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Separation control on high lift low-pressure turbine airfoils using pulsed vortex generator jets

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A B S T R A C T

Boundary layer separation control has been studied using vortex generator jets (VGJs) on a very high lift, low-pressure turbine airfoil. Experiments were done under low (0.6%) freestream turbulence conditions on a linear cascade in a low speed wind tunnel. Pressure surveys on the airfoil surface and downstream total pressure loss surveys were documented. Instantaneous velocity profile measurements were acquired in the suction surface boundary layer. Cases were considered at Reynolds numbers (based on the suction surface length and the nominal exit velocity from the cascade) of 25000 and 50000. Jet pulsing frequency and duty cycle were varied. In cases without flow control, the boundary layer separated and did not reattach. With the VGJs, separation control was achieved. At sufficiently high pulsing frequencies, separation control was possible with low jet velocities and 10% duty cycle. At lower frequencies, a 50% duty cycle helped by separating the disturbances associated with the jets turning on and turning off, thereby doubling the frequency of separation control events above the pulsing frequency. Phase averaged velocity profiles and wavelet spectra of the velocity show the VGJ disturbance causes the boundary layer to reattach, but that it can re-separate between disturbances. When the disturbances occur at high enough frequency, the time available for separation is reduced, and the separation bubble remains closed at all times.

1. Introduction

Gas turbine engines power nearly all commercial and military aircraft and are used extensively for ship propulsion and land based power generation. Given the hundreds of billions of liters of fuel used in gas turbines each year, any improvement in their efficiency, even an improvement of only 1%, would result in a huge savings in fuel and reduction in emissions. The low-pressure turbine (LPT) is the heaviest component in a gas turbine engine and produces the net power from the engine. Increases in LPT component efficiency result in almost equal increase in overall engine efficiency [1]. One way to potentially improve the LPT is to reduce part count, weight and cost through the use of very highly loaded blading. The limitation on loading is boundary layer separation, which leads to partial loss of lift and higher aerodynamic losses (e.g. Mayle [2]).

Separation and separated flow transition, which can lead to boundary layer reattachment, have received considerable attention, as noted by Volino [3,4]. In general, previous work shows that the strong acceleration on the leading section of the airfoil keeps the boundary layer thin and laminar. When separation does occur, it is usually just downstream of the suction peak. If transition then occurs in the shear layer over the separation bubble, it is typically rapid and often causes the boundary layer to reattach [4,5].

Airfoils can be designed with high resistance to separation, as described by Praisner and Clark [6], but a loading limit will always exist, above which separation will still occur. If flow control were incorporated in the design of an advanced airfoil, it might be possible to increase the loading limit. Passive devices such as boundary layer trips (eg. Zhang et al. [7] and Bohl and Volino [8]) have been shown effective for separation control and have the distinct advantage of simplicity, but they also introduce parasitic losses and cannot be adjusted to account for changes in flow conditions. Active devices would be more costly and potentially risky in terms of reliability, but could potentially provide better control over the entire operating range of interest.

The literature contains many examples of active separation control. In turbomachinery, plasma devices, as used by Huang et al. [9], could be viable. Vortex generator jets (VGJs), as introduced by Johnston and Nishi [10], are another alternative and the subject of the present study. Blowing from small, compound angled holes is

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