BIOINSPIRED DRAGONFLY CONCEPT FOR MARS EXPLORATION: ANALOGOUS TO MARS INGENUITY HELICOPTER. Naga Praveen Babu Mannam[1], Prashant Kumar Duba[2,] and P. Rajalakshmi[3], [1]NMICPS TiHAN IIT Hyderabad, Kandi – 502284, India, ee20pdf09@iith.ac.in. [2]NMICPS TiHAN IIT Hyderabad, Kandi – 502284, India, ee20resch11008@iith.ac.in. [3]NMICPS TiHAN IIT Hyderabad, Kandi – 502284, India, raji@ee.iith.ac.in.

Introduction: The MARS exploration research program has been carried out by various space organizations like ESA, NASA, ISRO, Blue Origin, SpaceX, and other academic institutions. Despite the ongoing research interest, flying on Mars remains challenging, owing to the Martian atmosphere's ultra-thin density. Because Mars' gravitational acceleration is 38 % of Earth's 9.8 m/s^2, its atmospheric density is just 1.3% that of Earth's. The aerodynamic forces are related to the density of the surrounding fluid. As a result, flying near the surface of Mars has been deemed nearly impossible. The suggested mission architecture (Fig. 1) includes a pre-existing Mars rover that acts as a mobile base for Mars bees, a deployable swarm of micro bioinspired flapping-wing vehicles (Dragonflies). Each Mars bee would include an inbuilt stereographic video camera in one ConOps scenario, allowing the swarm to create a 3D topographic model of the local terrain for rover path planning. The use of insect-inspired lift production to achieve flight on Mars has also been considered. The flapping-wing vehicle, Entomopter is designed with a blown-wing lift concept [1,2].

The first reference vehicle, the AeroVironment Nano Hummingbird [3], has a wingspread of 16 cm and a mass of 19 grams, including motors, batteries, controls, communication, and color video cameras. For a period of 10 minutes, the fully controllable vehicle was able to hover and fly ahead at 6.7 m/s. The Micro Aerial Vehicle (MAV) (Fig. 2) was developed and manufactured as the second reference vehicle. With motors, batteries, controllers, and communications, but no payloads, this vehicle weighs around 250 grams. This MAV can now fly for 10 to 15 minutes under control. We believe this vehicle is currently feasible after analyzing the current status of battery and sensor technologies. Miniaturization and energy storage advances and multi-functional designs will enable a future vehicle that weighs less than 100 grams.

The dragonfly based aerial vehicle consists of a pair of forward and backward wings consists of heave and pitch motions results in producing maximum lift and thrust forces [4]. In realistic, the horizontal figure-of-eight motion, the lift force of the wings contributes 35% of total force; the coefficient of lift for a 3D flapping wing is 20% less than that of a 2D airfoil [5]. Wingtip vortices can generate lift during a hover in an unstable flow rather than only drag on the wing. The thrust/propulsion efficiency of the dragonfly can be described as follows: when flapping with a 90°/180° phase lag, the hindwing sees a phase shift in thrust generation [4]. Due to wing deformations, the effective angle of attack and thrust forces are increased within a reasonable range of span wise flexibility. Compared to a single flapping wing design, the interaction effect of tandem wings reduces the force required by fore and hindwings are 14 % and 16 %. The drag force is required as the primary source of support for the dragonfly's weight when hovering with a big stroke plane angle [5].

Fig. 1: Marsbee mission architecture

Design Methodology: The bioinspired unmanned aerial vehicle (UAV) consists of quad wings arranged in the tandem mode in a staggered manner. The quad wing UAV at different stages of free flight condition forward flight was shown in Fig. 3. These four wings are subjected to heaving and pitching motion for generating the forward thrust. The phase angle between the two wings is 180º in tandem mode. The overall length is 540 mm, and each wingspan, 700 mm. Wings are made of flexible materials of polyethylene sheet of less than 1 mm and generate thrust two times greater than the rigid wings. The main structure of the UAV is made of carbon fiber and consists of two servo motors that actuate the wings synchronously for generating sufficient lift and thrust forces. The primary servo motor is connected to the gear train via crankshafts and flaps the quad wings in prescribed motion. The flapping amplitude of the wings is 41º. The wing's action consists of upstroke and down stroke. The down stroke of the wings produces maximum thrust, whereas the upstroke is the recovery stroke. The full flying speed of the vehicle is 2.5 m/s. In conventional fixed-wing unmanned aerial vehicles, stability will be achieved by the fixed wings. The rudder and propellers will control vehicle maneuvering for generating the forward thrust. In bioinspired UAVs, the flapping wings eliminate rudders, propeller devices. These wings serve the purpose of propulsion, maneuvering, and stability. The UAV is controlled remotely using a transmitter and receiver, which are located inside the body. The UAV wing forces are measured using a six-axis force transducer. The experimental setup consists of a UAV on a custom test stand that allows measuring unsteady forces produced by the UAV.

Results and Discussions: The quad wing UAV with two asymmetrically flapping wings in tandem, a systematic series of tests for thrust force measurement are carried out. A force transducer (iloadcell, USA) is used to measure the forces and torques on the flapping wings along orthogonal axes. The forces in this experiment have a range of 0.01 N. Each measurement has a mean error of 0.005N. The obtained force measurements were then transformed to lift and thrust in global coordinates using appropriate trigonometric conversions. In this study, lift force refers to the vertical component, whereas thrust in the global coordinate frame refers to the horizontal component. The force sensors detect a combination of wing aerodynamic force and wing inertial force. We subtract the gravity of the wing from the raw data to derive the aerodynamic information. The maximum thrust generated by two pairs of tandem wings is 0.5 N at 80% throttle and the minimum thrust force obtained is 0.114 N at 40 %. The velocity of quad wing UAV at 80% of maximum throttle is 2.5 to 3 m/s. The thrust forces versus as a function of throttle are observed in Fig. 4.

Fig. 2: Dragonfly based UAV (Mars bee)

Fig. 3: Dragonfly during forwarding flight

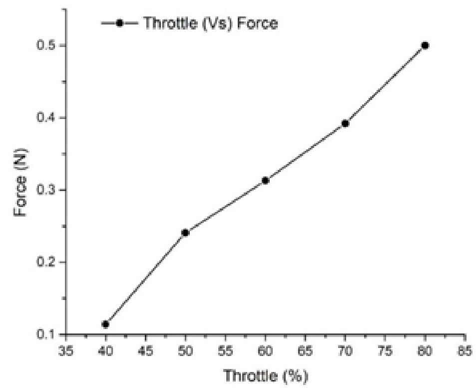

Fig. 4: Thrust force analysis of dragonfly.

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References:

[1] Colozza, A. & Michelson, R. C. "Planetary Exploration Using Biomimetics – An Entomopter for Flight on Mars," *NASA Institute for Advanced Concepts Phase II Project NAS5-98051 2002.*

[2] Bar-Cohen, Y., Colozza, A., Badescu, M., Sherrit, S. & Bao, X. "Biomimetic Flying Swarms of Entomopters for Mars Extreme Terrian Science Investigations", *Concepts and Approaches for Mars Exploration, held June 12-14, 2012 in Houston, Texas. LPI Contribution No. 1679, id.4075, 2012.*

[3] Keennon, M., Klingebiel, K., Won, H. & Andriukov, A. "Development of Nano Hummingbrd: A tailess flapping wing Micro Air Vehicle," *AIAA-2012-0588, 50th AIAA Aerospace Sciences Meeting, 09-12 January 2012, Nashville, Tennessee, 2012.*

[4] Lian Y, Broering T, Hord K, Prater R. The characterization of tandem and corrugated wings. *Progress in Aerospace Sciences* 2013; 65(1): 41-69.

[5] Sun M, Lan SL. A computational study of the aerodynamic forces and power requirements of Dragonfly (Aeschna juncea) hovering. *J Exp Biol* 2004; 207(11): 1887-901.