Propulsion and Power Research 2014;3(1):29–40

http://ppr.buaa.edu.cn/

Propulsion and Power Research

www.sciencedirect.com

ORIGINAL ARTICLE

Compressible flow characteristics around a biconvex arc airfoil in a channel

Md. Abdul Hamid[a], **A.B.M. Toufique Hasan**[a,*], **S.M. Alimuzzaman**[a], **S. Matsuo**[b], **T. Setoguchi**[b]

[a]*Department of Mechanical Engineering, Bangladesh University of Engineering and Technology (BUET), Dhaka-1000, Bangladesh*
[b]*Department of Advanced Technology Fusion, Saga University, Saga 8408502, Japan*

Received 4 August 2013; accepted 18 November 2013
Available online 21 March 2014

KEYWORDS

Compressible flow;
Shock waves;
Shock induced oscillation;
Frequency;
Reynolds-averaged Navier-Stokes (RANS)

Abstract Shock wave-boundary layer interactions (SWBLI) are observed in several practical high-speed internal flows, such as compressor blades, turbine cascades, nozzles and so on. Shock induced oscillations (SIO), aerodynamic instabilities so-called buffet flows, flutter, aeroacoustic noise and vibration are the detrimental consequences of this unsteady shock-boundary layer interactions. In the present study, a numerical computation has been performed to investigate the compressible flow characteristics around a 12% thick biconvex circular arc airfoil in a two dimensional channel. Reynolds averaged Navier-Stokes equations with two equation k-ω shear stress transport (SST) turbulence model have been applied for the computational analysis. The flow field characteristics has been studied from pressure ratio (ratio of back pressure, p_b to inlet total pressure, p_{01}) of 0.75 to 0.65. The present computational results have been compared and validated with the available experimental data. The results showed that the internal flow field characteristics such as shock wave structure, its behavior (steady or unsteady) and the corresponding boundary layer interaction are varied with pressure ratio. Self-excited shock oscillation was observed at certain flow conditions.

---

[*] Corresponding author: Tel.: +880 1730714444.

E-mail address: toufiquehasan@me.buet.ac.bd (A.B.M. Toufique Hasan).

Peer review under responsibility of National Laboratory for Aeronautics and Astronautics, China.

Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.jppr.2014.01.002

Moreover, the mode of unsteady shock oscillation and its frequency are varied significantly with change of pressure ratio.

1. Introduction

Shock wave-boundary layer interactions (SWBLI) are not only fundamental research topics of aerodynamics but are observed in several practical high-speed internal flows, such as turbine cascades, compressor blades, butterfly valves, fans, nozzles, diffusers and so on. Shock induced oscillations (SIO), aerodynamic instabilities so-called buffet flows, high cycle fatigue failure (HCF), nonsynchronous vibration (NSV), flutter, aeroacoustic noise and vibration and so on are the detrimental consequences of unsteady shock/boundary layer interactions [1–3]. McDevitt et al. [4] and Levy [5] performed an experimental and theoretical study of transonic flow over a 18% thick arc airfoil. The results stated that the shock-boundary layer interaction phenomena are strongly dependent on Mach number and Reynolds number. Tijdeman [6] had described the behavior of the transonic flow around an oscillating airfoil. The interaction of steady and unsteady flow fields and periodic motion of the shock were focused in that study. Yamamoto and Tanida [7] investigated the self-excited oscillation of transonic flow in a cascade model. The measurements of the shock wave and wake motions, and the unsteady static pressure field predicted a closed loop mechanism for the self-excited shock oscillation. In the same year, Lee [8] proposed and quantified a feed-back mechanism of shock oscillation for flow over a supercritical airfoil. It was observed that the time to take a disturbance to propagate from the shock to the trailing edge plus the additional time it takes for an upstream traveling wave generated at the trailing edge to reach the shock agreed quite closely with the period of shock oscillation measured from unsteady force spectra. Alshabu et al. [9] investigated the upstream moving pressure wave for shock oscillation around a supercritical airfoil. Time-resolved pressure measurements revealed the unsteady behavior of these waves and the measured frequencies were in the order of kHz. Raghunathan et al. [10] performed a computation using thin-layer Navier-Stokes approximate to investigated the origin of shock oscillation around a 18% thick biconvex aerofoil. Results indicated that the shock induced separation plays the leading role of the origin of shock oscillation. However, in the review article of Lee [11], it was concluded that the complete understanding of the mechanisms responsible for self-sustained oscillations of the shock waves under wide ranges of conditions, such as Mach number, incidence angle, Reynolds number, and airfoil geometry has not yet been achieved.

Recently, Xiong et al. [12] performed a 2D numerical simulation using Unsteady Reynolds Averaged Navier-Stokes (URANS) and Detached Eddy Simulation (DES) to investigate the transonic shock oscillation over a 10% thick circular arc airfoil in a channel. These methods could predict the overall shock oscillatory behavior. However, the computationally obtained frequency varied considerably in the range of 50% to 100% with the experimental frequency of Yamamoto and Tanida [7]. Chen et al. [13] performed a DES study of compressible flow past a 18% thick circular arc airfoil. Various fundamental mechanisms dictating the intricate flow phenomena such as moving shock wave behaviors, turbulent boundary layer characteristics, kinematics of coherent structures had been studied. Moreover, the effect of air humidity on the shock oscillation around an airfoil in 2D channel was performed by Hasan et al. [14]. And it was revealed that the non-equilibrium condensation of moist air reduces the unsteady shock behavior compared to dry air case.

Though there have been a great deal of researches on high speed aerodynamics over airfoils, the understanding of the compressible flow characteristic over an airfoil in a channel is not completely clear until now. In the present study, a 2D numerical computation is performed to investigate the shock wave generation and its behavior in compressible flows around a 12% thick biconvex circular arc airfoil. Different compressible flow conditions are considered by varying the pressure ratio, *PR* which is defined as the ratio of back pressure to inlet total pressure. The steady shock wave and shock waves with unsteady oscillation in the flow field are captured at different flow conditions. Various aerodynamic parameters such as time histories of static pressure, root mean square (RMS) of pressure oscillation and fundamental frequency of shock oscillation are discussed.

2. Numerical methods

2.1. Governing equations

The flow field in this study is considered to be viscous, compressible, turbulent, and unsteady. Governing equations for the present RANS computations are the conservation of mass, conservation of momentum and the energy equations written in 2D coordinate system (x, y). Two additional transport equations of k-ω SST (Shear Stress Transport) turbulence model [15] are included to model the turbulence in the flow field. The governing equation can be written in the following vector form:

$$\frac{\partial \boldsymbol{U}}{\partial t}+\frac{\partial \boldsymbol{E}}{\partial x}+\frac{\partial \boldsymbol{F}}{\partial y}=\frac{\partial \boldsymbol{R}}{\partial x}+\frac{\partial \boldsymbol{S}}{\partial y}+\boldsymbol{H} \qquad (1)$$