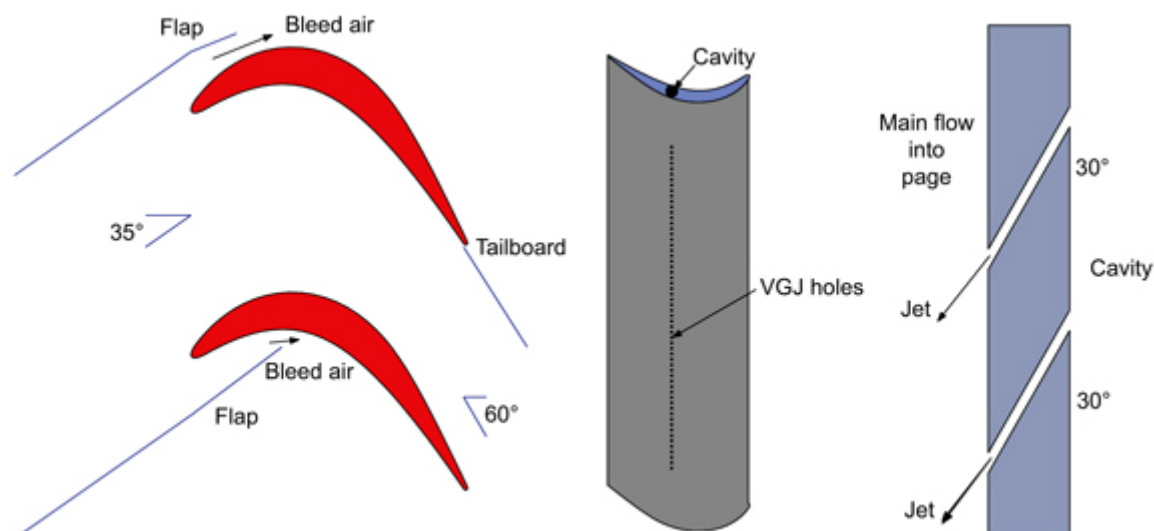


Synthetic Vortex Generator Jets Used to Control Separation on Low-Pressure Turbine Airfoils

Low-pressure turbine (LPT) airfoils are subject to increasingly stronger pressure gradients as designers impose higher loading in an effort to improve efficiency and lower cost by reducing the number of airfoils in an engine. When the adverse pressure gradient on the suction side of these airfoils becomes strong enough, the boundary layer will separate. Separation bubbles, particularly those that fail to reattach, can result in a significant loss of lift and a subsequent degradation of engine efficiency. The problem is particularly relevant in aircraft engines. Airfoils optimized to produce maximum power under takeoff conditions may still experience boundary layer separation at cruise conditions because of the thinner air and lower Reynolds numbers at altitude. Component efficiency can drop significantly between takeoff and cruise conditions. The decrease is about 2 percent in large commercial transport engines, and it could be as large as 7 percent in smaller engines operating at higher altitudes. Therefore, it is very beneficial to eliminate, or at least reduce, the separation bubble.

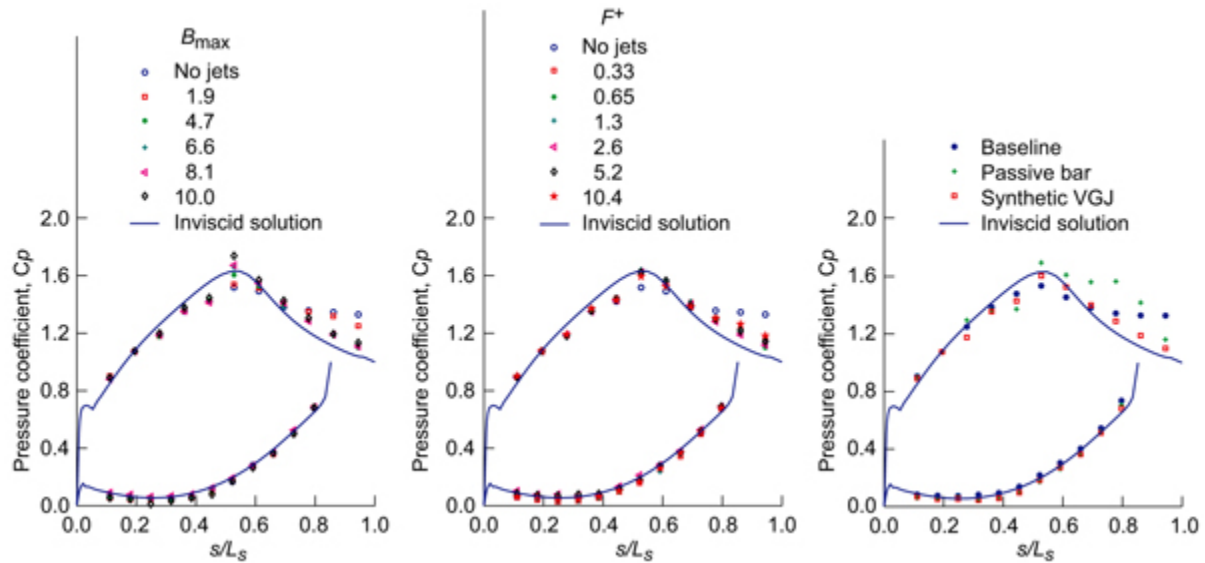
The focus of this research project was the development and experimental study of active separation control using synthetic vortex generator jets (VGJs). The results demonstrated successful significant reduction of the separation in simulated LPT flow conditions in a wind tunnel, laying the foundation for further development of the technology.



Test setup. Left: Test section. Center and right: Suction-side airfoil with cavity and VGJ's showing full airfoils (center) and cross section of VGJ holes (right).

The focus of this project was on using a synthetic VGJ for separation control. A VGJ is a small jet that is injected from the surface through a small hole that is slanted relative to the streamwise and spanwise flow direction. It creates a streamwise vortex pair in the

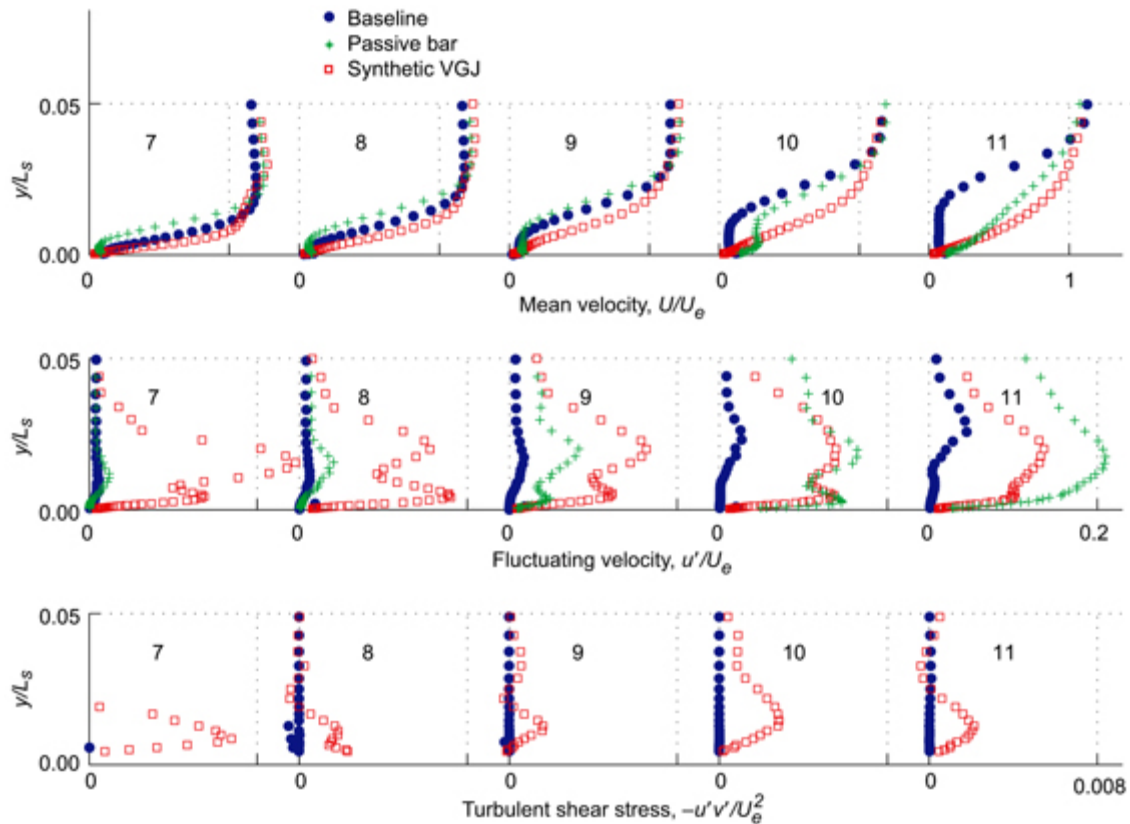
flow. The generation of VGJ involves the consumption of supply high-pressure air. In the research described here, a new type of oscillatory VGJ, called a synthetic VGJ, was developed and tested. The synthetic VGJ is a combination of a device known as a synthetic jet and a steady-flow VGJ; it has the advantage of being a zero-net-mass device that does not consume any supply air.



Pressure coefficient profiles. In each graph, the top line and data points are for the suction surface, and the lower line and data points are for the pressure surface; s , streamwise distance along the suction surface; L_s , wetted surface length of the suction surface. The closer the points are to the inviscid line on the downstream portion of the suction surface, the more effective the flow control is and the smaller the separation bubble is. Left: Effect of blowing ratio, B_{max} , at constant nondimensional frequency, $F^+ = 0.65$. Center: Effect of nondimensional frequency, F^+ , at constant blowing ratio, $B_{max} = 5$. Right: Comparison of baseline (no control), passive bar tripping, and synthetic VGJ with $B_{max} = 4.7$ and $F^+ = 0.65$.

The experiments were conducted in a wind tunnel that simulates the Reynolds number range of a typical LPT. A spanwise row of synthetic VGJs were incorporated in the surface and powered by a speaker. The measurements included surface pressure measurements using pressure taps and boundary layer velocity and shear stress measurements using hot-wire anemometry along streamwise stations on the suction surface. A range of VGJ oscillation frequencies and blowing velocities was tested.

The results show that the separation bubble was reduced significantly and remained very thin. The losses associated with the separation were substantially reduced in comparison to the baseline case without any flow control and to a passive flow-control device based on tripping with a rectangular bar strip.



Dimensionless time-averaged profiles as a function of normalized distance normal to surface, y/L_s ; comparison of baseline, passive bar, and synthetic VGJ. The inflected profiles in the top graph indicate separation. The fuller profiles with control indicated attached or almost-attached flow.

This work was performed by Professor Ralph Volino at the U.S. Naval Academy under a contract from the NASA Glenn Research Center. The research is described in detail in reference 1. It is part of an ongoing sponsored and in-house Glenn research activity in the active and passive flow control of LPT flows (refs. 2 to 6).

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