Some Basic Issues and Developments in Analytical and Experimental Work on Turbine Blade Flows

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Long Abstract

For the prediction of flows over turbine blades it is clearly essential that attention is paid to the modeling of three dimensional (3-D) flows; arguably all turbomachinery flows are three-dimensional and unsteady. However this should not be at the expense of adequate attention to physics of two-dimensional (2-D) flows that provide the foundation and are the subject matter of this paper. These flows have generally been treated as 2-D but are not strictly 2-D as the section on stationary streamwise vorticity will make clear. Many details of these quasi 2-D flows are not yet fully understood. Only when these are fully represented will we acquire more confidence in blade design. An emphasis on representing the flow physics is needed, not only for code validation, but also to predict laminar boundary layers, transition to turbulence, separation, heat transfer, base pressure etc. These all affect performance and efficiency.

In this paper some features of the 2-D flow over turbine blades that are not understood have been identified and several are discussed in more detail. The planar cascade of blades is a model that gives valuable information and understanding for the flow through all turbomachinery blade rows. Although the flows through a blade row are essentially 3-D and unsteady, the 2-D cascade can still give detailed information on the flow physics that is otherwise not well-predicted. Some gaps in knowledge will be identified, covering entire blade and nozzle vane surfaces from leading edge to trailing edge and beyond. To give improved prediction capability, these gaps require improved understanding. As well as work on blade cascades this research draws on investigations of the flow over flat plates and circular cylinders. Similar behavior has been observed between tests under strong adverse pressure gradient conditions on triggered spots, wake-perturbed flat plate boundary layers, and on turbine blading. The open questions in the physics of blade flows start ahead of the leading edge and continue to the trailing edge and into the wake. Figure 1 gives the layout of a 2-D turbine nozzle passage, indicating regions where there are gaps in knowledge. In this paper, an attempt is made to identify areas where substantial research on planar turbine cascades is ongoing or is still needed. As an example, the question of shock boundary layer interaction is addressed here, followed by the listing of some other phenomena.

Figure 1. Some Physical Features in Turbine Nozzle Flows.

High loading requirements in modern axial flow machines often call for transonic and supersonic flows. The fan blades of high by-pass engines operate with supersonic inlet velocities and these result in a shock-boundary layer interaction, often in the leading edge region. For turbine nozzle vanes, high loadings may call for supersonic discharge flows. The modeling of the shock-boundary layer interaction is not yet reliable and this can affect flow predictions downstream of the shock impingement and hence the loss. It is particularly difficult when a laminar separation bubble is triggered or when the shock is oscillating under the influence of vortex shedding. In turbine blading, the shock wave emanating from the trailing edge of one vane may impinge on the adjacent vane at around 45% of true chord (70% axial chord). There is the potential for 55% of the suction surface to be wrongly predicted if the physical representation of flows in the shock impingement region and further downstream are not correctly modeled. The test case of Fig. 2 has been used for validating a number of codes; 2-D time-accurate numerical simulations of the mid-span flow were performed over the discharge Mach number range up to 1.43 and selected examples are shown in Fig. 2. At a discharge Mach number of 0.8, the agreement between computational predictions and experimental measurements is good. At a Mach number of unity, the shock impingement appears to be adequately predicted. At discharge Mach numbers of 1.16 and 1.43, the agreement on both surfaces is excellent apart from the crucial region downstream of the shock impingement. The shock-boundary layer interaction here results in a significant discrepancy between computation and experiment. The prediction is adversely affected and, at supersonic speeds, it fails to predict the strength of the expansion downstream of the shock or the nature of the subsequent recovery.

Other issues to be addressed, with examples, will include boundary layer transition and vortex shedding. At subsonic speeds, vortex shedding gives energy separation and base pressure and at supersonic speeds it gives exotic vortex shedding modes. Also addressed will be stationary streamwise vorticity. An emphasis will be retained on representing the flow physics. More work is needed, even to predict laminar boundary layers, heat transfer and separation. Experimental work is needed for understanding and validation and this should be supplemented by analytical work. The computer modeling of blade flows will then be able to proceed with confidence.

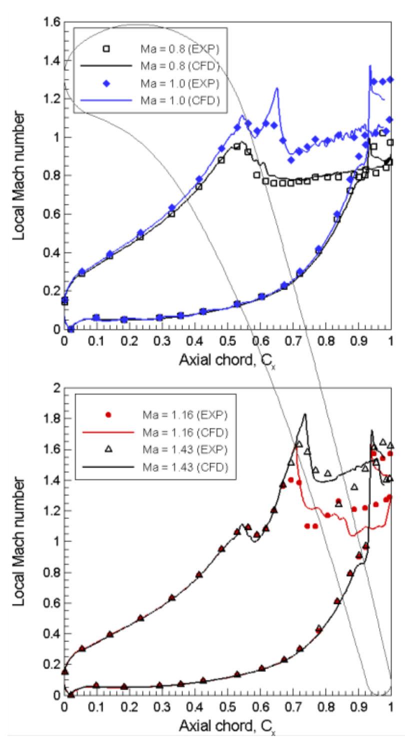

Figure 2. Experiment and Computation Compared for CNRC Nozzle Cascade at Four Discharge Mach Numbers.