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蜻蜓前后翼相位特性和气动干扰的数值研究

肖天航，昂海松

南京航空航天大学 航空宇航学院

Numerical Study of Unusual Phase Relationships and Aerodynamic Interaction Between Forewing and Hindwing of Dragonfly Model

Xiao Tianhang, Ang Haisong

College of Aerospace Engineering, Nanjing University of Aeronautics and Astronautics

摘要 蜻蜓能通过改变前后翼间的相位实现对不同飞行姿态的控制。通过在动态非结构嵌套网格上求解非定常Navier-Stokes(N-S)方程，数值模拟三维蜻蜓模型在悬停(前进比$J=0$)和中等前飞速度($J=0.3$)两种状态下的流场，每种状态各计算0°~360°间隔30°的13个不同相位。考察气动力和气动功率随相位的变化关系以及前后翼间的气动干扰。结果发现，平均举力和平均气动功率随相位的变化呈U型分布，举力足够用于平衡重力，气动功率也符合蜻蜓真实飞行的统计数据。90°～270°的较宽相位范围内，两翼间的气动干扰较为强烈且比较稳定，该范围内能量消耗较小，功率最省，在一定程度上解释了蜻蜓翼具有特定相位的现象。

关键词： 蜻蜓 非定常流场 气动干扰 相位特性 数值模拟

Abstract: Dragonfly has the ability to control the aerodynamic forces for flight by modulating the phase relationship between their forewings and hindwings. In this article, unsteady flows of a dragonfly model in hovering (advance ratio $J=0$) and in forward flight with medium speed ($J=0.3$) are simulated by solving unsteady Navier-Stokes (N-S) equations on dynamic overset unstructured grids. At each advance ratio, thirteen phases from 0° to 360° with intervals of 30° each are considered. The variation of aerodynamic force and power with phase as well as the aerodynamic perturbation between the forewing and hindwing are studied. It is found that the period average vertical force and power varies in a “U” shape as a function of the phase. The vertical force generated by the model is enough to balance the weight, and the data for aerodynamic power also agree with the statistical data of real dragonflies. In the wide phase region of 90° 270°, aerodynamic interaction between the wings is relatively strong and stable. The vertical force and power is relatively small and stay roughly constant. All these results may be useful for explaining the unusual phase relationships between the wings of dragonflies.

Keywords: dragonfly unsteady flow aerodynamic interaction phase relationship numerical simulation

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Corresponding Authors: 肖天航

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