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Trailing edge shock modulation by pulsating coolant ejection

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ABSTRACT

In transonic and supersonic turbomachinery, shock waves appear at the trailing edge, generating substantial losses due to the interaction with the boundary layer. A novel proposal to control the resulting fish tail shock waves consists on, pulsating coolant blowing through the trailing edge of the airfoils. This paper presents an unprecedented experimental and numerical research. A linear cascade representative of modern turbine bladings was specifically designed and constructed. The test matrix comprised four Mach numbers, from subsonic to supersonic regimes (0.8, 0.95, 1.1 and 1.2) together with two engine representative Reynolds numbers (4 and 6×10^6) at various blowing rates. The blade loading and the downstream pressure distributions allowed understanding the effects on each leg of the shock structure. Minimum shock intensities were achieved using pulsating cooling. A substantial increase in base pressure was observed for low coolant blowing rate. Analysis of the high-frequency Schlieren pictures revealed the modulation of the shock waves with the coolant pulsation. The Strouhal number of the vortex shedding was analyzed for all of the conditions.

1. Introduction

Trailing edge shock interactions are one of the major sources of losses in supersonic airfoils. Additionally, vane shocks cause large pressure fluctuations that may result in low and high cycle fatigue problems. Previous research related to the present investigation may be classified in four topics: trailing edge shock wave interactions, base pressure losses, trailing edge vortex shedding, and effects of the coolant ejection.

The downstream flow field of nozzle guide vanes in modern high pressure turbines suffers fish tail shock structures [1]. The trailing edge shock pattern has been well documented in the literature. Denton and Xu [2,3] quoted that the trailing edge losses contribute typically to a third of the total losses in transonic turbines. The impingement of those compression waves on the downstream rotor row and rear suction side of the adjacent vane results in unsteady entropy generation. Quantification of unsteady loss and pressure variation in a transonic turbine was studied numerically and experimentally in the literature [4].

Regarding the base pressure losses Gostelow et al. [5] analyzed computationally and experimentally the trailing edge structure and the related losses. Uzol et al. [6,7] documented the performance of different trailing edge geometries. Schobeiri and Pappu [8] found an optimal geometry and blowing ratio that minimize the mixing losses of a cooled gas turbine blade. Sieverding et al. [9] determined an experimental correlation of the base pressure in function of the downstream static pressure, that allows accurate predictions of base pressure losses.

Concerning the vortex shedding, Rowe et al. [10] observed that a thick boundary layer upstream of the trailing edge reduced the shedding frequency, resulting in decreased base pressure losses. Sieverding and Heinemann [11] demonstrated the influence on the vortex shedding of the boundary layer state on both pressure and suction sides. Furthermore, the vortex street exhibits a 2D structure only in the mid-span region [12]. Cicatelli and Sieverding [13] characterized experimentally the time averaged and unsteady pressure field in the base region.

Studies on the effect of coolant ejection on the vortex shedding were presented by Motallebi and Norbury [14] based on Schlieren images of the vortices shed from a blunt trailing edge at subsonic and supersonic conditions. A certain rise in the base pressure was noticed corresponding to a moderate coolant flow rate. The disappearance of the trailing edge vortex motion was observed over a range of bleed air mass flows near to the value producing a maximum level of base pressure. Sieverding [15] showed that a higher base pressure and a consequent reduction of the trailing edge shock intensity corresponded to a moderate coolant flow rate. Raffel and Kost [16] gathered similar results at supersonic conditions using PIV data. Saracoglu et al. [17] obtained analogous

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