Turbine Airfoil Leading Edge Aerodynamics and Heat Transfer – A Review

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Abstract

In a gas turbine, the leading edge of a turbine vane or blade withstands the highest gas path pressures and temperatures of any part of the airfoil surface. Detailed knowledge of the aerodynamics and heat transfer sustained by a turbine airfoil leading edge can help engineers develop designs that facilitate higher gas temperatures and reduced cooling air loads, which leads to enhanced efficiency, durability, and power density.

High pressure turbine blades are made from nickel-based super alloys which soften and melt at temperatures between 2200^{o}F (1205^{o}C) and 2500 ^{o}F (1372 ^{o}C). High pressure turbine inlet temperatures in the gas path of modern high-performance commercial jet engines can exceed 3,000 ^{o}F (1650 ^{o}C), while nonaviation gas turbines operate at 2700 °F (1480 °C) or lower. The newest military jet engines are up in the 3600 °F (1650 °C) range, greatly exceeding super alloy melting temperatures (and the boiling point of molten silver). This all means that knowledge of turbine airfoil leading edge aerodynamics and heat transfer is critical for the turbine designer.

For example, consider the turbine designer's task in specifying leading edge film cooling hole location and cooling air flow rates, necessary to protect a turbine airfoil immersed in gas path flows whose temperatures exceed the airfoil's super alloy melting point. An error in hole location or in the cooling air pressure ratio in relation to the leading edge gas path stagnation line might cause airfoil gas path inhalation rather than film cooling exhalation, inducing airfoil expiration. Avoiding that situation requires excess cooling air, the use of which can be reduced only through improved design based on a more thorough knowledge of leading edge boundary layers and distributions of pressure and temperature.

Some of the earliest work used by turbine designers was based on experimental and analytical studies of the forward stagnation region of flow around cylinders in cross flow. The work, going back to the 1930’s, is reviewed and discussed in this paper.

Since 1980 there have been numerous turbine airfoil cascade studies involving experimental, analytical and computational efforts to quantify and predict leading edge fluid mechanics and heat transfer. This body of work is reviewed, along with some recent work that the authors of this paper have contributed.