Manta Ray Inspired Drone for Venus Exploration: Biological-Solution for Extreme Conditions.

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Introduction: Venus is the second planet from the sun and possesses characteristics similar to Earth. It is approximately the same size as Earth and has a similar chemical composition and density. However, Venus is also very different from Earth. The lack of a magnetic field and a runaway greenhouse effect cause Venus to be swelteringly hot. Venus's atmosphere is made up of mostly carbon dioxide and the clouds that exist there are composed of sulfuric acid. The pressure on Venus's surface is around 90 atmospheres, which is similar to the pressure on Earth 1 km below the surface of the ocean. While the temperature on Venus can be over 740 K, which would boil any trace of liquid water away, the atmospheric chemistry of Venus suggests that oceans may have once existed on its surface. Further exploration of Venus is necessary to determine the reasoning why this planet has a similar makeup to Earth but a very different outcome.[1] Past spacecraft have not survived on Venus's surface for more than an hour. This is due to the acidic clouds, intense heat, and crushing pressures present there. In order to explore this planet further, a spacecraft will need to be designed that is able to withstand these extreme conditions. Due to the high density of Venus's atmosphere and the lowered gravity, drone exploration is a viable solution to this problem. A drone would be able to soar from higher to lower elevations to escape the high pressures and extreme temperatures present on Venus.[2]

Manta ray-inspired concept: Manta rays are extremely graceful and efficient swimmers. Their pectoral fins are large and attached to their head, which forms a broad, flat disc that can be manipulated into a variety of shapes. Primarily, manta rays use oscillatory motion similar to that of a bird flapping its wings, but an undulatory component of motion is also present. When mantas use a flapping wing, they can generate a great deal of power. Because of the large surface area of their pectoral fins, mantas can swim at incredible speeds. A manta can weigh over 1580 kg and has a high aspect ratio of 3.5 with a wingspan of over 9 m.[3] Manta rays offer a good solution to UAVs in that their body is rigid and they are efficient swimmers. The stiffness of their body would allow for easy integration of electronics for the design of a bioinspired manta ray UAV. Manta rays have a small turning radius of 0.27 of its body length, which also allows them to maneuver easily. While manta rays are fast and efficient, they are also able to withstand high pressures while hunting, diving over 1 km below the ocean's surface.[4] Many bioinspired manta ray robots have been designed to swim and fly on Earth but none have been proposed for use in space exploration.[5] This study analyzes a bioinspired manta ray wing shape for use on an exploratory UAV on Venus. Presented is the analysis for a flapping-wing and fixed-wing drone in Venus's atmosphere. Shown in Fig. 1 is the wing shape used for this analysis alongside the wing shape of a manta ray.

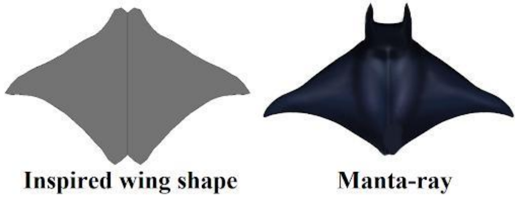

Figure 1: Manta ray bio-inspired wing shape.

Flapping-wing Manta ray inspired drone: The flapping-wing and fixed-wing drone proposed in this paper are analyzed for the flight on Venus at an altitude between 30 and 70 km above Venus's surface. The density of the Venus atmosphere in altitude around 50 km is similar to Earth. The drone would soar to the surface of Venus, take measurements for a period of time, and fly back to a safer altitude. The flapping wing drone was designed in FlapSim with a wingspan of 2 m, an elevation amplitude of 75 degrees, a pronation amplitude of 20 degrees, a stroke plane of -10 degrees, and a velocity of 10 m/s. Using these parameters, the lift, drag and mechanical power for a flapping-wing drone of the defined wing shape are calculated. These can be seen in Figs. 2 to 4. From these figures, it can be seen that the lift force, drag force, and mechanical power are all maximized closer to the surface of Venus. This is due to the increased density closer to Venus's surface. Also, to be seen from Fig. 4 is the large amount of mechanical power that is generated by the large surface area of the manta ray wing shape. These values can be investigated to find the altitude that would allow the drone to be safe from the extreme conditions on Venus's surface, but would allow for maximum power savings. Some tabulated average values for these aerodynamic properties are shown in Table 1. The visualization of the drone's phase is shown in Fig. 5.

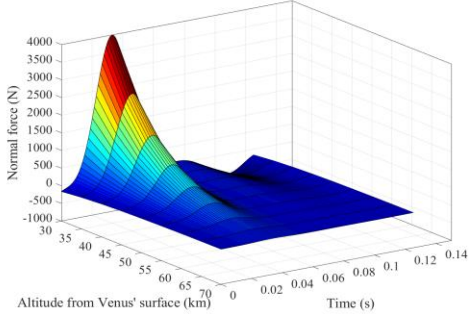

Figure 2: Lift force of flapping-wing drone on Venus from 30 km to 70 km.

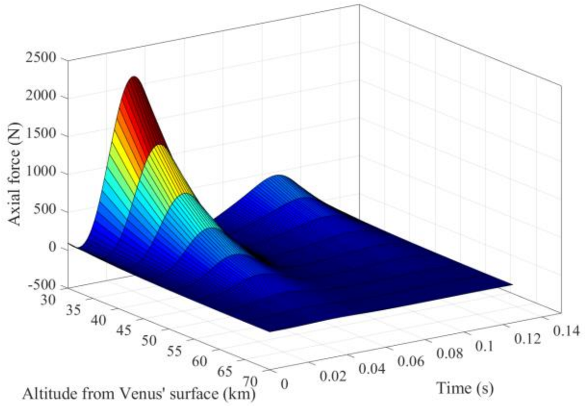

Figure 3: Drag force of flapping-wing drone on Venus from 30 km to 70 km.

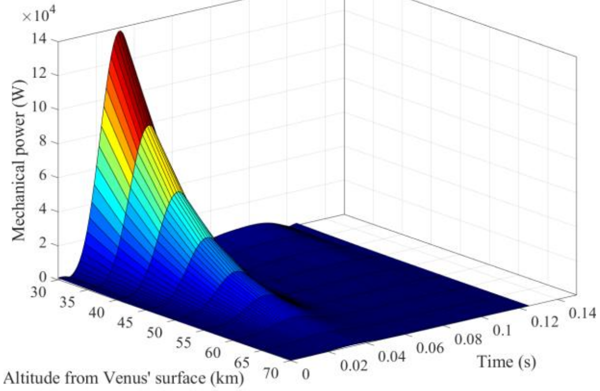

Figure 4: Mechanical power of flapping-wing drone on Venus from 30 km to 70 km.

Table 1: Average lift force, drag force, and mechanical power for a drone on Venus from 35 km to 70 km.

Altitude (km)	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**
Normal force (N)	659	422	264	164	97	58	25	11	4
Axial force (N)	586	376	235	146	86	51	23	10	4
Mechanical power (W)	28122	18027	11260	6995	4151	2468	1083	458	186

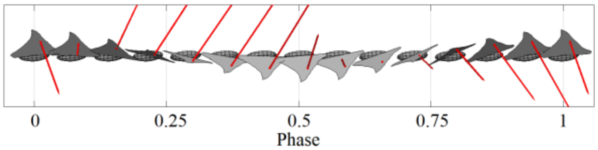

Figure 5: Visualization of one cycle of flapping-wing drone's flight progression.

The analysis for a fixed-wing drone was done in XFLR5 using the same wing shape and wingspan mentioned above. NACA 0012, 0015, and 0020 airfoils were used to create a wing shape that tapers, similar to that of a manta ray. This model is shown in Fig. 6. Using the described model, the lift and drag for a fixed-wing drone on Venus are calculated at an altitude between 30 km and 70 km. This is shown in Figs. 6 and 7. Similar to the flapping-wing drone, the lift and drag are maximized closer to Venus's surface. Additionally, a higher angle of attack generates a higher lift and drag force.

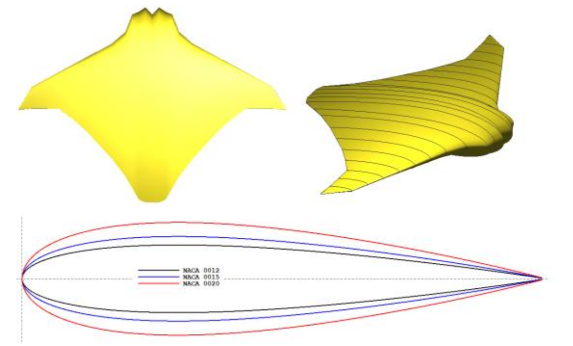

Figure 6: Model of the manta ray-inspired fixed-wing drone in XFLR5.

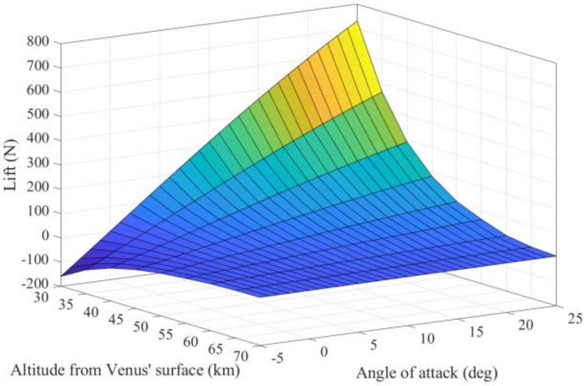

Figure 7: Lift force of fixed-wing drone on Venus vs. angle of attack from 30 km to 70 km.

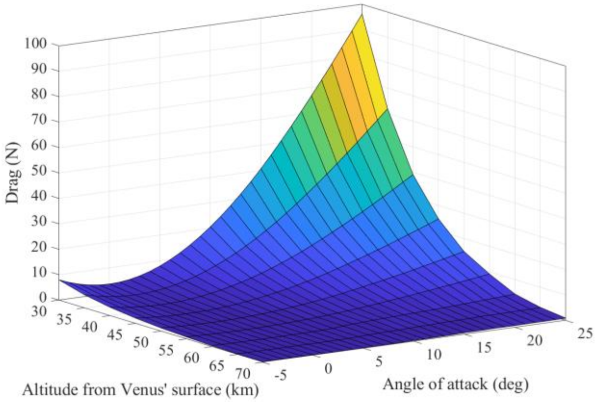

Figure 8: Drag force of fixed-wing drone on Venus vs. angle of attack from 30 km to 70 km.

References:

[1] Martin P. and Stofan E. (2004) *Phys. Educ.* [2] Acosta, G. A. (2019). *AIAA*, [3] Fish, F. E. (2018). *The Journal of Experimental Biology*, [4] Pennisi, E. (2011) *Science*, [5] Gao, J. (2007) *IEEE.*