Static Pressure Orifice Imaging & Data Correlation

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Motivation

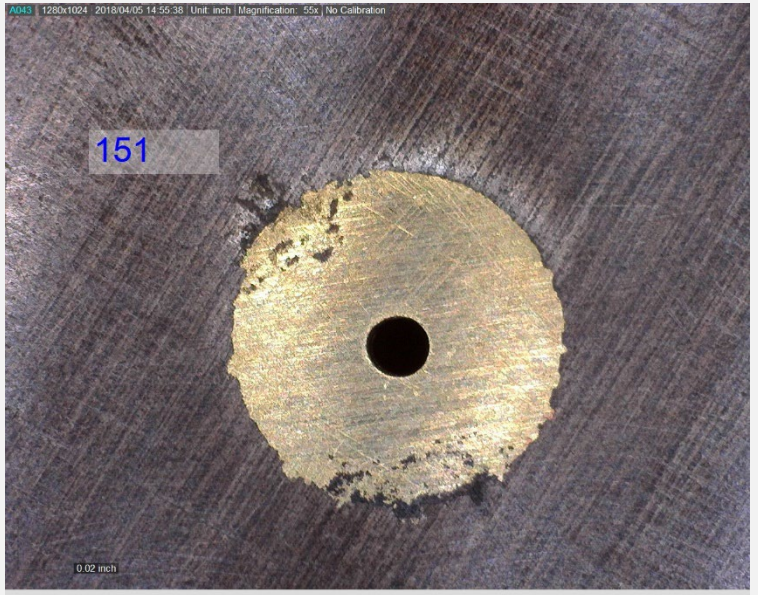
- It started with Mike:
  - Mike Mills (AEDC) suggested the DinoLite digital handheld microscope
  - Mike used these to diagnose long-pipe static pressure deviations in 16T
  - Aaron used the microscope to document tap quality on the GRC 4-inch-diameter cone cylinder for 8x6 SWT calibration

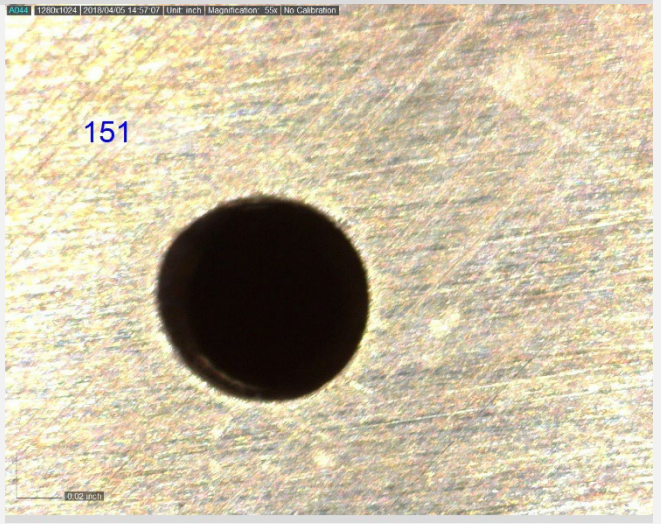
- Last month, I got a call from another Mike:
  - Mike Oliver from GRC's Propulsion Systems Lab (PSL)
  - Poor quality customer-installed static ports were observed during post-test documentation
  - Mike was looking for guidance on our quality control process, how to ensure better quality in the future, etc.

- This presentations attempts to use our existing images and data to put together a method to assess the expected error of a port's measurement based on how it looks.

Part I: Imaging & Analysis

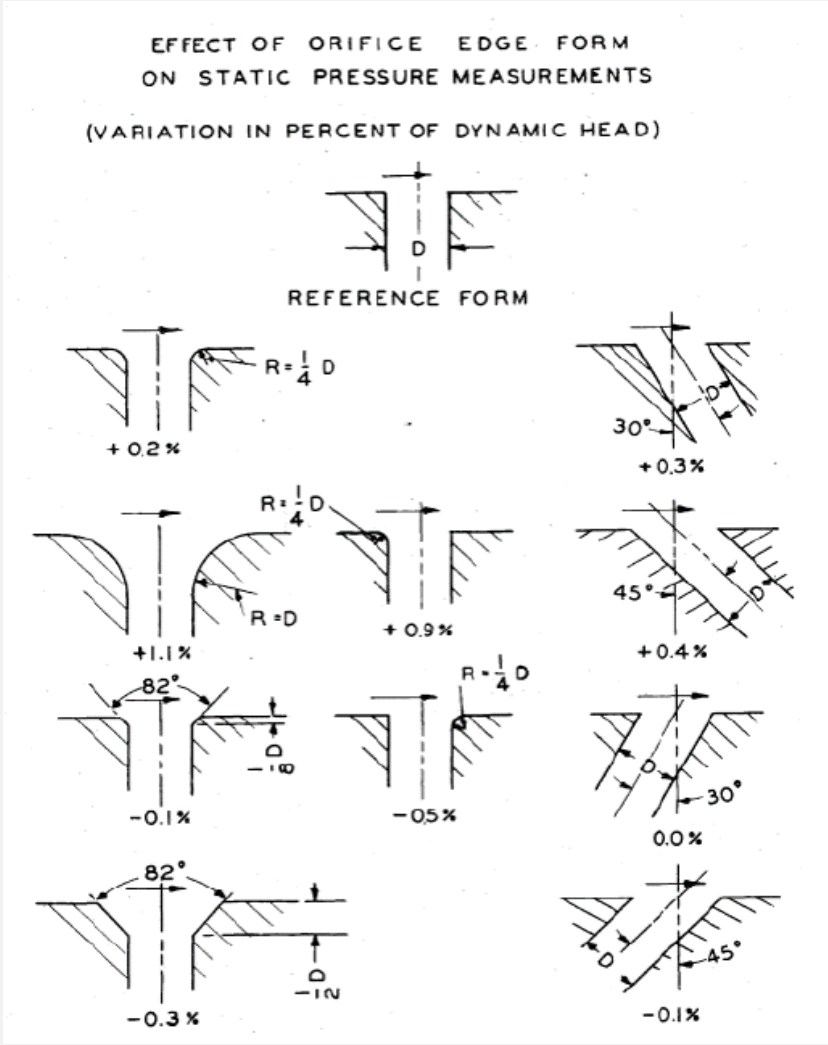
- Prior to 2019 8x6 SWT full characterization, 4-inch-diameter cone cylinder brough to instrument shop for cleaning, vacuum check, etc.
- Technicians opened holes from 0.020-in to 0.021-in diameter to “clean them up” and lightly hand-sanded surface
  - Brass static tap inserts in cone cylinder
- Instrumentation shop then used DinoLite (AM4815ZT) to image 132 static ports in
  - Zoomed-out (~50x) images
  - Highly magnified (~200x) images





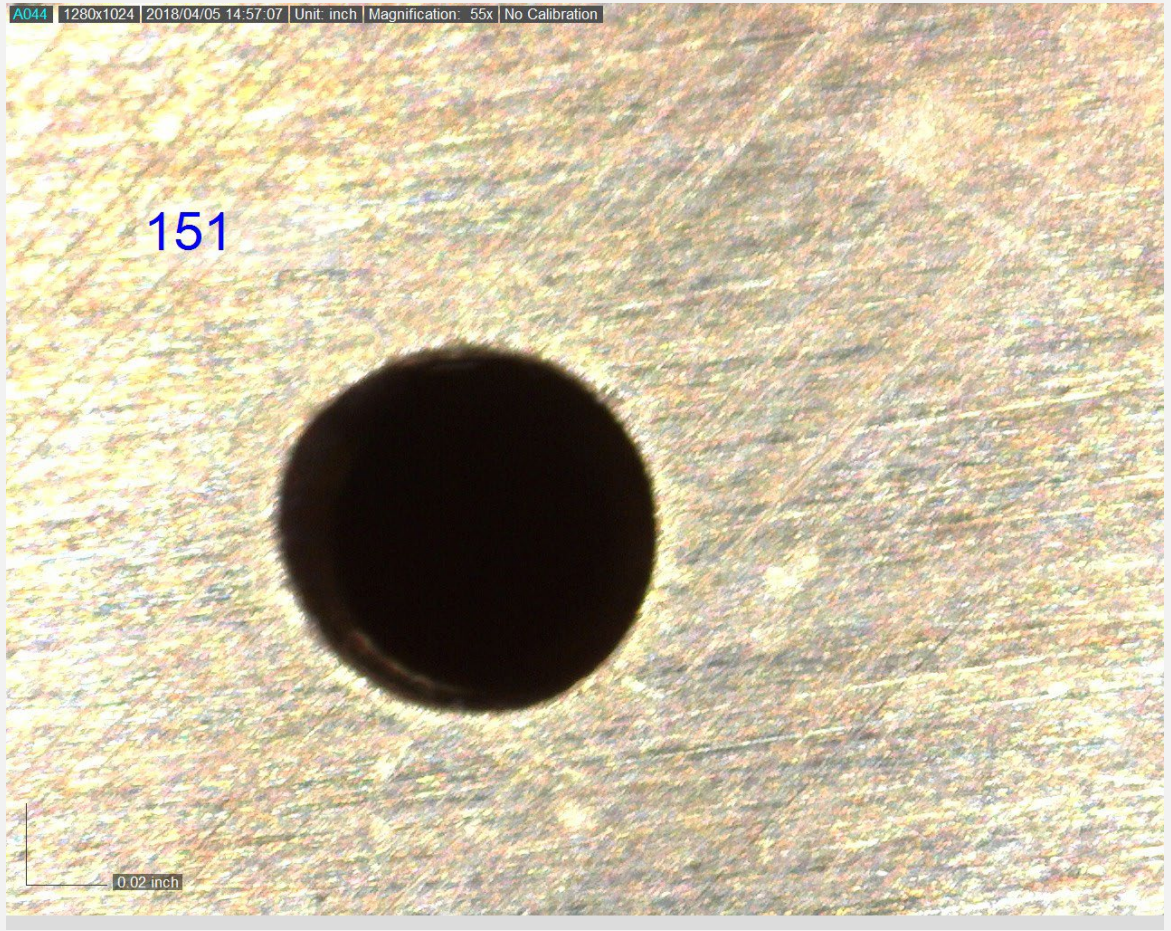
Part I: Imaging & Analysis

- How to detect flaws in the orifice, such as those in textbooks?
- Attempt to use MATLAB's capabilities to quickly churn through images and "quantify the flaws"



Part I: Imaging & Analysis

- Import highly magnified orifice images to focus on flaws associated with the port edges. Steps of my analysis in MATLAB:
  1. Find the orifice by strongly filtering out the background; trim edge text, etc.
  2. Refine the position of the orifice to center port in frame
  3. Filter to find orifice edge and determine circularity, flaws, etc.



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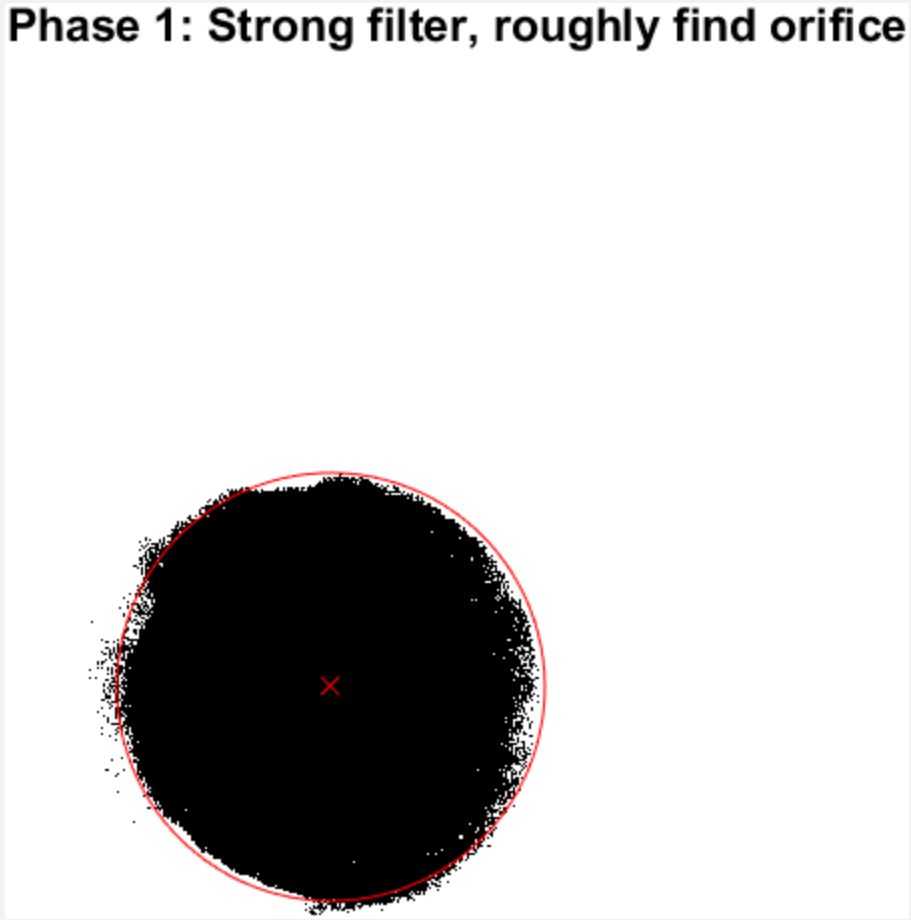

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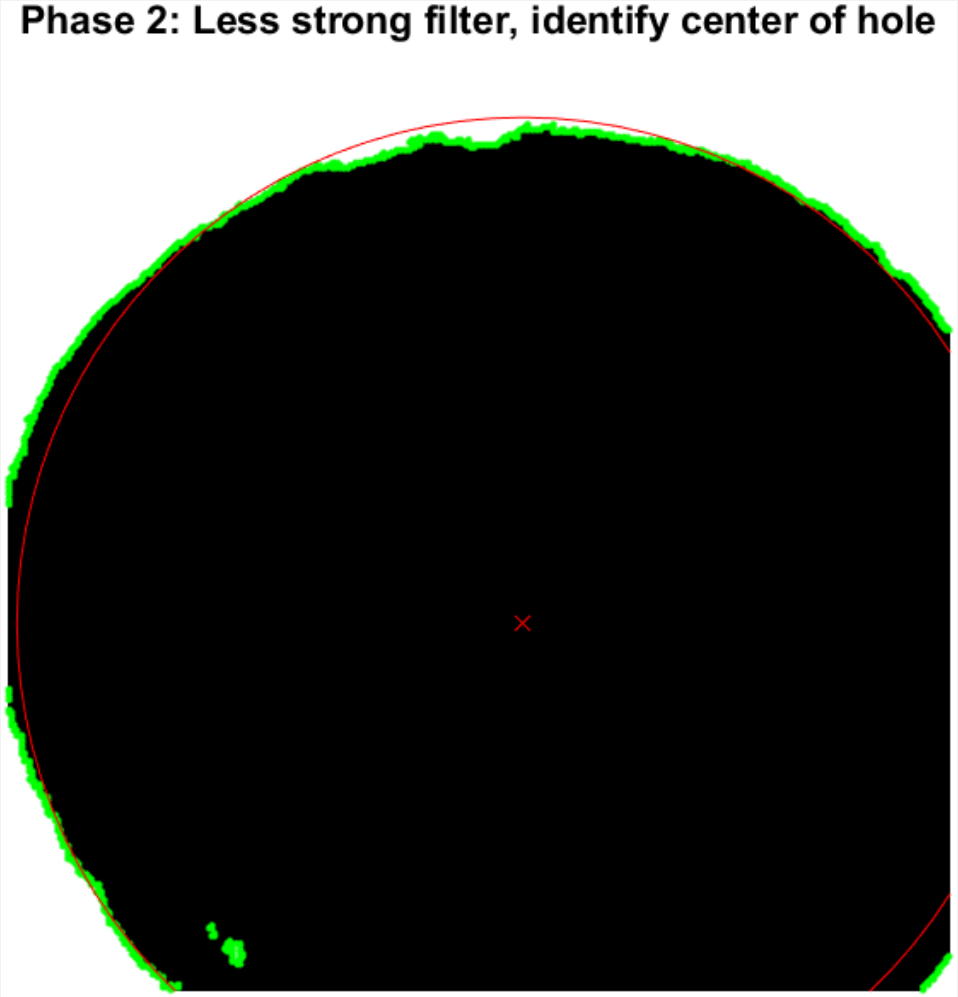

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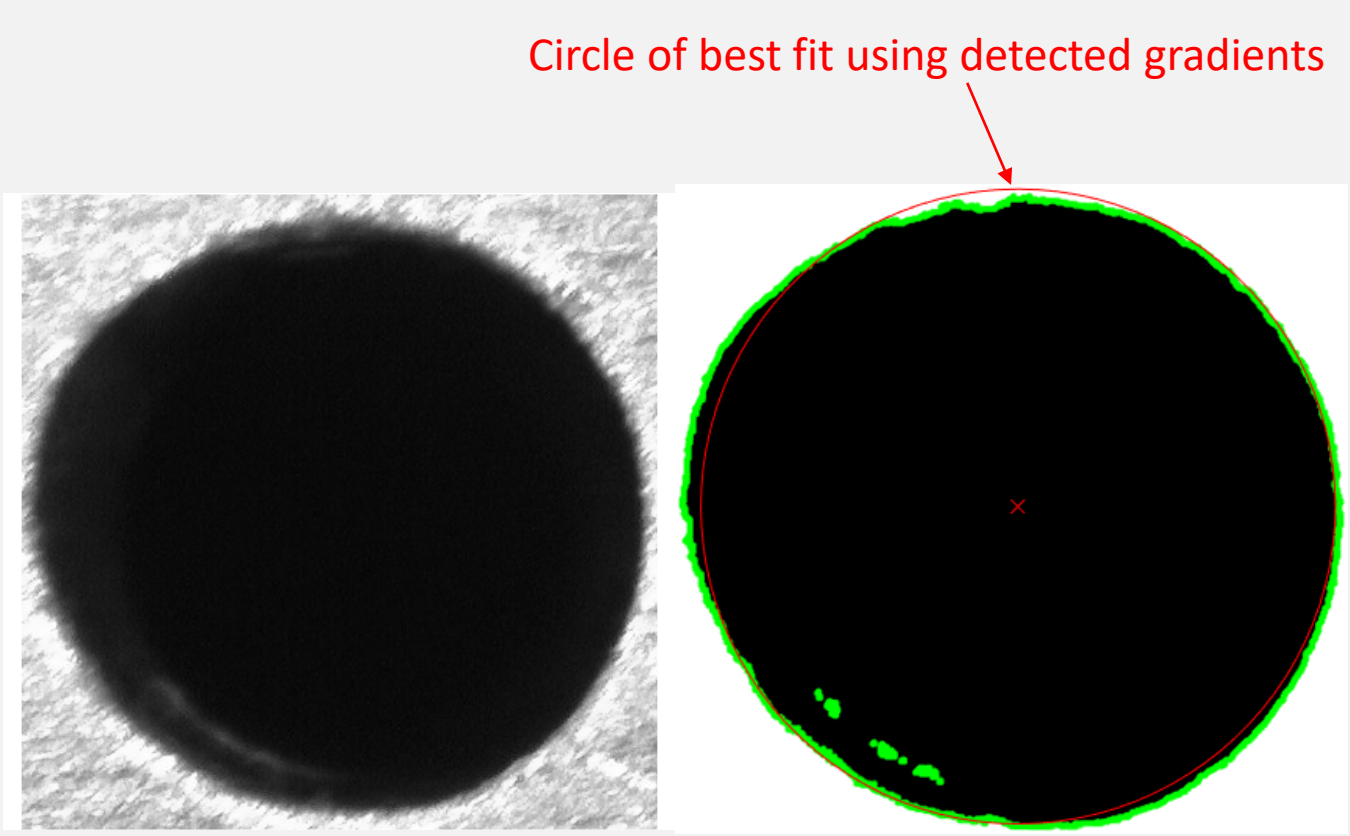
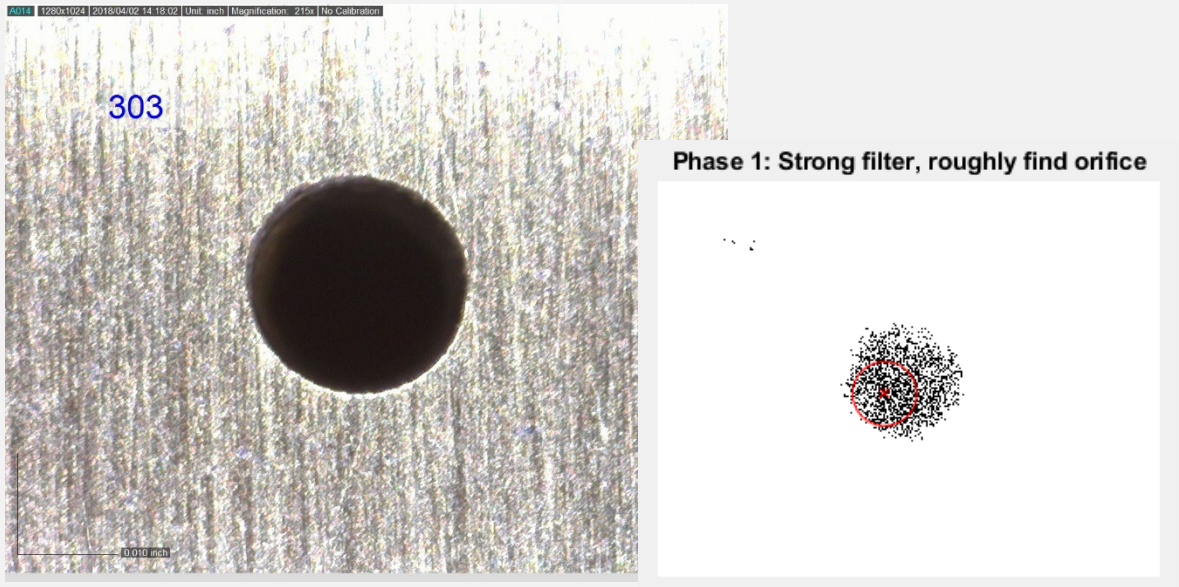
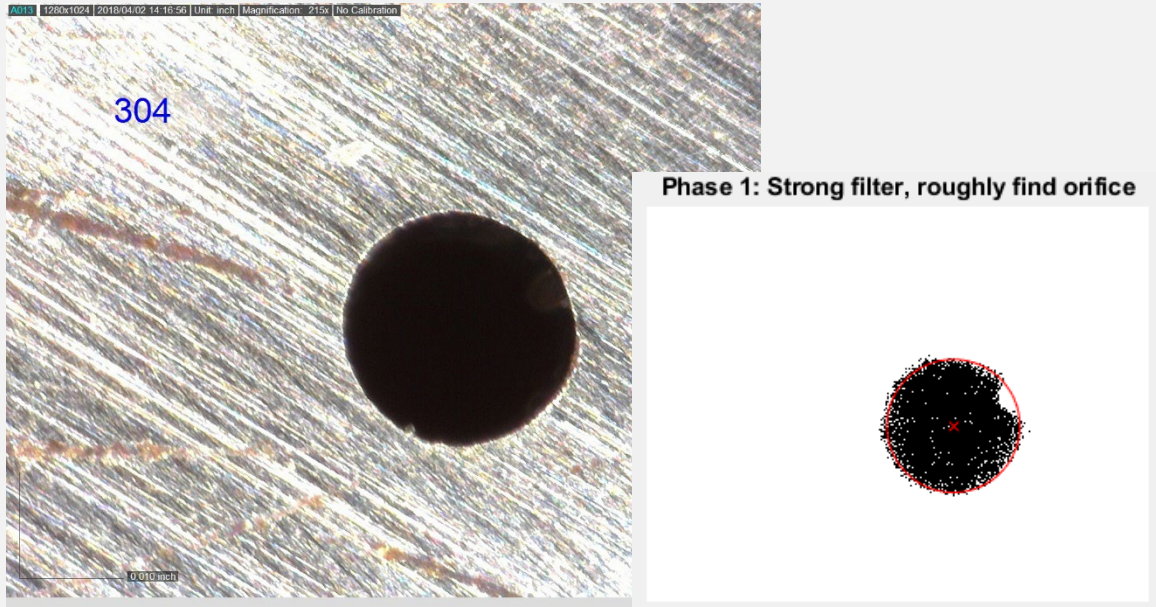


Part I: Imaging & Analysis

- A couple notes on images:
  - Lighting is very important; if every picture is different, under- or over-exposed, etc. efficient processing of dozens of images becomes difficult.
  - Don’t put text near the object of interest, unless it’s on the opposite end of the color spectrum. For example, use white/light text for a black orifice.
  - Use a jig or camera stand which touches the model/tunnel surface for consistent focus & magnification.



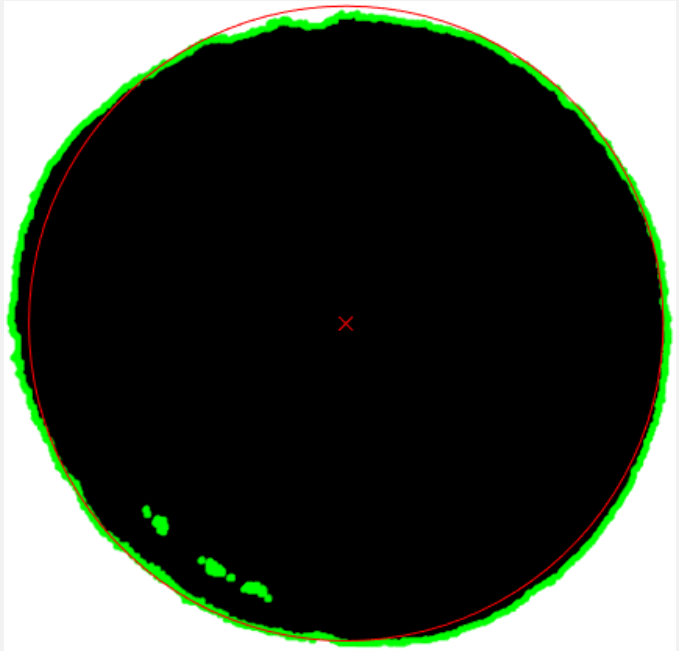
VS



Part I: Imaging & Analysis

Ways to quantify the “flaws”

- Simplest: choose a cut-off, make all pixels a 1 (white) or 0 (black)
  - White area inside the circle
    - Burrs
  - Black outside the circle
    - Gouges/scratches
    - Mishappen orifice

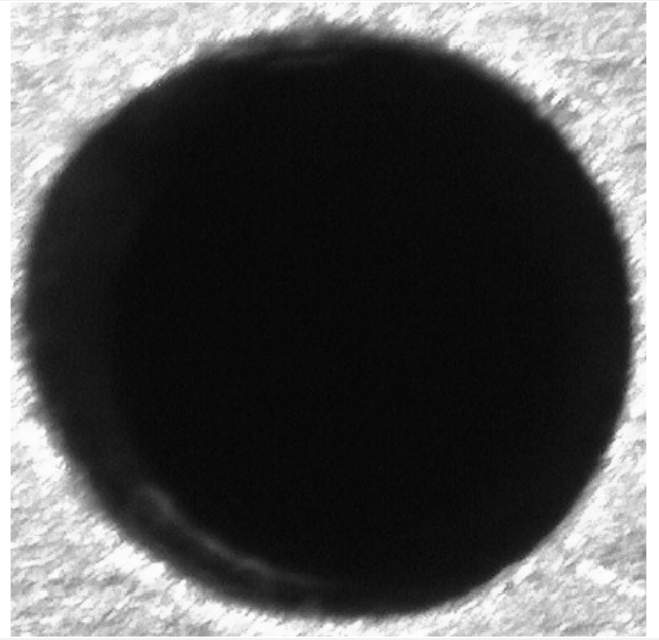


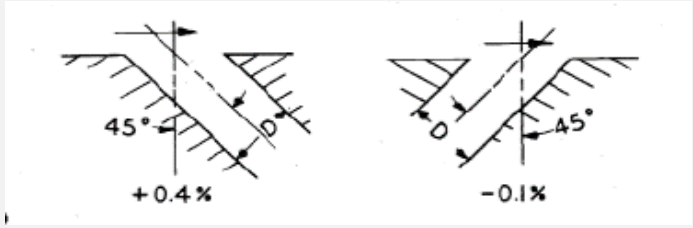
Part I: Imaging & Analysis

Ways to quantify the “flaws”

- Weight the pixels using their “gray value” (between 0 and 255)
  - Weighted gray area inside or outside could indicate:
    - Chamfered edges
    - Non-perpendicular holes

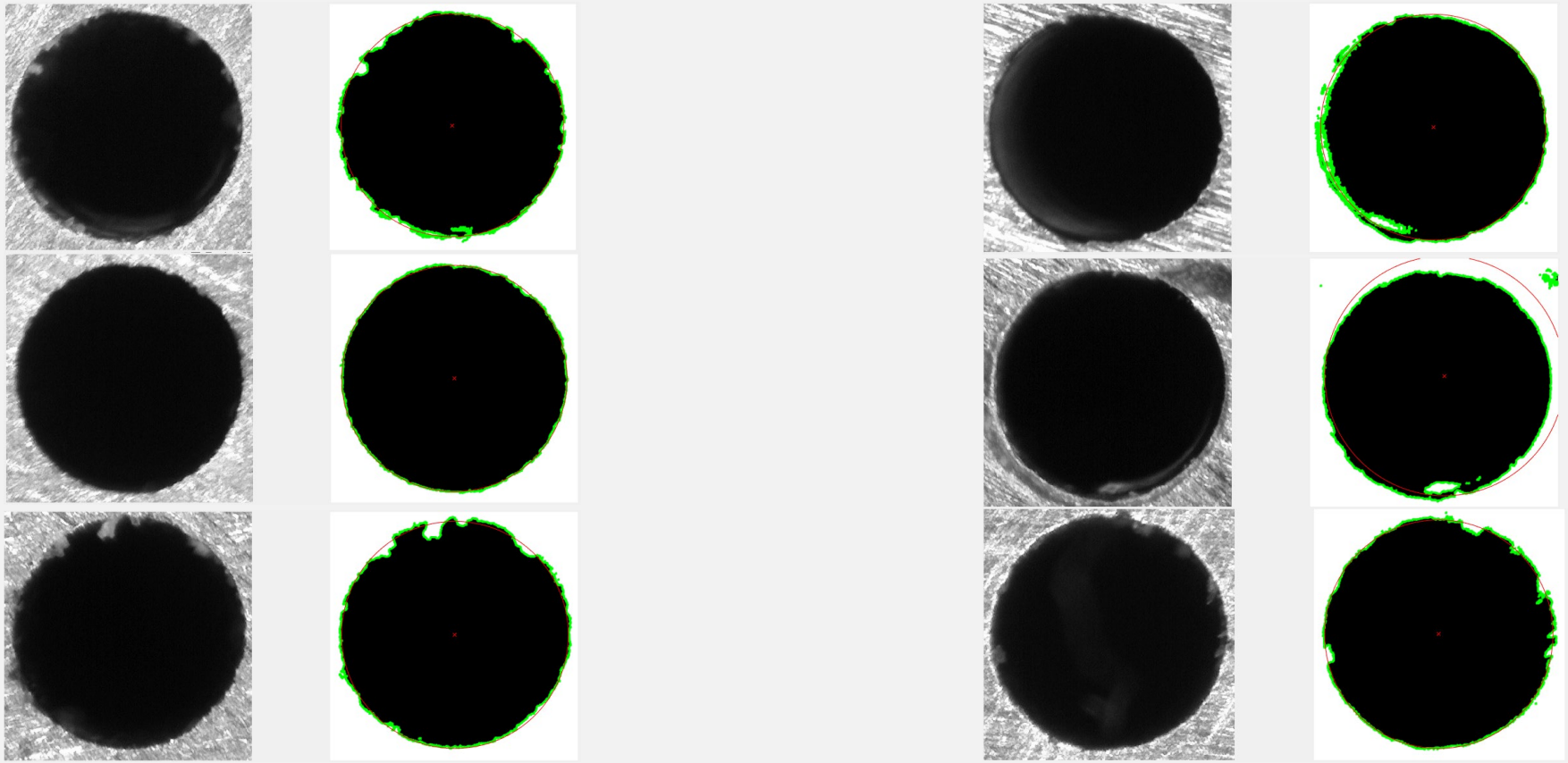
- Could potentially break up the images into halves, quadrants, pie-shaped pieces to determine upstream or downstream edge of orifice





Part I: Imaging & Analysis

Orifice flaws/features now have value(s) associated with them…

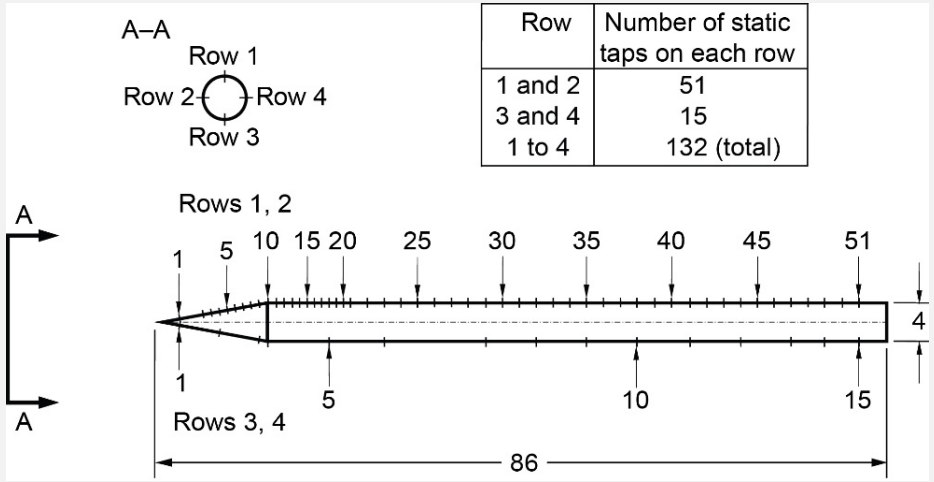


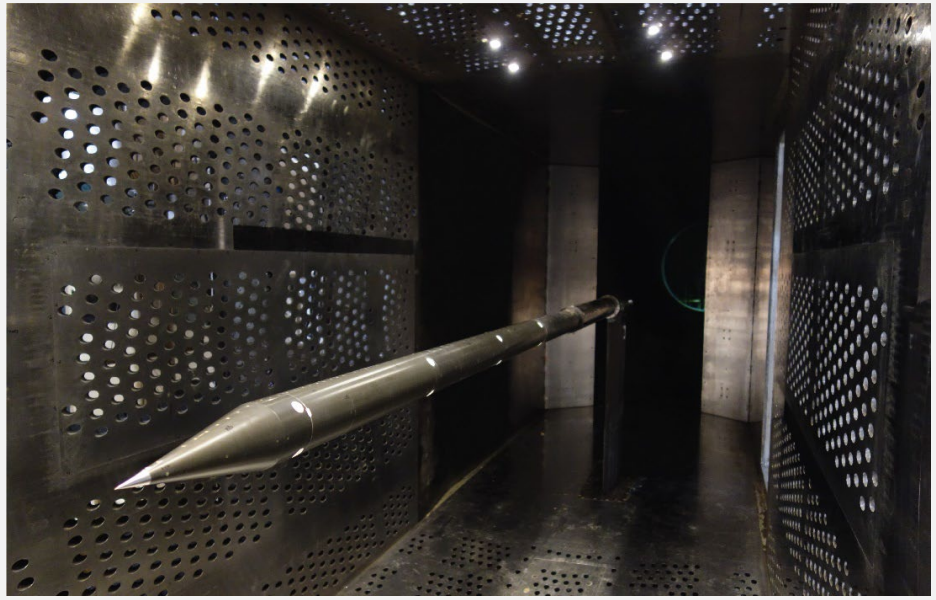
Now, the error produced by these flaws needs to be estimated.

Part II: Cone Cylinder Data

- 4-inch-diameter cone cylinder
  - Primary static pressure characterization tool for 8x6 Supersonic Wind Tunnel (SWT)
  - 132 static pressure taps in 4 streamwise rows
    - Two rows of 51 taps
    - Two rows of 15 taps

- During subsonic operation in the 8x6 SWT, the data from the aft portion of the cylinder is typically very consistent
  - Small gradients
  - No shock reflections





Images from NASA/CR-20205006102

Part II: Cone Cylinder Data

- Example of subsonic data from 2019 test section characterization

- Using just ports on the aft part of the cylinder (40 inches or more from the cone tip), estimate their error by checking them against the adjacent pressure measurements
  - Linearly interpolate between the adjacent upstream and downstream ports
    - Simple, but would also flag ports which are next to deviant ports

  - 2nd order fit of two upstream and two downstream ports.
    - More complicated, but reduces chance of flawed ports biasing data

  - A lot of other options to be explored

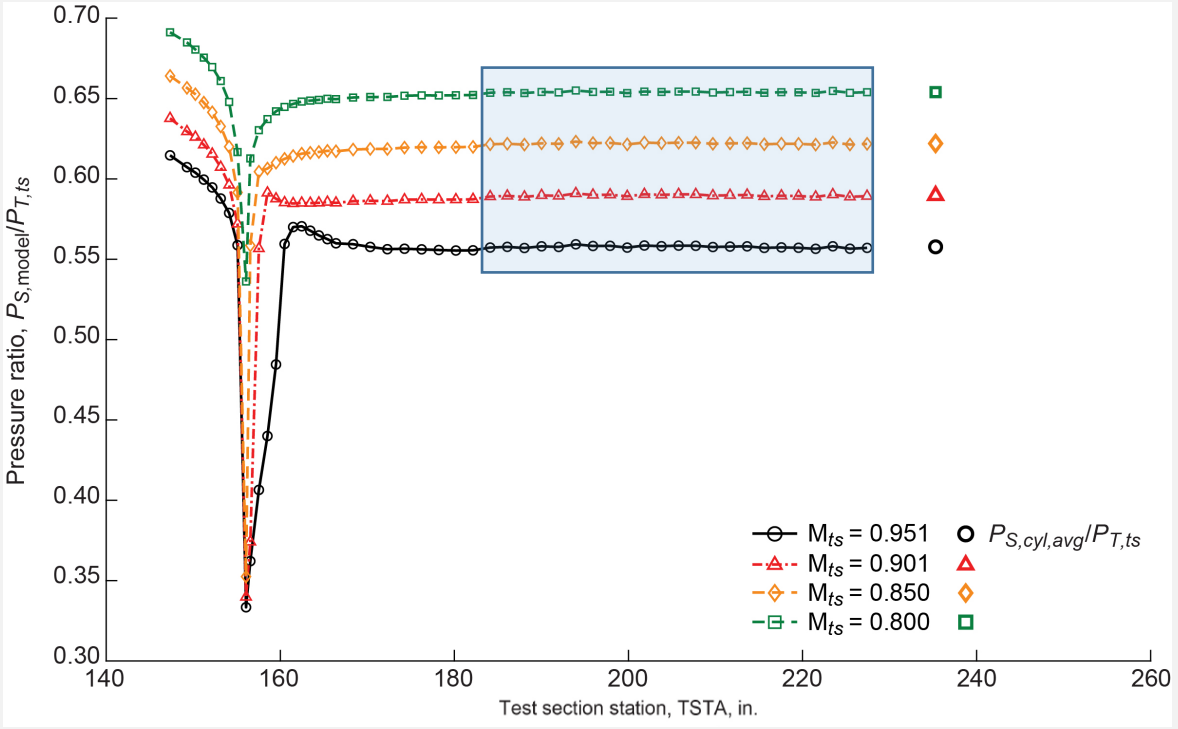
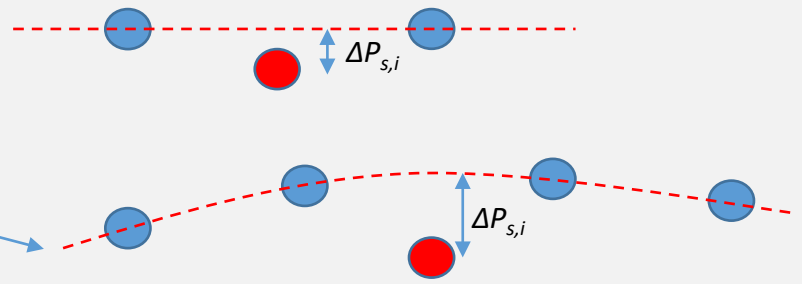
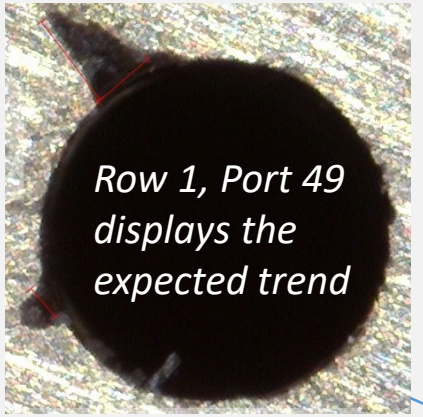


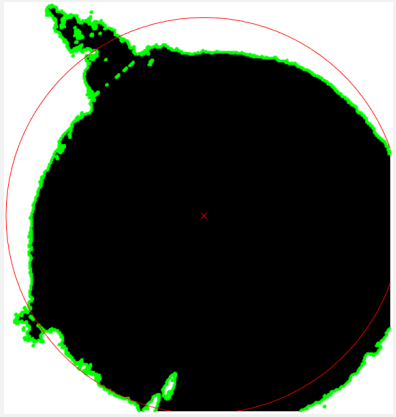
Image from NASA/CR-20205006102

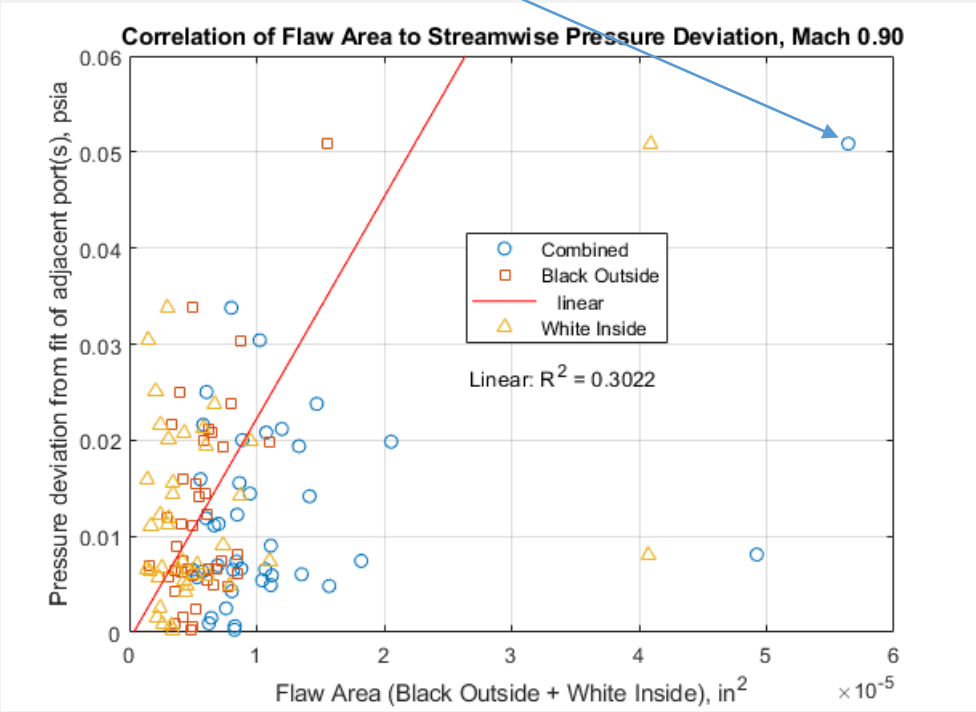


Part III: Image & Experiment Correlation

- Mach 0.90 (most conditions result in similar $\Delta P_{S,i}$)
  - Could normalize by *q* in future analyses
- Rows 1 & 2 on aft end of cylinder; linear interpolation method used with adjacent ports to estimate $|\Delta P_{S,i}|$
- No improvement to fit when 2nd order fit used between adjacent two upstream and two downstream ports.
- Using pure pressure deltas rather than $|\Delta P_{S,i}|$ makes the fit worse…





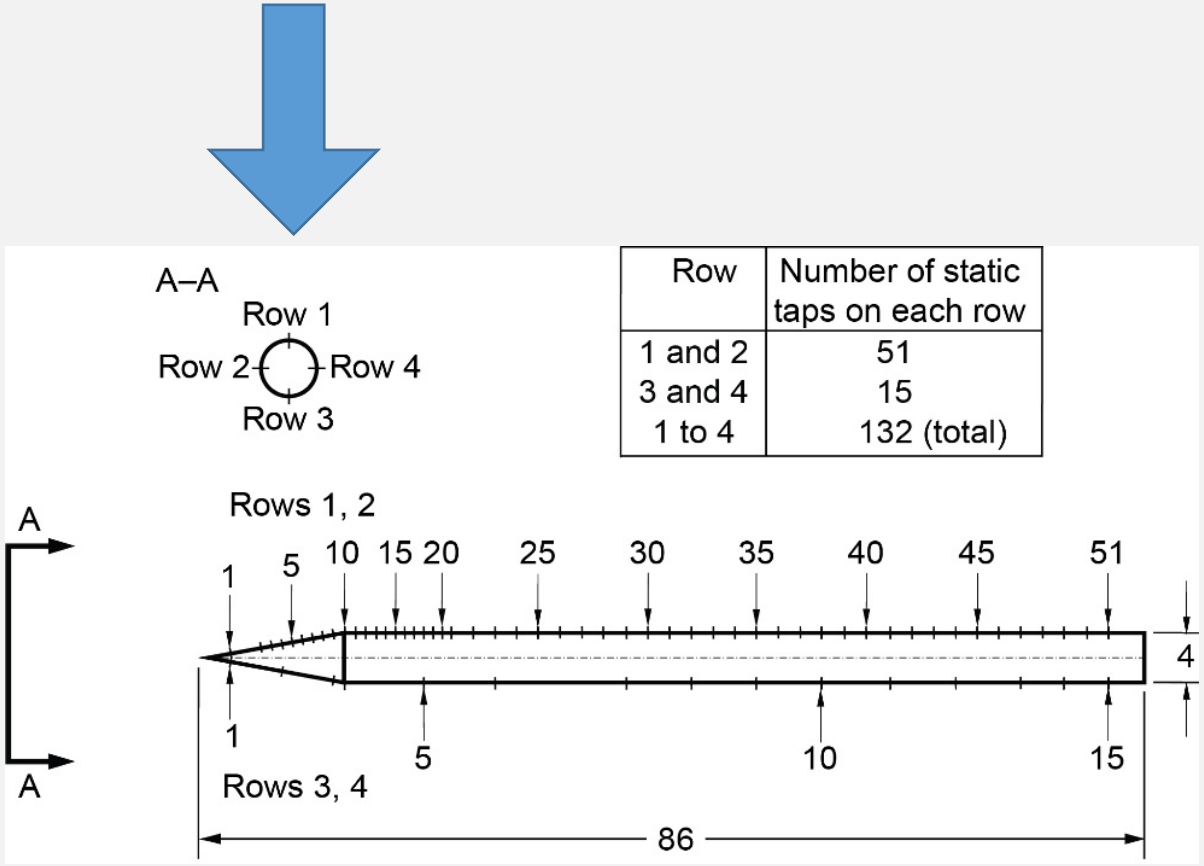


Part III: Image & Experiment Correlation

- Instead of assuming streamwise consistency in pressure trends, investigated the difference between a port and the avg. pressure at that given station (only use stations with 4 ports)

- Actually, made the curve fit attempts worse than before…

- By removed pressure deviations less than a threshold (i.e., 0.05% FS), the fits improve slightly, but fits are still not significant.



Conclusions & Future Work

- With the current set of images and the data set from the 8x6 SWT 4-inch cone cylinder, only a few data points display what would be considered the expected trend… More data is needed!

- At GRC, would like to repeat the image collection process with awareness of post-processing requirements (i.e., lighting, clarity, text location, consistency)
  - A more consistent set of images may produce better correlations.

Conclusions & Future Work

- At other centers, if there is open data and corresponding orifice images that can be shared, a more significant trend could be developed.
  - Similar to machine learning efforts: more data, better models.
  - Long-pipes, short static pipes, rows of wall statics, etc.

- Idea for the future of where this project could go:
  - When receiving customer hardware, buying-off probes/models, reviewing the health of test section wall/ceiling taps, etc., a digital microscope connected to a tablet/laptop could be quickly used to determine a quantitative pass-fail criteria on tap quality.
    - Standardization of the image acquisition and analysis would need to be achieved to ensure a consistent predictor variable.
    - May even be able to relate the allowable flaws to the desired accuracy of the static pressure measurement.

Questions?