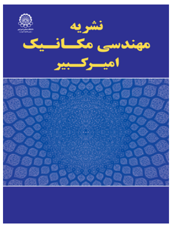

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 52(4) (2020) 247-250
DOI: 10.22060/mej.2018.14636.5901

Impact of Reduced Frequency on Pressure Distribution on the Lower Surface of a Supercritical Airfoil in Pitch-Pause-Return-Motion

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ABSTRACT: Effects of reduced frequency, pause duration and stop angle on pressure distribution on the lower surface of a thin supercritical airfoil undergoing the pitch-pause-return maneuver have been studied. The experiments have been performed in a subsonic wind tunnel for a fixed mean angle of attack and at a constant amplitude. The reduced frequencies were from 0.01 to 0.12, and three stop angles were chosen during upstroke motion in below stall, near stall and post-stall regions. For all angles of attack below the static stall, the pressure distributions are nearly identical at the rear quarter chord on the lower surface. For beyond the stall angles, the lower surface pressure distributions are observed to remain unchanged from the leading edge downstream to x⁄c=0.15. Also, dynamic results show that the behavior of pressure distribution at the lower surface taps for all stop angles, reduced frequencies and pause durations, are identical from the leading edge to x⁄c=0.70 and are higher than the static values at zero angle of attack. However, the lower surface pressure distributions have been observed to be entirely different at the rear %30 chord for various pause angles, which can be deemed to be the signature of the unsteady Gortler vortices.

Review History:

Received:20 Jun. 2018
Revised: 7 Dec. 2018
Accepted: 27 Dec. 2018
Available Online: 30 Dec.2018

Keywords:

Reduced frequency
Supercritical airfoil
Static stall
Dynamic stall
Gortler vortices

1- Introduction

The continuing development of high-performance aircraft has put unsteady problems into the forefront of aerodynamic investigations. Especially, research about oscillating airfoils has been a topic of study for decades. Because of the inherent complexities in such time-dependent problems, a great deal of both theoretical and experimental surveys have been performed to understand and explain the flow physics governing such motions. These studies have mostly focused on pure pitching or plunging airfoils, and very limited data is available for other types of motions, one of which is the pitch-pause-return maneuver. The pitch-pause-return motion has been introduced by the AIAA Fluid Dynamics Committee (FDTC), as a standard maneuver for fighter aircraft and Micro Air Vehicles (MAVs) [1, 2]. This motion is usually considered in studies involving the aerodynamics of aggressive perching maneuvers. In such maneuvers, large lift and drag forces are produced due to a rapid increase in the angle of attack. The capability to sustain the lift at an angle of attack typically higher than the static stall angle is the key feature to a successful maneuver. Herbst introduced for the first time the pitch-pause-return motion. This type of maneuver encompasses a rapid pitch-up to 90°, maintaining this condition for 2-3 s followed by a fast return to the initial conditions [3]. Ramesh et al. studied this pitch-pause-return motion for a flat plate, using theoretical computational and experimental approaches. They examined several locations for the pitch axis and compared the results obtained from different methods. They also investigated the effects of the pitch axis location and stop angles on the location of the leading-edge vortex, separation and vortex mechanisms at the beginning and end of the cessation of the motion. They observed that the leading-edge vortex formation is initiated at the upstroke, while the location of separation depends on the pitch axis and stop angle and differs between upstroke and downstroke motions. The Detachment of the vortex is accompanied by reversal of flow on the surface of the airfoil and causes a deep stall and a significant reduction in lift during the hold and downstroke phase [4]. Teyu et al. studied the pitch-pause-return motion of a flat plate in a water tunnel. They observed a strong dependency of lift to the stop angle. Just at the pause moment after pitch-up, if the vortices are not matured, the lift continues its increasing trend during upstroke to further growth of the leading-edge vortex. According to their results, for a pause angle of 33°, the leading-edge vortex had not grown enough, and the lift at the pause duration was still increasing. For 45° and 75° stop angles, a fully developed leading-edge vortex was observed, and the lift at the stop time was seen to be decreased [5, 6]. Up to now, valuable information has been obtained about the aerodynamic behavior of the supercritical airfoils in both steady and unsteady conditions. However at low speeds at which the aircraft take off, landing and various maneuvers are performed, a lot remained to be discovered about the flow field behavior, especially in unsteady conditions. Recently, some investigations have been reported on SC-0410 [7, 8].

2- Experimental apparatus

Experiments were conducted in a subsonic wind tunnel of a close return type having test-section dimensions of 80 cm×80

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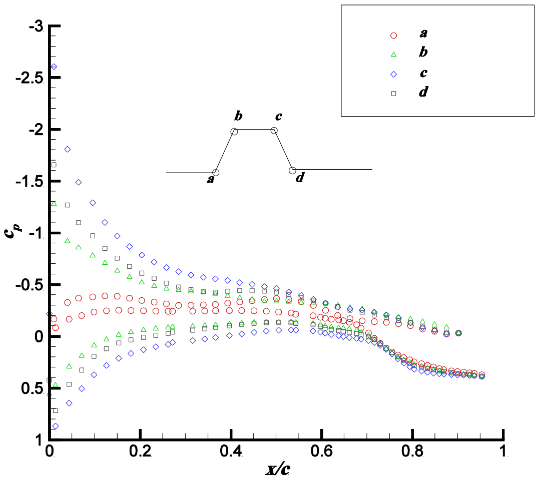

Fig. 1. Pressure distribution in four phases of the motion, k=0.01

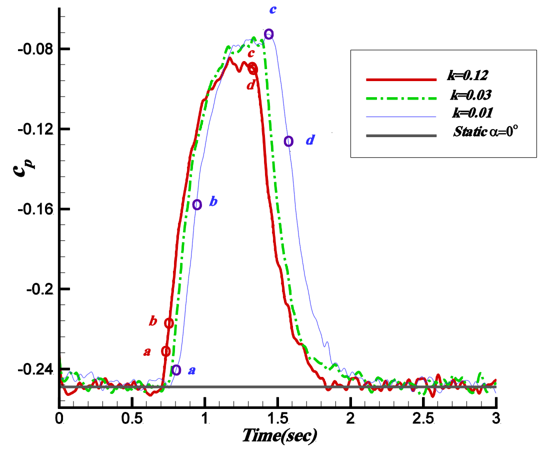

Fig. 2. Effect of reduced frequency on pressure distribution of x/c=0.53 at the lower surface, stop angle= 5^o

cm ×200 cm. The tunnel operates in a speed range from 10 to 100 m/s. The present experiments have been performed at a constant speed of 30 m/s corresponding to a Reynolds number of 0.45×106¬. The model used in the present experiments was a rectangular 2D wing with a supercritical airfoil section, SC-0410. The chord length was 30 cm, and the wingspan was 80 cm. The oscillation system produces a pitching motion about the quarter chord axis according to the equation:

$$\alpha = 7.05 + 15.65\,\mathrm{Sin}\left(2\pi f t\right) \tag{1}$$

f is the motion frequency and the reduced frequencies in these experiments were between 0.01 and 0.12. The static stall angle of attack for this airfoil has been measured to be about 10º [9].

3- Results and Discussion

The unsteady pressure distribution on the airfoil was measured for below, near, and beyond static stall conditions at pitch-pause-return motion. Fig. 1 shows the pressure distributions at below stop angle i.e. in four phases. The a, b, c and d phases are the start point of the upstroke, the start point of pause, the start point of downstroke, and the end of the down stroke, respectively.

From this figure, it can be observed that the pressure distributions for all the four phases are nearly identical at the rear part of the lower surface and this position moves to leading edge respect to the static case at . Shown in Fig. 2 is the reduced frequency independency on the behavior of pressure distribution at this position.

4- Conclusions

Static results show that for angles of attack below the static stall, the pressure distributions are nearly identical on the lower surface near the trailing edge. This region has a relatively high curvature, which is common to all supercritical airfoils. Furthermore, beyond the stall angles of attack, the pressure distributions are observed to be unchanged on the lower surface near the leading edge. Dynamic results show that the behavior of pressure distribution at the lower surface taps for all stop angles, reduced frequencies and pause durations, are identical, from the leading edge downstream to x/c=0.70 and are higher than the static values at zero angle of attack. However, the pause angle was shown to have a strong effect on the behavior of pressure distribution at the rear part of the lower surface. For a beyond-static stall pause angle, a dynamic stall was observed at the lowest reduced frequency. The maximum lift in a dynamic stall condition has been found to be higher than the corresponding value in the static stall and this phenomenon has a prominent effect on the behavior of pressure distribution at the rear part of the lower surface.

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