Energy Savings Through Effective Interstage Pipe Design of Centrifugal Compressor Stages

Eric Huss

Aerodynamicist

FS-Elliott Co., LLC

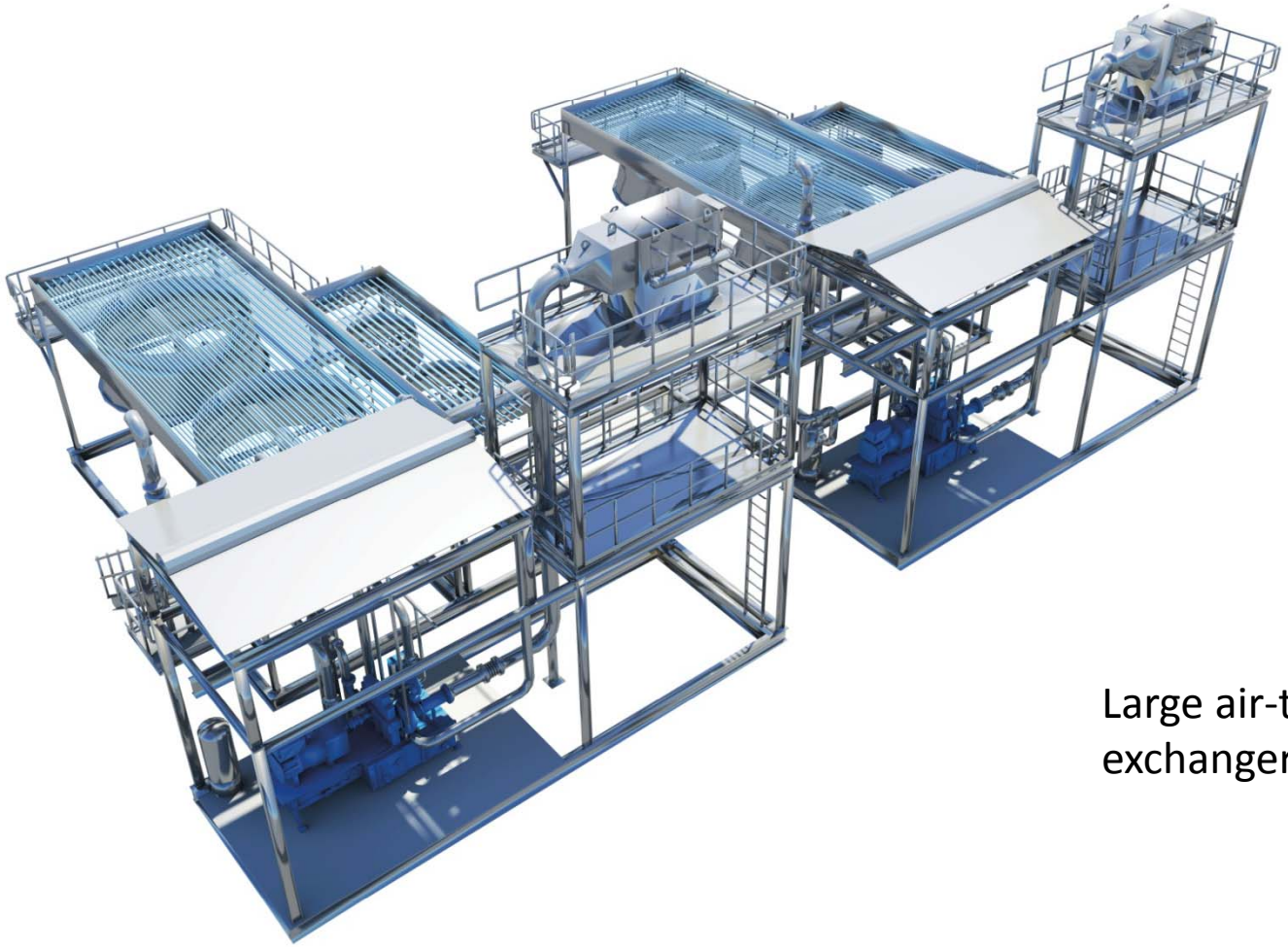
Background

- Customer requirements involve complex custom piping

Background

Remote mounted components

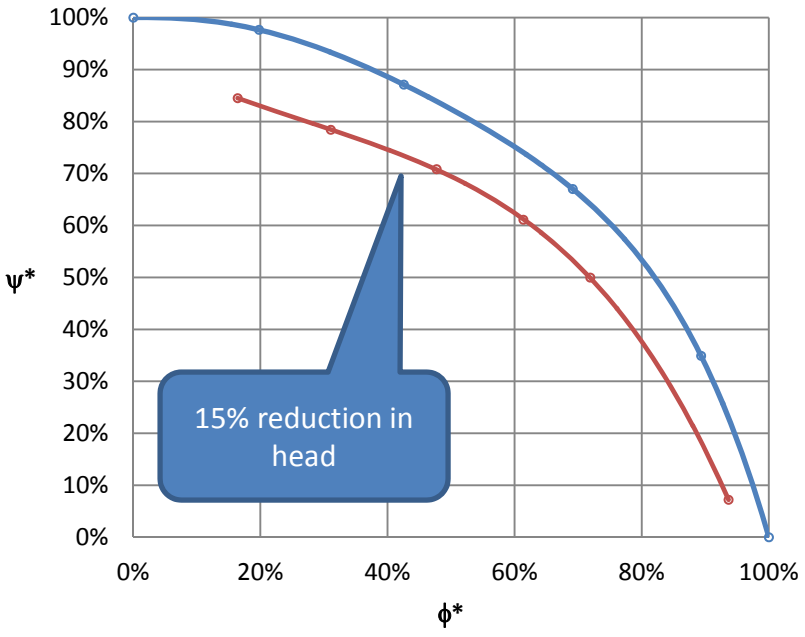
Background

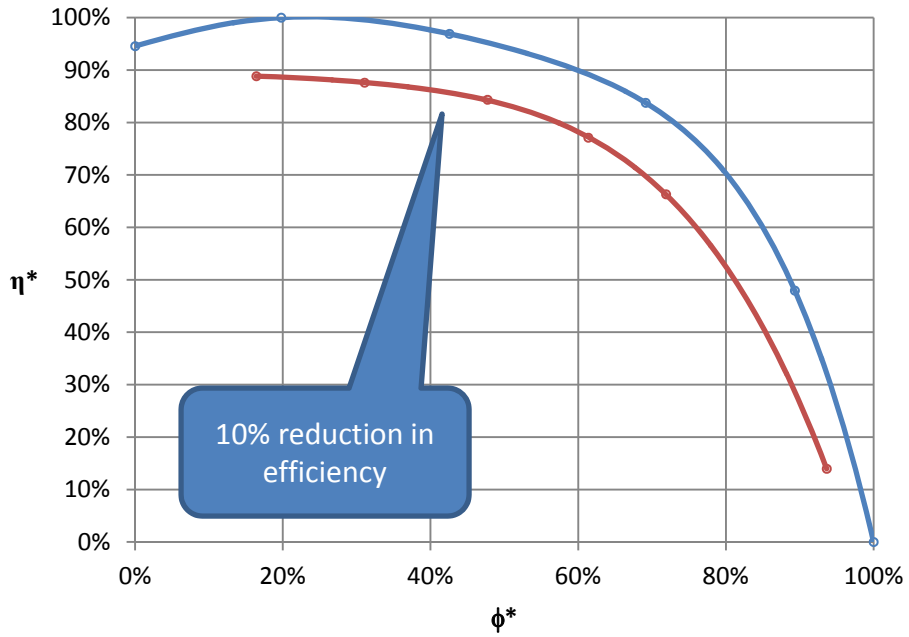


Large air-to-air heat exchangers

Problem Statement

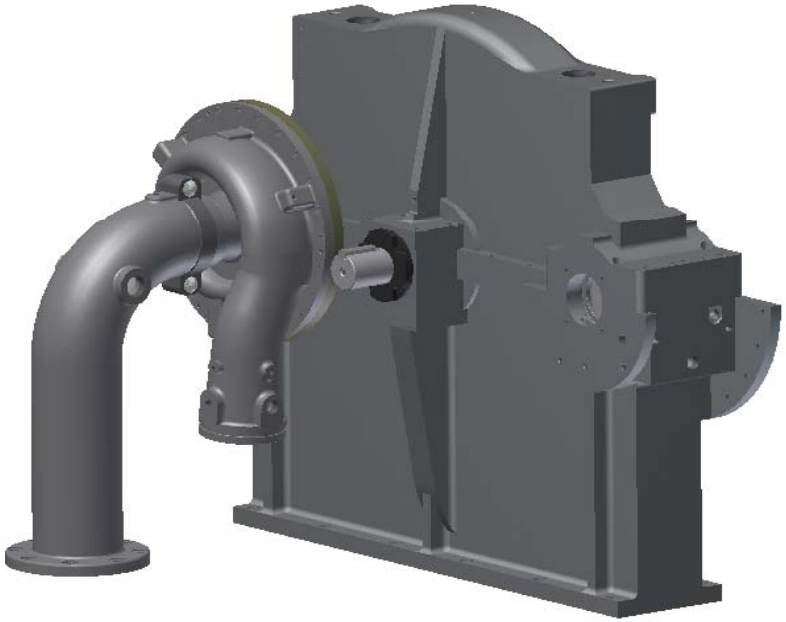
- One unit, using an existing aero design had radical drop in performance in the as-built form

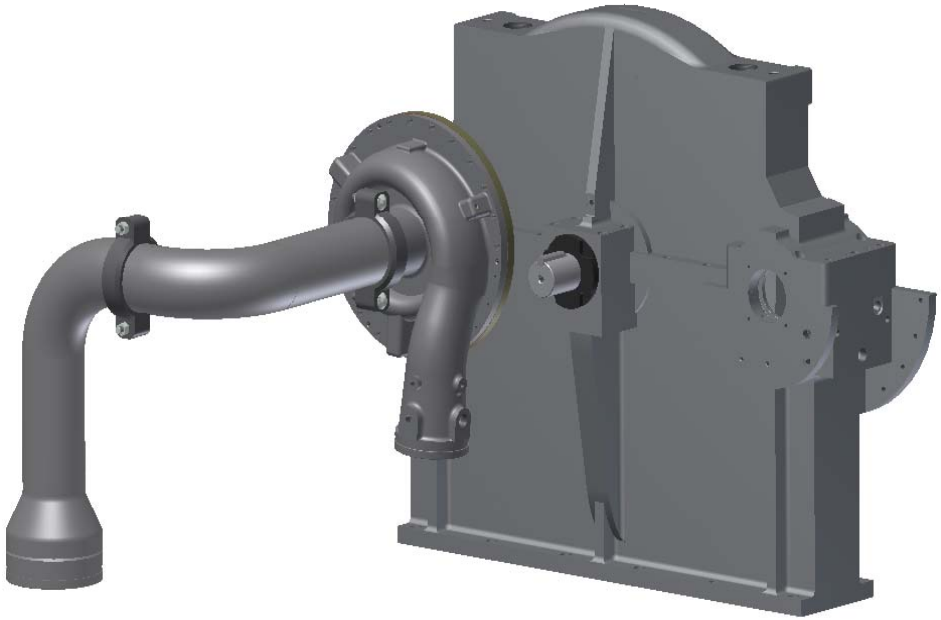




Problem Statement

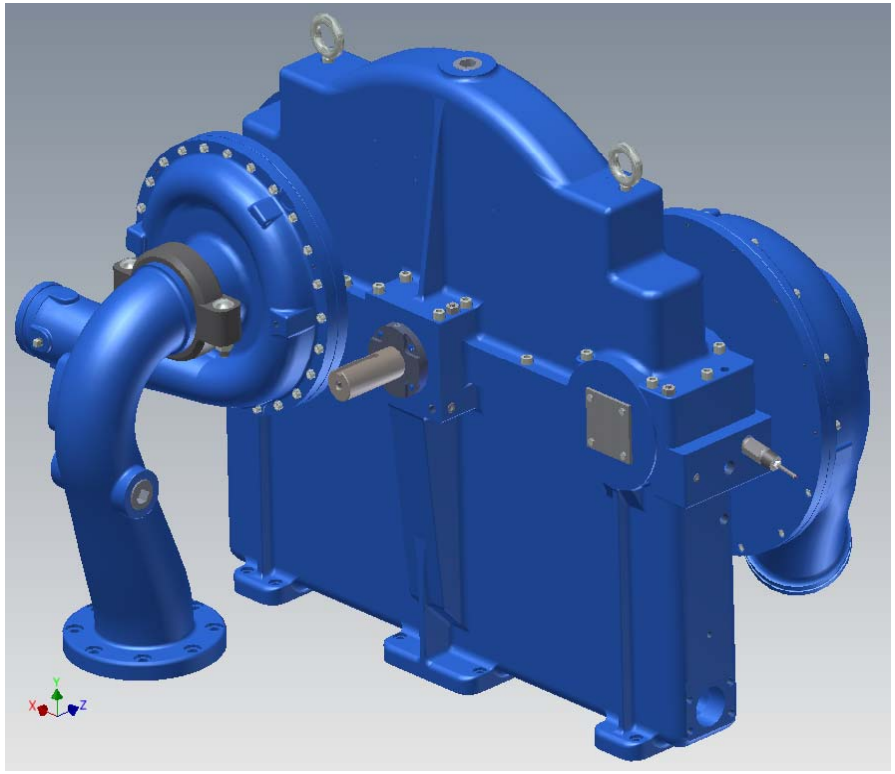
- The variable in the two units is the interstage piping
  - Pipe leading up to stage has multiple bends
  - Potential for non-uniform flow
  - **Same impeller, diffuser, casing, and instrumentation**





Problem Statement

- A smaller, more cost-effective unit was chosen as a test subject for the study
  - Suspected candidate based on the visible geometry
  - Smaller, easier to work with components
  - Less expensive testing

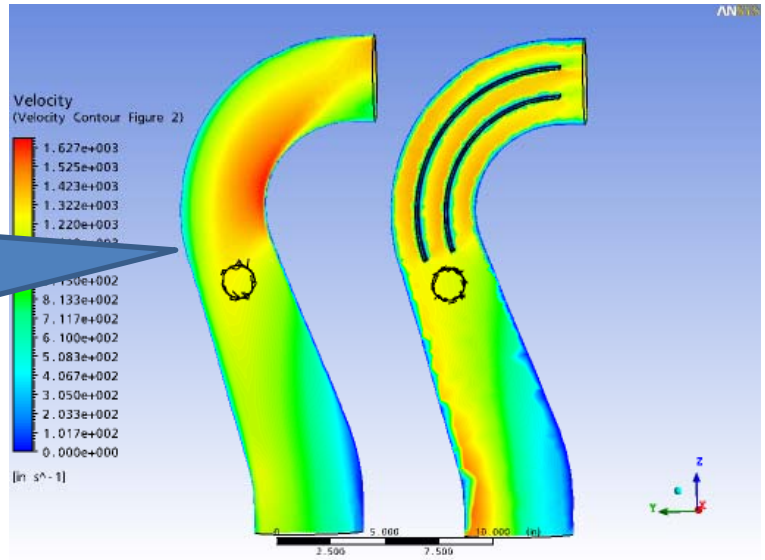


Problem Statement

- Embarked on an extensive study of the effect of vanes in elbows
  - CFD Analysis of pipe with and without turning vanes
  - Experimental study

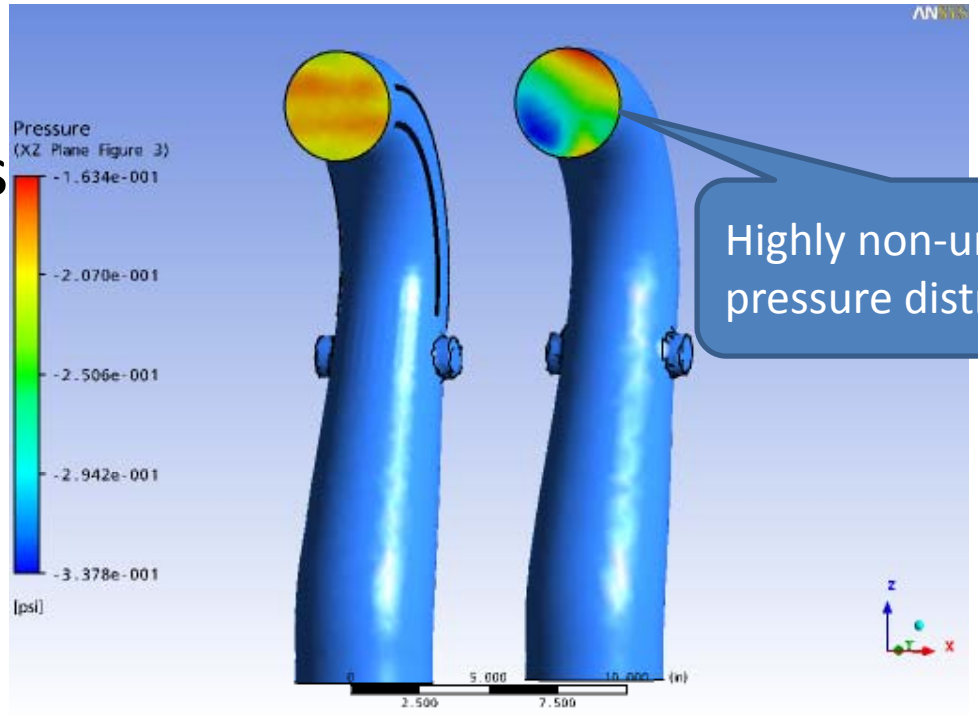
Interstage pipe with two opposing turns

Without any turning vanes, with vanes



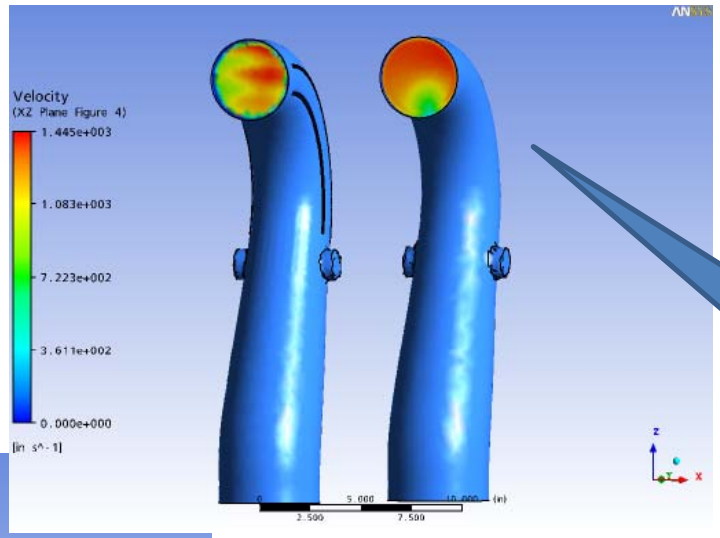
Results – Computational

- CFD Analysis
  - Tetrahedral mesh with inflated boundary layers
  - CFX version 14.0
  - 100,000 elements

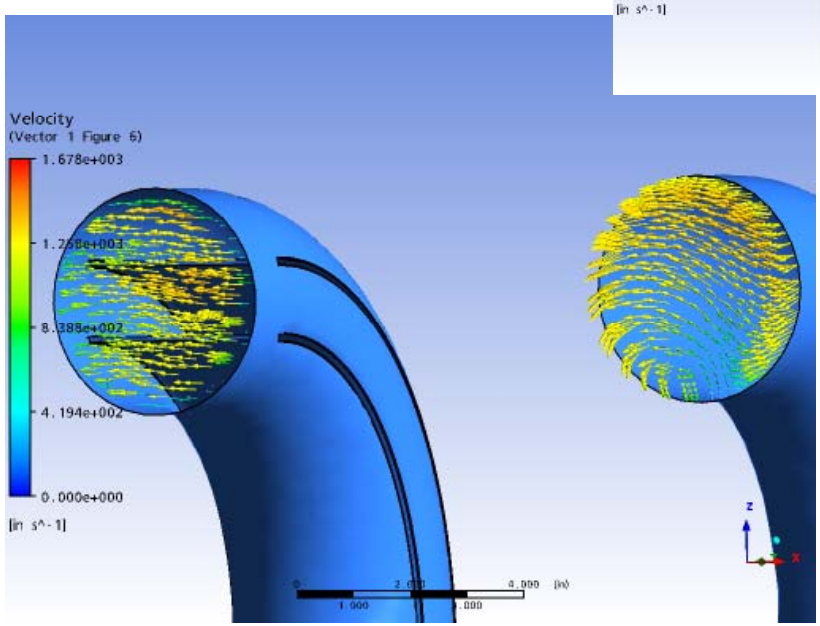


Results – Computational

- CFD Analysis



Corresponding non-uniform velocity distribution

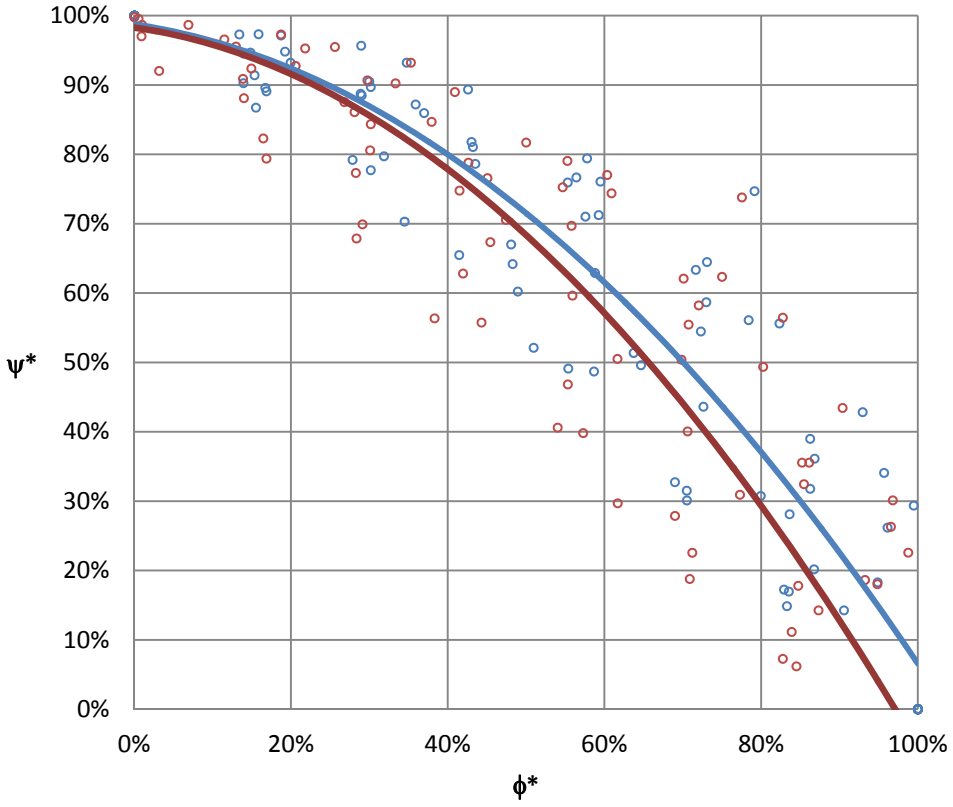


Significant swirl

Results - Experimental

- CFD results show directionally what to expect, but do not provide specifics
  - How much head recovery and efficiency improvement can we gain?
  - Experiments used a 700 (nominal) cfm stage, 4 different profiles, 5 different impeller diameters

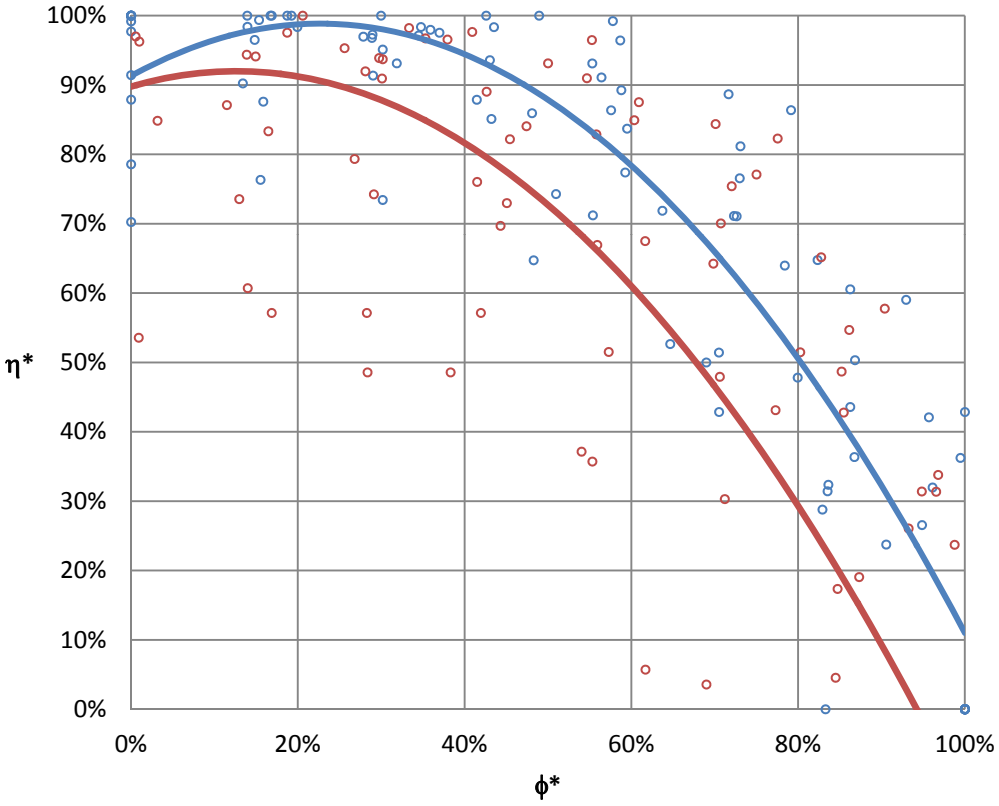
Results – Experimental



Head recovery with vaned pipe is a few points:

About 2-5% near typical design point

Results – Experimental



Efficiency recovery with vaned pipe significant:

5-10% better efficiency near typical design point

Conclusions

- Bigger effect at higher flow
  - To be expected
- Greater effect on efficiency vs. head
  - Indicates prevailing effect is poor pressure distribution (uneven density entering impeller)
  - Swirl is not so prevalent Euler: Head = $\Delta C_u U$
  - Able to recover some performance losses from convoluted piping

Conclusions

- What does this mean to the manufacturer and customer?
  - It is increasingly more common for a power penalty to be added to submitted proposals in some markets
    - Anywhere from $1,000 to $5,000 per kW depending on the application, capacity, motor size, discharge pressure, etc.

Conclusions

- What does this mean to the manufacturer and customer (cont'd.)?
  - Look at a 3,500 scfm compressor with a 5% difference in adiabatic efficiency for two stages of a three stage compressor
  - Compressor #1 – $175,000 price
    - 850 HP (634 kW)
  - Compressor #2 – $200,000 price
    - 826 HP (616 kW)

Conclusions

- **Using $2,000/kW power penalty, Compressor #1 becomes $211,000!**
    - $175,000 + (634 kW – 616 kW) * $2,000/kW

- **The cheapest upfront cost is not necessarily the most economical solution in the long run**