Integrating Flow Control into Low-Pressure Turbine Design

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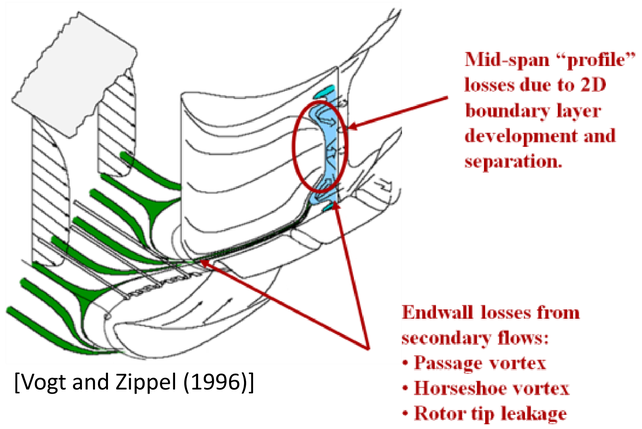
Background

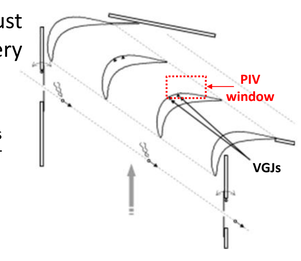


[Vogt and Zippel (1996)]

- Several factors increase likelihood and impact of PT loss generation resulting from separation, e.g.:
  - Low Reynolds number
  - Aggressive blade loading for increased work extraction
  - Reduced blade count for lighter components
- Judicious combination of endwall suction and midspan blowing using vortex generator jets (VGJs) applied simultaneously to improve overall PT recovery

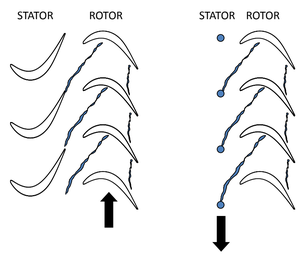
Upstream Wake Simulation

Flow Control applications must consider unsteady turbomachinery flow field

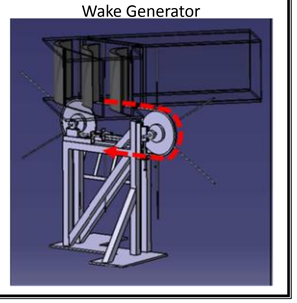


Exact wake simulation is only possible in a full annular cascade facility

Use moving cylinders to simulate stators for finite linear cascade



Wake Generator



Avails opportunity to explore synchronization of pulsed flow control

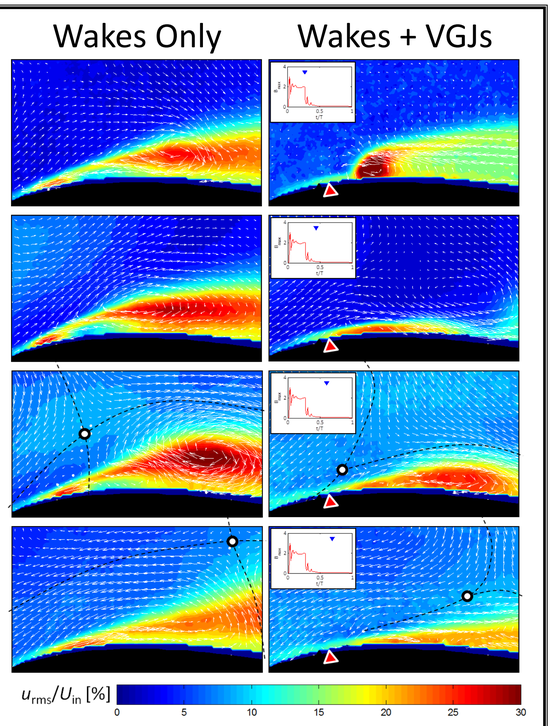
Phase-Locked PIV

2-D Phase-locked planar PIV is used to elucidate the fluid mechanisms that produce optimal synchronization between wake events and pulsed vortex generator jet (VGJ) control intervals.

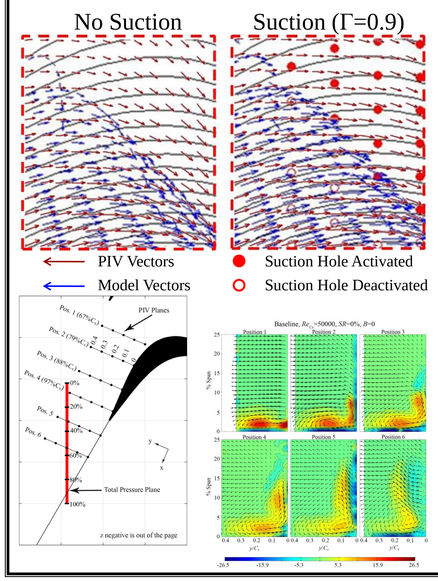
Streamwise vorticity generated by the pulsed VGJ promotes mixing, moving low-momentum fluid away from the surface, and replacing it with high-momentum freestream fluid.

Optimal synchronization is achieved by taking advantage of the phase-lagged boundary layer (BL) response to jet termination.

The wake disturbance forces BL fluid to roll-up and be shed from the blade, leaving behind a thinner BL with depressed turbulence levels.



Endwall Flow Control - Suction



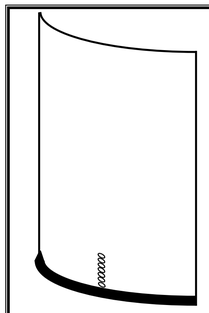
PIV has been used extensively to investigate the flow field near the endwall and to develop a flow control methodology.

A 2D model was developed to determine the trajectory of the low momentum fluid within the boundary layer.

Using the midspan pressure gradient from CFD, particles are fed into the pressure gradient with inlet velocities of 50% and 75% of the calculation velocity. The element trajectories are calculated using a time stepping Lagrangian approach. Suction holes are modeled as point sinks. The model is validated using planar PIV at 5% from the endwall.

The passage vortex is visualized through planar PIV in various spanwise planes to track it's development.

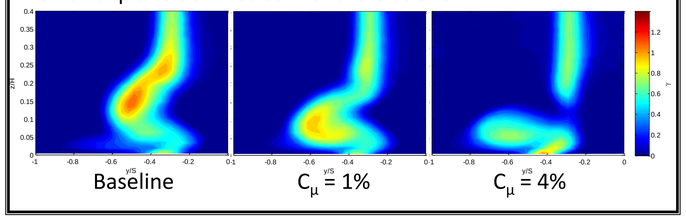
Endwall Flow Control - Blowing



Highly loaded LPTs with a front-loaded pressure distribution have been shown to represent a worst-case scenario for losses due to the flow near the endwall.

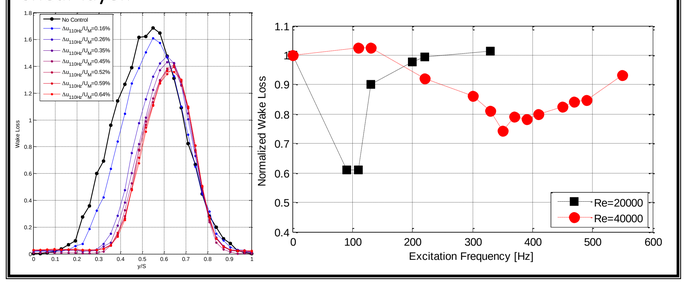
Current research seeks to use blowing to mitigate these losses by affecting the flow field. Jets are placed in a spanwise row on the suction surface at 60% of the axial chord.

Loss reduction has been proven using total pressure loss contours in an axial plane down stream of the blade row.



Shear-Layer Excitation

An ongoing investigation looks at the effect of excitation with sound at discrete frequencies for LPT BL separation control.
Wake pressure loss surveys show substantial improvement at different frequencies for two Reynolds numbers, with excitation amplitude playing a significant role.
Hot-film measurements verified that the most effective frequencies correspond to the Kelvin-Helmholtz instability of the shear layer.



Current/Future Work

- Endwall flow control through blowing for a front-loaded low-pressure turbine.
- Control of separation by excitation of separated shear layer instabilities in engine representative conditions.

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