USE OF BLADE LEAN IN TURBOMACHINERY REDESIGN

John Moore, Joan G. Moore, and Alex Lupi

Mechanical Engineering Department
Virginia Polytechnic Institute and State University
Blacksburg, Virginia 24061-0238

Blade lean is used to improve the uniformity of exit flow distributions from turbomachinery blading. In turbines, it has been used to control secondary flows by tailoring blade turning to reduce flow overturning and underturning and to create more uniform loss distributions from hub to shroud.

In the present study, the Pump Consortium centrifugal impeller has been redesigned using blade lean. The flow at the exit of the baseline impeller had large blade-to-blade variations, creating a highly unsteady flow for the downstream diffuser. Blade lean is used to redesign the flow to move the high loss fluid from the suction side to the hub, significantly reducing blade-to-blade variations at the exit.
Linear Cascade

No Lean

Static pressure contours established by primary flow.

Blade Lean

Boundary layer flow towards top endwall/suction side corner region.

Compound Lean

Boundary layer accumulation towards midspan.

Annular Cascade

No Lean

Expect more losses in hub/suction side corner region.

Tangential Lean

Opposing radially inward flow in suction side boundary layer.

Compound Lean

Spreading loss spanwise.
Effect of tangential lean on stator vane losses
Effect of compound lean on stator vane losses
Total pressure loss contours:
Phase II stator

Total pressure loss contours:
Phase I/
Model D stator
CONSORTIUM IMPELLER

BASELINE DESIGN
Consortium Impeller, Baseline Design
Exit Plane Distortion

\[ V_{\theta} \]

\[ V^2_{\alpha} \]
Equations for Incompressible Flow in a Rotating System

Reduced static pressure

\[ p_r = p - \frac{1}{2} \rho \omega^2 r^2. \]

Rotary stagnation pressure

\[ p^* = p + \frac{1}{2} \rho \Omega^2 - \frac{1}{2} \rho \omega^2 r^2 \]

Absolute vorticity

\[ \Omega = \nabla \times \mathbf{V} = \nabla \times \mathbf{W} + 2\omega \]

Momentum, inviscid flow

\[ (\mathbf{W} \cdot \nabla)\mathbf{W} + 2\omega \times \mathbf{W} = -\frac{1}{\rho} \nabla p_r \]
Determining the Stable Orientation Vector for Secondary Vorticity Suppression in Rotating Systems

Secondary Circulation, Hawthorne

\[ \frac{\partial}{\partial s} \left( \frac{\Omega_s}{W} \right) = \frac{2}{\rho W^2} \left( \frac{1}{\text{Re}} \frac{\partial p^*}{\partial b} + \frac{\omega}{W} \frac{\partial p^*}{\partial z} \right) \]

From momentum

\[ W \times \Omega = \frac{1}{\rho} \nabla p^* \]

or

\[ W \cdot \nabla p^* = 0, \quad \nabla p^* \perp W \]

Generation of secondary circulation = 0 when

\[ W \cdot \left[ \left( -\frac{1}{\rho} \nabla p_r - \omega \times W \right) \times \nabla p^* \right] = 0 \]

I.e. the component of the vector

\[ -\frac{1}{\rho} \nabla p_r - \omega \times W \]

perpendicular to the relative velocity points to the stable location of high loss fluid.
Consortium Impeller, Baseline Design

Stable location vectors

Contours of Pr and P*
Consortium Impeller
Stable location vectors
Contours of Fr
Baseline design
Design: lean A
Consortium Impeller, Design: Lean A
Exit Plane Distortion

\[ V_{\theta} \]

\[ V^2_{\alpha} \]
DIFFUSER VANE EXCITATION PARAMETER

\[ V^2(\alpha_{\text{maximum}} - \alpha_{\text{minimum}}) \]
Circumferential Averages

Baseline

\[ \delta P_t = 1.22 \quad \eta = 98\% \]

Lean A

\[ \delta P_t = 1.24 \quad \eta = 98\% \]
CONCLUSIONS

Consortium Pump Impeller

Redesigned using Blade Lean

Improved tangential uniformity of exit flow distribution

Reduced diffuser vane excitation forces