HYBRID AERIAL VEHICLE FOR EXPLORATION OF VENUS ATMOSPHERE. J. Rosales[1], A. Miller[1], E. Nunez[1], A. Gross[1], and N. Chanover[2], [1]Mechanical and Aerospace Engineering, New Mexico State University (Las Cruces, NM 88003), [2]Astronomy, New Mexico State University (Las Cruces, NM 88003).

Introduction: The number of in-situ measurements of the Venus atmosphere is very limited, thus there remains numerous unanswered questions regarding the Venus atmosphere composition, structure and dynamics . Understanding the physical processes at work in the Venus atmosphere can provide insight into the factors responsible for the divergent evolutionary paths of Venus, Earth, and Mars since the time of solar system formation.[1]. In 1985 the Vega balloon probes acquired hours of atmospheric data for the stable layer above the middle clouds at about 55 km altitude where the temperature and pressure roughly match those in the lower Earth atmosphere.

Resilient and maneuverable flight vehicles are needed for detailed in-situ measurements of the Venus atmosphere [1 – 3]. Different concepts are being explored for future Venus missions that range from simple balloons to airplanes. Simple balloons have little complexity and are thus less prone to failure. They do not expend energy to stay afloat, which allows for extended missions. A disadvantage of balloons is their inability to actively maneuver. On the other end of the spectrum are airplanes, which are highly dirigible but less complex. Also, typically the mission time for airplanes would be much shorter than for balloons. Hall et al. [5] proposed a balloon-type variable altitude aerobot to explore the Venus atmosphere between 52-62 km altitude. Solar powered airplanes for flight in the Venus atmosphere were proposed by, e.g., Landis et al. [5]. Bullock [6] proposed a dynamic soaring plane. The planned operating altitude for the airplanes would be above the clouds, where the atmospheric conditions are more Earth-like. However, strong winds, vertical shear and associated turbulence above the clouds provide a challenging environment that may limit the mission duration and negatively impact the chance of mission success.

Hybrid vehicles that are a blend between balloons and airplanes, such as the Venus Atmospheric Maneuverable Platform (VAMP), are thus a promising compromise for exploration of the Venus atmosphere between 55 and 70 km altitude [7]. This paper summarizes the conceptual design of a neutrally buoyant hybrid vehicle (i.e., aerobot) that employs propulsion and aerodynamic lift to increase its horizontal and vertical mobility.

Mission Environment: The average cruise altitude of the vehicle was set to 55 km. The temperature and atmospheric pressure at that altitude are about 286.8 K and 46.1 kPa. The density is 0.84 kg/m^3 and the solar irradiation is 311.9 W/m^2 [8 – 9]. A more detailed description of the operating environment is presented in [10].

Envisioned Operational Strategy: The vehicle will float like a balloon with the predominant wind field and circumnavigate the planet near the equator. For a wind velocity of 100 m/s, a radius of 6050 km, and a flight altitude of 55 km, the vehicle will circumnavigate the planet every ~107 hours. While traversing the sunlit side, the vehicle will harvest and store solar power, which will be used for operating instruments and for intermittent powered flight to explore areas of interest. Thermal expansion of the buoyant gas resulting from solar heating will make the vehicle climb in altitude on the day side.

Vehicle Conceptualization: The geometry of the Stingray inflatable aircraft by Prospective Concepts [11] is both aerodynamic and voluminous and was chosen as baseline for the Venus flier. The approximate geometry was reconstructed based on published photos. The relative thickness of the airfoil is 23 %. An artistic impression of the computer aided design (CAD) model, which includes solar panels (black) and propeller disc, is provided in Fig. 1.

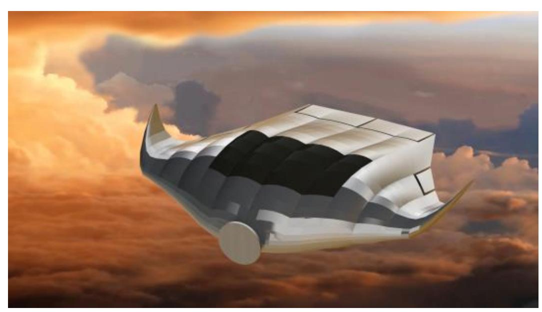

Figure 1. Artistic impression of Venus aerobot.

The larger structural members will be based on the tensairity concept (inflatable beams) [12] such that the structure is truly inflatable and fits into the reentry shell. The ribs will be made from fabric or film and maintain the airfoil shape of the inflatable wing during flight. Fluid-structure interaction will be a limiting design factor and its consideration will constitute a major focus area of future detailed design and analysis work.

Hall et al. [4] decided on a bi-laminate film that consists of a 0.025 mm thick fluorinated ethylene propylene (FEP) outer layer that is bonded to a 0.025

mm thick polyimide (Kapton) inner layer. The FEP layer is metalized on the back with silver to reduce the absorption and then Inconel to provide oxidation resistance. The same skin material will be used for our proposed vehicle.

We decided on a wingspan of b = 25 m. The volume and surface area for this wingspan are, respectively, V= 849 m^3 and S_f = 722 m^2. The wing aspect ratio is 1.9. The maximum cruise velocity will be 30 m/s, which is close to the nominal value for the VAMP [7]. The available mass at cruise altitude will be 510 kg. Details about the analysis employed to obtain these values as well as details on the instruments and devices needed for navigation, communication and science activities are provided in Ref. [11].

Thermal and Trajectory Analysis: Based on the differential equations for zero-pressure balloons by Carlson and Horn [13], differential equations for the altitude, film and gas temperature of the aerobot were developed [11]. The differential equations were solved numerically. Results for an example analysis for a constant amount of buoyant helium gas are presented in Fig. 2. The time-axis is normalized by the orbit period, T. As the vehicle enters the day side, the film and buoyant gas temperature increase and the vehicle climbs to a higher altitude.

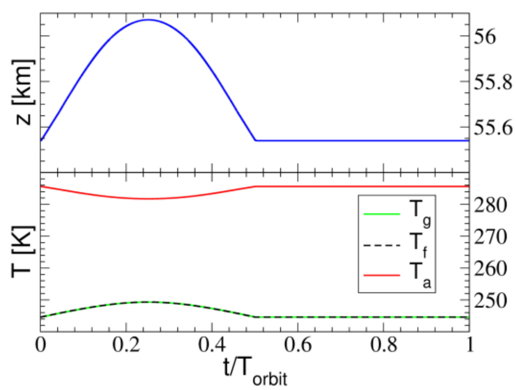

Figure 2. Vehicle altitude and temperatures for an entire orbit.

Aerodynamic Analysis: An aerodynamic analysis was carried out with the xflr5 and VSPAERO [14] design software. The Reynolds number based on mean aerodynamic chord was Re = 27.6 × 10^6. The geometries for the xflr5 and VSPAERO analysis were slightly different from each other but similar to that of the Stingray vehicle. Prospective Concepts carried out over 300 successful flight tests with the Stingray, which gave us confidence in our aerodynamic analysis. Both xflr5 and VSPAERO predict a zero-lift angle of attack of α_0 = -2 deg. VSPAERO predicts a negative moment coefficient slope, which is an essential requirement for the pitch stability of tail-less aircraft. Confirmation of the design software predictions with Navier-Stokes code results will be sought.

A rough analysis of the vehicle performance was also performed. For the chosen solar panel (20% of top surface covered) and battery size (≈95 kg lithium polymer), straight and level powered flight at 30 m/s requires a power of 28.4 kW and can be maintained for ≈40 min. If all stored energy is consumed over 10 min, the vehicle can sustain a maximum airspeed of 35.6 m/s in straight and level flight at an altitude of 64 km.

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