Inlet Guide Vane Monitoring System for Centrifugal Compressors

Engineering Design Day

Travis Carter

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Arnold Schaefer

Team 4: Visual Monitoring System for Danfoss Turbocor Compressor IGVs

Introduction to the Team

Team 4 – Danfoss Turbocor Inlet Guide Vane Monitoring System

Travis Carter
Product Engineer

Peter House
Mechanical
Design Engineer

Brandon Klenck
Controls Engineer

Arnold Schaefer
Team Leader

Danfoss Turbocor Funded Project

This engineering project titled “Inlet Guide Vane Monitoring System for Centrifugal Compressors” was funded by Danfoss Turbocor.

Project Objective

The objective of this engineering project is to provide a failure monitoring system to help Danfoss understand inlet guide vane problems in centrifugal compressors.

Presentation Overview

Section 1: Background Information and Project Introduction

Section 2: Concept Generation and Selection

Section 3: Detailed Design and Final Product

Section 4: Prototypes, Testing, and Results

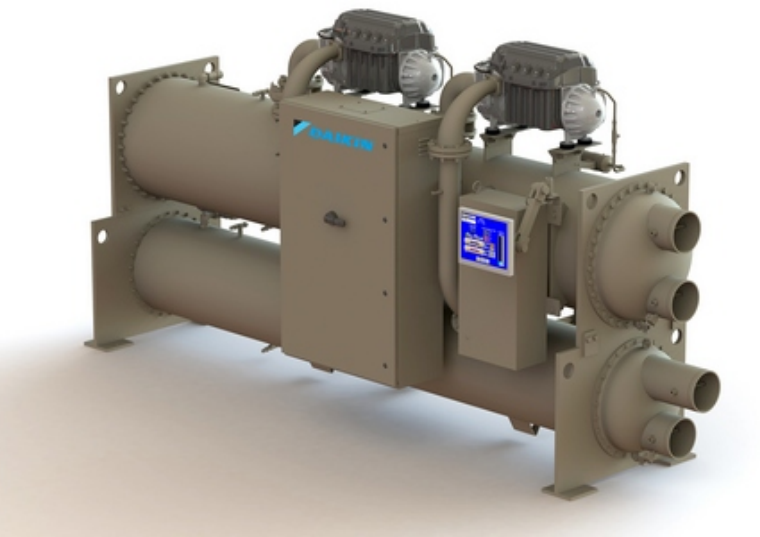
Section 5: Summary and Future Work

Background Information and Project Introduction

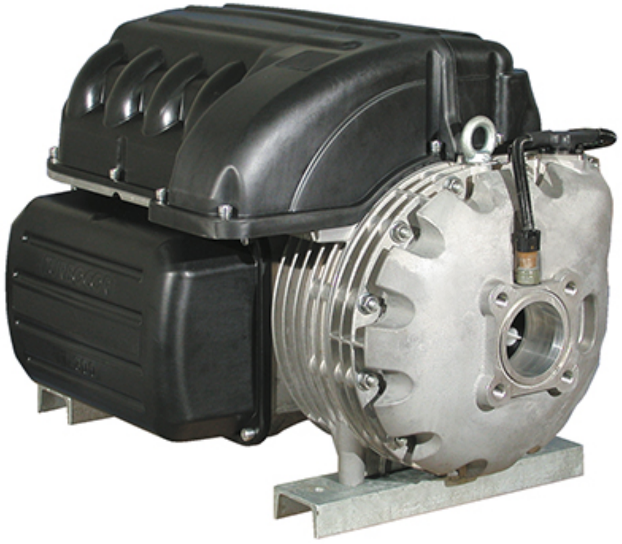
Presented by **Travis Carter**

Danfoss Turbocor Compressors

Dual centrifugal compressor application in a Daikin Applied chiller



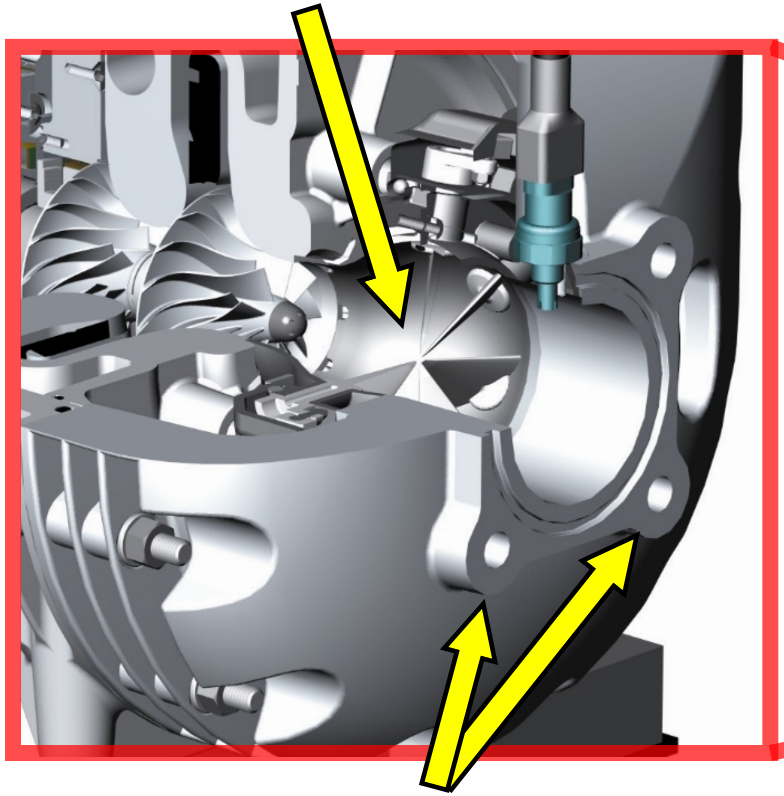
- Centrifugal compressors
  - R134a refrigerant
  - Magnetic bearing, oil-free
  - Inlet guide vanes (IGVs)
- Applied in chillers
  - Water cooled and air cooled
  - 60 - 200 tons
  - HVAC applications
  - Comfort cooling for buildings



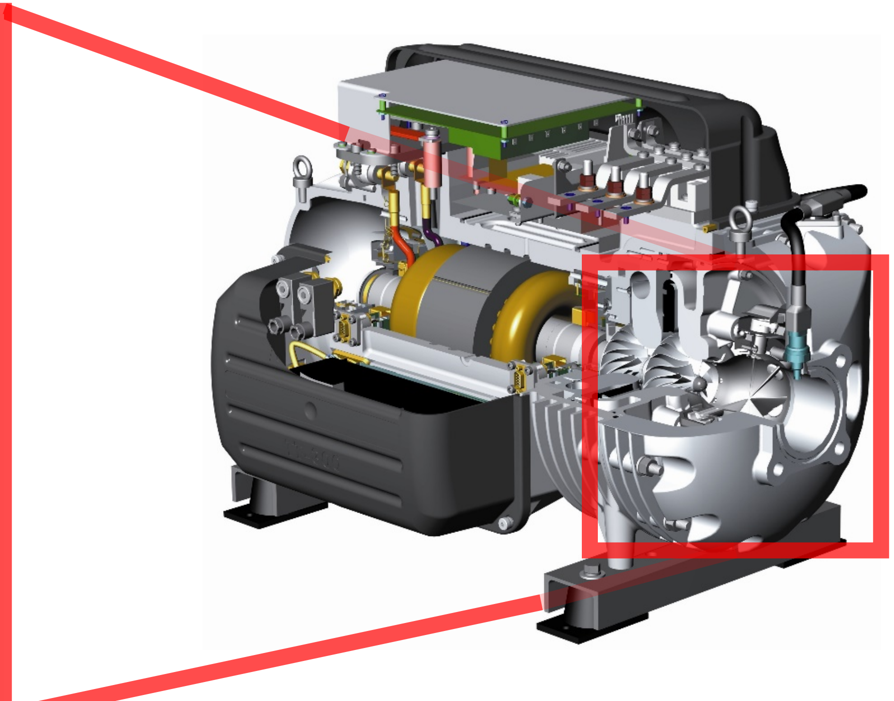
Danfoss Turbocor oil-free centrifugal compressor

Danfoss Turbocor Compressor

Inlet guide vanes (IGVs)



Inlet flange attachment for pipe
and monitoring system for testing

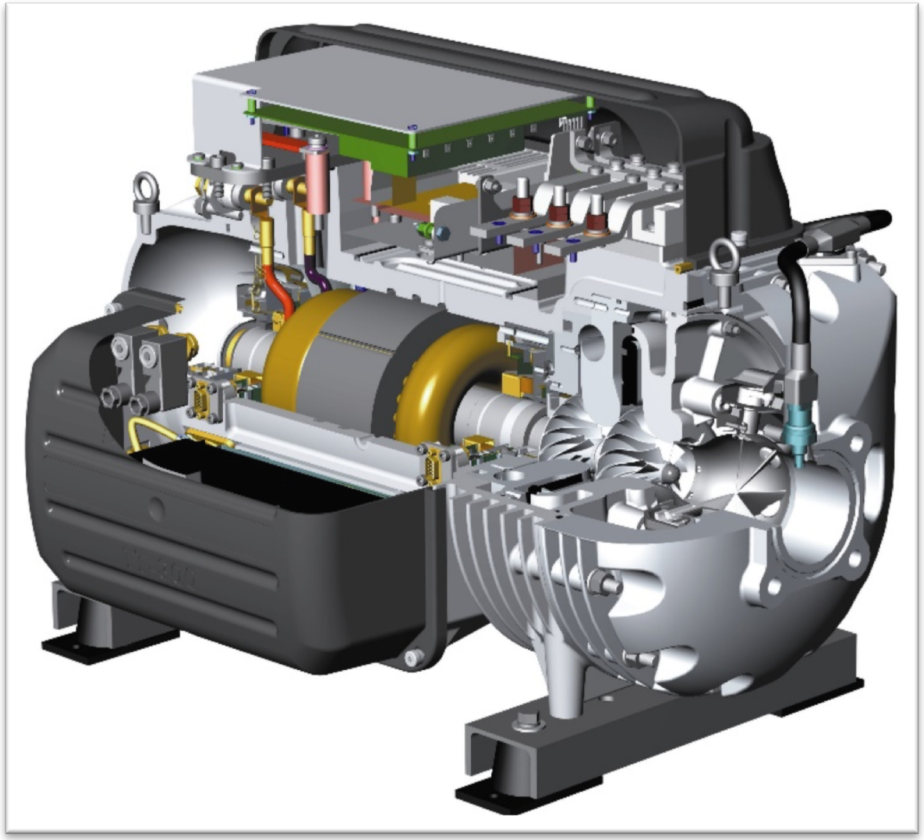


Inside cutout of compressor

Inlet guide vanes
enlarged view

Problems with Inlet Guide Vanes (IGVs)

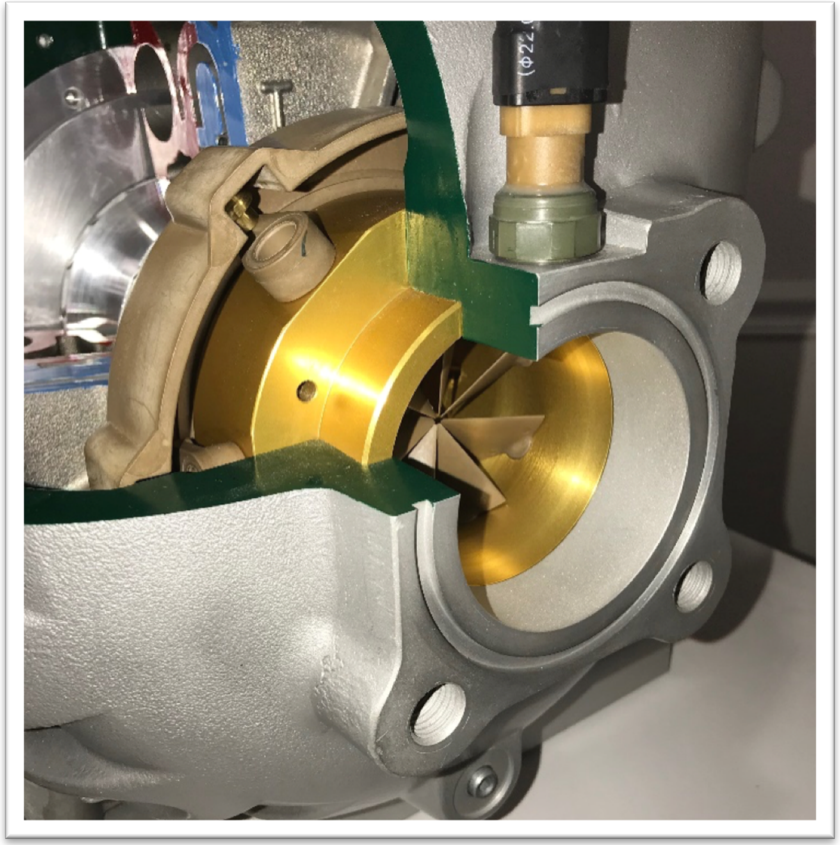
- IGV malfunction is a well known problem for field technicians
- Caused major data loss in test lab
- Currently no visual for IGVs
- Limited angle measurement
  - Stepper motor is used for angle control
  - No reliable feedback
- IGVs may flutter or vibrate
  - May be cause of IGV malfunction
- Single IGV latching or “sticking”



Inside cutout of Danfoss Turbocor compressor

Project Goals

1. Provide visual monitoring of inlet guide vanes (IGVs)
2. Detect angle position of individual IGVs
3. Minimize impact on the fluid flow



Compressor inlet cross-section with IGV detail

Concept Generation and Selection

Presented by **Travis Carter**

Concept Generation for Subsystems

Visual Monitoring

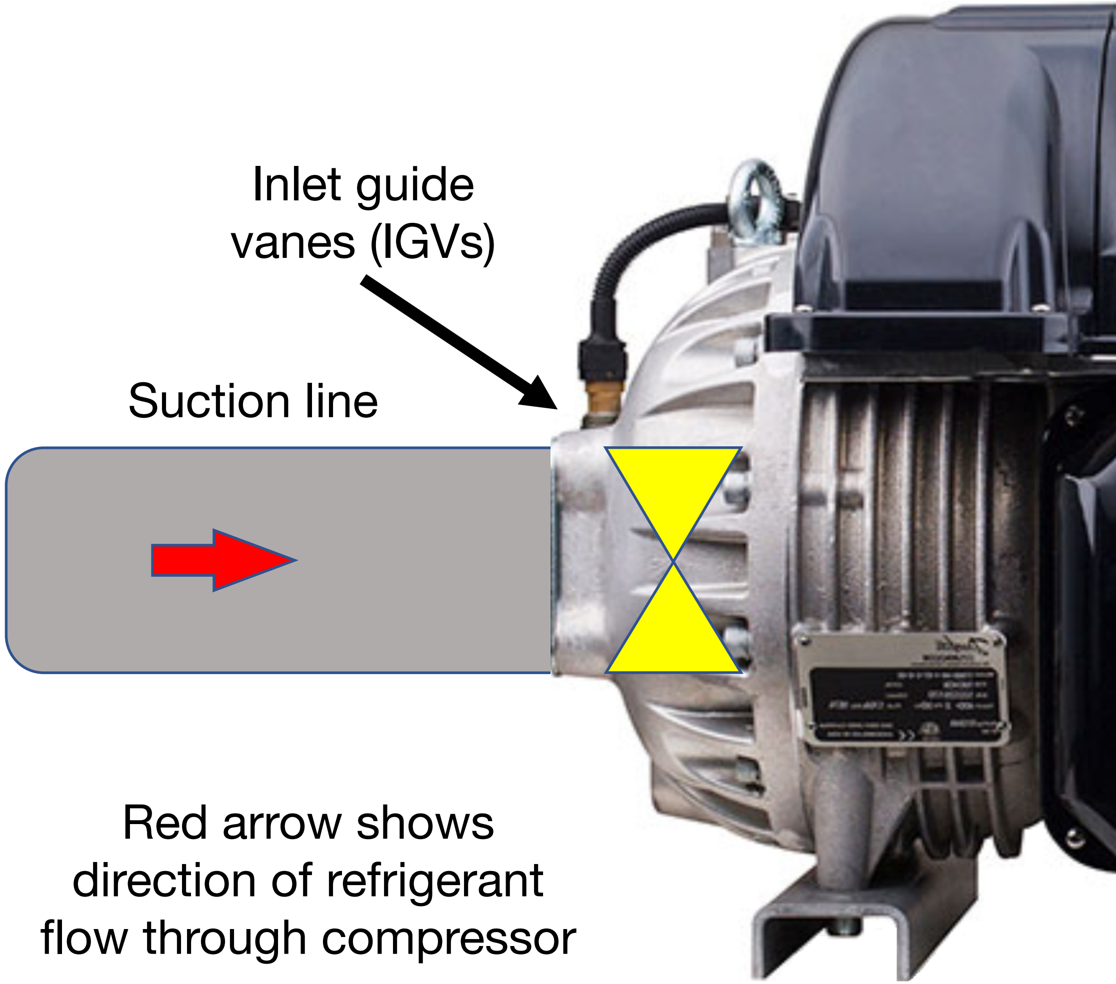
- Mirror in central body with camera outside of pipe
- Camera in elbow of pipe
- Composite imaging
- Camera in central body

IGV Angle Monitoring

- Potentiometer on string
- Laser vibrometer
- AprilTags with aspect ratio visual analysis

IGV Lighting

- Clear pipe with ambient lighting
- Central body lighting
- Lighting around inside of pipe



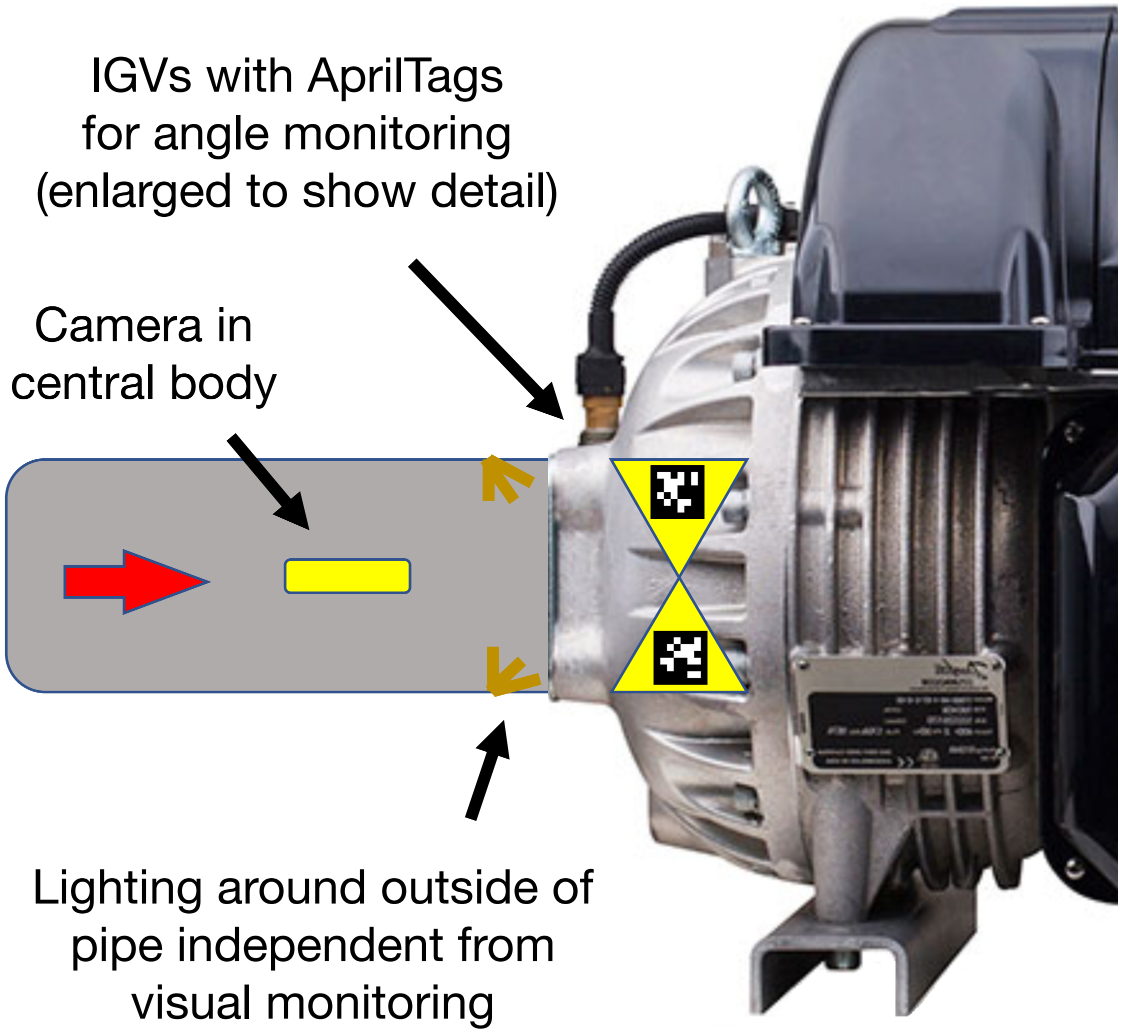
Decision Matrix for Monitoring Subsystem

- Weight factors determined by HOQ
- Similar decision matrix for each subsystem

		Camera in Elbow		Camera & Central Body Mirror		Camera in Central Body		Composite Imaging	
Option	**Weight Factor**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**	**Score**	**Rating**
Image Clarity	13	8	107	6	80	7	94	8	107
Camera Frame Rate	6	8	46	8	46	7	40	8	46
System Stability	26	8	211	5	132	6	158	8	211
System Length	11	2	22	8	89	8	89	6	67
Ease of Integration	6	3	19	8	51	7	45	5	32
Pressure Drop across System	7	8	52	7	46	7	46	9	59
Pipe Illumination	13	4	54	3	40	7	94	3	40
			511		**484**		**565**		**561**

Concept Selection

1. Camera in central body for visual monitoring
2. AprilTags with aspect ratio visual analysis for IGV angle monitoring
    - AprilTags are QR Codes
    - Camera reads the aspect ratio of the tags
3. Lighting around inside of pipe for IGV lighting

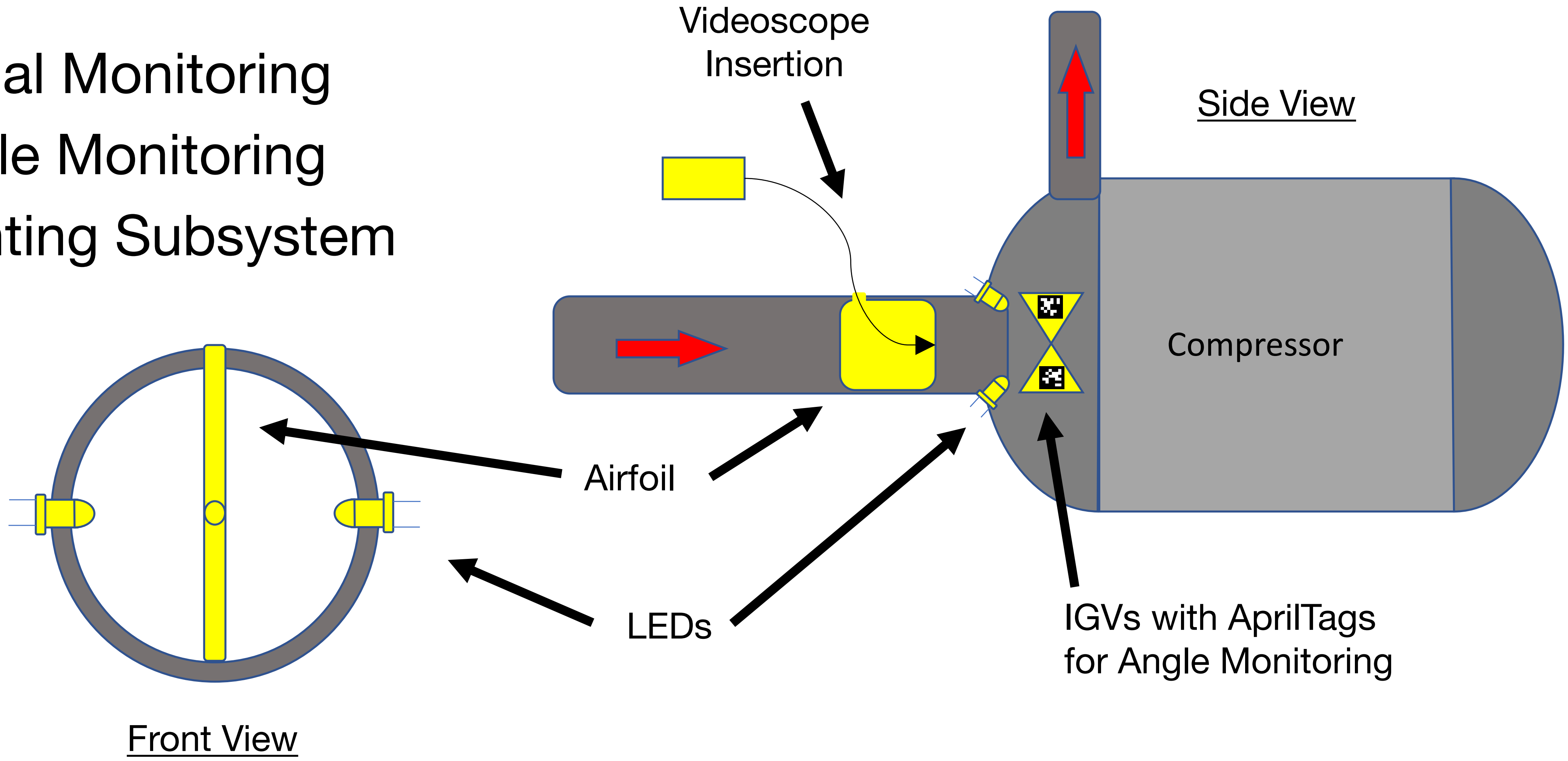


Detailed Design and Final Product

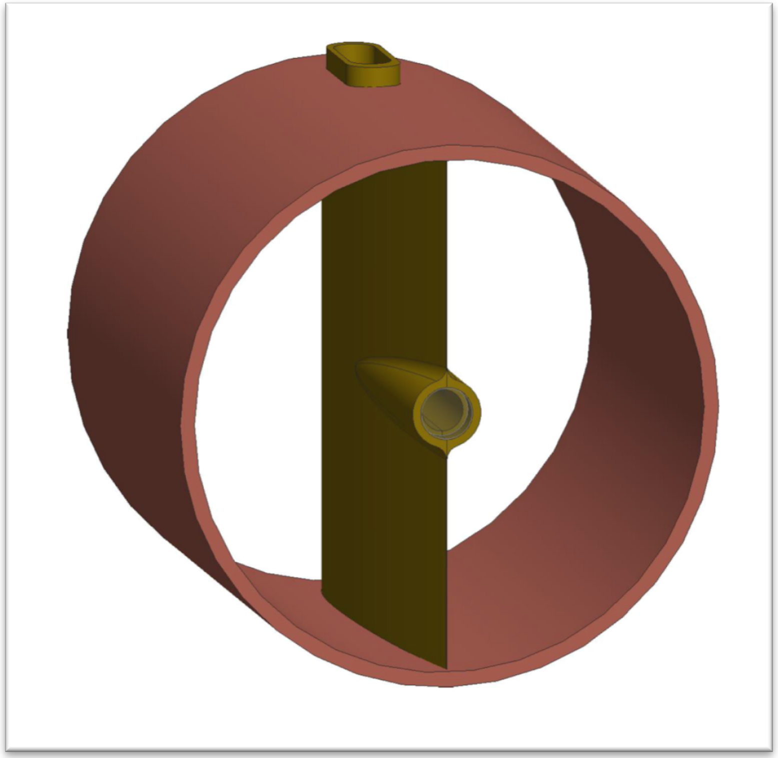
Presented by **Brandon Klenck**

Final Design Layout

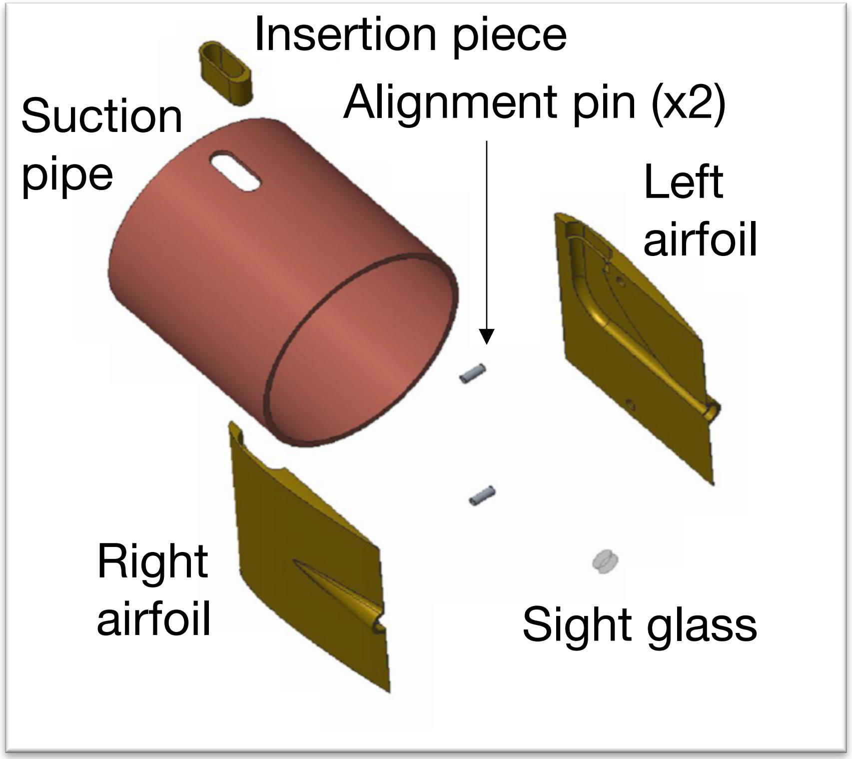
1. Visual Monitoring
2. Angle Monitoring
3. Lighting Subsystem



Final Design Assembly and Parts



Finished assembly view

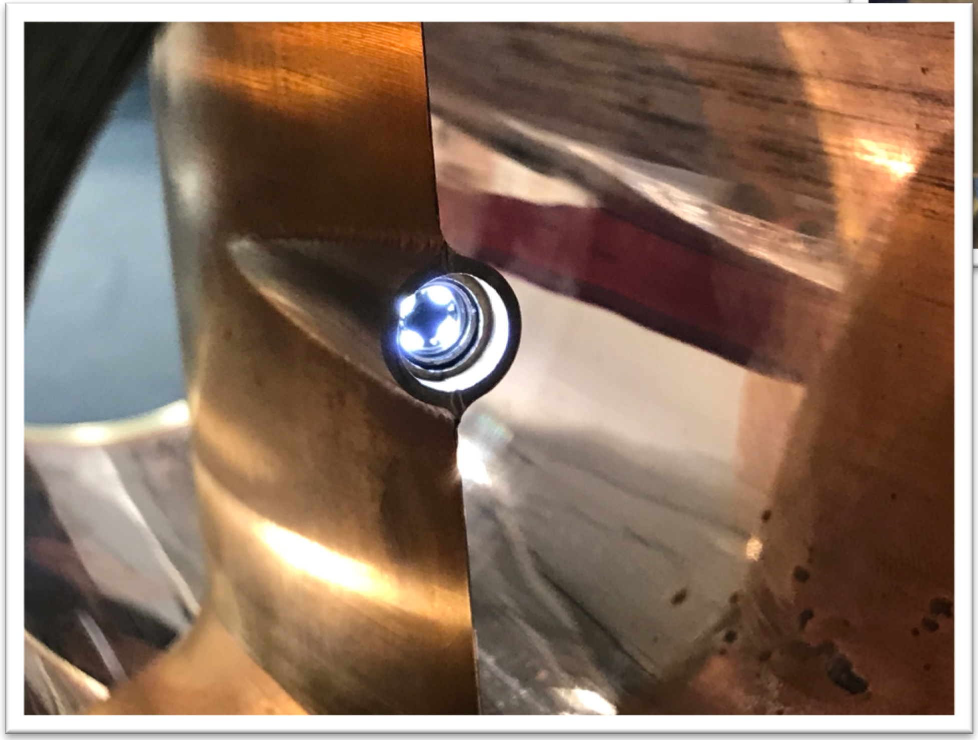


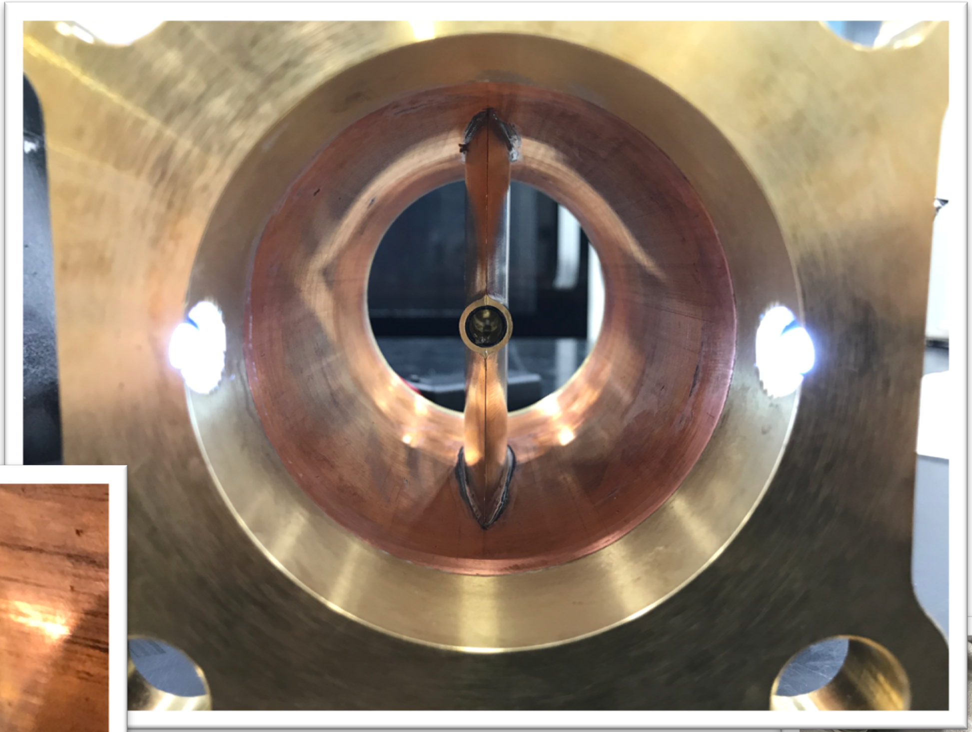
Exploded assembly view

*Lighting subsystem not included here

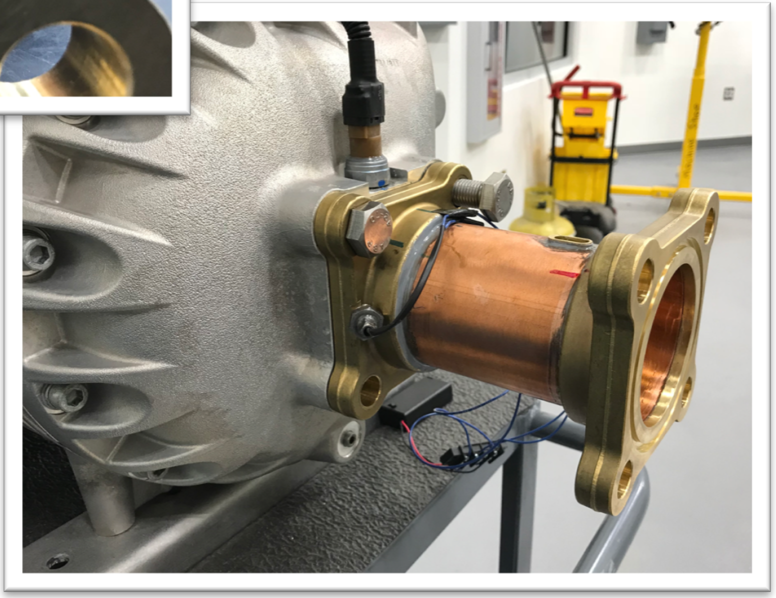
Final Product

Monitoring system with camera housed in central body of suction pipe



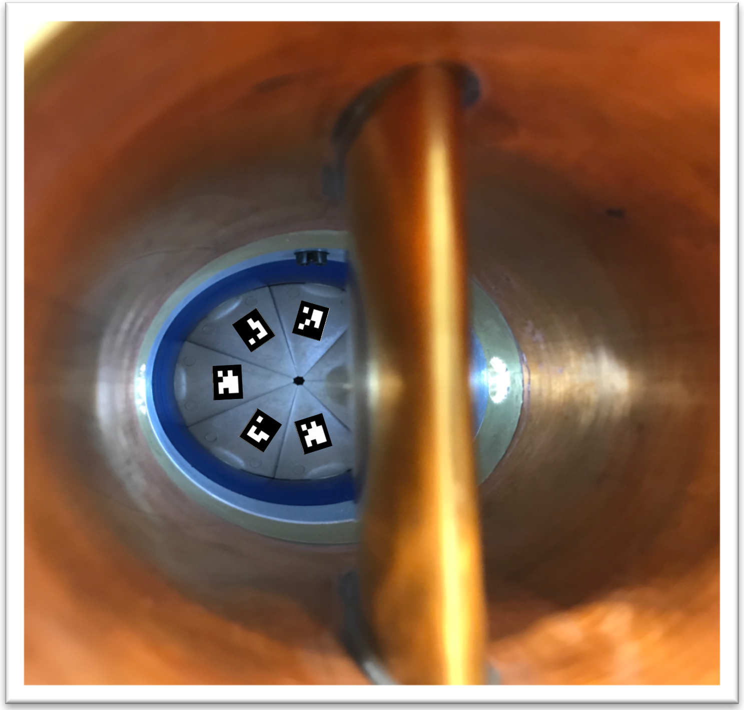


Front view of monitoring system



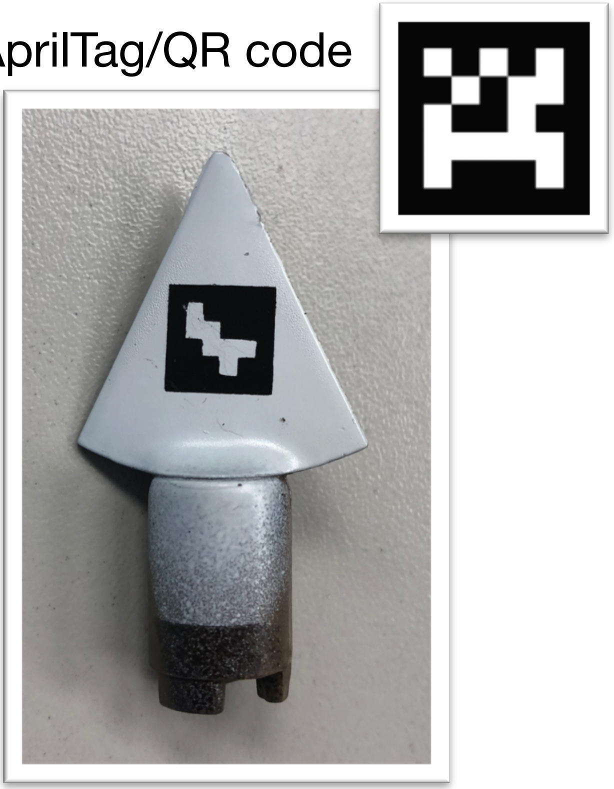
Outer view of monitoring system

AprilTag or QR Code for Angle Monitoring



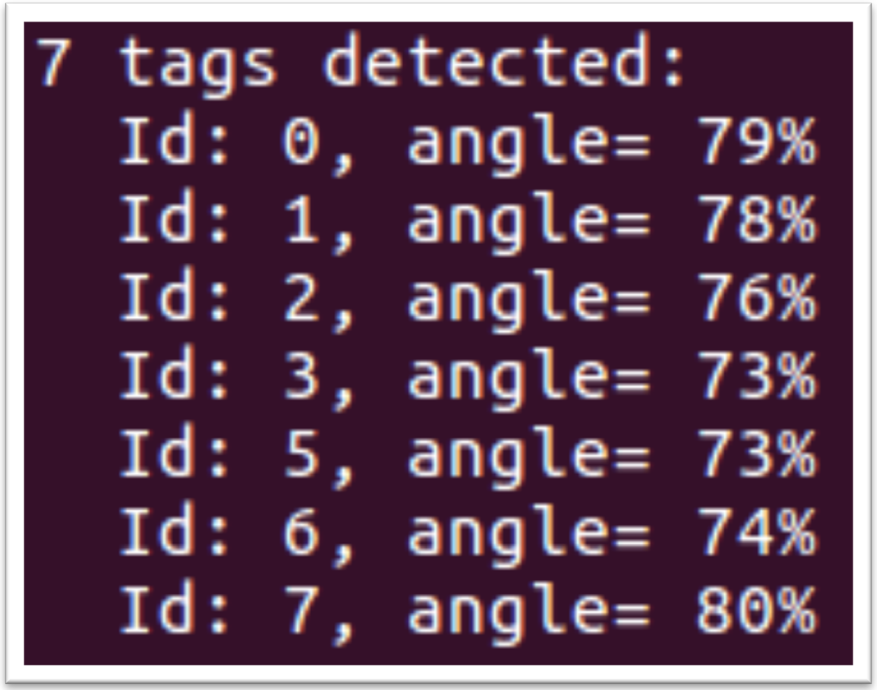
IGVs with AprilTags spray painted on

AprilTag/QR code



Single IGV with AprilTag

Software output of IGV angles

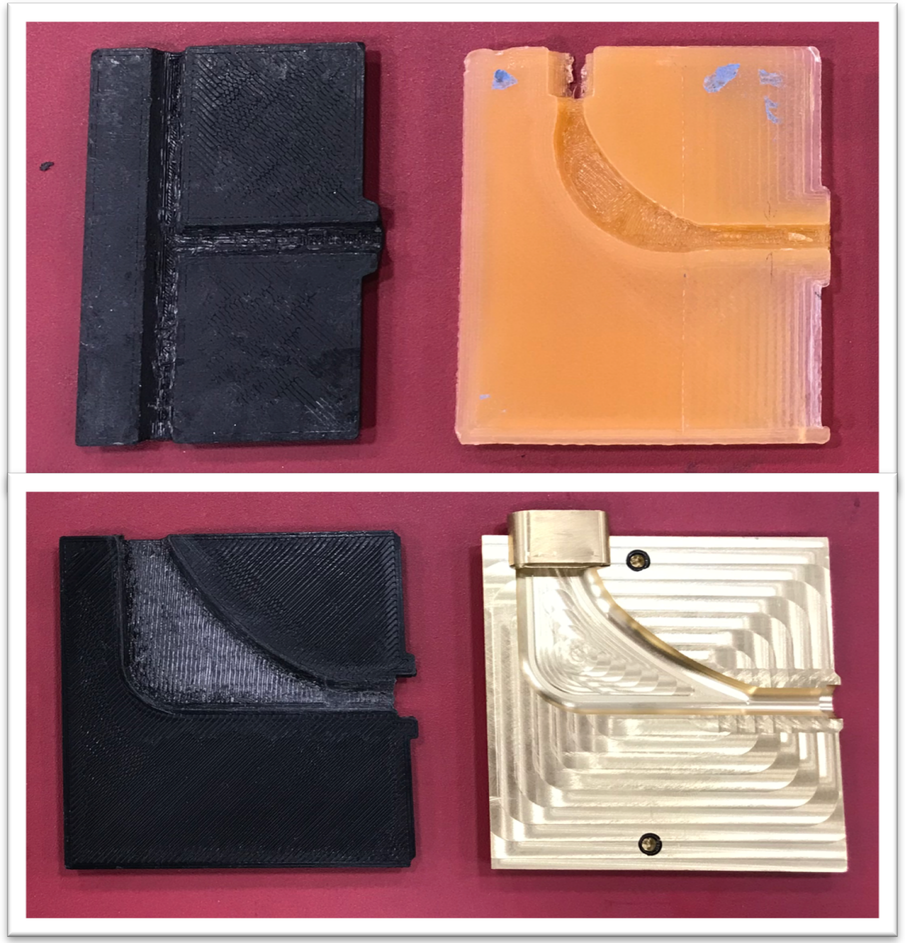


Prototypes, Testing, and Results

Presented by **Peter House**

Airfoil Prototypes

- 3D Models were cheaper in material and time than brass
- Learned from each prototype
  - The curvature of the channel
  - How to make the alignment pins
  - Tolerances for the different cuts
- Provided communication of ideas to sponsor
- Final prototype fit camera and sight glass

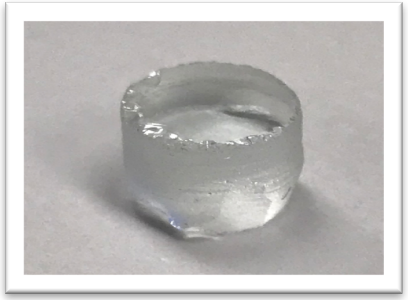


3D modeling prototypes with final brass airfoil

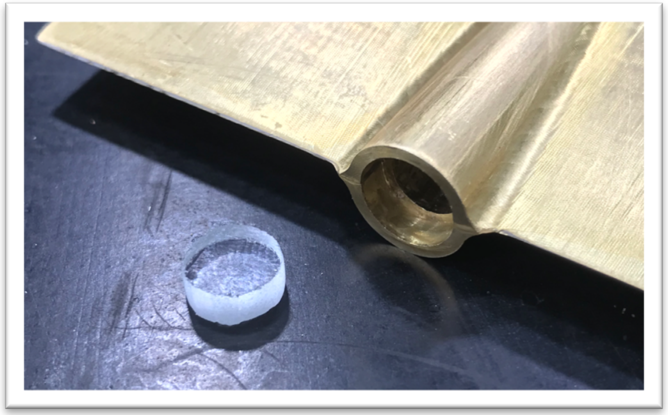
Sight Glass Testing

- Tested for overflow of epoxy into camera housing
- Tested several methods of insertion
- Hole dimensional check for engineering drawings
- Precise measurements done for optimized bond line thickness

Sight glass



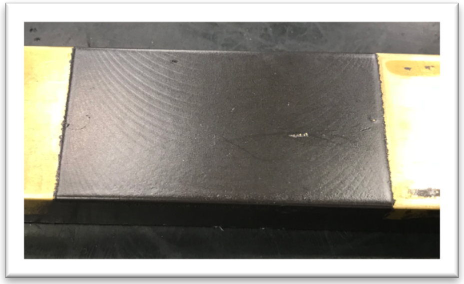
Airfoil sight glass housing



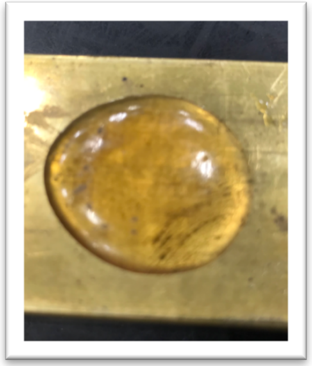
Aluminum Block Sight Glass Insertion Testing Apparatus

Epoxy and Spray Paint R134a Compatibility

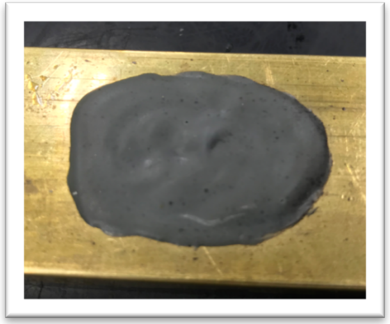
- Visually tested for possible chemical reaction to refrigerant
- Epoxies exposed to R134a for one week
- Spray paint passed test
- Clear epoxy failed, showing discoloration
- Gray epoxy passed test



Spray paint ✓



Clear epoxy ✗



Gray epoxy ✓

Pressure and Leakage Test

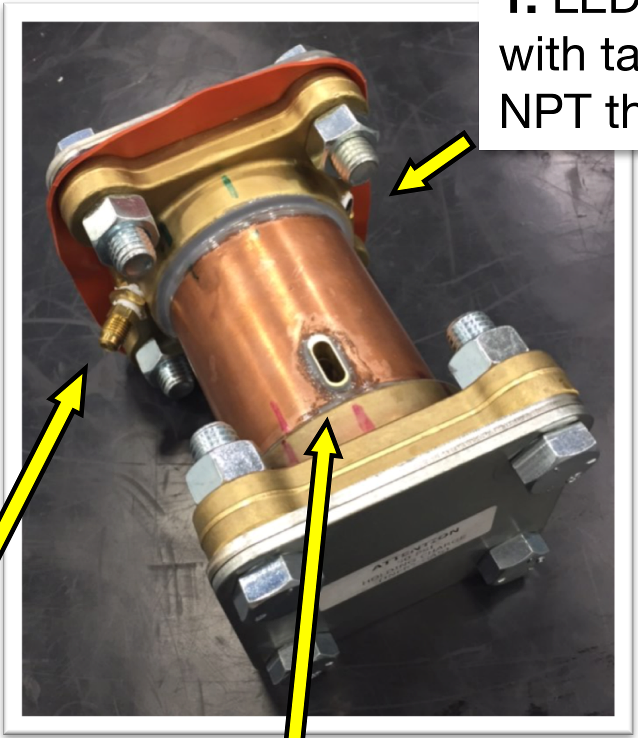
Pressure Test

- Pressure burst test with water for 12 minutes
- Tested up to 375 PSI with no failure

Leakage Test

- System passed leakage test
- Tested with Helium in a vacuum
- Three main areas for potential leakage

View of sight glass inside pipe as possible leakage area



1. LED lights with tapered NPT threads

Schrader valve for Helium insertion in place of left LED

2. Seal on edges around insertion piece
3. Seal from sight glass inside pipe

Testing and Project Target Results

Tested Target	Target Value	Result
Withstand test rig pressure	300 PSI	**PASS**, Withstood up to 375 PSI
No refrigerant leakage	No Helium leak	**PASS**, No detected leakage
Chemical reaction of materials to refrigerant	No reaction	**PASS**, No reaction detected
Minimum visual monitoring rate	1 Hz minimum	**PASS**, 60 Hz
Minimum angle sensor accuracy	±10 degrees	**FAIL**, for IGV positions 0° to 29° **PASS**, ±2° for IGV positions 30° to 110°
Maximum monitoring system length	50 cm maximum	**PASS**, 20 cm

Key Engineering Principles Used in Design

- Required sight glass thickness
- Required epoxy shear strength calculations
- AprilTag inlet guide vane angle calculation
  - 3D coordinate system modification
  - Programmed in C
- Technical specification analysis for camera selection

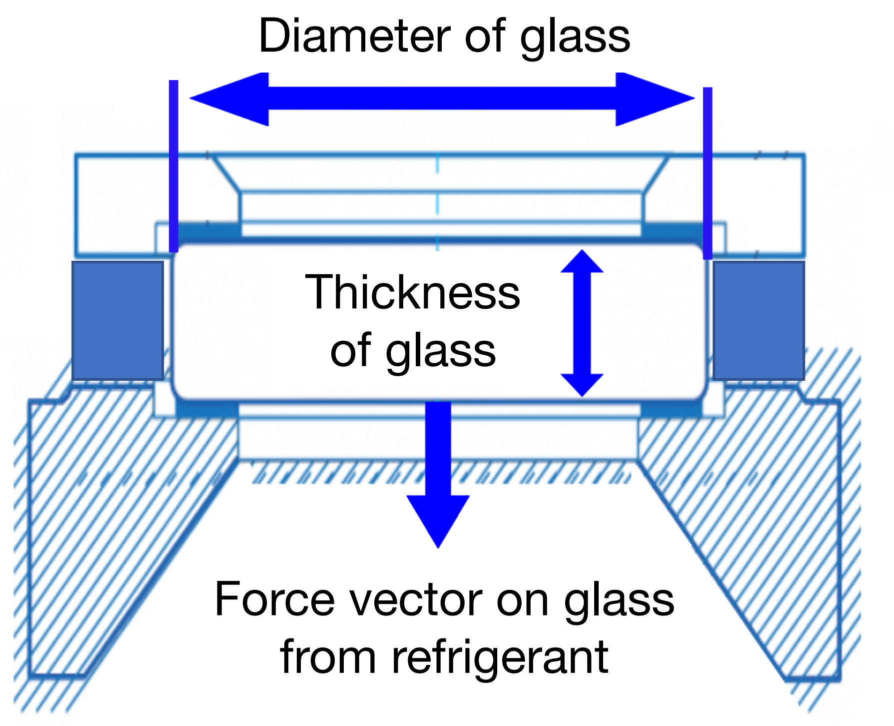
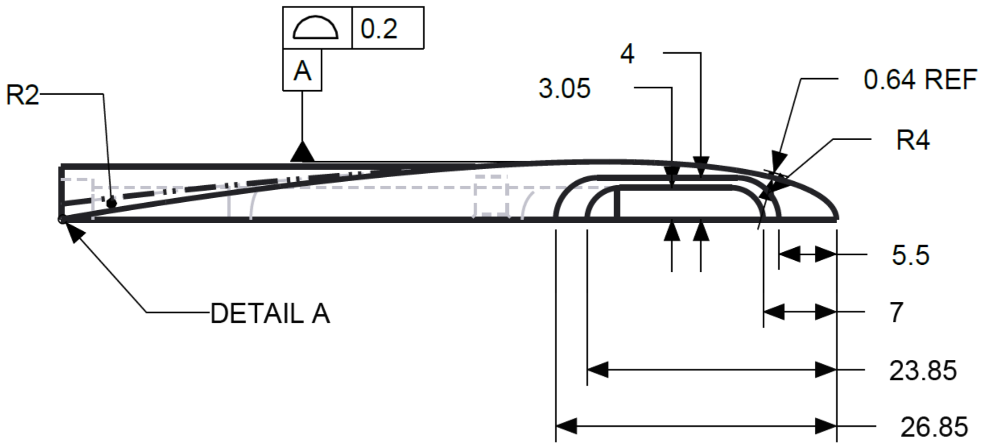


Diagram of sight glass used for epoxy strength and glass thickness calculations

Key Engineering Principles Used in Design

- NACA 15 airfoil profile implemented into Creo Parametric 3.0
- Calculated pressure drop across cross-sections using Bernoulli 's Equation
  - Airfoil reduces flow impact into compressor
  - Airfoil reduces drag of camera by factor of four

Airfoil half snapshot from engineering drawings



Taylor Series polynomial for NACA 15 profile

$$y_t = 5t\left[0.2969\sqrt{x} - 0.1260x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4\right]$$

* More Detailed Information Upon Request

Summary and Future Work

Presented by **Arnold Schaefer**

Problems Encountered and Lessons Learned

Problem Encountered	Solution	Lesson Learned
Camera reflection on sight glass	Used external LEDs for lighting	Use the critical path in you project timeline to plan around time delays
Soldering Airfoil halves together did not seal properly	Used epoxy to join the two halves	Have a backup plan for each project component
Glass drill bit shipped in the incorrect size	Had sight glasses cut with waterjet	Personal relationships with machine shop and your team are invaluable
AprilTag program not running properly	Spent countless hours troubleshooting	There will always be unforeseen problems so test often and early

Project Budget and Costs

$1,350 under budget

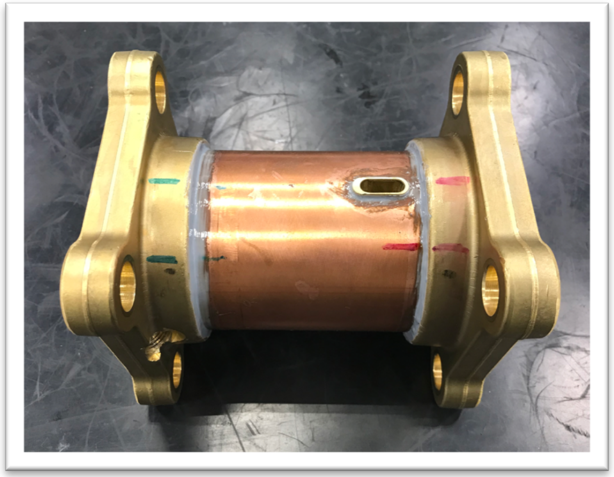
Total materials budget
- $3,000

Total material cost
- $1,650
- Main cost was the videoscope at $1,250
- Other costs:
  - Epoxies
  - Electronics
  - Plumbing hardware
- Some materials provided by Danfoss

3M high strength, refrigerant compatible epoxy

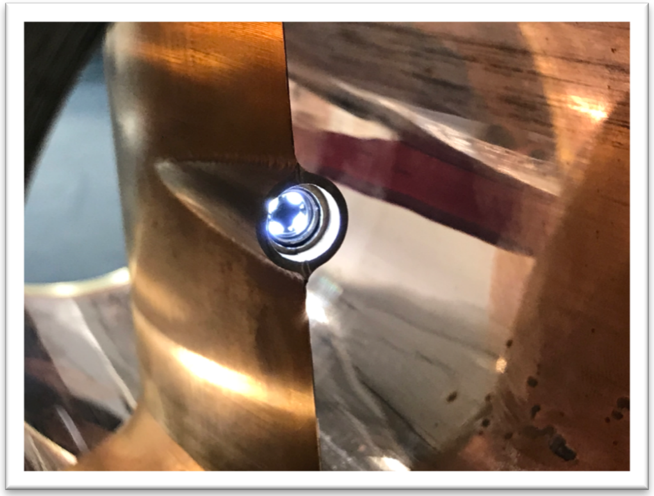
HDV540 Extech videoscope

Flanges and pipe provided by Danfoss Turbocor



Summary

Monitoring system airfoil camera position



Inlet guide vane view from camera

Final Product

- Airfoil in central body of pipe
- LED lighting
- AprilTag angle monitoring

Project Results

- Project Goals Achieved
    1. Provide visual monitoring of IGVs
    2. Detect angle of individual IGVs
    3. Minimize impact on the fluid flow

Lessons Learned

- Roadblocks are unavoidable
- Test early and often
- Communication is key

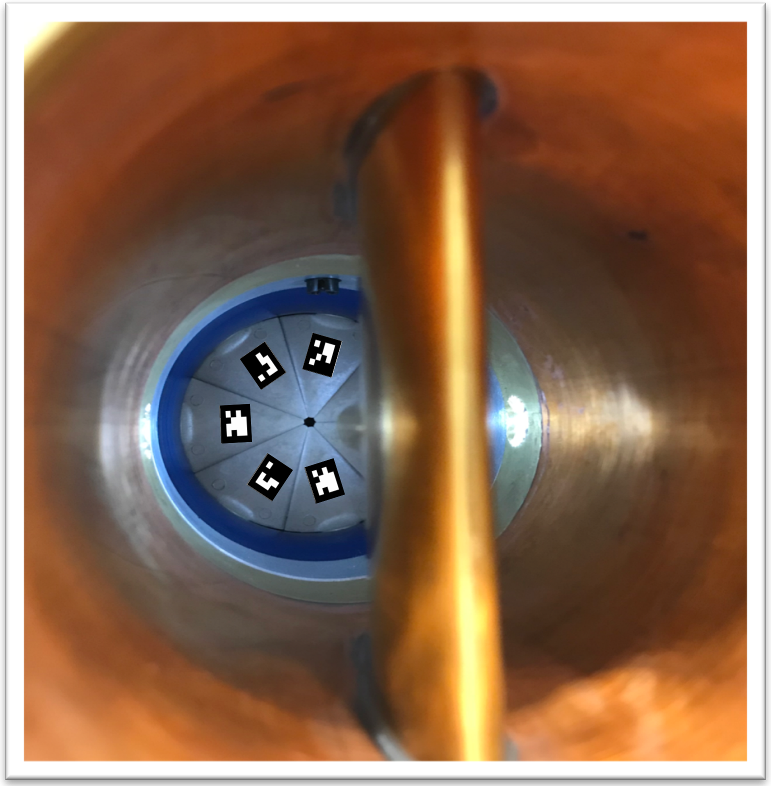
Future Work

Testing of inlet guide vanes (IGVs)

- Different material IGVs
- Determine causes of IGV failure

Improving the design

- High-cycle monitoring system
- Mechanical design to replace epoxy of sight glass
- Remove lighting around videoscope head
- Alarms for IGV malfunction



Back View of Airfoil Facing IGVs with AprilTags

Special Thanks and Acknowledgements

Danfoss Turbocor

- Mr. William Bilbow – Project Liaison
- Mr. Kevin Lohman for Machining the Airfoil

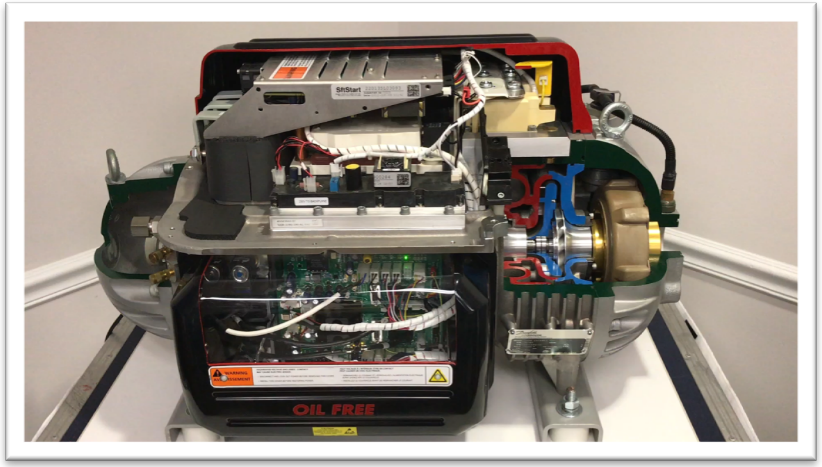
FAMU-FSU College of Engineering

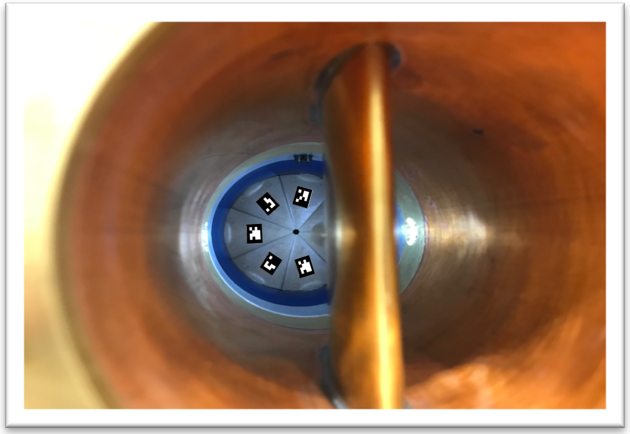
- Dr. Shayne McConomy – Class Professor
- Dr. Kunihiko Taira – Project Advisor
- Dr. Chiang Shih
- Our Class Teaching Assistant Obiechina Abakporo
- Mr. Jeremy Phillips with the Machine Shop
- Mr. Anthony Camarda with the 3D Print Club

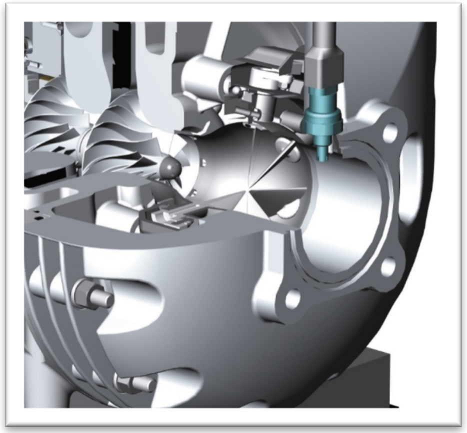
Other Contributors

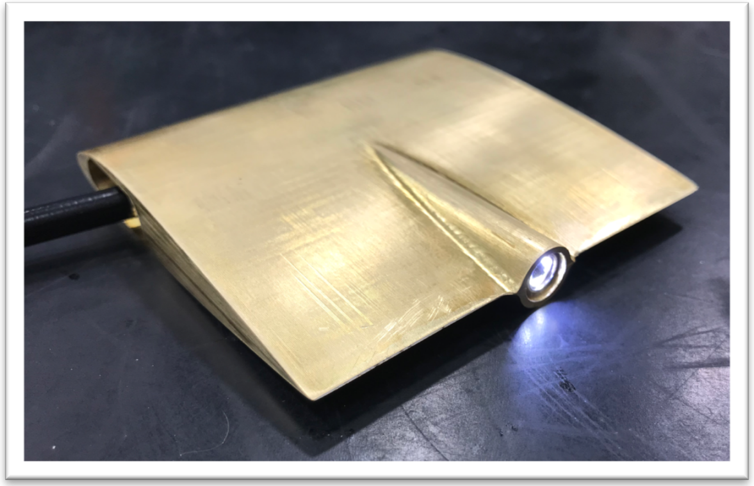
- Mr. David Johnson for use of personal compressor and insight
- Mr. Chuck Pierson for knowledge on refrigeration and helpful insight

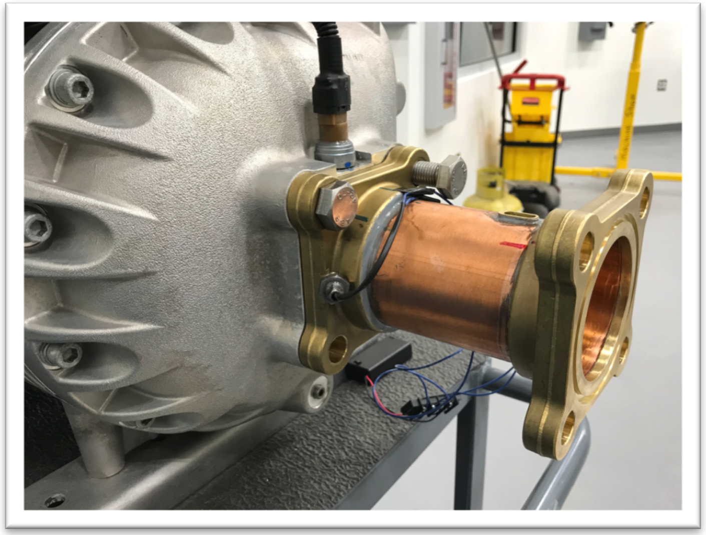
Thank You for Your Time. Questions?











Work Cited

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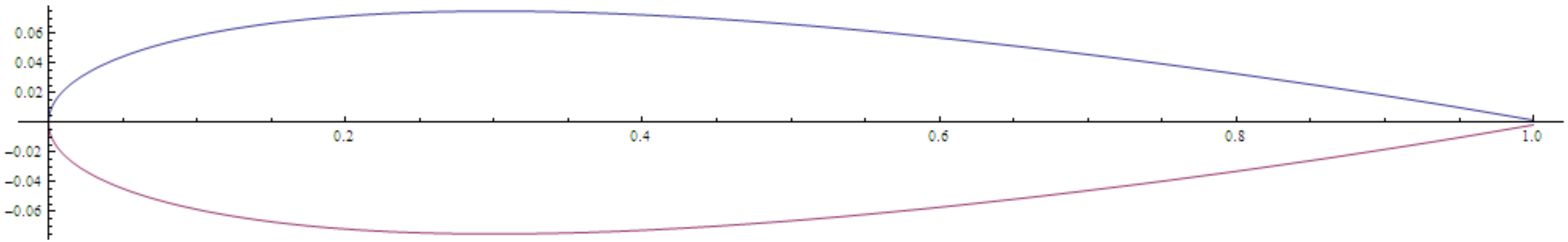
Magnitude® Magnetic Bearing Centrifugal Chillers. (n.d.). Retrieved October 08, 2017, from http://www.daikinapplied.com/chiller-magnitude-magnetic.php

Swatbotics. (2012, July 12). *Demo of April Tag localization system* [Videofile]. Retrieved from https://www.youtube.com/watch?v=Y8WEGGbLWIA

NACA 15 Airfoil Profile



$$y_t = 5t\ \left[0.2969\sqrt{x} - 0.1260x - 0.3516x^2 + 0.2843x^3 - 0.1015x^4\right]$$

- x is the position along the chord from 0 to 1.00, (0 to 100%)
- y_t is the half thickness at a given value of x (centerline to surface), and
- t is the maximum thickness as a fraction of the chord (so t gives the last two digits in the NACA 4-digit denomination divided by 100).