BIOMIMETIC FLYING SWARM OF ENTOMOPTERS FOR MARS EXTREME TERRAIN SCIENCE INVESTIGATIONS.
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Summary: Mars investigations using robots that mimic birds and insects flight [1] would be significantly attractive to the public and could enable unique access to measurable phenomena in extreme terrains to accomplish NASA science objectives. Constraints imposed by Mars conditions, the sophistication of Decadal Study science priorities, and limited Mars-mission budgets may comprise an amenable environment for biomimetic flight systems. Inclusion of biologically inspired devices that could perform multiple tasks including sensing and relaying data could be useful adjuncts in the Innovative Exploration Approach challenge area, for missions as early as the 2018-2024 timeframe. High lift-generating capability under low Reynolds-number flight conditions provides an innovative solution to the dilemma of atmospheric flight on Mars (Figure 1).

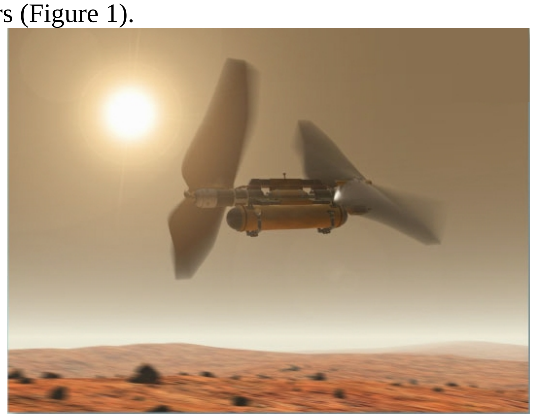

Figure 1: A concept of entomopter for flight on Mars

Flight on Mars: The first serious look at flying on Mars was done in the mid-1970's [2]. Since then numerous studies and designs for flying aircraft on Mars have been reported [2-4]. Because of the very low atmospheric density on Mars all conventional aircraft designs encounter the same limitation – the craft must be fast to generate sufficient lift. Also, the rough Mars terrain would make it virtually impossible for a conventional (fast) aircraft to successfully land and take off again. Therefore, previously proposed aircraft missions have posited single, very limited-duration flights, either gliding or fueled, and deployed upon atmospheric entry.

The entomopter concept (Figure 1) would be an alternative to the need to fly very fast at Mars. It would generate lift as insects do on Earth, by the continuous formation and shedding of vortices on their wings. Such vortex formation and shedding produces very high wing lift coefficients, on the order of 5 compared to maximum lift coefficients of 1 to 1.2 for conventional airfoils. The very high lift-generating capability allows insects to fly, hover and maneuver as they do. As Reynolds number increases the lift capability diminishes.

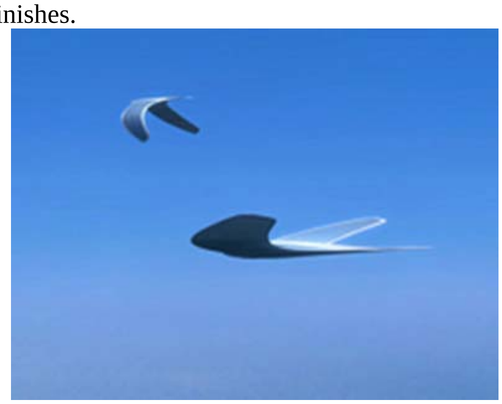

Figure 2: A flying mechanism that emulates birds was conceived for planetary exploration missions [3].

Wing-flapping drones (Figure 2) would need to account for Mars' low air pressure (much more difficult than on Earth) and operate in a very low Reynolds-number regime. In addition, there are practical size limitations for vehicles that could be deployed on missions launched from Earth. Because of the low atmospheric density, a wing span on the order of 1 m would be in the same flight Reynolds number regime as are most insects on Earth. Thus, it is conceivable to construct a vehicle that could fly near the surface of Mars (up to 100s of m in altitude), generating sufficient lift to allow it to fly slowly, maneuver easily, takeoff and land. This result is the genesis for the entomopter concept for Mars.

Entomopters as flapping wing drones on Mars: Terrestrially, entomopters were already conceived and operated inside buildings, including a hummingbird-like drone that was recently developed under a DARPA contract. The entomopter does not rely on a purely biomimetic paradigm for flight; it goes beyond biomimetics by using a resonantly-tuned circulation-controlled pair of autonomically-beating wings, that enable slow flight and landing as well as higher maneuverability than can be achieved with a fixed-wing vehicle. The approach is based on the use of a micro-scale vortex at the wing's leading edge [5].

Subsystems such as anaerobic propulsion and biologically-inspired wings capable of generating abnormally high coefficients of lift were recognized as having application to slow flight in the lower Mars atmosphere [2, 4]. It would not require a long taxiing and landing runway, and would be scalable: large units could reach great distances, carrying small units used for local applications. Under a NIAC sponsored study, researchers at the Ohio Aerospace Institute, Georgia Tech Research Institute, and NASA Glenn Research Center have made a preliminary confirmation that the concept may be feasible for use on Mars [2].

Innovative Exploration Approach for Mars: Our Mars Entomopter concept consists of a central fuselage housing propulsion system, fuel, and instrumentation. On top of the tubular fuselage are two sets of wings that oscillate 180° out of phase. These wings provide the flapping motion that generates lift. Beneath the vehicle are spring-loaded legs that absorb energy during landing, assist in takeoffs and stabilize the vehicle while on the ground. Flexible solar cells covering the wing would provide power.

The approach (Figure 3) would use small swarms of biomimetic entomopter vehicles. The entomopter swarm would conduct close-to-the-surface exploration, atmospheric and contact analysis, and sample acquisition over great swaths of terrain. Using a lander or rover as a "forward base" for recharging/refueling and data offload would substantially increase the coverage range. Some of the tasks of the entomopter may include flying into the skylights of Mars lava tubes to explore them where the vehicle would hover inside the opening while acquiring data (including photos and videos). The data can be downloaded once the entomopter comes out of the tube. Such a vehicle would be superior to the use of rovers or robotic snakes. Also, by collecting dust during flight using a sticky surface on a rolling tape, the entomopter vehicles would acquire samples from locations that may not be reachable otherwise and may provide information about presence of life near water gullies or surface ice edges.

Related Challenges and Timelines: Entomopters address all three Challenge Areas:

1. Instrumentation and Investigation-concept for investigations in lava tubes, gullies, ice edges.
2. Innovative Exploration Approaches - lightweight, lower cost for investigating extreme terrain and surface sampling.
3. Mars Surface System Capability - increased range, larger-area simultaneous geographic coverage, sample caching.

The technology required for a mission that could use entomopters has been in development for over ten years and could be ready for near-term (2018-2024) or longer-term (2024-mid-2030s) Mars missions. The science experiments in such a mission would benefit from the numerous micro- and nano- instruments and devices that are being developed.

Figure 3: Entomopter Flight Mission [2, 3]

References:

[1] Bar-Cohen Y. (Ed.), Biomimetics: Nature-Based Innovation, ISBN: 9781439834763, ISBN 10: 1439834768, CRC Press, Taylor & Francis Group, Boca Raton, Florida (Sept. 2011), pp. 1-788.

[2] Colozza A., et al., "Planetary Exploration Using Biomimetics - An Entomopter for Flight on Mars," Phase II Project NAS5-98051 (2002) pp. 1-344.

[3] Colozza A.J. (PI), "Solid State Aircraft," Phase II Final Report, Prepared for NASA Institute for Advanced Concepts, May 2005.

[4] Kulfan B. K., and A. J. Colozza, "Biomimetics and Flying Technology," Chapter 18 in Ref. [1], pp. 527-674.

[5] Ellington, C., "The Aerodynamics of Flapping Animal Flight," American Zoology, vol. 24, 1984, pp. 95-105.