69th International Astronautical Congress (IAC), Bremen, Germany, 1-5 October 2018.

IAC-18-B3.IP.14

Proposal for a Floating Habitat Design for Manned Missions to Venus

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Abstract

While Mars has been the focus of most recent attention as a target for human exploration in the near future, human exploration of other bodies in the Solar System may yield scientific advances in areas that cannot be studied in Martian conditions. One of these bodies is Venus, a planet commonly considered Earth's "sister planet" due to its similar size, in addition to possessing an atmosphere more comparable in thickness to Earth's than that of Mars. In this work, we propose a potential design concept for a manned mission to Venus. We begin by exploring the anticipated challenges faced by manned missions to Venus, including harsh surface conditions, challenging atmospheric characteristics, exposure to radiation, and questions regarding energy sources. We then review previously proposed ideas for manned missions to Venus. Finally, we propose a floating habitat design as a possible concept for addressing the challenges that a manned Venus mission would face. This habitat would allow establishment of a four- to six-member crew within the cloud layer of Venus at an altitude of 50 km. We propose this in preference to a surface-based habitat due to the harsh surface conditions of Venus that preclude easy establishment of a manned station. We discuss the expected solar power available for such a design, highlight features of the proposed design that address challenges discussed previously, and discuss areas that will require further research to make this concept a reality. Ultimately, in proposing this design, we intend to stimulate further discussion and research into manned missions to Venus, both to advance knowledge in the scientific community, and to foster humankind's curiosity in space exploration.
Keywords: Venus, manned, habitat, cloud layer

1. Introduction

Manned space exploration is an opportunity not only to conduct unique science, but also inspires technological advancement and public interest in space research. Thus far, the only manned exploration of an extraterrestrial body has been that of the Moon, last visited in 1972. A recent resurgence in interest in manned missions continues to focus on the Moon, as well as on the planet Mars.

While Venus has not been the subject of similar increased interest, there exists the potential for much to be gained with manned exploration of Venus. While Mars is of interest given the possibility of subsurface water and perhaps even signs of life, extant or extinct, Venus has various qualities that Mars does not possess. Venus is commonly considered Earth's "sister planet": it is more similar in size to Earth than Mars, and is a terrestrial planet possessing a thick atmosphere, albeit with a different composition to that of the Earth's.

A manned mission to Venus would require overcoming several challenges that are different than those faced by a manned Mars mission. Venus has extremely high surface temperatures and an atmosphere containing various sulphur compounds. However, like other space exploration, challenges such as protecting the crew from high energy radiation and the selection of an appropriate power source are important.

In this work, we review the challenges faced by a manned Venus mission, highlight past manned mission concepts to Venus, then present our own proposal in light of the information presented. Specifically, we propose a floating solar-powered habitat with a four- to six-member crew within the cloud layer of Venus at an altitude of 50 km. Lastly, we discuss the expected solar power available for such a design, highlight features of the proposed design that address challenges discussed, and explore areas that will require further research to make this concept a reality.

2. Challenges facing manned Venus missions

In order to effectively plan for a manned Venus mission, it is imperative to first understand the challenges that must be overcome.

2.1 Surface conditions

The surface of Venus presents a challenging environment not just to manned missions, but also to unmanned robotic landers. The surface of Venus was last visited in 1985 by *Vega 1* and *2*, while the record for the longest survival by an unmanned mission on Venus was 127 minutes, by *Venera 13* [1]. Conditions on the Venusian surface include temperatures approximately 740K (467°C) and atmospheric pressures of 93 bar [2].

At such high temperatures, conventional electronics do not function well; thus, any surface mission would necessitate electronics that can withstand much higher temperatures than normal. Temperature poses an even greater challenge for manned missions; whereas high-temperature silicon-on-insulator microcontrollers can function if cooled to 300°C [3], humans would require cooling to 33°C or lower [4]. In comparison, astronauts working on the International Space Station must be cooled from a temperature of 121°C when they are in direct sunlight [5].

The high atmospheric pressures are an additional challenge. With surface pressures of around 93 bar, spacecraft materials and design must be capable of withstanding such high pressures. Furthermore, such extreme pressure makes manned exploration of the surface impossible with current technology: atmospheric diving suits used in deep-ocean conditions have been tested to depths of 900 meters, where the pressure is approximately 90 bar [6]; however, they function only because their significant weight is offset while underwater, which would not be the case on Venus. Thus, manned mission would be confined to non-suit structures, if they were to target the surface.

2.2 Atmosphere

While the atmosphere of Venus is one aspect that makes it an interesting scientific target, it also possesses characteristics that may pose difficulties to manned missions to Venus. The atmosphere of Venus is composed primarily of carbon dioxide [3]. In addition, dioxygen gas is absent from the atmosphere of Venus, making it unbreathable for humans. An additional 3.4% of the atmosphere is composed of nitrogen gas, along with trace amounts of other gases [7]. Most significantly, these include various sulphur-containing species that participate in a sulphur cycle. This includes sulphuric acid, which can be found in the atmosphere and in clouds, though the high temperatures at the surface preclude its aqueous form from being present at the surface. However, other corrosive species are present at surface conditions, with other anhydrous sulphur compounds such as SO_3 [3].

The Venusian atmosphere is not static, which will be another factor to consider in the event atmosphere-based missions are being planned. An equatorial jetstream is present at an altitude of 45-60km. Furthermore, Venus' atmosphere undergoes superrotation, which continues to be the subject of study [8]. These atmospheric circulation patterns would have effects on winds experienced at different levels of the atmosphere, as well as on the chemical composition of the atmospheric environment that an airborne Venus mission would be in.

The temperature profile of Venus' atmosphere varies with altitude as well. Of particular note, the altitude range around 50km is close in temperature to that of Earth [9]. Lastly, the presence of an atmosphere requires accounting for atmospheric entry. Thus, heat shielding for atmospheric entry will be needed, which will contribute weight to any mission to Venus, manned or unmanned. With the different characteristics of the Venusian atmosphere, atmospheric entry shielding must withstand more extreme conditions than those required for terrestrial atmospheric entry [10].

2.3 Radiation

The thick Venusian atmosphere provides shielding from high-energy solar and extrasolar electromagnetic radiation, as well as cosmic radiation [3,11]. This is particularly true below the cloud layer around 50km, as much of this radiation is attenuated by the clouds: at the surface, solar intensity is 2% that at the top of the atmosphere, and is less than 10% the intensity on Earth's surface [3,12]. However, above the cloud layer, cosmic radiation is higher than in Earth's atmosphere, with a peak at 63km altitude in the Venusian atmosphere; while the Earth's magnetosphere shields the atmosphere from the charged particles that make up cosmic radiation, Venus has only a weak induced magnetosphere in comparison [11]. Thus, any manned mission above the cloud layer would need to account for protecting astronauts from high-energy radiation, which can have negative impacts on health.

2.4 Energy source

The selection of a power source for a Venus mission would also be an important consideration. As noted above, only solar radiation intensity at the Venusian surface is only 10% that of Earth; 75% of the radiation is reflected by the cloud layer alone [2]. There are currently solar panels being developed specifically for the low-intensity high-temperature conditions of Venus [13]. However, as the panels are still under development, the amount of power available from such a source is currently unclear.

Another option is to use a radioisotope thermal generator (RTG). This has previously been used on missions such as *Curiosity* to Mars and *New Horizons* to Pluto. Supplying power using RTG would ensure a consistent supply, unaffected by any fluctuations in the level of sunlight. However, a manned mission would likely have much greater energy consumption than an unmanned robotic mission for life support and other requirements not found in unmanned missions. As such, a manned mission may require a greater number of RTGs to supply enough power. Disadvantages of RTGs include the need for a radioactive fuel along with the risks associated with use of such materials, and the production of excess heat that will need to be dissipated [14].

Lastly, batteries have also been under development for the high temperature conditions of Venus. This includes primary batteries, with a current design offering the potential to store energy sufficient for 30 days; batteries of current design would only be able to supply energy for 2 hours in Venusian conditions. In addition, secondary batteries, which would be rechargeable by such sources as solar panels, are being designed with the aim of being capable of 100-150 discharge cycles under Venusian conditions [15].

3. Previously proposed manned mission concepts

Manned missions to Venus have been proposed since as early as the 1960s. One of the first proposed manned missions to Venus was put forward by NASA as part of the Apollo Applications Program. This mission would have made use of technology developed for the Apollo moon missions to execute a manned fly-by of Venus in the 1970s [16]. However, this proposal was never carried through.

Another early proposal was TMK-MAVR, a mission proposed by the Soviet space agency. This would have been a manned fly-by of Venus on the return trip from Mars with 3 crew [17].

More recently, Landis [18] detailed a proposal for manned aerostat habitats in the atmosphere of Venus, situated at an altitude of 50 km, which has temperature and atmospheric pressure close to that on Earth. He proposed using breathable air as a lifting gas, as the ambient pressure at that altitude would be approximately 1 bar, allowing the habitable interior to serve a dual purpose in contributing to producing lift. A further advantage was noted to be that the low pressure differential between the interior and exterior of the habitat would allow leaks to be repaired with reasonable safety, given the slow diffusion of the interior gases outward. Finally, Landis calculated that with the use of breathable gas to generate buoyancy would allow a city-sized lifting vessel to support a mass equal to that of a comparably sized city, thus representing a design capable of supporting large numbers of humans. From this habitat, he suggested that exploration of the surface and access to resources there could be achieved through aircraft or balloons [18].

Finally, another proposed design for a manned mission to Venus is the High Altitude Venus Operational Concept (HAVOC) by NASA, which proposes a floating habitat concept for crewed mission of 2 members lasting about 30 days spent on Venus, along with crew return afterwards. The proposal includes a large solar-powered airship that would keep a crew module airborne around 50 km using helium as a lifting gas [19]. Helium was chosen after calculations demonstrated that using breathable air as the lifting gas would require much greater mass to be transported to Venus [20]. It was suggested that fluorinated ethylene propylene would provide a good material to protect the surface of the solar panels [21].

4. Our proposal

After considering all the atmospheric parameters and studying the requirements of a manned mission to Venus, we conceptualized the design of a floating habitat for the manned exploration of Venus. The conceptual design and modelling of a floating habitat within the clouds of Venus requires knowledge of the cloud movements. Assuming the fast-moving atmosphere of Venus will cause the floating habitat to move along with it, an aerodynamic shape is required.

We propose that the Spherical Habitat for Exploration of Venus (SHEV), which would be situated in the cloud layer, at an altitude of approximately 50 km. Our reason for this choice is similar to that for both Landis and HAVOC, in that the ambient temperatures and pressures will be similar to those on the surface of the Earth. This will create various benefits, including but not limited to minimizing energy requirements for temperature control. Furthermore, the clouds will afford protection from high-energy ionizing radiation to the crew.

The design of such a habitat is shown in Fig. 1. The SHEV will be equipped with control surfaces to control its motion, in addition to a pair of retractable wings, which will help generate additional lift when required. The habitat will be coated with polychlorotrifluoroethylene, which has excellent thermal characteristics and can protect the habitat from atmospheric sulphur compound droplets at this altitude. An additional layer of polyvinylidene chloride will provide protection from any acids or alkalis in the atmosphere.

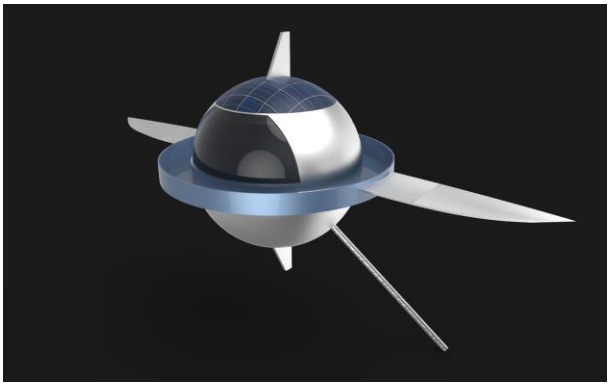

Fig. 1. Proposed design of the Spherical Habitat for Exploration of Venus (SHEV)

We propose that the power source of this floating habitat include both solar arrays and a radioisotope thermal generator (RTG). It has previously been calculated that solar cells at an altitude of 50 km would generate 256 $W \cdot m^{-2}$ [22]. However, given that the habitat will travel around the planet along with the winds and thus be subject to nighttime conditions, we propose inclusion of an RTG to provide a consistent source of power.

The habitat will be required to serve the purpose of hosting crew experiments and allowing in-situ observations. The floating habitat will contain a living environment for the crew, including facilities such as crew quarters, a bathroom, a kitchen, store rooms, a scientific laboratory, a hydroponics laboratory, and a command centre. The habitat would also require components to allow for crew communication with people on Earth. The habitat will support the crew in an Earth-like environment, with a pressure of 1 atm and a temperature comfortable to the crew. From within the SHEV, we expect that the crew would be able to conduct a variety of scientific investigations. The SHEV could also act as a platform for access to the planetary surface.

5. Conclusion

In this work, we reviewed the challenges facing a manned mission to Venus, including high temperatures and pressures, radiation, atmospheric composition, and the need for a suitable energy source. High temperatures and pressure will pose a significant challenge on the surface, requiring materials that can withstand such extremes. Radiation intensity is low near the surface, but is a significant risk higher in the atmosphere, where temperature and pressure conditions are less severe. The atmosphere also contains various sulphur-containing compounds, which can be corrosive to spacecraft materials. Any manned mission will also require a power source: we discussed ongoing research and development of low-light-intensity-suited solar panels and high-temperature batteries. We also discussed prior manned mission proposals.

We propose the SHEV, a floating habitat design, having considered the potential hazards faced when sending humans to the clouds of Venus. This proposal will be powered by both RTG and solar array, be situated within the cloud layer at an altitude of approximately 50 km, and be protected from corrosive chemicals with polychlorotrifluoroethylene and polyvinylidene chloride coatings. At the proposed altitude, we expect high-energy ionizing radiation to pose less danger to crew; furthermore, ambient temperatures will be close to those on the surface of the Earth.

Ultimately, in producing this proposal, we aim to stimulate discussion, interest, and further research into manned exploration of Venus. Future work could further explore the expected power requirements for a manned mission to Venus in order to elucidate the mass of power-generating equipment that would be required on such a mission.

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