# Aero Losses, Heat Transfer, Discharge Coefficients for Different Vane Trailing Edge Cooling Technologies for Syngas-Fired Gas Turbines

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**Project completion date: 30 September 2008**

**Project Need**

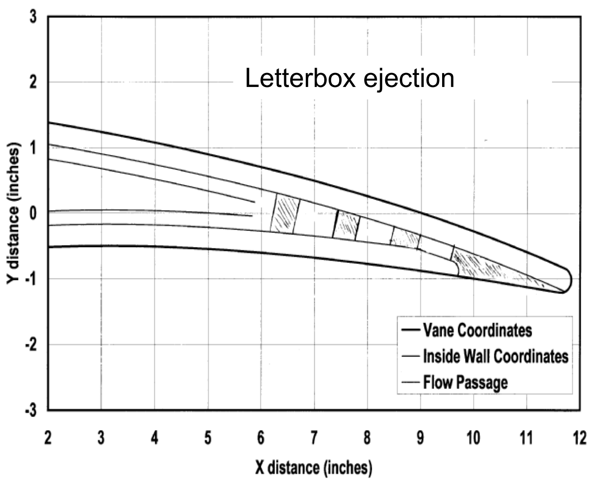
One of the most difficult regions of a gas turbine to cool is the trailing edge of a vane or blade. Aerodynamic considerations require the trailing edge to smoothly narrow to a small radius, while controlling the diffusion of boundary layers. Heat transfer challenges include cooling a surface with a high heat load far downstream from where film cooling protection is optimum in a region with little area for the flow of cooling air. At the same time strong market forces are pushing the power industry toward the use of coal derived syngas in gas turbine systems. However, even the cleanest syngas will contain small amounts of sulfur and particulate contamination, which can be expected to roughen turbine surfaces due to deposition and corrosion. Surfaces roughened from deposition and corrosion will produce higher surface heat transfer coefficients, higher aerodynamic losses, reduced film coverage, and reduced effective throat area. Turbine systems fueled by syngas will need designs tolerant of these affects. Consequently, the trailing edge region of vane and blades will be even more difficult to design.

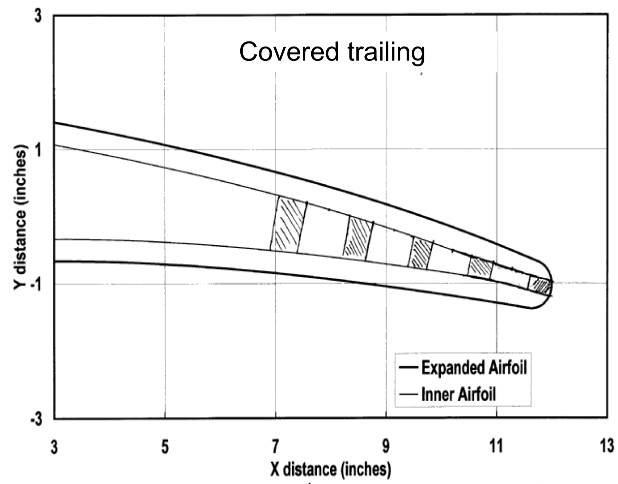
**Project Objectives**

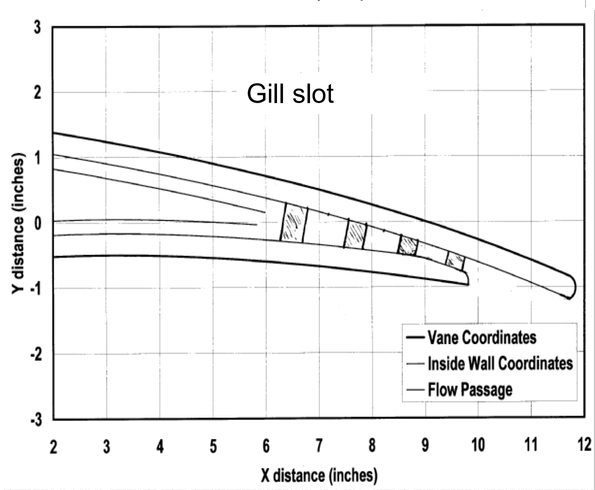
The objective of this proposed study is to comprehensively investigate alternative trailing edge cooling technologies for gas turbines fueled with syngas. Syngas fuels are expected to cause deposition onto and corrosion of turbine surfaces. These surface effects can be expected to cause blockage of coolant discharge exits, increase aerodynamic losses, decrease turbine flow area, increase external heat transfer rates, and reduce trailing edge film cooling effectiveness levels. Trailing edge designs are often a focal point of a design team due to competing demands of aerodynamics, heat transfer, stress, and manufacturing.
Within this context, the project will investigate aerodynamic losses, surface heat transfer coefficient distributions, surface film cooling effectiveness distributions, and discharge

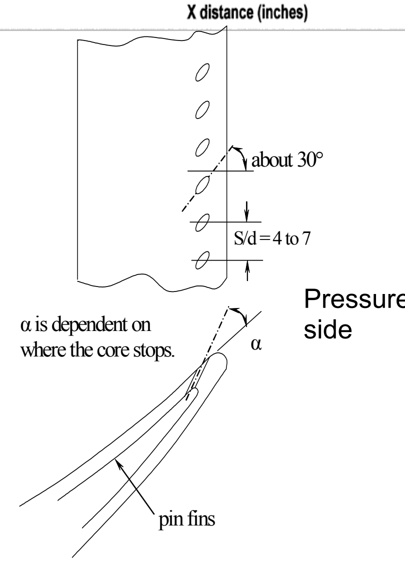
coefficients for different vane trailing edge cooling configurations. Surface heat transfer coefficients will be measured on external vane surfaces and on the surfaces of internal trailing edge cooling passages, also modeled to match operating vanes, with different pin fin arrangements. The vane configurations which will be investigated include:

(i) baseline condition (solid airfoil),
(ii) covered trailing edge,
(iii) letterbox ejection,
(iv) gill slot, and
(v) pressure-side holes.




**Internal Cooling Arrangements**

The internal arrangements under consideration (shown below) include:

(1) high solidity, low pressure drop internal pedestal configuration, with 45% solidity, L/W = 2.35, R/W = 0.75, and θ = variable (44°), arranged such that the spacing between pedestals is designed to minimize pressure drop by keeping the effective flow area about constant,

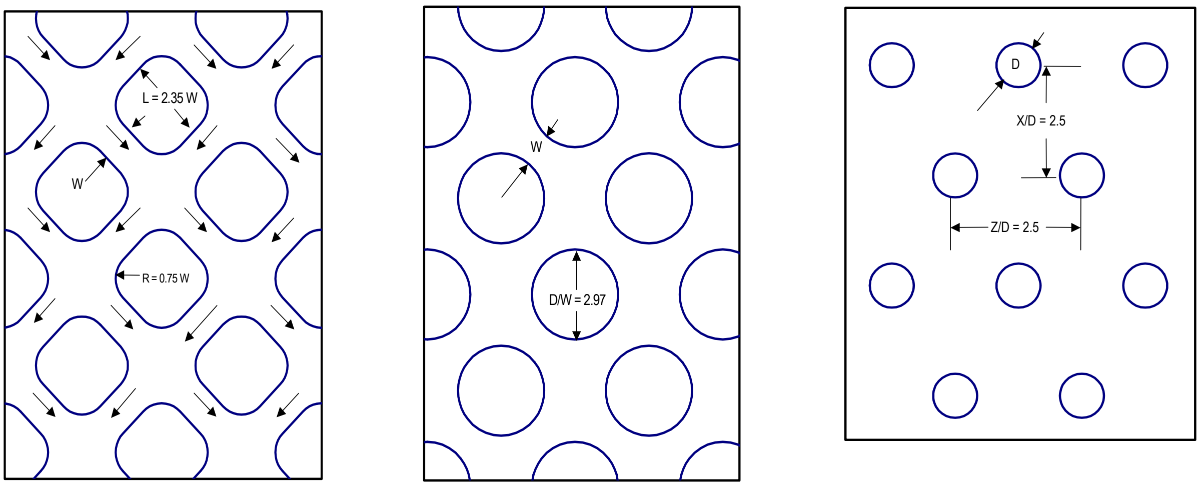
(2) high solidity (45%) pin fin pattern with pin diameter (D) to minimum gap width (W) of 2.97, Z/D = 1.674, and X/D = 1.043, arranged with the characteristic length for round pedestals to be larger than for rounded diamonds with similar solidity, and

(3) low solidity pin fin pattern with 12.6% solidity, Z/D = 2.5, and X/D = 2.5.

High solidity, low pressure drop **internal pedestal configuration**

High solidity (45%) **pin fin pattern**

**Low solidity pin fin pattern.**




**Parameters Investigated**

**Parameters to be investigated include:**
(i) blowing ratio, (full design flow, half design flow),
(ii) vane chord exit Reynolds number (0.5 million, 1.0 million, 2.0 million)
(iii) turbulence intensity (baseline-0.6%, grid-8%, and aero-derivative-14%)

**Quantities investigated include:**
(i) wake characteristics (1/4 and 1/2 axial chord downstream)
(ii) exit cooling feature internal heat transfer and exterior surface heat transfer (and exterior adiabatic film effectiveness where needed)
(iii) vane surface static pressure (all configurations)
(iv) hole discharge coefficients

**Wake characteristics (item (i)) includes 2-D and 3-D surveys of flow behavior:**
(a) wake performance parameters,
(b) velocity,
(c) flow turning angles,
(d) Reynolds stress components, turbulence length scales, and spectra.

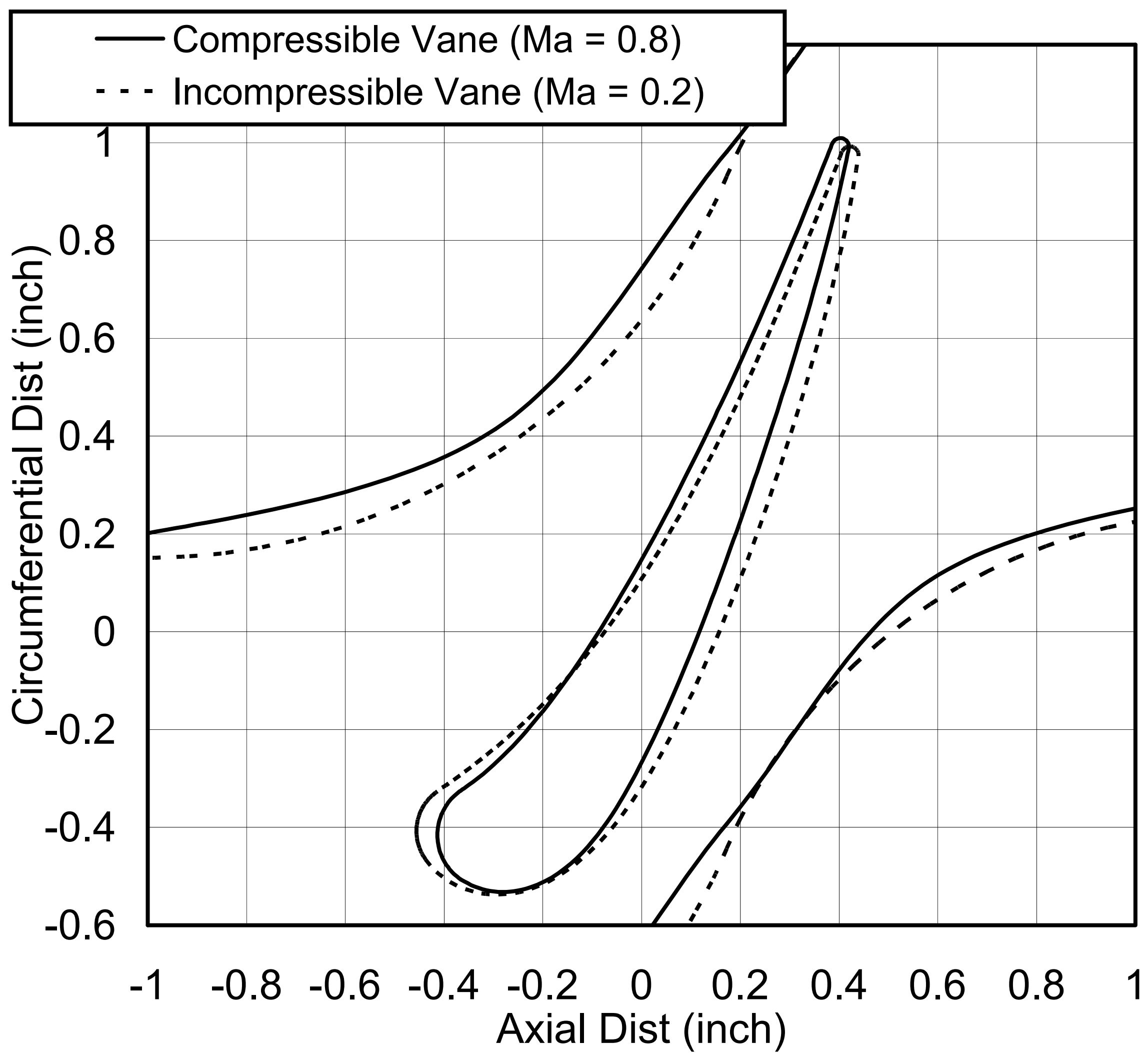
**The roughness portion of the investigation involves several parts:**
(i) characterization of airfoil roughness from utility power engines operating with syngas.

(ii) creation of airfoils with composite roughness for testing at the UND and the U of U, with surface roughness that matches that from the vanes of utility power engines operating with syngas.

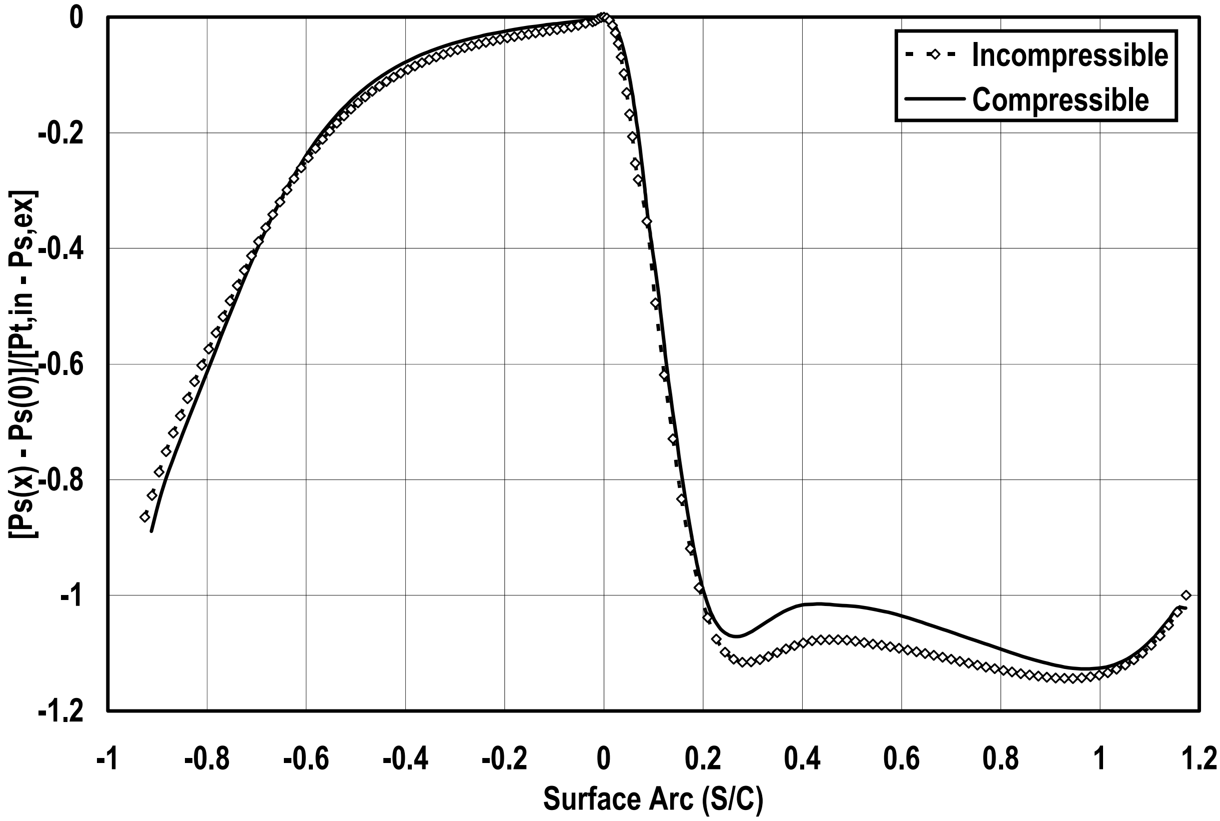
(iii) Investigate the effects of surface roughness (as produced by the presence of syngas) on trailing edge surface heat transfer, film cooling effectiveness, discharge coefficients, and aerodynamic losses.

**Project Approach**

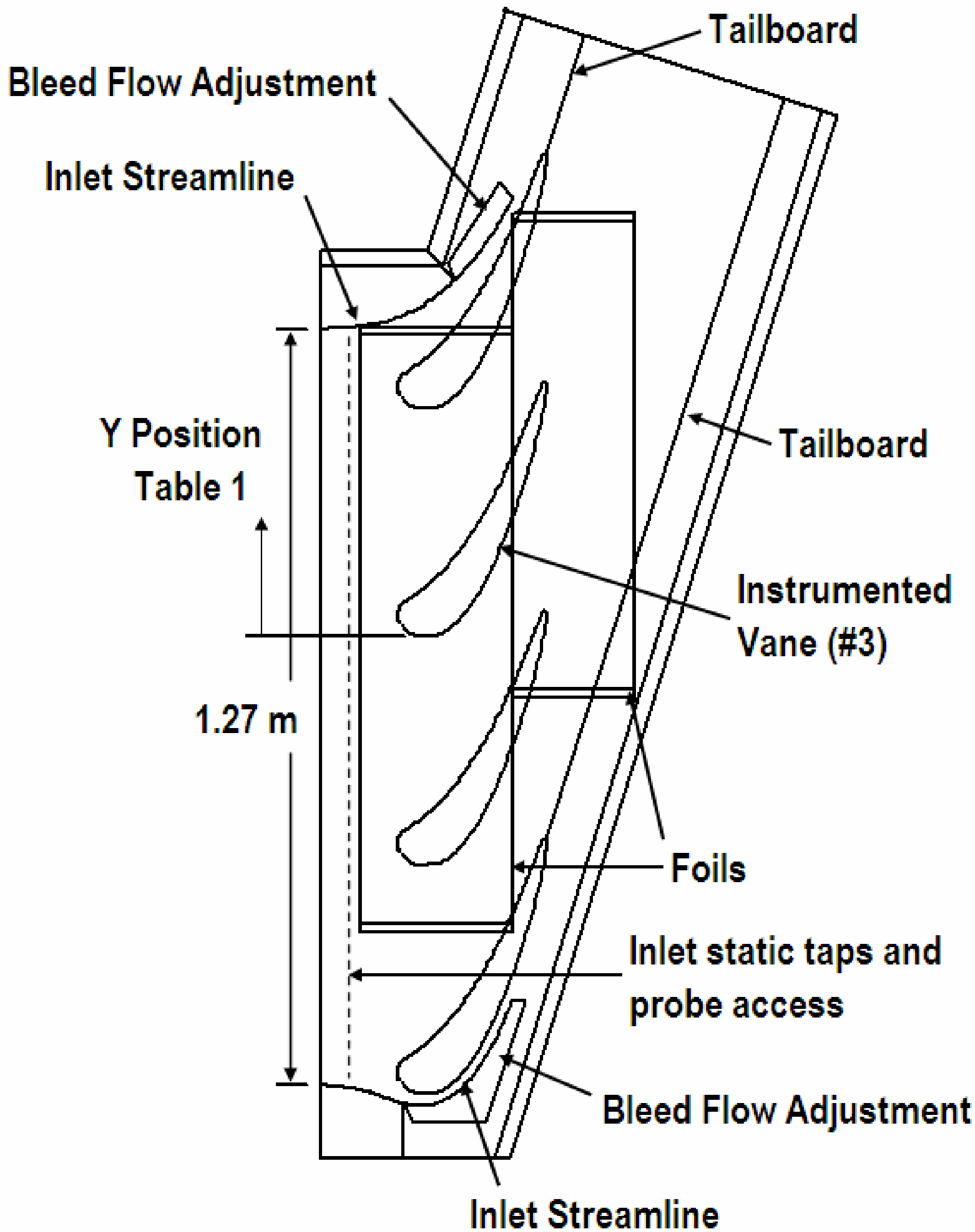
The measurements will be conducted using a conventionally loaded vane. A large-scale, low-speed cascade facility at the U. of North Dakota, and a high Mach number facility at the U. of Utah will be employed. The two cascades, run at low and high Mach numbers, require two different geometries to achieve the same loading profile. The large scale low speed cascade can be run at steady state allowing for detailed 3D exit surveys and greater detail in internal and external heat transfer and pressure distribution investigations. The high speed facility allows the investigation to look at aerodynamic issues related to higher Mach numbers and achieve higher Reynolds numbers.



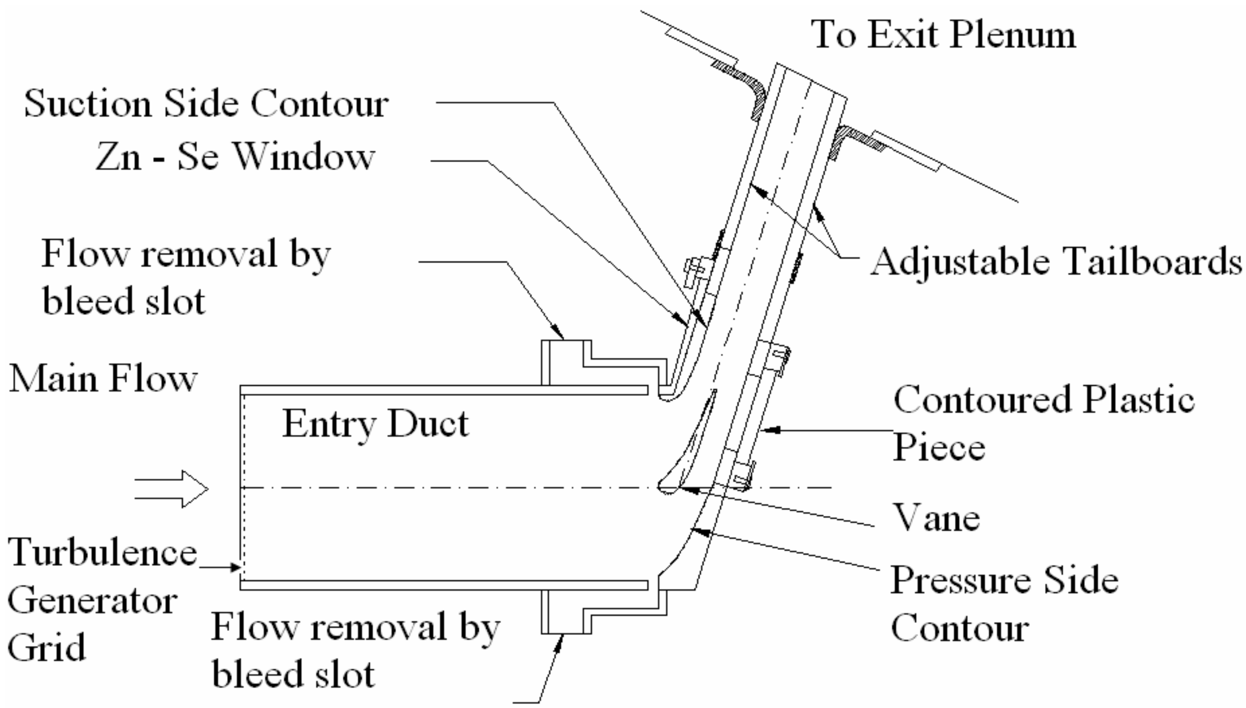

**Comparison of compressible and incompressible vane geometries**



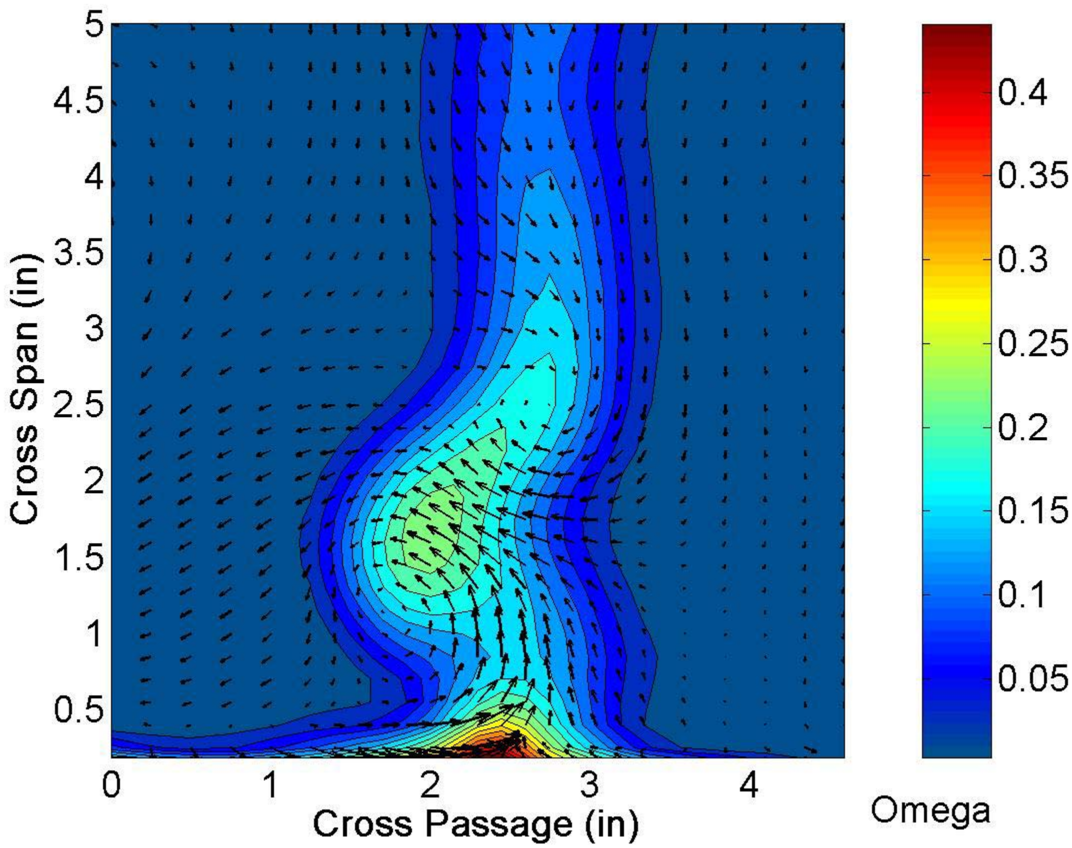

**Comparison of compressible and incompressible pressure distributions**




**University of North Dakota large scale low speed cascade test section**




**University of Utah transonic cascade test section**




**Recent results: Exit loss contours and secondary velocities, baseline vane, low Tu, ReCex = 2,000,000, ½ axial chord.**