paper AIAA-2020-4152

Settling Venus: A City in the Clouds?

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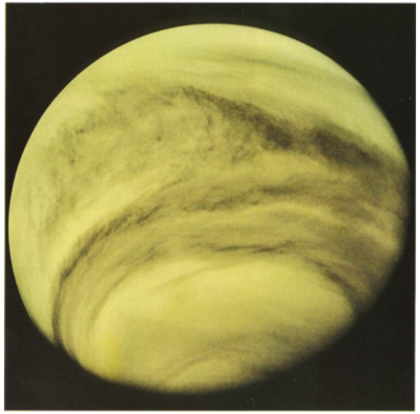
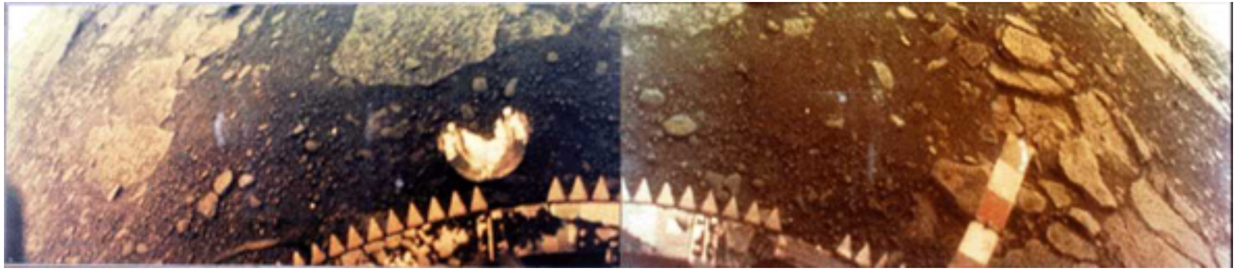
2020 AIAA Ascend, Nov. 16-18 2020

Venus: the Hell Planet

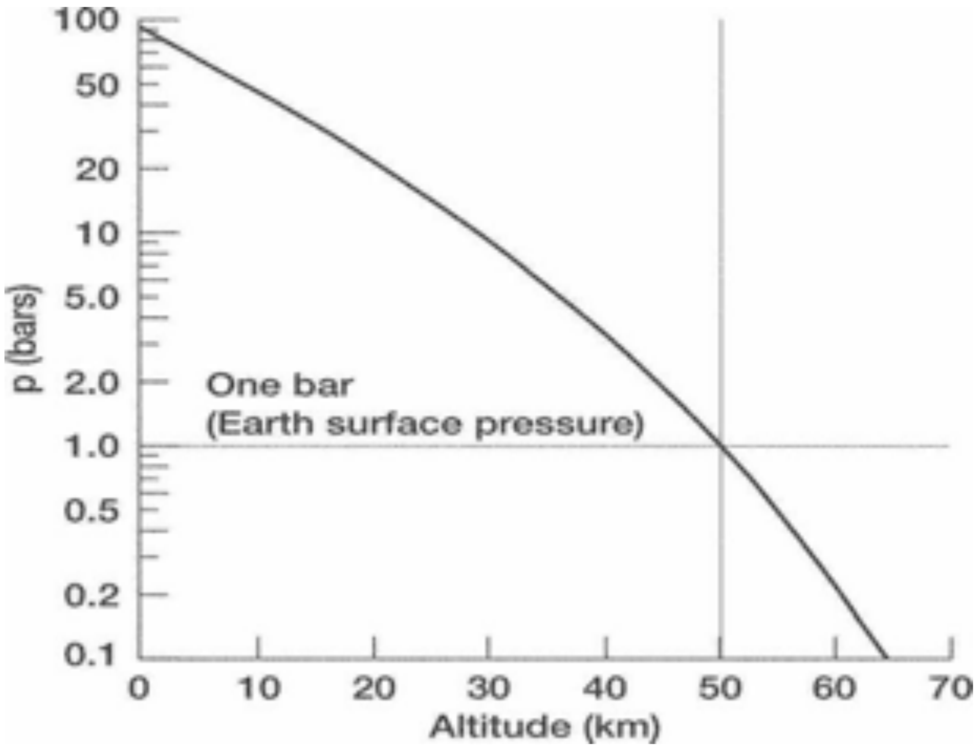


At 450°C and 90 bars of atmospheric pressure, the surface of Venus is an extremely hostile environment.

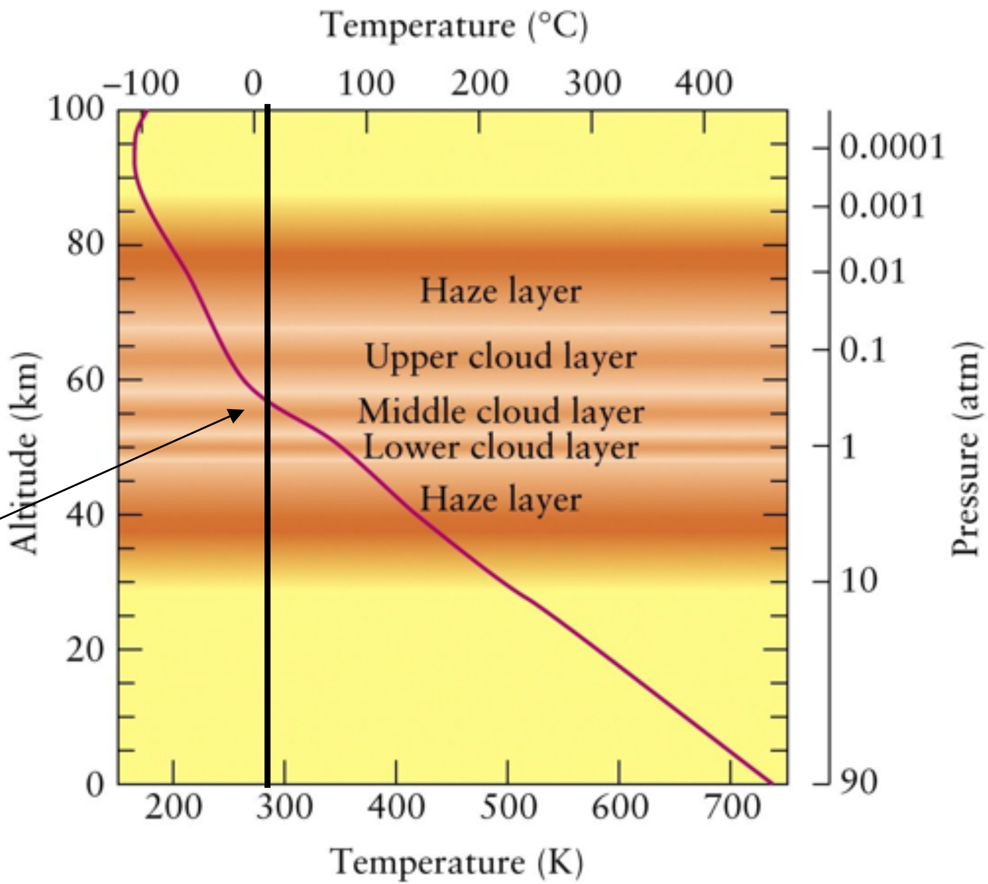
But… at about 50 kilometers above the surface the atmosphere of Venus is the most earthlike environment (other than Earth itself) in the solar system.



Venus: pressure as a function of altitude



Venus: temperature as a function of altitude



Room temperature at about 56 km

Habitability of Venus

The case for human settlements at the habitable level of the Venus atmosphere has been made in earlier work

At an altitude slightly above fifty km above the surface, the atmospheric pressure is equal to the Earth surface atmospheric pressure of 1 bar. At this level, the environment of Venus is benign.

- above the clouds, there is abundant solar energy
- temperature is in the habitable "liquid water" range of 0-50C
- atmosphere contains the primary volatile elements required for life (Carbon, Hydrogen, Oxygen, Nitrogen, and Sulfur)
- Gravity is 90% of the gravity at the surface of Earth.

* G.A. Landis, "Colonization of Venus," Conference on Human Space Exploration, *Space Technology & Applications International Forum*, Albuquerque NM, 2-6 Feb. 2003. *AIP Conference Proceedings Vol. 654,* 1193-1198.

"Venus morning." Artwork by Jett Furr, used with permission.

Habitability of Venus: advantages over moon & Mars habitats

- The habitat interior would not need to hold a pressure differential.
  - Since at the altitudes of interest the external pressure is nearly one bar, atmospheric pressure inside the envelope would be the same, or nearly the same, as the pressure outside. A habitat in the atmosphere thus would not require a high-strength pressure vessel, and could be extremely lightweight.
  - With zero pressure differential between interior and exterior, even a rather large tear in the envelope would take thousands of hours to leak significant amounts of gas, allowing ample time for repair.
- While the atmosphere contains droplets of sulfuric acid, materials to avoid acid corrosion have been known for centuries.

Habitability of Venus: advantages over zero-gee habitats

- The thick atmosphere provides about one kilogram per square centimeter of mass shielding, sufficient to shield the humans from most radiation
- The gravity, slightly under one Earth gravity, is likely to be sufficient to prevent the adverse effects of microgravity on the muscles, cardiovascular system, and bone of the inhabitants
- Above the thick middle cloud layer, solar power is abundant, and, in fact, solar arrays would produce nearly as much power pointing downward (toward the reflective clouds below) as they produce pointing toward the sun.

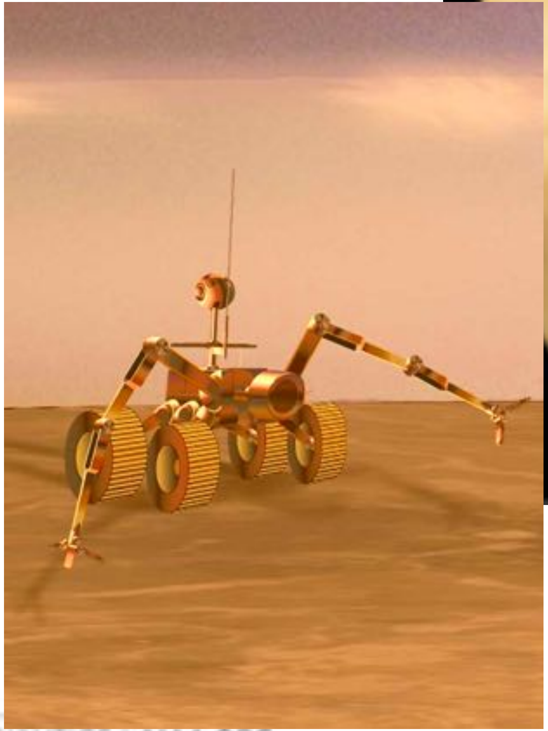
Habitability of Venus: path forward

- In the near term, human exploration of Venus could take place from aerostat vehicles in the atmosphere
- and in the long term, permanent settlements could be made in the form of cities designed to float at fifty to sixty kilometers above the surface.

Venus aerostat

Near Term: Human Exploration by Telerobotic Operation

Humans explore using high-temperature electronics for a telerobotic rover, giving "virtual telepresence" to humans overhead to operate the telerobots in real time ("HERRO")



Near Term: Human Exploration by Telerobotic Operation

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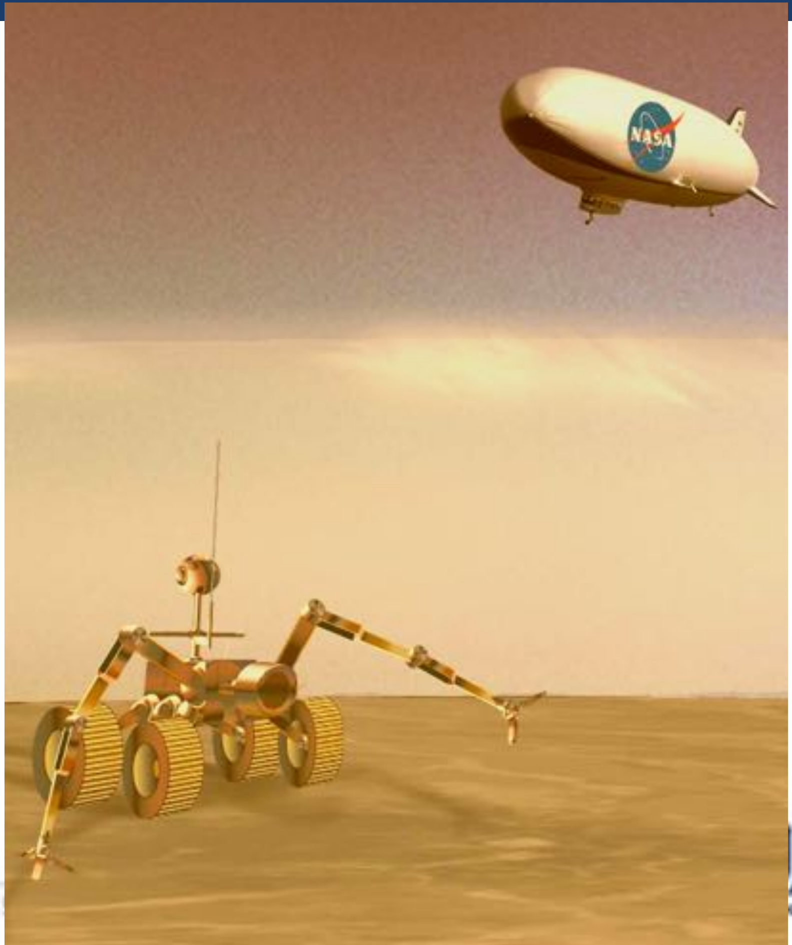
Humans operating a surface telerobot from an overhead aerostat.
The vehicle requires propulsion to remain overhead despite the high-level winds



Near term: HAVOC concept for Human Venus Mission

Detailed study of an atmospheric habitat for human exploration is done by Dale Arney and Chris Jones and collaborators of NASA Langley Research Center, “High Altitude Venus Operational Concept” (HAVOC). The initial human mission envisioned a 129-meter long airship designed to support a crew of two at a 50-km float altitude for a mission duration of 30 days.

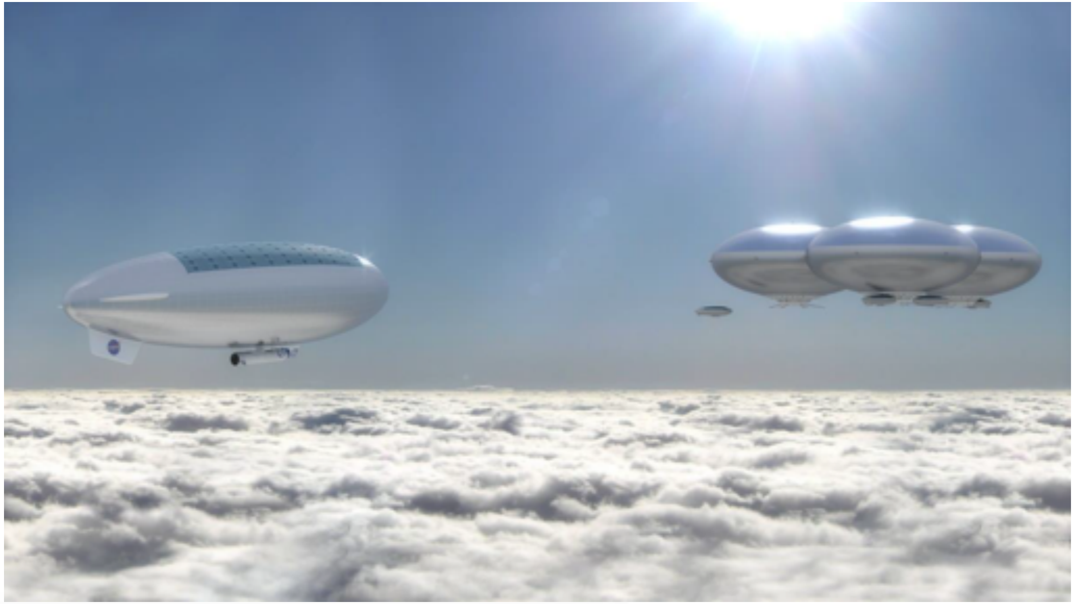
The design study included an analysis of how such vehicles would enter the atmosphere of Venus and deploy to operational altitude, as well as incorporating an ascent vehicle to launch the crew out of the atmosphere to Venus orbit.

Havoc aerostat. image from NASA Langley Research Center

D.C. Arney and C.A. Jones, “High Altitude Venus Operational Concept (HAVOC): An Exploration Strategy for Venus,” *AIAA Space 2015 Conference and Exposition*, Pasadena, CA, 31 Aug-2 Sep 2015.

HAVOC concept for Human Venus Mission

In the long term, the HAVOC design study was intended to be a starting point with a possible evolution to longer missions and eventual sustained habitation.



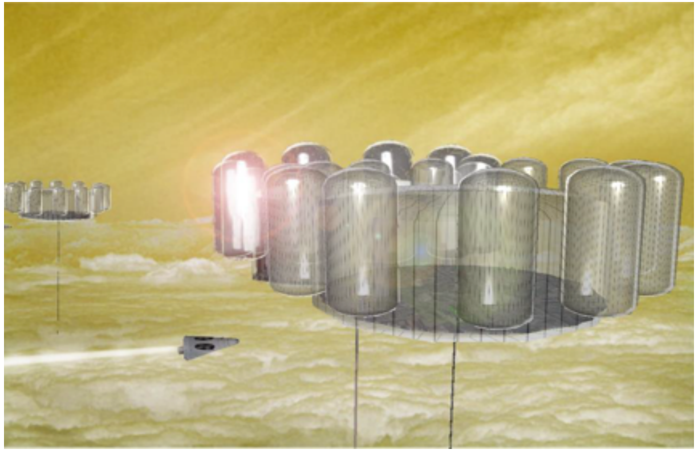
HAVOC
image from NASA Langley Research Center

Venus floating City: selection of altitude

In the long term, permanent settlements could be made in the form of cities designed to float above the cloud altitude in the atmosphere of Venus.

Selection of altitude: A temperature of 20°C is achieved at about 56 km. At this altitude, pressure is about 0.56 bar, where an atmospheric mix of 37% oxygen: 63% nitrogen results in sea-level breathability.

O_2/N_2 mixtures are lifting gases in the CO_2 atmosphere. Greater lifting capability is achieved if the lifting gas is hydrogen or helium. Air has a lifting capability of 0.28 kg/m^3 at 56 km altitude; while hydrogen has a lifting power of about 0.78 kg/m^3 at 56 km. Thus, hydrogen will lift three times the mass of the same volume of air.



An artist's conception for a buoyant city floating above the Venus clouds.

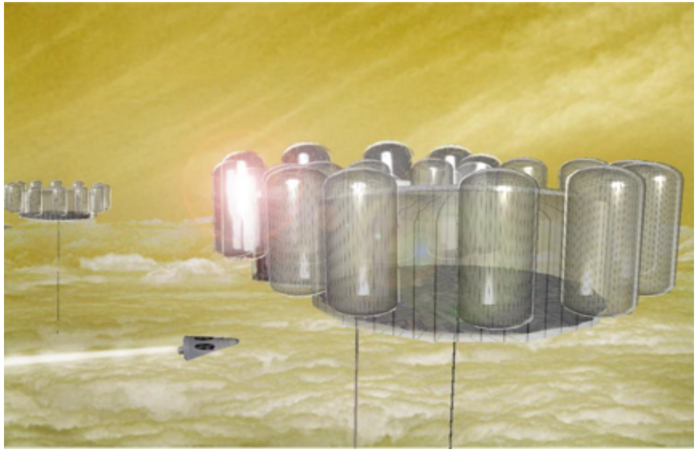
Artwork by Steve Bowers, used with permission

Venus floating City: selection of altitude

In the long term, permanent settlements could be made in the form of cities designed to float above the cloud altitude in the atmosphere of Venus.

Selection of altitude is a function of temperature and pressure
A temperature of 20°C is achieved at about 56 km. At this altitude, pressure is about 0.56 bar, where an atmospheric mix of 37% oxygen: 63% nitrogen results in sea-level breathability.

If heat rejection is a significant problem, a higher altitude might be preferred



An artist's conception for a buoyant city floating above the Venus clouds.

Artwork by Steve Bowers, used with permission

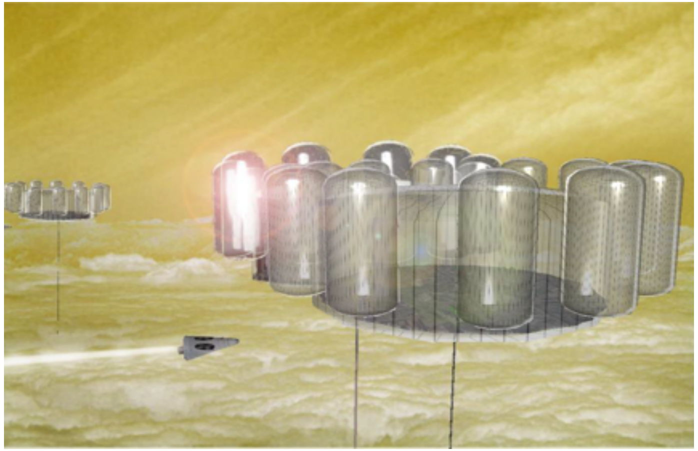
Venus floating City: lifting gas

Air (oxygen/nitrogen mixtures) is a lifting gas in the carbon dioxide atmosphere. Use of air for buoyancy would result in the full envelope being habitable volume.

However, Air has a lifting capability of 0.28 kg/m^3 at 56 km altitude; while hydrogen lifts 0.78 kg/m^3. Thus, hydrogen will lift nearly three times the mass of the same volume of air.

The leak rate of hydrogen will be high, however, and hydrogen would have to be continuously replenished, most likely from stripping hydrogen from available sulfuric acid.

(Note that, unlike earth, the ignition risk of hydrogen is low, since the atmosphere of Venus does not contain oxygen.)



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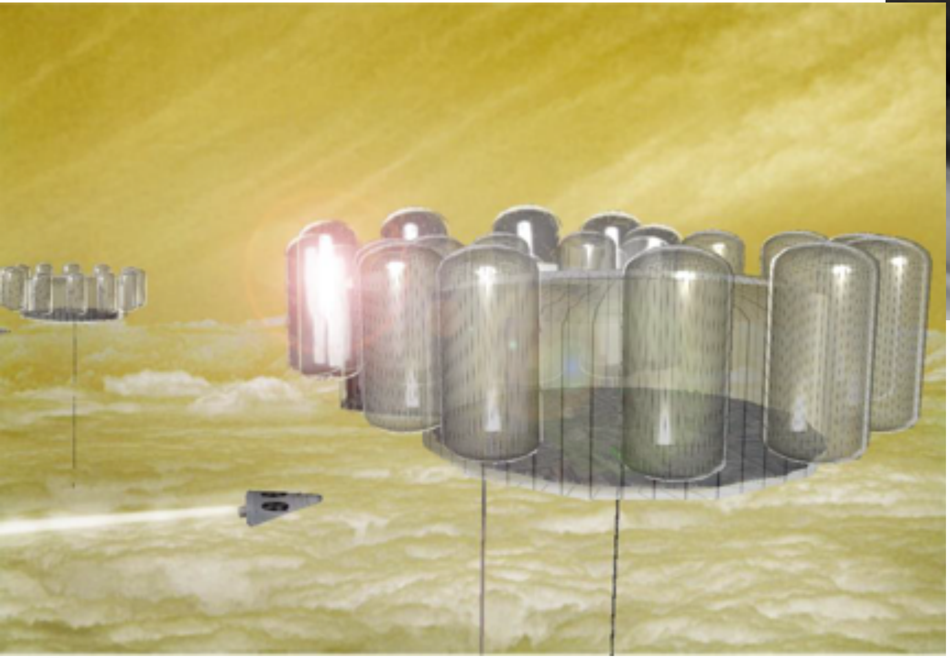
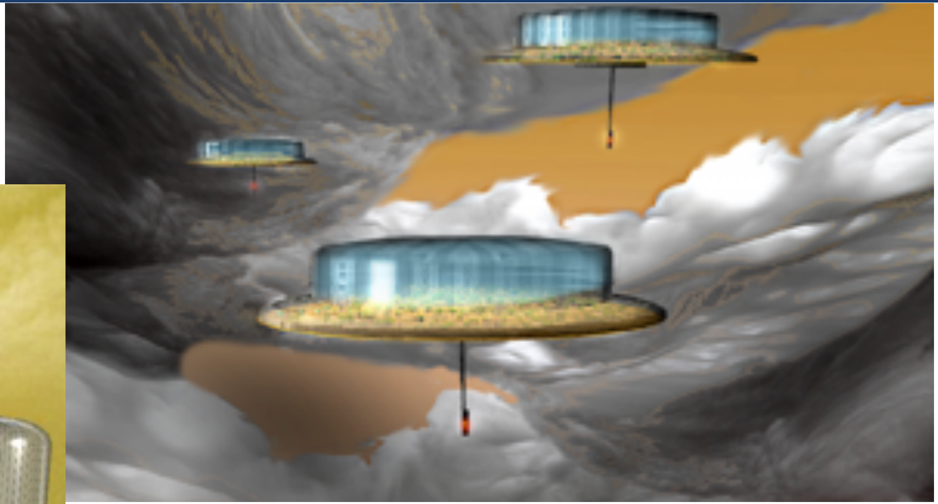
Comparison: Venus floating City





Two views of buoyant cities, both by artist Steve Bowers: on the left, the city has a separate envelopes for the lifting gas, allowing hydrogen or methane to be used. The right image shows buoyant cities with an oxygen-nitrogen mixture as the lifting gas, allowing the full volume to be habitable area, but with lower lifting power

Artwork by Steve Bowers, used with permission

Venus floating city

With surface area 3.1 times the land area of Earth, Venus has plenty of room. A billion habitats, each one with a population of hundreds of thousands of humans, could be easily float in the Venus atmosphere without crowding the airspace

"Venus morning." An artist's view of a Venus floating city. Artwork by Jett Furr, used with permission.

https://aerojett.artstation.com

Terraforming

While space settlement advocates propose terraforming Venus, such a project would be tremendously difficult. Essentially, any effective terraforming method would require removing about 500 quintillion kilograms of carbon dioxide. If this were to be done by physically converting the carbon dioxide into carbonate, for example, it would require pulverizing the surface to a depth of at least 1 kilometer (and most likely more) to produce enough rock surface area to convert enough of the atmosphere.

The energy costs of doing this would be enormous.

G.A. Landis, "Terraforming Venus: A Challenging Project for Future Colonization," paper AIAA-2011-7215, *AIAA Space 2011 Conference & Exposition*, Long Beach CA, 26-29 Sept. 2011.

Partial Terraforming

An alternate could be considered partial terraforming. In principle, structures could be built up from the surface to an altitude of 55 km to reach that earthlike level, made from high temperature materials such as graphite composite or carbon nanotubes, manufactured from the available carbon-dioxide atmosphere.

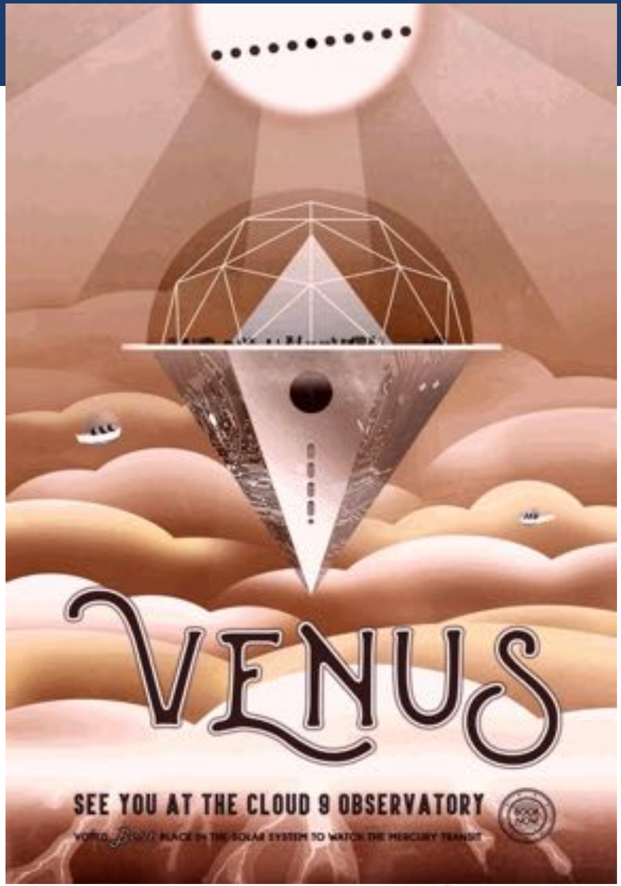
Such a structure would still not have the breathable atmosphere desired by humans, but photosynthetic plants could convert the top portion of the atmosphere to oxygen

G.A. Landis, "Terraforming Venus: A Challenging Project for Future Colonization," paper AIAA-2011-7215, *AIAA Space 2011 Conference & Exposition*, Long Beach CA, 26-29 Sept. 2011.

Conclusions

Space settlements are often pictured as being located on the surface of a planet or moon,; or proposed to be floating in near-Earth space, but it is also plausible that cities could be made to float in the atmosphere of Venus.

The Venus atmosphere has significant advantages over planetary surface and free-space locations, and a path for development of such floating settlements could start from short-duration human missions in aerostat habitats, and eventually grow to cities.



Stylized vision of a Venus floating city, from the JPL "Visions of the Future" poster series. Image courtesy NASA/Caltech JPL

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