Aerodynamic Performance Evaluation of Leading Edge Tubercle on Blades of a Low Pressure Turbine at Very Low Reynolds Number and Higher Turbulence.

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The performance of the turbine section of an aircraft gas turbine engine plays a major role in the overall efficiency of the engine. The low-pressure turbine (LPT) section of the turbine is a crucial component for power extraction and also one of the heaviest. Increasing LPT efficiency can potentially lead to a reduction in the number of blades, stages, and overall turbine weight. LPT losses depend on blade profile and associated secondary flows, and incoming flow condition. At higher altitude, the LPT is susceptible to a substantial decrease in performance commonly called the Reynolds Lapse. This phenomenon is caused by suction surface boundary layer separation. Alleviating these negative aspects could lead to safer and efficient high-altitude operations. In an effort to enhance LPT performance, aerodynamic work-load enhancement and various methods of flow control, both passive and active, have been employed over the years. This paper presents results and recommendations from an experimental application of leading edge tubercles as passive flow control devices for a purpose-designed, aft-loaded, high-lift, LPT profile. These bio-inspired geometric features have been shown to delay stall and improve post-stall operability of airfoils and wings. In the present study, tubercle geometry was designed with guidance provided by a neural network technique called Self-Organizing Maps, trained by available published data. In addition to low turbulence tests, the performance of the baseline and tubercled blade were also investigated at higher turbulence (approximately 3.5%), representative of engine operation. The baseline and tubercled blades were manufactured using rapid prototyping. The experimental LPT performance evaluation took place in a cascade of seven blades and included measurement of mid-span surface pressure on two blades, signal variance on blade surface using hot-film and cascade-exit mixed-out losses using multi-hole pressure probe. The higher turbulence level at the cascade inlet was produced using a passive turbulence-generating grid. Conclusions were drawn after consideration of wake traverses, area-averaged exit losses and surface pressure measurements at various axial-chord Reynolds numbers between 15,000 and 90,000. The suction-surface pressure provided information on blade loading, laminar separation bubble, and flow separation; and hot-film provided information on the state of boundary layer. The analysis of these measurement provided information on effectiveness of tubercle in modifying the suction surface flow and characterizing baseline flow. Substantial reduction in exit losses and increased performance at higher Reynolds numbers was noted; however, tubercles were not as effective as expected at lower Reynolds number. Valuable insight as been gained on the challenges associated with very low Reynolds number testing ; and recommendations have been made for sustained future work.

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