Venus Climate Orbiter and Autonomous Explorer

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1 Narrative

The 2013 - 2022 Planetary Sciences Decadal survey expressed the need for careful study of Venus' Climate as the only other example of a dense terrestrial planet atmosphere in our solar system. Venus with its greenhouse atmosphere has the potential to increase our understanding of climate change and its potential effects on our own planet. The Venus Climate Orbiter and Autonomous Explorer [VCOAX] aims to address this particular need of the scientific community by placing a highly capable orbiter around Venus as well as deploying an autonomous semi-buoyant helicopter to study the atmosphere and landscape of Venus in-situ.

While the data to be collected by the orbiter will be novel and more extensive than anything previously available to scientists, the spacecraft itself will not require any new technology. The scientific objectives of the mission do not require any particularly novel instrumentation to achieve. Basing the orbiter technology on proven hardware with flight legacy will allow the mission to fly sooner and with a higher chance of success.

The in-situ explorer [ISX] will build on the success of the Mars Ingenuity helicopter that was a part of the Mars 2020 mission. Ingenuity demonstrated that not only could a rotor aircraft be flown extra-terrestrially, but that such a device could have significant value to a mission. Ingenuity far exceeded expectations in an environment that makes flying a helicopter extremely difficult. Venus on the other hand has a much more favorable environment for rotor aircraft, with a much denser atmosphere that significantly expands what a helicopter could accomplish.

One of the main challenges of sending a device such as a rover to the surface of Venus is engineering it to survive the extreme temperatures and pressures that are found on the surface. By utilizing a semi-buoyant design, the ISX will be able to avoid those engineering challenges. ISX will be a quad-copter with a deployable balloon allowing it to operate in two primary modes: Active observation and Passive sleep. In Active observation the ISX will activate its motors and actively control the pressure of its balloon allowing it to fly freely around Venus's atmosphere. In Passive sleep, ISX will inflate its balloon in order to hover at a predefined safe altitude. This will allow ISX to recharge its batteries without ever being required to land on the surface. The mission will set a minimum possible altitude for ISX below which the pressure will be too great for it to descend. In order to communicate data back to Earth, ISX will use the orbiter as a relay to minimized its communication needs.

ISX will be a flying instrument platform capable of sampling and analyzing Venus' atmosphere, weather patterns and climate dynamics using an on board suite of instruments. It will also include ground sensing instruments in order to look for evidence of hydrological cycles, past life and evidence of oceans on the surface. The capabilities of ISX align with the goals of the proposed in-situ explorer in the 2013-2022 Planetary Science Decadal survey.

2 Conceptual Images

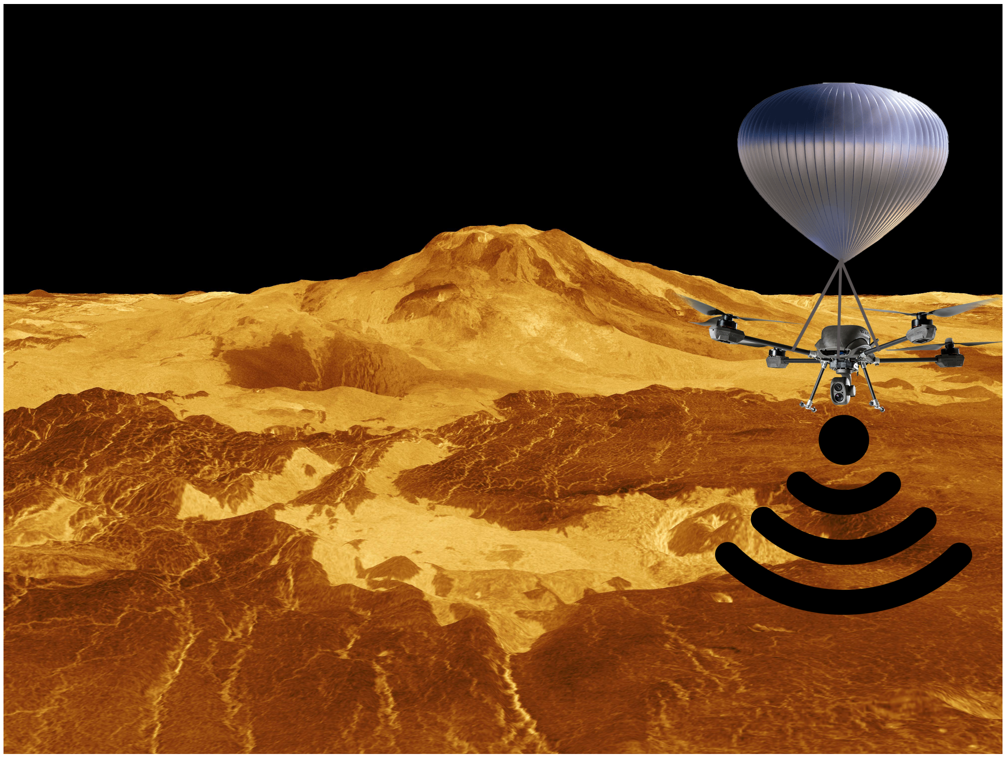

Figure 1: ISX Quadcopter flying over Venusian surface (Background image: JPL)

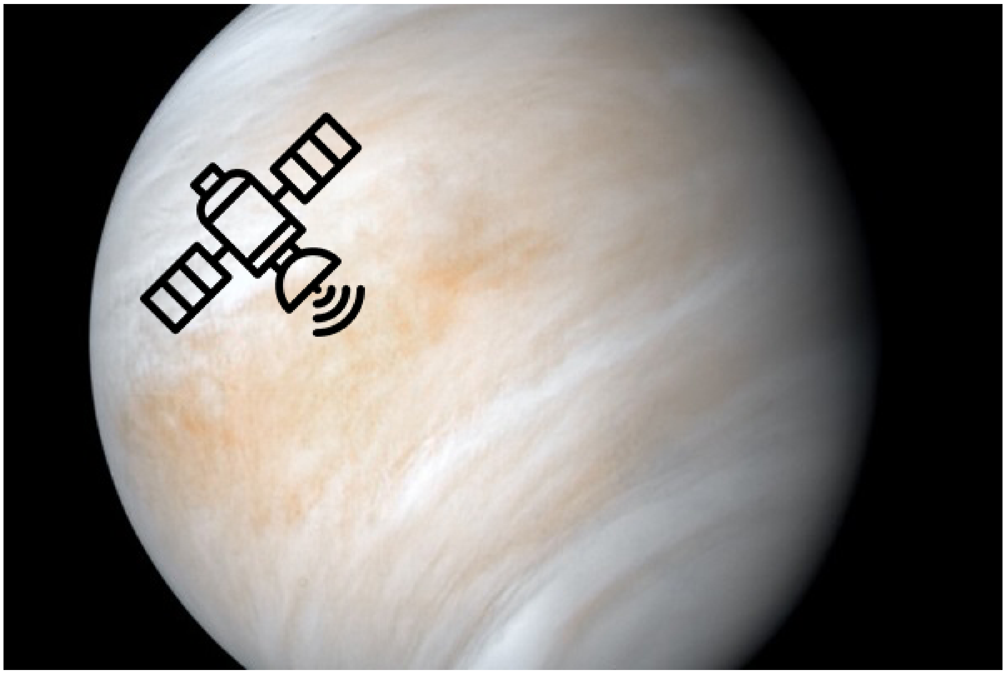

Figure 2: Satellite in orbit of Venus (Background image: JPL)

3 Mission Success Criteria

Our mission success criteria have been defined from the following high level mission design criteria:

1. Design a spacecraft capable of studying the climate of the planet Venus from orbit.
2. Design an in-situ element capable of entering Venus' atmosphere and studying the surface, atmospheric composition, and weather patterns.

MSC1: The first mission success criteria will be defined by the Orbiter segment entering a stable orbit about Venus and transmitting data back to Earth. The climate research mission of the orbiter has been identified as a flagship class mission need by the 2013 - 2022 Planetary Decadal Survey, and is the most critical component to the VCOAX mission. A successful insertion into Venus Orbit enables all other parts of the mission.

- **Minimal Mission Success**: The orbiter enters an orbit capable of observing 30% of the planet's surface
- **Partial Mission Success**: The orbiter enters an orbit capable of observing 60% of the planet's surface and transmits data back to Earth.
- **Full Mission Success**: The orbiter enters an orbit capable of observing 100% of the planet's surface and transmits data back to Earth.
- **Extended Mission**: The orbiter is able to observe long term climactic cycles over a period of 15 Venusian years and transmits data back to Earth.

MSC2: The second mission success criteria is defined by the in-situ mission segment entering the atmosphere of Venus, deploying itself into its exploration configuration, and establishing communication with the orbiter and thus Earth. Exploration configuration for the ISX will be defined as having its propellers deployed and its balloon deployed and inflated. Entry into Venus' atmosphere

- **Minimal Mission Success**: The ISX has inflated its balloon and established communications with the Orbiter and Earth. The propellers have either failed to deploy or are unresponsive.
- **Partial Mission Success**: The ISX has inflated its balloons, deployed its propellers and established communications with the Orbiter and Earth. The ISX remains in contact with the Orbiter and Earth for a period between 1 Venusian and 90 Venusian Days.
- **Full Mission Success**: The ISX has inflated its balloons, deployed its propellers and established communications with the Orbiter and Earth. The ISX remains in contact with the Orbiter and Earth for a period of 90 Venusian Days.
- **Extended Mission**: The ISX has inflated its balloons, deployed its propellers and established communications with the Orbiter and Earth. The ISX remains in contact with the Orbiter and Earth for a period of 90 Venusian Days.

4 System-level Requirements

1. The spacecraft shall be launched in a single launch.
2. Launch operations shall be performed at TBD
3. The spacecraft shall be comprised of an orbiter spacecraft and an in-situ vehicle.
4. The spacecraft shall have a probability of failure less than a value specified by NASA.
5. The orbiter spacecraft shall function for 5 years once in orbit around Venus.
6. The orbiter spacecraft shall have sensors for monitoring the climate and atmosphere of Venus.
7. The orbiter spacecraft shall have sensors for studying the geology of Venus.
8. The orbiter spacecraft shall have an attitude control system capable of maintaining a pointing requirement of TBD.
9. The orbiter spacecraft and in-situ vehicle shall have electrical power generation systems.
10. The orbiter spacecraft shall not exceed a launch mass of TBD.
11. The orbiter spacecraft shall store propellant.
    (a) The spacecraft shall store enough propellant for course correction, orbital insertion and station keeping.
12. The spacecraft shall be designed to withstand radiation encountered during interplanetary travel.
13. The spacecraft shall be designed to withstand an impact from dust and orbital debris up to TBD in size.
14. The spacecraft shall be placed into an orbit allowing it to observe the entire Venusian surface.
15. The in-situ vehicle shall have a thermal protection system to enable entry into the Venusian atmosphere.
16. The in-situ vehicle shall have instrumentation for analyzing the Venusian atmosphere.
17. The in-situ vehicle shall have sensors for analyzing the Venusian surface.
18. The in-situ vehicle shall not exceed a mass of TBD.
19. The in-situ vehicle shall communicate with the orbiter 3 times a Venusian day.
20. The in-situ vehicle shall be able to store data between uplinks with the orbiter.
21. The orbiter shall perform data analysis for the in-situ vehicle.
22. The in-situ vehicle shall not reach an altitude below TBD meters above the Venusian surface.
23. The in-situ vehicle shall have a flight computer capable of autonomous operations.
24. The in-situ vehicle shall be able to withstand Venusian weather.
25. The orbiter spacecraft shall communicate with Earth.

4.1 Regulatory Requirements

1. The spacecraft shall comply with the requirements for a Category II interplanetary mission to Venus as defined by NASA NPR 8715.24, Planetary Protection Provisions for Robotic Extraterrestrial Missions.

5 Top-level subsystem Requirements

5.1 Propulsion

1. The launch vehicle shall put the spacecraft on a Earth Venus Transfer orbit. [SYS1.1 SYS1.15]
2. The spacecraft shall be capable of inserting into orbit about Venus from a Earth Venus Transfer orbit [SYS1.14]
3. The spacecraft shall be capable of adjusting its orbit to a predetermined orbit within TBD tolerance. [SYS1.14 SYS1.11]
4. The in-situ vehicle shall be capable of placing itself on a Venus entry trajectory. [SYS1.15]

5.2 Power

1. The orbiter spacecraft shall be capable of generating TBD watts in Venus orbit. [SYS1.9]
2. The in-situ vehicle shall be capable of generating TBD watts while in Venusian Atmosphere [SYS1.9]

5.3 Structure

1. The in-situ vehicle shall be able to withstand wind speeds up to TBD knots. [SYS1.24]
2. The in-situ vehicle shall be able to withstand entry conditions in a protective shell. [SYS1.15]
3. The in-situ vehicle shall be able to seperate from the orbiter spacecraft. [SYS1.3]

5.4 Attitude Control and Navigation

1. The orbiter spacecraft shall be capable of maintaining or modifying its orbit. [SYS1.5 SYS1.11]
2. The orbiter spacecraft shall maintain pointing accuracy of TBD arcseconds. [SYS1.8]

5.5 Command and Data Handling

1. The orbiter shall have a flight computer with TBD processing power. [SYS1.21]
2. The orbiter spacecraft shall have data storage for in-situ data and orbital data [SYS1.21]
3. The in-situ vehicle shall have a flight computer with TBD processing power. [SYS1.23]

5.6 Thermal

1. The in-situ vehicle shall have a detachable ablative heat shield. [SYS1.15]
2. The in-situ vehicle shall be able to maintain a temperature between TBD and TBD in the Venusian atmosphere. [SYS1.24]
3. The orbiter vehicle shall maintain a safe operating temperature of TBD. [SYS1.5]

5.7 Telemetry and Control

1. The in-situ vehicle shall have a data transfer rate of TBD to the orbiter spacecraft. [SYS1.20]
2. The orbiter spacecraft shall have a data transfer rate of TBD to Earth. [SYS1.25]
3. The orbiter spacecraft shall have a high gain antenna with a TBD arcsecond resolution. [SYS1.25]

5.8 Payload

1. The orbiter spacecraft shall have a instruments capable of characterizing the properties, dynamics and chemistry of Venus's atmosphere. [SYS1.6]
2. The orbiter spacecraft shall have a camera capable of imaging venus with a resolution of TBD. [SYS1.6 SYS1.7]
3. The in-situ spacecraft shall have a instruments to sample and analyze the gasses in the atmosphere. [SYS1.16]
4. The in-situ spacecraft shall have an instrument for sensing surface features of Venus. [SYS1.17]

5.9 Mobility

1. The in-situ vehicle shall be able to operate for 24 hours without contact with Earth (via orbiter) [SYS1.23]
2. The in-situ vehicle shall control its altitude with a deployable balloon with a minimum pressure of TBD. [SYS1.22]
3. The in-situ vehicle shall be able to navigate the Venusian atmosphere using four propellers. [SYS1.23]

6 Key Trade Studies and Analysis

While VCOAX will represents the most comprehensive NASA mission to Venus in the agencies history, orbital missions to the inner terrestrial solar systems are very well studied. However, the in-situ component of VCOAX is completely novel and will require significant study in order ensure mission success.

6.1 Orbiter Instrumentation

The goal of the orbiter segment of VCOAX is to study the climate and atmosphere of Venus. This trade study will investigate the possibility of using instruments already in use on Earth based climate and atmospheric research satellites for this mission. Earth's atmosphere is studied by a large number of satellites and by conducting a study of the instruments that they use, we will be able to determine what instruments may be best suited to VCOAX. Additionally we will be able to study the reliability and quality of data from these instruments and ensure that the final scientific payload will not only be sending back the best possible data, but will also be highly reliable.

6.2 ISX Entry and Deployment

The goal of this study will be to investigate the reentry needs of the in-situ segment. Unlike any other atmospheric entry vehicle, ISX will never reach the surface of the body it is entering. Extensive study will need to be done on slowing the reentry vehicle to a low enough velocity in order to deploy ISX at an appropriate altitude. There have been a number of mission concepts that utilize balloons in Venus' atmosphere, and it would be appropriate to thoroughly investigate the proposed entry methods for these missions in order to inform the ISX deployment procedure. It will also be necessary to study ideal entry trajectories in order to determine the thermal protection requrired.

6.3 Dynamics of Semi-Bouyant Quadcopter

The ISX is a novel vehicle that is both a balloon and a quadcopter, a vehicle configuration that has not been extensively studied. It will be necessary to extensively characterize the dynamics of such a vehicle in order to properly design flight control software. The design will need to be tested in a a chamber simulating the pressures and temperatures in which ISX will operate in order to verify both the dynamics and the flight control software. Furthermore, the acceleration and force envelope must be characterized to ensure that the ISX does not tear itself off of its balloon. These problems requrie extensive study in order to ensure mission success.

7 Design Decision References

- Vision and Voyages for Planetary Science in the Decade 2013-2022
- MAE 5160 Lecture Notes
- The New SMAD
- NPR 8715.24, Planetary Protection Provisions for Robotic Extraterrestrial Missions
- COSPAR Policy on Planetary Protection