Slide 1 (MEEREX, www.meerex.com):
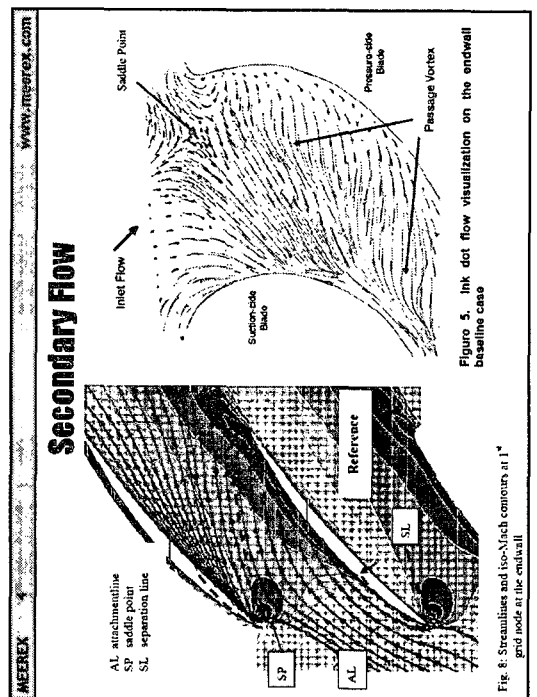
Numerical Investigation of Secondary Flow in Centrifugal Compressor Stage

December 2005

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Slide 2 (MEEREX, www.meerex.com):

SECONDARY FLOW in Turbomachinery

- Deviation of low-momentum fluid from main stream flow
- Due to Unbalance of pressure gradient & Centrifugal forces (Coriolis)
- Meridional symmetry is destroyed
- High loss core established to reduce performance

Slide 3 (MEEREX, www.meerex.com):

Secondary Flow

Figure 1: Schematic of secondary flow structure in a compressor cascade with tip clearance, hung. [9]
PV - Passage vortex; HV - Horseshoe vortex; TLV - Tip leakage vortex; TSV - Tip secondary vortex;
SV - Secondary vortex; CSV - Concave-sided vortex; CV - Corner vortex.

Slide 4 (MEEREX, www.meerex.com):

Secondary Flow

AL attachmentline
SP saddle point
SL separation line

Fig. 8: Streamlines and iso-Mach contours at 1ˢᵗ grid node at the endwall

Figure 5. Ink dot flow visualization on the endwall baseline case

(labels: Saddle Point, Pressure-side Blade, Passage Vortex, Inlet Flow, Suction-side Blade, Reference, SL, SP, AL)
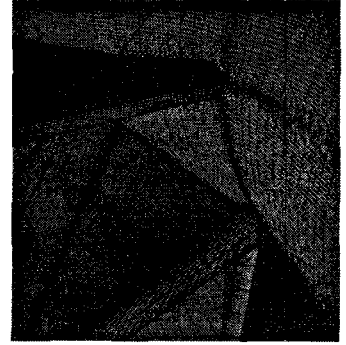
Secondary Flow

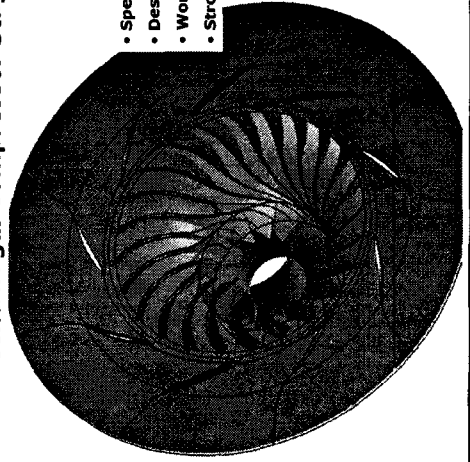Secondary flows have a number of undesirable effects as described by Gregory-Smith (1997):

- The work output from a turbine stage depends on the turning of the flow, secondary flow alters the flow angle which changes the work output
- Extra loss is produced
- A non-uniform flow is provided at exit of the blade row reducing the efficiency of the blade row downstream
- Secondary flows can introduce unsteadiness into the flow which can cause mechanical problems

CFD Code

- One of the Well-known Commercial CFD Codes
- Finite Volume Time Marching Method
- 4-step Runge-Kutta Time Integration Scheme
- Artificial Dissipation Terms with 2nd/4th order
- Structured H-type Grids
- Extended k-epsilon Two Equations for Turbulence Closure
- Multi-block and Multi-grid Scheme
- Rotor/Stator Interaction with Mixing Plane Approach

Centrifugal Compressor Stage for Study

- Specific Speed = 89 (US)
- Design PR (T-T) = 3.7
- Working Fluid = Air
- Strong Backswept Impeller

Numerical Environment

- Geometry = Impeller (Splittered) + Diffuser Vane
- Total 700,650 grid points
- Design point calculation
- Tip clearance included with rectangular cross-section

Static Pressure Contours on suction and pressure surface

Stronger pressure gradient on suction surface

Impeller Cm Contours (1)

Meridional velocity (Cm) contours

Tip leakage vortex

High velocity core is detached from suction surface

Impeller Cm Contours (2)

Meridional velocity (Cm) contours

Wake away from suction surface

Larger accumulation of low-momentum fluid near shroud

Asymmetrical distribution for splitter blades

Impeller Secondary Flows

- Blade passage vortex towards shroud and suction side
- Wake pushed away from suction side driven by tip leakage vortex

Static Pressure Contours on Shroud

* Development of tip leakage vortex

JET & WAKE

* Eckardt's radial-bladed impeller
  (Test results)

* NASA backswept impeller
  (Test results)

Diffuser Vane Cm Contours

Meridional velocity (Cm) contours

* Wake moves from shroud towards suction surface

Summary

* Wake is formed away from suction surface near shroud at impeller exit.
* Wake location is determined by a force balance from secondary flows : between blade passage vortex and tip leakage vortex.
* Pressure gradient drives secondary flow in the inducer region, while in the remaining region the following sources drive together :
  > Pressure gradient
  > Coriolis force
  > Tip leakage vortex
* Wake moves from shroud towards suction surface of diffuser vanes.