Microrobots Inspired by Oceanic and Bacteria Organisms for Observations of Venus' Upper Atmosphere. M. R. Sherman[1] and M. Hassanalian[2], [1]Graduate student, Department of Electrical Engineering and Mathematics, New Mexico Tech, Socorro, NM 87801, USA, [2]Assistant Professor, Department of Mechanical Engineering, New Mexico Tech, Socorro, NM 87801, USA.

Introduction: Since the 1960's, several countries such as the United States, Russia, Japan, and Europe have planned and executed missions to observe atmospheric, climate, and structural characteristics of Venus. The last dedicated mission to Venus was in 1989 with NASA's Magellan spacecraft that used a Synthetic Aperture Radar to map its surface. The spacecraft that had the longest duration of survival on the surface of Venus was the USSR's Venera 13 probe, which lasted for 127 minutes. The lander touched down on March 1, 1982 and took panoramic images of the Venusian surface, transmitting the first colored pictures. The lander also carried out scientific studies related to Venus' atmosphere and soil composition.

Due to its similar size, complex atmosphere, and surface composition, Venus is commonly known as Earth's twin. However, Venus is not as welcoming with overwhelming temperatures (over 800ºF), thick atmosphere, corrosive, and high-pressure environments. Fig. 3(a) shows the average temperature profile as a function of altitude for Venus. At the surface, temperatures of almost 900ºF are recorded, which is hot enough for conventional electronic systems to overheat.

Many projects issued by NASA and other space agencies have investigated the feasibility of a purely mechanical based rover to perform scientific analyses on the hot planet's surface. One example is the Automation Rover for Extreme Environments (AREE, see Fig. 1), which uses gears, springs, and other mechanical components to provide rover mobility, power generation, and functionality without having the worry of electronic overheating. Other projects, such as aerial platforms, have also been explored to investigate the Venus environment and avoid the harsh conditions of the surface looking at the atmosphere circulation and chemical nature.

Figure 1. Wind-powered rover concept for potential Venus mission [1].

There is an interest in the aerospace and scientific community for developing new concepts and methodologies with energy harvesting techniques that can broaden the scope and range of Venusian scientific discoveries. This work discusses a new concept involving a hybrid aerial system inspired by a bacteria-based organism – Flagellates – that utilize the strong winds in the upper atmosphere of Venus to power their onboard equipment (see Fig. 2). These Flagellate systems are equipped with various sensors needed for climate monitoring, topographical mapping, chemical composition and much more. This concept can provide answers to VEXAG's goals and objectives for Venus Exploration, such as Venus' atmospheric development, evolution, and climate history.

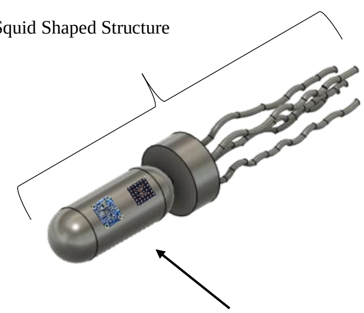
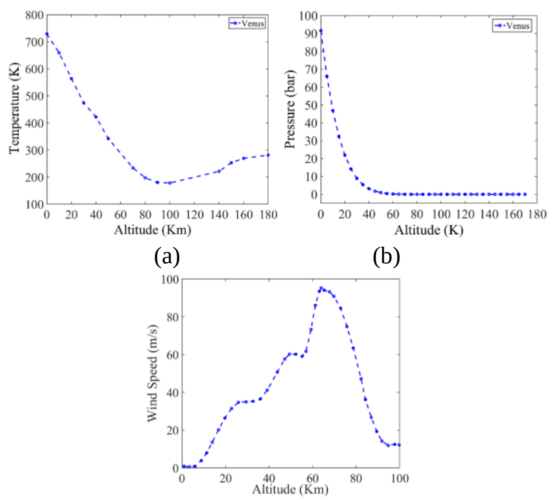


Figure 2. Flagella Micro-Robot Concept for Venus Upper Atmosphere Exploration.

The Climate of Venus: Venus has a similar mass, density, chemical composition, and gravity compared to Earth's. However, as discusses, it also has un-friendly qualities like hot temperature extremes, acidic-like atmosphere, and crushing pressures (about 92 times that of Earth's). Its atmosphere is almost entirely composed of Carbon Dioxide and is much denser than Earth, composed of opaque clouds of sulfuric acid. The upper atmosphere of Venus exhibits a super-rotation effect where the atmosphere circles the planet in just 4 Earth days. High wind speeds in higher elevations support this super-rotation phenomenon.

Due to these harsh conditions, information about the planet's topography has been made though radar imaging. Venus' characteristics make it extremely challenging in designing surface and atmospheric exploration systems intended to have long-duration missions. However, at around a range between 50 to 65 km above the surface of the planet, the atmospheric pressure and temperature are comparatively the same as that of Earth's. In fact, Venus' upper atmosphere is marked as the most Earth-like atmosphere in the Solar System and is the designated location for exploration and colonization.

Average temperature, pressure, and wind speed profiles for Venus are shown in Fig. 3. Observe that within the 50 to 65 km range, wind speeds are at a maximum, reaching up to about 96 m/s. That is a significant amount of energy that can be stored and harvested from a low-power, lightweight system that will have months to year-long mission durations. In addition, within this altitude range, standard electronics would be able to operate. Commercial/standard electronics have an operational range between 32ºF to 158ºF. Thus, the operation of a small system within this range, can be equipped with various sensors and equipment needed to conduct various scientific experiments.



(c)

Figure 3. Views of (a) temperature, (b) pressure, and (c) wind speed profiles as s function of altitude for Venus [2, 3].

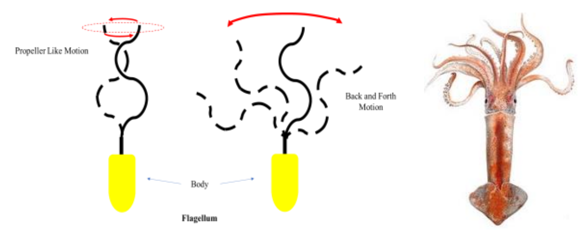
Wind-Energy Harvesting on Venus: The upper atmosphere of Venus rotates at an incredible velocity, forcing winds to accumulate to up to about 345 kilometers per hour. Conversely, at the surface, there is almost little to no wind or just a gentle breeze. In February 2020, NASA ran a public challenge to develop an obstacle avoidance sensor for a potential Venus rover, the AREE. While previous landers lasted from minutes to a couple hours, AREE would be powered for long-duration surface missions utilizing a wind-turbine mechanism that harnesses the available Venusian winds to provide power for scientific instruments and mobility.

Wind energy harvesting can be achieved by considering wind power principles from fluid mechanics. In the case of a wind turbine, power generation can be highly effective during high-velocity winds. NASA has performed tests of wind turbines in Antarctica stations where there are extreme temperatures. According to Betz' Law, the theoretical maximum power produced from a wind turbine is about 60%. The amount of power (P) than can be extracted from a turbine depends on the turbine efficiency (η), atmospheric density (ρ [kg/m^3]), swept area of the turbine (A [m^2]), and the wind speed (v [m/s]), modeled by Eq. 1 [4].

$$P = \tfrac{1}{2}\,\dot{m}v^2 = \tfrac{1}{2}\,\eta\rho A v^3 \quad \textbf{[Eq. 1]}$$

The scope of this work focuses on the development of a singular device that harnesses the available atmospheric winds, which can provide reliable, year-round power on Venus.

Flagellates/Squid-Like Hybrid System: Bacteria Flagellum is a thin, hair-like structure that acts like an actuator in the cells of organisms. There are many types of flagella, but both prokaryotic and eukaryotic flagella are primarily used for "swimming" locomotion, providing a whip-like, propulsive movement. This mobility is similar to that found in the flying squid. The flying squid uses a jet propulsion by taking water into its siphon muscle from one side and pushing it out the other side. They have been observed to reach distances up to 30m above the ocean surface.



(a) (b)

Figure 4. (a) Bacterium Flagella and (b) Flying Squid.

Studies have tried to replicate this method of locomotion from both organisms to produce aquatic-aerial vehicles [5]. Considering Venus's' dense atmosphere, it would be a scientific breakthrough to develop an aerial system that harnesses this propulsion power while simultaneously using the available winds for power. This concept enables a whole new perspective of aerospace missions and provides a great leap in capabilities for NASA and VEXAG. These bacteria-like structures can "swim" through the upper atmosphere of Venus, undertaking future aerospace missions, expanding the region covered by traditional rovers, landers, and orbiters, recording a variety of sensory measurements such as air temperature, ground-penetrating radar, pressure, climate conditions, etc.

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