National Aeronautics and Space Administration

Fundamental Aeronautics Program

Supersonics Project

Fundamental Inlet Bleed Experiments (FIBE) Overview

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FUNDAMENTAL INLET BLEED EXPERIMENTS (FIBE)

FIBE Team Members

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Michael Eichorn – CWRU Graduate Student

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

Background

- June 1992 – Inlet/Nozzle Technology for the 90's Workshop was held at OAI.
  - An outcome of that workshop was the need for a Bleed Specific Workshop
- Sept. 1993 – Inlet Bleed Technology Workshop was held at OAI.
  - Bleed research needs were identified.
- 1994 to1997 – NASA LeRC had an active bleed research program primarily in the 1x1ft SWT but also the 15x15cm SWT.
- 2008 - NASA GRC made a decision to re-establish bleed research capability in the 15x15cm SWT.
  - Cost was a factor for selecting 15x15cm SWT.
  - New test section had been installed in the 1x1ft SWT and incompatible bleed test hardware had been scrapped

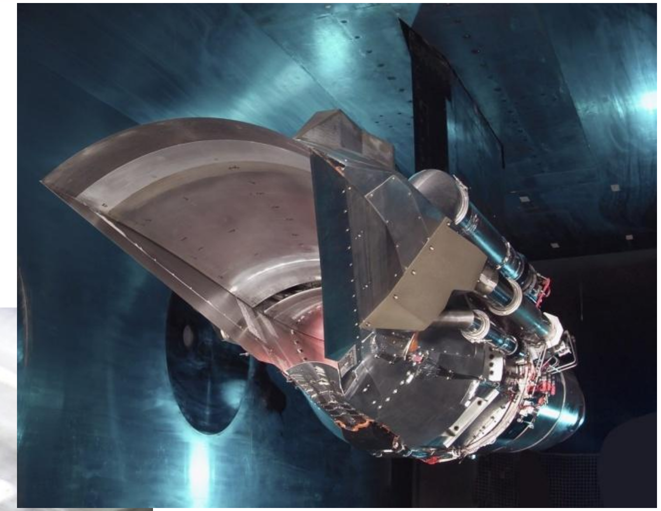
Motivation – Why Bleed Research?

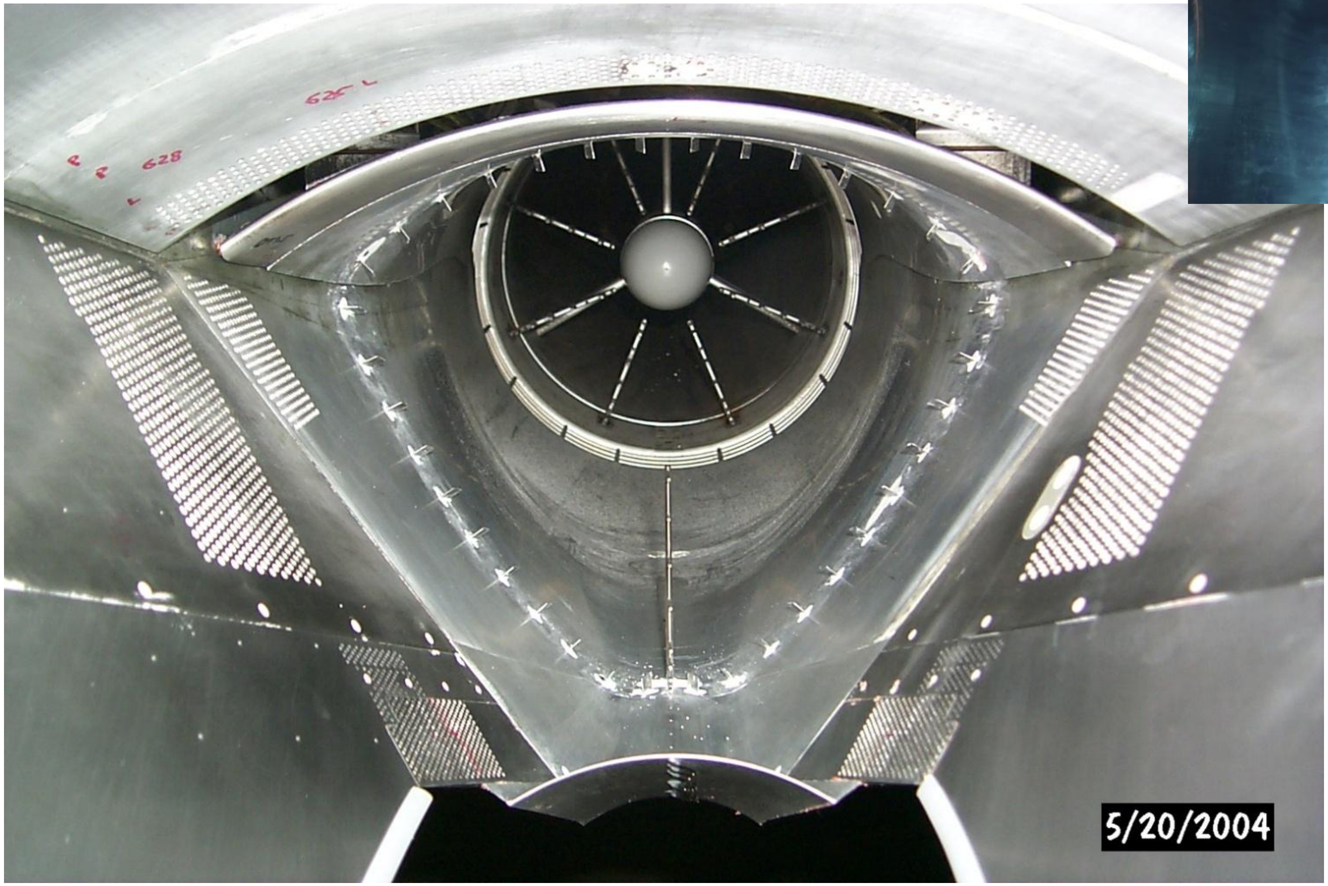
- Recently there has been a substantial amount of research on low-bleed and no-bleed inlet designs that use alternate flow control devices:
  - Micro-vanes, micro-ramps, and hybrid micro-ramp/blowing
  - Corner fillets
  - Plasma actuators
- These devices will likely first find their way onto lower Mach number axisymmetric external compression inlets. Corner interactions on 2-D external compression inlets creates a greater challenge.
- Higher Mach (>2.0) mixed compression inlets require stability bleed and will likely to continue to require performance bleed.
- Further, there is also the persistent discrepancy between bleed requirements of scale model inlets and flight inlets that needs to be better understood.*

*Inlet/Engine Compatibility - From Model to Full Scale Development (SAE AIR5687)

Parametric Inlet with Bleed

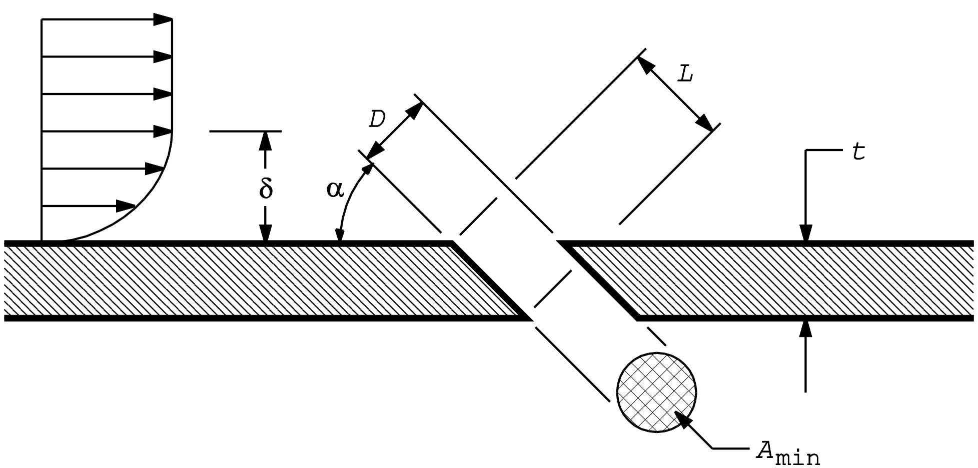
Design Mach Number =2.4
External Compression





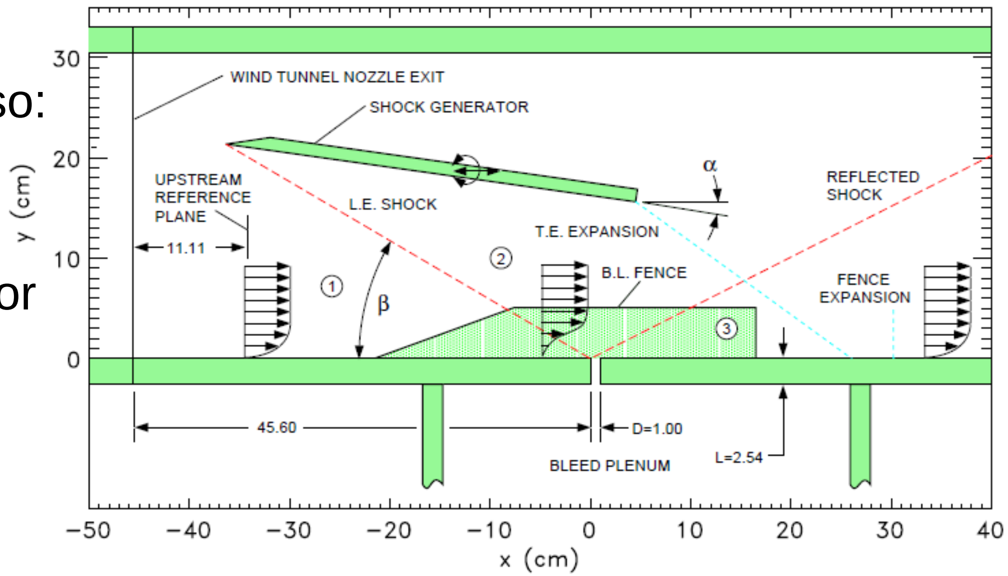
FIBE Phase Objectives

- 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.
    - Establish measurement uncertainty.
  - Phase II – 15x15cm SWT
    - Obtain flow coefficient data for single-hole or non-interacting multi-hole configurations.
      - Inclination Angle
      - L/D
      - D/δ_1
    - Dynamic Plenum Pressure Measurements

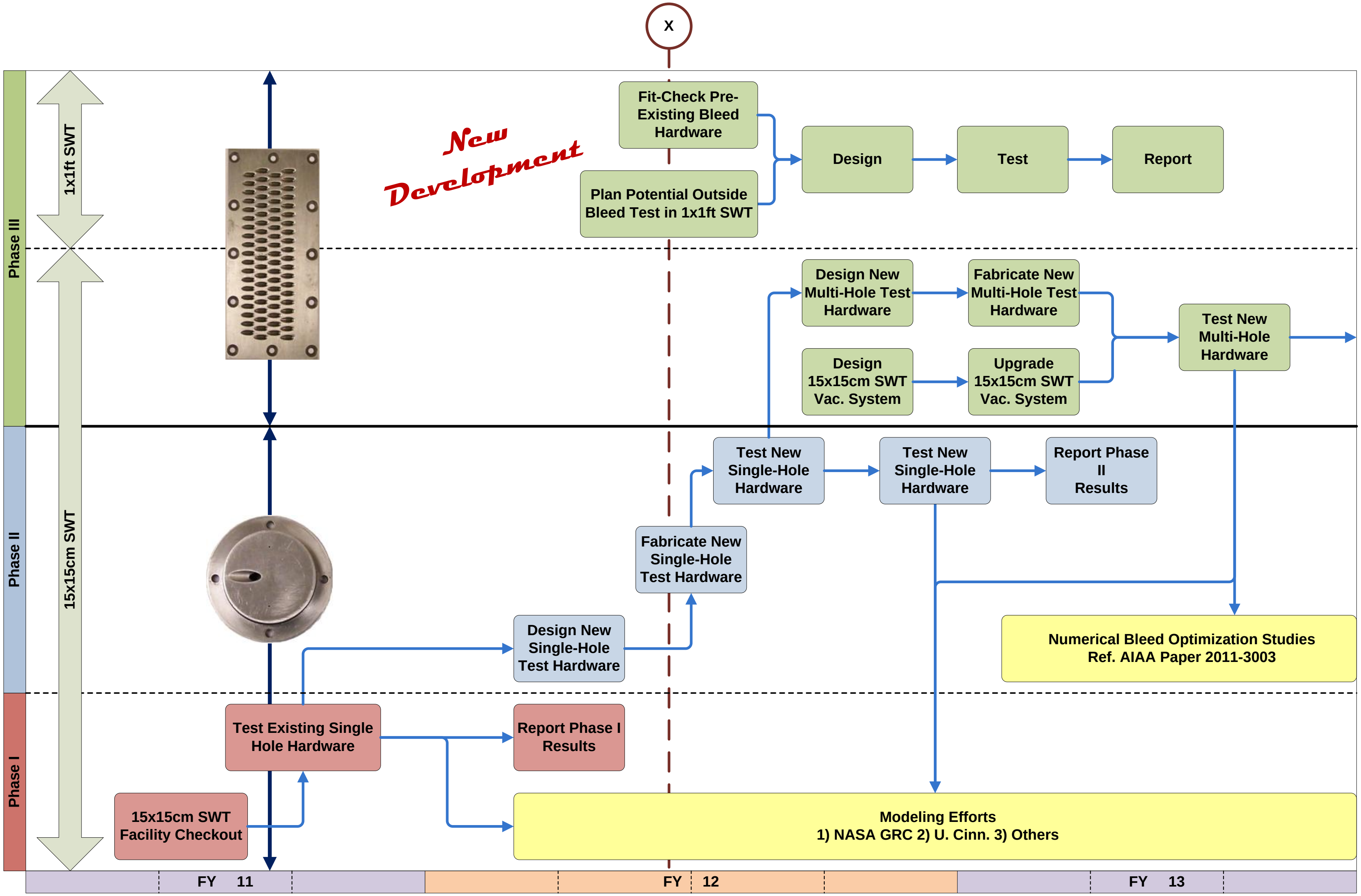


FIBE Phase Objectives

- 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.



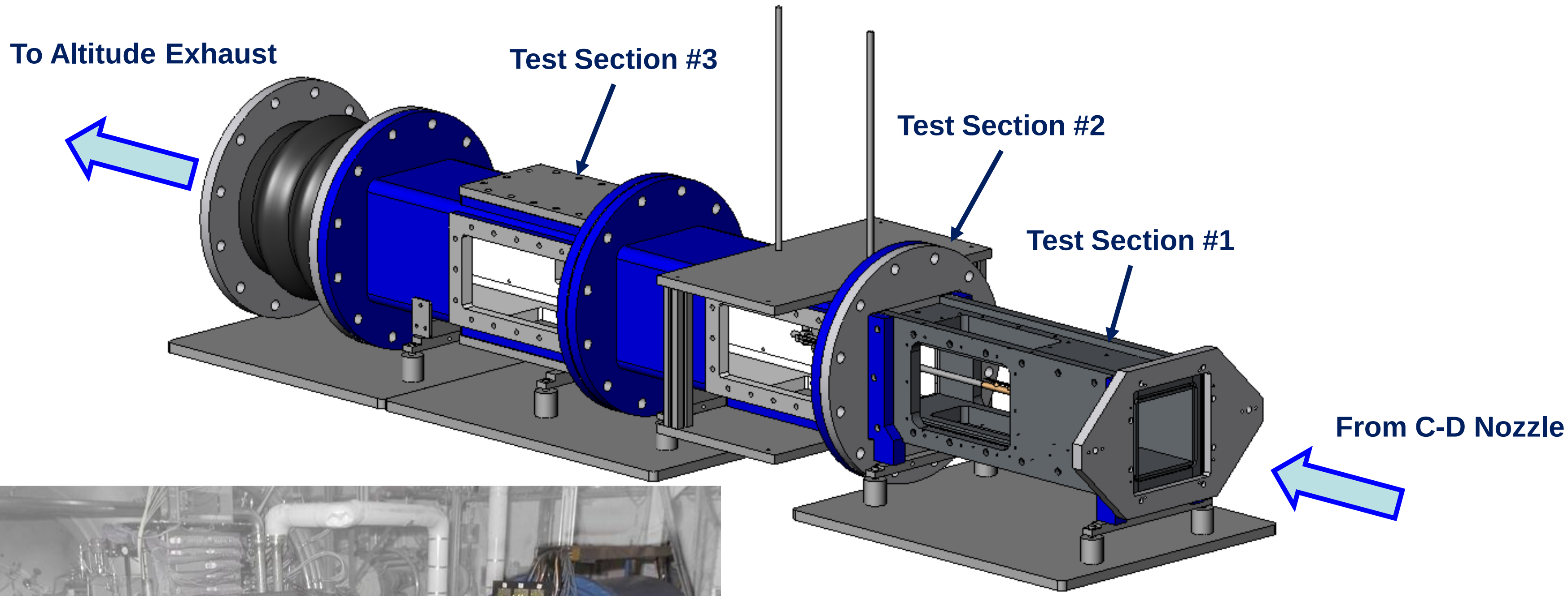
FIBE Project Flow Logic



FIBE PHASE I TEST PROGRAM

Results Summarized in AIAA Paper 2012-0272

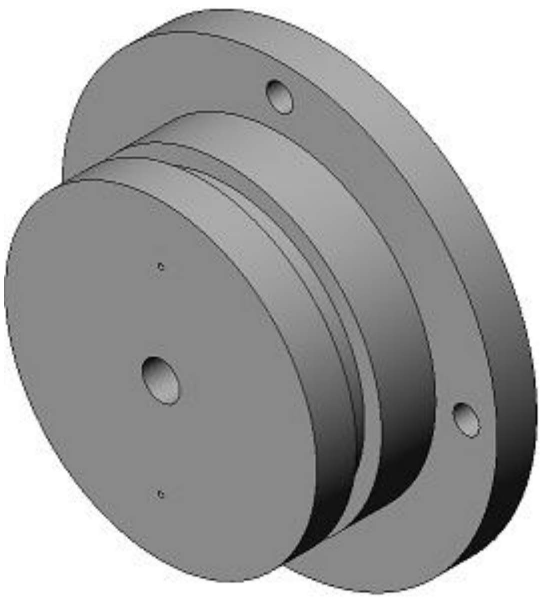
15x15cm Supersonic Wind Tunnel



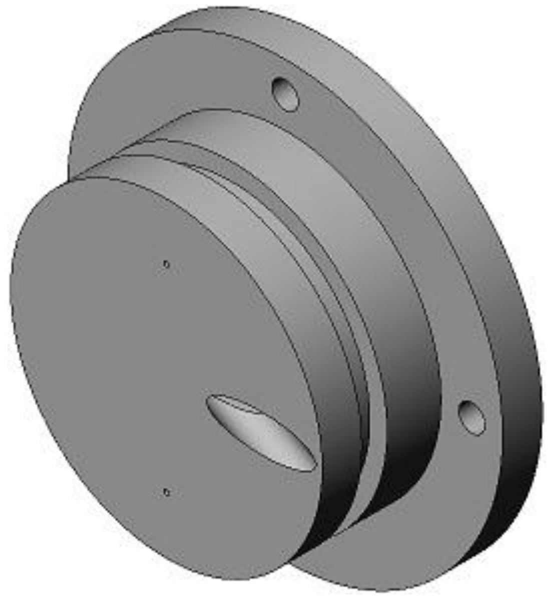
15x15 cm Supersonic Wind Tunnel

- 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

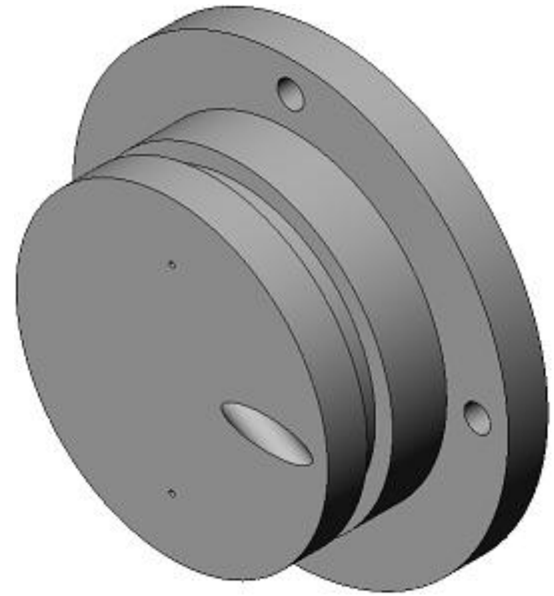
Pre-Existing Test Articles



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

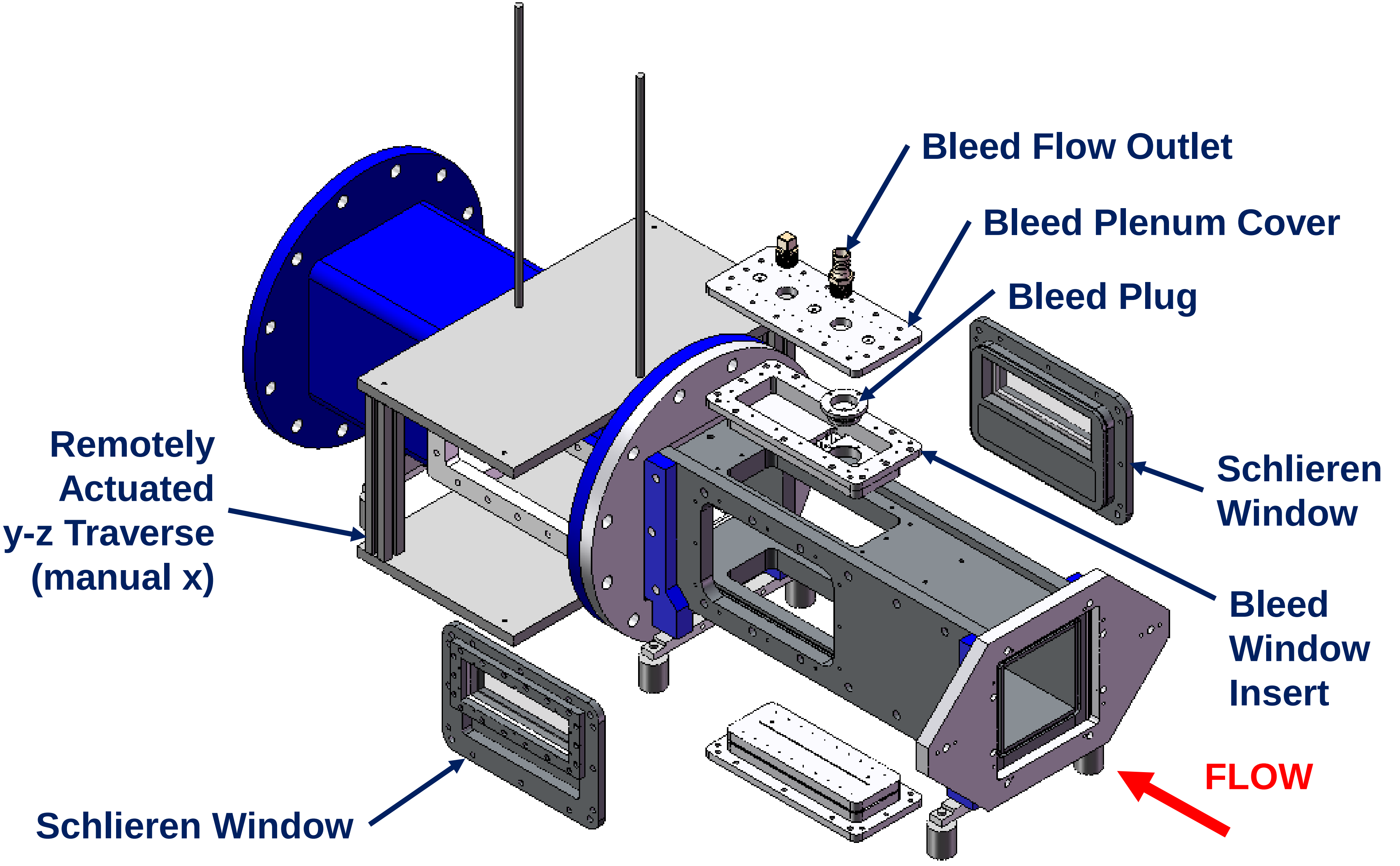


C02
D=6.029mm
α=20°
L/D=2.0
t/D=0.684
A/A_b=1.248

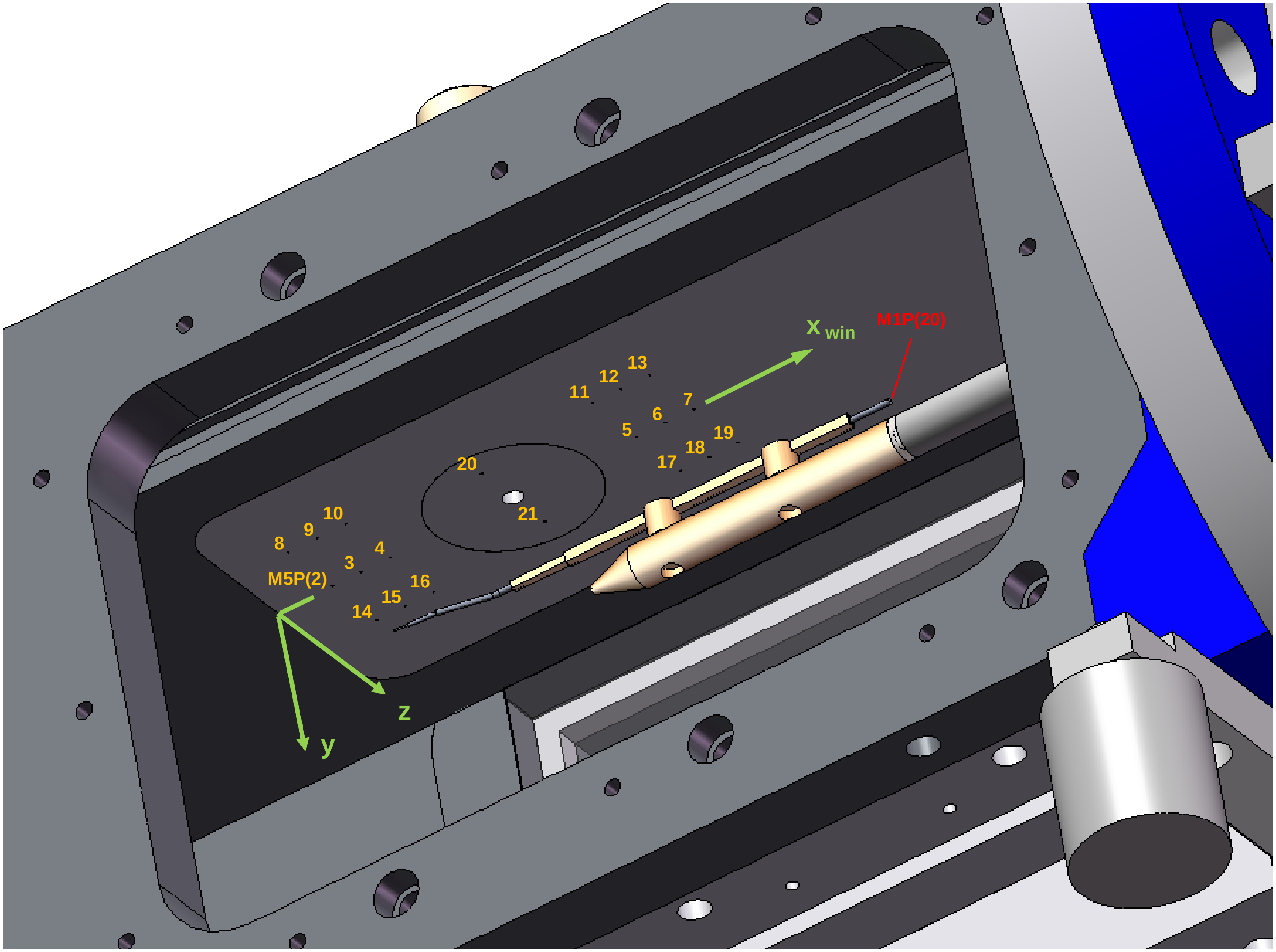


C03
D=5.018mm
α=20°
L/D=2.92
t/D=1.0
A/A_b=1.0

Test Section Window Configuration



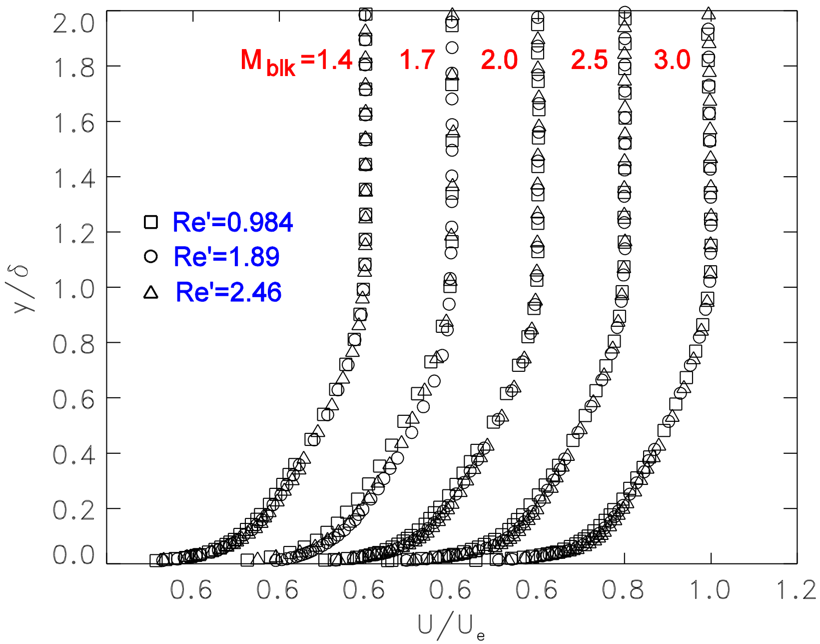
Top Window Static Taps

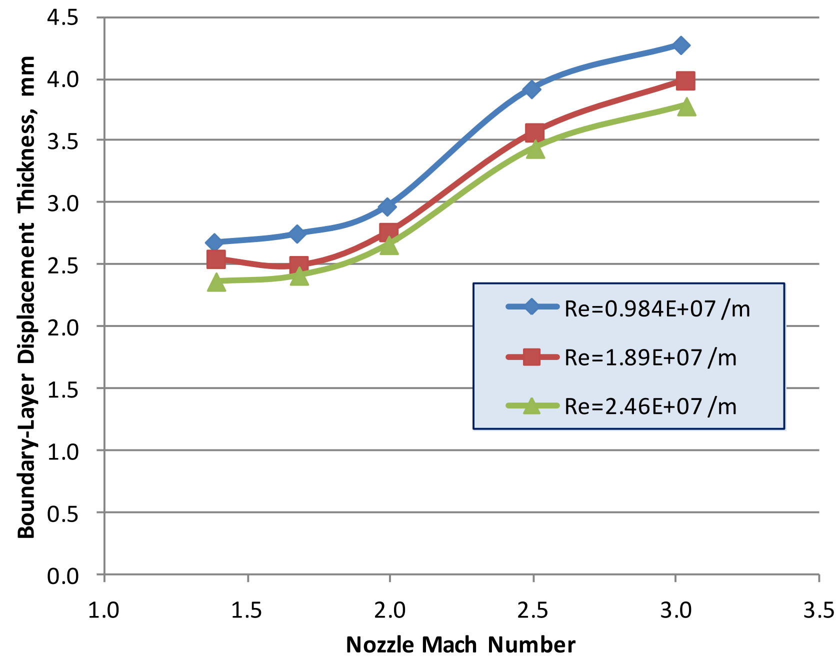


Operating Conditions

- Wind Tunnel Operating Conditions
  - No Flow (M=0) (C01,C02,C03)
  - Flow (C01,C02 only)
    - M_{blk}=1.4,1.7, 2.0, 2.5, 3.0
    - Re'=0.984, 1.89, 2.46
- Survey Summary
  - 15 Approach Boundary-Layer Profiles
  - 33 Flow Coefficient Surveys

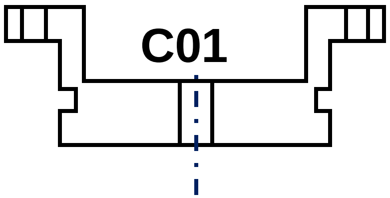
Approach Boundary-Layer Profiles

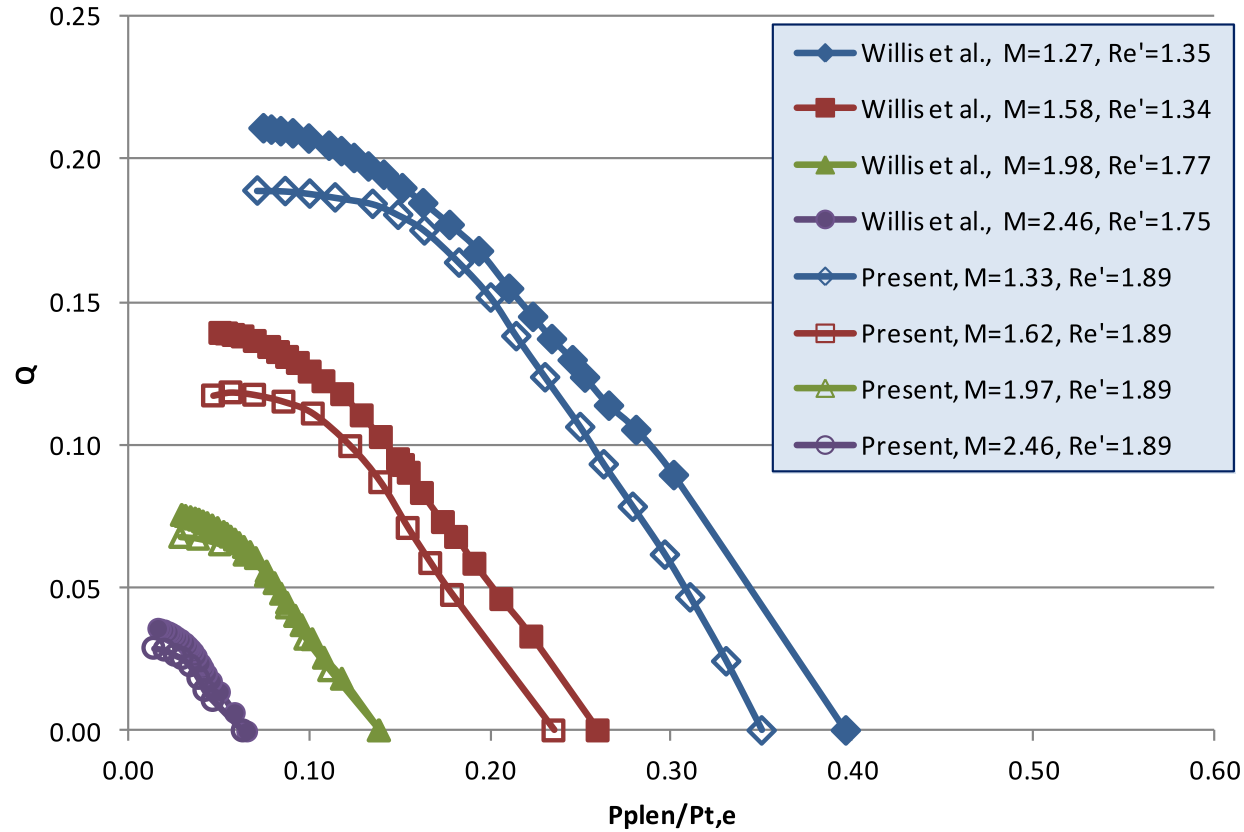




Displacement thickness variation is consistent with Reynolds number.

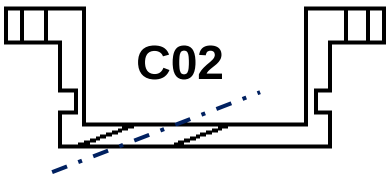
Flow Coefficient for C01 Configuration

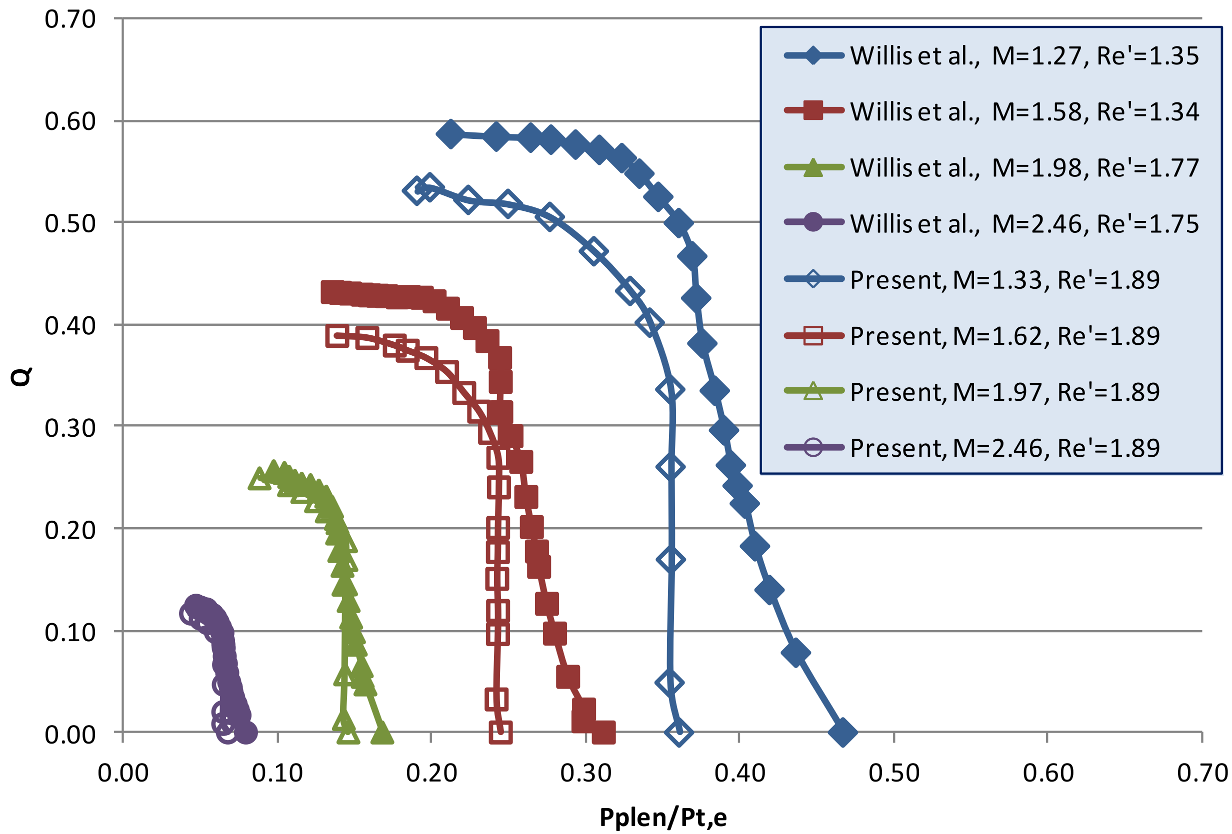




Single-hole data generally follows trends of multi-hole data except at choke conditions where lower levels are observed.

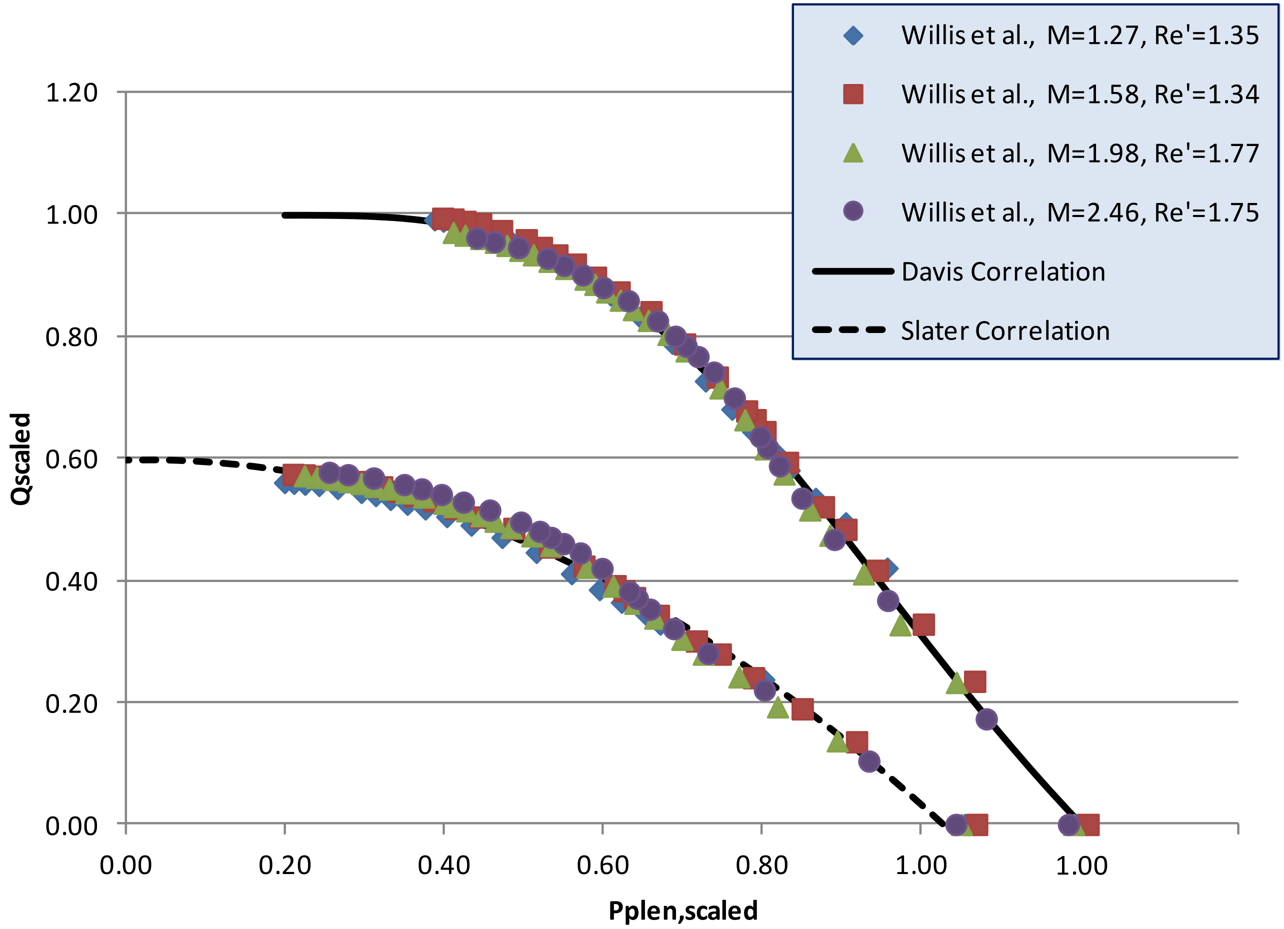
Flow Coefficient for C01 Configuration





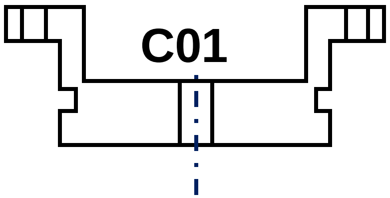
Multi-hole data deviates significantly from multi-hole data at subcritical conditions.

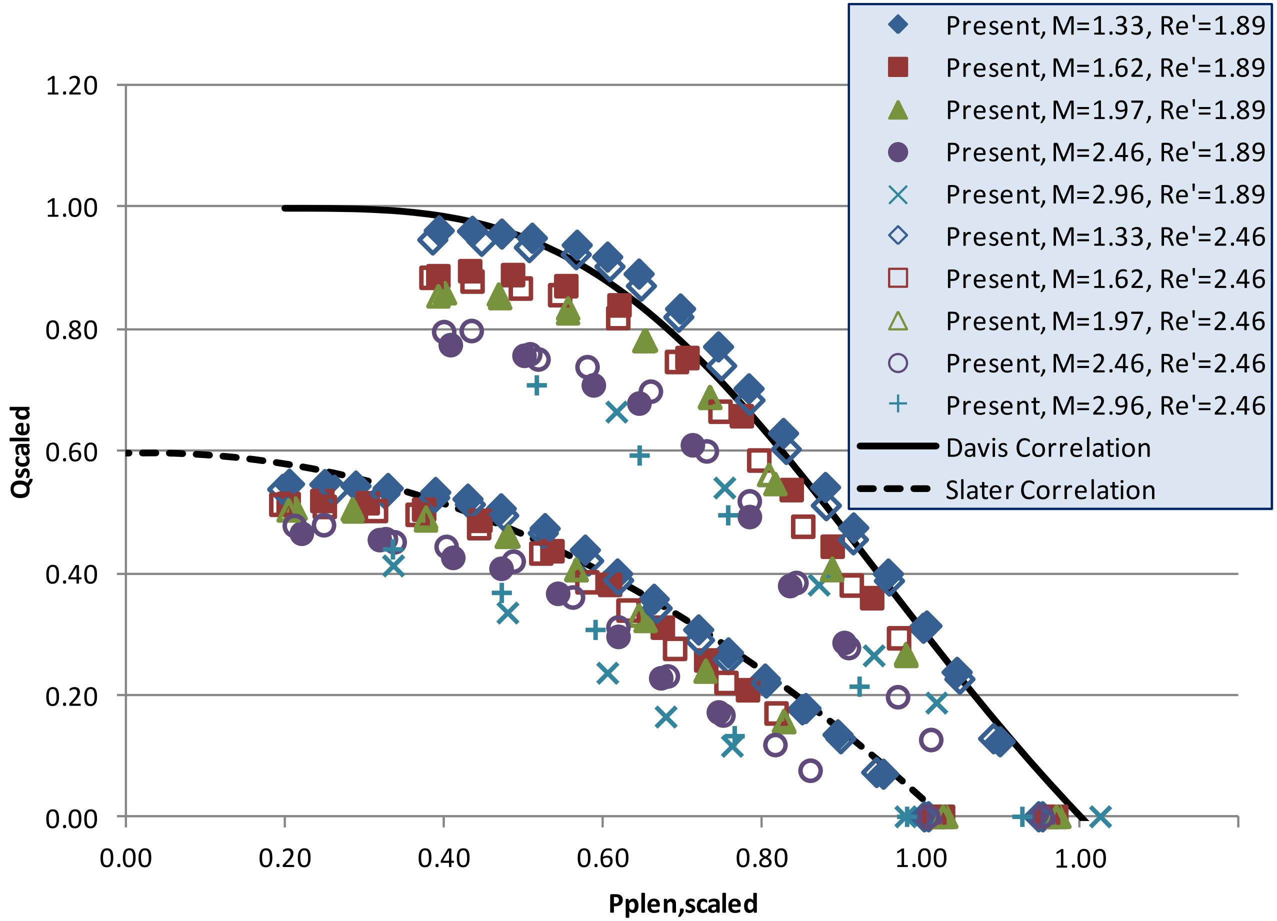
Flow Coefficient Scaling



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

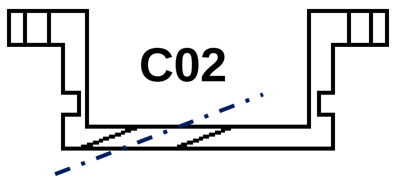
Flow Coefficient Scaling

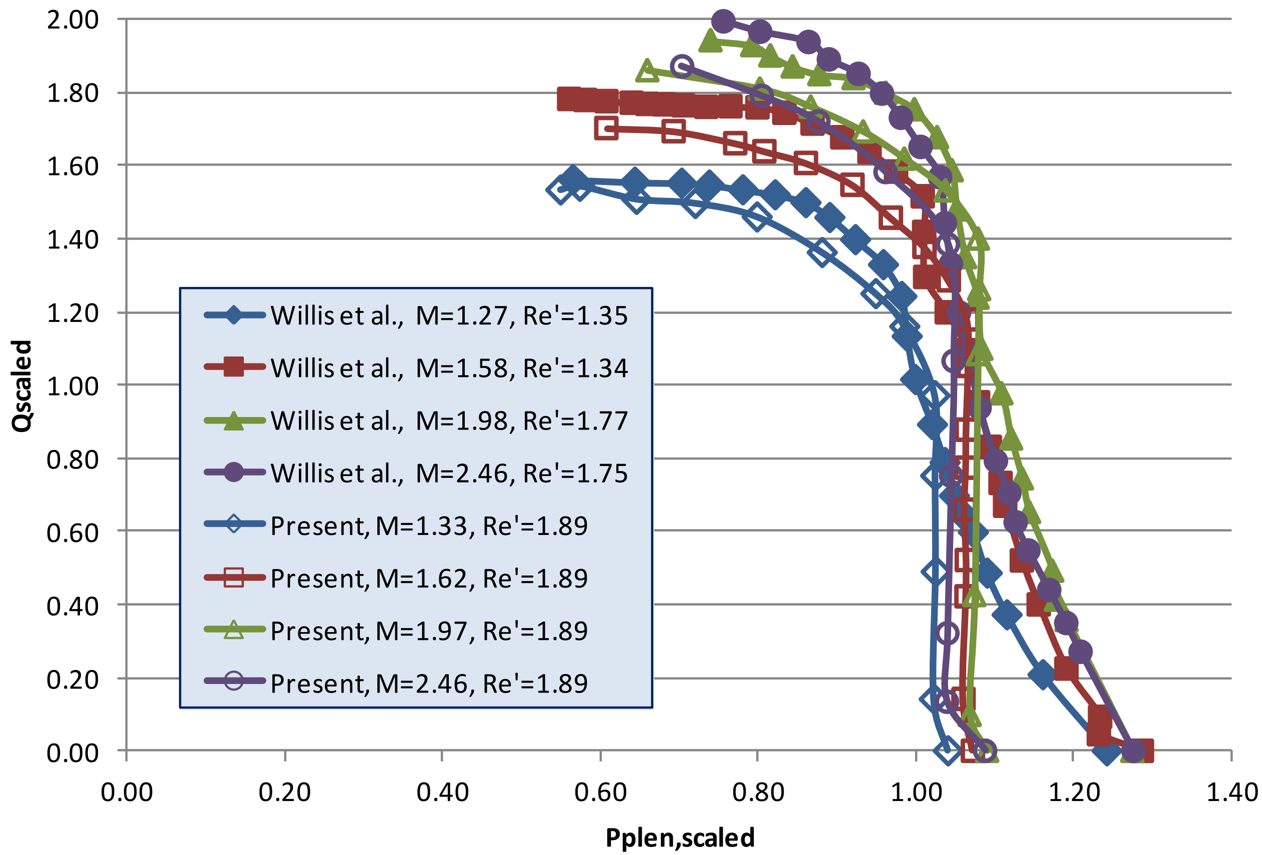




Slater correlation agrees well with present single-hole data except at choke conditions

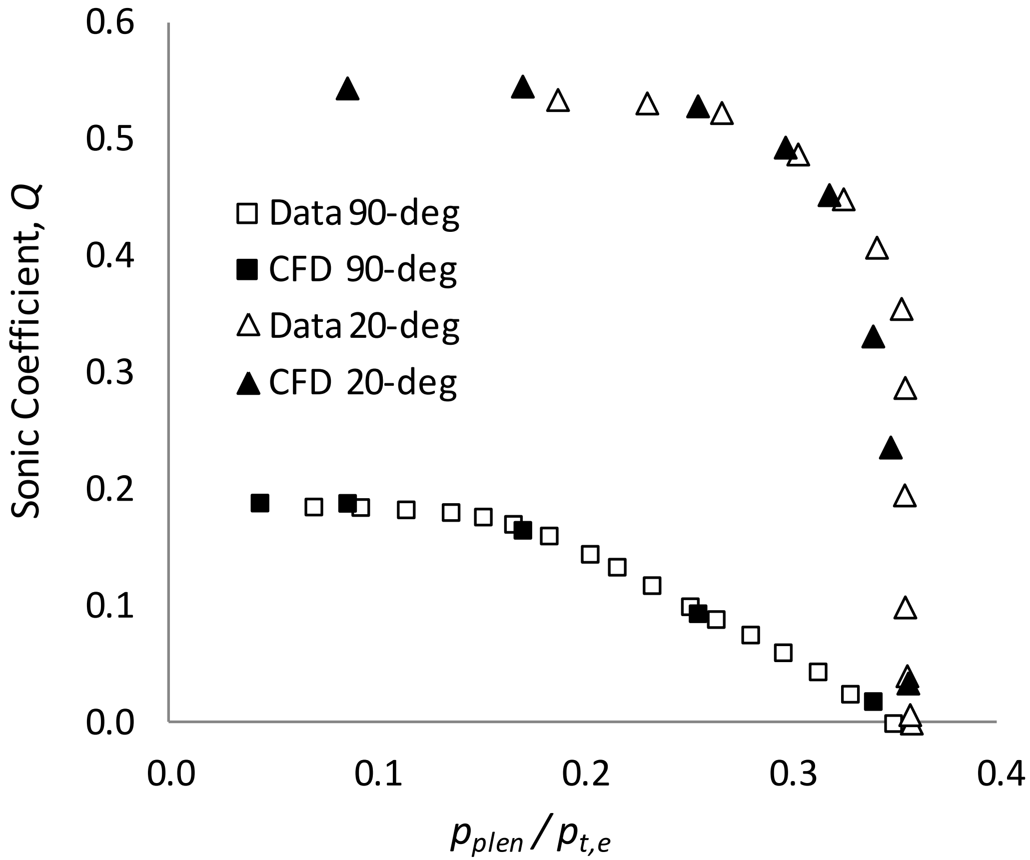
Flow Coefficient Scaling

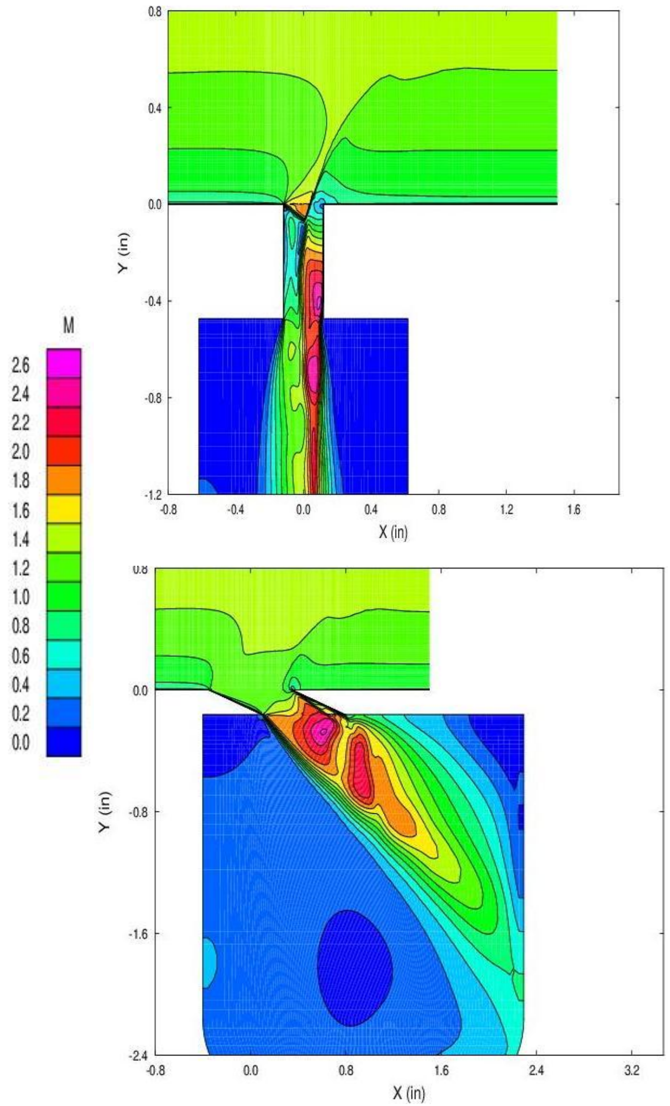




Scaling by static pressure does not capture inclined hole behavior.
Total pressure in hole not equal to surface static.

Preliminary CFD Results





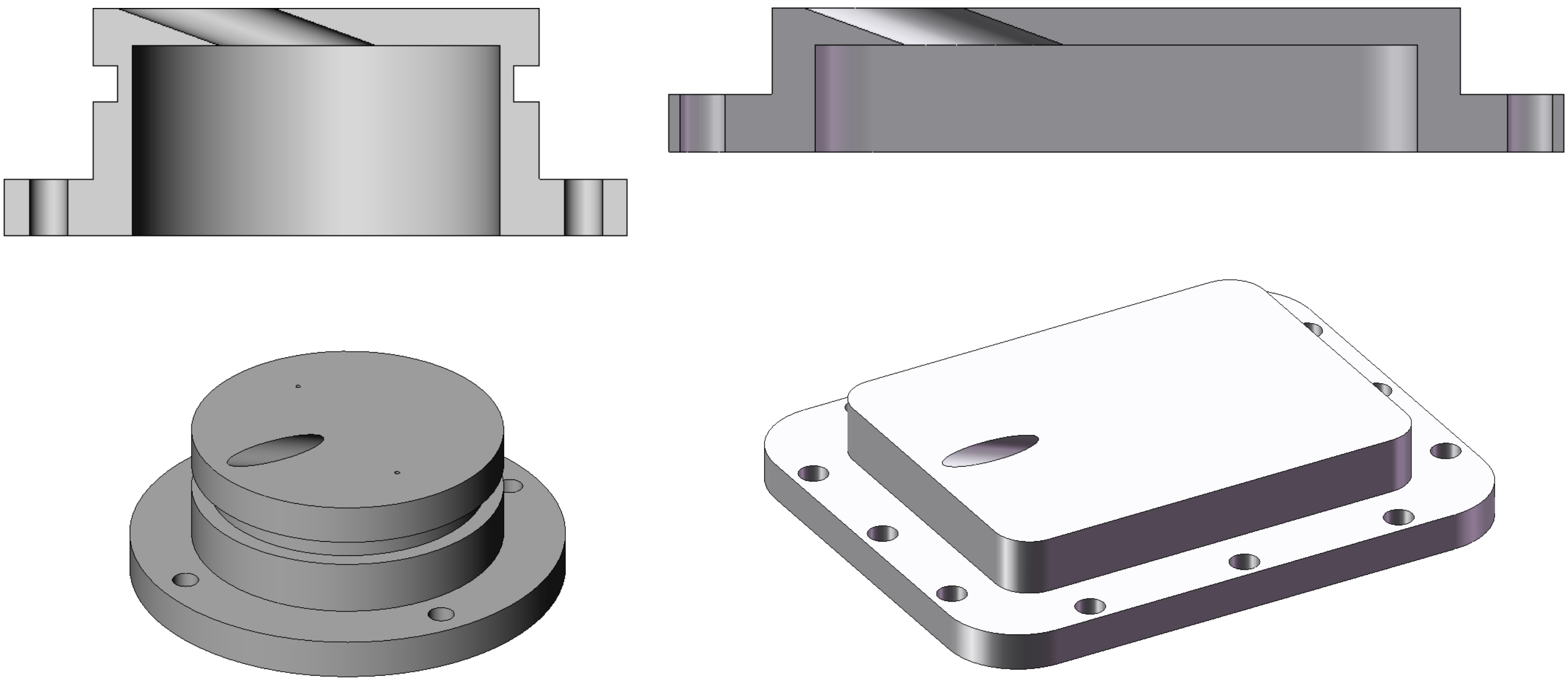
Phase I Summary

- Flow coefficient data for 90° and 20° single bleed holes have been obtained and compared to multi-hole data under similar conditions.
  - The results show that the 90° hole data differs most under supercritical operation and the 20° data differs most under subcritical operation.
- The preliminary CFD shows good agreement with the experimental results.

FIBE PHASE II TEST PROGRAM

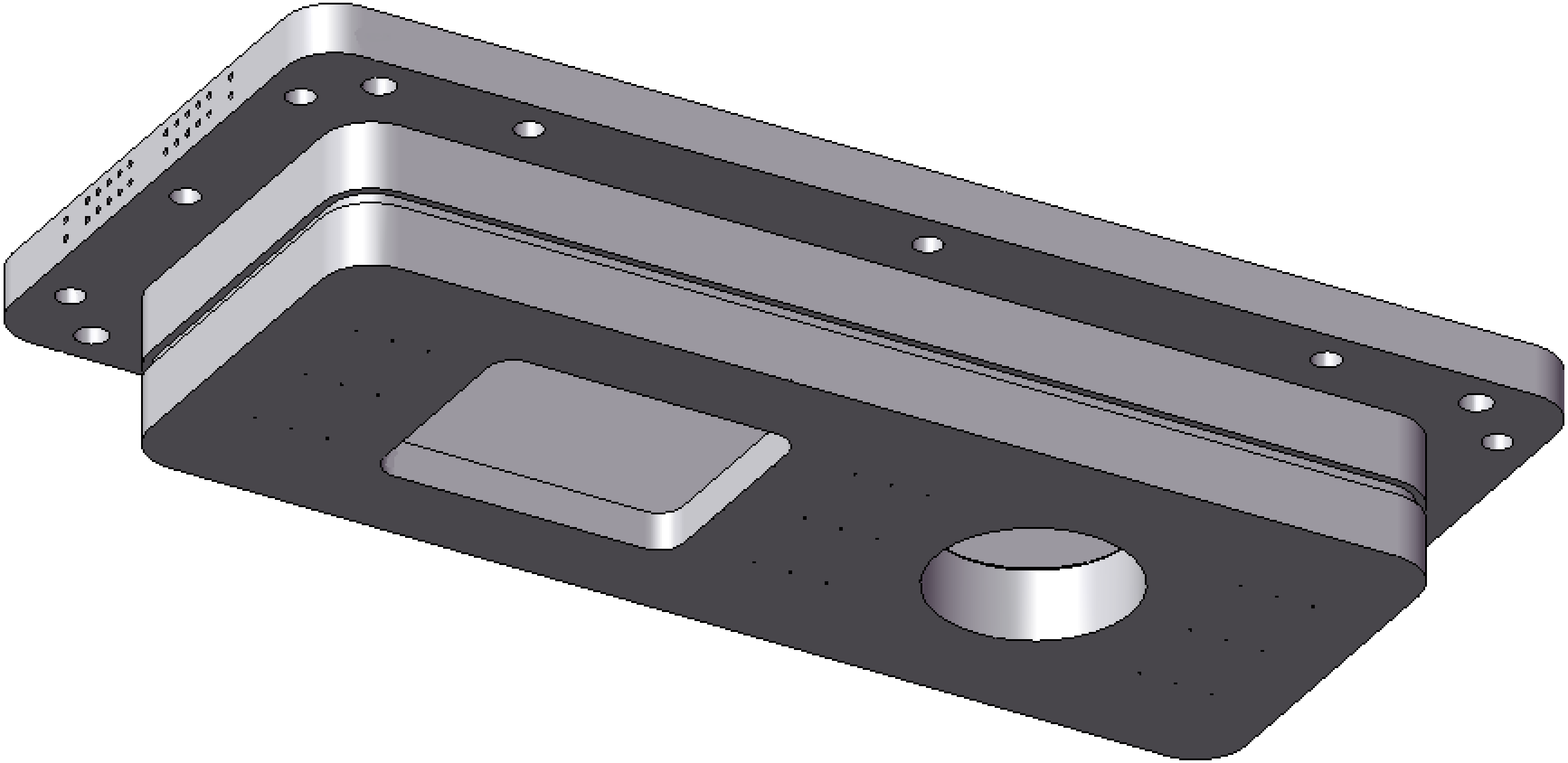
FIBE Phase II Hardware

- Bleed “Plugs” from Phase I are being replaced with Bleed “Plates” for Phase II which will allow more flexibility in bleed configurations.



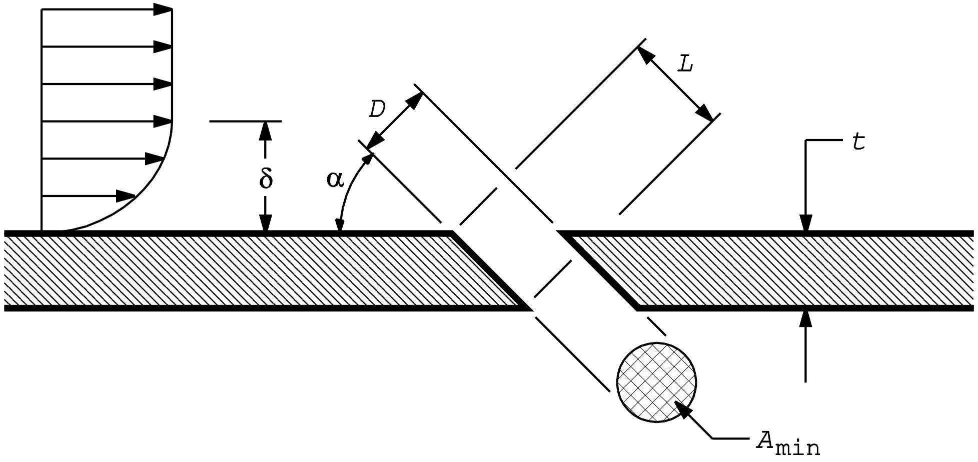
FIBE Phase II Hardware

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

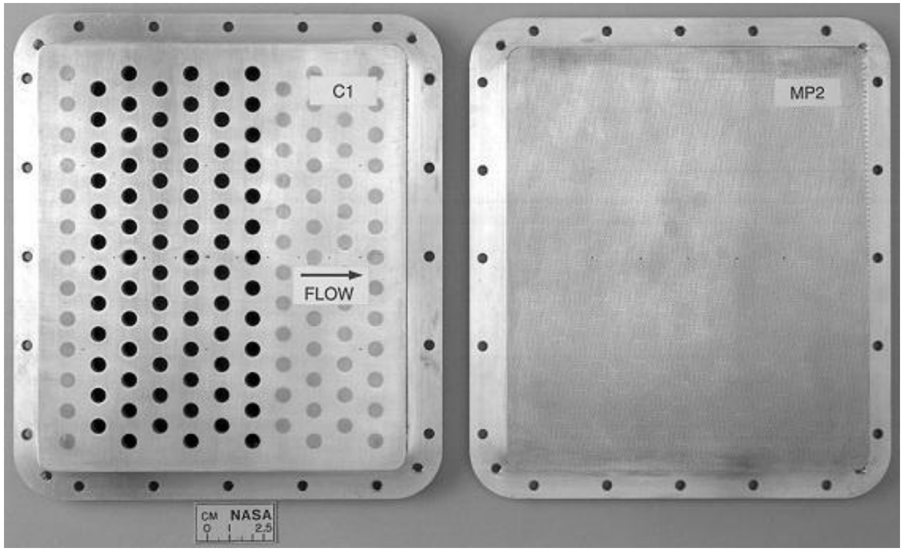


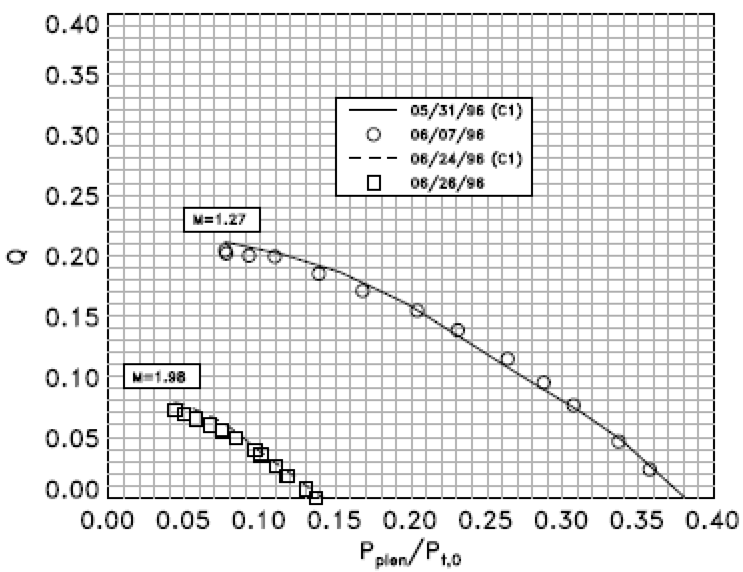
FIBE Phase II Hardware Matrix

- Hole Inclination angles (α) from 20 to 90 degrees.
  - α=20, 30,45, 60, 90
- Length-to-Diameter Ratios (L/D) from >0 to 3.0
  - Trend is towards smaller L/D
- Diameter-to-Displacement Thickness Ratios (D/δ_1) from >0 to 5.0
  - Previous data suggests that smaller is better but there is a practical limit.

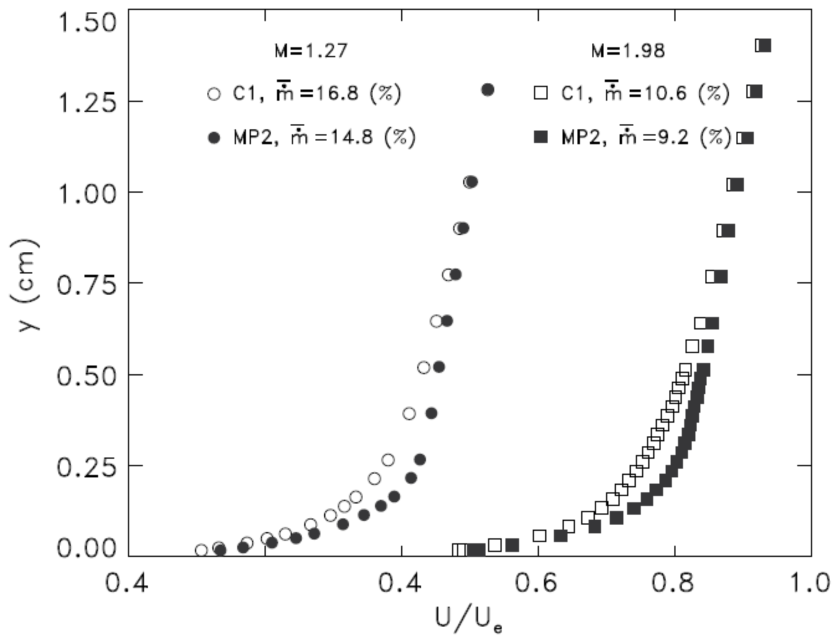


Limit of D/δ_1 effect





b) MP2 plate (21% porosity).

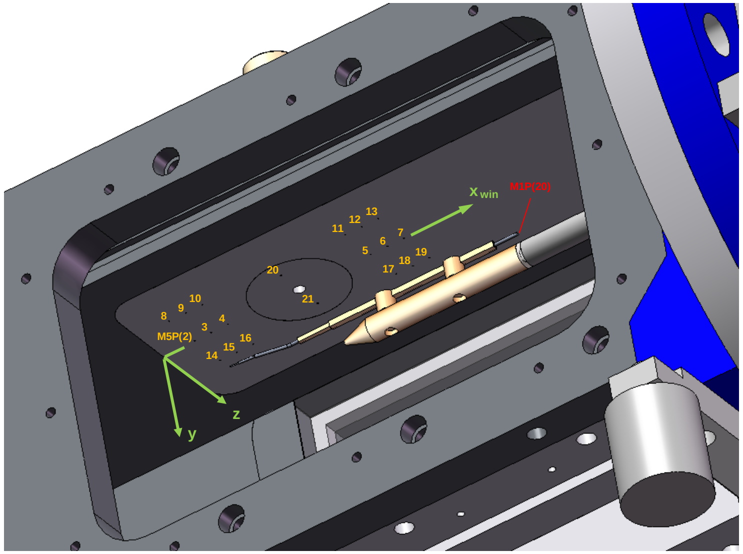


Data from AIAA Paper 97-3260

FIBE PHASE III TEST PLANNING

FIBE Phase III Test Planning

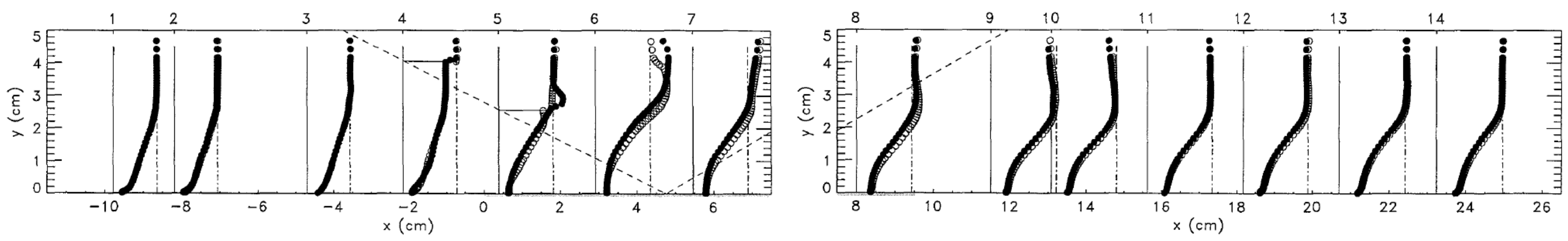
- Due to cost considerations, Phase III test planning initially called for testing to be done primarily in the 15x15cm SWT.
- However, limited testing in the 1x1ft SWT at a larger scale has always been carried as a potential option.
  - Corner bleed and glancing shock interactions not as easily incorporated into the 15x15cm SWT.



15x15cm SWT Test Section

FIBE Phase III Test Planning

- Recent interest in bleed tests conducted in the 1x1ft SWT in the 90's coupled with interest from Boeing to partner on research* and help seek outside funding led us to investigate resurrecting the bleed capability of the 1x1ft SWT.



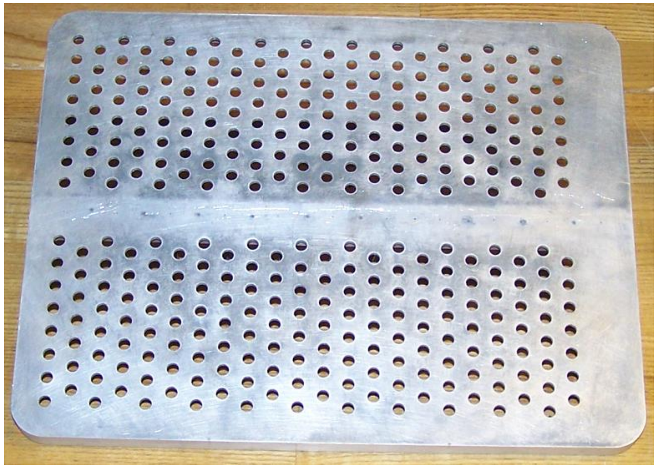
Data from AIAA Paper 95-2885

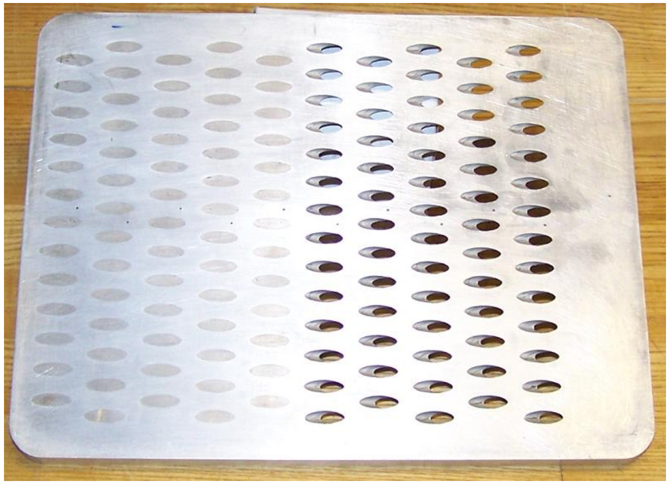
*In support of current National Center for Hypersonic Combined Cycle Propulsion (NCHCCP) Hypersonics Project being run from University of Virginia (UVA)

FIBE Phase III Hardware – 1x1ft SWT

Bleed Flow Surface

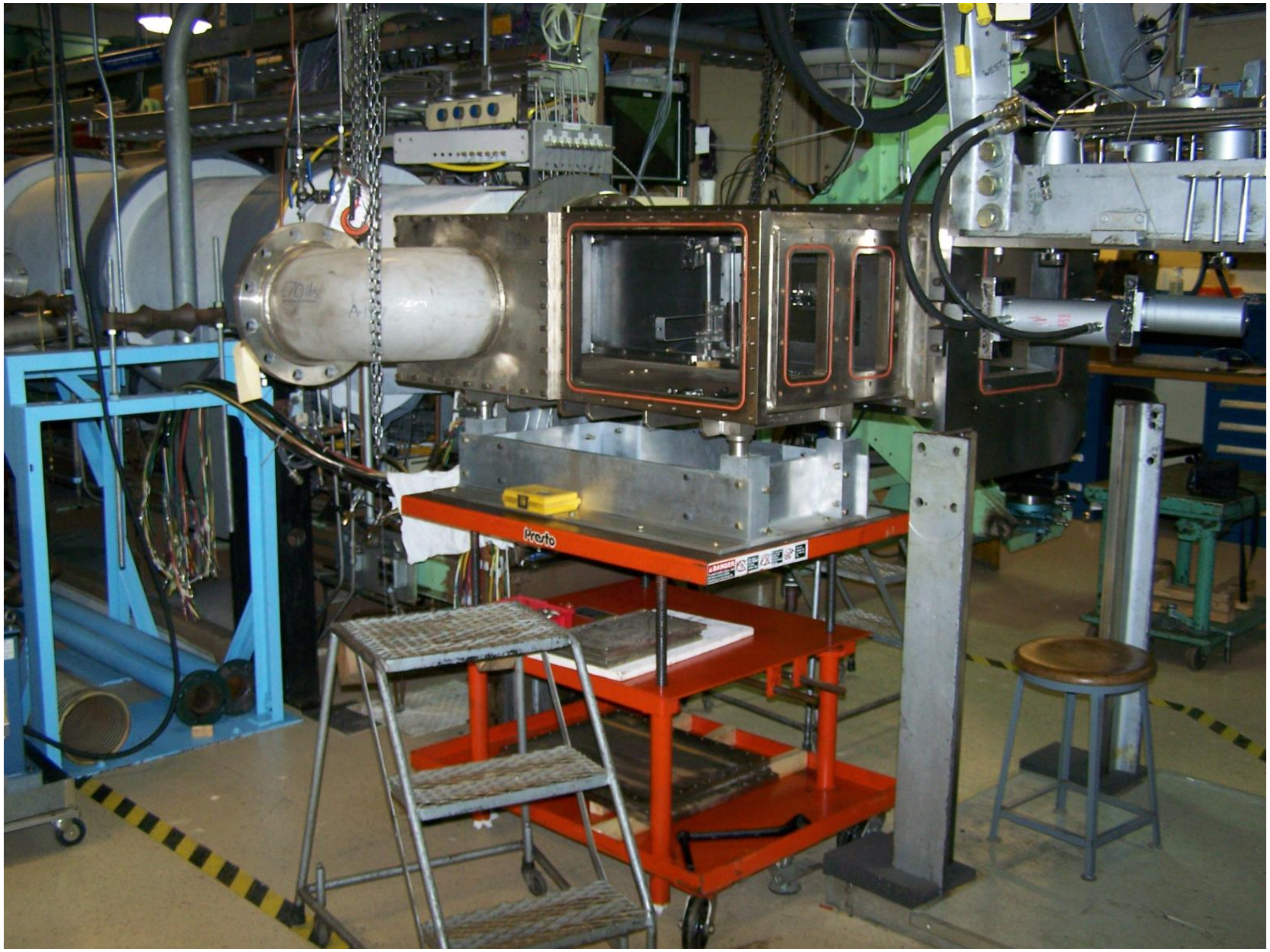
Bleed Plates





FIBE Phase III Hardware – 1x1ft SWT

Bleed Plenum Exterior



FIBE Phase III Hardware – 1x1ft SWT

Bleed Plenum Interior

FIBE Phase III Test Planning

- Phase III 1x1ft SWT Go Forward Plan
  - Boeing is interested in performing 1x1ft SWT tests this year which is sooner than original Phase III testing called for.
  - Near Term Tasks:
    - NASA GRC
      - Fit check pre-existing but unused bleed hardware.
      - Identify missing components.
      - Evaluate pre-existing model actuation assemblies for suitability for mounting shock generator plate.
      - Investigate configuration for corner/glancing interaction bleed.
      - Provide cost estimate for tunnel operation.
    - Boeing
      - Evaluate test setup for their future CFD validation efforts.
      - Create prioritized (cost and technical value) test matrix.

Summary

- Phase I testing is complete and results have been presented and made available for model development.
- Phase II hardware is beginning fabrication with an anticipated start of testing in early April.
- Phase III testing in 1x1ft SWT is under accelerated planning to accommodate Boeing desire to test earlier for results to be available to UVA NCHCCP and greater bleed research community.

- Questions?