The mechanism of thrust generation by dynamic stall in flapping flight

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Abstract

This paper deals with a thrust generation of flapping-airfoil by dynamic stall. From many other previous research results, phase angle ϕ between pitching and plunging mode of flapping motion must be 90 deg. to satisfy maximum propulsive efficiency. In this case, leading edge vortex is relatively small. This phenomenon is related dynamic stall. So preventing leading edge vortex induced by dynamic stall guarantees maximum propulsive efficiency. But, in this paper we insist the leading edge vortex yields quite a positive influence on thrust generation and propulsive efficiency. In order to certify our opinion, pitching and plunging motions were calculated with the parameter of amplitude and frequency by using the unsteady, incompressible Navier-Stokes flow solver with a two-equation turbulence model. For more efficient computation, it is parallelized by MPI programming method.

Keyword: *Flapping, Dynamic Stall, Thrust, Propulsive efficiency*

1. Introduction

1.1 Flapping-Airfoil

Recently, flapping motion of airfoil (or wing) has been considered as a promising propulsive technique in many engineering applications, including the very tiny ornithopter type reconnaissance flying object called MAV (Micro-Aerial Vehicle) and an unconventional type boat that uses a newly developing propulsive device called flappers. Flapping is considered as a natural means of motion among some creatures such as birds, insects and aquatic animals. They use their wings or tail to produce locomotive force. Especially, flying creatures flap their wing to generate a lift that can overcome over their weight by unsteady aerodynamics. However, flapping motion of airfoil is inherently unsteady aerodynamics which is related to complex flow physics such as dynamic stall. And there is yet insufficient knowledge on this flapping foil in term of the aerodynamic perspective. Therefore, further researches on flapping airfoil or wing is necessary in order to adopt bird or fish-like propulsion system

1.2 Physical Background

From the first explanation on the concept of thrust produced by flapping airfoil in 1909 by Knoller, several scientists have conducted in this area. In the course of these, researches, the flapping airfoil problem was solved in 1935 by Von Kármán and Burgers. They were successful in theoretically explaining that drag or thrust production is based on the resulting vortex street. Kármán vortex street appears in the rear region of the airfoil, drag product. When the flow condition satisfies a certain condition, an inverse Kármán vortex is induced, resulting in thrust being generated. Inverse Kármán vortex induces jet-like flow field in the rear region of airfoil. In this case flow gains some momentum and then flow feeds reaction force to the airfoil. This reaction force is referred to thrust. But, in this paper we insist the leading edge vortex yields quite a positive influence on thrust generation and propulsive efficiency.

2. Numerical Approach

Since the flow field around flapping airfoil has characteristics of low-Reynolds number flow due to low freestream velocity, two-dimensional unsteady incompressible Navier-Stokes equations are employed in this work. To simulate flapping-airfoil aerodynamics, we adapted Osher's FDS (Flux Difference Splitting) for spatial discretization. And 3rd order MUSCL (Monotone Upstream-centered Scheme for Conservation Law) was also introduced to attain higher order spatial accuracy. For the time integration, Yoon's LU-SGS (Lower Upper – Symmetric Gauss Seidal) was used together with dual time stepping method. Also the present study employs a baseline-SST (Shear-Stress Transport) turbulence model. For more efficient computation, we used MPI-Parallel programming method.

3. Results

The mechanism of thrust generation of flapping-airfoil by dynamic stall can be explained by Fig. 1. It is well known that dynamic stall can induce a leading edge vortex. This vortex makes large pressure difference between lower and upper surface of airfoil. Therefore this pressure difference contributes the thrust component.

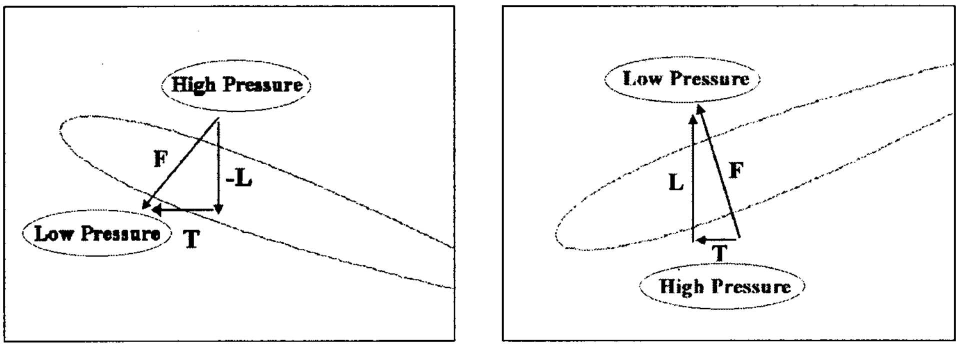

Fig. 1 The mechanism of thrust generation by dynamic stall.

We have simulated the flapping motion for NACA0012. In this case, pitching and plunging amplitude was 20 (deg.) and 0.2 respectively, *Re* $=1.2\times10^4$, and reduced frequency was 8. Fig. 2 is the above computational case results. And these figures show the comparison of pressure field and aerodynamic coefficients. From this comparison, we can confirm our opinion. The leading edge vortex induced by dynamic stall contribute thrust component. The second figure of Fig. 2 shows that relative lower pressure cause by leading edge vortex can induce large thrust coefficient. So, when the lift coefficient reaches maximum absolute value, thrust coefficient (negative drag coefficient) reaches maximum value. In full paper, we will show the physically detailed explanation about sequence of thrust generation. And we will describe the difference of the thrust generation mechanism cause by dynamic stall and inverse Kármán vortex.

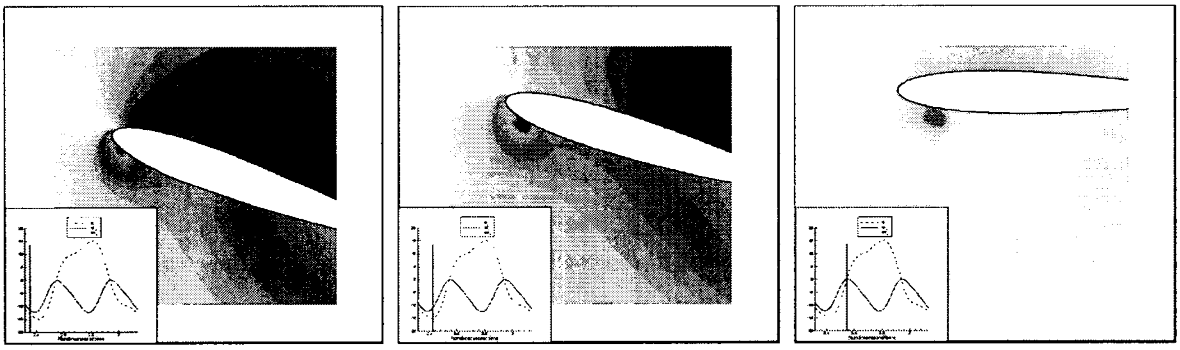

Fig. 2 The sequence of thrust generation by dynamic stall.

Fig. 3 shows the difference of the thrust generation mechanism, left shows dynamic stall domina thrust generation mechanism and right shows inverse Kármán vortex one. As shown in this figures, we can see the difference aerodynamic characteristics. In the dynamic stall dominant case, the absolute maximum lift coefficient agree with maximum thrust coefficient. But inverse Kármán vortex dominant case is not. In the full paper, we will describe the difference of other aerodynamic characteristics such as propulsive efficiency. Also we will explain the reason of thin wing section of insect in the point of aerodynamic characteristic.

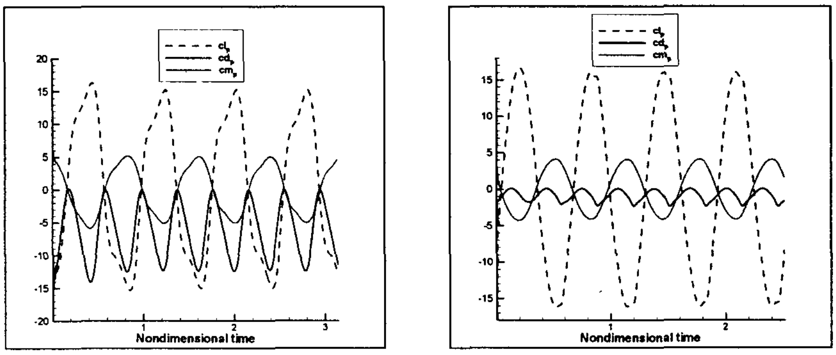

Fig. 3 Aerodynamic coefficients variation with time

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