

Exploring Venus by Solar Airplane

Geoffrey A. Landis

*NASA John Glenn Research Center, mailstop 302-1, 21000 Brookpark Road, Cleveland, OH 44135
(216) 433-2238 e-mail: geoffrey.landis@grc.nasa.gov*

Abstract. A solar-powered airplane is proposed to explore the atmospheric environment of Venus. Venus has several advantages for a solar airplane. At the top of the cloud level, the solar intensity is comparable to or greater than terrestrial solar intensities. The Earthlike atmospheric pressure means that the power required for flight is lower for Venus than that of Mars, and the slow rotation of Venus allows an airplane to be designed for continuous sunlight, with no energy storage needed for night-time flight. These factors mean that Venus is perhaps the easiest planet in the solar system for flight of a long-duration solar airplane.

INTRODUCTION

The surface of Venus is an extremely hostile environment, but for exploration at roughly the level of the cloud tops, the environment of Venus is comparatively benign. Table 1 shows some of the relevant parameters of Venus (Hunten *et al.*, 1983; Bougher, Hunten, and Phillips 1997). From an altitude of approximately 45 km, where the pressure is two bars (twice the Earth surface pressure), to approximately 60 km, where the pressure is 0.2 bars, terrestrial airplane experience can be easily applied to a Venus airplane design. The atmospheric temperature is roughly 80 °C at 45 km, decreasing to -35 °C at 60 km. At the cloud level, the environment of Venus is an easy one in which to make an airplane fly.

A solar-powered airplane is proposed to explore the atmospheric environment of Venus.

Venus has several advantages for a solar airplane. The exoatmospheric solar intensity is 2.6 kW/m² (nearly double the value of 1.37 kW/m² at the orbit of Earth). At the cloud level, this solar intensity is somewhat attenuated by atmospheric opacity, but at the higher altitudes the solar intensity is comparable to, or even greater than, terrestrial solar intensities. The surface gravity of Venus is 10% lower than Earth's. An additional design factor is the high albedo of Venus. According to measurements by the 1978 Pioneer Venus probe, for example (Fimmel, Colin, and Burgess 1983), at an altitude of 60 km the reflected (upward) solar intensity is equal to 90% of the downward solar intensity, allowing both the top and bottom surfaces of a solar airplane to produce power.

The Earthlike atmospheric pressure means that the power required for flight is lower for Venus than, for example, Mars, where airplane flight is difficult due to the low density atmosphere.

Finally, the planet Venus allows the possibility of designing an airplane for continuous sunlight, thus eliminating the requirement for energy storage during night-time flight. These factors mean that Venus is perhaps the easiest planet in the solar system for flight of a long-duration solar airplane.

DESIGN FACTORS FOR VENUS AIRPLANE

The extraordinarily slow rotation rate of Venus results in a very long solar day, of duration 117 (Earth) days. This means that the ground speed required for an airplane to remain at the subsolar point is extremely slow, only 13.4 km/hr at the equator.

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TABLE 1. Basic Information about Venus

Distance from sun (average)		108 million km (0.72 AU)
Orbital period		224.7 (Earth) days
Surface Gravity		8.87 m/sec ² (90.7% of Earth)
Synodic period (time between launch windows)		583.9 days (1.6 years)
Solar day		117 days (retrograde)
Solar Constant		2.62 kW/m ²
Albedo		0.8
Atmospheric pressure at surface		90 bar
Pressure decrease with altitude		$P = P_0 \exp[-h/15.8\text{km}]$
Temperature at surface		462 ± 2 °C
Temperature decrease with altitude		8 °C per kilometer
Atmospheric composition		96.5% CO ₂ , 3.5% N ₂
Wind velocity as function of altitude (Eastward) (note: depends on latitude)	45 km	44 m/sec
	53 km	65 m/sec*
	60 km	100 m/sec

* measured by Vega balloon mission

Unfortunately, at the cloud-top altitudes of interest to airplane exploration, the wind velocities are considerably higher than the actual rotation rate of the planet, circling the planet at the cloud-top level in a period of 4 to 5 days. At an altitude of 45 km above the surface the wind speed is about 45 m/sec (160 km/h), increasing to 100 meters per second (360 km/hr) at 60 km.

This puts engineering constraints on an airplane designed to remain in the sunlight. Three possible design approaches to keeping the airplane in constant sunlight are: design for an airspeed of 100 m/sec speed; design to fly at lower altitudes where the wind speed is lower (but solar intensity is also less), or to operate at near-polar latitudes, where the wind speeds are reduced (but the sun angle is high). Each of these approaches drives the design toward a different optimum configuration.

An environmental hazard unique to the Venus environment is the chemical reactivity of the atmosphere. The primary component of the Venus clouds is droplets of sulfuric acid. This will require that all exposed surfaces of the airplane be coated by materials impervious to chemical attack; for example, the solar arrays must be encapsulated with no exposed openings, e.g., by a combination of glass and Teflon coatings. However, sulfuric acid is a common industrial chemical, and the technology of dealing with it is well developed. With careful design, there is no reason why a solar airplane could not remain airborne in the Venus atmosphere indefinitely.

The proposed Venus airplane uses a folding-wing design to fit the solar airplane into an atmospheric-entry "aeroshell". Figure 1 shows one possible configuration for a folding-wing airplane, sized to fit inside the 1.2-meter diameter Pioneer-Venus "small probe" aeroshell. The wing folds in two places. The unusually wide chord of the wing is sized in order to maximize the solar array area.

After heat-shield separation, parachute deployment, and stabilization of descent, the airplane is unfolded and is dropped from the parachute at an altitude of 65-70 km above the surface. The airplane then slowly descends to the desired flying altitude and begins its observations.

SCIENCE MISSION FOR A VENUS AIRPLANE

There are a number of important science questions, which can be addressed by flying a probe at the cloud level of Venus. This is the altitude at which the largest fraction of solar energy is absorbed, so questions relating to understanding the greenhouse effect on Venus are best probed at this level. A Venus airplane could, for example, provide valuable "atmospheric truth" measurements to ground the general circulation models of planetary climates. Improved knowledge of the climate of Venus is critical not only to planetary science, but also to our understanding of our own planet Earth.

In addition, the Venus atmosphere holds significant scientific questions that have yet to be answered (Bougher, Hunten, and Phillips 1997): what causes the superrotation of the atmosphere? What is the composition of the

atmospheric ultraviolet absorber? What is the size, shape, and composition of the "mode-three" particles, which are the primary component (by mass) of cloud particles between the altitudes of 30-58 km?

As a geology instrument, a long duration Venus airplane could be used to probe the surface by radar, giving an order of magnitude in resolution of ground features. This might be done by using the airplane as a receiver, using an orbital microwave transmitter.

An airplane would also be an ideal delivery vehicle to drop surface probes at geologically interesting locations, and to "sniff" for the chemical signature of the plumes from volcanic eruptions, to answer the now-open question of whether Venus currently has active volcanism.

Previous proposals for atmospheric probes of Venus have suggested the use of balloons. Balloons were used, for example, in the 1985 Russian "Vega" mission (Bougher, Hunten, and Phillips 1997). While a balloon must drift with the atmospheric motion, however, an airplane has the advantage of allowing considerable better control of position, allowing measurements above a specific location and at a range of altitudes.

Two or more airplanes can also be used to fly in formation, allowing measurement of the correlation of atmospheric properties as a function of altitude or position.

In addition to its scientific value, however, a significant benefit of the Venus airplane will be its "fun" factor. As the first airplane flown on another planet, it is certain to attract a lot of public attention. And the Venus airplane can serve to show the way to future exploration by solar airplanes on Mars, Jupiter, Saturn, and Titan.

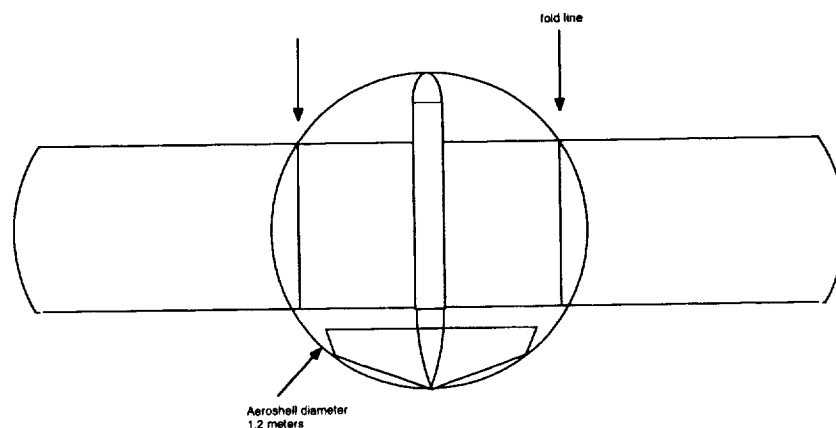


FIGURE 1. Schematic Showing Wing Fold for Venus Solar Airplane, Sized to Fold Into the 1.2-meter Pioneer Venus Small-probe Aeroshell.

CONCLUSIONS

With a thick atmosphere, gravity that is slightly less than that of Earth, high solar constant, and a slow rotation, at the cloud-level of the atmosphere of Venus flight is easy for a solar powered airplane. A solar powered airplane flying in the atmosphere of Venus could do significant scientific objectives, as well as demonstrating, for the first time, atmospheric flight on another planet.

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