Fundamental Inlet Bleed Experiments (FIBE)

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Agenda

- FIBE Overview
- Facility Overview
- Phase I Summary
- Phase II Results
- Phase III Planning
  - 15x15cm Bleed Capacity Upgrade
  - 15x15cm Axisymmetric Test Section

FIBE Overall Objective

- The Fundamental Inlet Bleed Experiments (FIBE) project is primarily an experimental program to establish a comprehensive experimental bleed database to advance the understanding of how bleed systems can be improved through:
  - Improved bleed modeling (Design and CFD)
  - Bleed placement within a high-speed inlet
  - Alternate bleed configurations
    - Bleed orifice inlet conditioning
    - Non-circular bleed orifices
    - Bleed patterns

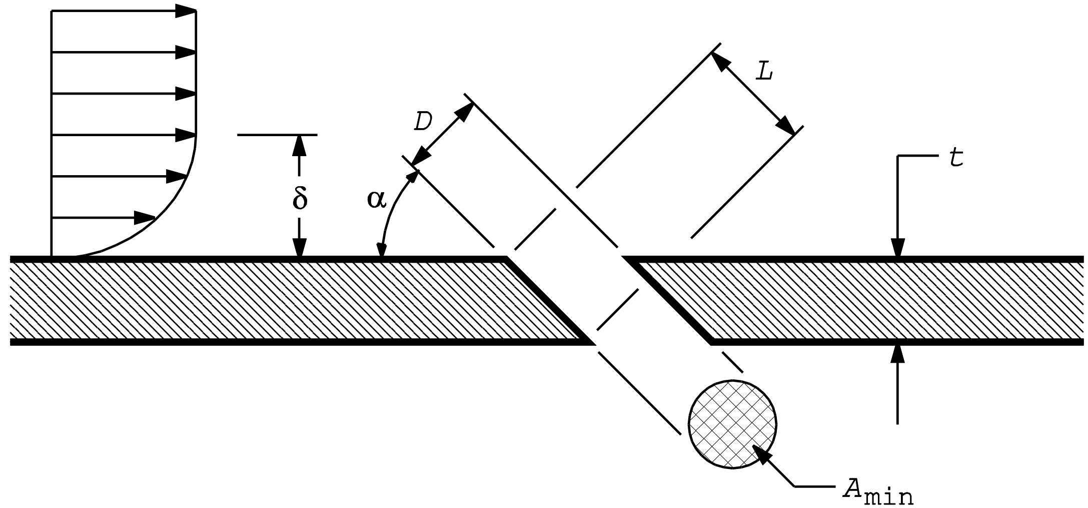
Slot Array **Radiused Edges**

Bleed Hole Parameters

"Thick" Bleed Plate

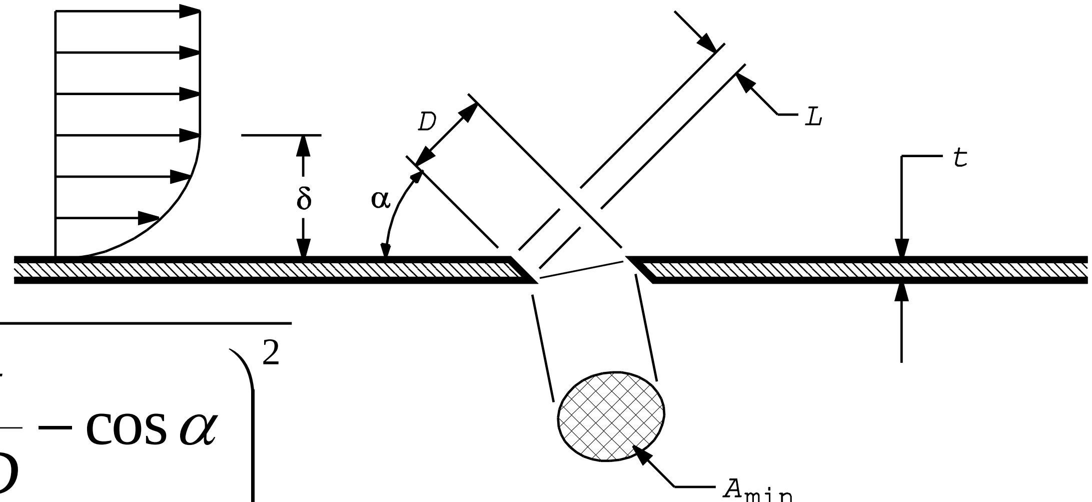
$$\frac{t}{D} \geq \cos\alpha$$

$$A_{\min,thick} = A_b = \frac{\pi}{4} D^2$$



"Thin" Bleed Plate

$$\frac{t}{D} < \cos\alpha$$



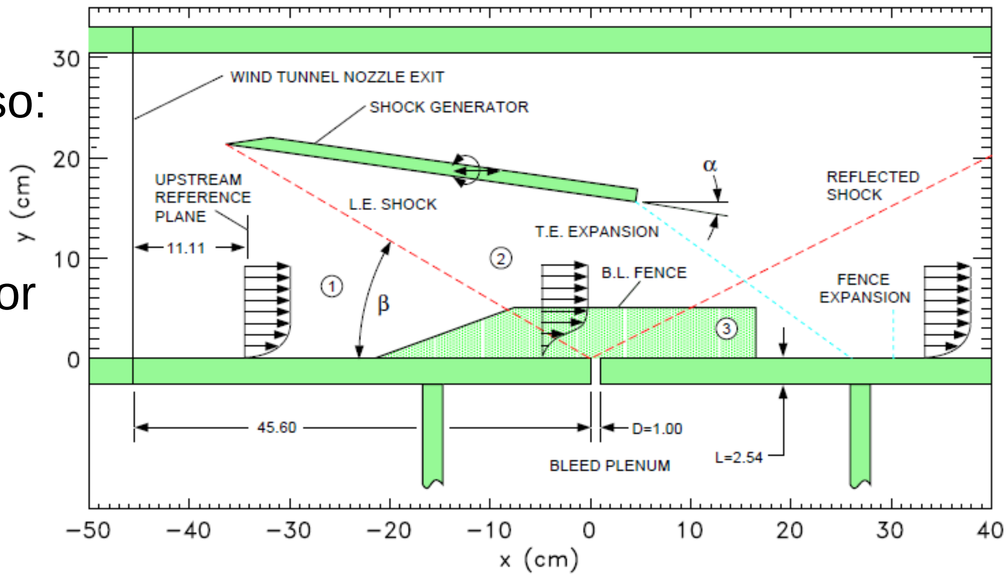
$$A_{\min,thin} = A_b \sqrt{\left(\frac{t}{D}\right)^2 + \left(\frac{\frac{t}{D} - \cos\alpha}{\sin\alpha}\right)^2}$$

FIBE Phase Objectives

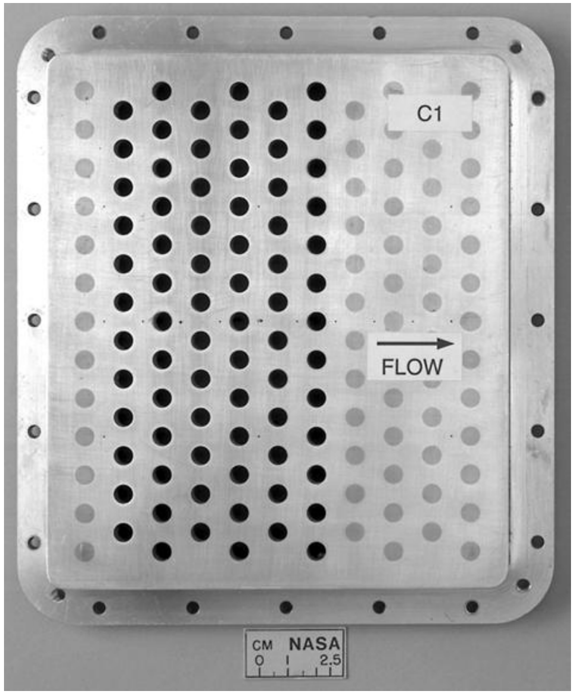
- The FIBE program will be conducted in three phases. The primary objectives for each phase are:
  - Phase I - 15x15cm Supersonic Wind Tunnel (SWT)
    - Checkout of facility, bleed system, and instrumentation.
    - Document approach flow conditions for this and subsequent Phases.
    - Obtain flow coefficient data for pre-existing single-hole test articles.
  - Phase II – 15x15cm SWT
    - Obtain flow coefficient data for single-hole or non-interacting multi-hole configurations.
      - Inclination Angle
      - L/D
      - D/δ^*
    - Dynamic Plenum Pressure Measurements

FIBE Phase Objectives

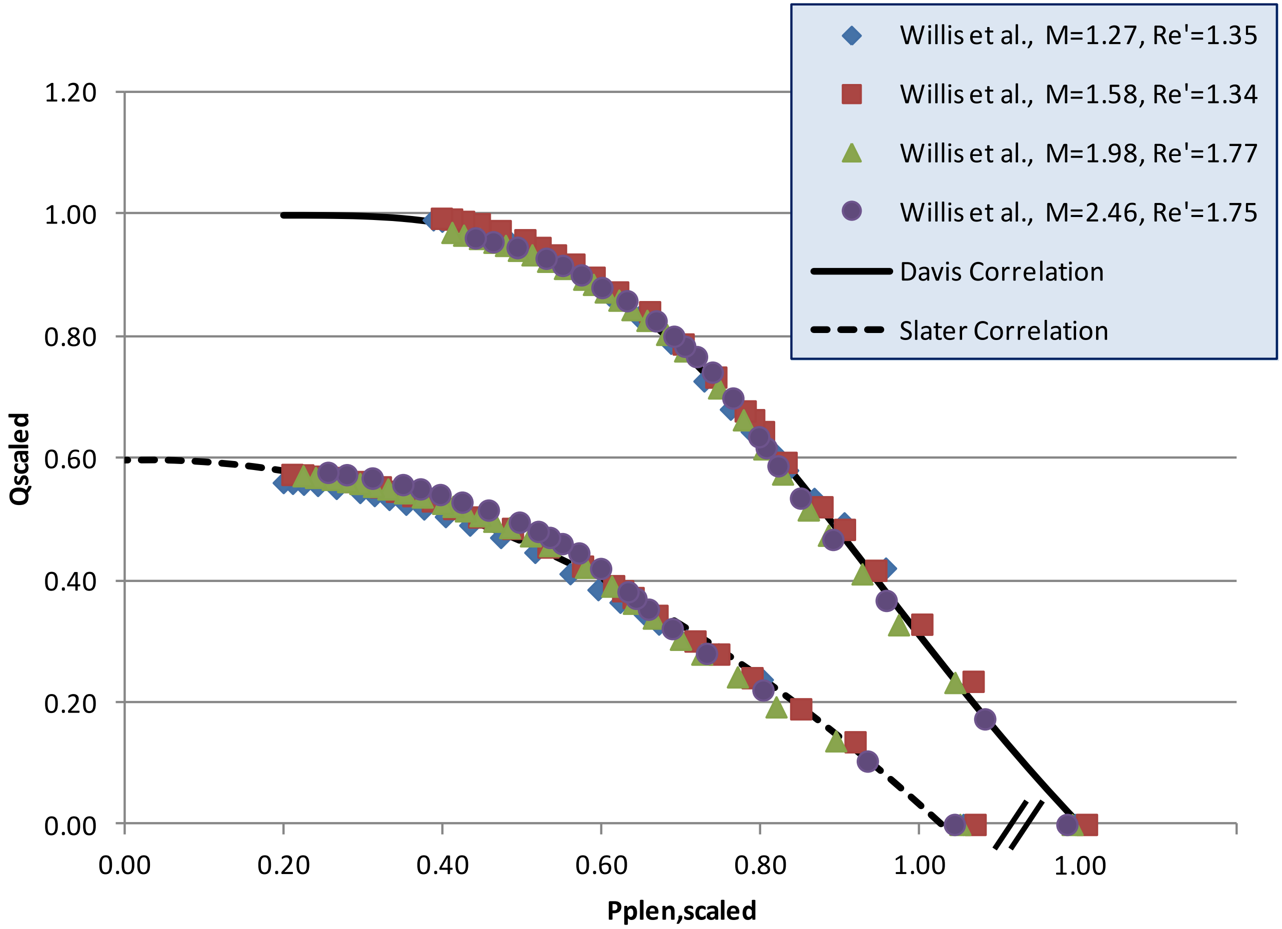
- Phase III - 15x15cm SWT
  - Full bleed regions without and with oblique or normal shock using multi-hole patterns with similar geometry as Phase II single-hole tests.
    - Flow coefficient
    - Downstream flow-field measurements
    - Dynamic Plenum and Surface Pressure Measurements
  - Facility Upgrades
    - Reinstall and upgrade ejector system.
    - Larger bleed lines.
- Phase III – 1x1ft SWT
  - Similar data as above but also:
    - Glancing interaction
    - Corner interaction
  - Bleed system/shock generator assembly require some minor additional component fabrication.



Flow Coefficient Scaling



α=90°
L/D=1
D/δ*~1
20% Porosity

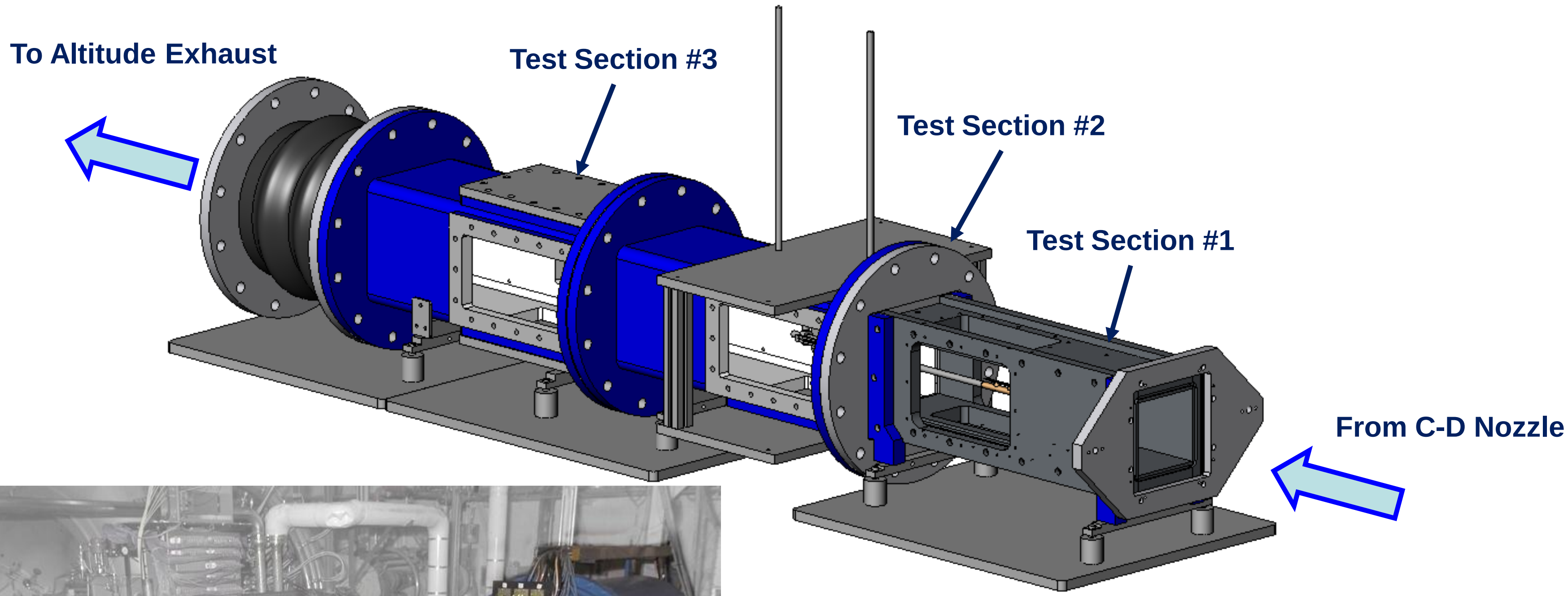


Correlations based on multi-hole data of Willis et al.

FACILITY OVERVIEW

15x15cm Supersonic Wind Tunnel

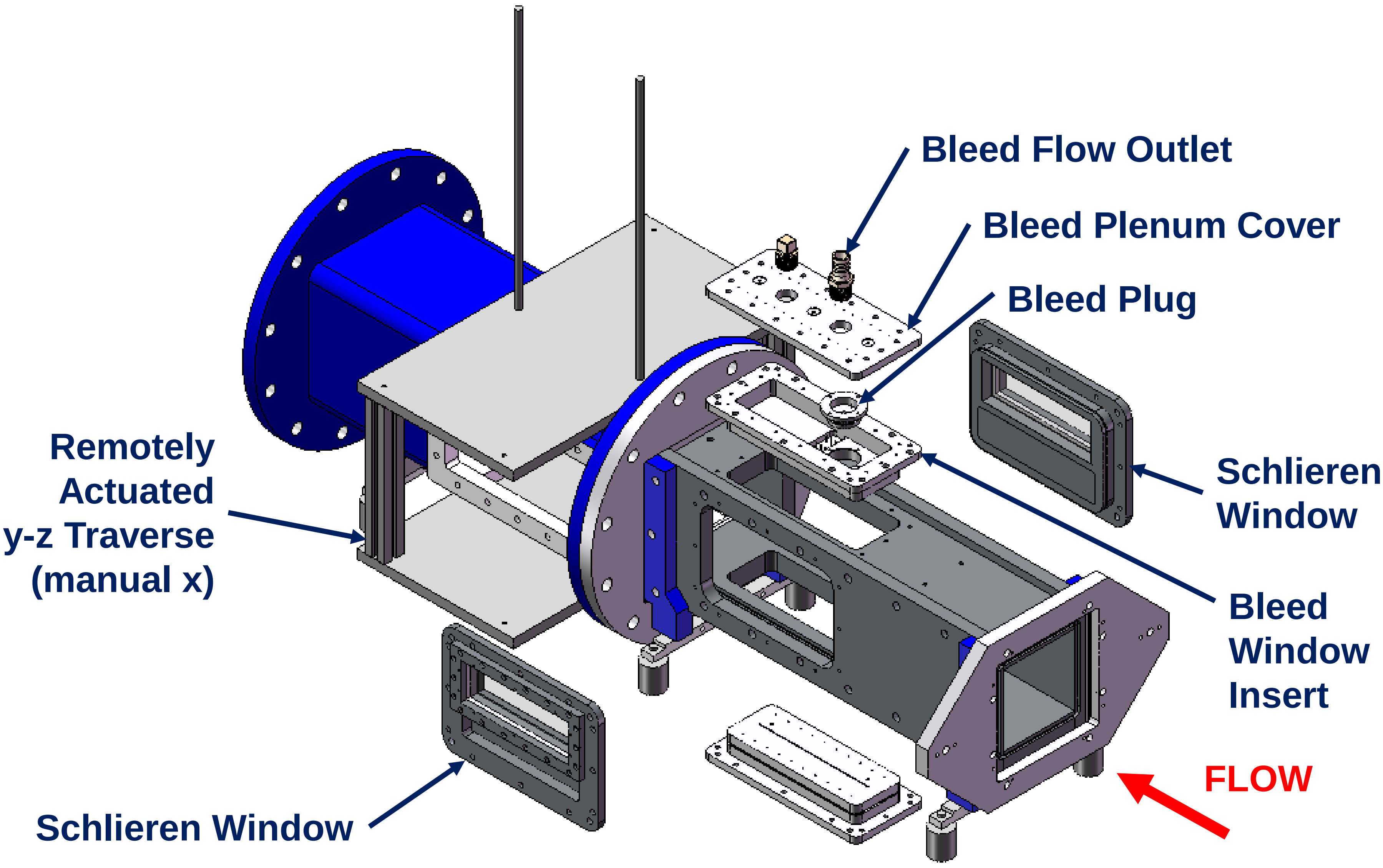
15x15cm Supersonic Wind Tunnel



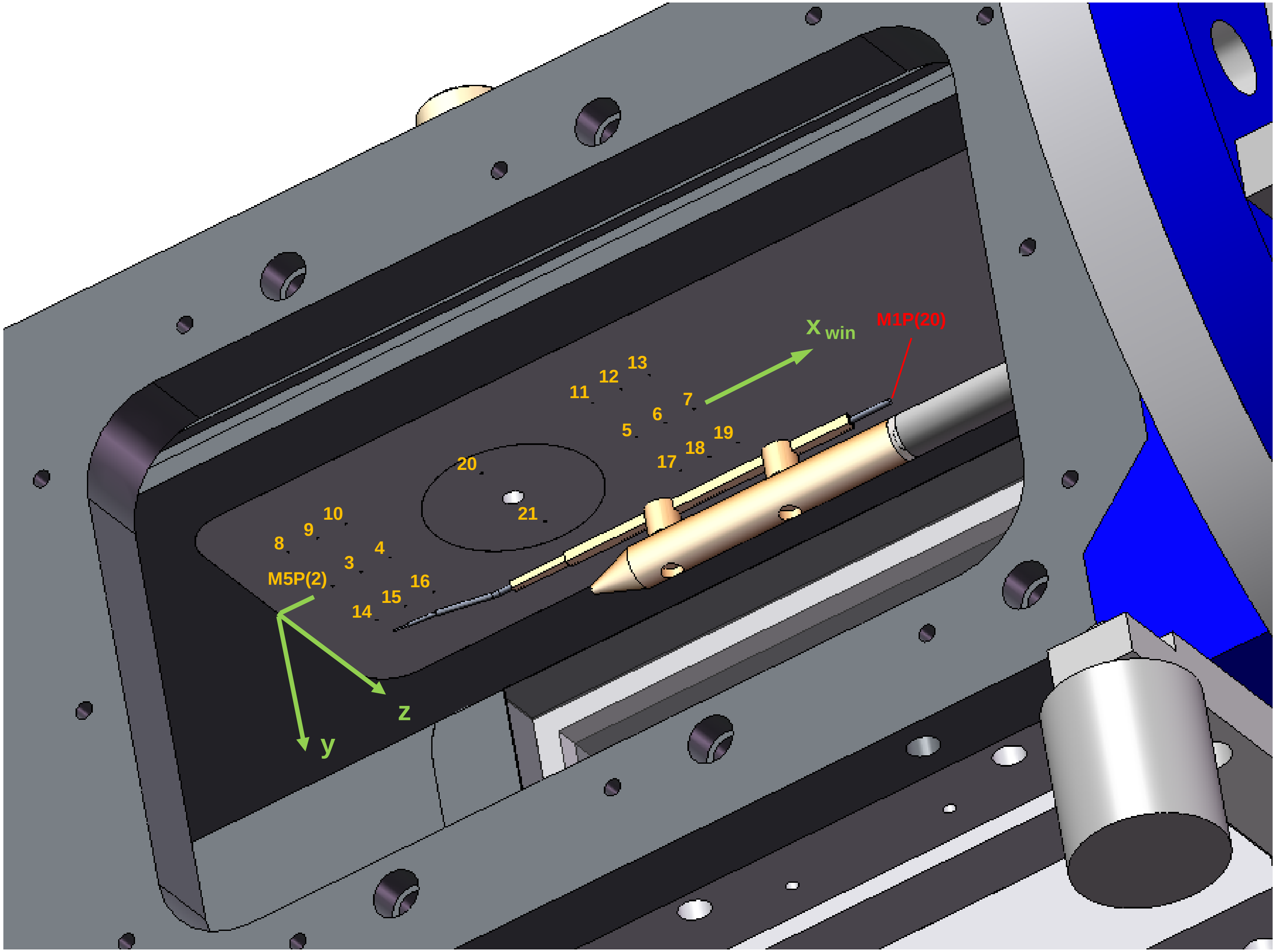
<u>15x15 cm Supersonic Wind Tunnel</u>

- Continuous Flow
- Fixed Geometry Nozzle Blocks
  - Blocks rotatable so “good” B.L. can be on horizontal or vertical walls.
- 40psig Combustion Air Supply
- Ambient Total Temperature

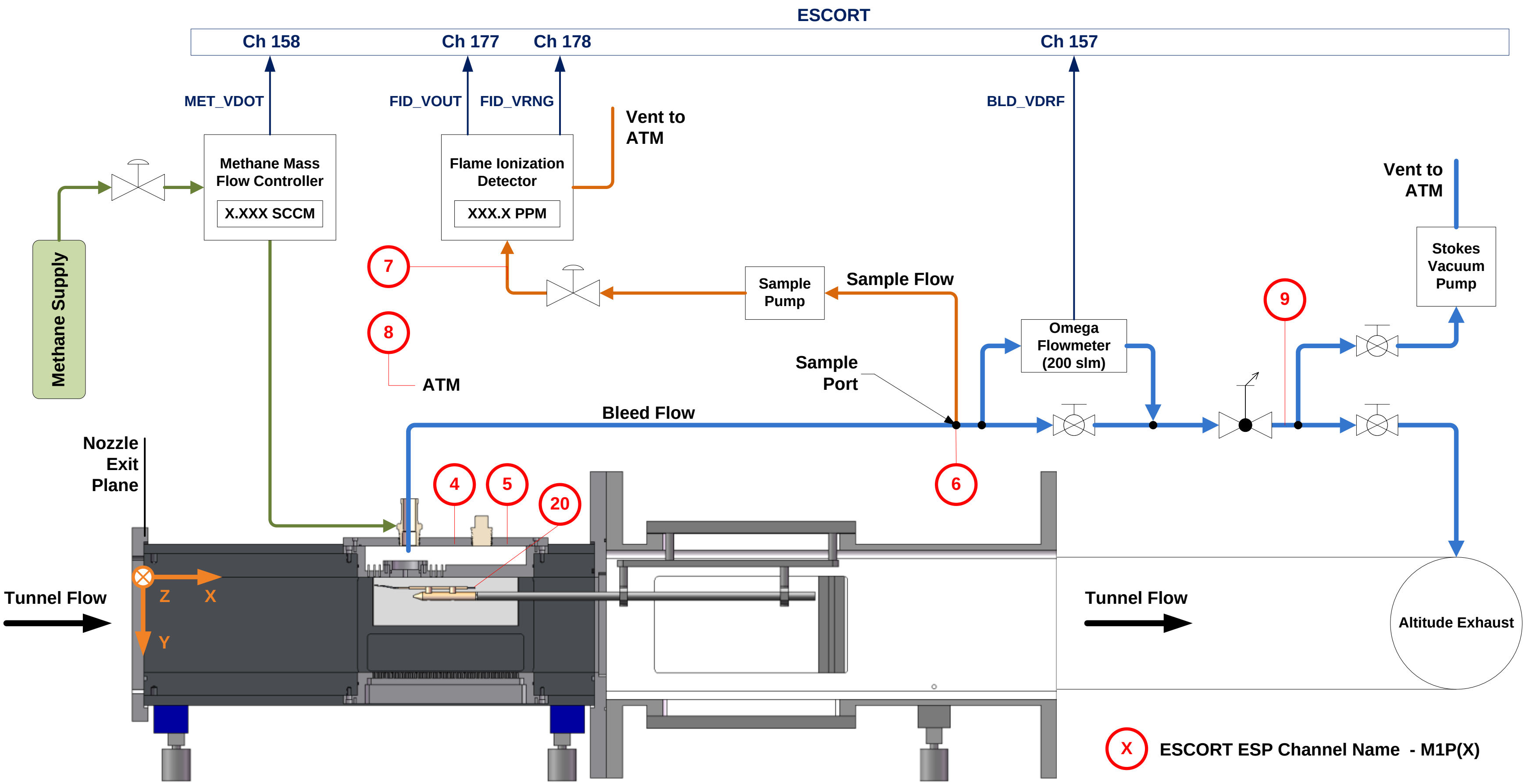
Test Section Window Configuration



Top Window Static Taps



FIBE Test Schematic



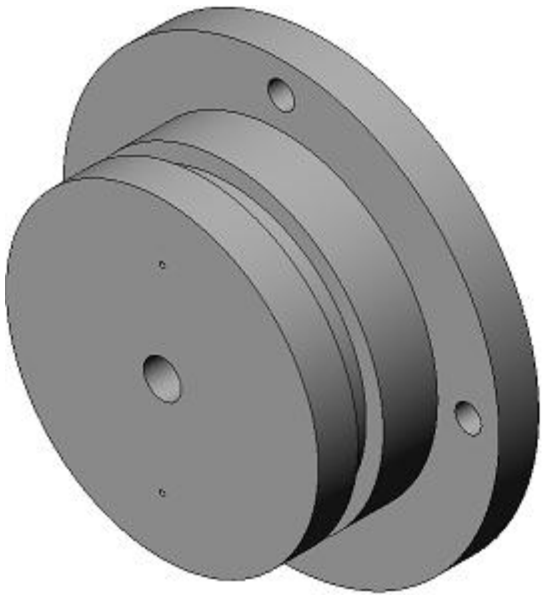
"Method-of-Mixtures"

$$w_{air} = \left(\frac{M_{air}}{M_{met}}\right)\left(\frac{1-\nu_{met}}{\nu_{met}}\right) w_{met}$$

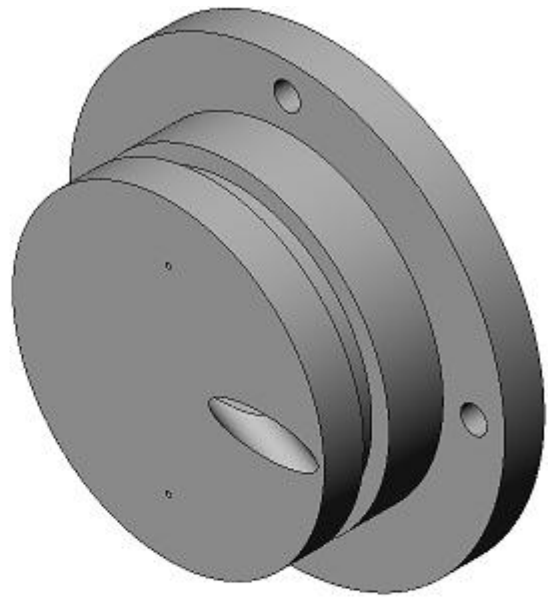
FIBE PHASE I SUMMARY

Results Summarized in AIAA Paper 2012-0272

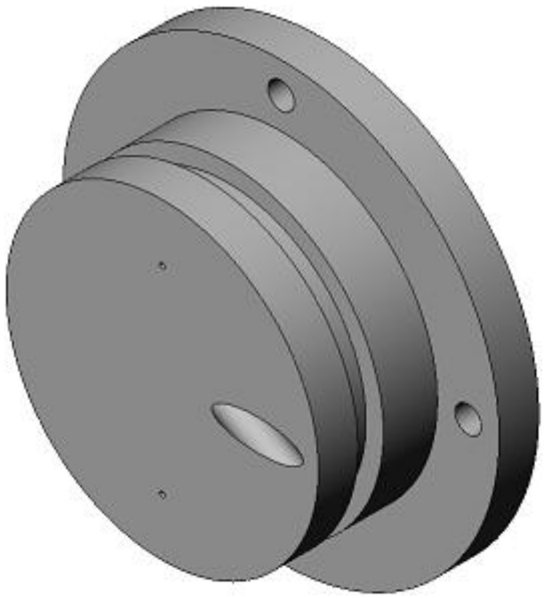
Pre-Existing Test Articles



C01
D=6.010mm
α=90°
L/D=2.0
t/D=2.0
A/A_b=1.00

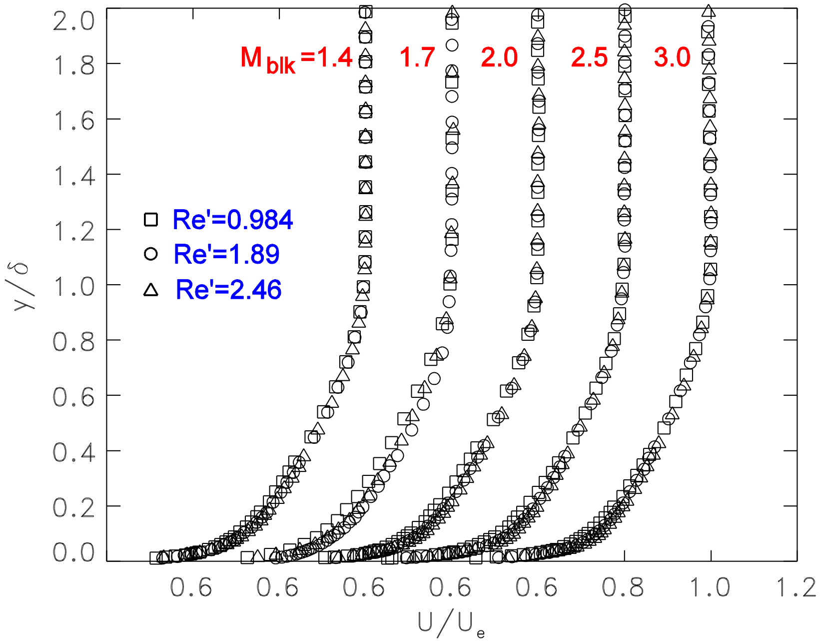


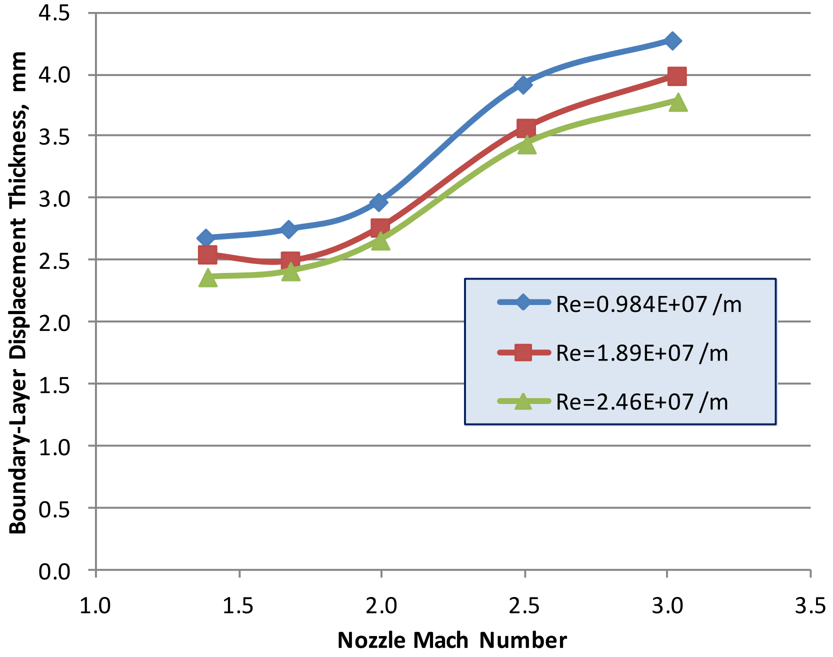
C02
D=6.029mm
α=20°
L/D=2.0
t/D=0.684
A/A_b=1.248



C03
D=5.018mm
α=20°
L/D=2.92
t/D=1.0
A/A_b=1.0

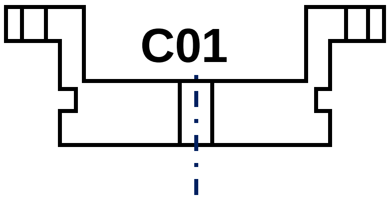
Approach Boundary-Layer Profiles

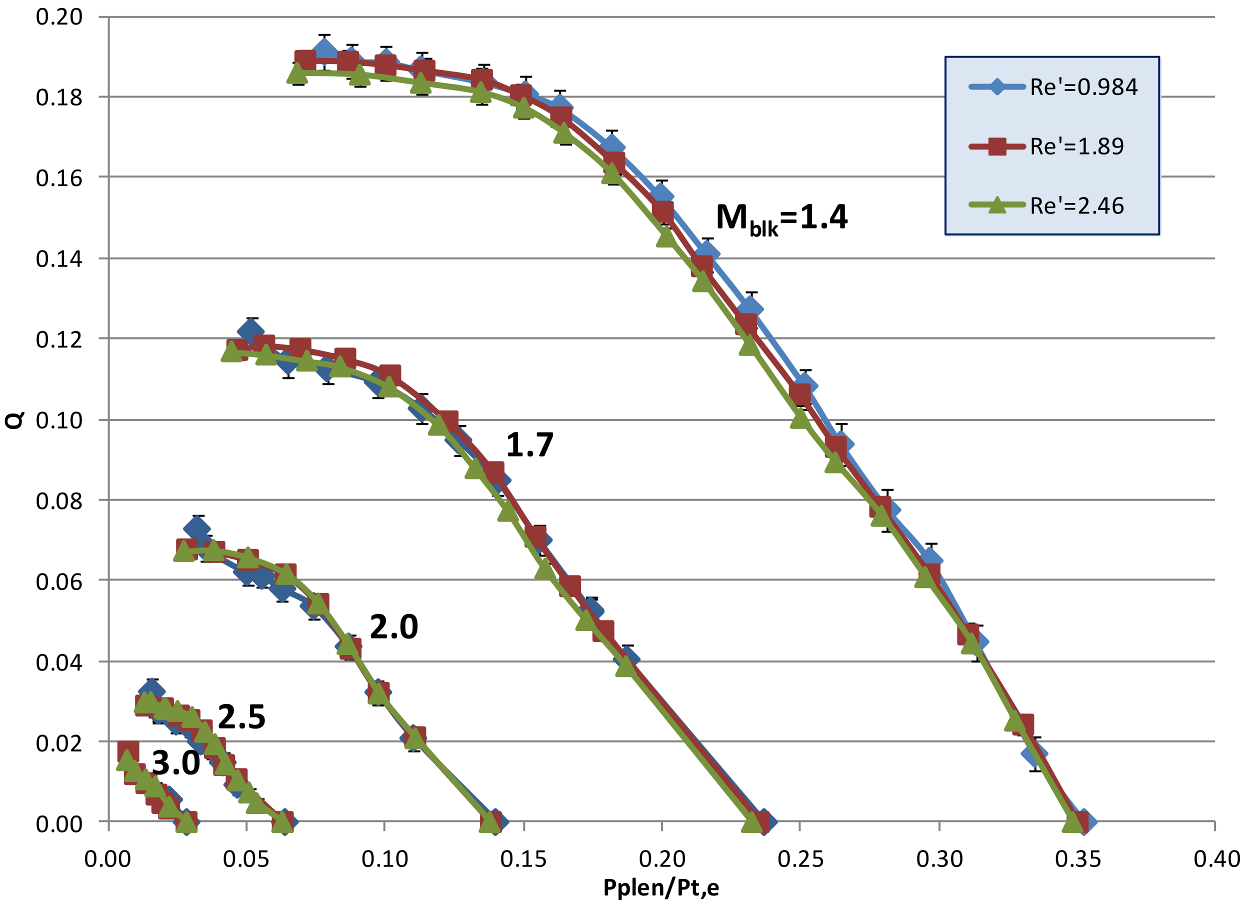




Displacement thickness variation is consistent with Reynolds number.

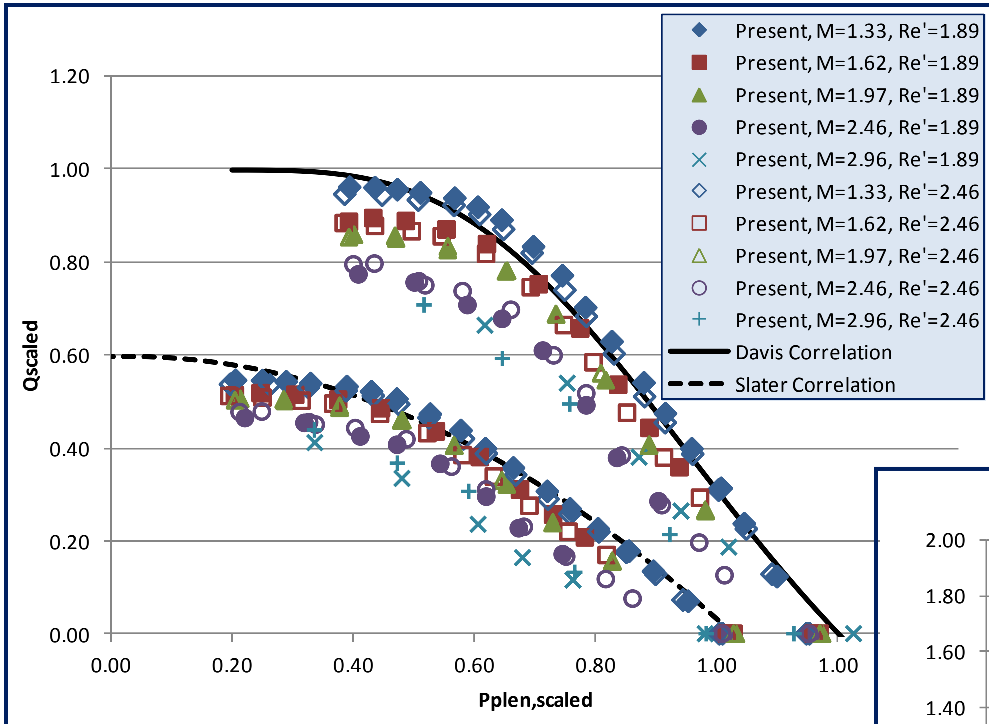
Reynolds Number Dependence

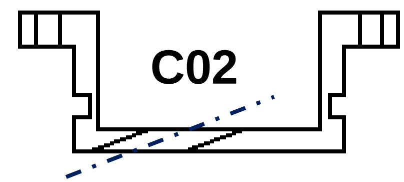


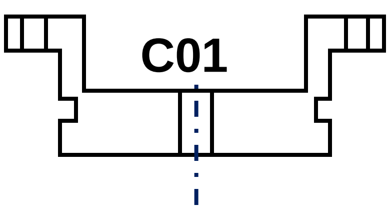


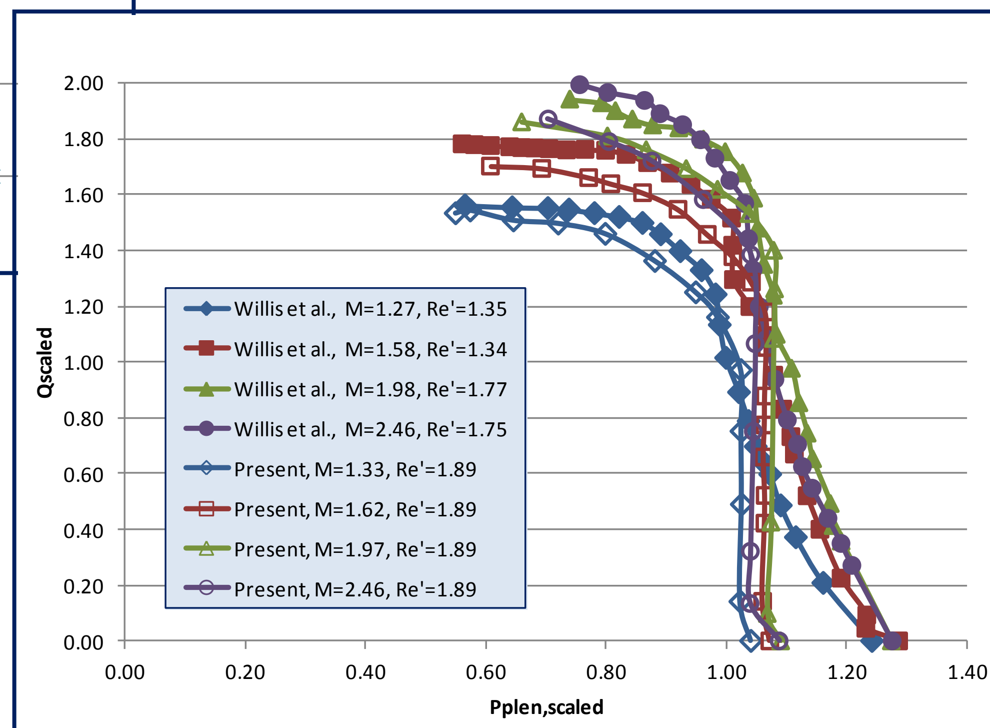
- Tail-up behavior due to sample pump limitation
- Generally there is only a small Reynolds number dependence.

Flow Coefficient Scaling









Phase I Conclusions

- Approach flow conditions established for all Mach numbers and Reynolds numbers.
- Results only weakly dependent on Reynolds number.
- Static pressure scaling:
  - α=90° - Data collapses but not quite as good as multi-hole data of Willis et al.
  - α=20° - As anticipated, data does not collapse.

FIBE PHASE II RESULTS

Results Summarized in AIAA Paper 2013-0272

and

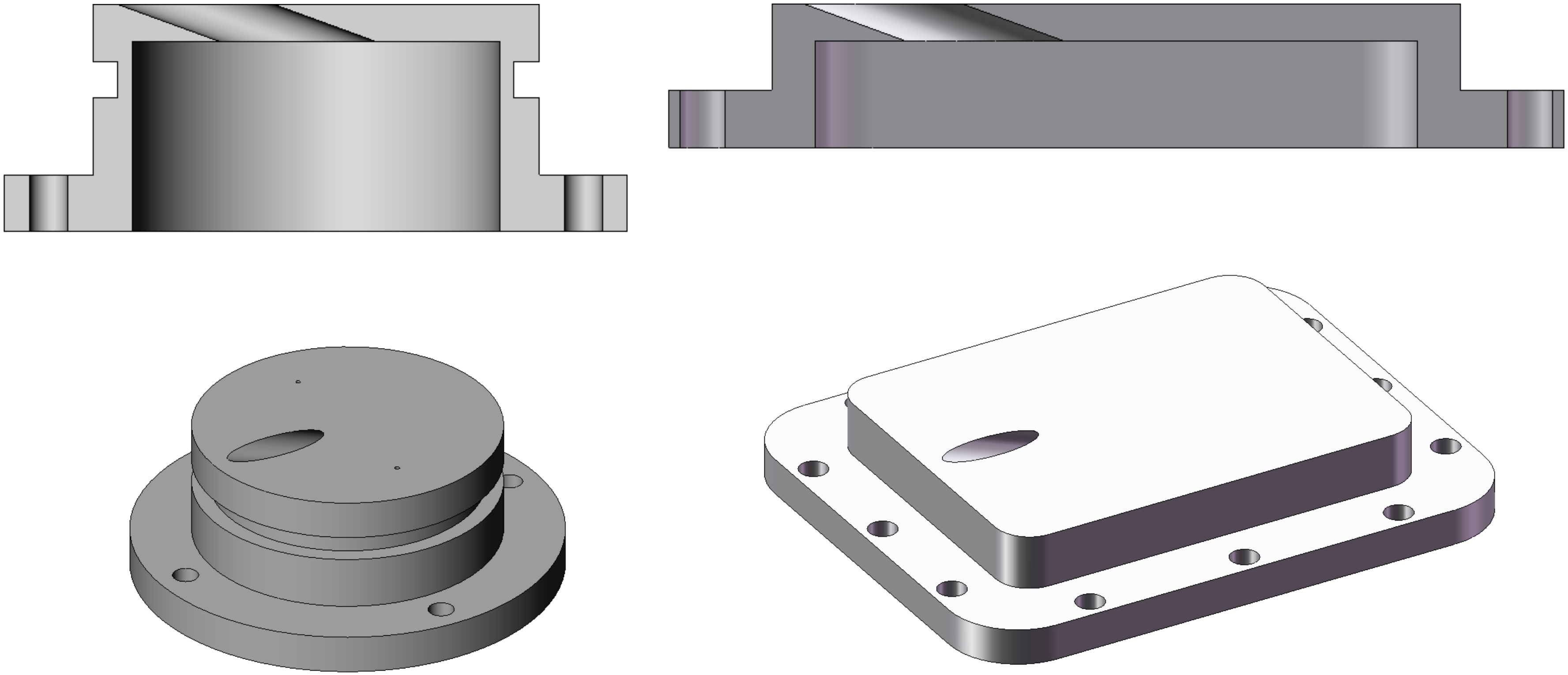
M. Eichorn's MS Thesis (CWRU, In Progress)

Geometry Variavles

- Parameters: α, D, t/D
- Ranges permitted:
  - α – 20° to 90°
  - D – 0.794 to 6.35 mm (0.0313 to 0.250 in)
  - t – 0.893 to 12.7 mm (0.0352 to 0.500 in)
  - t/D – 0.250 to 2.000
- Results in:
  - L/D – 0.250 to 5.85
  - D/δ^* – 0.210 to 2.68

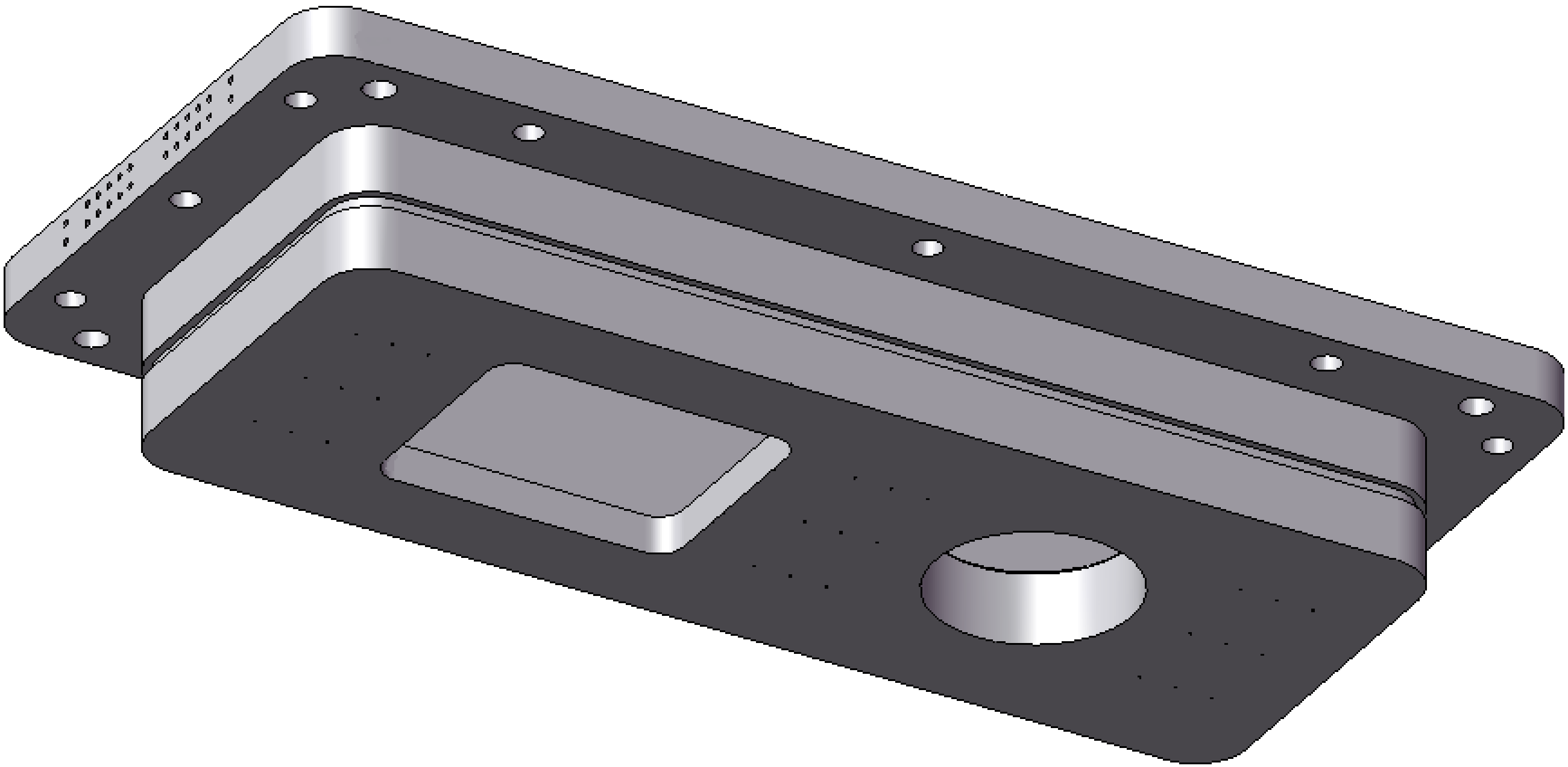
FIBE Phase II Hardware

- Bleed "Plugs" from Phase I were replaced with Bleed "Plates" for Phase II which will allow more flexibility in bleed configurations.



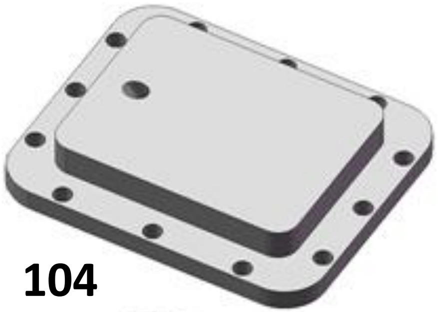
FIBE Phase II Hardware

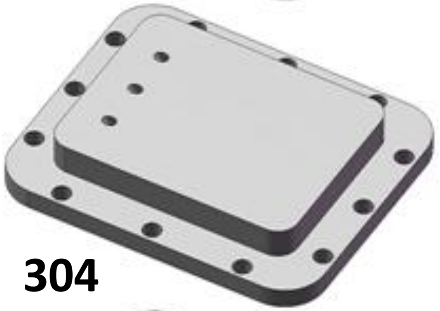
- Phase I top wall is being modified to accept new Bleed Plates. Either Plug or Plate can be used by reversing top wall.



Test Configurations

Config.	Alpha	D (mm)	t (mm)	t/D	L/D	N	Amin/Ab
101	90	6.350	12.700	2.000	2.000	1	1.0
102	90	6.350	7.144	1.125	1.125	1	1.0
103	90	6.350	1.588	0.250	0.250	1	1.0
104	55	6.350	12.700	2.000	2.442	1	1.0
105	55	6.350	7.144	1.125	1.373	1	1.0
106	55	6.350	1.588	0.250	0.305	1	1.1
107	20	6.350	12.700	2.000	5.848	1	1.0
108	20	6.350	7.144	1.125	3.289	1	1.0
109	20	6.350	1.588	0.250	0.731	1	2.3
301	90	3.572	7.144	2.000	2.000	3	1.0
302	90	3.572	4.018	1.125	1.125	3	1.0
303	90	3.572	0.893	0.250	0.250	3	1.0
304	55	3.572	7.144	2.000	2.442	3	1.0
305	55	3.572	4.018	1.125	1.373	3	1.0
306	55	3.572	0.893	0.250	0.305	3	1.1
307	20	3.572	7.144	2.000	5.848	3	1.0
308	20	3.572	4.018	1.125	3.289	3	1.0
309	20	3.572	0.893	0.250	0.731	3	2.3
1501	90	0.794	1.588	2.000	2.000	15	1.0
1504	55	0.794	1.588	2.000	2.442	15	1.0
1507	20	0.794	1.588	2.000	5.848	15	1.0


104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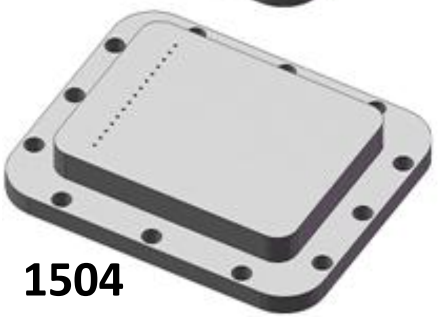
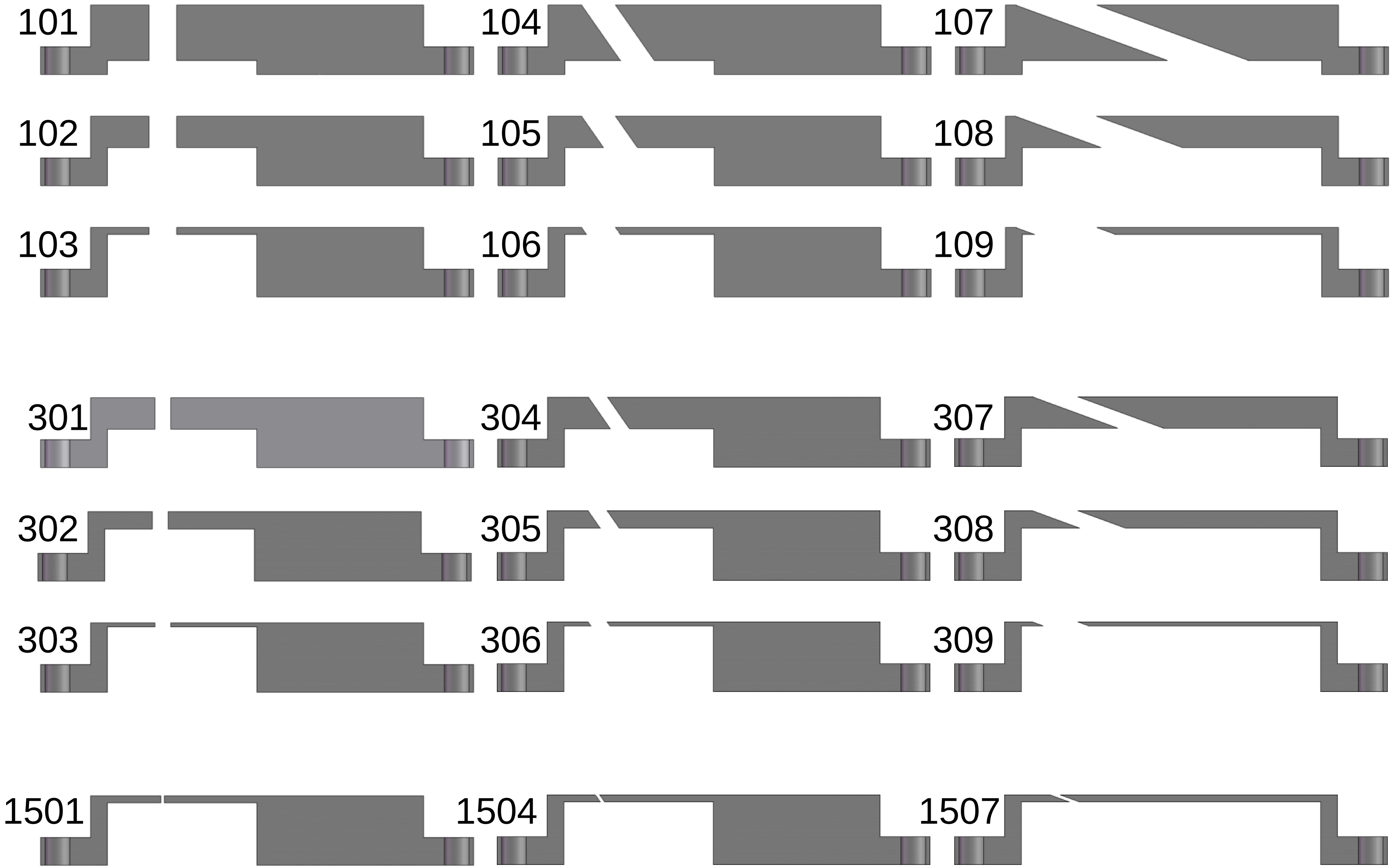
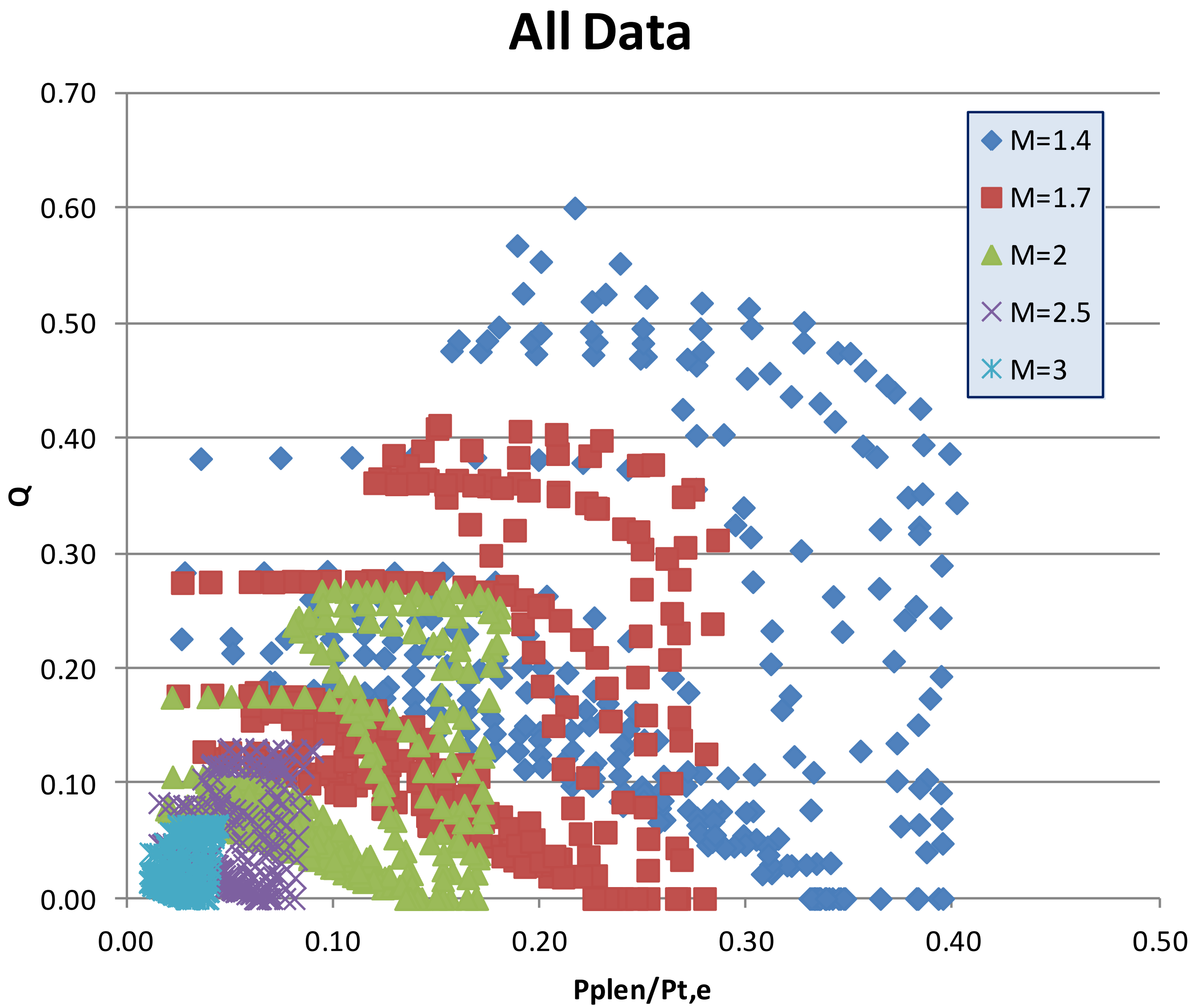

1504

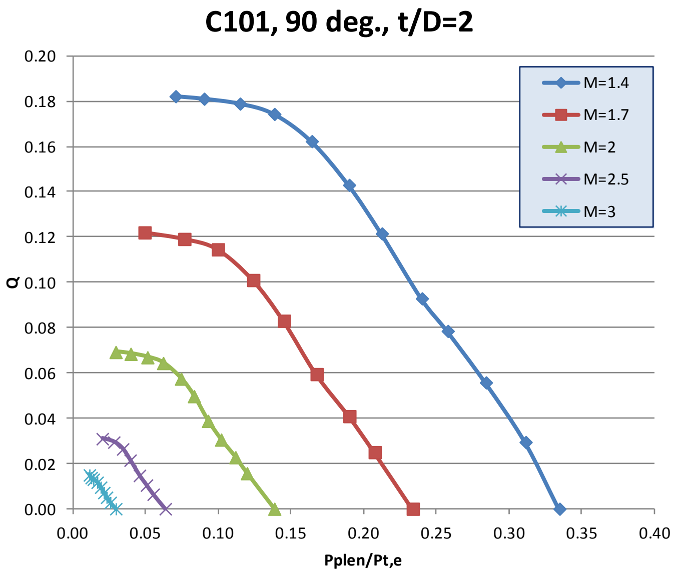
FIBE Phase II – Test Article Matrix

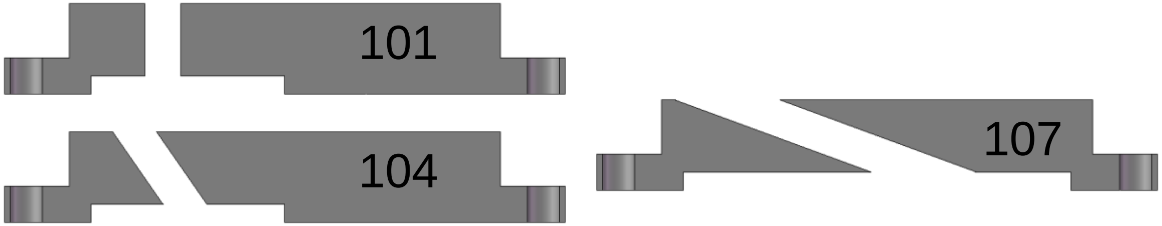


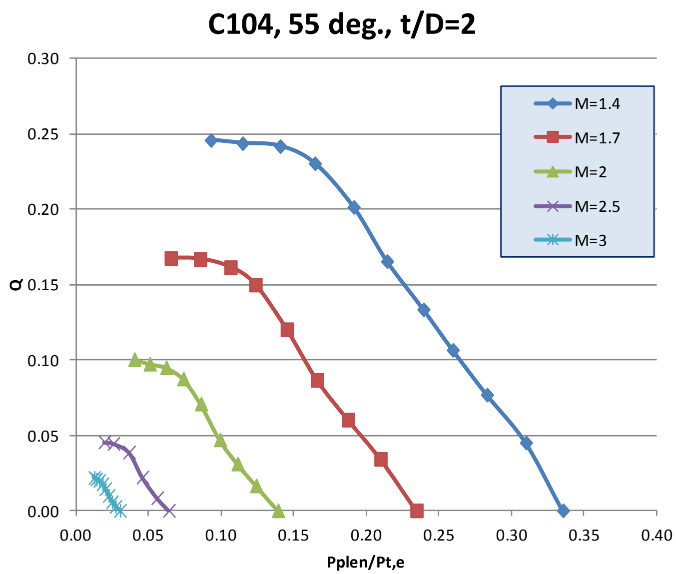
FIBE Phase II Data

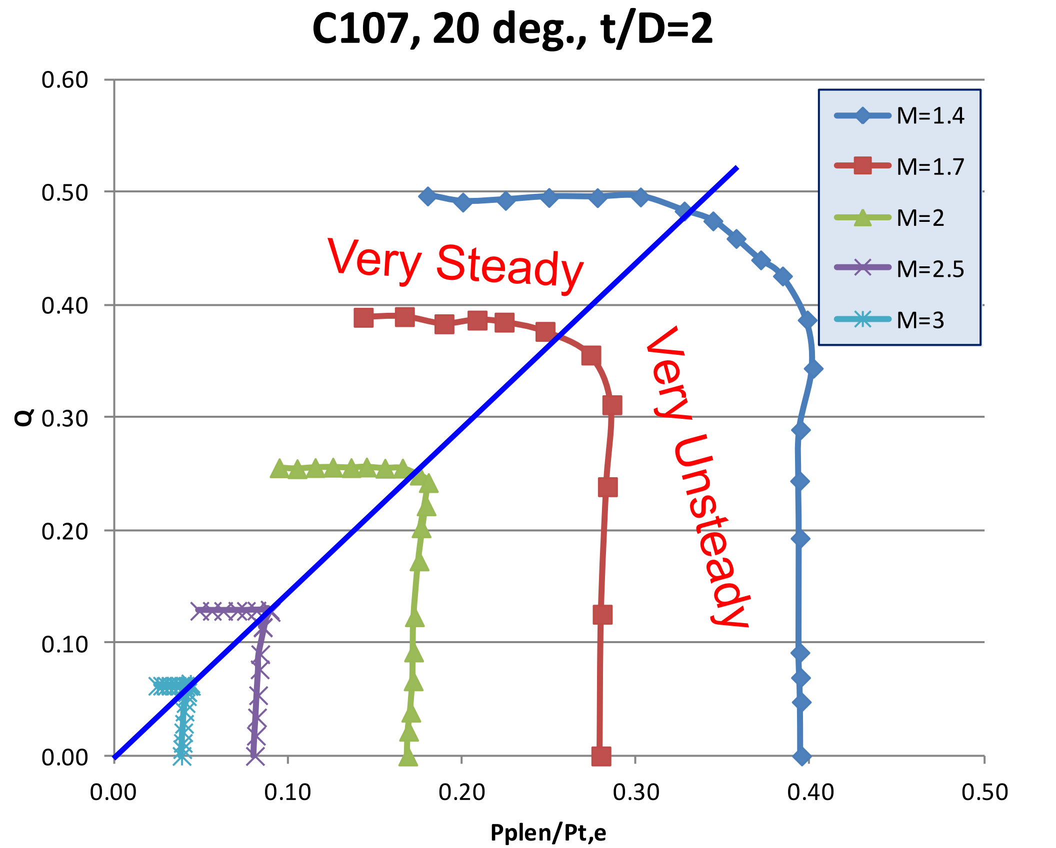


Effect of Mach Number

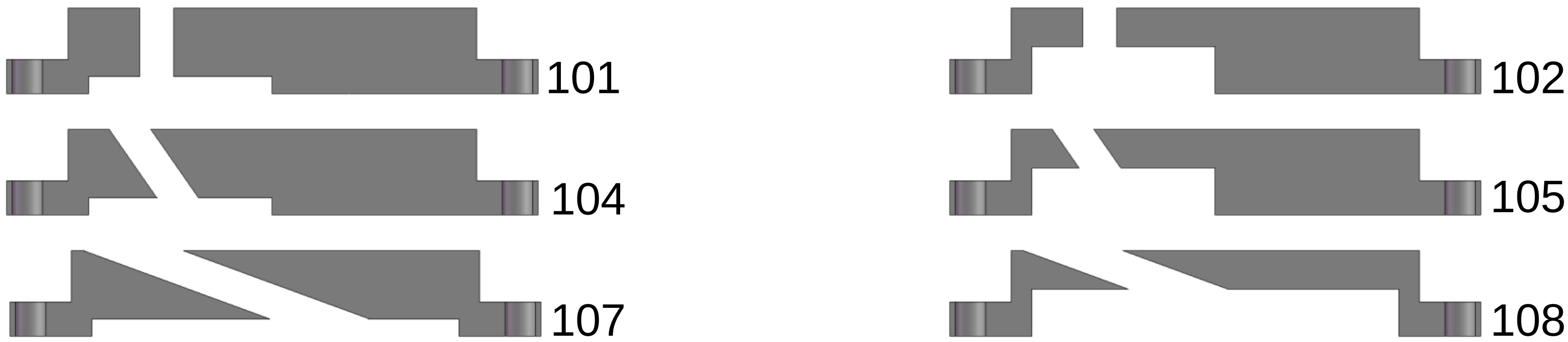


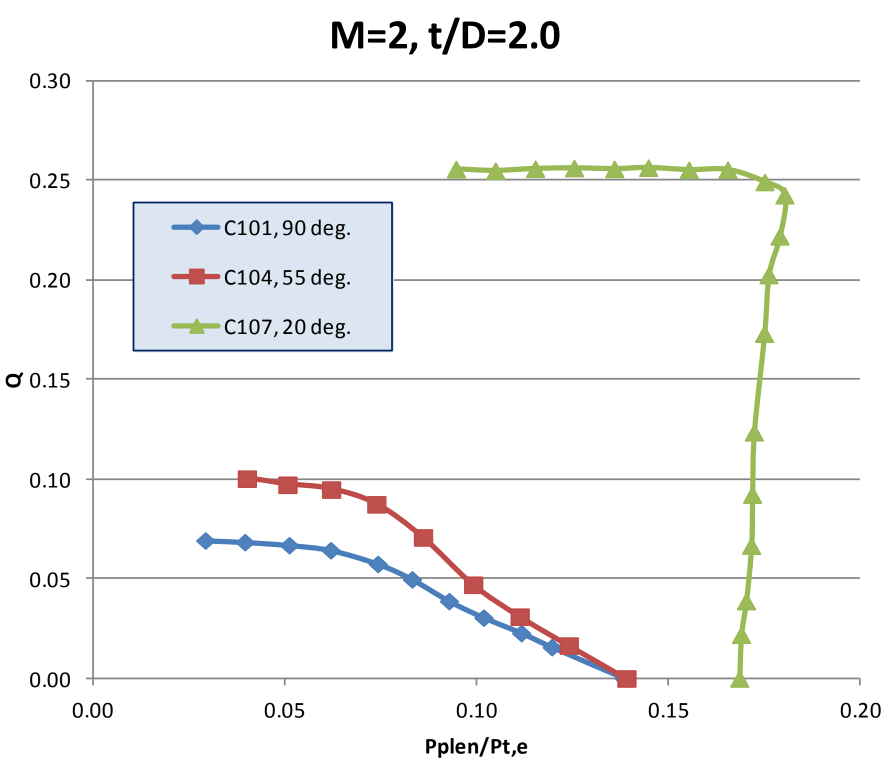


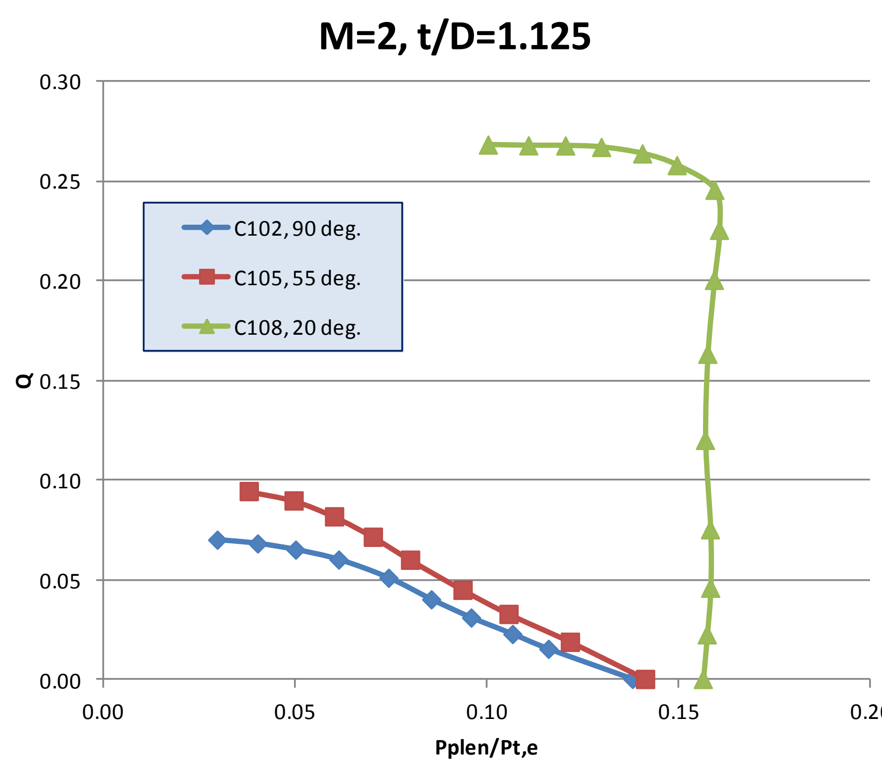




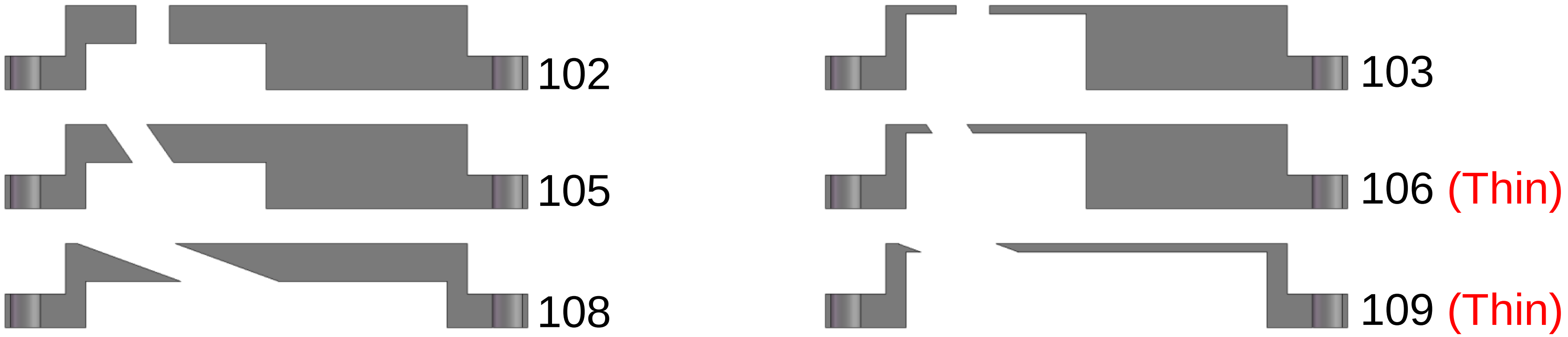
Effect of Hole Inclination Angle

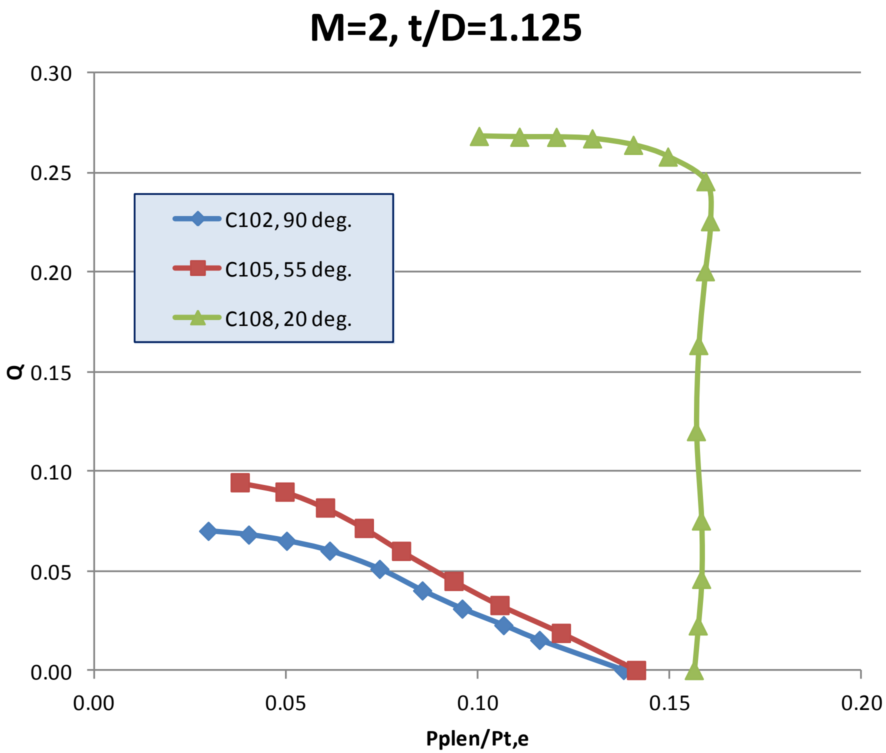


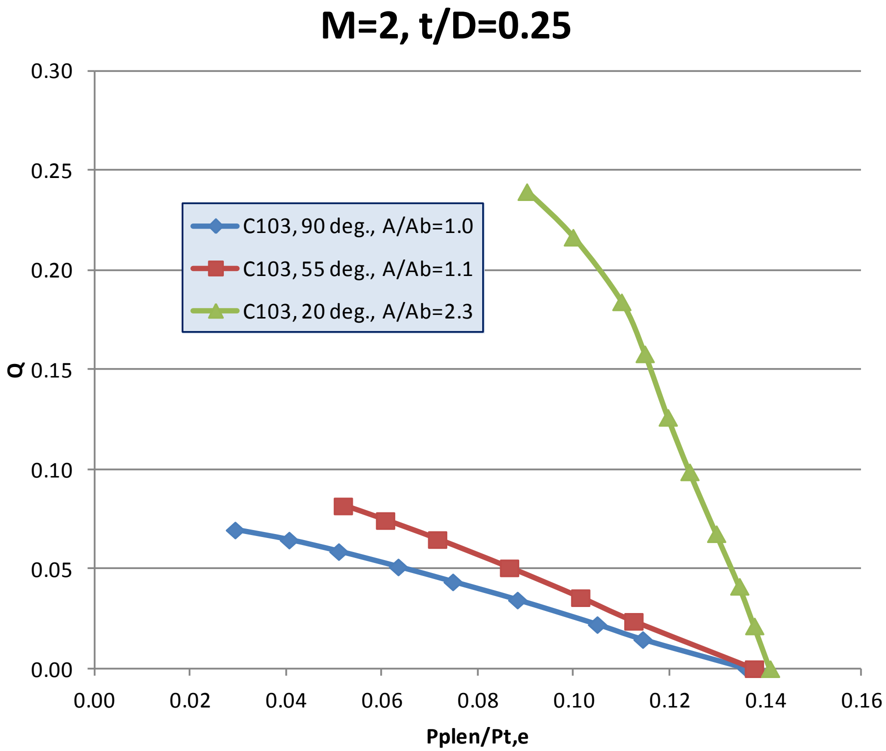




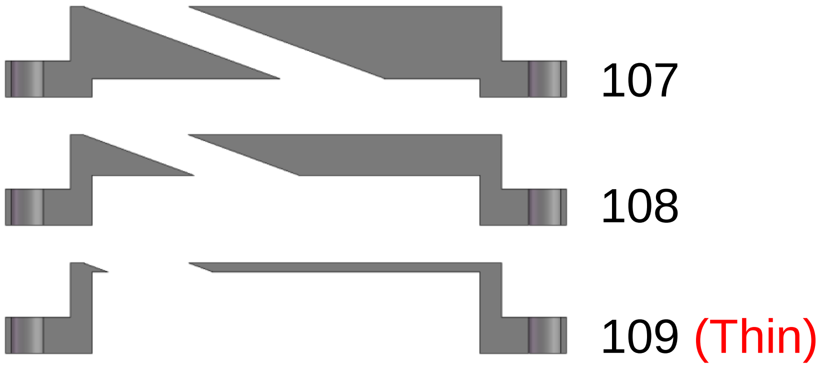
Effect of Hole Inclination Angle (cont).

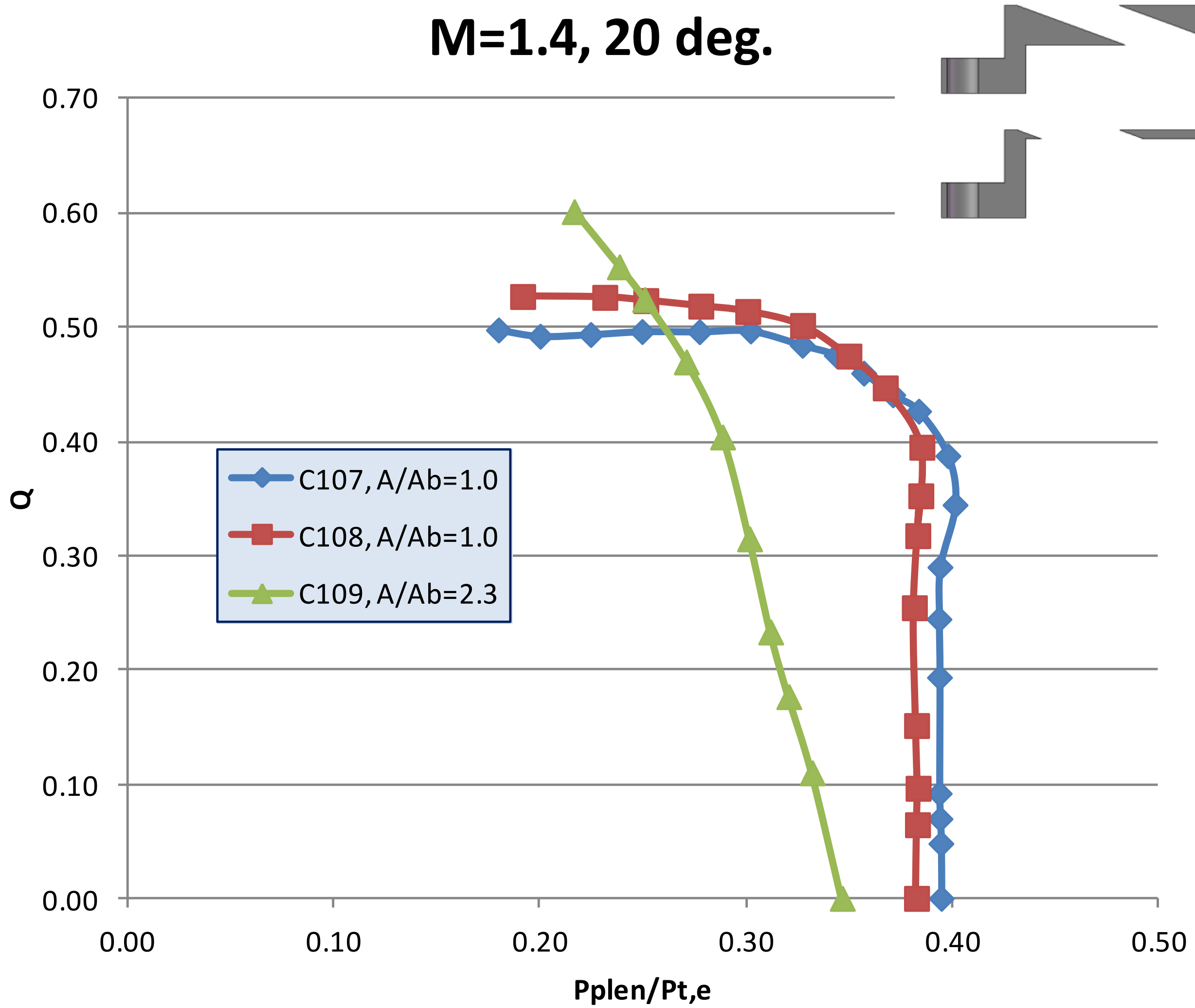






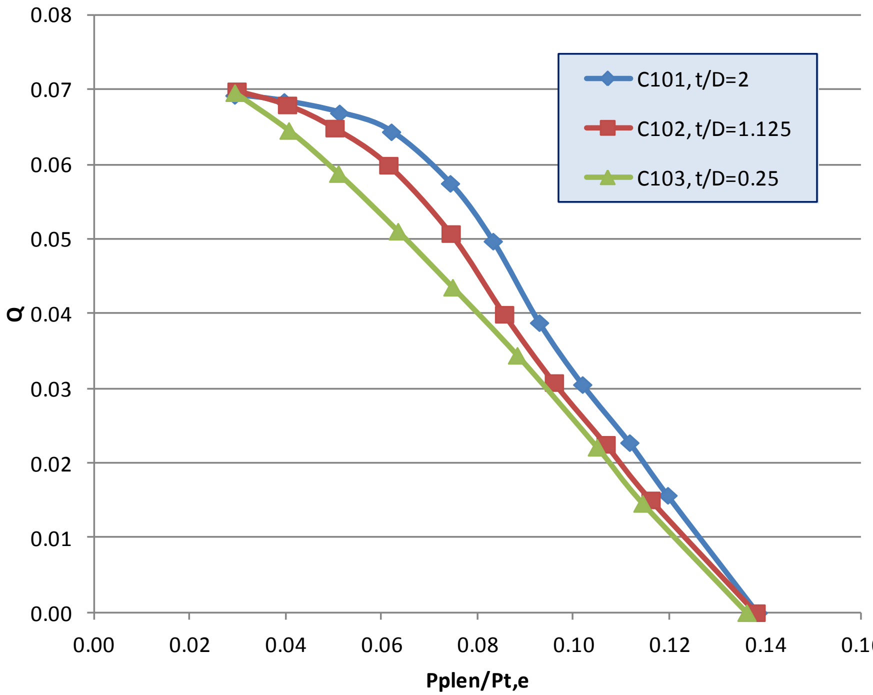
Thick vs. Thin Plate



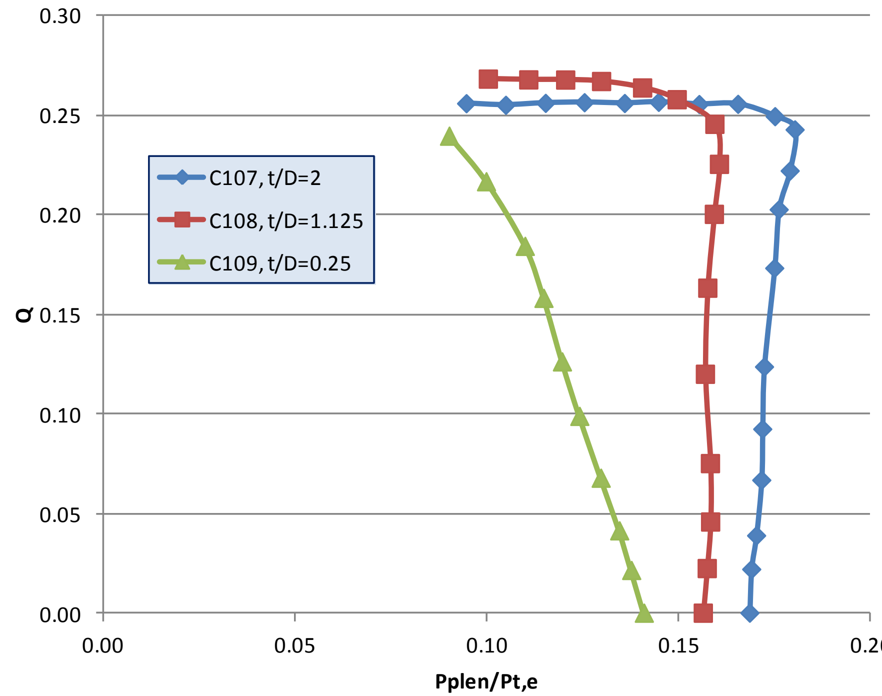


Effect of t/D

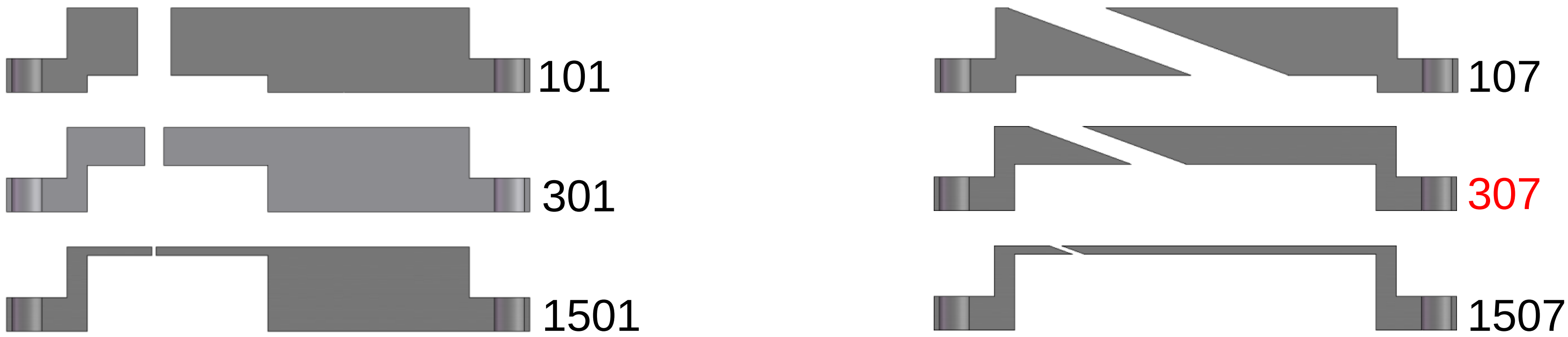
M=2, 90 deg.



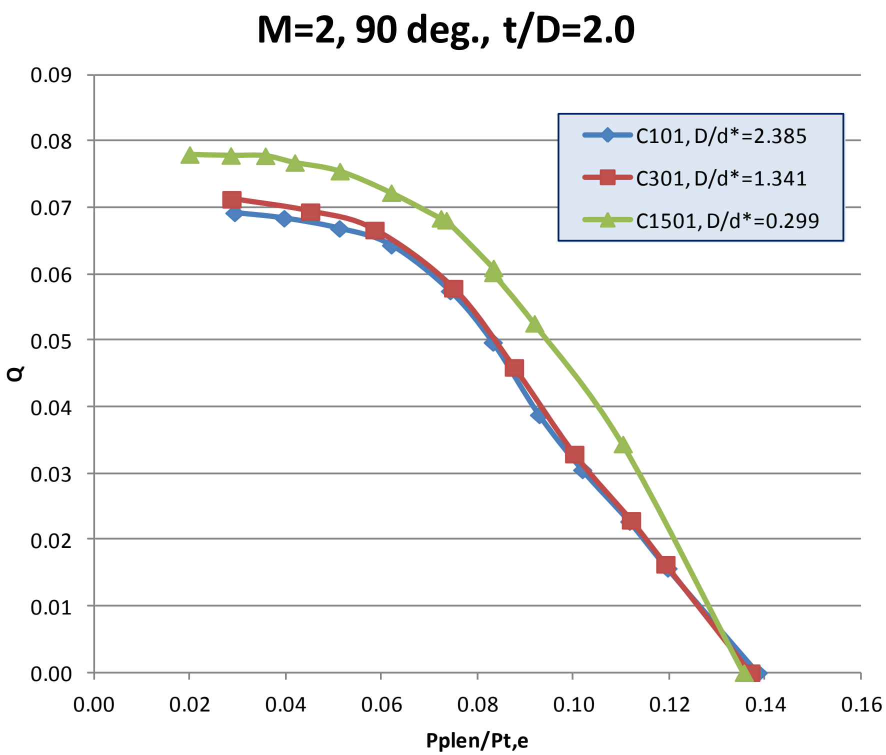
M=2, 20 deg.



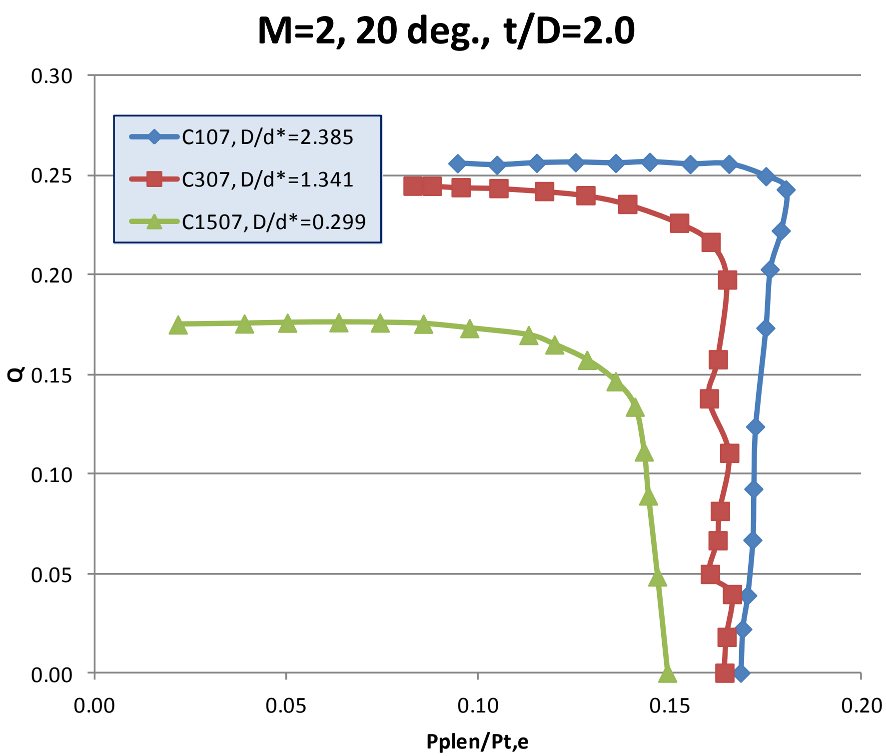
Effect of D/δ*



101
301
1501
107
307
1507

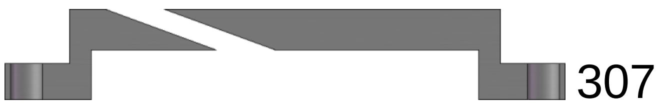


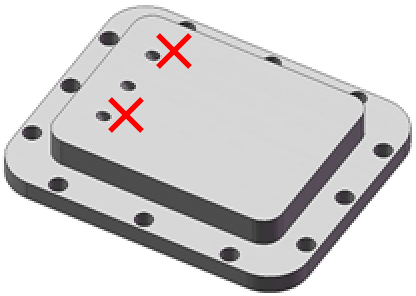
M=2, 90 deg., t/D=2.0
Q
Pplen/Pt,e
C101, D/d*=2.385
C301, D/d*=1.341
C1501, D/d*=0.299
0.00
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.02
0.04
0.06
0.08
0.10
0.12
0.14
0.16



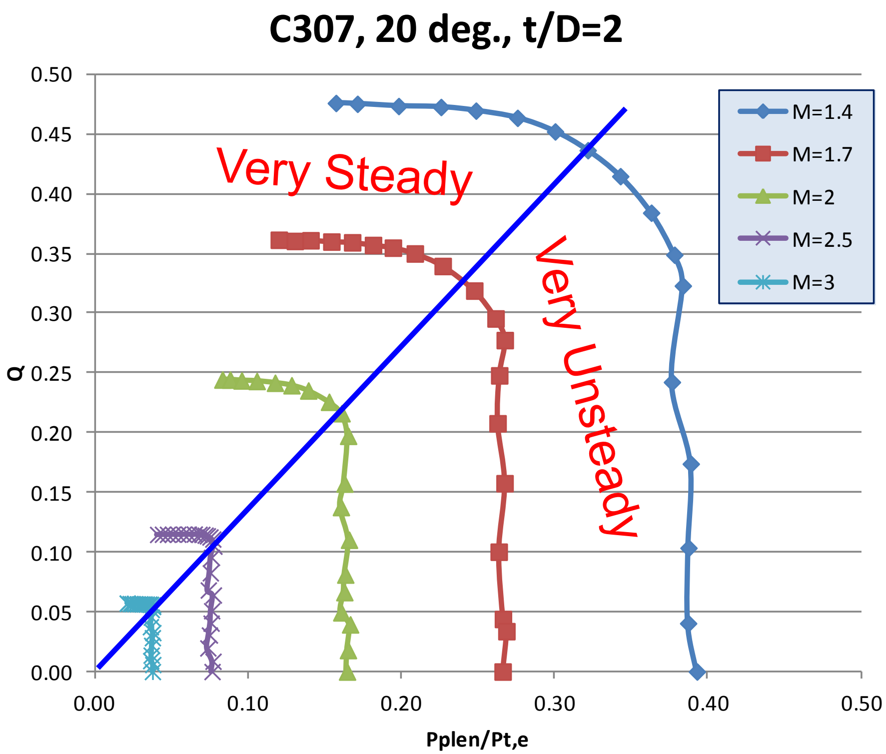
M=2, 20 deg., t/D=2.0
Q
Pplen/Pt,e
C107, D/d*=2.385
C307, D/d*=1.341
C1507, D/d*=0.299
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.00
0.05
0.10
0.15
0.20

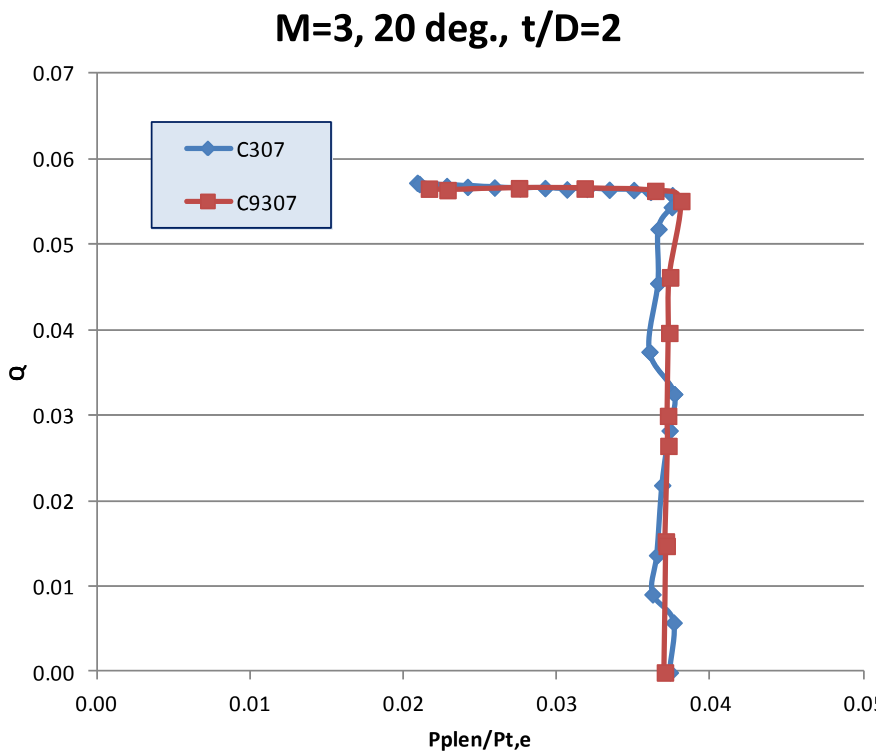
Unsteady Observation



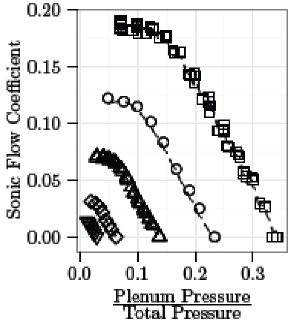


9307 has outboard holes of 307 plugged

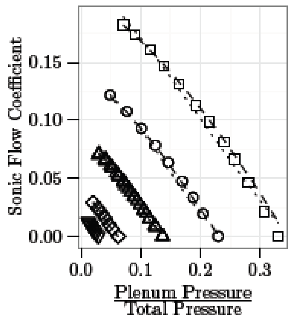




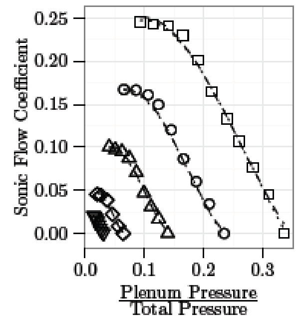
Preliminary Statistical Model



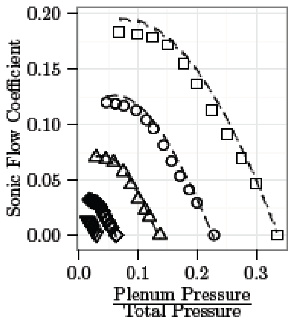
(a) Plate 101: $\alpha = 90°$, $D = 6.339\,\text{mm}$, $t/D = 2.011$



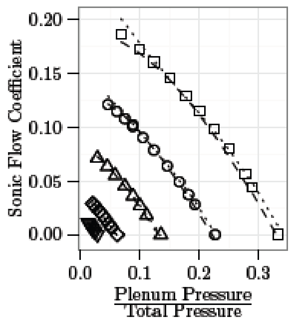
(b) Plate 103: $\alpha = 90°$, $D = 6.337\,\text{mm}$, $t/D = 0.259$



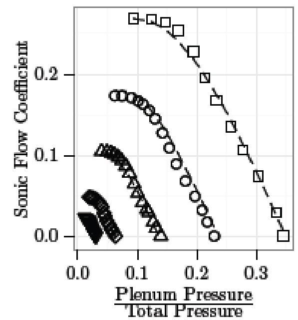
(c) Plate 104: $\alpha = 55°$, $D = 6.354\,\text{mm}$, $t/D = 2.005$



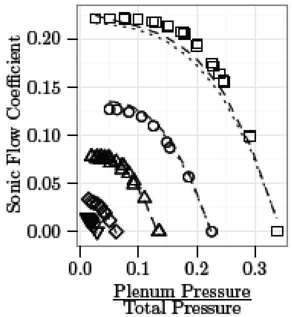
(d) Plate 301: $\alpha = 90°$, $D = 3.585\,\text{mm}$, $t/D = 1.984$



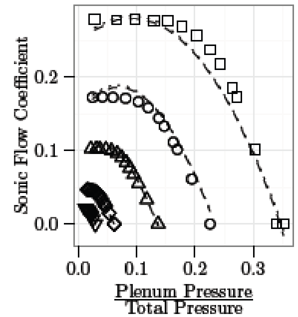
(e) Plate 303: $\alpha = 90°$, $D = 3.561\,\text{mm}$, $t/D = 0.266$



(f) Plate 304: $\alpha = 55°$, $D = 3.545\,\text{mm}$, $t/D = 2.002$



(g) Plate 1501: $\alpha = 90°$, $D = 0.794\,\text{mm}$, $t/D = 2.115$



(h) Plate 1504: $\alpha = 55°$, $D = 0.794\,\text{mm}$, $t/D = 2.003$

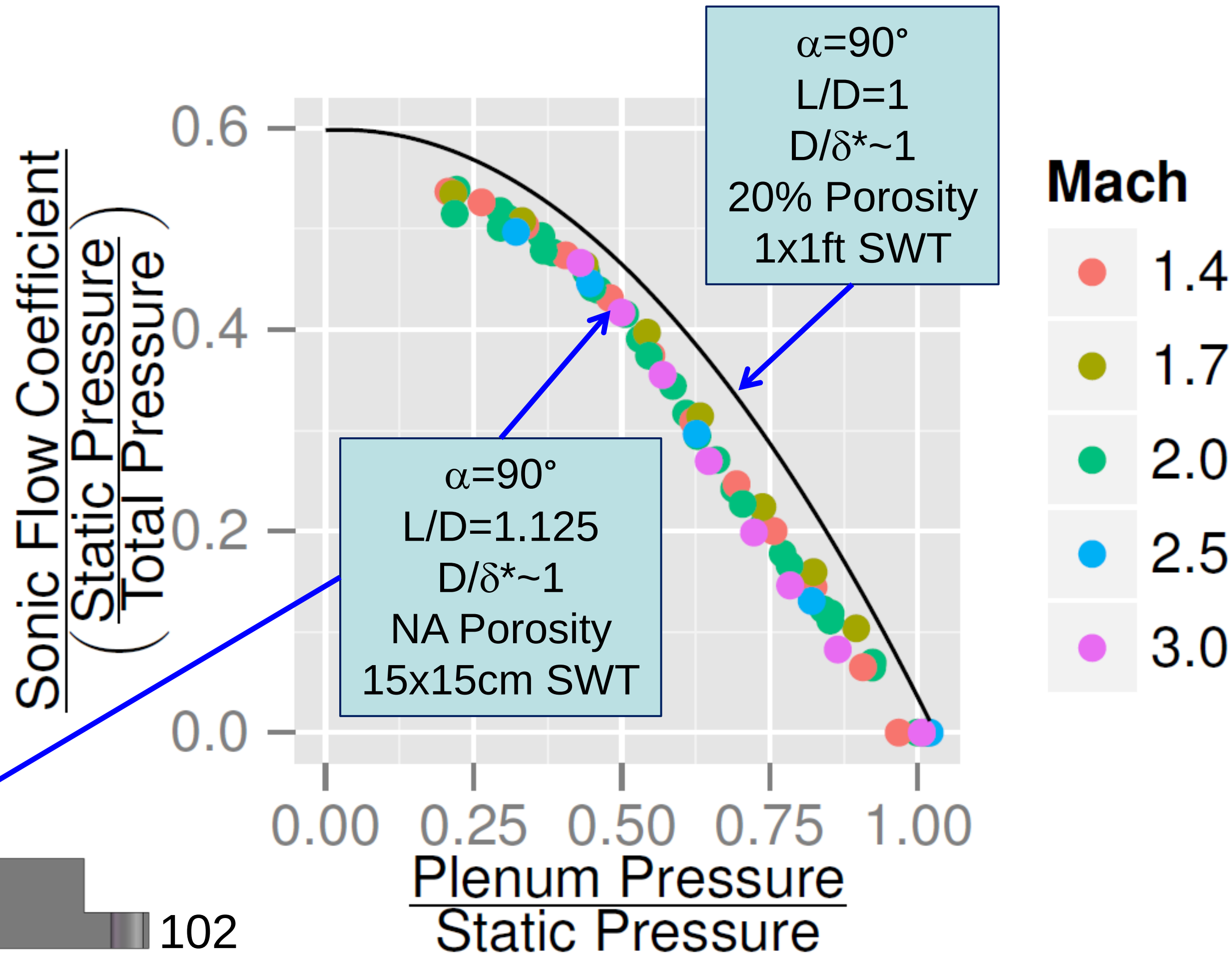
$$Q_{scaled} = \sum_{i=1}^{N_t} c_i \cdot I_i$$

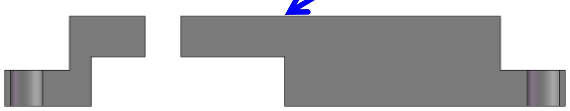
Model excludes 20° data

·············· Nt = 26

- - - - - Nt = 43

Flow Coefficient Scaling





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FIBE Phase III testing to look at multi-hole arrays under same conditions as isolated holes.

Phase II Summary

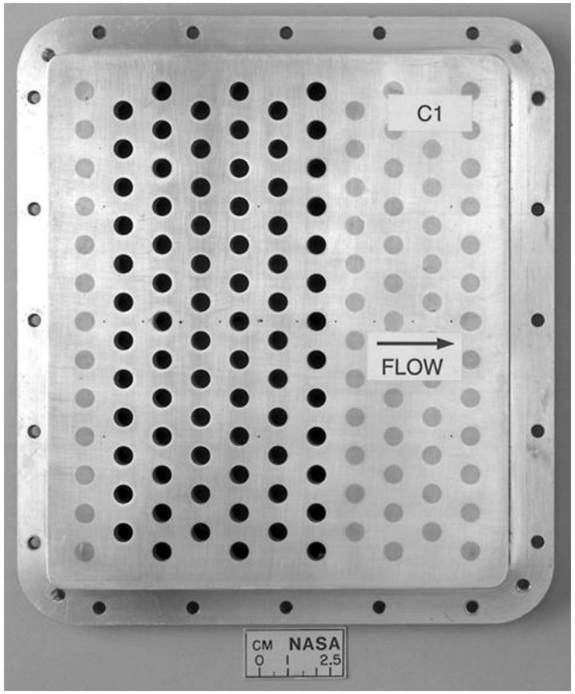
- Comprehensive isolated-hole flow coefficient database obtained.
  - Some cases incomplete surveys due to bleed capacity limitations.
  - Plenum dynamic pressures recorded.

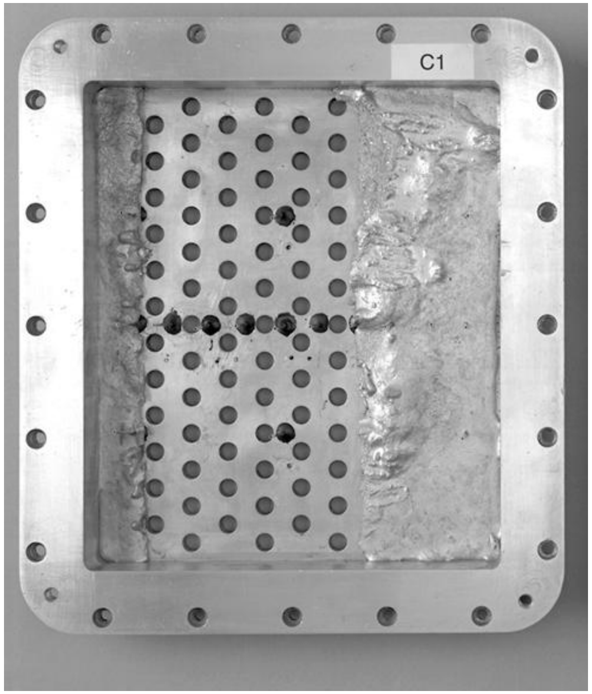
- Analysis and model development continues at CWRU
  - M. Eichorn MS Thesis (Summer 2013)
  - Improved statistical model
  - Flow physics based model
  - Unsteady pressure data analysis

FIBE PHASE III TEST PLANNING

FIBE Phase III

- Near Term – Flow Coefficient for Hole Arrays
  - 15x15cm SWT – Same flow conditions as Phase II
  - Initially focus on 90° holes with same parameters as Phase II
  - Porosity 10, 20, 30, 40%
  - Accumulate data with N_{row}=1, 2, 3, etc



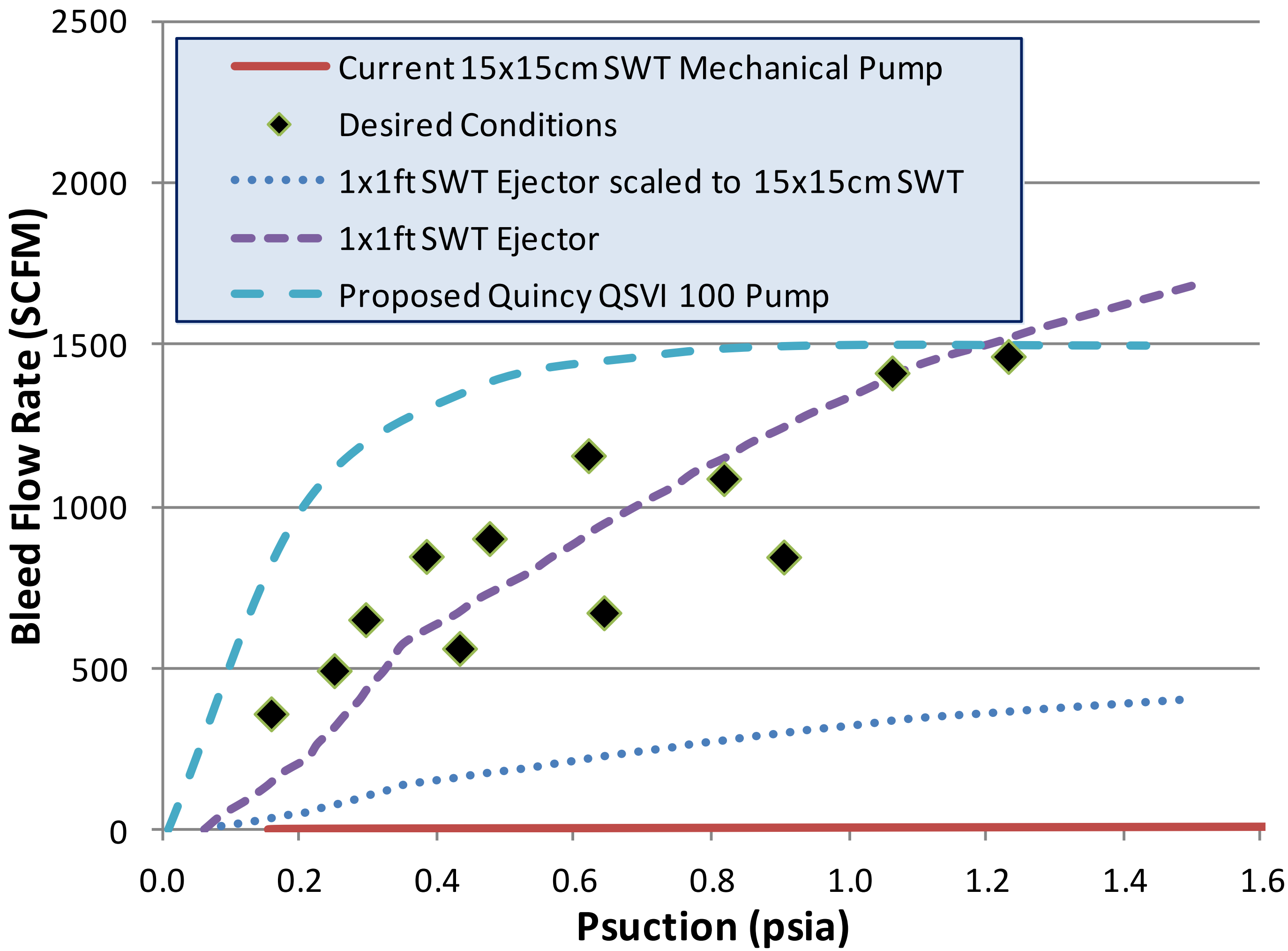


Rows filled with Cerrobend (low melting point alloy)

FIBE Phase III

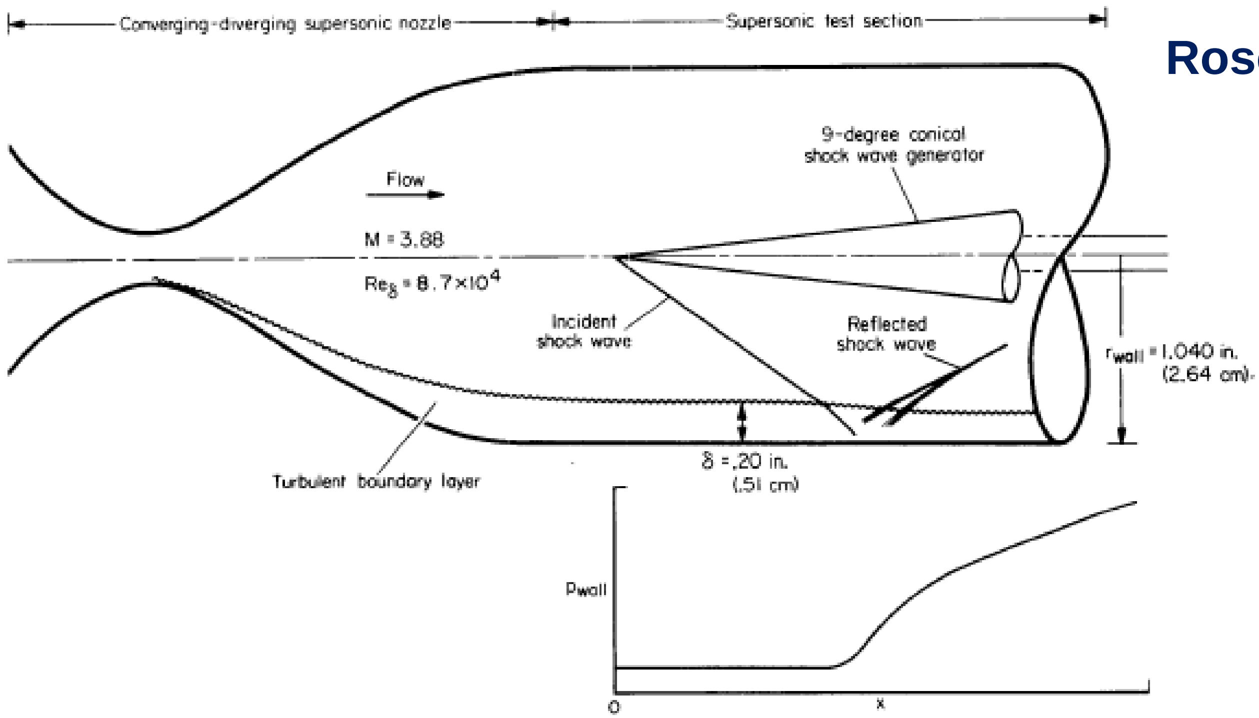
- 15x15cm SWT Bleed Capacity Upgrade
  - Current mechanical Stokes pump capacity limits bleed configurations to isolated-hole.
    - Not adequate for all the configurations of Phase II
  - To perform Phase III testing, target is to have ability to remove 100% of the boundary layer on two walls of the tunnel over Mach number range from 1.4 to 3.0.
  - Proposal submitted to NASA GRC Technology Investment Fund
    - TIF funds $100K (later augmented to a higher level)
    - Proposal total cost $57K (excludes some installation costs)

FIBE Phase III

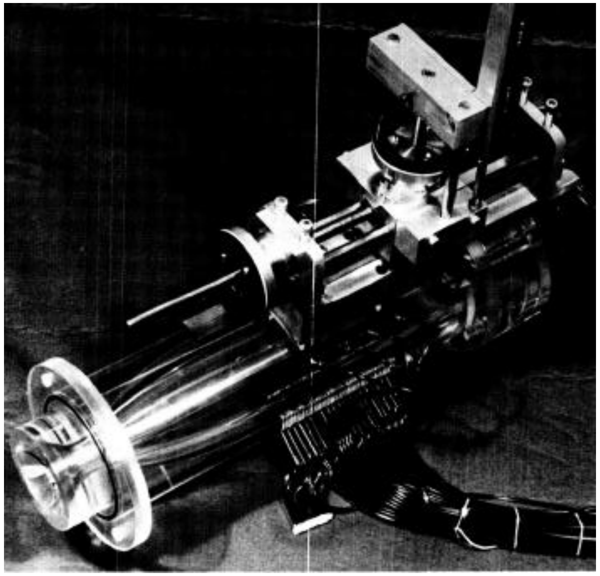


FIBE Phase III

- 15x15cm SWT Axisymmetric Test Section
  - Genesis from CFD Turbulence Model Validation Experiments
    - NASA FAP Aero Sciences Project study.
  - Also appropriate for “Cornerless Bleed Experiments”
    - Test Section Diameter ~ 17cm (6.7in)
    - Still need enhanced bleed capacity.



Rose, 1973, NASA TN D-7029



Questions?