仿飞鱼跨介质无人平台的探索研究

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摘要：跨介质飞行器是一种既能在空中飞行，又能在水下潜航的新概念飞行器，它兼有飞行器的速度和潜航器的隐蔽性。本文以自然界的飞鱼为模仿对象，研究了一种仿飞鱼的跨水气介质无人平台。仿生飞鱼的身体长度约 25cm，排水重量约为 0.18kg。作为探索性研究，本文主要采用计算流体力学的手段，研究了仿生飞鱼水下游动、水面滑跑及空中滑翔阶段的水动\空气动力学特性。首先，针对空中滑翔阶段，提出了三种不同的飞鱼外形，比较了不同攻角下的升阻力系数、升阻比等关键气动参数，并采用三自由仿真模型，对飞鱼的空中滑翔轨迹进行了预测。研究结果表明飞鱼的最大升力系数为 1.03、升阻比为 4.7，与前人的风洞试验结果吻合；飞鱼空中滑翔的最远水平距离可达 45.4m、最高飞行高度可达 13.2m，与生物学家的现场观测结果吻合很好。在研究水中游动与水面滑跑过程中，重点比较了飞鱼达到巡航状态所需功率，以证明飞鱼可以通过水面滑跑过程进一步加速到起飞状态。首先，对于水下游动状态，当巡游速度为 10m/s，尾鳍拍动频率为 145Hz 时，在小拍动幅度工况下，飞鱼达到巡游状态需要的输入功率约为 350W，此时，通过身体重量计算出的肌肉功率密度为 3664W/kg，该数值可以在生物学上找到合理解释。当飞鱼在水面滑跑时，同样输入功率为 350W 时，滑飞速度可达到 16.5m/s。显然，飞鱼通过水面滑跑进一步将自身加速到起飞状态。

关键词：仿生飞鱼；跨介质飞行器；滑翔；滑跑；游动

A preliminary study on aerial-aquatic unmanned vehicle mimicking flying fish

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Abstract: Aerial-aquatic unmanned vehicles are new concepts of robots with hybrid and multi-modal locomotion, referring specifically to those that can both swim in water and fly in air. They have both advantages of moving as fast as aircrafts and low detestability as submerged. In this paper, we study a new concept of aerial-aquatic unmanned vehicle mimicking flying fish, which is 0.25 m in length and 0.191 kg in weight. Its hydrodynamic characteristics are studied by computational fluid dynamics (CFD), with all the three locomotive modes considered, i.e., swimming, taxiing and gliding. First, in the gliding stage, three different geometries are considered, between which the lift, drag coefficients, and lift-to-drag ratio are compared. Furthermore, we build a three-degree-of-freedom (3-DOF) dynamic model to predict the gliding trajectories. The results show that a maximum lift force coefficient of 1.03 and a maximum lift-to-drag ratio of 4.7 can be achieved, consistent with the previous wind tunnel experiments. The flying fish can reach a distant up to 4.5 m, and a height of 13.2 m, indicating an extraordinary gliding performance. In the stages of underwater swimming and surface taxiing, we focus on the direction comparison in power consumption between these two modes. Underwater, when the fish swims at a constant speed of 10 m/s, the minimum power required is 350 W, achieved at a flapping frequency of 145 Hz and with a small flapping angle. The corresponding muscle density for the fish is 3664 W/kg, which is considerably higher than the normal muscle power density for a fish, but still a reasonable estimation for a real flying fish at this length scale. In contrast, in the taxiing stage, at the same level of power input, i.e., 350 W, the fish can reach a speed of 16.5 m/s. It is apparently evidenced that the flying fish can be further accelerated before take-off by taxiing on the water surface.

Key words: Biomimetic flying fish; Aerial-aquatic unmanned vehicles; Gliding; Taxiing; Swimming.