49TH TURBOMACHINERY & 36TH PUMP SYMPOSIA

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Aerodynamic Design of Centrifugal Compressor Components Around Existing Rotor

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DOW

Presenter Bios

Thomas Smith has been with Elliott Group since 2012 serving as an Aerodynamic Engineer in the Engineered Solutions department focusing on aftermarket rerates and modifications. His responsibilities include compressor aerodynamic design, performance modeling, field performance troubleshooting, and reverse engineering. He holds an MS in Mechanical Engineering from Penn State University.

Shane Scott, P.E. has been employed with The Dow Chemical Company in Freeport, Texas since 2000 as a rotating equipment engineer. Some primary responsibilities are to provide technical support for new projects, re-rates, maintenance activities, performance analysis and long term reliability initiatives for site turbomachinery equipment and auxiliary support systems. He graduated from the University of Texas at Austin with a BS in Mechanical Engineering.

Abstract

This case study covers the aerodynamic design of a centrifugal compressor that replaced an aging compressor experiencing leakage issues. The replacement compressor was required to reuse the existing rotor, bearings, seals, and baseplate. The existing diaphragms and casing internals were not available for inspection. A performance model had to be developed based on the existing spare rotor geometry and a flowpath that was designed and matched to the rotor. The predicted performance exceeded the existing compressor performance and was verified on test.

Introduction

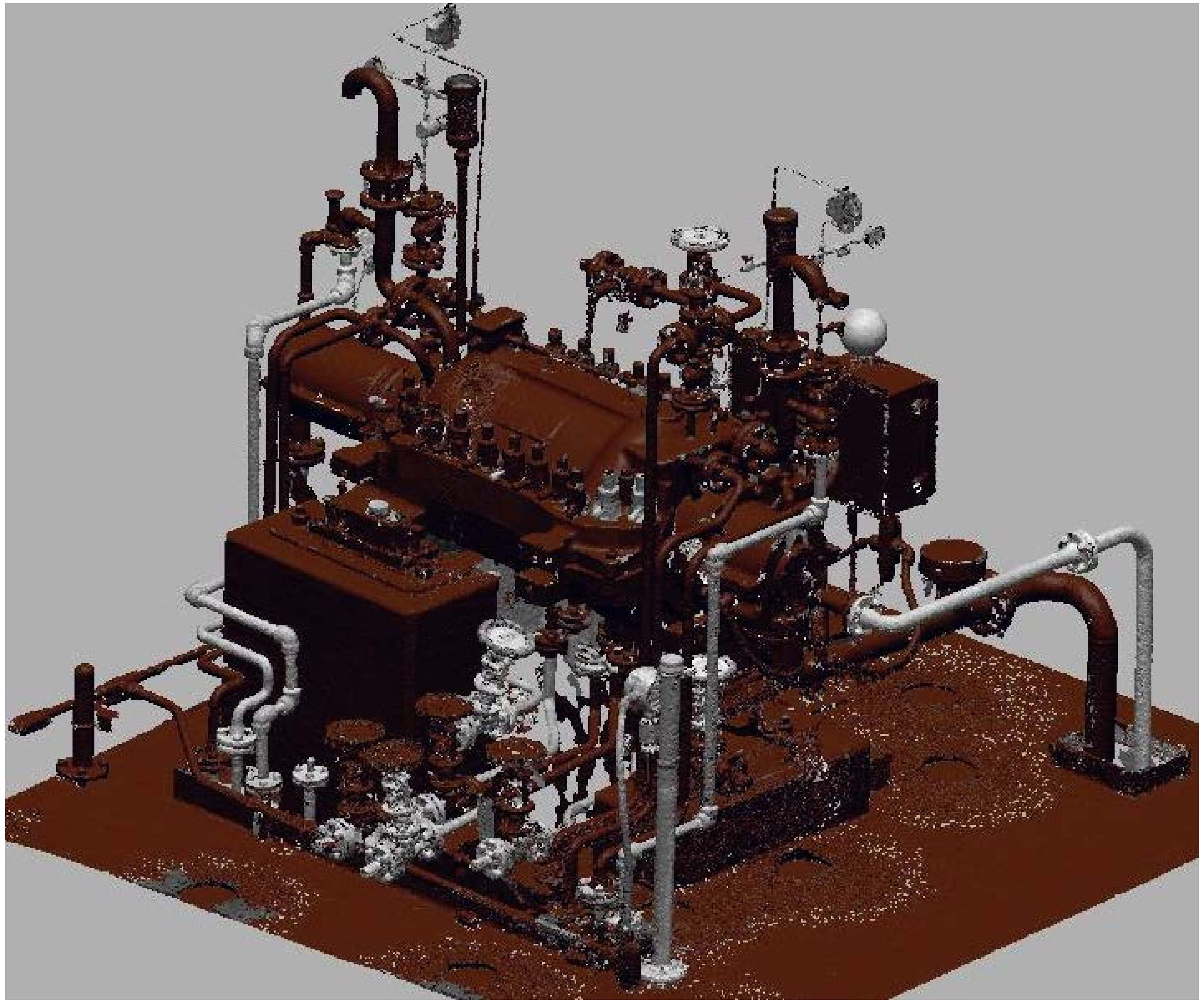
- Existing compressor in service since 2000
  - Experienced leaks at seal housing, compressor casing, and casing splitline
  - Numerous solutions had been attempted to fix or minimize the leak
  - Leakage issues persisted and worsened over time
- The end user was interested in a more long term solution with a new casing that used the existing rotor, bearings, and seals

Problem Statement

- Leaking casing necessitated a replacement compressor
  - Required to reuse existing rotor, bearings, seals, and baseplate
  - Did not have access to diaphragms or casing internals

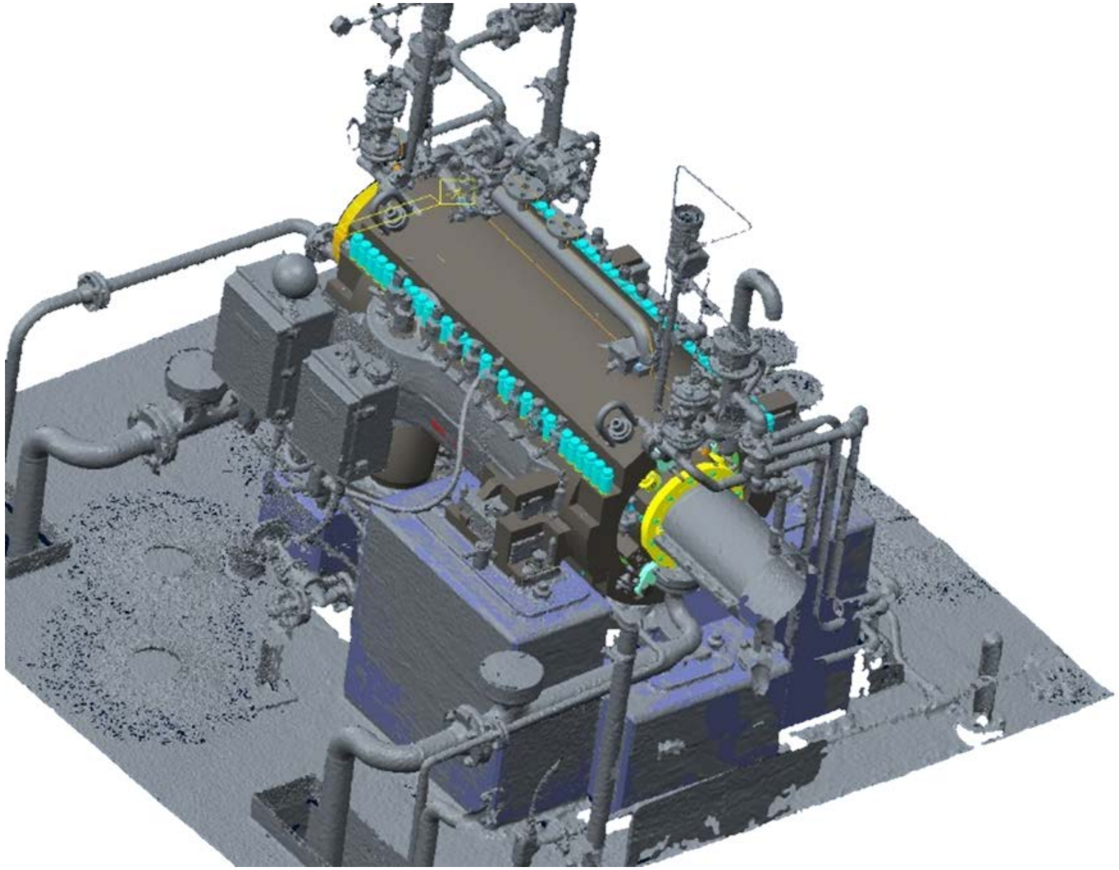
Site Compressor Scan

- Performed a scan of the existing compressor casing and compressor deck while in operation using a 3D laser scanner



Casing Modeling

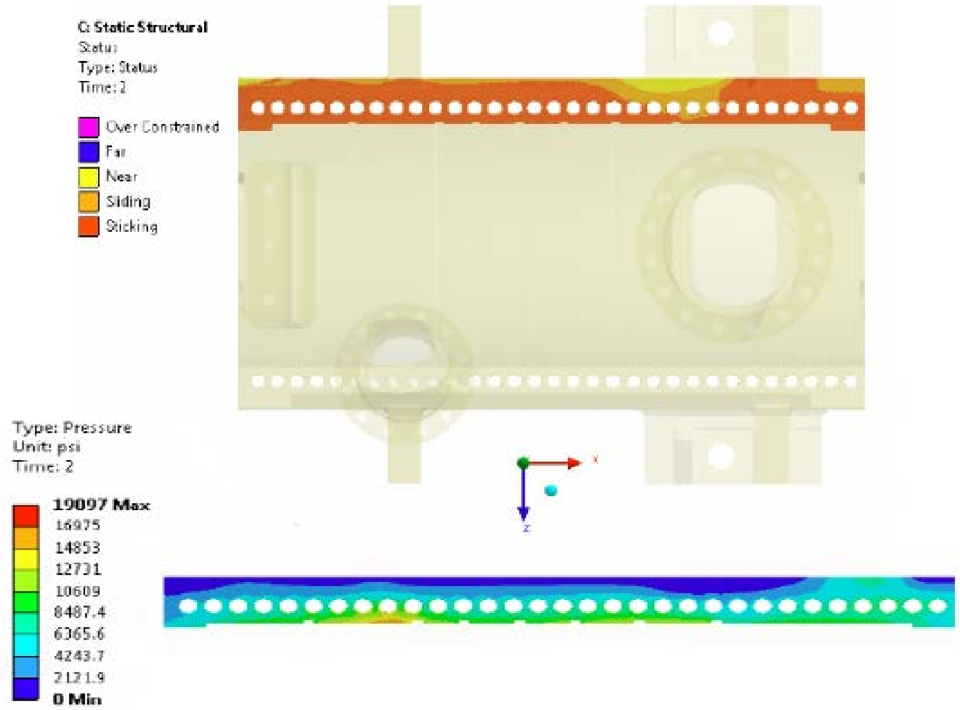
- External scan of the compressor and deck was used to determine:
  - Casing support locations
  - Main process piping flange locations
  - Small bore piping flange locations
- Connection locations were met as much as possible
- The site scan data was overlaid on the new casing model to ensure there was no interference

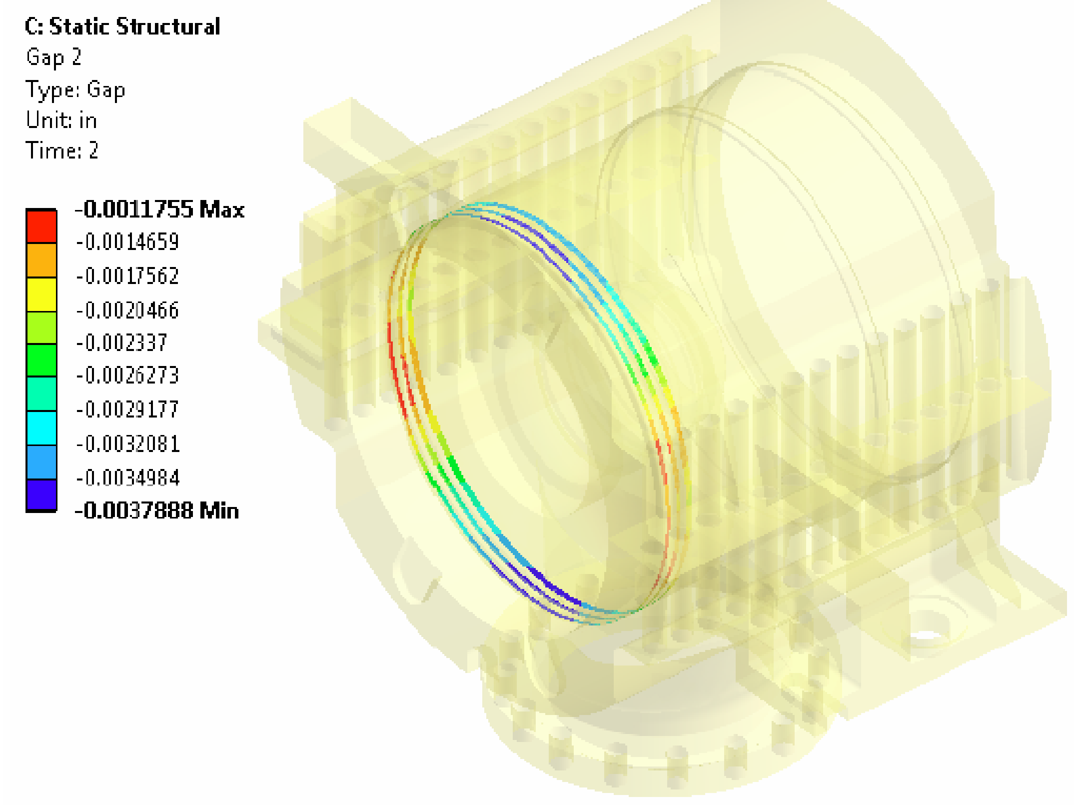


Replacement compressor overlaid on scan of existing compressor

Casing Finite Element Analysis

- An FEA was performed on the casing model to ensure there would be no leaks across the splitline or endwall O-rings while under load





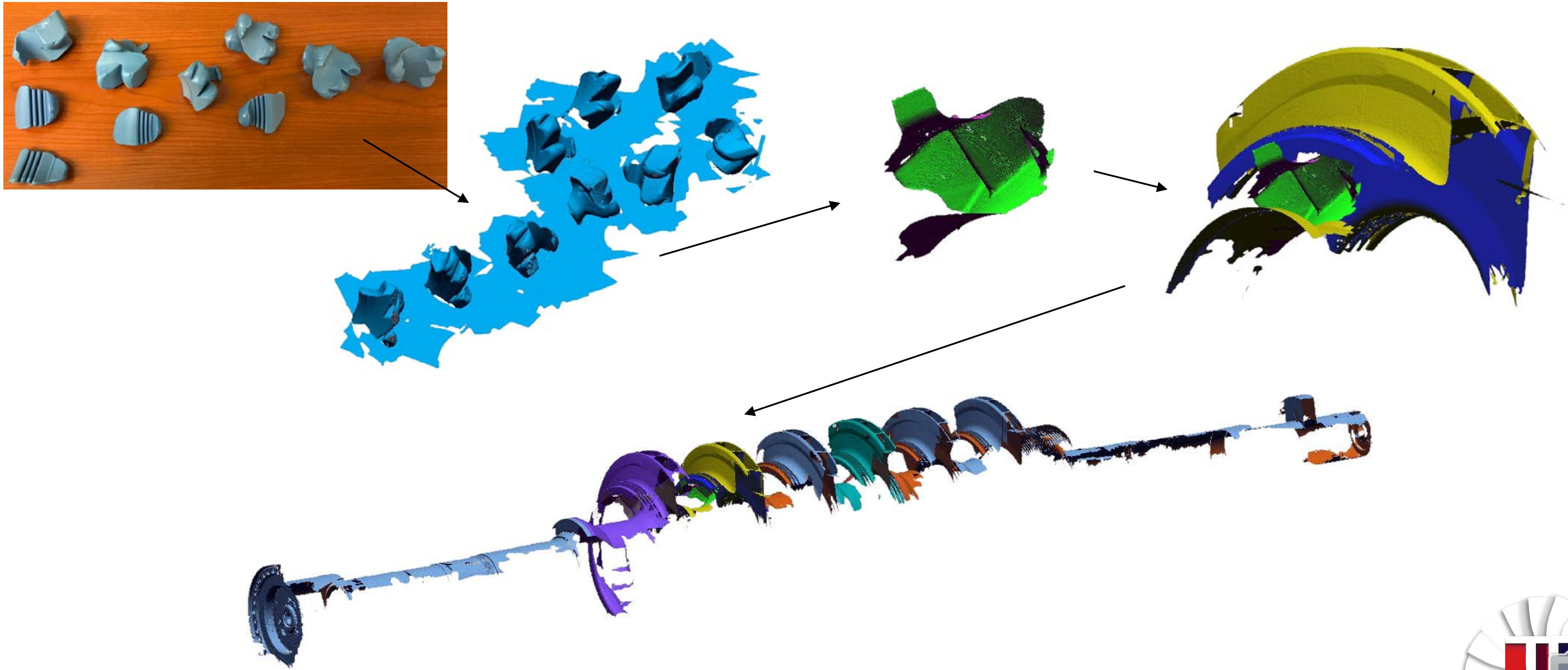
Spare Rotor Inspection

- Inspected the spare rotor using a portable CMM arm with a touch probe and laser line probe (LLP)
- Critical diameters were measured using micrometers

Spare Rotor Inspection

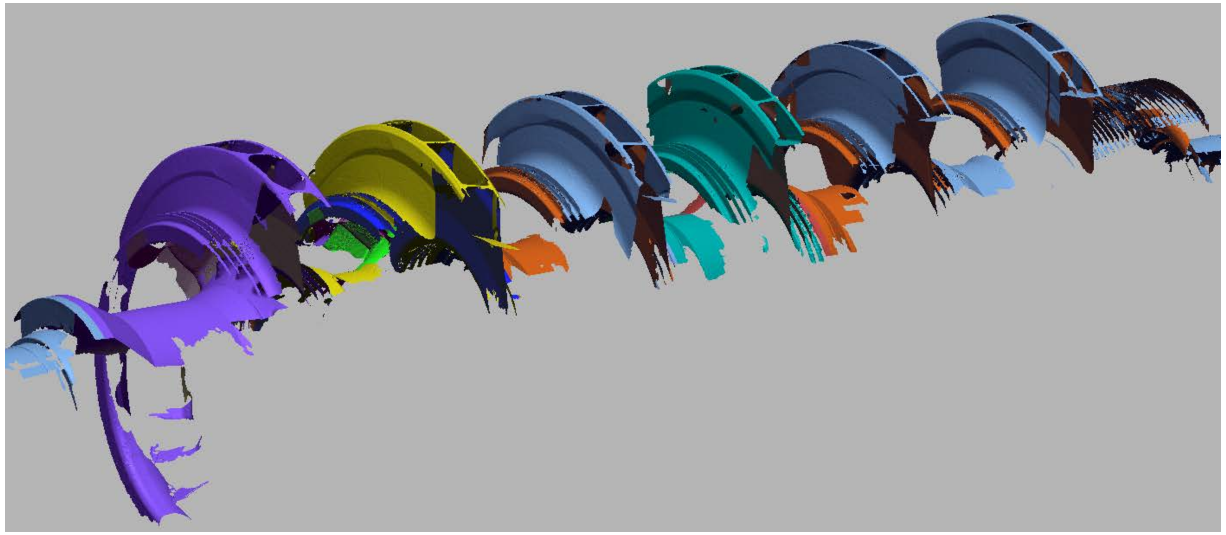
- The impeller eye and leading edge geometry was captured using metrology grade putty
  - The putty molds were scanned with the LLP and aligned with the rotor scan to fully define the rotor flowpath

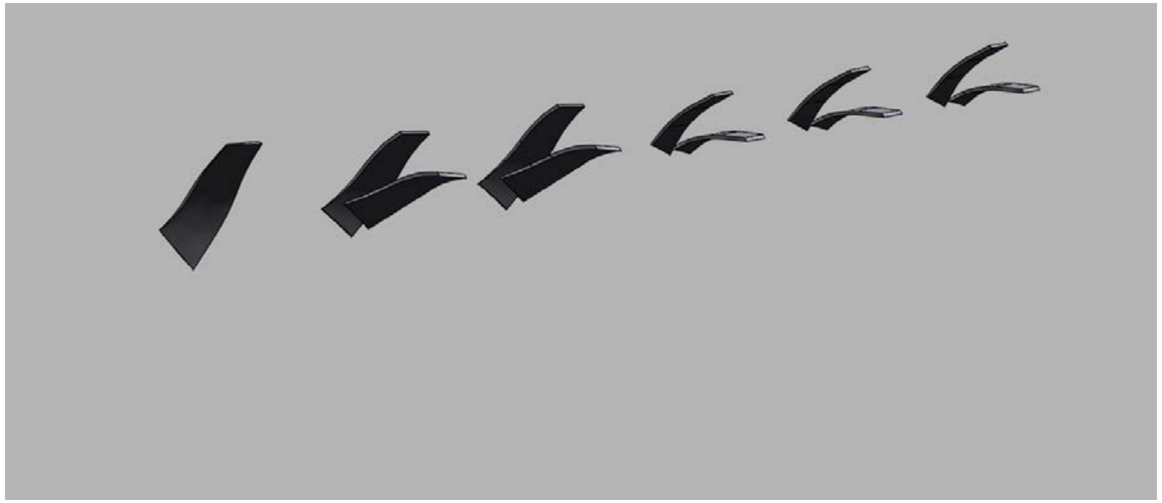
Spare Rotor Inspection



Impeller Reverse Engineering

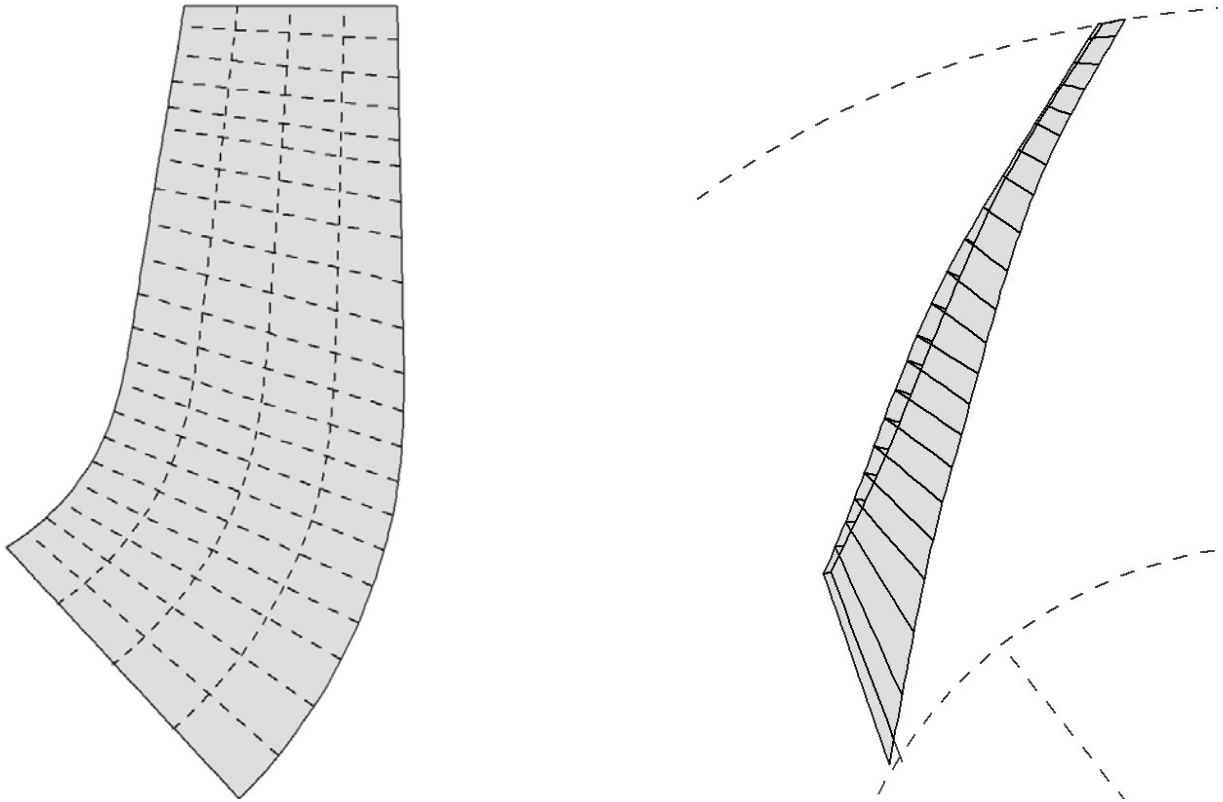
- The impeller blades were modeled using the rotor scan data and touch probe dimensions





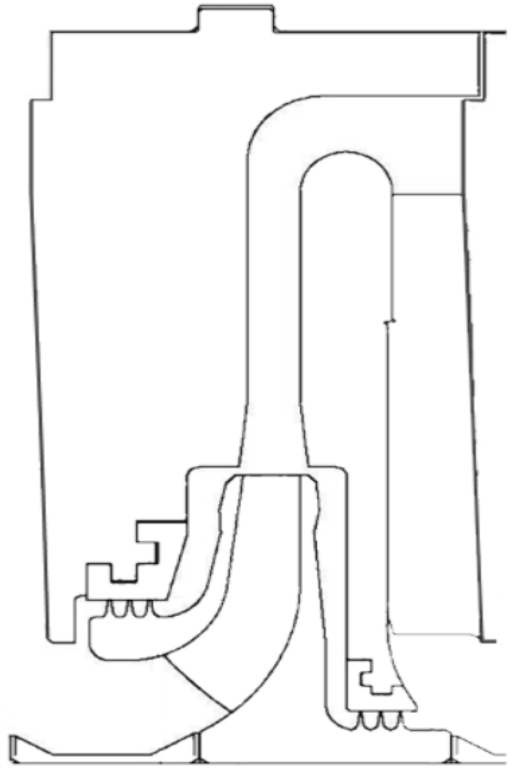
Impeller Performance Model

- The impeller flowpath geometry was loaded into a mean-streamline aerodynamic code to determine the impeller performance



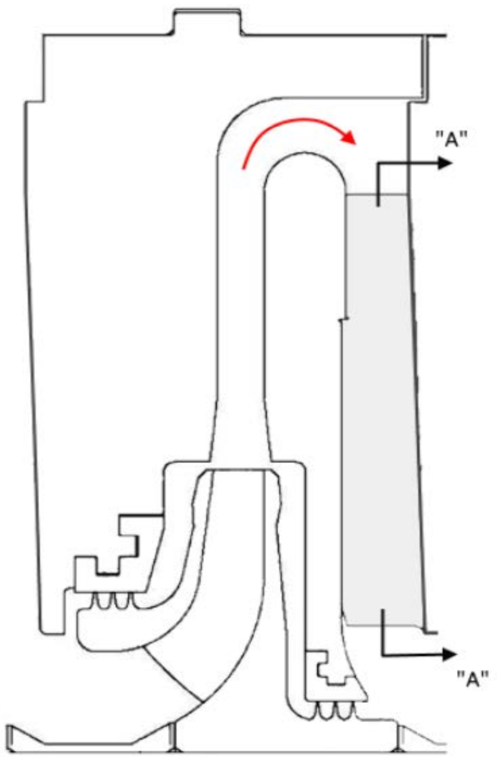
Stationary Flowpath Design

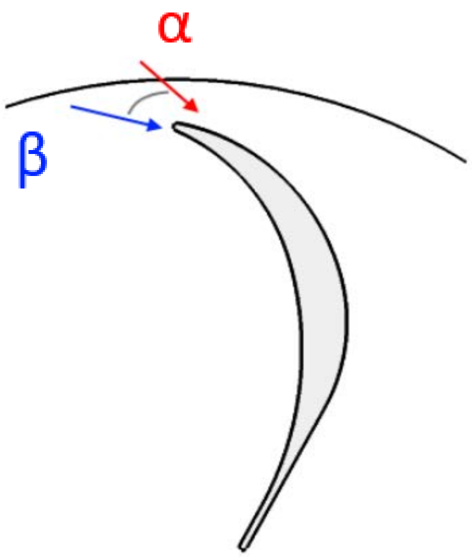
- The initial diffuser, crossover, and return channel flowpath geometry was modeled based on scaling the existing compressor cross section



Return Channel Vane Design

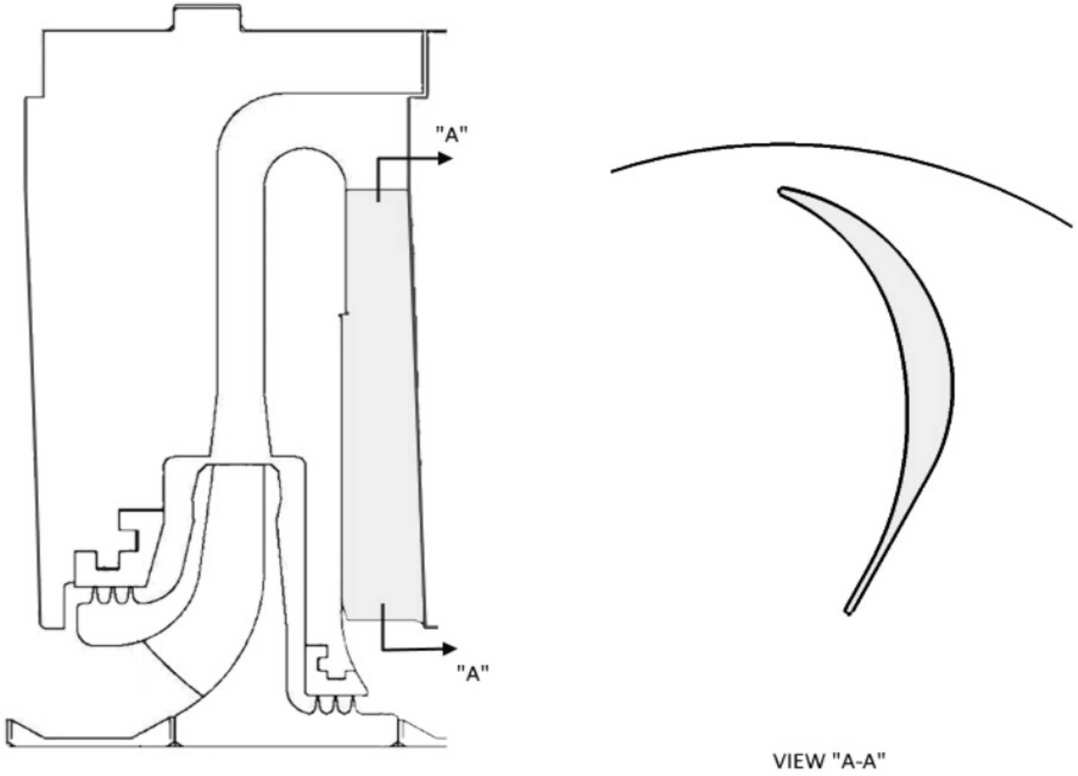
- The return channel vane design was based on:
  1. Checking the return channel vane incidence angle resulting from the predicted flow angle exiting the upstream crossover





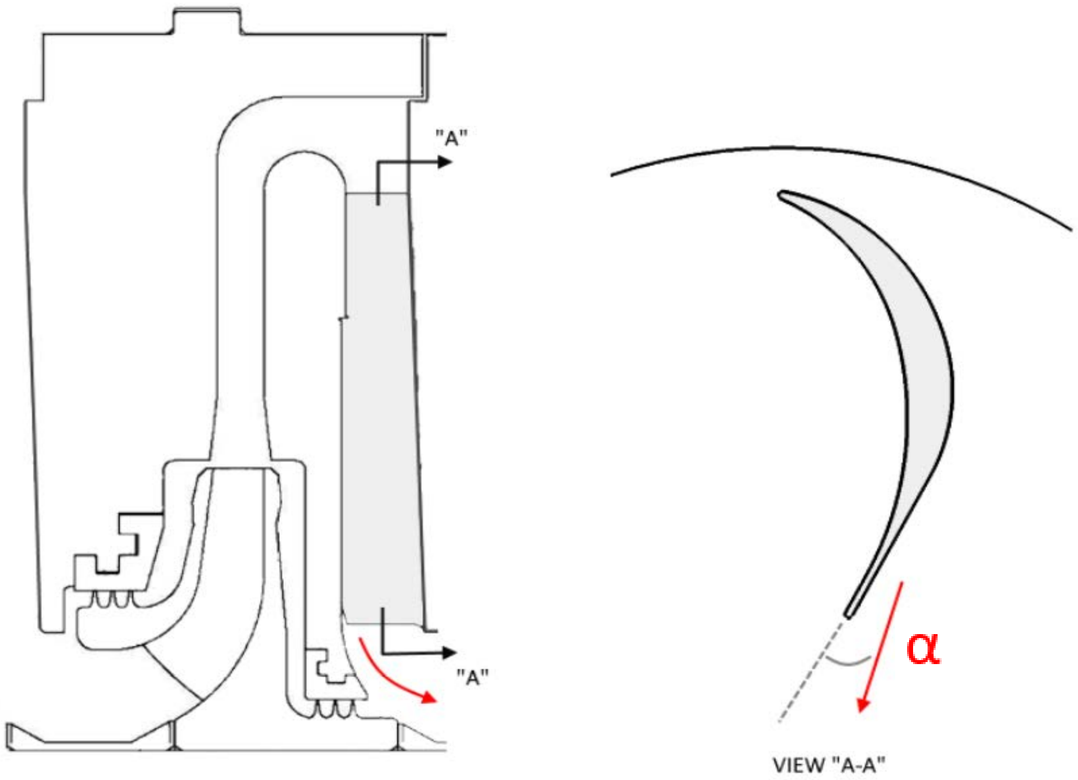
Return Channel Vane Design

- The return channel vane design was based on:
  2. Minimizing the predicted return channel loss coefficient



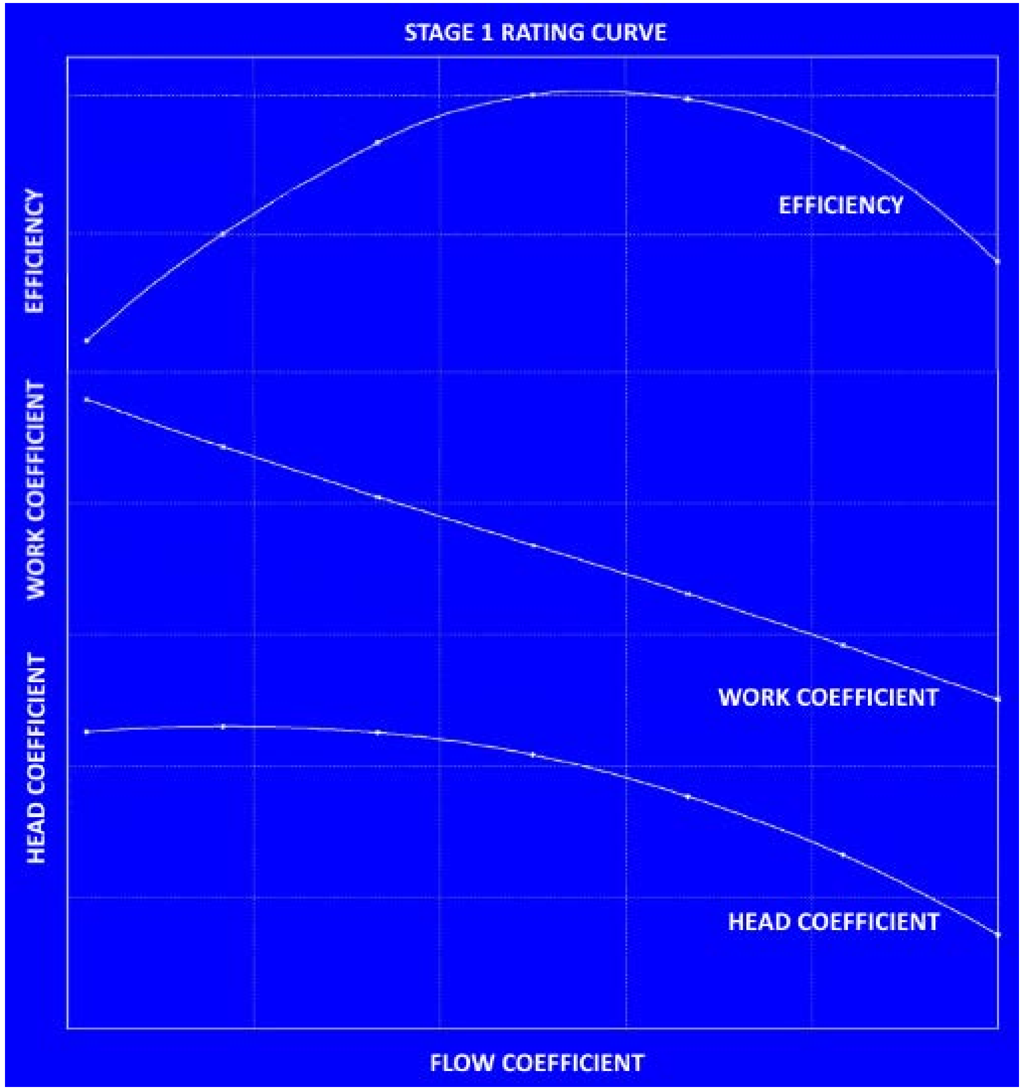
Return Channel Vane Design

- The return channel vane design was based on:
  3. Ensuring that the swirl component was sufficiently removed from the flow at the return channel exit



Aerodynamic Stage Performance Model

- The mean-streamline model was run to generate rating curves for the complete aerodynamic stage (impeller, diffuser, crossover, return channel)
- The process was repeated for each aerodynamic stage



Compressor Performance Model

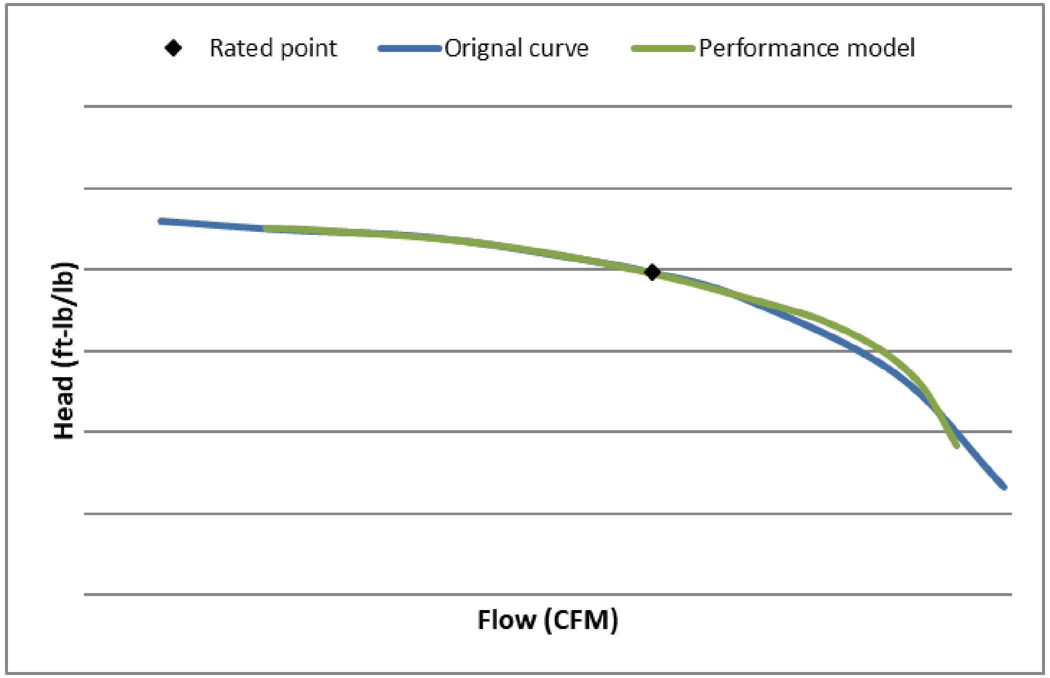
- The individual stage curves were loaded into an in-house compressor performance program to determine the overall flange-to-flange performance
- The model was run using original design conditions and compared against the original performance curves to validate the model
- Very iterative process as the mean-streamline models and in-house model were adjusted based on inspection data and assumptions to achieve a better performance match

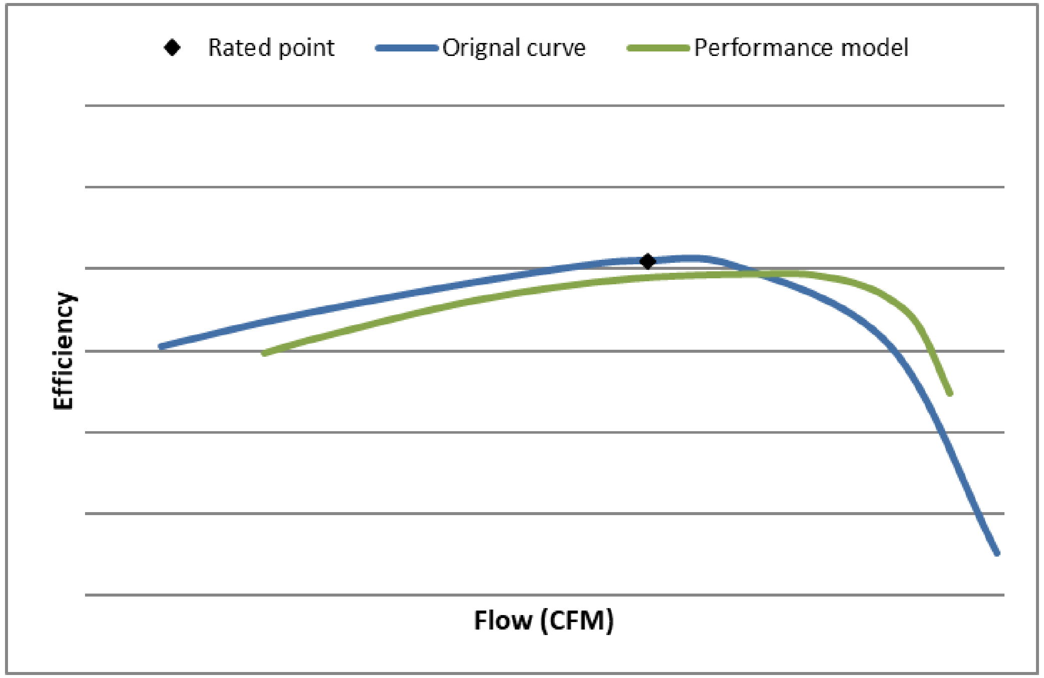
Compressor Performance Model

- Parameters that were adjusted included:
  - Surge and choke limits of the stage rating curves
  - Assumed speed margin for fixed speed application
  - Inlet loss coefficient
  - Balance piston seal and buffer leakage
  - Impeller construction flow area blockage
  - Swirl parameter

Compressor Performance Model

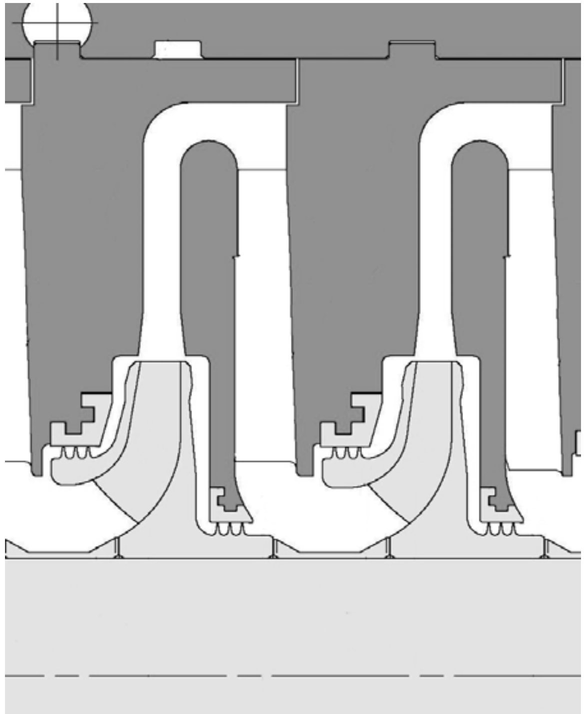
- Predicted head and efficiency was within 1.5% of original performance at the design point

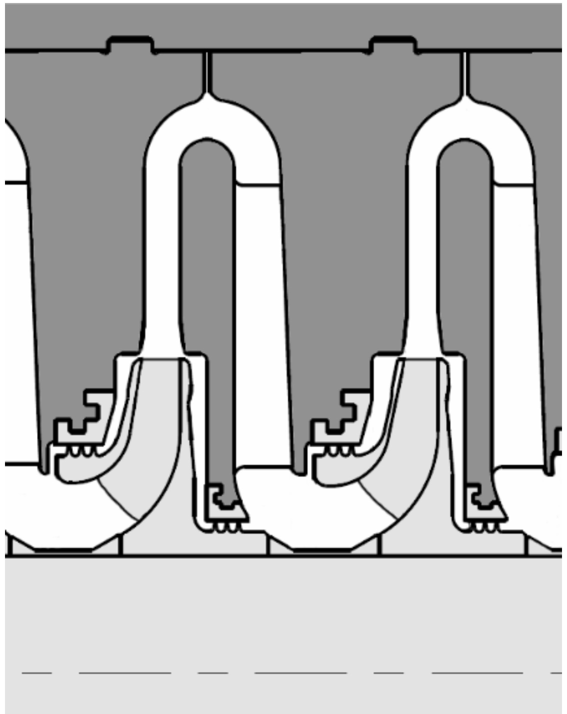




Flowpath Design Changes

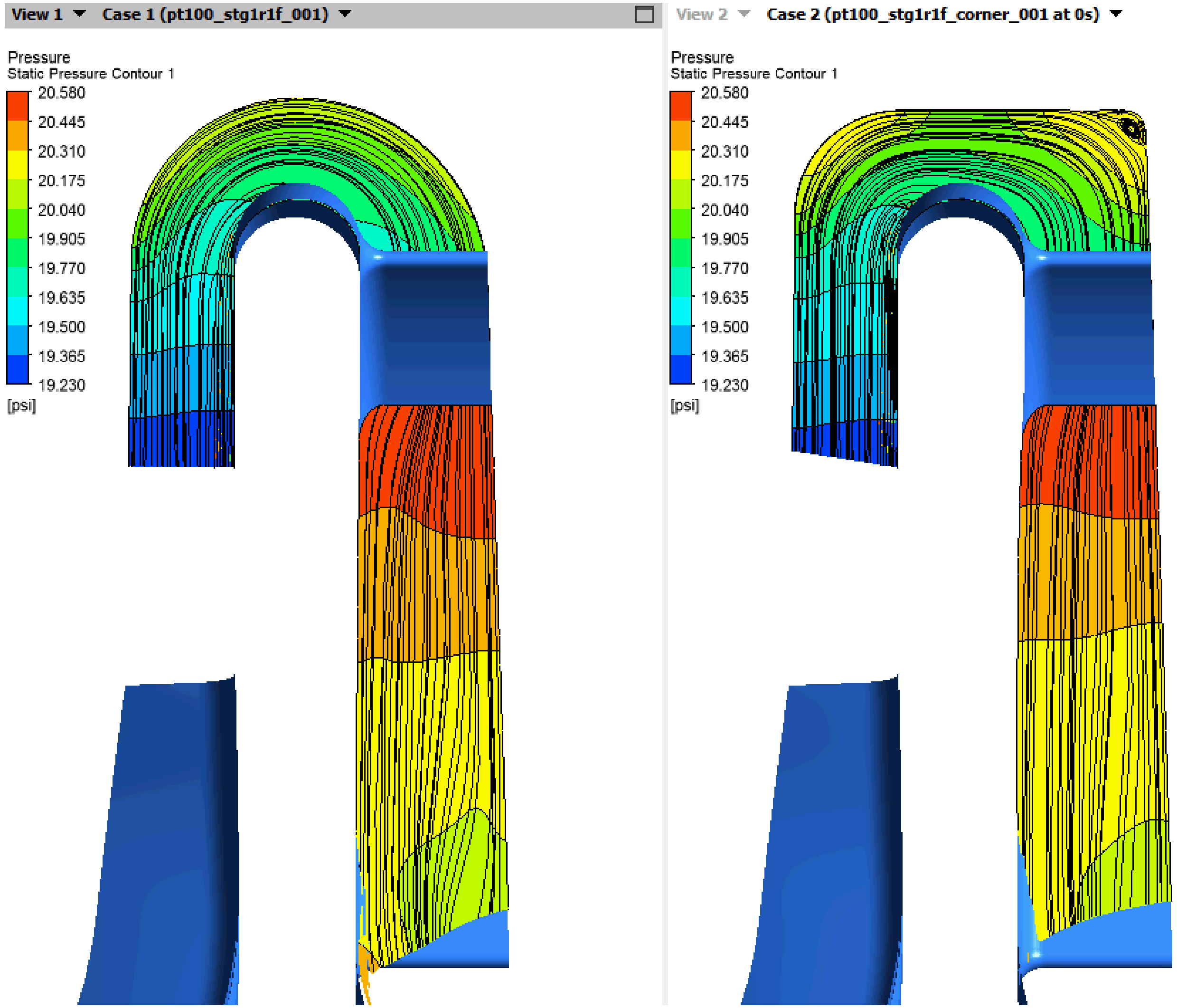
- Improved crossover design
  - Changed to an elliptical crossover design
  - Better area transition through the crossover





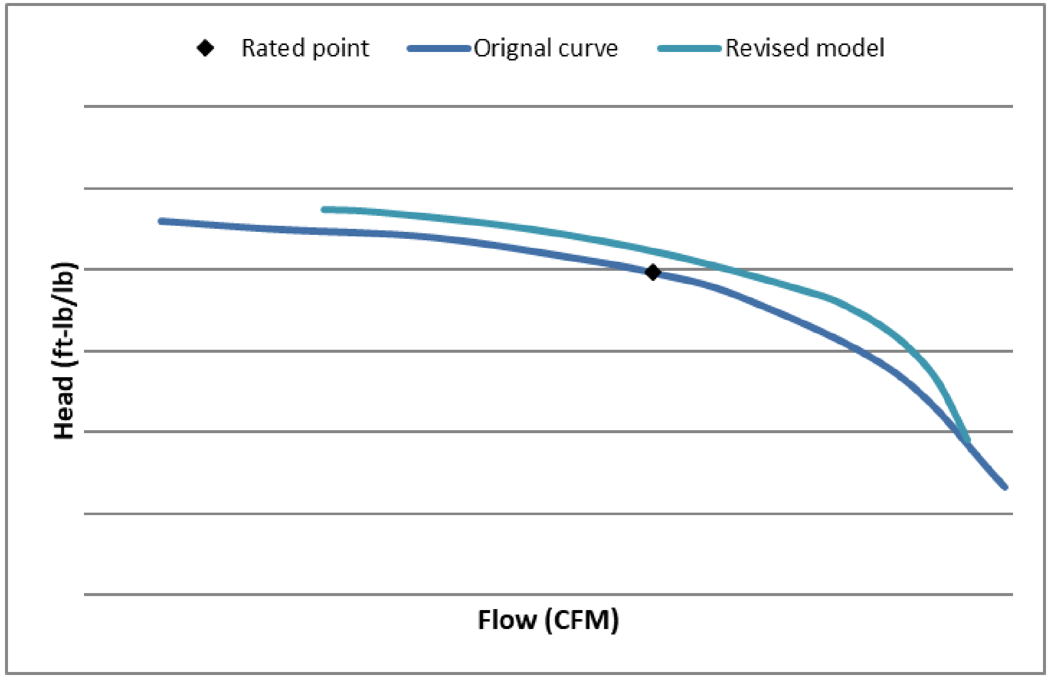
Flowpath Design Changes

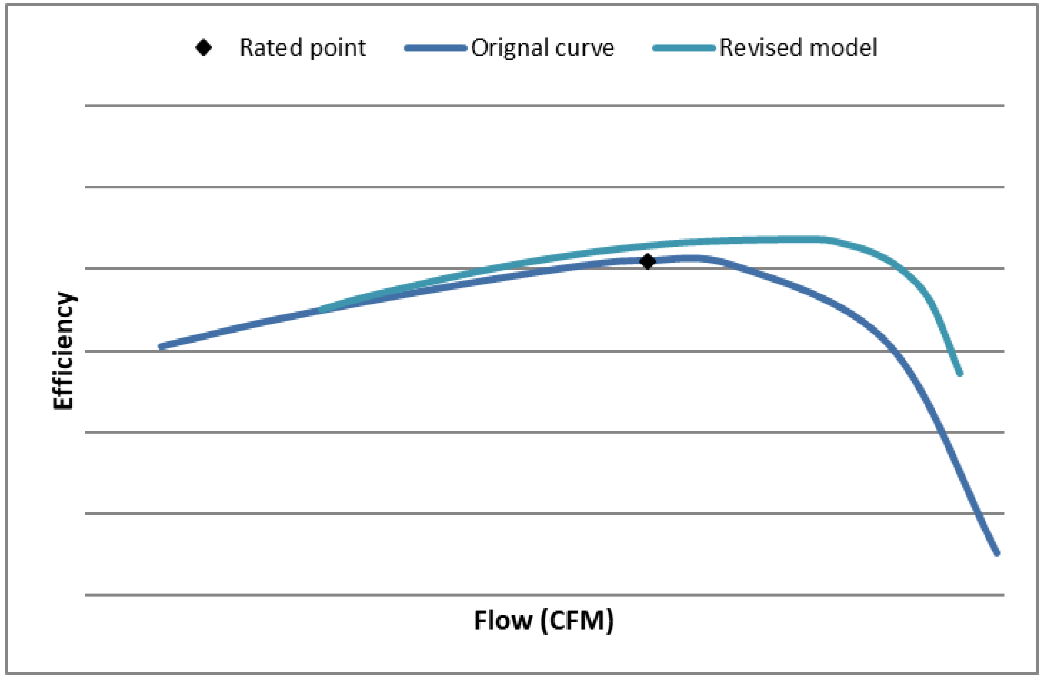
- Eliminated the corner which created an area of recirculating flow



Flowpath Design Changes

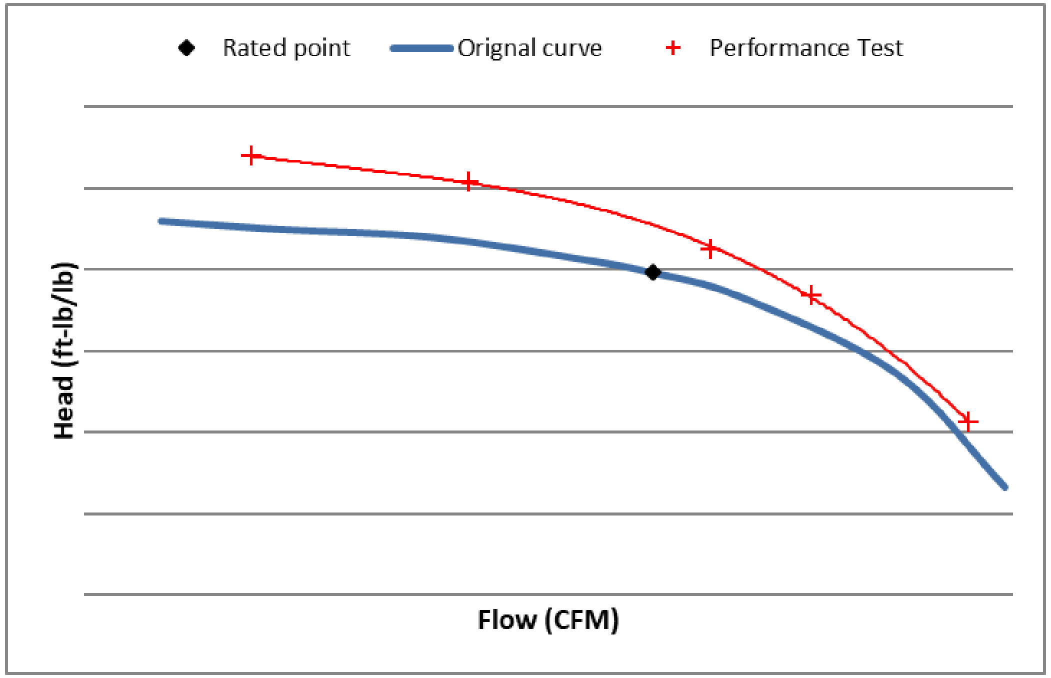
- Implementing the changes predicted a 2.5% increase in head and 3.8% increase in efficiency at the design point

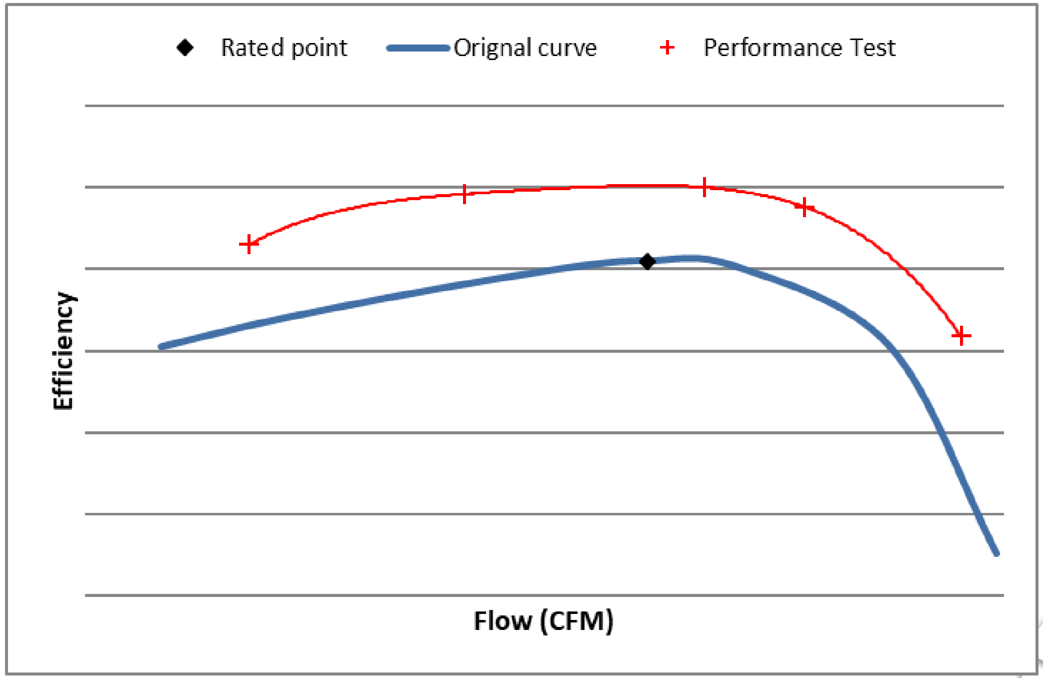




Results and Testing

- Factory performance tested per ASME PTC 10
- Exceeded the original predicted head and efficiency at the design point by 8.4% and 7%, respectively





Installation

- Connections and support locations carefully matched
  - Process piping
  - Foot elevations on upgraded sole plates
  - Coupling and shaft spacing (DBSE)
  - Lube oil connections
  - Seal gas connections
  - Case drain piping required only minimal modifications
- Existing coupling guard modified to accommodate new case fit
- No interferences with foundations or other permanent fixtures during installation due to careful upfront design considerations

Commissioning and Start-up

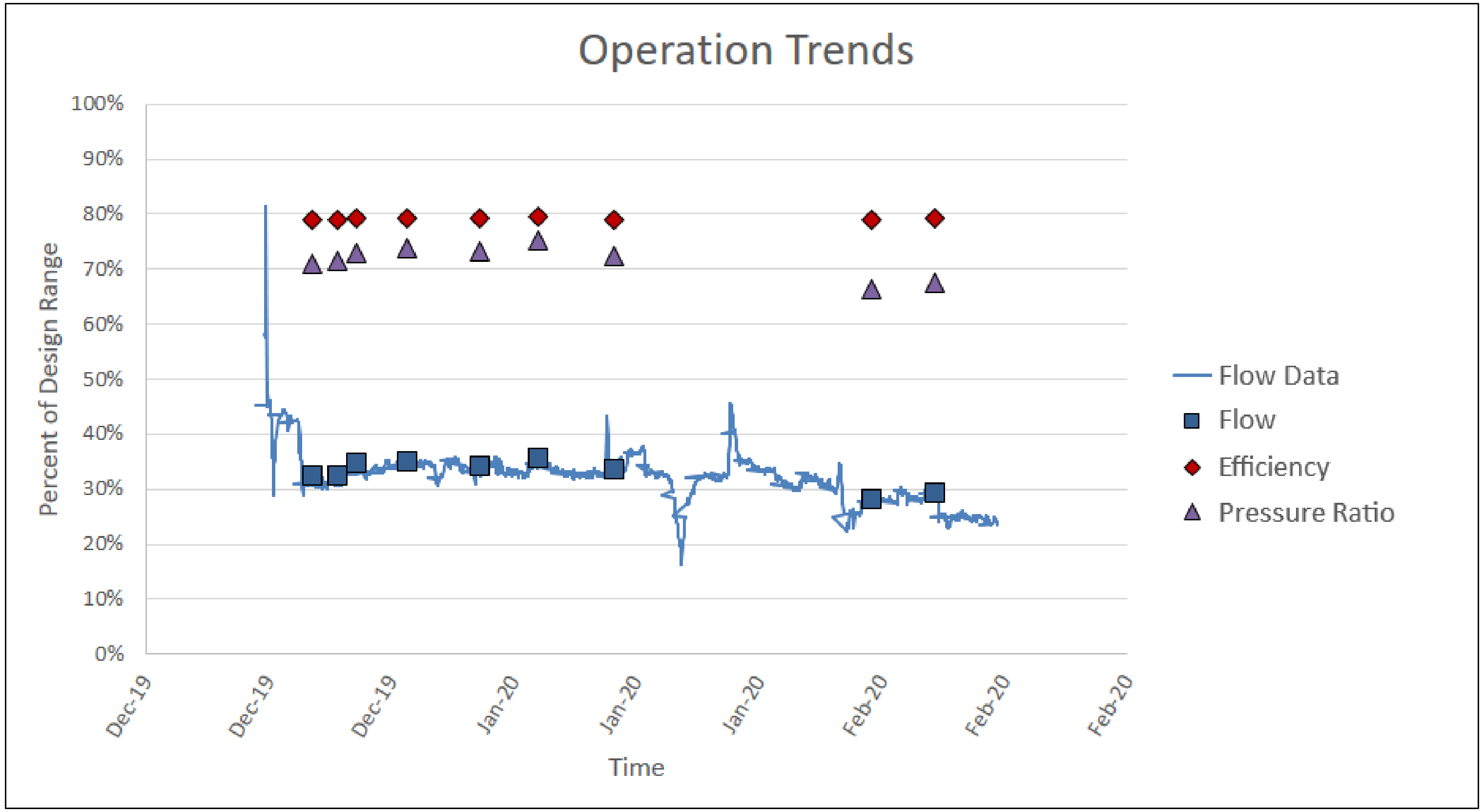
- No leaks observed during startup on the casing
- Compressor went through 4 startup iterations due to other plant issues without any deviations to expected operation

Machinery Health and Monitoring

- Radial vibration stable ranging between 0.3-0.5 mils
- Axial rotor position stable and moved approximately 8 mils from start up to current running position
- Radial bearing temperatures steady in the mid 150 degrees Fahrenheit
- Active thrust bearing temperatures steady and running in the upper 160 degrees Fahrenheit

Current Operating Performance

- Compressor has maintained stable operation since startup



Lessons Learned

- Upfront communication and scope definition are highly important
- Arriving at the final model required extensive engineering judgement backed by numerous analytical iterations
- Tested performance was higher than the original and higher than predicted. Possible reasons are as follows:
  - Losses were over-predicted trying to match the original performance
  - Did not account for potential performance improvements caused by better matched return channel vanes, improved surface finish, improved manufacturing methods and tolerances
- Difficult to accurately predict surge flow from compressor geometry
  - Illustrated by the discrepancy in the surge flow of original curve, modeled performance, and tested performance