Experimental Evaluation of BLI Propulsion: The Boundary Layer Ingesting Inlet / Distortion-Tolerant Fan Solution

David J. Arend, Research Lead
Boundary Layer Ingesting Inlet / Distortion Tolerant Fan (BLI^{2}DTF) Task
NASA Glenn Research Center at Lewis Field

Supported by: **NASA Advanced Air Transport Technology Project**
Unconventional Propulsion Airframe Integration Subproject

AIAA Propulsion and Energy Forum
Cincinnati, OH – July 11, 2018

Agenda

- Current State of the Art in Propulsion-Airframe Integration
- New Aircraft Configurations and Technologies Drive Testing Needs
- Embedded BLI Propulsor Test Requirements
- Integrated BLI^{2}DTF Propulsor Wind Tunnel Experiment
- NASA 6.5’ x 6’ Transonic Embedded Propulsor Testbed
- Raised Floor Flow Conditioning Features and Instrumentation
- Raised Floor Boundary Layer Bleed System
- Flow Simulation Establishment and Verification
- Summary

The Current State of Propulsion Airframe Integration is…

Boeing 777

Credit: Public Domain / Adrian Pingstone

Northrop Grumman B-2

Credit: USAF / MSgt Val Gempis

Boeing F-18E/F

Credit: US Navy

Boeing MD-10

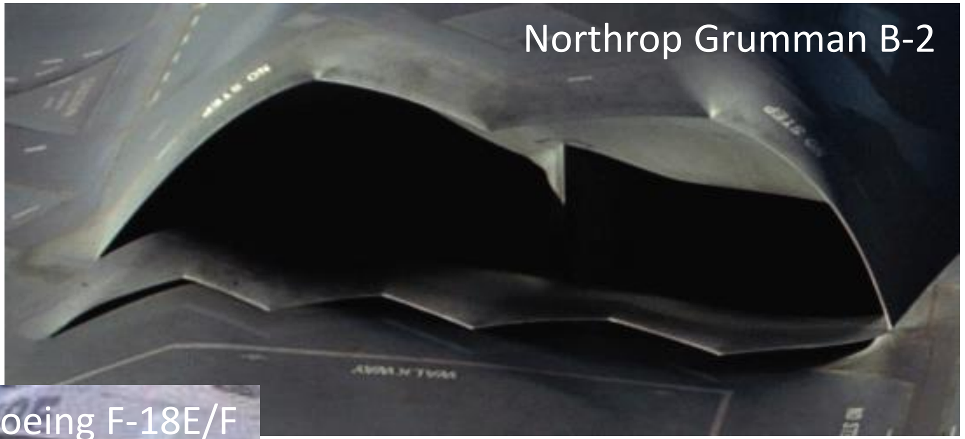
Credit: CC BY-SA 2.0 / Tomas Del Coro

Lockheed Martin F-35

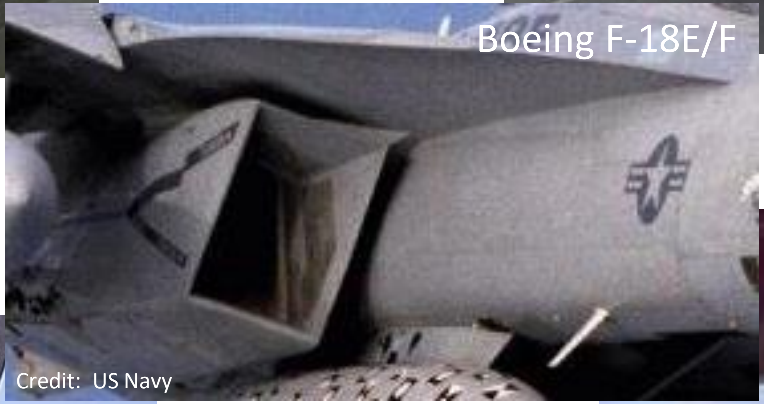
Credit: USAF / MSgt Donald R. Allen

Boundary Layer Avoidance, Diversion and Removal

Credit: Public Domain / Adrian Pingstone



Credit: USAF / MSgt Val Gempis



Credit: US Navy

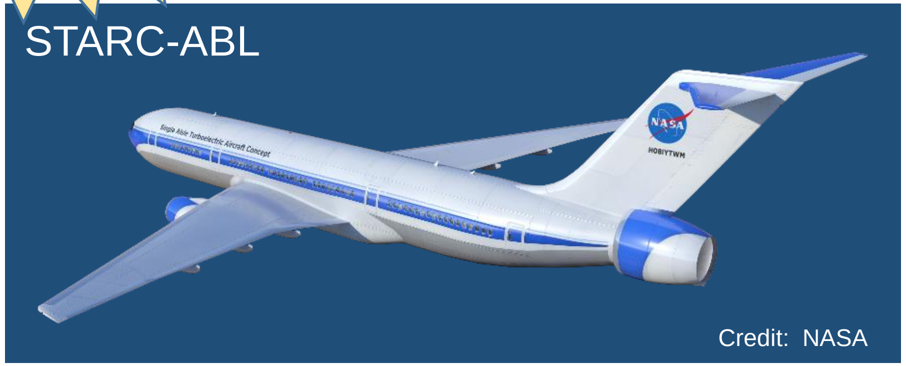
Credit: CC BY-SA 2.0 / Tomas Del Coro

Credit: USAF

New BLI Aircraft Configurations and Technologies Drive Testing Needs

Objective:
Improve Fuel
Efficiency

TBD Future Aircraft

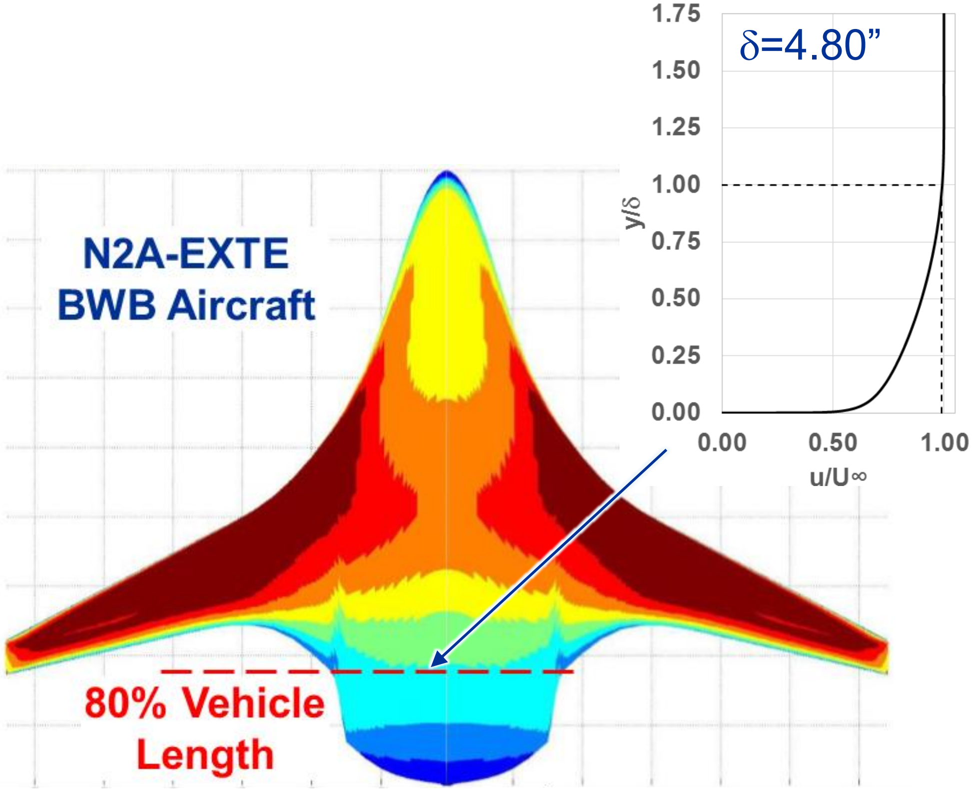


Embedded BLI Propulsor Test Requirements (BLI^{2}DTF Specs)

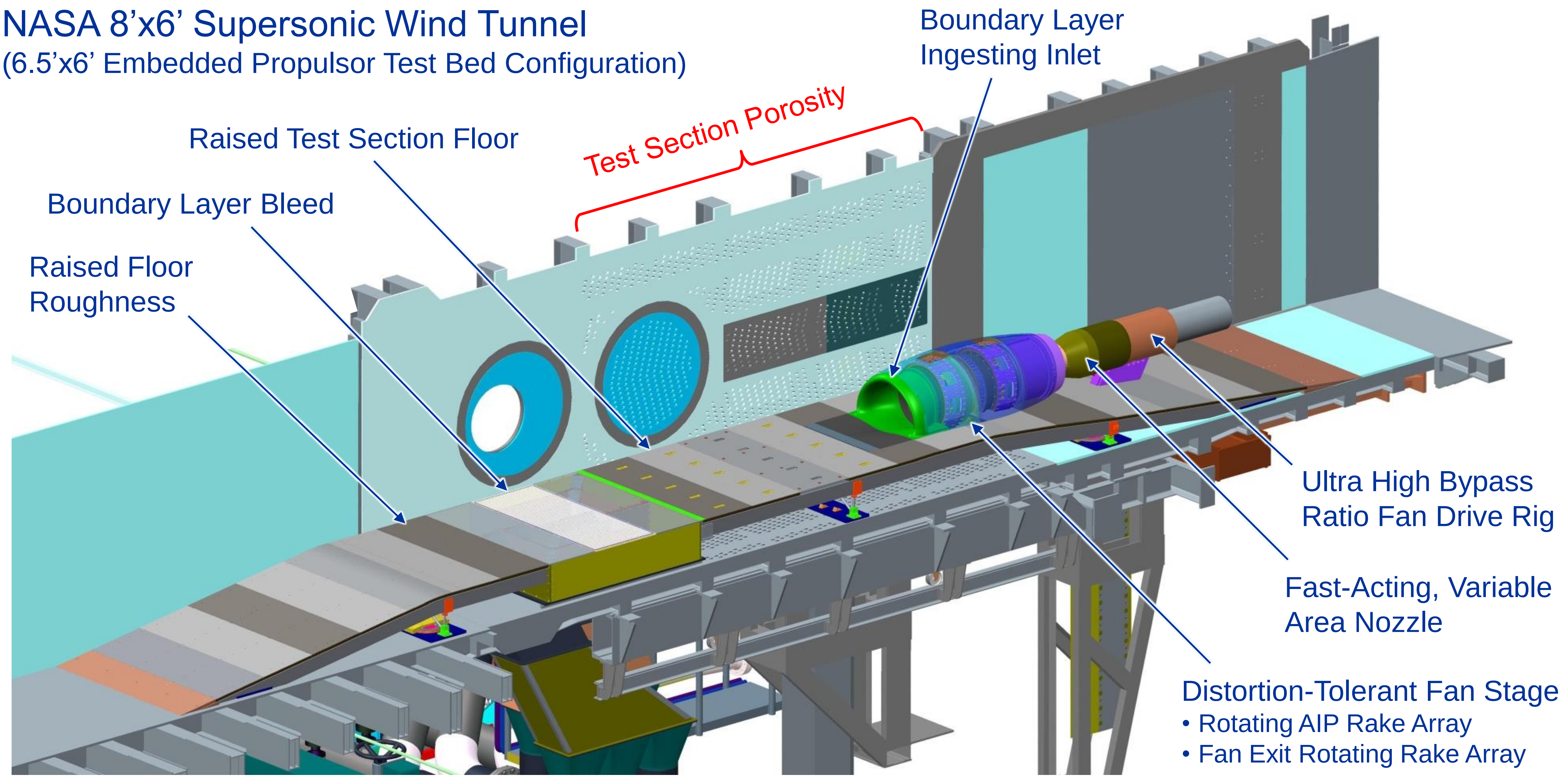
- Aircraft Propulsion-Local Flow Field Simulation
  - Tailorable aircraft flow field distribution
  - Quality on and off design flow conditions
- BLI Thickness, Profile and Distribution
  - Head / tail room for setting BL thickness
  - Matched flow simulation throughout experiment
  - Fast acting bleed to safe propulsor from aero loads
- Embedded / Airframe Integrated Propulsors
  - Adequate scale, Close-coupled inlet / fan stage
  - Rotating AIPRRA and FERRA measurements
  - Integrated weight flow measurement
  - Adequate blockage relief, powered drive rig
- Fully Instrumented, Rapid Modular Installation
- Durable Infrastructure for Many Test Programs

Target WT Freestream Conditions

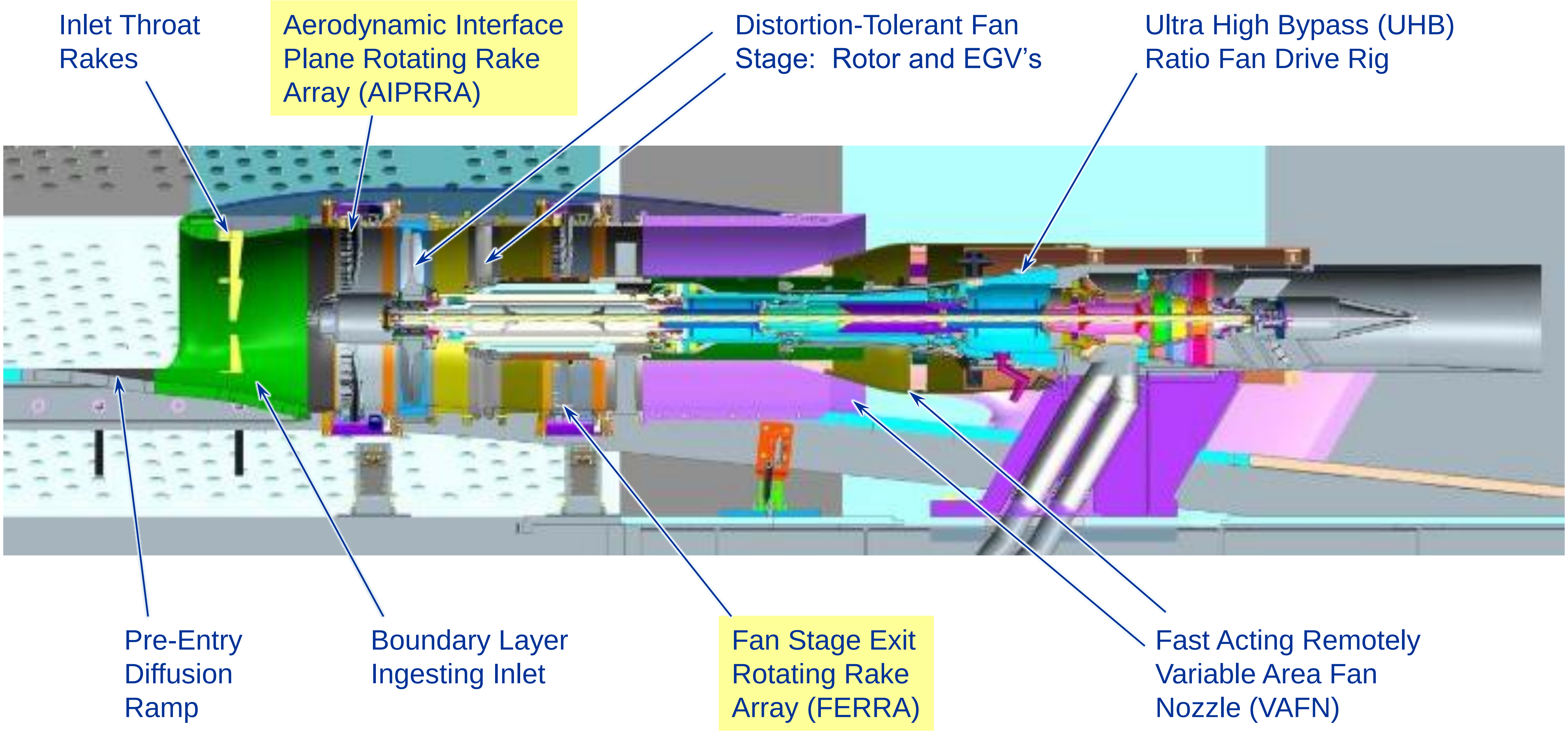
Mach Number	0.78
Total Pressure	16.9 psia
Total Temperature	560 R
Reynolds Number	4.47×10^6 1/ft



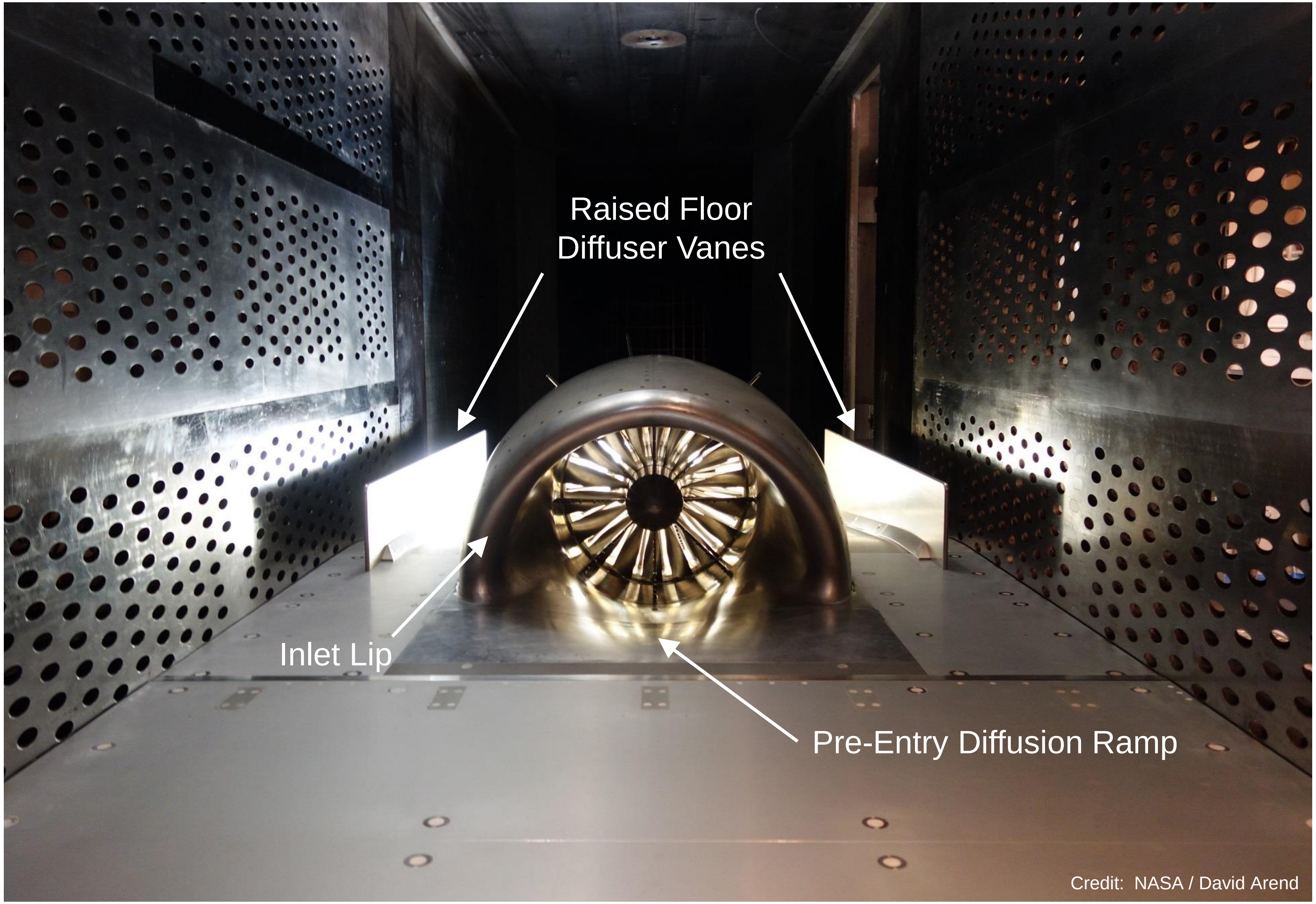
Integrated BLI^{2}DTF Propulsor Wind Tunnel Experiment



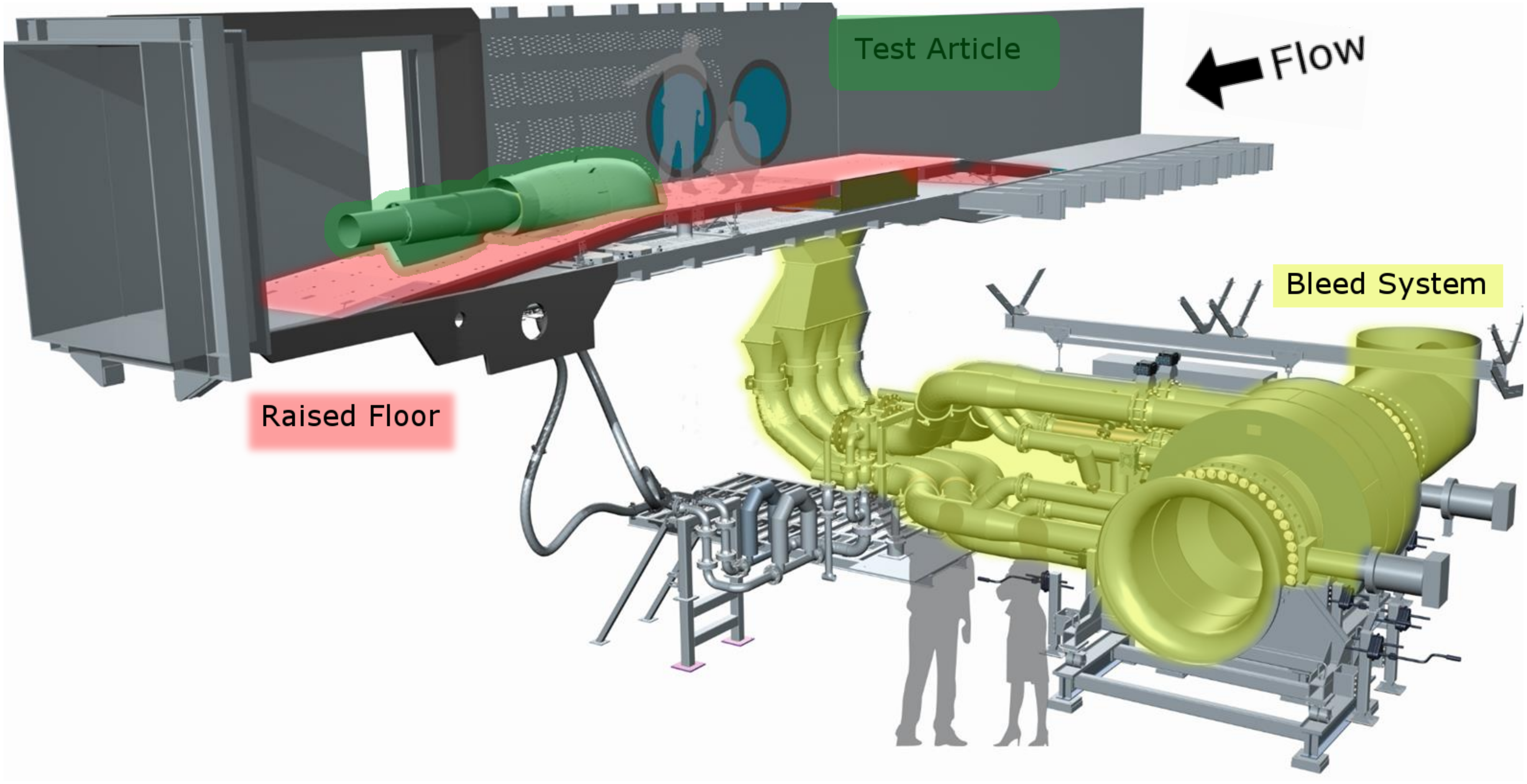
Integrated BLI Propulsor Features and Instrumentation



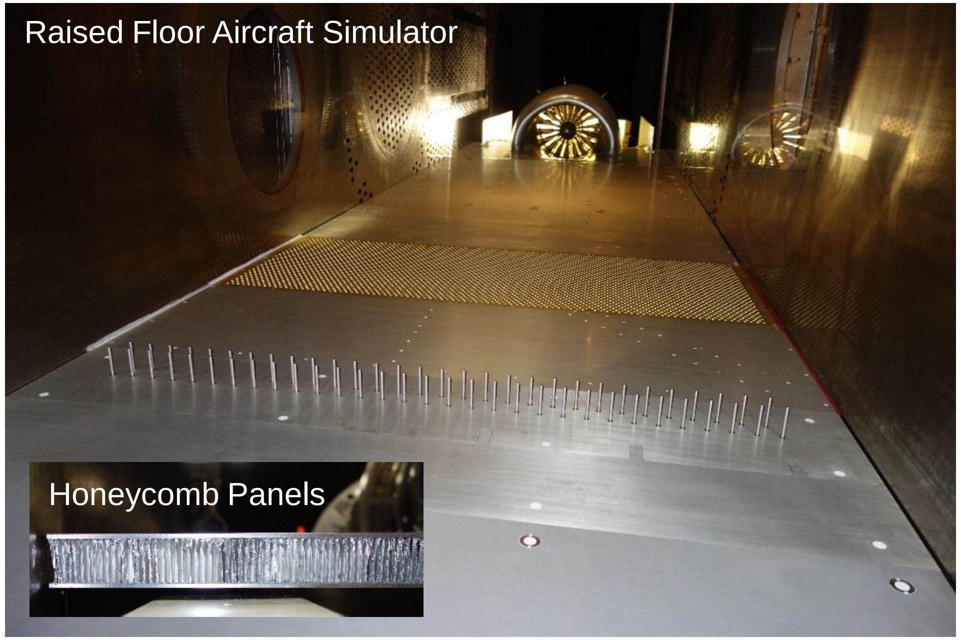
BLI²DTF Propulsor Wind Tunnel Experiment



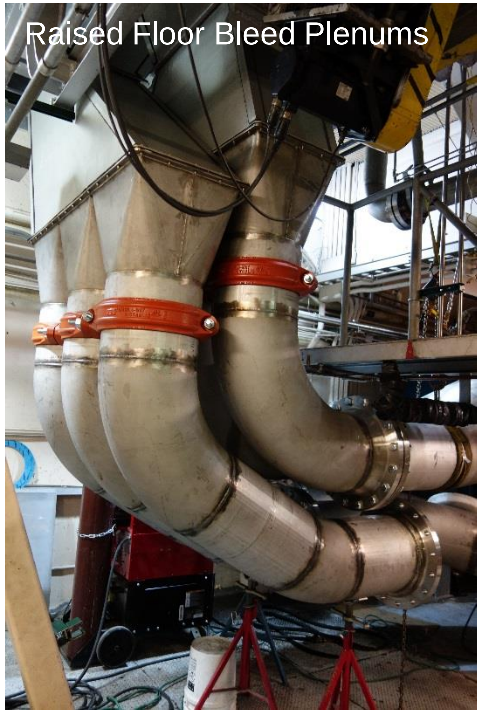
NASA 6.5’x6’ Transonic Embedded Propulsor Testbed

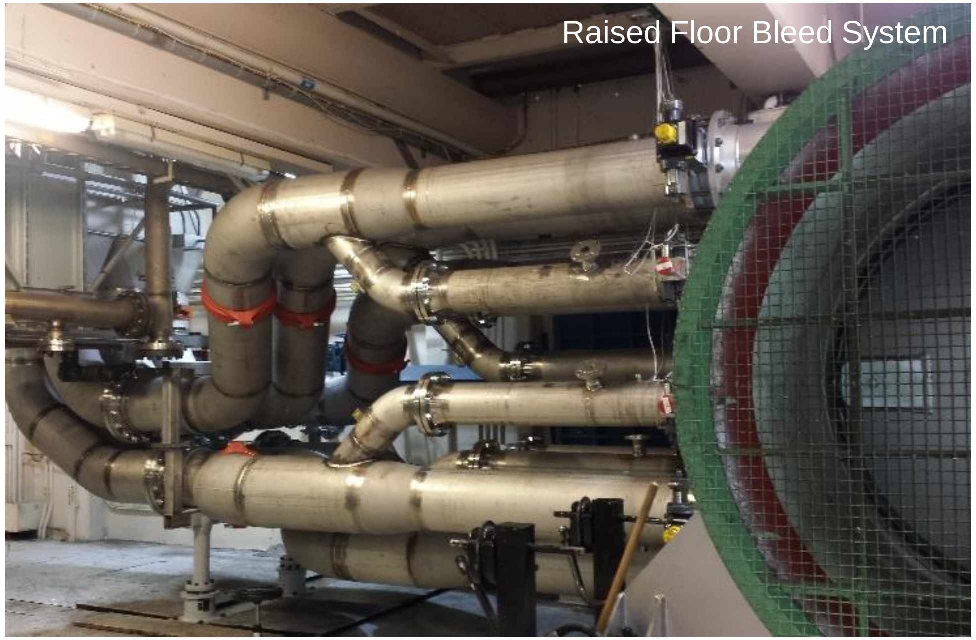


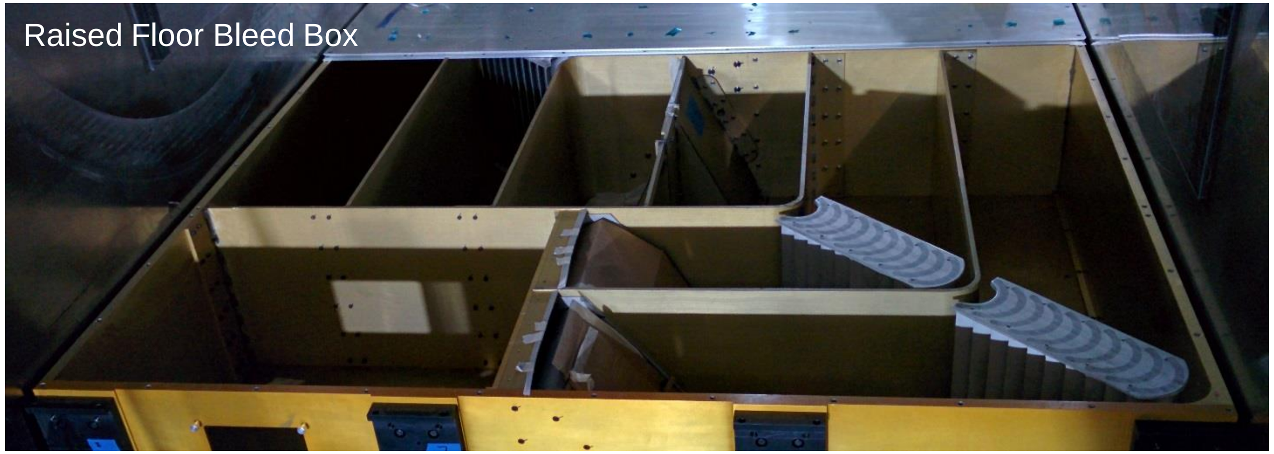
NASA 6.5’x6’ Transonic Embedded Propulsor Testbed

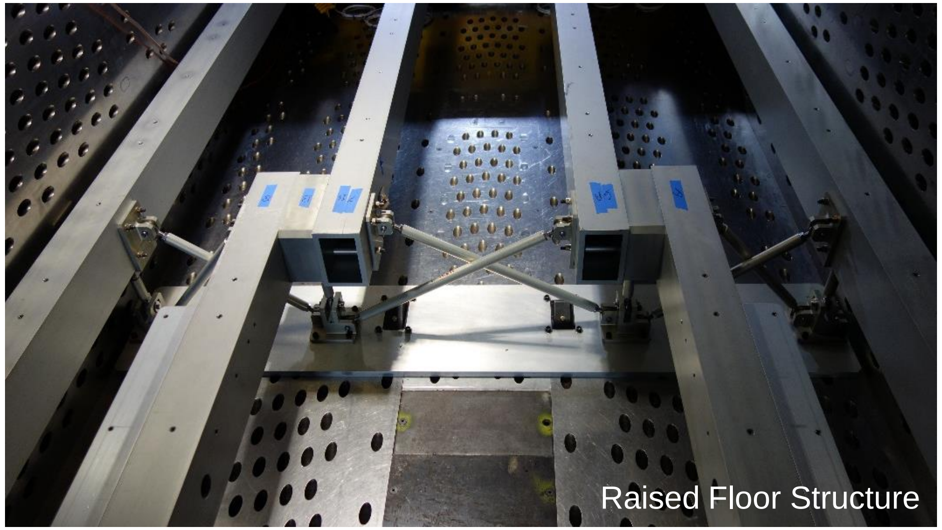

Raised Floor Aircraft Simulator

Honeycomb Panels


Raised Floor Bleed Plenums


Raised Floor Bleed System


Raised Floor Bleed Box


Raised Floor Structure

Raised Floor Flow Conditioning Features and Instrumentation

Boundary Layer Thickening Pins

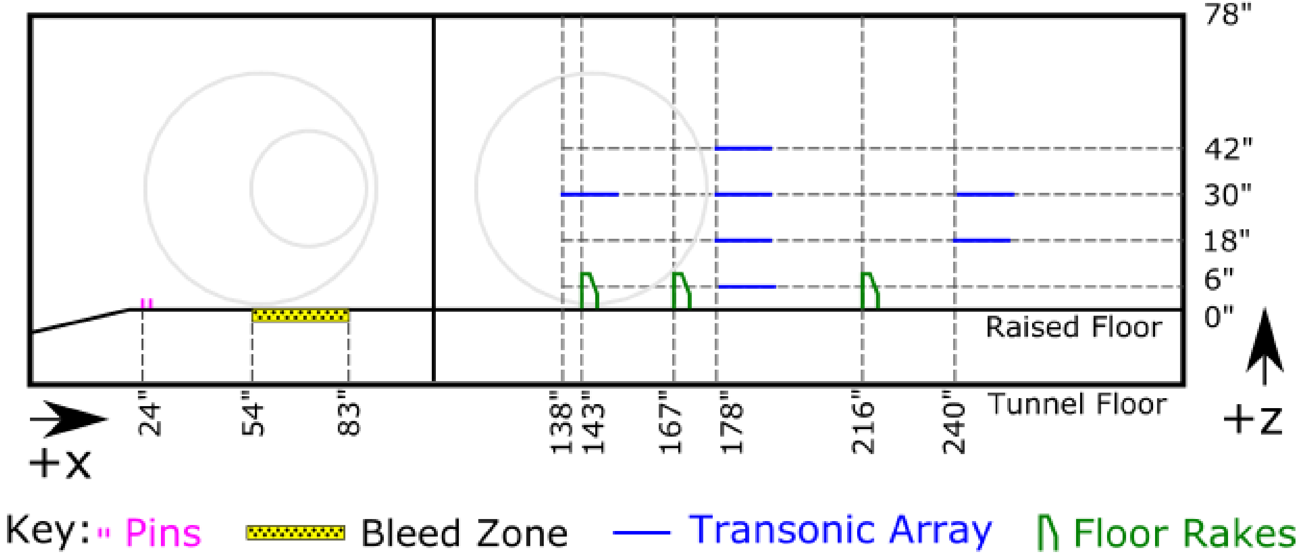
Bleed

Transonic array

- Measures P_t, P_s, T_t, α, and β
- 11 Measurements Across the Tunnel Each for P_t, P_s, and T_t
- 5 Measurements Across the Tunnel for α and β

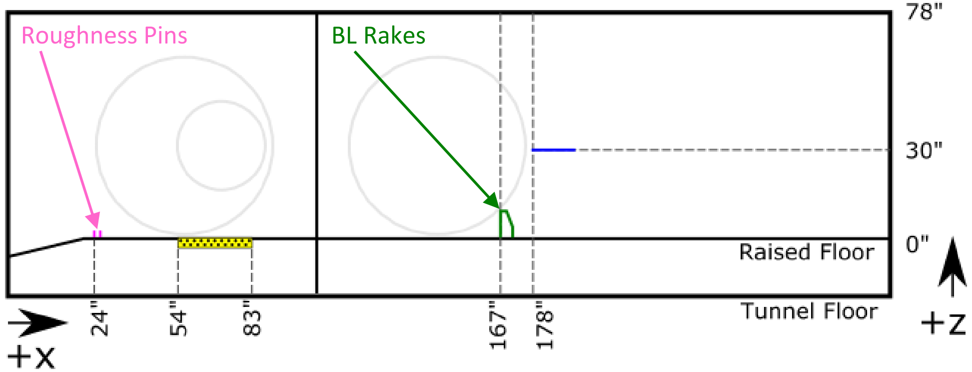
Raised Floor Boundary Layer Rakes

- 18 P_t Probes Distributed to Measure Pressure in the Boundary Layer
- 5 Rakes Spaced 14 Inches Apart Across the Tunnel
- Center Rake on Tunnel Centerline



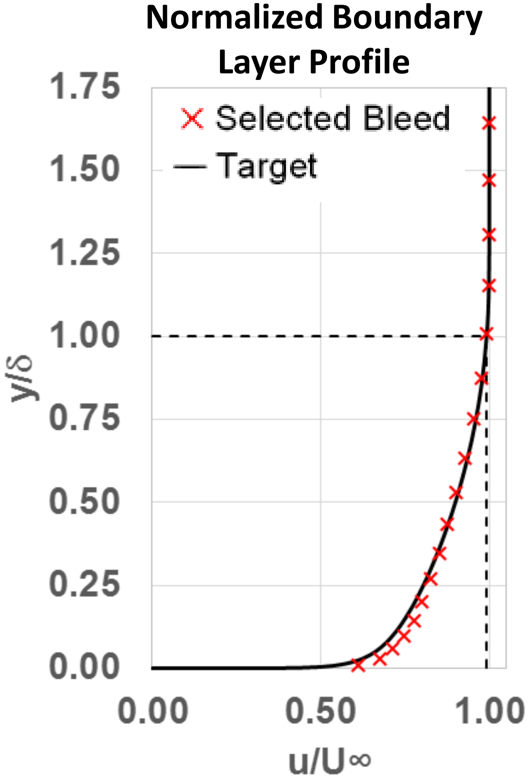
Match Plane Boundary Layer Requirements Met

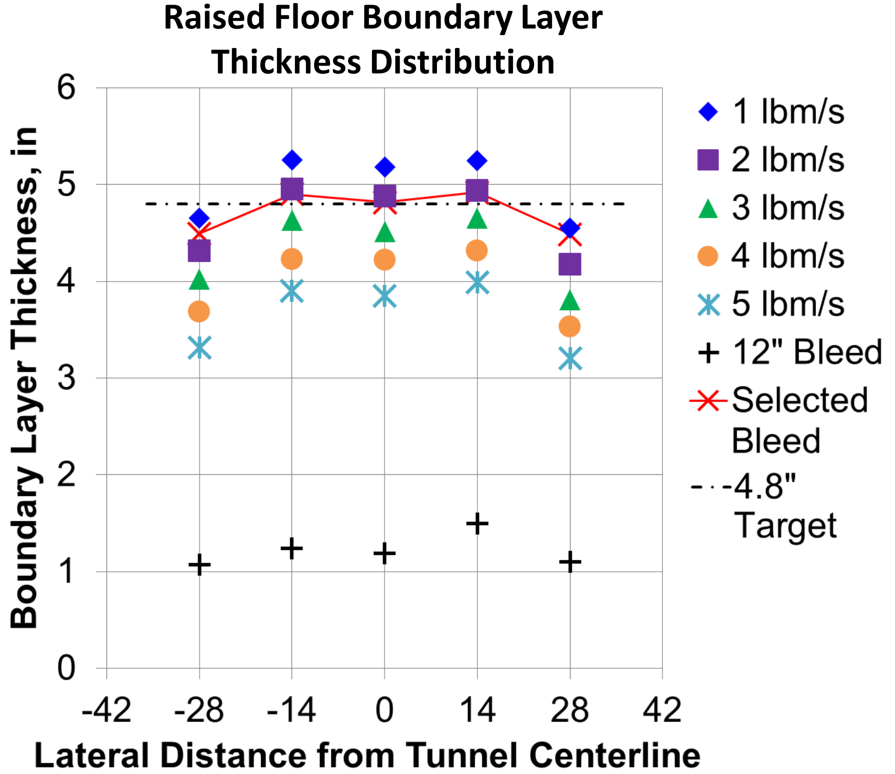
- Raised Floor Bleed Distribution Varied to Provide the Target Boundary Layer Distribution (δ=4.80”) at the Match Location (x/c=0.80)
- Increasing the Bleed Flow Rate in Each Zone Consistently Reduced the Boundary Layer Thickness
- Raised Floor Roughness and Bleed Provided Both the Desired Boundary Layer Thickness and Profile
- Tailored Boundary Layer Thickness Distributions May Be Possible



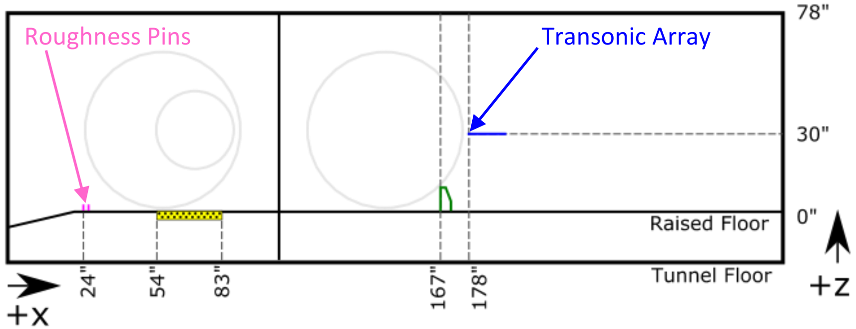
× Selected Bleed

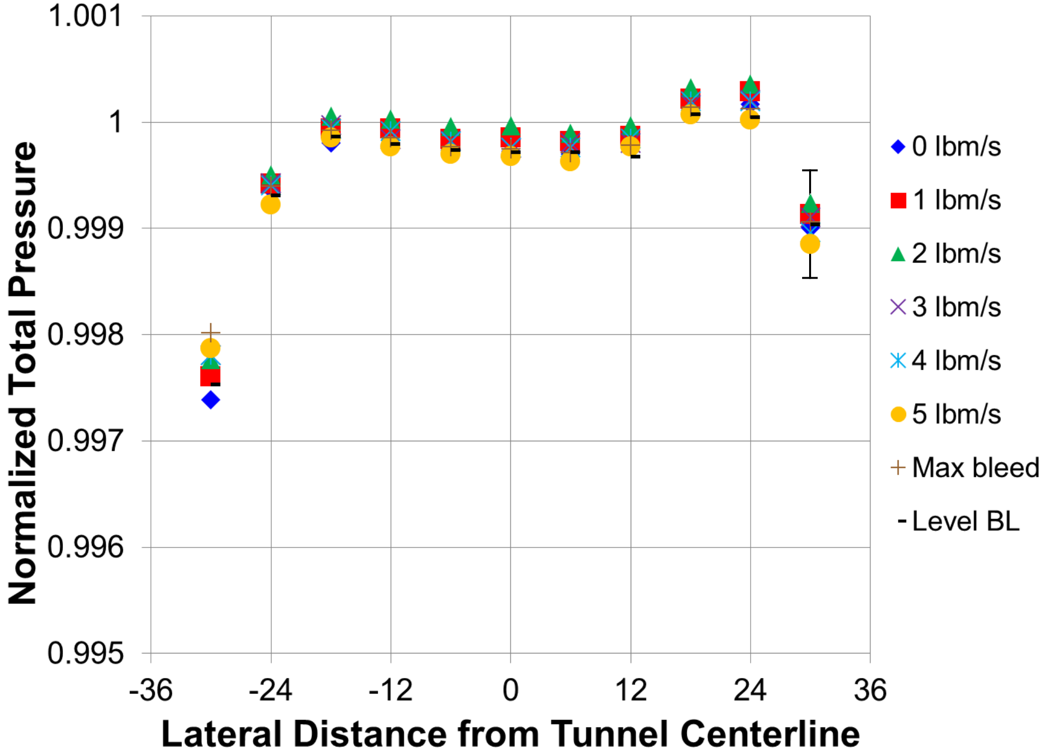
Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6
1.0 lbm/s	2.25 lbm/s	2.25 lbm/s	2.25 lbm/s	2.25 lbm/s	1.1 lbm/s



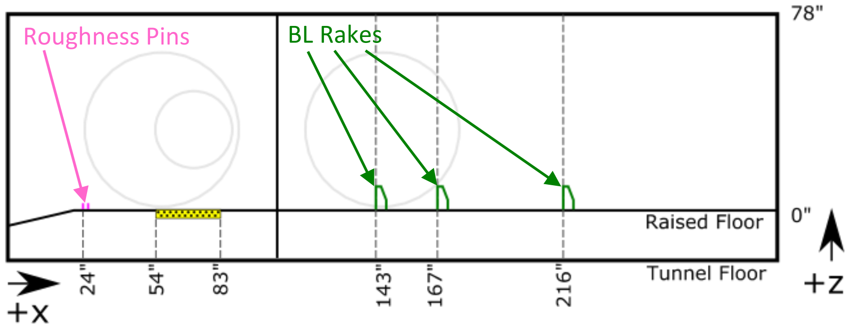


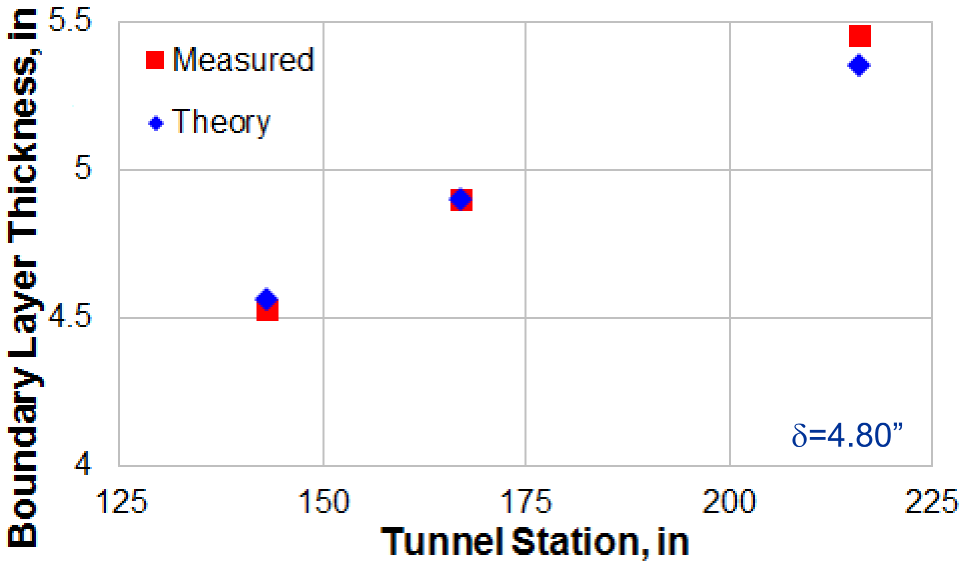
Robust Freestream Flow and Simulation Zone BL Distribution Achieved





Freestream Flow Unaffected by Raised Floor Bleed





Boundary Layer Established Throughout Propulsor Flow Simulation Zone (Measured vs Theoretical (Tucker) Turbulent Compressible BL Thickness)

Summary

- Improved Fuel Efficiency Focus on Embedded Propulsors
- New BLI Aircraft Configurations and Technologies Drive Testing Needs
- Relevant PAI Flow Physics Must be Included to Conduct Adequate Experiment (Pre-Entry Diffusion, Aperture Integration, Dynamics and Coupled Inlet-Fan)
- New Embedded Propulsor Testbed Established for Airframe Integrated Propulsors
  - Adequate scale, reduced wind tunnel power requirement, cost effective solution
  - Fully instrumented, rapid modular installation, 8’x6’ SWT instrumentation upgraded
  - Structure proven for current and future flow field simulations
  - Remotely variable boundary layer distribution with high response safety bleed
  - High quality combined boundary layer and freestream flow field simulation
  - Durable infrastructure for many future test programs
- Modified Existing Ultra High Bypass Fan Drive System Incorporated and Proven
- New Testbed Calibrated, Validated Through BLI^{2}DTF Tests – Meets Requirements