Numerical Investigation of Secondary Flow in 3 Pump Stages :

Centrifugal Multistage/ Mixed-flow Stage/ Axial-flow Stage

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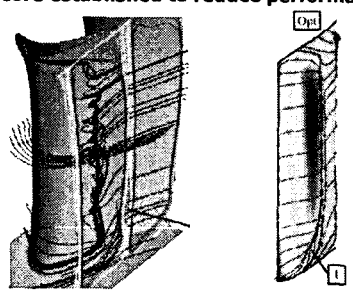
SECONDARY FLOW in Turbomachinery

- **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**



Secondary Flow

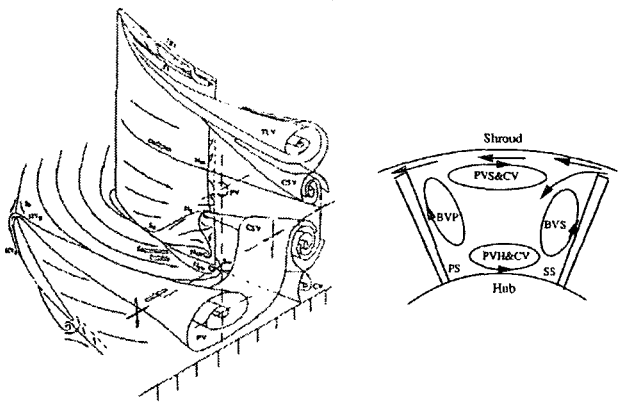
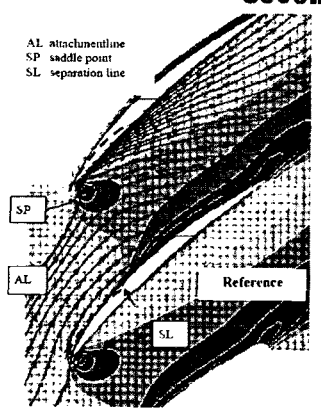


Figure 1. Schematic of secondary flow structure in a compressor cascade with tip clearance, from [6]
PV – Passage vortex; HV – Horseshoe vortex; TLV – Tip leakage vortex; TSV – Tip secondary vortex;
SV – Boundary vortex; CSV – Concentrated shed vortex; CV – Corner vortex.

Secondary Flow



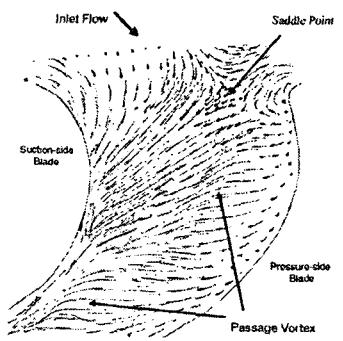


Figure 5. Ink dot flow visualization on the endwall baseline case

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

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**
- **Pre-conditioning Scheme for Incompressible Flow**

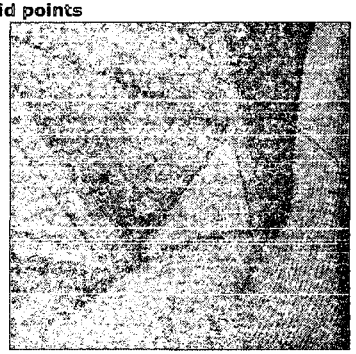
Secondary Flow

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

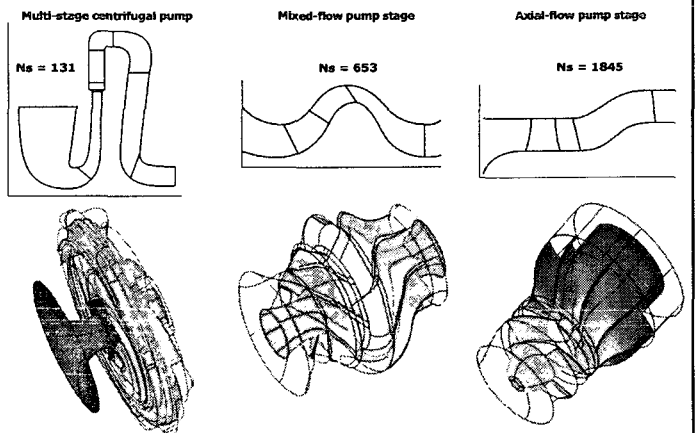
- The work output from a turbine stage depends on the turning of the flow, secondary flow alters the flow angle which changes the work output
- Extra loss is produced
- A non-uniform flow is provided at exit of the blade row reducing the efficiency of the blade row downstream
- Secondary flows can introduce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

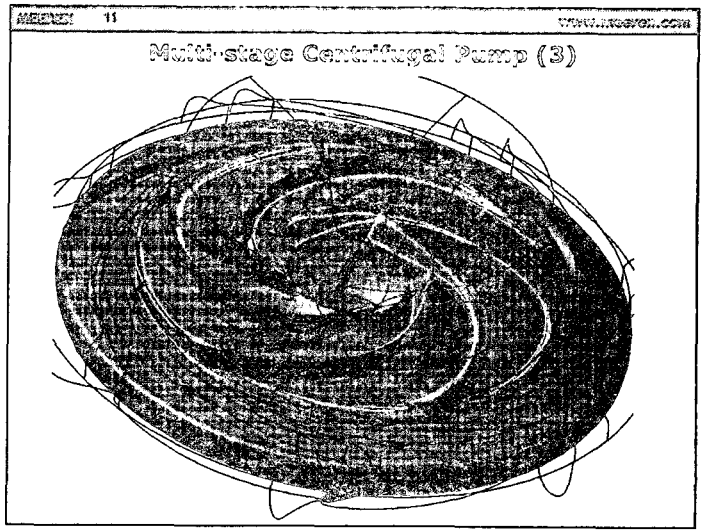
Numerical Environment

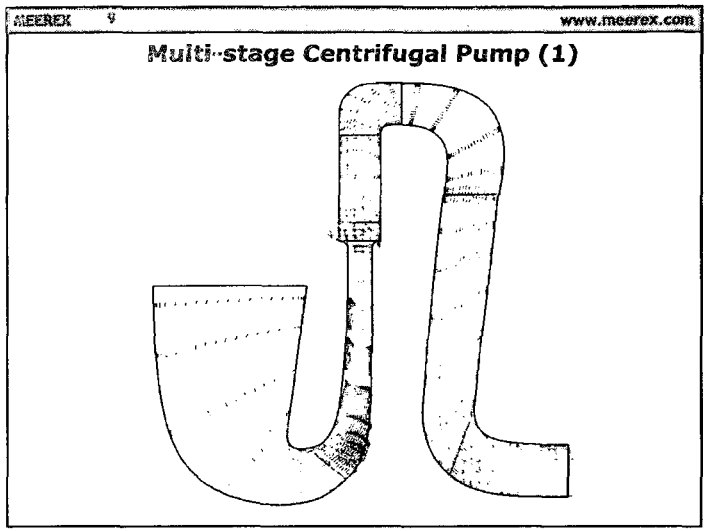
- **Geometry = Impeller (or Rotor) + Stationary Vane Stages**
- **Total 700,000 – 900,000 grid points**
- **Design point calculation**
- **Tip clearance included with rectangular cross-section when unshrouded**



Pump Stages for Study




MEEREX 11
Multi-stage Centrifugal Pump (3)


MEEREX 9
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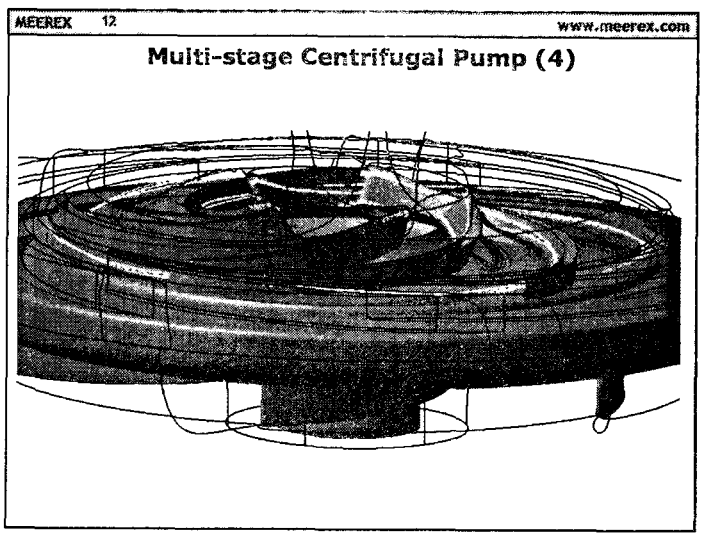
Multi-stage Centrifugal Pump (1)


MEEREX 12
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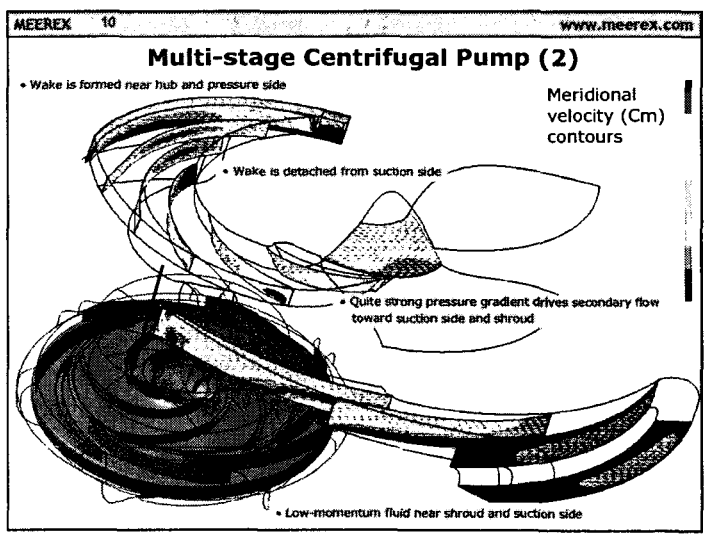
Multi-stage Centrifugal Pump (4)


MEEREX 10
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Multi-stage Centrifugal Pump (2)
• Wake is formed near hub and pressure side
Meridional velocity (Cm) contours
• Wake is detached from suction side
• Quite strong pressure gradient drives secondary flow toward suction side and shroud
• Low-momentum fluid near shroud and suction side

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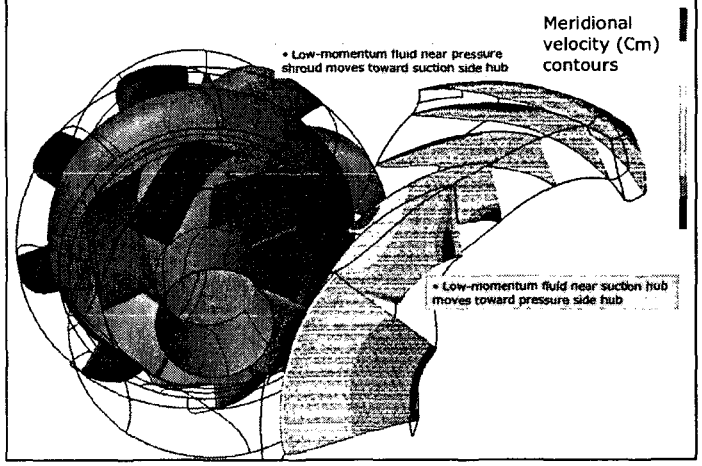
Mixed-flow Pump Stage (1)



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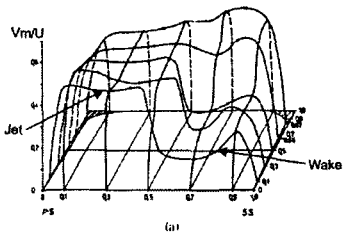
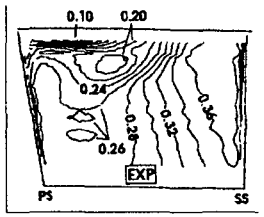
JET & WAKE





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

• NASA backswept impeller
(Test results)

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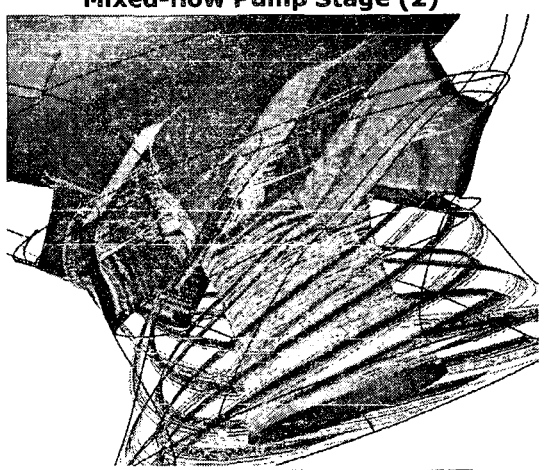
Mixed-flow Pump Stage (2)



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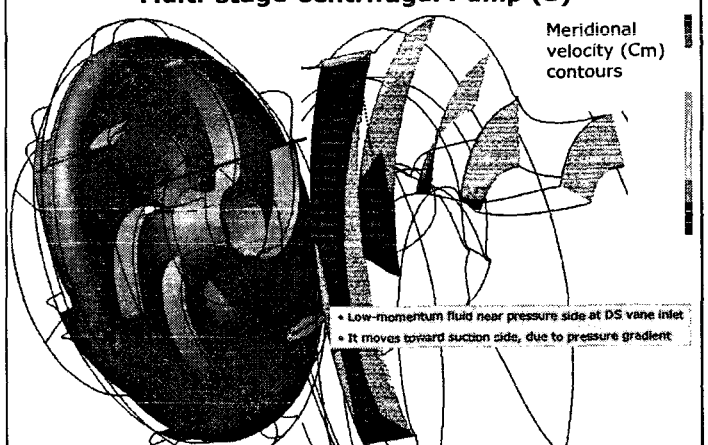
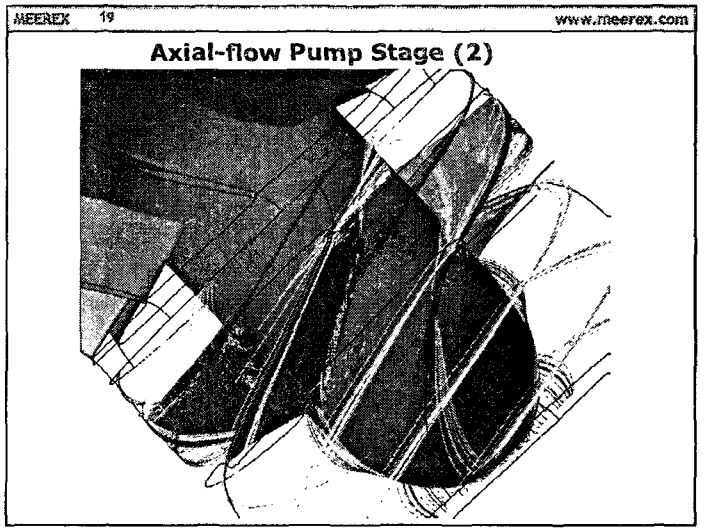
Multi-stage Centrifugal Pump (5)




MEEREX 19
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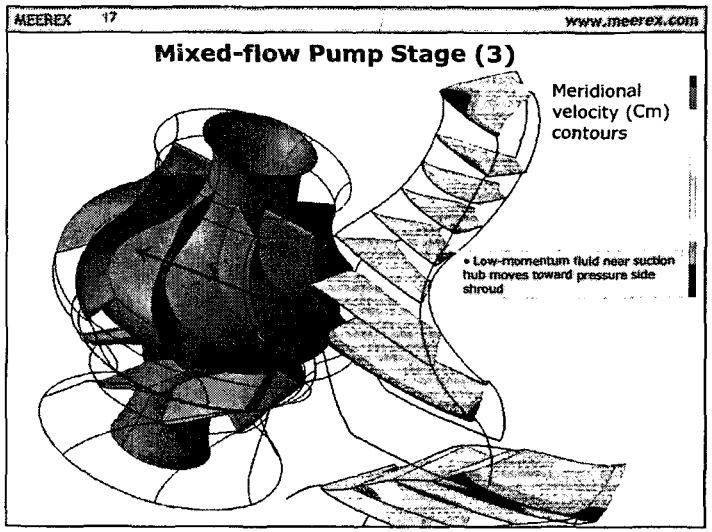
Axial-flow Pump Stage (2)


MEEREX 17
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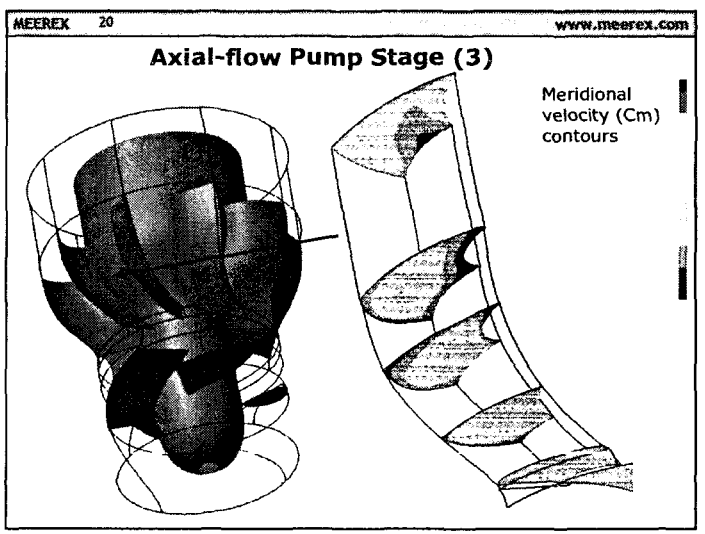
Mixed-flow Pump Stage (3)
Meridional velocity (Cm) contours
• Low-momentum fluid near suction hub moves toward pressure side shroud


MEEREX 20
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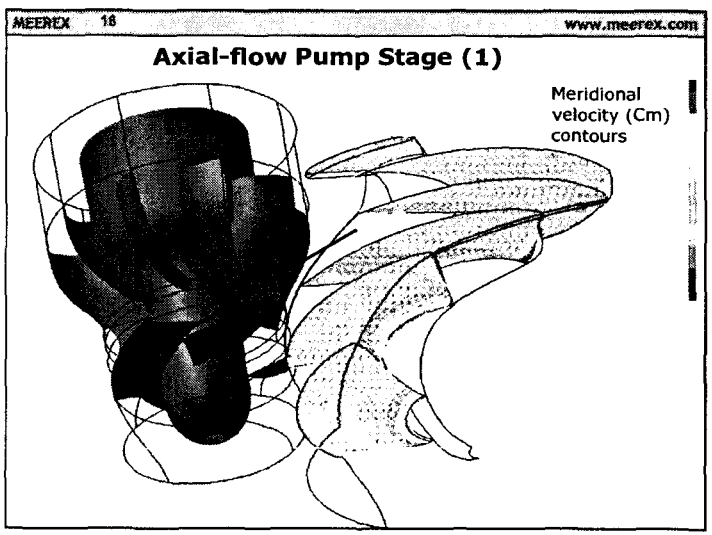
Axial-flow Pump Stage (3)
Meridional velocity (Cm) contours


MEEREX 18
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Axial-flow Pump Stage (1)
Meridional velocity (Cm) contours

Summary

- Centrifugal pump shows the strongest secondary flow.
- Wake is formed near pressure surface close to hub at impeller exit for centrifugal pump impeller.
- Pressure gradient drives secondary flow in the inducer region, while in the remaining region the following sources drive together :
  - > Pressure gradient
  - > Coriolis force
- Low-momentum fluid near suction surface hub moves toward pressure surface hub in mixed-flow pump impeller.
- Tip leakage vortex dominate secondary flow in axial-flow pump impeller