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.

Axial Flow Turbine Stators

Consortium Pump Impeller Problem

Secondary Flow Analysis for a Rotor

Stable Location of High Loss Fluid

Impeller Redesign

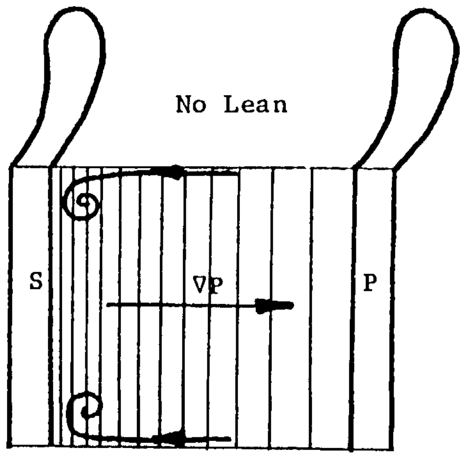
Improved Performance

Use of Blade Lean
in
Axial Flow Turbine Stators

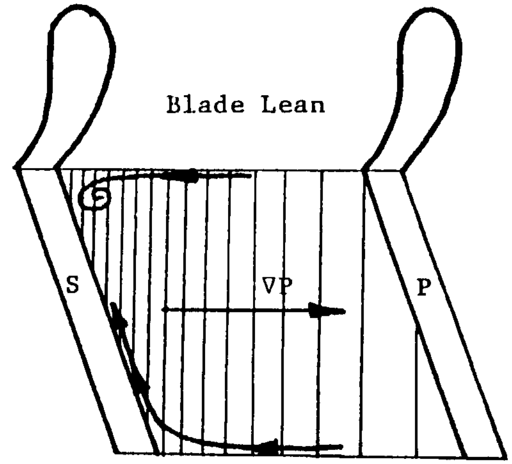
∇P in Cross-Sections

Controlling Exit Loss Distributions

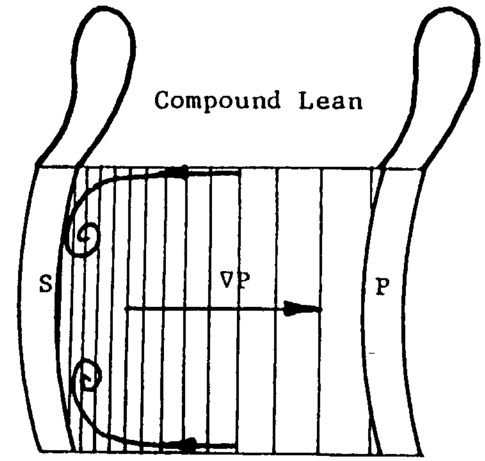
Linear Cascade



Static pressure contours established by primary flow.

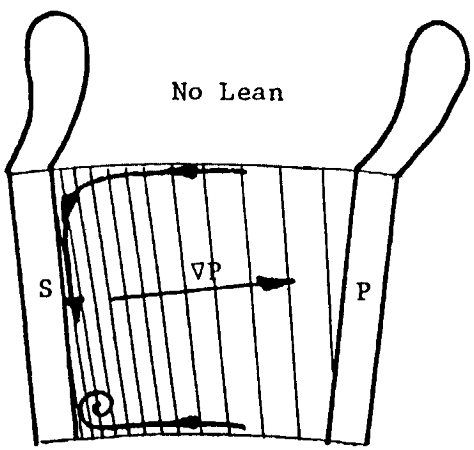


Boundary layer flow towards top endwall/ suction side corner region.

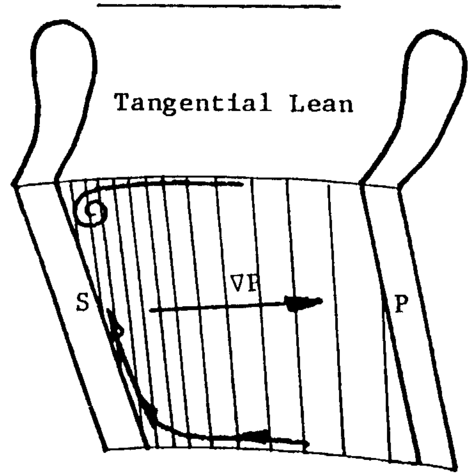


Boundary layer accumulation towards midspan.

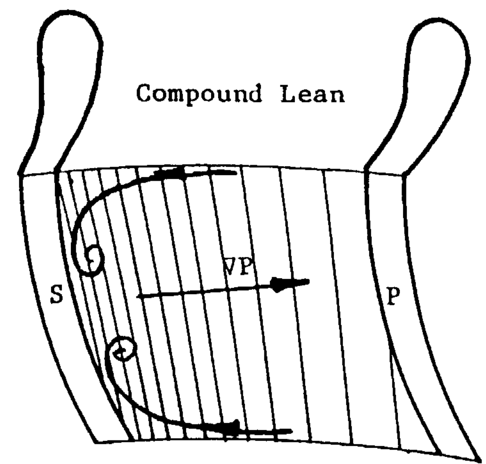
Annular Cascade



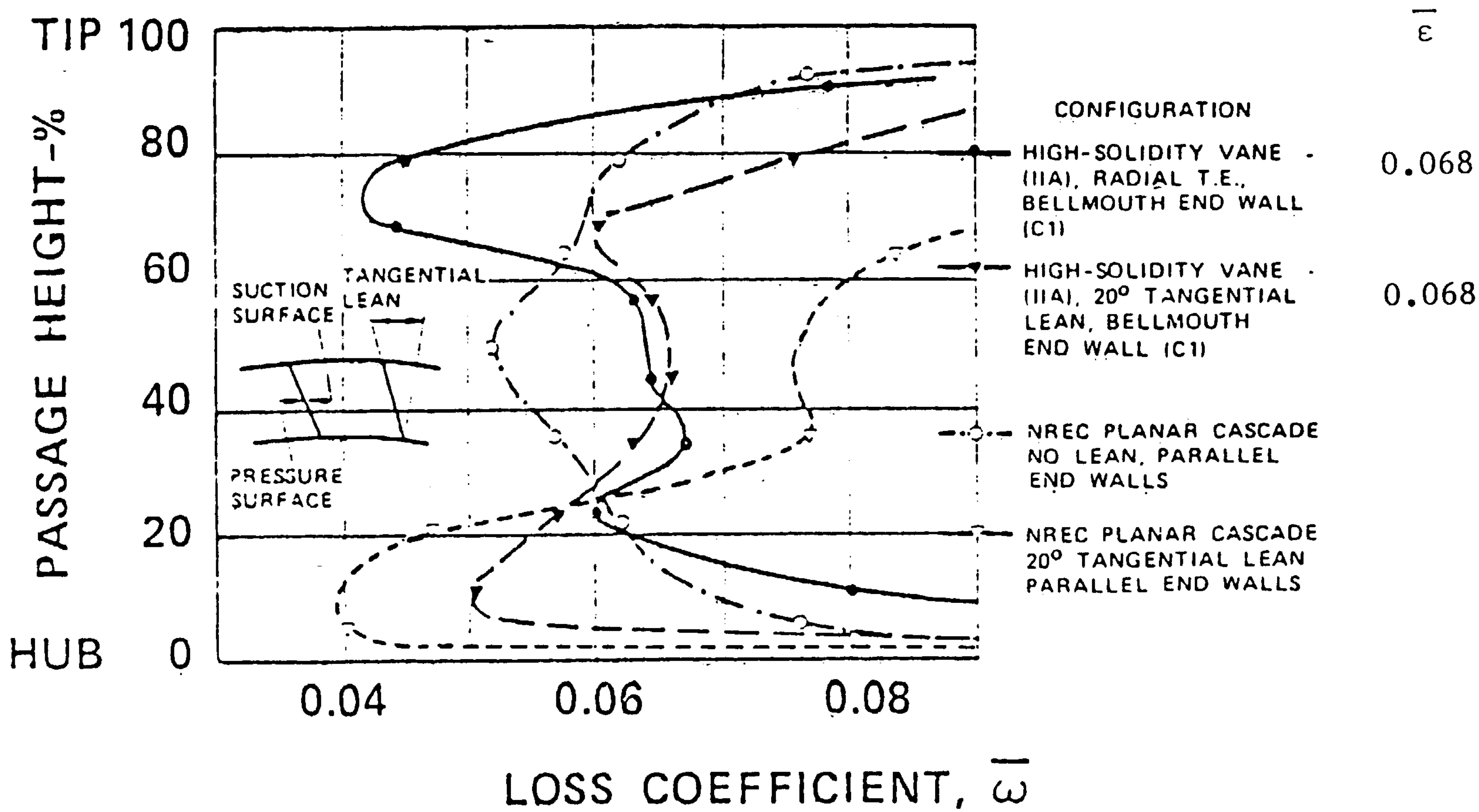
Expect more losses in hub/suction side corner region.



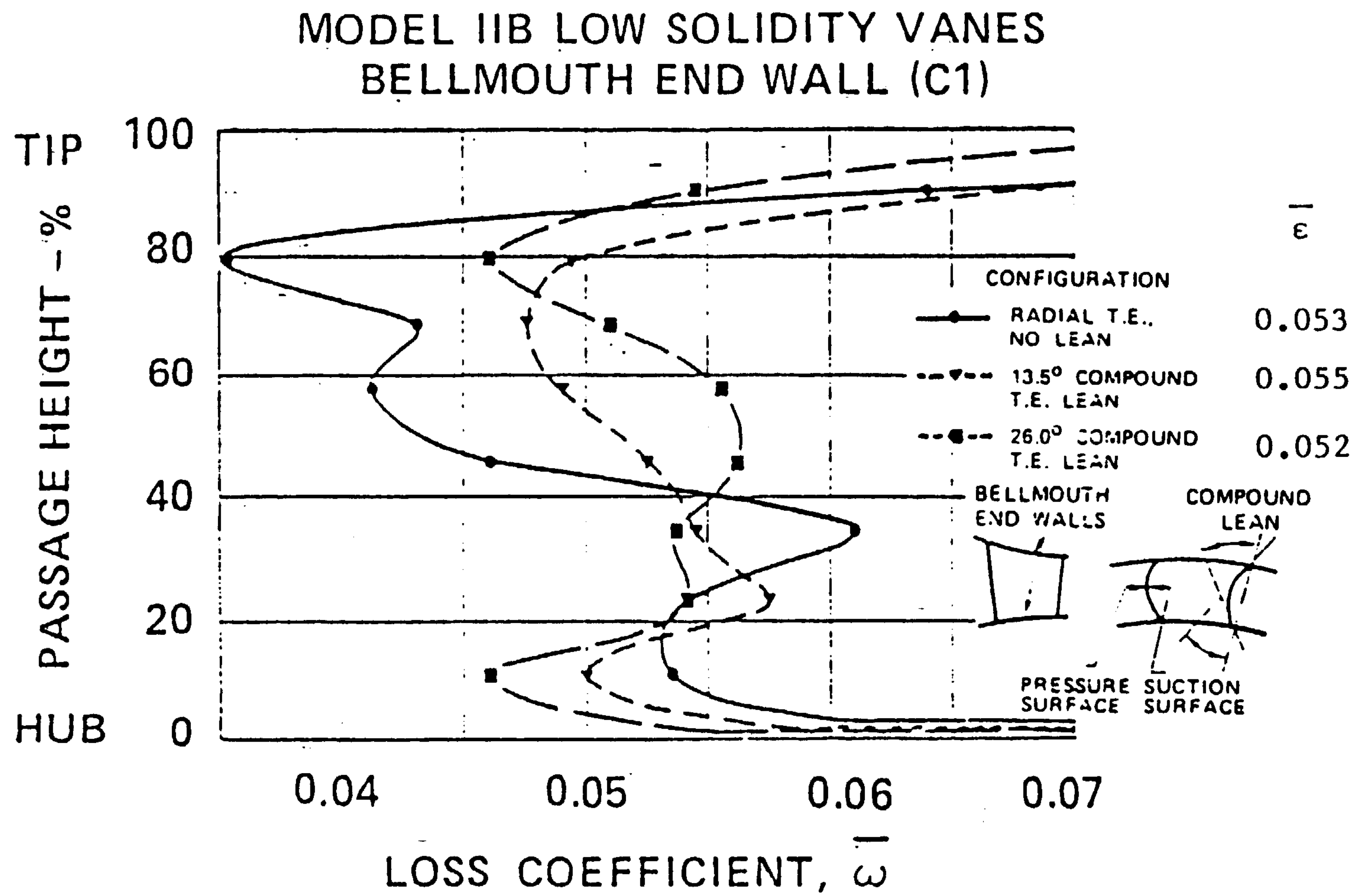
Opposing radially inward flow in suction side boundary layer.



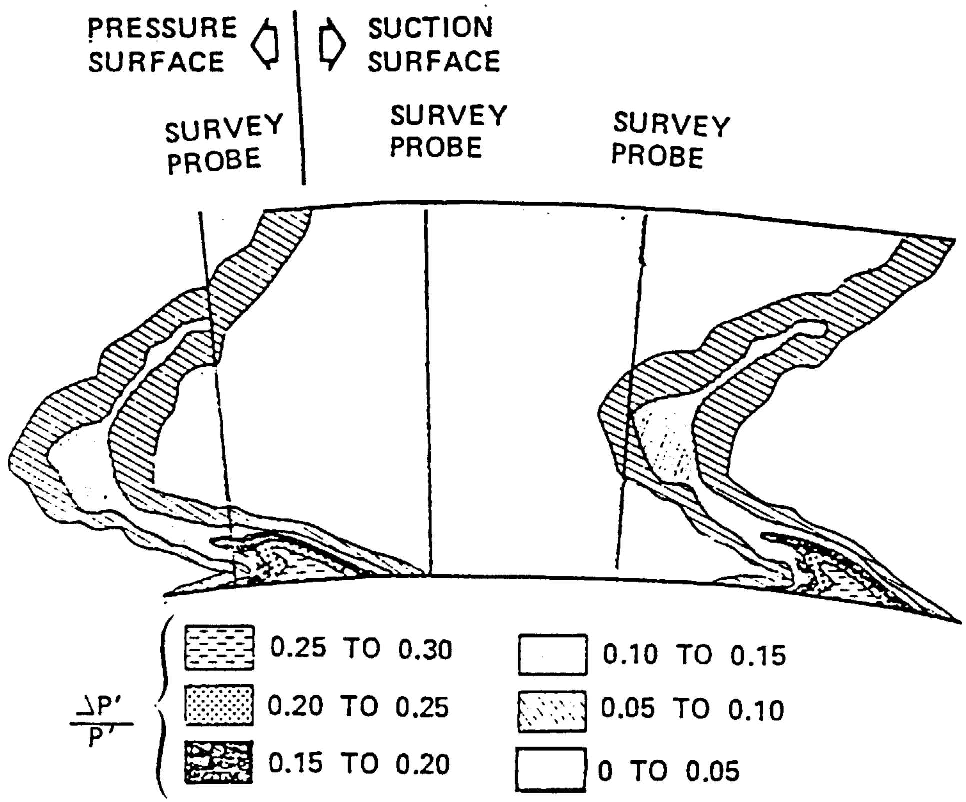
Spreading loss spanwise.



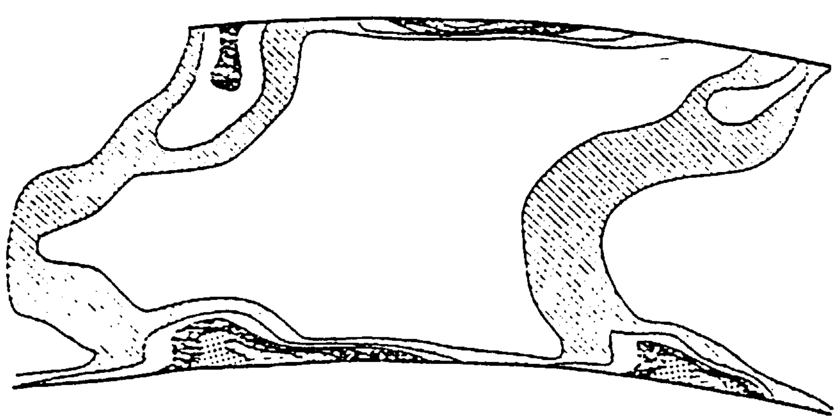
Effect of tangential lean on stator vane losses



Effect of compound lean on stator vane losses

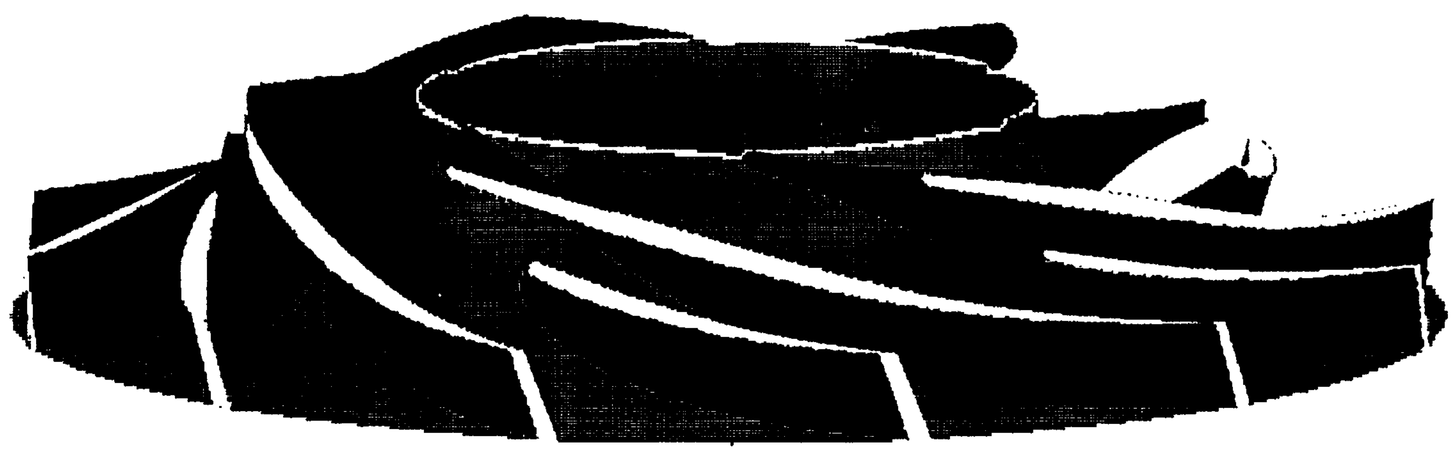


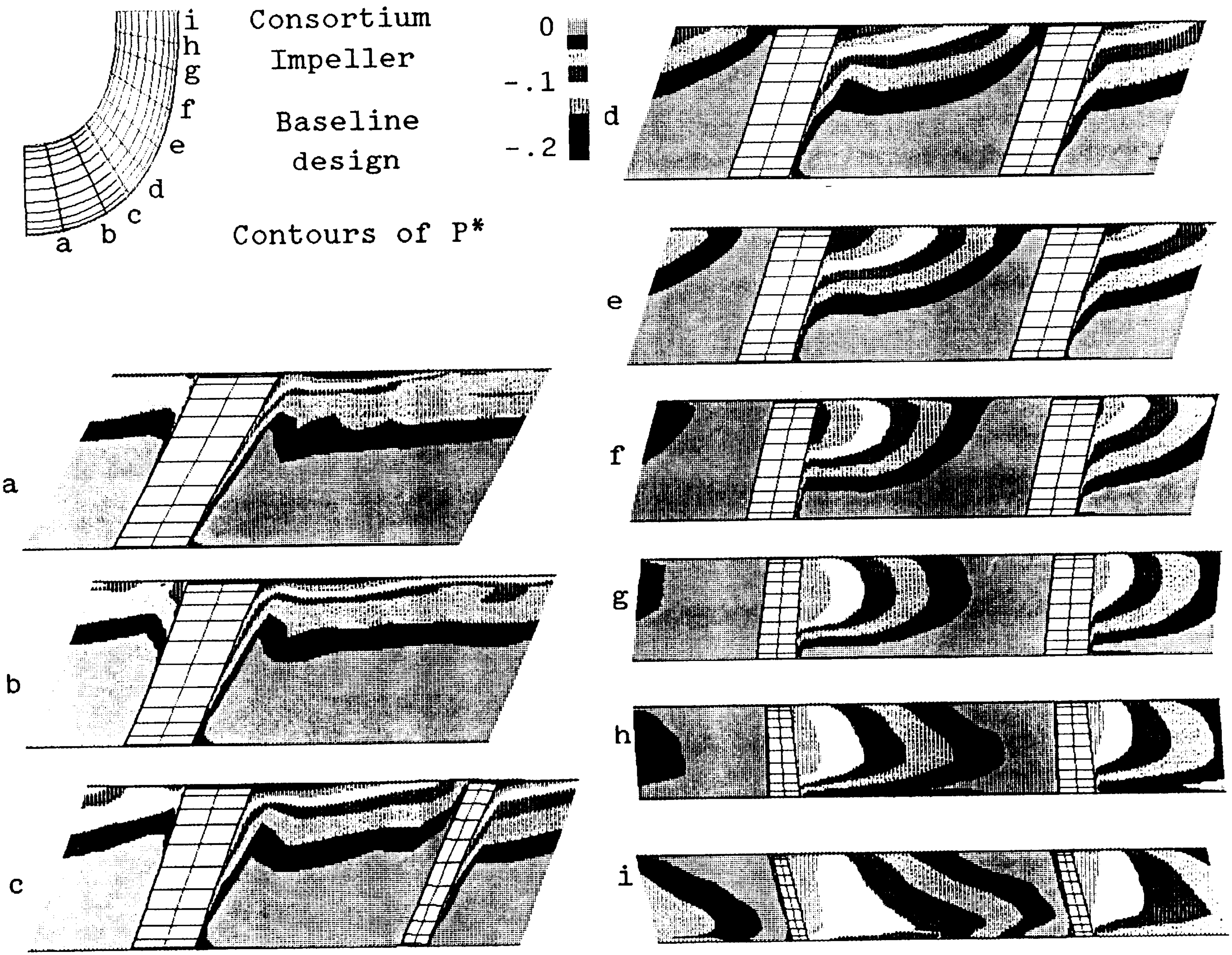
Total pressure loss contours: Phase II stator



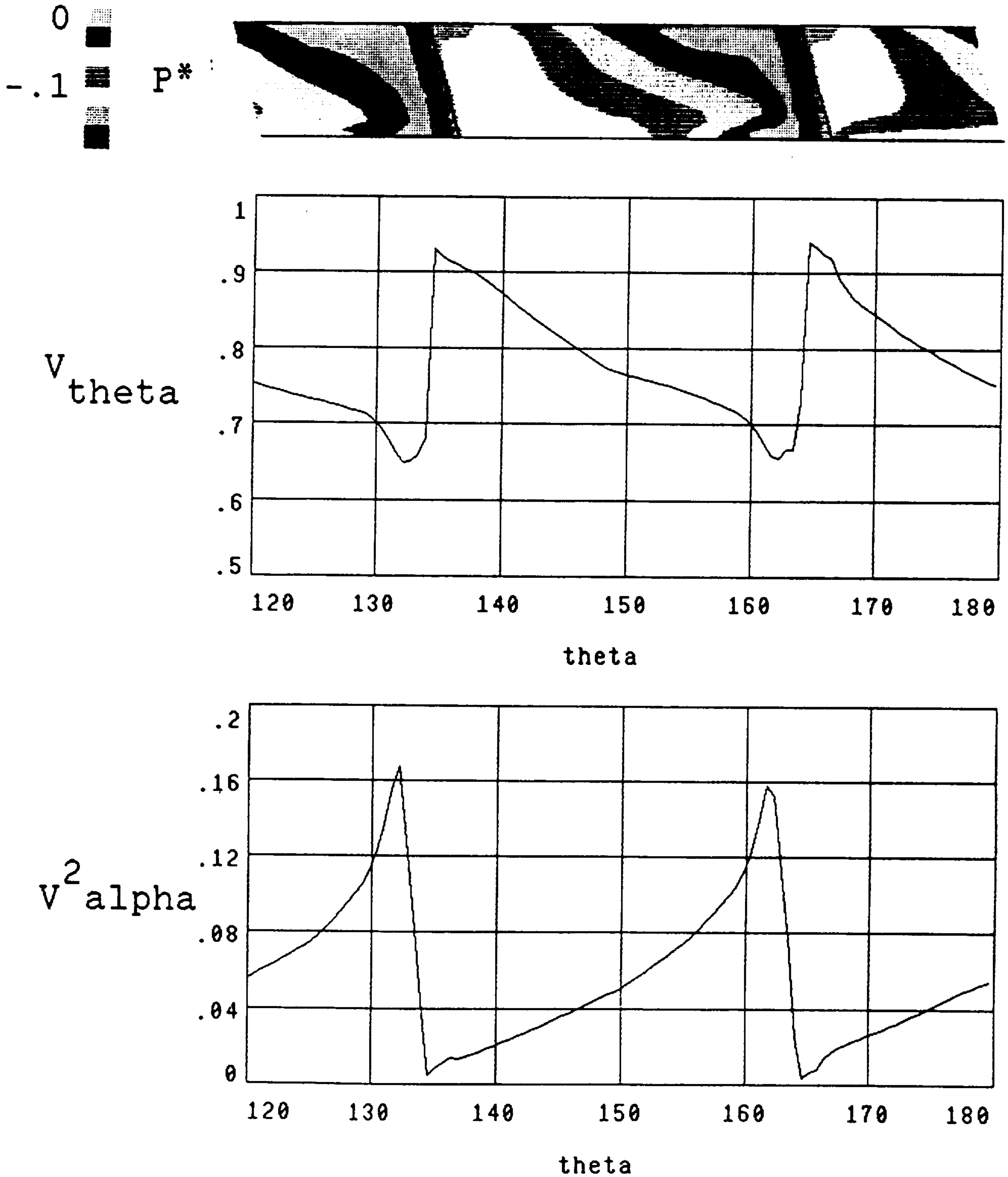
Total pressure loss contours: Phase I/ Model D stator

CONSORTIUM IMPELLER BASELINE DESIGN




i
h
g
f
e
d
c
b
a
Consortium
Impeller
Baseline
design
Contours of P*
0
-.1
-.2
a
b
c
d
e
f
g
h
i

Consortium Impeller, Baseline Design
Exit Plane Distortion



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

$$p^* = p + \frac{1}{2}\rho W^2 - \frac{1}{2}\rho\omega^2 r^2$$

Absolute vorticity

$$\underline{\Omega} = \nabla \times \underline{V} = \nabla \times \underline{W} + 2\underline{\omega}$$

Momentum, inviscid flow

$$(\underline{W} \cdot \nabla)\underline{W} + 2\underline{\omega} \times \underline{W} = -\frac{1}{\rho}\nabla p_r$$

Determining the Stable Orientation Vector for Secondary Vorticity Suppression in Rotating Systems

Secondary Circulation, Hawthorne

$$\frac{\partial}{\partial s}\left[\frac{\Omega_s}{W}\right] = \frac{2}{\rho W^2}\left[\frac{1}{R_n}\frac{\partial p^*}{\partial b} + \frac{\omega}{W}\frac{\partial p^*}{\partial z}\right]$$

From momentum

$$\underline{W} \times \underline{\Omega} = \frac{1}{\rho}\nabla p^*$$

or

$$\underline{W} \cdot \nabla p^* = 0, \qquad \nabla p^* \perp \underline{W}$$

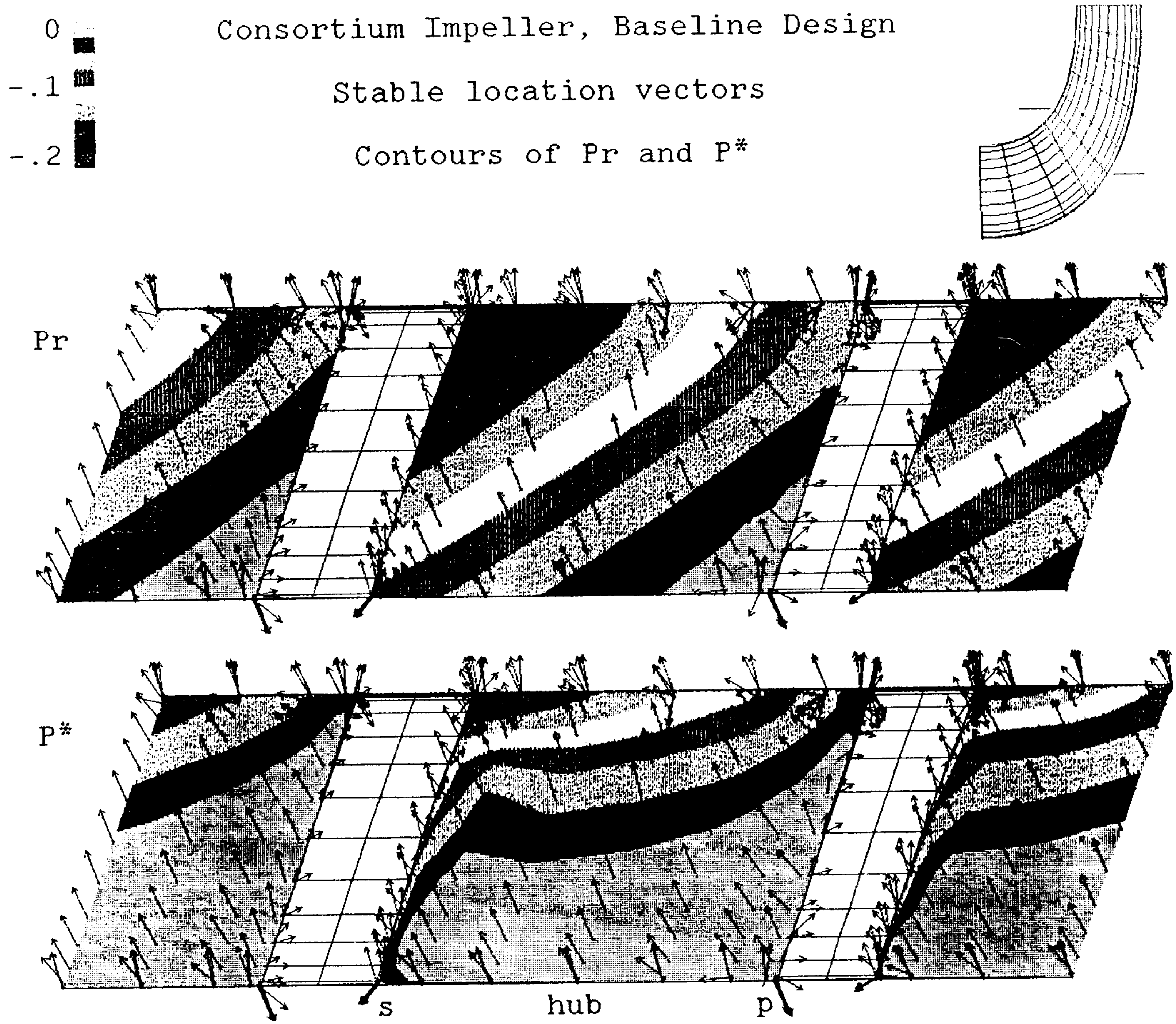
Generation of secondary circulation = 0 when

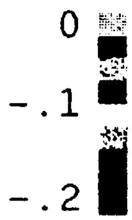
$$\underline{W} \cdot \left\{\left[-\frac{1}{\rho}\nabla p_r - \underline{\omega} \times \underline{W}\right] \times \nabla p^*\right\} = 0$$

I.e. the component of the vector

$$-\frac{1}{\rho}\nabla p_r - \underline{\omega} \times \underline{W}$$

perpendicular to the relative velocity points to the stable location of high loss fluid.

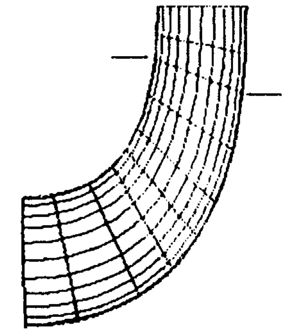

Consortium Impeller, Baseline Design
Stable location vectors
Contours of Pr and P*
0
-.1
-.2
Pr
P*
s
hub
p



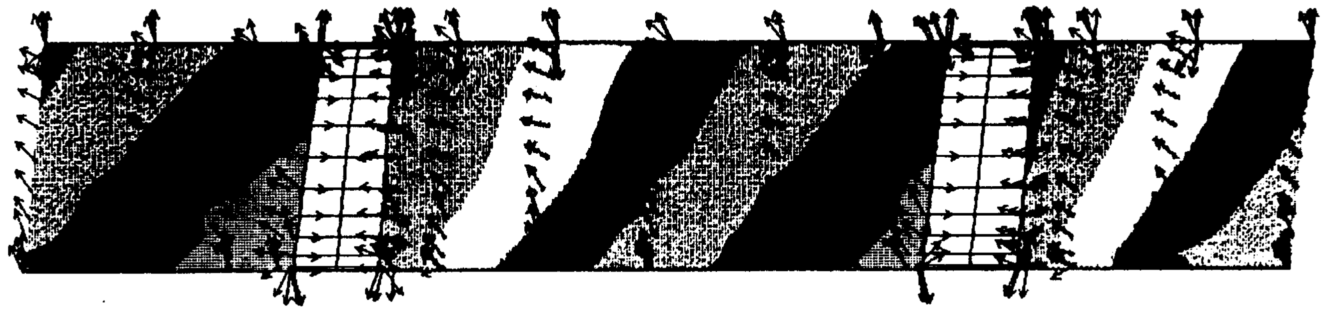
Consortium Impeller

Stable location vectors

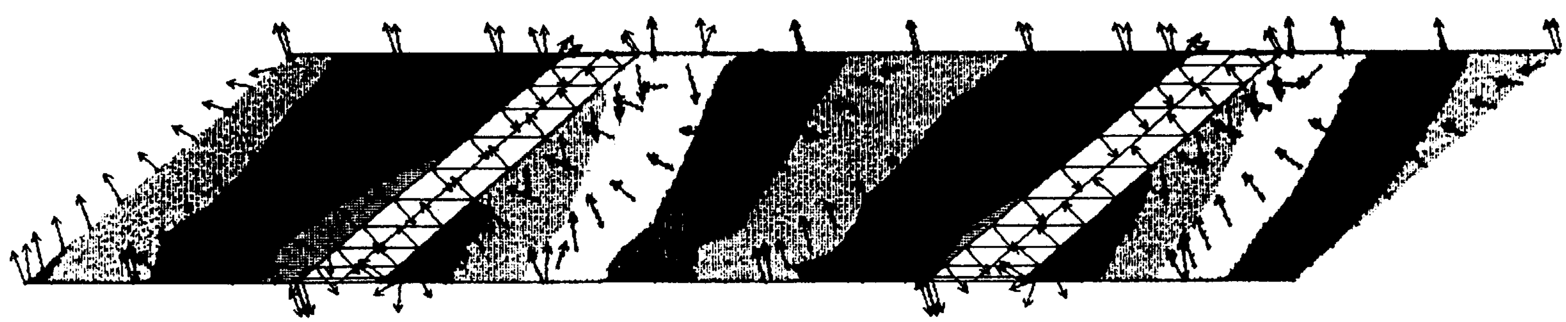
Contours of Pr



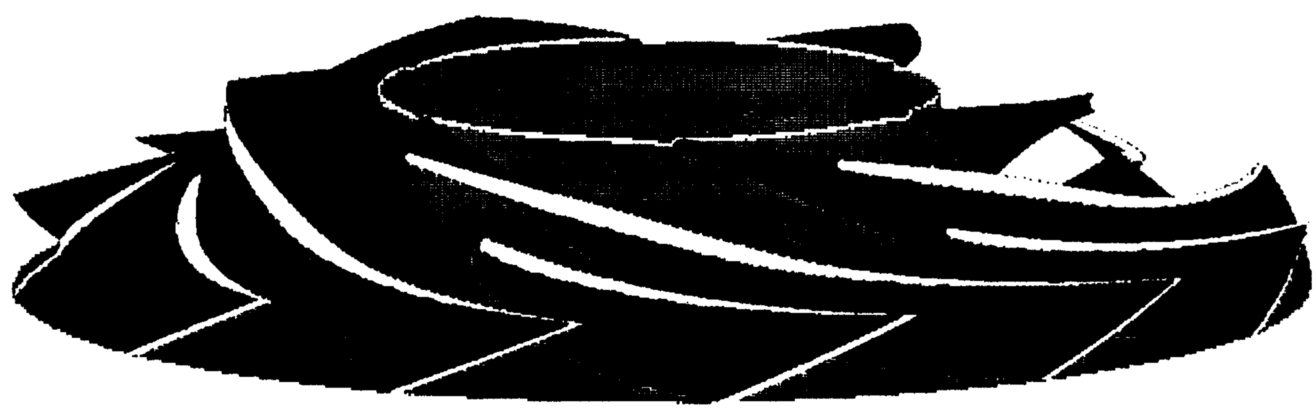
Baseline design

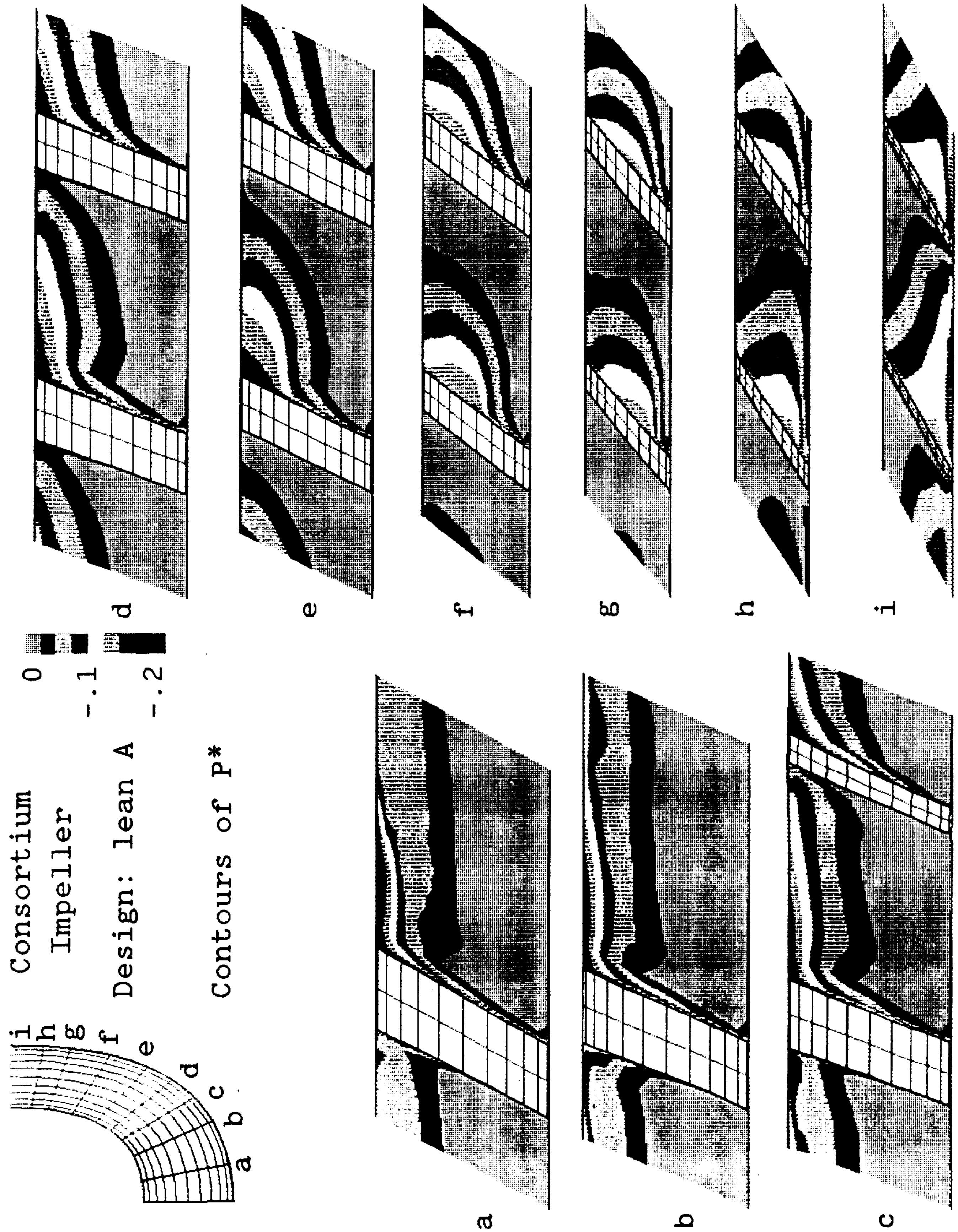


Design: lean A



CONSORTIUM IMPELLER REDESIGN: LEAN A

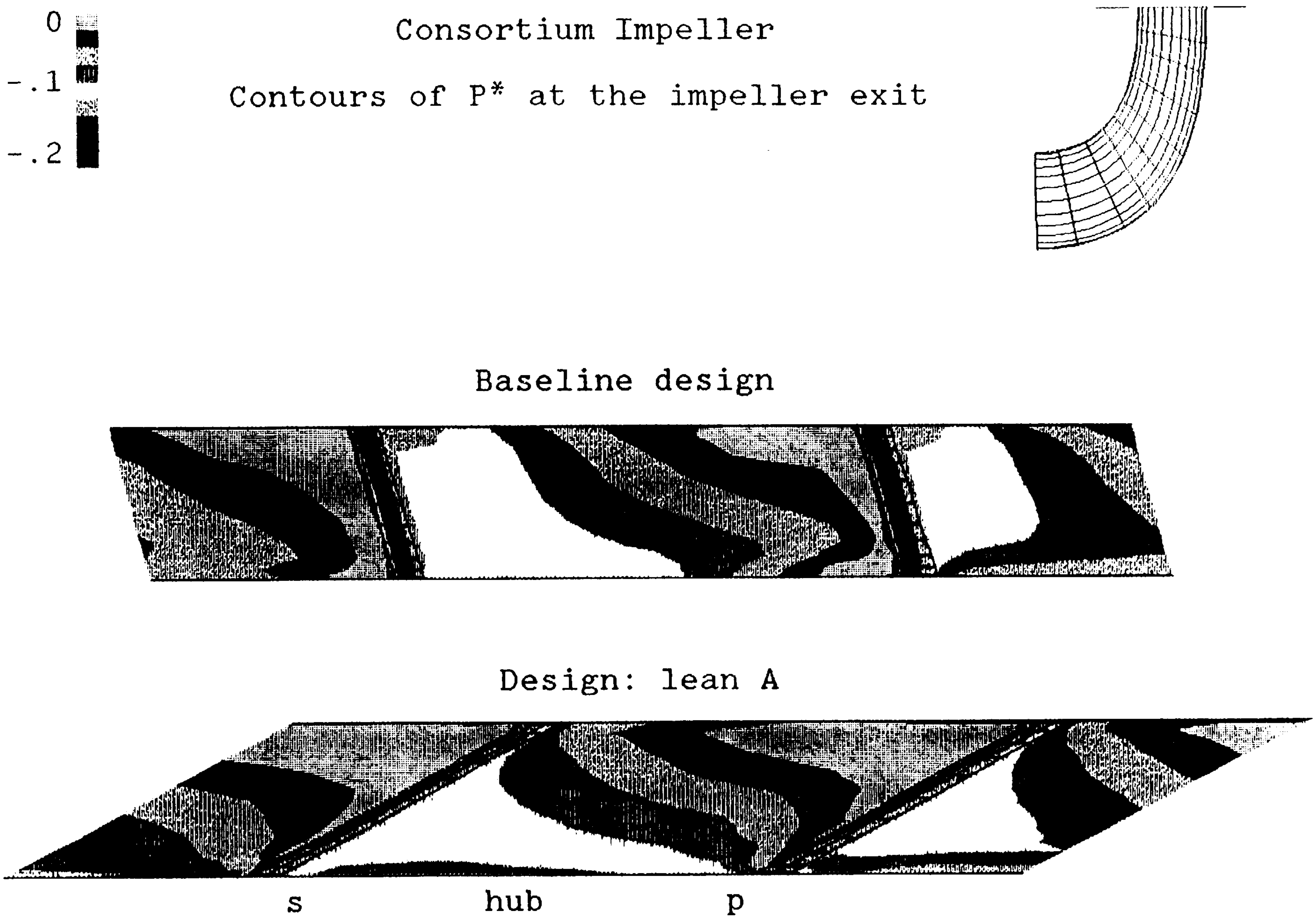




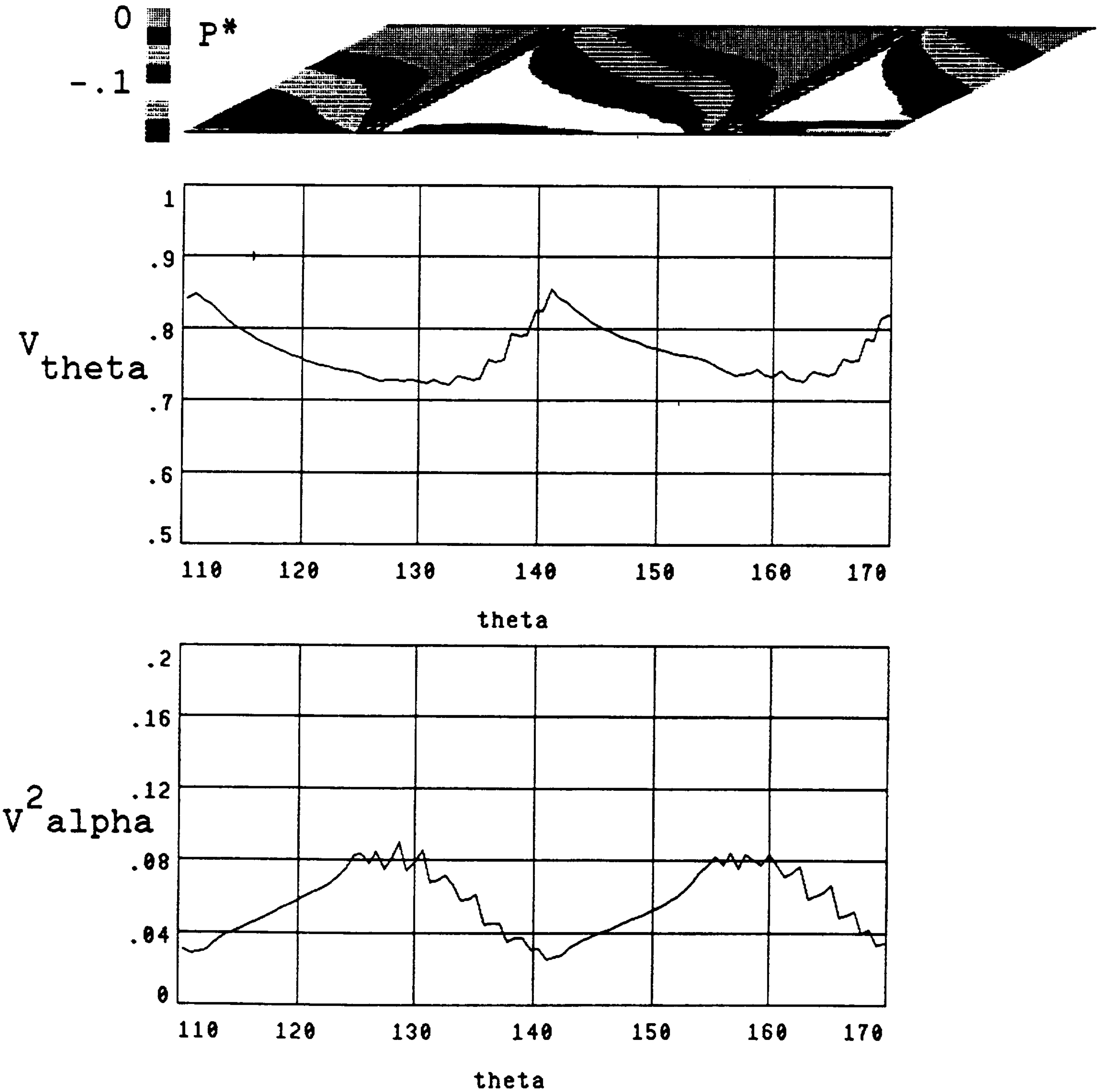
Consortium
Impeller
Design: lean A
Contours of P*
0
-.1
-.2
a
b
c
d
e
f
g
h
i

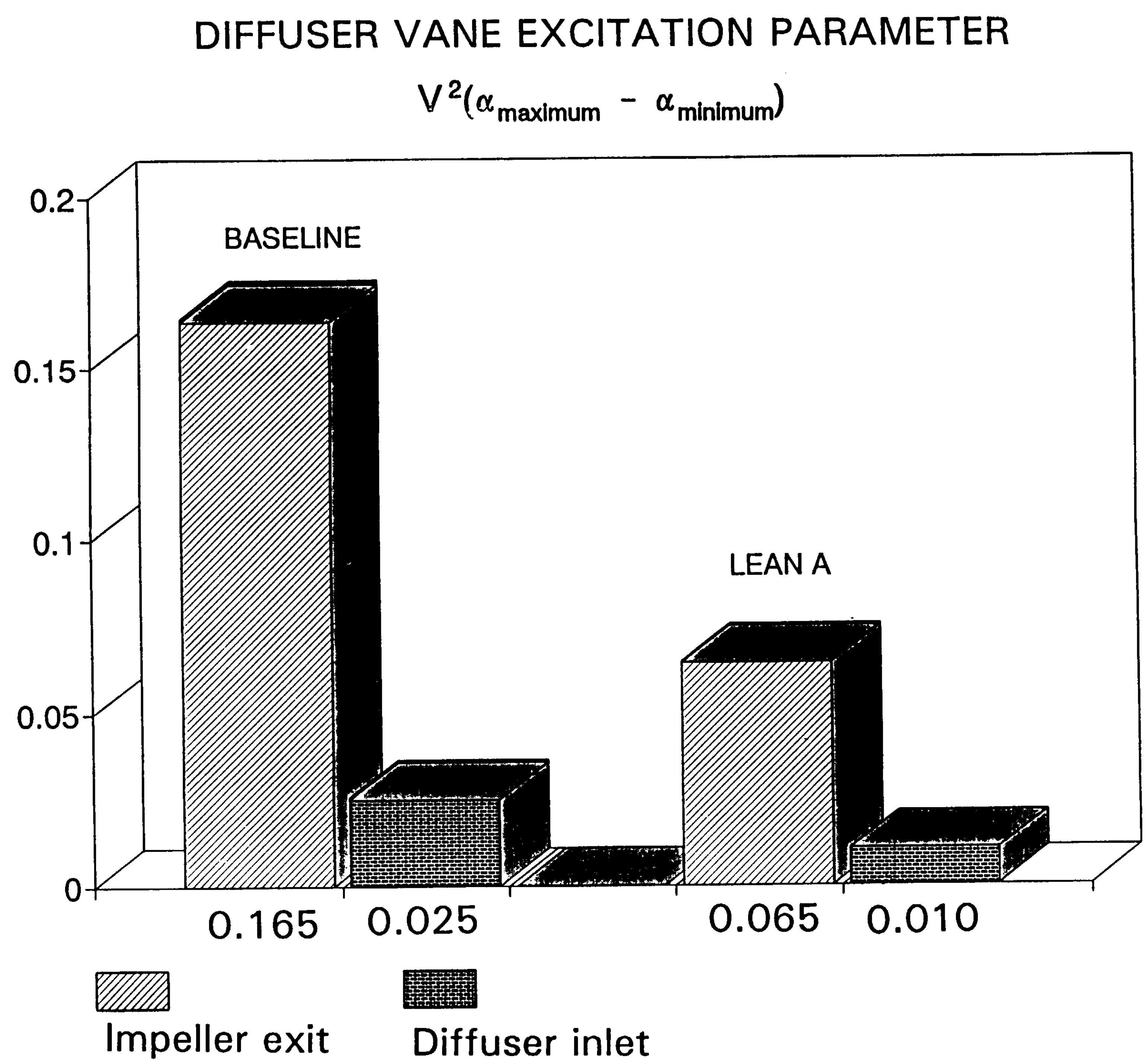
Consortium Impeller

Contours of P* at the impeller exit



Consortium Impeller, Design: Lean A
Exit Plane Distortion

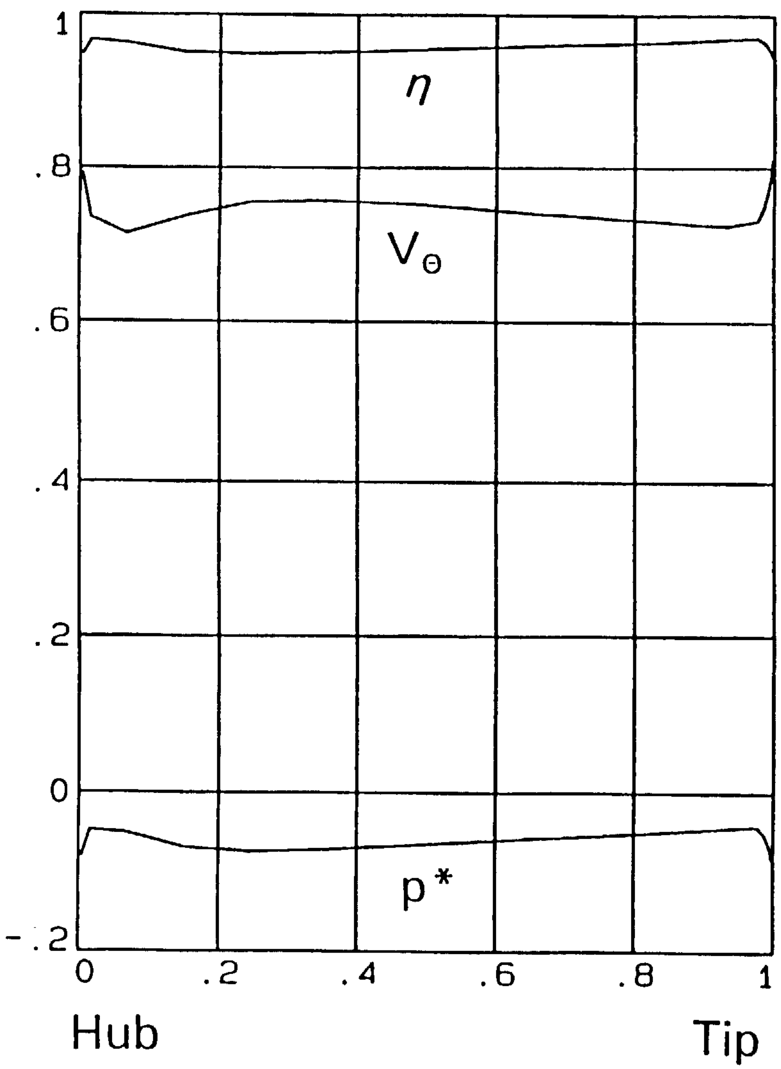



DIFFUSER VANE EXCITATION PARAMETER
V²(α maximum - α minimum)
0.2
0.15
0.1
0.05
0
BASELINE
LEAN A
0.165
0.025
0.065
0.010
Impeller exit
Diffuser inlet

Circumferential Averages

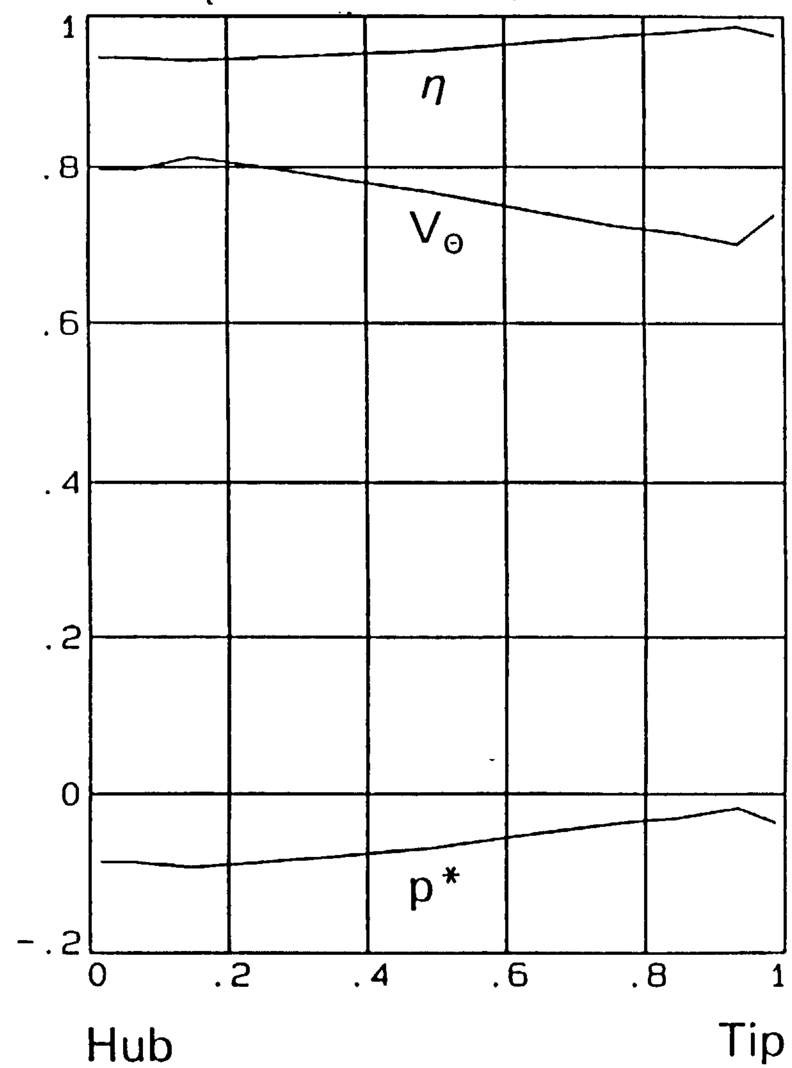
Baseline

$\delta P_t = 1.22 \quad \eta = 98\%$



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