's future problems lies at our doorstep; continuous analysis of the Venusian atmosphere through a Long-Term *In-Situ* Laboratory is the key to unlocking the next mysteries of the cosmos.

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I. Introduction

Humanity is destined to be a star-faring civilization in the near future. Earth will become a Type 1 Civilization on the Kardashev Scale near the end of the century due to the rate at which technology is advancing. Effects such as complete control over the energy output of our planet will allow for additional attention and funding to be directed toward extra-planetary endeavors. Missions to planetary bodies will become a normality as both private and governmental agencies will seek to profit off of the abundance of extraterrestrial resources.

The desire to consume more will continue to grow, along with the amount of resources that will be widely available to our civilization. In this way, humanity will begin to expand outside of our solar system not long after departing from Earth for the first time. It is at this moment, where data, akin to the research objectives of this study, will be the defining factor in whether or not the future can be deemed a success. Venus has the capability to provide information that is otherwise foreign to every other planetary body within close proximity to Earth. Having said this, many of these Venusian characteristics that appear to be an anomaly for planets in our star system happen to be prevalent attributes for exoplanets as a whole in the greater universe. It is through the same probability analysis that the vision of the future of Venus' atmosphere has been created.

A. Vision

In the broadest sense, a vision for research and analysis discussions attempts to provide blanketed inspiration that the more detailed aspects of a mission aspire to accomplish. Humanity will inevitably expand beyond the realm of the familiar and it is the duty of the edified to prepare society for the challenges that will come with such an undertaking. There are a plethora of avenues that can be utilized to reach a level of comfortability with regards to future exoplanet missions, all of which have their own advantages and disadvantages.

The atmosphere of Venus is home to several interactions whose nature is mysterious to humanity at this point in time. Interplay between Ultra Violet Light (UV) Absorbers and external solar events are believed to have a substantial impact on the planet's super-rotational effect. That is, the difference in speed at which the atmosphere of Venus rotates compared to that of the planet itself. The super-rotation effect has secondary implications regarding other aspects of the planet. Three of these planetary features are as follows: the heightened global albedo level, severe discrepancies of thermal gradient pressure, and the sporadic adiabatic heating process.

All of these conditions, when understood in totality, will provide additional information about the chemical makeup of the Venusian atmosphere. Data revolving around how certain compounds react with one another throughout a variety of temperatures, pressures, and density thresholds. Research can be conducted from a distance to garner an elevated understanding of the atomic composition regarding each atmospheric zone. However, in order to answer the questions of '*why*' and '*how*' these interactions between molecules occur, *In-Situ* scientific and technical testing is required.

In order to achieve a successful mission, preliminary actions need to occur that enable the site in question, the atmosphere of Venus, to be fully defined. Clarity surrounding the destination for an architectural concept, such as an *In-Situ* Research + Technical Demonstration Laboratory, enables the program of said architecture to be established. A defined program validates the requirements of the architecture that are needed to accomplish the scientific and technical objectives of the mission. Positioning a network of four satellites in a series of strategic orbital locations around Venus will generate the required data to understand the site in totality. Each of the four satellites, in conjunction with the *In-Situ* laboratory, will conduct scientific measurements to learn more about the Venusian atmosphere.

In the interest of acquiring information about the chemical makeup and molecular interaction within the atmosphere of Venus, four satellite missions have been proposed. A multitude of objectives have been assigned to obtain the desired knowledge, they are as follows:

1) Provide continuous coverage of Venus' night-side and magnetotail

2) Establish a line of communication and data transfer

3) Provide continuous coverage of Venus' day-side

4) Monitor the impact that solar events have on the atmosphere

5) Monitor the effect of atmospheric loss

6) Monitor chemical and atomic fluctuation in the atmosphere

7) Monitor the extent through which photochemistry impacts atmospheric ozone levels

8) Monitor the effect of airglow emissions on both the night and day-side

9) Monitor high energy collisions of electromagnetic radiation inside the magnetotail

Understanding the interaction between hazardous environments and common construction materials will enable our civilization to be better prepared for when similar ecosystems inevitably reveal themselves in the future. This, as well as having a better grasp on how certain elements react with one another, in a variety of atmospheric situations, will elevate humanities overall readiness level when exploring exoplanets. Establishing a network of autonomous *In-Situ* laboratories and orbiting satellites is a genuine proposal to achieve the stated vision.

II. A Brief History of Venus

Apart from each planet's geographical evolution, Earth and Venus have shared qualities that have led to the collaborative alias of sister planets. Some of these traits include the mass, volume, equatorial radius, mean density, and surface gravity [1]. Due to this similarity, copious amounts of information regarding our home planet can be learned by studying the impact that external effects have on Venus and its atmosphere. Likewise, events that are foreign to our understanding of the universe can also be recognized on a fundamental level by researching why Venus chemically evolved in a radically different manner.

The planet itself is in a prime location to act as a celestial laboratory. Venus maintains the closest proximity to Earth, thereby allowing for a high volume of missions to be organized without having to consider launch windows as a primary issue [2]. This, in conjunction with the frequency through which each of the two planets' orbits align, allows for a reduced cost per mission with regards to the economical, fuel, and time investments. A simplified business plan allows for additional resources to be allocated towards materials and scientific instruments. Thereby authorizing a budget to primarily be focused on optimizing the methods of obtaining scientific and technical results. In short, due to Venus being the most accessible planetary body to Earth, any future mission launched to Venus will comparatively yield the greatest value of scientific knowledge at the lowest average cost of invested resources.

For the past sixty years, this pristine level of return on investment for Venusian missions has not been the case. The foremost factor being the inadequate level of technology that is required to survive the harsh conditions that the planet is known for. However, with the development of increasingly durable materials and fundamentally sound scientific instruments, the cost to benefit ratio of prioritizing missions to Venus continues to grow. Historically, missions to Venus have been directed at mapping the planet's surface. A majority of these missions failed, with only sixteen of the forty-six attempted being deemed a success [3]. Table 2.1 illustrates eight of the most influential missions as it pertains to the atmosphere of Venus.

The first successful orbital mission to Venus occurred in 1967, when the Soviet Union, at the time, inserted Venera-4 into the clouds of the lower atmosphere [3]. The main objective of this probe was to develop a more complete mapping of the surface in conjunction with the information gathered from USA's Mariner-5 flyby mission [3]. Two more successful missions occurred in 1969 with Venera-5 and Venera-6 [3]. These two probes implemented photometers to provide a more detailed picture of how light interacts in the lower atmosphere. Three years later in 1972 the Venera-8 lander was the first successful mission to touch the surface of Venus while remaining operational, albeit only for fifty minutes and eleven seconds [3]. This monumental achievement would pave the way for future orbital / lander missions and provided important data on where the lower atmosphere ends and the upper atmosphere begins.

Table 2.1. Previous Venusian Orbital Missions

Mission	**Start of Operation**	**End of Operation**	**Orbital Altitude**	**Measurement Altitude**
			Km	Km
Venera-9	Oct. 21, 1975	Mar. 22, 1976	1,500	30 - 40
Venera-10	Oct. 24, 1975	Jun. 14, 1976	1,500	40 - 60
Pioneer Venus	Dec. 05, 1978	Oct. 08, 1992	180	70 - 80
Venera-15	Oct. 09, 1983	Jun. 29, 1984	1,000	10 - 50
Venera-16	Oct. 10, 1983	Jun. 13, 1985	1,000	10 - 50
Magellan	Aug. 10, 1990	Oct. 13, 1994	200	Surface - 10
Venus Express	Apr. 15, 2006	Nov. 27, 2014	250	Surface - 40
Akatsuki	Dec. 07, 2015	In Orbit	500	10 - 70

The next wave of Venusian missions began with Venera-9 and Venera-10 in 1975, three years after the most recent Venera-8 lander [3]. A substantial jump in available technology allowed for the capture of the first image of Venus from the surface. In addition to this, supplementary data regarding the depth and composition of Venus' cloud cover was obtained. Following the immense success of the Venera program, USA produced its own Venusian orbiter with the Pioneer Venus 1 and 2 missions in 1978 [3]. A plethora of information was gathered, including data on the vertical distribution of clouds, IR emissions from the upper atmosphere, characterization of the planet's magnetic field, thermal properties of the ionosphere, and additional topography and surface condition data.

The Venera program progressed in 1981 with the successful landings of Venera-13 and Venera-14 [3]. A continuation of the scientific interests presented in their predecessors, the thirteenth and fourteenth Venera missions had objectives based in capturing photographs of the planet's surface that may show indications of prior or existing life. Unfortunately, no such evidence was recorded. However, further information on the soil composition of the landing site was acquired, as well as the first sound to be transcribed back to Earth. Two years later, in 1983, the Venera-15 and Venera-16 missions were successfully put into Venusian orbit [3]. These orbiters marked the longest duration for an orbiter around the planet, as they were able to provide nine months of continuous data. Together, these orbiters were able to image the entirety of the north pole down to the 30 degree latitude region.

The next mission to be successfully put into long-term Venusian orbit was USA's Magellan in 1989. The most successful Venusian operation to date, Magellan was able to produce several high-resolution photographs of the planet's surface, establish a consistent communication and data processing line. In addition to this, a nearly complete geographic map of Venus was constructed during its four and a half year mission duration. Magellan would set the precedence for what a successful mission to Venus should entail for the coming century. Thirty years later, the images captured by this orbiter are still the highest resolution photographs taken of the Venusian surface.

A decade and a half later, in 2005, Venus Express would take up the mantle that Magellan left behind [3]. An orbiter produced by the European Space Agency (ESA), Venus Express would stay in orbit around the planet for over nine years. The objectives of this orbiter were to observe the lower atmosphere in depth, specifically how plasma impacts atmospheric circulation. A variety of instruments were installed on the spacecraft to provide a wide range of channels through which data can be accumulated. Some of these instruments include a Magnetometer (MAG), an Analyzer of Space Plasmas and Energetic Atoms (ASPERA-4), and a Planetary Fourier Spectrometer (PFS) [3]. The information gained from Venus Express would prove to be the most influential data on understanding Venus as a whole, until JAXA launched Akatsuki in 2015 [4].

Akatsuki is the only current operational mission for Venus in the year 2023. The orbiter is planned to be active until 2027, as it is continuing to provide valuable information on the lower atmosphere. Complexities surrounding the upper regions of Venus' cloud cover were made apparent with additional data from the satellite. The orbiter is equipped with six instruments, the most important of which are an Ultraviolet Imager (UVI), a Long-Wave Infrared Camera (LIR), and a Lighting and Airglow Camera (LAC). These three tools measure the distribution of sulfur dioxide in the formation of clouds in the lower atmosphere, the convection and temperature of clouds circa the 80 kilometer mark, and the circulation of airglow produced by O_2. Additional instruments such as an IR1, IR2, and ultra-stable oscillator (USO) provide ancillary data through varying frequencies [4]. Future missions to Venus have been deemed secondary due to the rise in popularity regarding the Artemis program and Mars as a whole. However, a few select journeys to our sister planet are planned to be launched around 2030.

Davinci+ is a probe set to descend slowly through the Venusian atmosphere down to the surface. The objective of this mission is to collect data about the chemical makeup and thermal gradient pressure of the various atmospheric thresholds. The probe will achieve this through *In-Situ* surveys of noble and trace gases utilizing a quadruple mass spectrometer (QMS) [3]. Its Russian counterpart, Venera-D is the continuation of the highly successful Venera program [3]. Unlike Davinci+, Venera-D is first and foremost an orbiter, cataloging

Table 2.2. Future Venusian Missions

Mission	**Start of Operation**	**Mission Type**	**Orbital Altitude**	**Measurement Altitude** Km
			Km	300 - Surface
Davinci+	2031	Probe	0	120 - 300
Venera-D	2029	Orbiter + Lander	400	Surface
EnVision	2031	Orbiter	300	Surface
~~Veritas~~	~~-~~	~~Orbiter~~	~~-~~	

information from the outer reaches of Venus' extended ionosphere and upper atmosphere. The data this mission will collect, in conjunction with that of ESA's EnVision 2031, will be an essential step in formulating a complete understanding of the impact that the atmosphere has on the planet as a whole through spectrometric research [3].

NASA had planned to launch an accompanying mission for Davinci+ in the Veritas program [3]. However, as of March, 2023, the current status of that program has been terminated due to a lack of funding. Two fundamental aspects regarding humanity's role surrounding Venus have become clear throughout the sixty-year history of missions: the lack of knowledge surrounding the atmosphere and the impressive rate at which technology has been developed to confront the harsh Venusian conditions. These two parallel attributes are the key to accumulating an elevated understanding of Venus, Earth, and the greater cosmos.

III. A Network of Satellites

The state of the art regarding the overall knowledge of Venus has numerous gaps that need to be addressed before future missions and investments should be considered. The dynamics and chemical tendencies of the atmosphere being the largest of these voids. A series of dedicated orbiters whose objectives are to develop a better understanding of planetary characteristics is a step in filling this cavity.

A. Atmospheric Stratification

Venus' atmosphere begins above the surface and stretches out into the extended ionosphere, the edge of which is located at 350 kilometers [1]. The lower atmosphere (Surface - 80 kilometers) consists of two primary thresholds that are accompanied by two auxiliary regions. These being the Troposphere, Mesosphere, Tropopause, and Mesopause, respectively. Venus' Troposphere begins at the surface and extends to the 65 kilometer mark, containing nearly ninety-nine percent of the planet's atmosphere by mass [1]. This region also includes the Venusian habitable zone, a sector with comparable pressure and temperature to that of Earth (1 Bar / 300 K), existing in the space between 52.4 and 54.1 kilometers (Image 001) [5]. In conjunction with the homogeneous pressure and temperature, this small two kilometer region maintains a cyclostrophic flow of wind [6]. In short, the atmospheric distribution of pressure is balanced in this zone, resulting in minimal centrifugal forces. These three factors distinguish the habitat zone as an optimal location for human-centered design platforms to reside at in the future. The HAVOC theory is one such proposal that seeks to take advantage of these conditions [7].

The Troposphere is home to the Tropopause (60 - 70 kilometers), also referred to as the upper cloud deck [3]. The majority of information regarding the motion of Venusian clouds have been observed in this zone through ultraviolet wavelengths. The Tropopause is a transition region of the atmosphere, as it blends with the emerging Mesosphere. The Venusian Mesosphere (65 - 120 kilometers) extends much farther than Earth's, whose upper limits of the lower atmosphere ends at 80 kilometers. Venus' Mesosphere is divided into three regions, the lower (62 - 73 kilometers), the upper (73 - 95 kilometers), and the Mesospause (95 - 120 kilometers) [3]. The Mesospause indicates the beginning of the upper atmosphere as it pertains to Venus.

Located in the middle of the Mesospause is a thin Ozone layer circa the 100 kilometer mark. This section of Ozone is crucial to the development of chemical reactions between the upper and lower atmosphere and will play a pivotal role in understanding the planet's complex atmospheric systems [8]. At the height of 120 kilometers the Mesosphere bleeds into the Thermosphere.

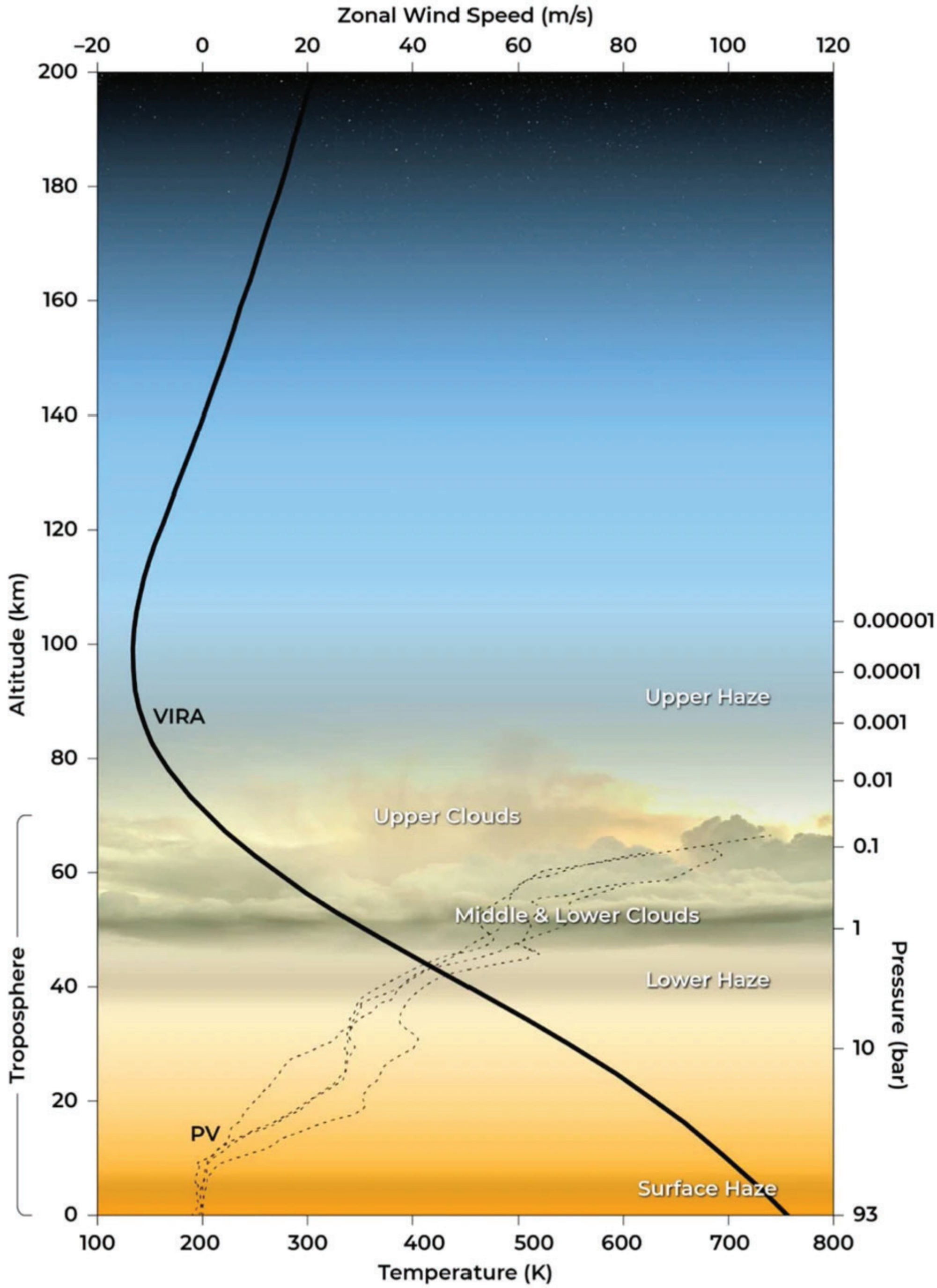

Figure 3.1. The Present Day Atmosphere of Venus

The Thermosphere, (120 - 220 kilometers) is throughly blended with the Ionosphere (120 - 300 kilometers), as each of these regions do not have a definitive beginning and end like their counterparts in the lower atmosphere. This is mainly due to the lack of research. Three subsections reside in this portion of the upper atmosphere: V_1 (120 to 150 kilometers), V_2 (140 - 160 kilometers), and V_3 (200 - 250 kilometers).

Each of these atmospheric divisions host varying chemical compositions and UV absorbers, allowing for the volume of external heat trapped to far exceed the natural limit, thereby contributing to the heightened global albedo level [8]. Two final zones occupy the edge of the upper atmosphere, the Ionopause (220 - 375 kilometers) and the Magnetopause (300 - 350 kilometers) [3]. These regions are heavily influenced from external solar events and act as the chemical gatekeeper of the planet.

Venusian atmospheric zones have noticeable chemical reactions due to the differences in temperature, pressure, atmospheric loss, and susceptibility to external solar effects. Venus' atmosphere consist of 96.5% CO_2, 3.4 % N, 0.5 % Sulfur Dioxide, as well as several other inconsequential compounds and elements that generate the remaining 0.1% of the atmosphere [1]. CO_2 is an excellent compound at trapping heat. Therefore, there is no surprise that Venus has the highest albedo level in the solar system. However, the method and quantity in which this heat is trapped is dependent on each atmospheric strata, a process that requires further investigation to fully comprehend. Furthermore, having an abundance of CO_2 in the atmosphere enables a large sample size of how the compound interacts with external elements present in the upper atmosphere, as well as with Ozone (O_3).

Currently, the information provided regarding the upper atmosphere shows that CO_2 reacts with trace levels of Atomic Oxygen (AO) near the 100 kilometer mark, that being the thin layer of Ozone [8]. The specifics of this reaction are unknown, but the end result is Hydroxide (OH) that is produced and emitted out of the upper atmosphere in the form of Hydroxyl airglow [8]. This process is an indication that certain compounds are being decomposed into core elements and then reconstructed, potentially multiple times within multiple stratas. Further research on how and why these chemical reactions occur would allow these processes to be reverse-engineered, enabling additional methods of creating vital elements and compounds in future scenarios. Table 3.1 illustrates four proposed satellite missions that aim to garner more information regarding this process.

Table 3.1. Proposed Satellite Missions

Mission	Start of Operation	End of Operation	Orbital Altitude	Measurement Altitude
			Km	Km
Asimov	2029	2040	15,000	15,000 - 2,000
Farley	2029	2050	1,000,000	300 - 150
Burroughs	2032	2040	2,000	150 - 70
Clarke	2032	2040	30,000	250 - 100

B. Asimov

The proposed satellite missions are designed to provide detailed information about a specific region of the atmosphere, while accomplishing secondary objectives that are unique to their orbital altitude. Each satellite's long-term goal is to act as a relay network once the *In-Situ* laboratory has been deployed in the atmosphere of Venus itself. The nomenclature of each satellite was derived from that of a prominent science fiction author that wrote extensively on the wonders of Venus. The objectives for the Asimov orbiter are as follows:

1) Provide continuous coverage of Venus' night-side and magnetotail

2) Determine current technological limits as it pertains to communication, power, and navigation

3) Gather data on the manifestation process of space weather

Asimov is to be located in Upper Venusian Orbit (UVO), 15,000 kilometers above the surface, for a period of ten years. The satellite seeks to gather data about Venus' Ionosphere and Magnetotail, that is, information on how airglow emissions interact with the highly eccentric ions outside of the upper atmosphere. Data will be collected via three main scientific instruments: a Michelson Interferometer for Global High Resolution Thermospheric Imager (MIGHTI), a Far Ultraviolet Imager (FUV), and an Ion Drift and Ion Velocity Meter (IVM). MIGHTI is focused on gathering additional statistics on how Atomic Oxygen interacts with the shifting temperatures and circulation velocity within the upper atmosphere [9]. Data that could be crucial when attempting to solve the mystery of Hydroxyl Airglow. FUV's are a supplementary imager that provide data on where these reactions with Atomic Oxygen are occurring.

IVM's are a device that are designed to collect *In-Situ* data about the velocity and motion of nearby ions [10]. Asimov will be orbiting within Venus' magnetotail, allowing for a continuous influx of information to be obtained and cataloged regarding the tendencies of ions in an extra-planetary environment. The objectives of Asimov are akin to a satellite currently positioned over Earth: the Ionospheric Connection Explorer (ICON), launched in 2018 [10]. NASA developed this program to garner a better understanding of the interaction between space weather and Earth's own weather patterns in the upper atmosphere. Asimov will seek to accomplish a similar goal for Venus.

C. Farley

The objectives for the Farley satellite are as follows:

1) Provide continuous coverage of Venus' day-side

2) Monitor the impact that solar events have on the upper atmosphere

3) Establish climate and temperature profiles in the 150 - 300 kilometer range

4) Establish a line of communication and data transfer

Farley is unlike the other three proposed satellite missions, as it will be positioned in the Venus-Sun Lagrange Point 1, a million kilometers away from the planet. Here, the satellite will stay in a periodic orbit around the libation point to maintain equilibrium. The purpose of this location is two-fold. First, to act as a lighthouse for Venus, alerting other satellites and future ISRU research platforms when a solar event is moving toward the planet. This allows the data collected during these periods of elevated solar activity to be understood with greater clarity. Secondly, due to the stability of Lagrange Point 1, a satellite will be able to maintain its position indefinitely, allowing for continuous coverage of the planet's Thermosphere and Ionosphere.

In order to take advantage of this opportunity, four scientific instruments will be installed on Farley:

a Faraday Cup (FC), a Venus Polychromatic Imaging Camera (VPIC), a Plasma Magnetometer (PlasMag), and a National Institute of Standards and Technology Radiometer (NISTAR) [11]. FC's serve the role of the light in the lighthouse analogy. Providing real-time data on proton density, speed, and direction within incoming solar winds. This information, coupled with data gained from the PlasMag, will begin to illustrate how external events affect the induced magnetic field around Venus [11].

NISTAR is incorporated into Farley's arsenal to provide additional data on Venus' global albedo effect. This device can measure the reflection levels off of the planet and be used to create climate pattern databases [11]. The most important aspect of Farley, however, is the ability to provide continuous coverage of Venus' day-side. A satellite whose location can be maintained allows for a clear line of data transfer, which will become vital when attempting to establish the *In-Situ* research station [12]. Many of Farley's objectives align with that of the Deep Space Climate Observatory (DSCOVR) satellite launched by NASA in 2015 [13].

D. Burroughs

The objectives for the Burroughs orbiter are as follows:

1) Monitor the effect of atmospheric loss

2) Monitor chemical and atomic fluctuation in the upper atmosphere

3) Monitor the extent through which photochemistry impacts atmospheric ozone levels

The Burroughs satellite mission is set to be located in Middle Venusian Orbit (MVO), 2,000 kilometers above the surface. This orbiter's objectives are the forerunner for the objectives of the *In-Situ* research platform. Three scientific instruments are installed on the satellite to monitor Venus' Tropopause, Mesosphere, and Mesospause: a Venus Atmospheric Structure Investigation Tool (VASI), a Planetary Fourier Spectrometer (PFS), and a Spectroscopy Suite in the H + U domains (Spec).

VASI is designed to reveal aspects of the electromagnetic spectrum in infrared, a channel of data that distinguishes the innate differences in chemical reactions based on the atmospheric strata they are occurring in. PFS is an instrument that was incorporated into the Venus Express mission, however the technology failed to work as intended and was not able to provide data [3]. A new design that is more robust, as well as a more insightful orbital altitude, will allow the instrument to succeed. PFS is designed to reveal minor atmospheric constituents that may have additional ramifications in upper atmospheric chemical processes [14]. Spec, on the other hand, is meant to obtain data on UV absorbers in the upper atmosphere [3].

E. Clarke

The objectives for the Clarke orbiter are as follows:

1) Monitor the effect of airglow emissions on both the night and day-side

2) Monitor the high energy collisions of electromagnetic radiation inside the magnetotail

The Clarke satellite mission is set to be located in Greater Venusian Orbit (GVO), 30,000 kilometers above the surface. The orbiter's objectives are to develop a greater understanding of Venus' Mesosphere, Thermosphere, Thermopause, Extended Ionosphere, and Magnetotail. Clarke will be equipped with three measurement devices: an Analyzer of Space Plasmas and Energetic Ions (ASPERA), a Magnetometer (MAG), and a Solar Occulation Infrared Spectrometer (SOIR). Venus Express boasted an ASPERA-4 on its mission in 2005, an upgrade from the previous model, ASPERA-3 that was utilized on the Mars Express mission [3]. Clarke will be equipped with an ASPERA-5, an innovation that allows the device to analyze the impact of plasma, ions, and electrons in the upper atmosphere, like its predecessors. However, with the additional ability to analyze data in multiple wavelengths, expounding upon the details of what elements and compounds are causing reactions to occur with plasma.

MAG's measure the strength of Venus' induced magnetic field. Coupled with Farley's PlasMag, positioned on the day-side of the planet, a complete picture of how the magnetic field is affected by ions, solar events, and the magnetotail can be constructed. SOIR is a device that will be used to monitor the Sun through the particles of Venus' atmosphere. Thereby providing a better understanding of what a perspective from the planet may look like [3].

F. The Machined Condition

Establishing an *In-Situ* research platform marks the transition of Venus from an organic planetary body to that of Neo-Machine Landscape. In essence, the arrival an architecture shifts the planet's ideologies to be rooted in synthesis rather than in nature. This manufactured conversion is inevitable as long as humanity remains at the helm of innovation and exploration. In this way, it is vital that precautions are put into place to understand the current and future state of the atmosphere, enabling the machined condition. Humanity's current knowledge of the planet demonstrates that atmospheric conditions are the result of several key interactions dependent on one another. The process begins externally, as the proximity of Venus' orbit permits solar events to have a greater effect on the planet. These events penetrate the upper atmosphere, elevating the adiabatic heating process in the upper cloud deck (90 - 150 kilometers) [12]. In short, the reactions that occur in this zone are happening at such a rate that the process through which heat should be able to escape is being prevented. A heightened adiabatic heating process provides evidence that these reactions have an intrinsic chemical reason to rapidly occur. The tentative answer for why this is the case is due to the number of mysterious UV absorbers that are known to be present within the upper atmosphere [15].

The Farley satellite, proposed to be stationed at the Venus-Sun Lagrange Point 1, has a set of objectives aimed at cataloging additional data to better comprehend this concept. Likewise, Burroughs, positioned in MVO, provides more information on the tendencies of said UV absorbers. The population and diversity of which is believed to be the leading cause for Venus' severe global albedo effect. Additional details regarding the Mesosphere and Thermosphere enables a level of clarity to comprehend '*why*' and '*what*' these UV absorbers are.

Asimov and Clarkes' proposed objectives are directed at understanding Venus' night-side and magnetotail. Auroral emissions are believed to have a substantial impact on ions' velocity and direction within the extended ionosphere. Future data will be vital in grasping how interplanetary communication between Earth and Venus could be impacted in the future. In a sense, the collective knowledge of orbital missions generate a chemical map of the atmosphere that future architectures will inhabit, such as the proposed *In-Situ* Research and Demonstration Laboratory: The Floating Allotment.

IV. Floating Allotments

The proposed *In-Situ* research and technical demonstration platform (*Floating Allotment*) has been designed to fill the scientific gaps that orbital missions do not have access to. In this way, a Floating Allotment demonstrates the capabilities of an autonomous system in a hazardous environment. As such, the requirements to develop a successful architecture are prioritized first through generating the necessary scientific data from the atmosphere of Venus, and secondly by establishing a platform through which human-factor expansions can be executed.

The platform's objectives will be separated into two categories, scientific and technical. The iterative use of form and material will foster a better prepared mission planning process for subsequent operations, allowing the architecture and equipped technology to gradually adapt to the surrounding environment. Both the scientific and technical objectives have been instrumental in deriving the form of the float and the Laboratory, (Gondola) itself.

A. The Built Environment

Developing an architecture that is designed to endure the harsh conditions of the Venusian atmosphere for an extended period of time requires an in-depth analysis into the aerodynamics, external atmospheric conditions, form, function, and materials. The proposed result is an autonomous float that resides near the equator at a stable altitude of 52.4 kilometers. Incorporating the right combination of flotation gases is critical to ensure the architecture maintains hydrostatic balance. As such, the form, total mass, and location of the floating allotment has been thoroughly programmed.

Measuring 18.5 Feet in Length, 15 Feet in Width, and 10.5 Feet in Height, the Gondola is supported through four (16' x 2' x 3.5') Tethers. Each of the four Tethers are installed with internal ballonets, designed to filter the quantity of flotation gases entering the aerostat. The aerostat measures 70 Feet in Length, 18 Feet at its widest point, and 65 Feet in Height.

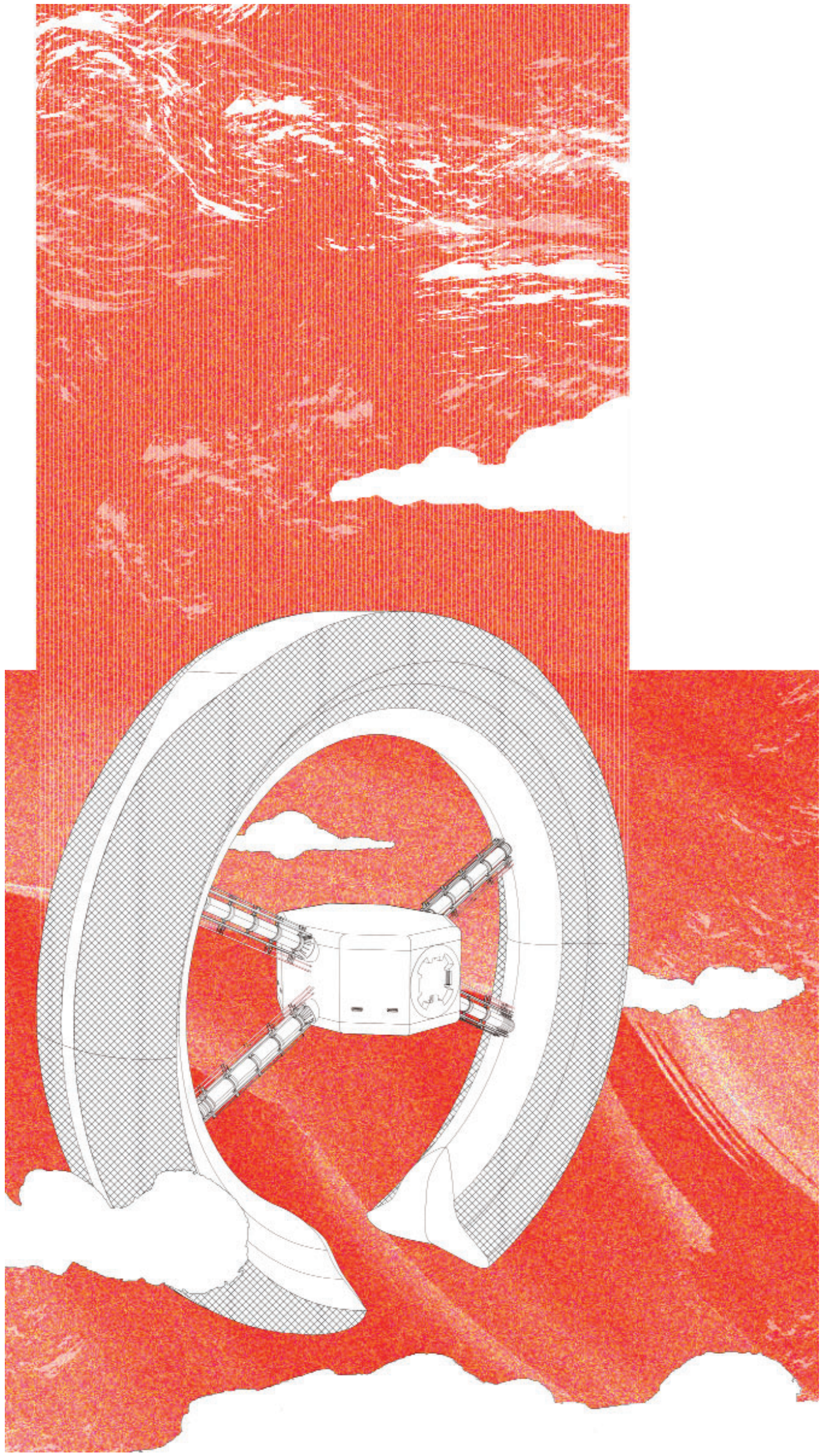

Figure 4.1. Floating Allotment Concept Illustration

The material pallet is paramount in determining the effectiveness of an aerostat proposal in Venus' atmosphere. The ability to resist the perpetual bombardment of Sulfuric Acid as well as maintaining the lightest total mass were the main drivers in material selection. Table 4.1 shows the core materials selected to perform these tasks.

Table 4.1. The Built Environment

Material	Molecular Composition	Grams / Molar Mass	Applied Location	H_2SO_4 Exposure
			Floating Allotment	Days before Spalling
Inconel 625	Ni + Cr + Fe + Mo	60.1863	Laboratory	486
Stainless Steel 304	Fe + Cr + Ni	53.1135	Lab + Tether	182
Iridium	Ir	192.217	Tether	674
Mylar (PET)	$C_{10}H_8O_4$	25	Envelope Shell	- -
Teflon (PTFE)	$C_2 F_4$	450	Envelope Shell	- -

Inconel 625: Ni (67%, >58) / Chromium (20%) / Iron (5%) / Molybdenum (8%)
Stainless Steel 304: Iron (70%) / Chromium (18%) / Nickle (8%)

Stainless Steel (SS) 304 and Inconel 625 are the primary materials of construction for several reasons. Studies conducted in 2018 showed that Nickle, Platinum, Copper, and Lead demonstrated the highest risk to react and form sulfides when exposed to H_2SO_4 for long periods of time [16]. However, Nickle is a strong resistant metal that exhibits remarkable tensile strength. A small amount of Nickle has proven to be more beneficial than none at all, as the amount of strength that it provides to the overall material composition is greater than the vulnerability it has toward Sulfuric Acid. SS 304 has an optimal amount of Nickle (roughly 8%) to provide that strength boon, while letting Iron and Chromium do the majority of the work. In accordance with this, Iron and Chromium are both lighter metals than Nickle (55.8, 51.9, and 58.7 Grams / Molar Mass), allowing the overall mass of SS 304 (53.1135 Grams / Molar Mass), and the Gondola itself, to be evaluated at an efficient mark. SS 304 is the optimal secondary material to support the primary, Inconel 625.

a higher percentage of Chromium into its composition. Consisting primarily of Nickle (roughly 65%), it is known to be an expensive metal that is extremely resistant to acidic properties. Slightly heavier than SS 304, due to the added percentage of Nickle, Inconel 625 has demonstrated its ability to be highly resistant to corrosive properties, with studies showing that the super-alloy is less brittle when exposed to higher temperatures [17]. These qualities are ideal when discussing the Venusian atmosphere due to the potentially large fluctuations of heat from the planet's super-rotation and global albedo effects. For these reasons, Inconel 625 can be considered one of the more complete metals when designing a long-term mission to Venus' atmosphere. The super-alloy will be the primary material used to construct the Gondola, with many of the internal support and Tether systems fashioned out of SS 304 to reduce the total mass.

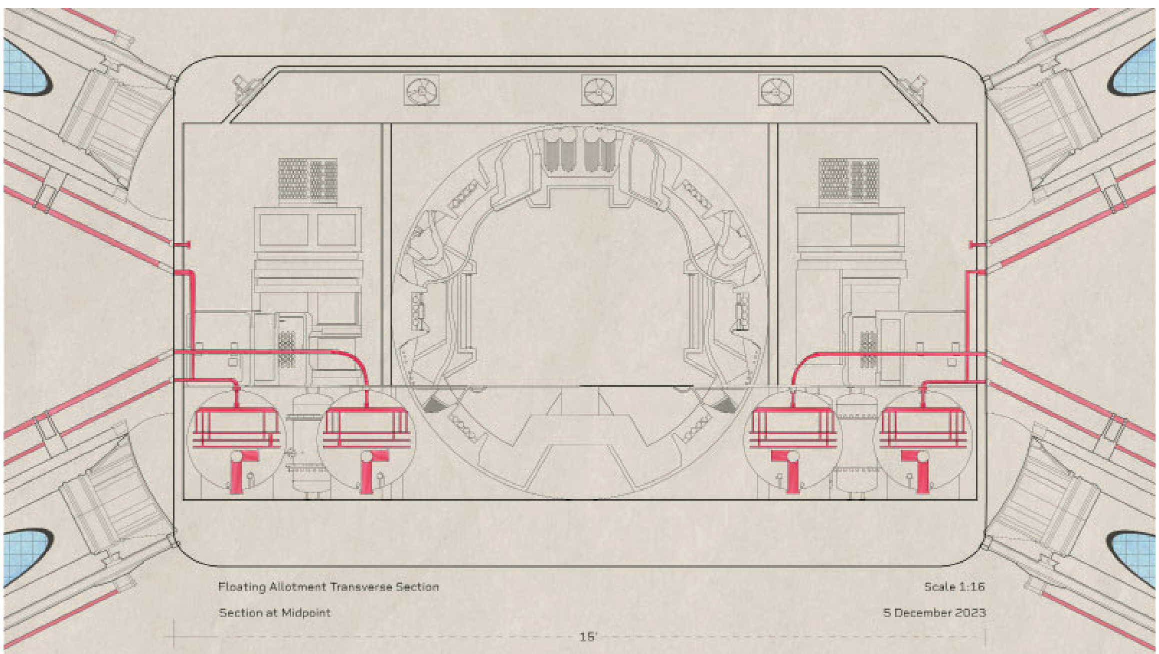

Figure 4.2. Floating Allotment Gondola Transverse Section

Each of the four supporting Tethers are constructed primarily of Stainless Steel 304 with ancillary parts being fabricated from Iridium. Iridium is a transition metal in the platinum group with the atomic number of 77. The element is known to be durable at higher temperatures and extremely resistant to corrosive substances at the cost of being a fairly dense metal. (192.217 Grams) [18]. The Tether's architectural makeup is fairly simple, as the main function is to provide support between the central Gondola and the exterior envelope of the surrounding aerostat. Iridium Beams support a SS 304 Frame that houses four chambers which are used to separate two of the flotation gases that control the buoyancy level of the entire system. The four chambers are separated into two groups: two main chambers that loosely hold the heavier of the two gases, Silane (SiH_4), and two ballonets that contain the lighter of the two gases, Ammonia (NH_3). Each of the Tethers are attached to the central Gondola through a gimbal. This half-sphere connection completes several engineering objectives through one mechanical design. That is, the gimbal allows for the Tethers to have a flexible range of motion once fully deployed, thereby adding yet another layer through which the system can bend rather than break. Furthermore, the gimbal is triple insulated, granting a much lower risk of corrosive failure. This is to say, as opposed to a single-point connection, a sphere allows the natural degradation of sulfuric acid to be spread out across a larger surface area before the system is compromised. As a final layer of support, Iridium beams that run the length of the Tether are firmly attached to the Gondola's external frame. A series of exposed piping runs parallel to the Iridium supports, whose entire function is to facilitate the buoyancy levels between the Gondola, Tethers, and Aerostat. The piping is encased in a double laced Inconel 625 tube.

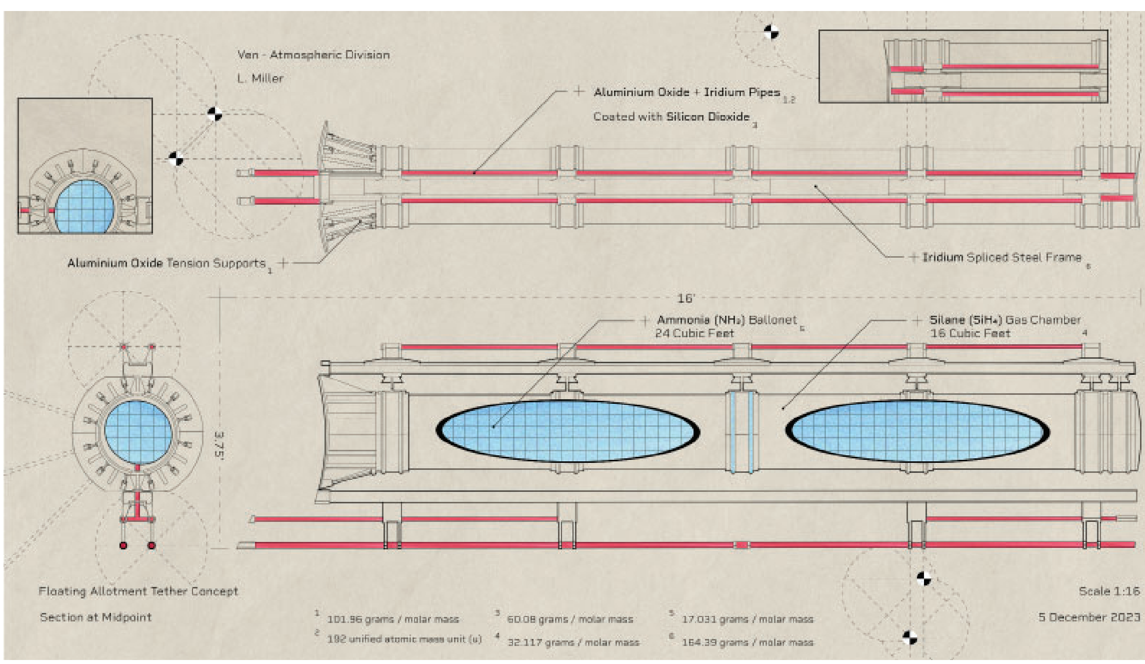

Figure 4.3. Tether System Diagram

The third, and most prominent, aspect of the Floating Allotment is the surrounding aerostat, which boasts an approximate volume of 22,654 cubic feet, when fully inflated. This internal volume can easily be categorized into sections, allowing for the user to facilitate the separation of flotation gases. The toroidal shape is what enables this flexibility, as each connected Tether can be assigned a specific duty that either works independently of the other Tethers, or together, as a cohesive structure. The toroidal form has been derived from functional purposes that the floating allotment needs to achieve. In essence, it is a combination of several types of platforms, those being Zero-Pressure Balloons (ZPB's), Super-Pressure Balloons (SPB's), Solar Powered Airships, and Phase Change Balloons (PCB's) [19]. Further research into trade studies such as Thermal Platforms, Probes, Gliders, and Kites were conducted, but found no substantial impact for the requirements of this proposal.

ZPB's are designed to have a freely expandable envelope, which typically means that their buoyancy equilibrium changes based on the altitude that said platform is either ascending or descending toward. In addition to this, many ZPB's are designed with a venting mechanism, which enables the platform to maintain control over the status of its internal equilibrium. Unlike ZPB's, SPB's look to maintain their envelope's volume, which in turn restricts the platform to a fixed altitude [20]. As such, the vertical stability of SPB's is much higher. Two types of SPB's are commonly used, near-spherical platforms (VEGA 1 + 2) and pumpkin platforms (terrestrial use) [19]. The most complicated of the three balloon types are PCB's, as they use Phase Change Fluids (PCF's) to alter their internal buoyancy levels depending on the situation [19]. This either occurs in a cyclical fashion during the mission, or once, initially, during the descent of the vessel into the atmosphere.

The Floating Allotment proposal is a mixture of these three platform types, with the added benefit of solar powered photo-voltaic panels. A defined altitude of operation (52.4 Km) means aspects can be absorbed from SPB's to increase the vertical stability of the Floating Allotment. A descent from orbit means that strategies can be incorporated from PCB's to ensure proper deployment into the lower atmosphere. A fluctuating internal buoyancy level from an autonomous laboratory means that features from ZPB's can be integrated to maintain hydrostatic balance.

The Floating Allotment is most akin to PCB's with regard to each being designed around accomplishing scientific objectives. Figure 4.4 Demonstrates a general proposal for how PCB's operate in the Venusian environment [19].

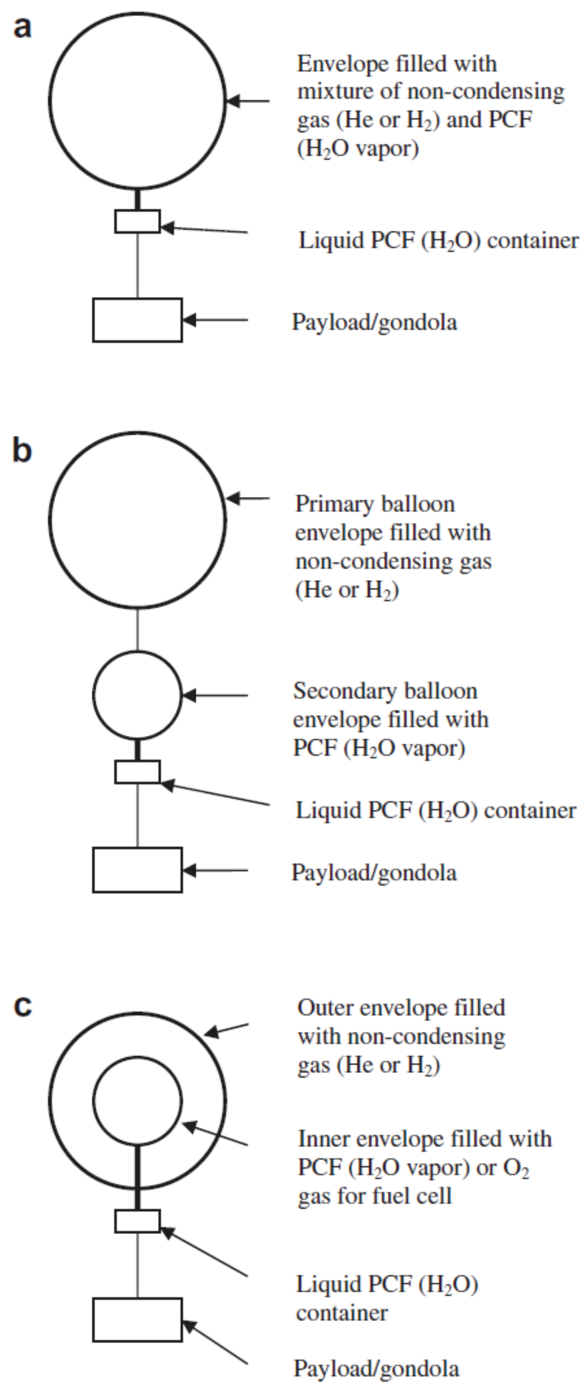

Figure 4.4. Schematics of Phase Change Balloons

PCB’s are typically prepared for short-term missions, and as such contain much lighter payloads. This is evident through the one supporting tether between the gondola and envelope, a liability for any long-term mission. For this reason, a more durable support system (Figure 4.3) had to be developed for the Floating Allotment proposal. In doing so, the float itself needed to be designed around the ability to accommodate the new support system, ergo, the development of the toroidal form.

In addition to this, the form is more aerodynamic, when considering long-term missions, than the traditional near-spherical platform proposals. This rudimentary shape is excellent for what it is designed for, short-term expenditure. However, when asked to perform over the course of months and years, a sphere is much more susceptible to damage that could compromise the mission due to how smooth the exterior envelope is. A toroidal shape not only reduces the total mass of the float, but allows for a greatly reduced surface area, thereby minimizing the risk of damage to the envelope. Furthermore, a sphere-shaped platform has no strong or weak points, meaning the same level of protection is needed at every point of contact. A toroidal shape allows for a “guarded zone” to occur, that is a space on the inside of the float that is more shielded that other portions of said aerostat. Therefore, hazardous sulfuric acid is less likely to impact this inside area of the float. Yet another way to save mass through the use of lighter, less durable material.

The envelope of the float is comprised of two materials, a Teflon-based Polytetrafluoroethylene (PTFE) and a Mylar-based Polyethylene Terephthalate (PET). The PTFE is the heavier material, useful for the most exterior layer due to how resistant it is toward corrosive environments. On the other hand, PET, a material that is eighteen times lighter than PFTE (Table 4.1), is best suited for the guarded zones of the Floating Allotment. Still highly durable against the Venusian Atmosphere, just not to the degree that PFTE has proven to be [21]. Featured at the zenith of the aerostat is a band of forty photo-voltaic panels (PvP). Each panel measures three feet by three feet, and can produce around 2,640 Watts / M^2 at a 38% rate of efficiency; The global albedo effect of Venus elevates the effectiveness of solar panels by nearly 18%. Only 8,000 Watts / M^2 is needed to power the entire system (4 PvPs), however ten times that amount, in addition to sodium sulfur batteries, have been included in the proposal for a power-safety factor of twelve. Figure 4.5 diagrammatically depicts the Floating Allotment proposal in its entirety.

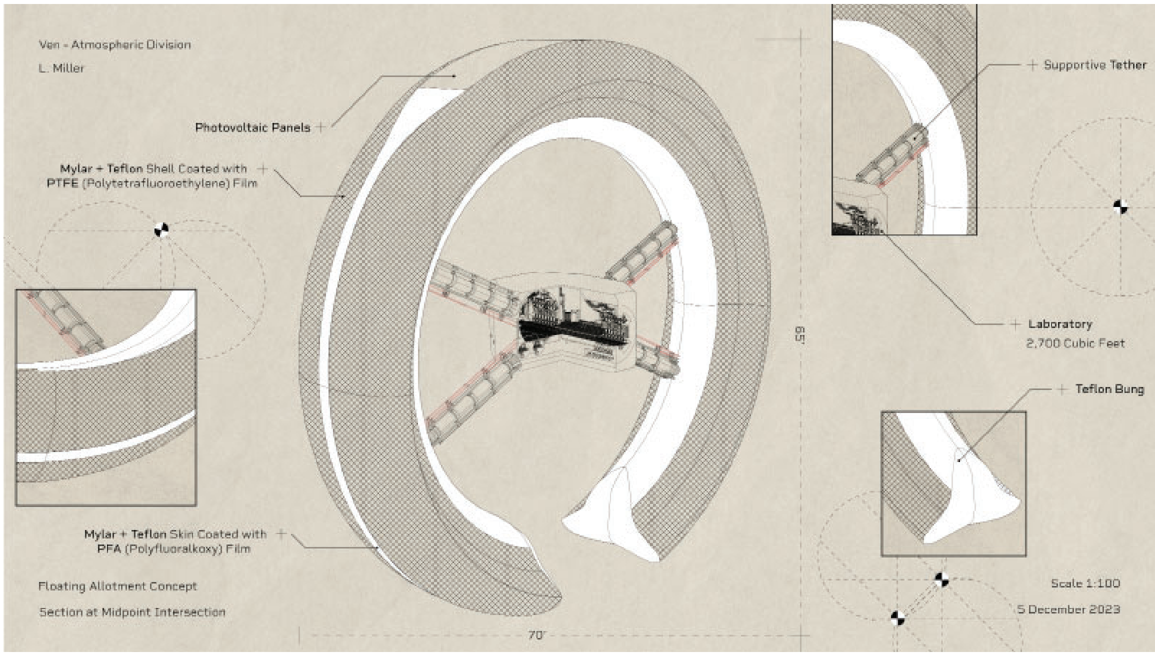

Figure 4.5. Floating Allotment Diagram

The interior of the gondola is the heart of the scientific operation, with several instruments positioned on-board to diagnose and analyze incoming data and chemicals. These include: an atmospheric inlet and outlet system, sulfuric acid distillation chamber + sulfur trioxide exit portal, fluid cables and piping, communication and data transfer systems, Nitr-Oxy decomposition and evaluation station, and a series of

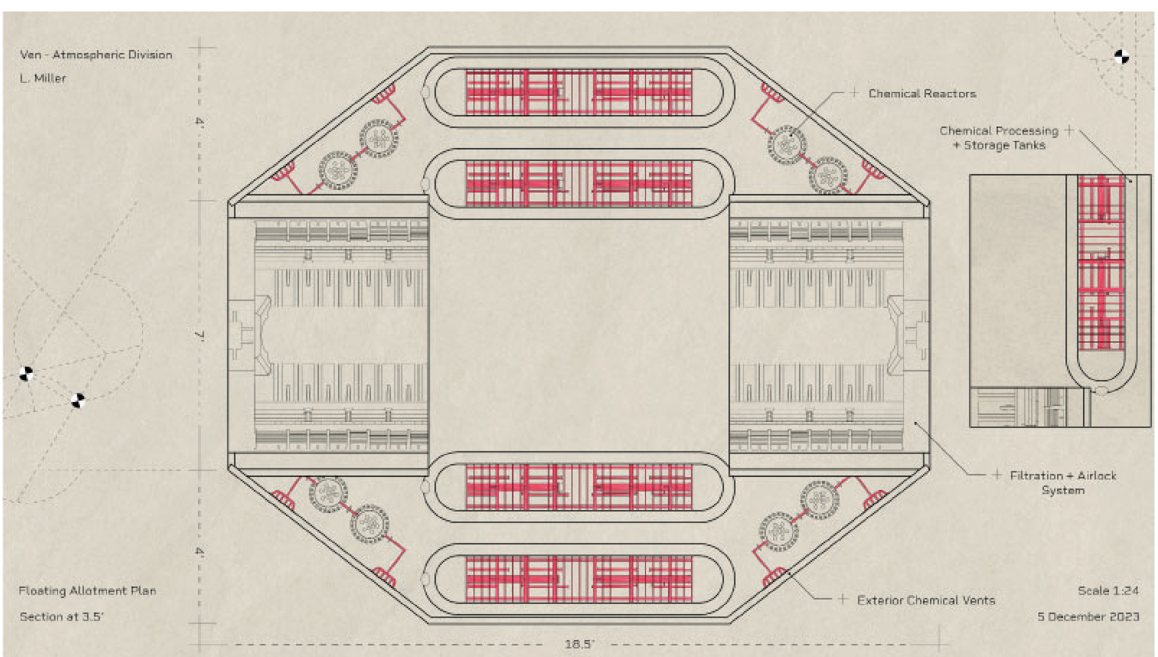

Figure 4.6. Floating Allotment Plan Diagram

All of the mass-mitigation strategies add up, allowing the entire architecture to have a total estimated mass of around 2,300 Kilograms. An extremely efficient number for the scale and duration of the proposed mission. Table 4.2 breaks down the mass of each relevant feature.

Table 4.2. Floating Allotment Total Mass Projections

Component	Quantity	Durability Factor	Mass	Volume
		Years Until Repair	Kg (Total)	Cubic Feet (Total)
Tether Shell	4	6	13.15 (52.6)	80 (360)
Ballonet	12	- -	0.624 (7.49)	24 (288)
Gondola (Lab)	1	1.5	(1,150)	(2,700)
Lab Equipment	24	2	(100.31)	Circa (80)
Float	1	8	(573.091)	(22,654)
Float (Envelope)	1	8	(248.061)	- -
Photo-voltaic Panels	40	2	13 (520)	4.5 (180)

Gondola Composition: Stainless Steel 304 (65%) + Inconel 625 (35%) = 55.58871 g/Mm

Float Envelope Composition: Teflon (PTFE) (80%) + Mylar (PET) (20%) = 365 g/Mm

B. Flotation Methodology

Archimedes' principle (1) is what allows an aerostat to maintain buoyancy equilibrium in Venus' atmosphere.

$$F_a = pgV \qquad 1$$

Weight of Displaced Fluid = Weight of Object in Vacuum - Weight of Object in Fluid

For this reason, lighter gases, such as breathable air, O_2, Nitrogen, etc. can be used as flotation gases. Table 4.3 lists the gases that have been selected to maintain the Floating Allotment's altitude level for this proposal.

Table 4.3. Flotation Methodology

Molecule	Molecule Composition	Grams / Molar Mass	Lifting Potential	Proposed Volume
			Mass(Tons) / Diameter(ft.)	Cubic Feet
Breathable Air	$N_2 + O_2$	28.96	4,000 / 500	1,520
Ammonia	NH_3	17.03	8,000 / 500	892
Silane	SiH_4	32.12	3,000 / 500	692
Methane	CH_4	16.04	8,250 / 500	- -

The Atmosphere of Venus is Primarily Constructed of CO_2 (96.5%) + N_2 (3.5%)

CO_2 Grams / Molar Mass: 44.095

N_2 Grams / Molar Mass: 28.0134

Breathable air can be featured as a flotation gas in the confines of the Gondola, as gas ventilation chambers separate the central Laboratory from the exterior atmosphere, acting like an airlock (Figure 4.6). This enables the Gondola itself to contribute to the total hydrostatic balance of the entire system, a benefit many proposals are not able to achieve. Breathable air is best suited for this scenario due to the idea that human involvement is a possibility during the deployment of the Floating Allotment. An interior space flooded with lighter gas such as Ammonia may be more efficient, but eliminates the possibility of human-centered repairs and experiments. However, Ammonia should be utilized to elevate the aerostat, as neither of the two prior conditions apply within the float. Ammonia has the greatest lifting potential at 8,000 Tons per 500 feet [22]. Silane has been proposed as a secondary flotation gas in order to provide a level of control and precision over the total buoyancy of the system. Both of these gases are stored within tanks in the central Laboratory, as well as in separate chambers / ballonets within the Tether system.

Figure 4.7 Illustrates the process through which flotation gases are deposited into the aerostat.

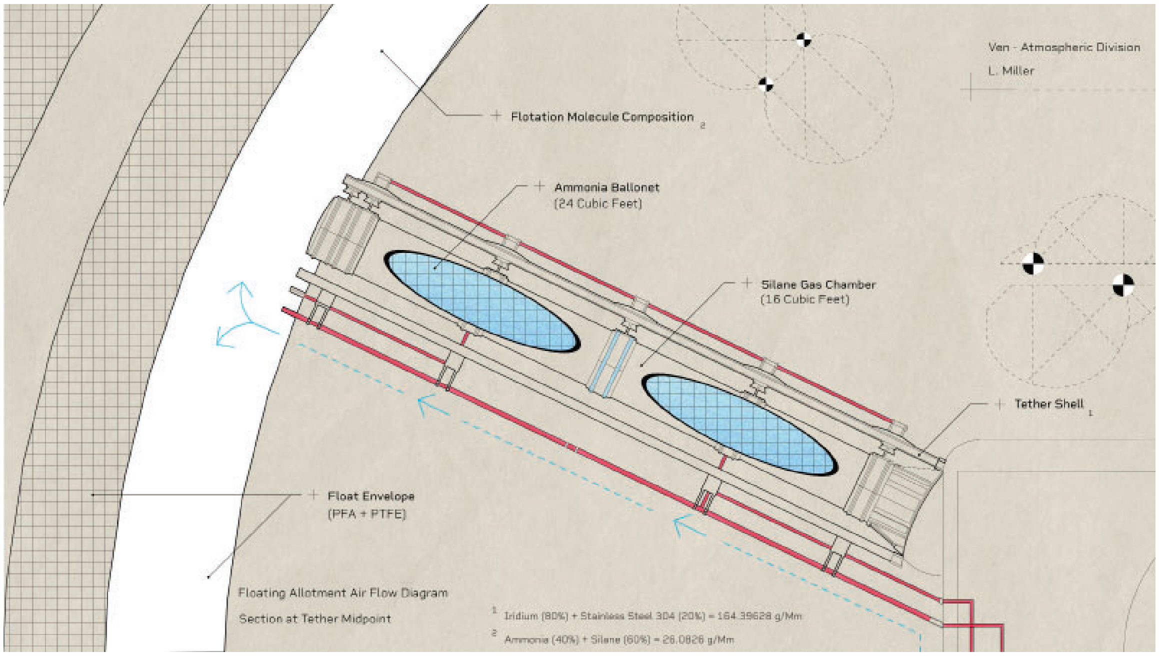

Figure 4.7. Injection of Flotation Gases into Aerostat

The process through which gases are deposited into the aerostat has been proven to work through the Maxwell-Boltzmann Velocity Distribution Law, which describes how the speed of individual gas molecules is affected through temperature. As the temperature rapidly changes during the descent of the Floating Allotment from orbit, the gas molecules within the Tethers will become excited, allowing for an intense amount of pressure to be released into the aerostat. Thereby providing a rapid boost in lifting potential during the initial descent. Similar strategies are used in PCB's [19]. The following laws are instrumental in understanding how a level of hydrostatic balance can be achieved over a long-term period of operation.

Boyle's Law (2) states that pressure exerted by a given mass is inversely proportional the volume it occupies if the temperature remains unchanged within a closed system [23]. This is critical in maintaining control over how much, and what gas, should be pumped into the aerostat, once equilibrium is initially achieved, to maintain the system's hydrostatic balance.

$$PV = k \tag{2}$$

Pressure multiplied by Volume = Constant

Charles' Law (3) states that when a pressure of a dry gas is held constant, the temperature and volume will maintain direct proportional status [23]. Similar to Boyle's Law, Charles' law emphasizes the importance of regulating temperatures within the gas chambers and ballonets. Thankfully, the proposed location (52.4 Km) has a fairly low temperature of 300 K, meaning that not a lot of energy will be needed to maintain a healthy temperature for the gases.

$$V = kT \tag{3}$$

Volume = a non-zero Constant multiplied by the Temperature of the Gas

Avogadro's Law (4) states that equal volume of all gases, at the same temperature and pressure, have the same number of molecules [23]. Tripling down on maintaining constant temperatures and pressures, Avogadro's Law proves that the amount of gas deposited from one source to another, down to a single molecule, will be constant.

$$V / n = k \tag{4}$$

Volume divided by the amount of Gas = a Constant

All of these laws add up into the Ideal Gas Law (5), which states that the state of a gas is determined by its pressure, volume and temperature [23].

$$pV = nRT = nk_BN_AT = Nk_BT \tag{5}$$

R = Universal Gas Constant (Product of Boltzmann + Avogadro Constants)

k_B = Boltzmann Constant

N_A = Avogadro Constant

In totality, complete knowledge of how each of these gas laws interact with the system and surrounding atmosphere is critical towards establishing an autonomous long-term mission.

C. Scientific Objectives

The scientific objectives for the *In-Situ* research platform are as follows:

1) Study heavy molecular ions

2) Monitor the meridional transfer of heat

3) Test the chemical production process of OH from O3

Heavy molecular ions (O_2^+ / CO_2^+ / N_2^+ / CO^+ / NO^+) have a tendency to escape Venus' atmosphere through a plasma sheet [14]. This is not the case for traditional ions, as generally they are gravitationally bound to the planet. The current theory for why heavy molecular ions supersede the gravitational effects lie with the interaction between external solar effects. Further testing of the intricacies of heavy molecular ions' atmospheric escape will provide additional measurements on the rate and quantity through which these ions are departing. This research, in conjunction with continued testing of the Bates-Nicolet mechanism and Kirchoff's Law of radiation, could lead to a breakthrough in replicating additional methods of producing H_2O and O_2 in hazardous and alien environments [8].

The proposed site for the floating allotment is within the Goldilocks zone, near the equator, at 52.4 kilometers above the surface. The interplay between the Mesosphere and Thermosphere, the lower and upper atmosphere, causes erratic weather patterns to occur. A perfect location to study how much of an impact the meridional transfer of heat has on these climate conditions. Physical testing of the interaction between O_3, AO, H, and OH will be influential in applying the theory behind the Bates-Nicolet mechanism paradox. A study that was conducted in 1950 revealed the production process for excited OH molecules escaping from the atmosphere [24]. This experiment was operated in Earth's atmosphere, but when the same modular process was applied to Venus, the vibrational intensity, when observed in infrared, of OH molecules, did not align with previous research [8]. Additional studies were conducted in other planetary atmospheres, yet the data for every other planet was in-line with that of Earth's atmospheric escape equation, Venus was an exception.

Generating a formula for how the Bates-Nicolet mechanism can be applied to the chemical reactions within Venus' atmosphere will provide details on how the complex photochemistry of each atmospheric strata interacts with each other. Moreover, an elevated acumen regarding the planet's thermal gradient pressure can be established within the same research process. Greater insight on these two processes could enable the synthetic process of reverse-engineering the chemical reactions between O_3, AO, H, and OH; allowing for yet another method of decomposing existing compounds into vital resources such as O_2 and H_2O.

Table 4.4 shows these gases of scientific interest.

Table 4.4. Gases of Scientific Interest

Molecule	Altitude	Observation Instrument	Window of Coverage	Analysis Type
$NO + O_2$	110	IR + UV Spec	Night-side	Data + Chemical
Hydroxyl Glow(OH)	95.3 ± 3	VIRTIS-H	Continuous	Data
O+	300 ± 50	IVM + PlasMag	Day-side	Data
O_3	100	VASI	Continuous	Chemical

VIRTIS-H: Visible + Infrared Thermal Imaging Spectrometer

IVM: Ion Drift / Velocity Meter

PlasMag: Plasma Magnetometer

VASI: Venus Atmospheric Structure Investigation Tool

D. Technical Objectives

The technical objectives for the *In-Situ* research platform are as follows:

1) Test the durability of the built environment in preparation for human-centered design additions

2) Test the reliability of data and information transfer technology

3) Experience the atmospheric habitable zone first-hand

4) Enable the arrival of human-tested habitat expansions in the future

Constructing an architectural platform that is able to withstand the hazardous conditions of the Venusian atmosphere is a challenging task. Material selection has a greater impact than in other scenarios, both for the survivability of the mission at hand and for conducting research that can be applied to future iterations. The same concept of material selection is applicable to the protective strategies put in place for the

Various equipment on-board. Two main obstacles will plague the developmental stages of establishing the Floating Allotment: maintaining a connection between orbiters and the Laboratory, and forging a built environment that can withstand hazardous atmospheric conditions while being accessible to maintenance.

Consequently, the secondary role of a floating allotment is to prepare the site for the pending arrival of a human presence, albeit for a short duration. The architecture must be designed to quell the demands of human-centered expansions, as well as preserve its core function of operating as an autonomous scientific and technical demonstration platform.

Figure 4.8 Illustrates what this may look like, with the arrival / departure ship containing all of the necessary ECLSS systems on-board.

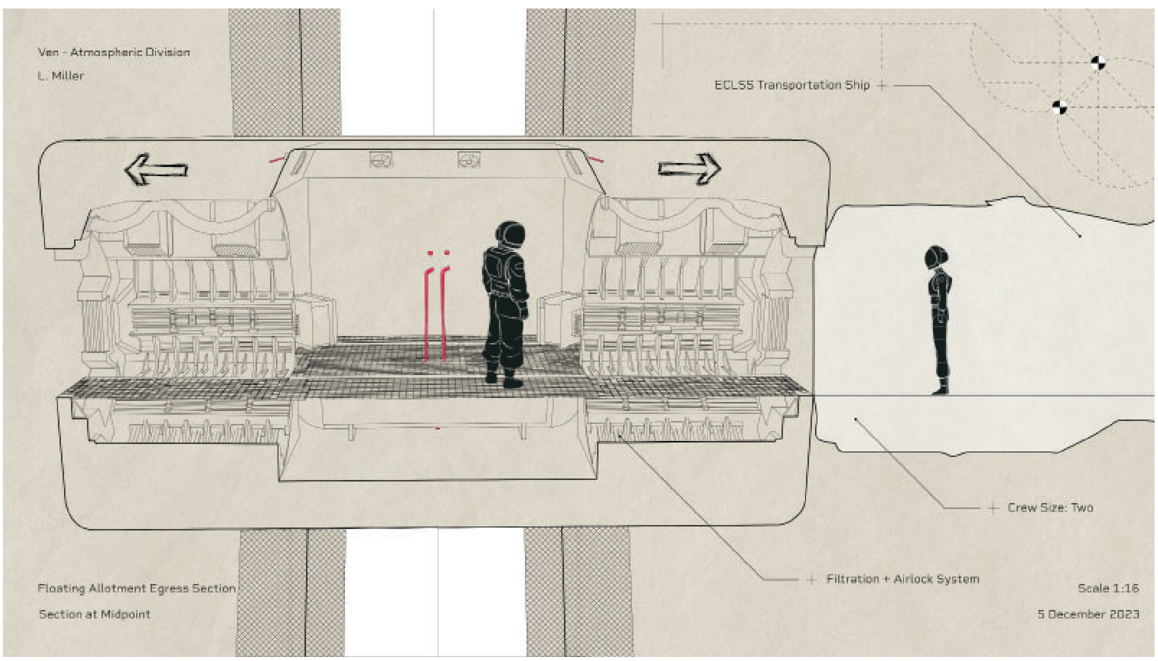

Figure 4.8. Floating Allotment Egress Section

E. Conclusion

Venus is the most accessible planet to Earth. It presents a plethora of atmospheric factors and concepts that are foreign to the rest of the solar system, yet abundant in the greater scope of the cosmos. Extreme shifts in pressure and temperature between stratas in the atmosphere, a heightened global albedo level, a planetary defining super-rotation effect, and strange reactions between foundational compounds and heavy molecular ions.

Investing in a series of missions that are dedicated at unveiling the secrets of Venus' atmosphere is the first step in truly preparing the future of human civilization for the challenges of the universe. Establishing *In-Situ* research stations in conjunction with a network of satellites enables the archival of these bizarre atmospheric interactions. In this way, humanity's comfort and readiness level with regards to extra-planetary exploration will be raised due to the technical and scientific knowledge gained from investing in Venus' atmosphere. As such, a greater percentage of future destinations can be considered habitable, expanding the scope through which the arms of humanity can grace the stars.

Venus can be the gateway for deep-space exploration. A proving-ground for hostile environments and delicate technology. An answer to future problems lies at the doorstep of Earth. Let's take advantage of it.

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