SECONDARY FLOWS IN AXIAL TURBINES – A REVIEW

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Abstract

An important problem that arises in the design and the performance of axial flow turbines is the understanding, analysis, prediction and control of secondary flows. The designer of work-extraction flow paths of such turbomachines – e.g. in a gas turbine – might define secondary flow as that which is not primary. Customarily, primary or uniform flow is an idealized two-dimensional picture of the streamlines between the suction and pressure surfaces of a turbine blade passage. Flow deviations from the idealized picture have come to be called "secondary", even though their presence may constitute whole regions of the turbine blade passage flow field. Secondary flows include endwall boundary layers, their separation, and other portions of the primary flow influenced by three-dimensional effects, whatever those effects might be.

During the last two decades, mastery of secondary flow phenomena has become critical to modern turbine designs. Turbine airfoil aspect ratios have decreased, leading to higher ratios of endwall-to-airfoil area, causing secondary flows to actually dominate gas path aerodynamics. Also, with advanced jet engine turbine inlet temperatures at the 3000° F (1650° C) level, accurate prediction of heat transfer coefficients in film cooling applications where secondary flow fluid mechanics predominate, is essential to keep a 1900° F (1040° C) melting-point alloy airfoil surface from being damaged.

This paper is a review of aspects of secondary flow in axial turbines reported on in the open literature. Sieverding (1985) has given a review of secondary flow literature, covering up to 1985. The goal in this paper is to briefly review some of the pre-1985 literature and then to survey in more detail secondary flow investigations that have been reported on since the Sieverding review.

The fluid flow in a turbine airfoil cascade (plane or annular) is the simplest of configurations. It is used here as a means of explanation, to put forth views from which the subject of secondary flow appears in its greatest simplicity. To more completely understand various aspects of secondary flows, it is also necessary to consider elemental flow geometries. To this end, literature concerning the flow around wall-mounted cylinders is reviewed.

Aspects of axial flow turbine secondary flows have long been indirectly measured and studied through heat and mass transfer research. There has also been at least one insightful study in which it is proposed that secondary flow losses be calculated based on entropy generation. Literature on these subjects as it bears directly on important aspects of secondary flow is also considered in this paper.

Finally, as has been written, the right answer to a trivial question is also trivial, but the right question even when insoluble in exact form can be a guide to major discovery. In that spirit, the paper ends with a consideration of what is not known about secondary flow in axial turbines, to pose some important questions which might lead to future solutions or discoveries.