An Assessment of NASA Glenn's Aeroacoustic Experimental and Predictive Capabilities for Installed Cooling Fans
Part 2: Source Identification and Validation

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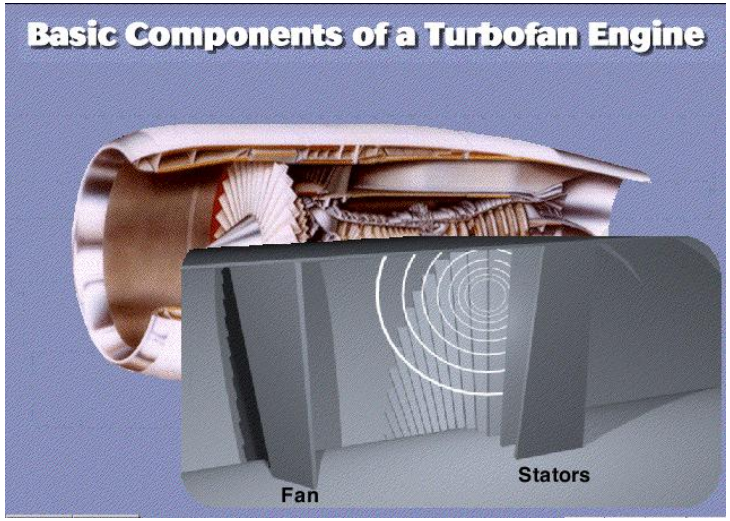
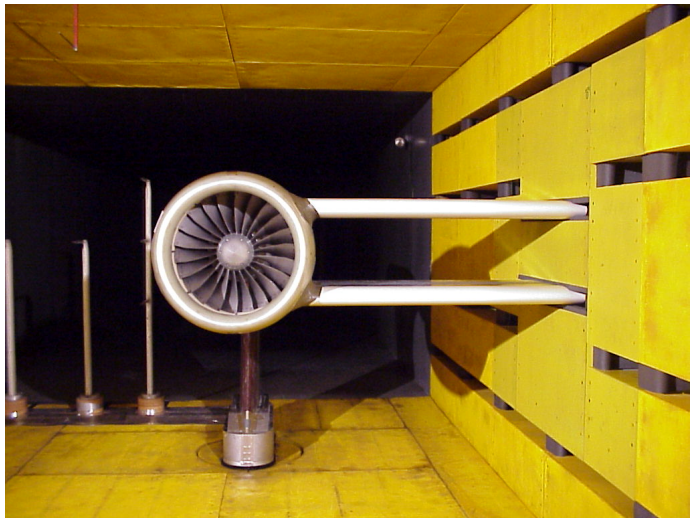
Overview of NASA Glenn Fan Acoustics Research

- Fan noise is known to be a dominant source of turbofan engine noise.

- The NASA Glenn Acoustics Branch continues to research fan broadband and tone noise experimentally and computationally.





Challenges of Fan Noise Reduction

- Fan Manufactures
  - Accurate source identification is required to develop low noise fans
- Fan System Designers
  - Installation effects can alter the fan aero and acoustic performance significantly
  - Accurate aerodynamic and acoustic performance maps are required
- Fan Noise Researchers
  - Accurate source identification is needed to tailor experimental and computational efforts
- Program Managers
  - Synergy exists between spaceflight hardware developers, researchers, and industry—but goals and timescales differ

Lessons Learned from the International Space Station

From Goodman, "International Space Station Acoustics," *Inc03_125*

- Acoustics should be included early in the design process
- Program noise requirements should be well founded and treated as true require
- Noise limits should be stipulated for components as well as full systems
- Complicated systems such as modules and payload racks should have a documented noise control plan identifying all noise sources, proposed development and verification tests
- All modules should undergo a common, well-controlled set of verification tests
- An appropriate level of oversight needs to be applied during system design
- System designers would benefit significantly from access to a well experienced independent team able to provide design support during system development

Mechanisms of Fan Noise Generation

From Fitzgerald and Lauchle, “Reduction of discrete frequency noise in small, subsonic axial-flow fans,” JASA 76(1) 1984.

- Tones at constant blade passing frequency harmonics
  - Steady spatial distortion ingested by the fan
  - Spatial variations of boundary layer thickness
  - Interaction of the rotor blades with the potential fields of nearby stationary objects (motor struts, guide vanes, obstructions)

- Tones at varying phase blade passing frequency
  - Boundary layer thicknesses changing in time and space
  - Inlet turbulence
  - Slowly varying inlet distortions

Mechanisms of Fan Noise Generation

From Fitzgerald and Lauchle, “Reduction of discrete frequency noise in small, subsonic axial-flow fans,” JASA 76(1) 1984.

- Tones at shaft rotational frequency harmonics
  - Blade-to-blade irregularities (including variations in tip clearance, stagger angle, and skew)
  - Irregularly positioned blades
  - Blade form imperfections
  - Long-time scale boundary layer variations
- Peaks at Non-rotational ordered frequencies
  - Rotating inlet distortions
  - Mechanical vibrations of the rotor blades

Mechanisms of Fan Noise Generation

From Fitzgerald and Lauchle, “Reduction of discrete frequency noise in small, subsonic axial-flow fans,” JASA 76(1) 1984.

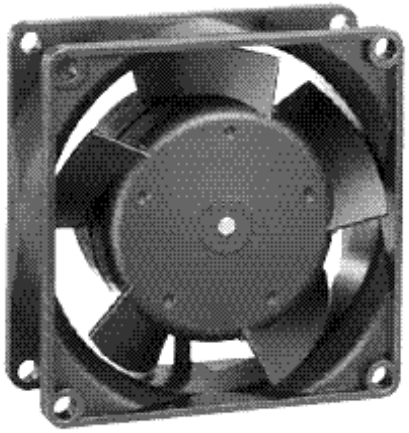
- Peaks at varying frequencies and broadband noise
  - Detailed variations in the annulus boundary layer
  - short-term, small scale inlet turbulence
  - Short-term boundary layer fluctuations

Results and Recommendations

Using a spaceflight qualified 80 mm cooling fan, a suite of acoustic and aerodynamic experiments were conducted at NASA Glenn to:

- Determine if the facilities and instrumentation historically used for acoustic verification could be used for fan noise source identification and prediction code validation
- Determine if the facilities and instrumentation typically used for aircraft engine research could measure the desired quantities in suitable detail for a computer cooling fan
- To characterize the aero and acoustic performance of the cooling fan itself.

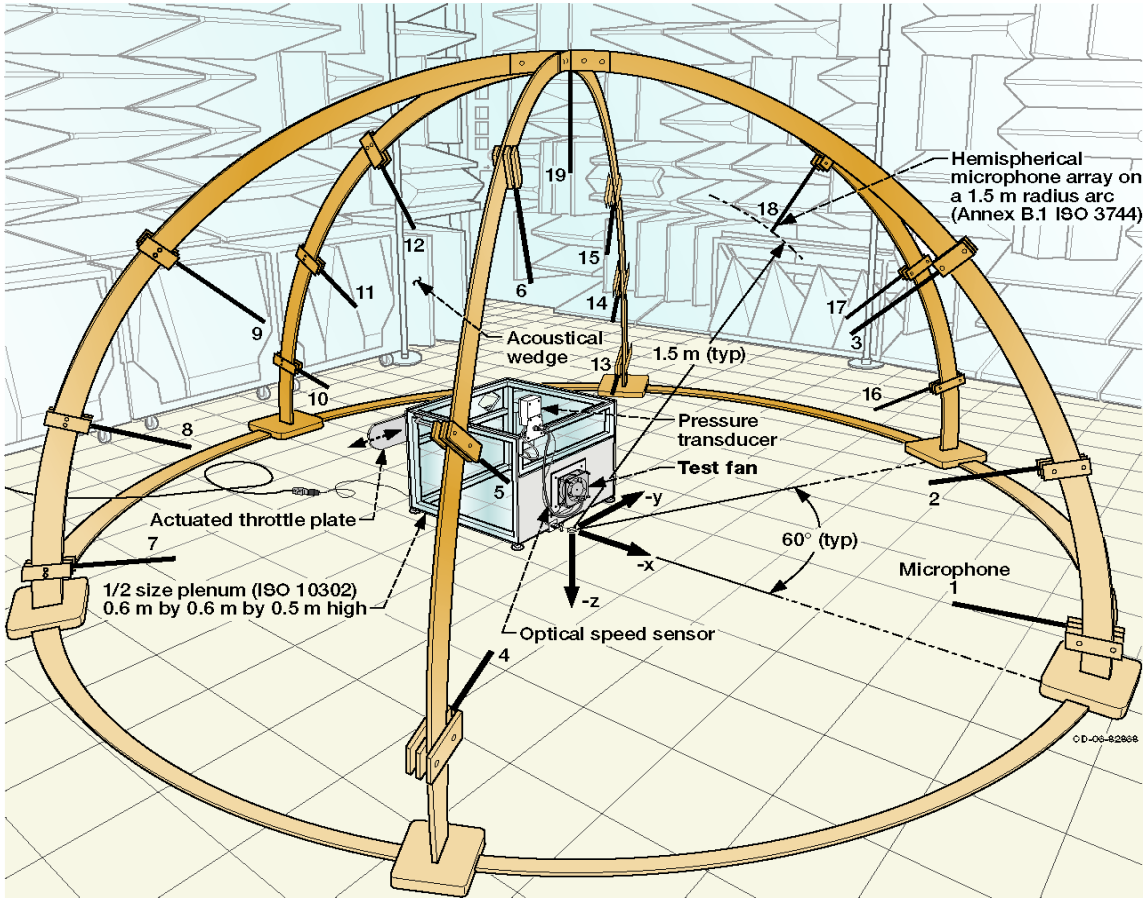
Results and Recommendations



Case Dimensions	80 x 80 x 32 mm
Duct Diameter	77 mm
Hub Diameter	42 mm
Number of blades	5
Number of motor struts	4
VDC	24
Maximum Flowrate	54 m^3/hr
Power	2.5 W

- An 80 mm cooling fan considered for spaceflight applications was used for acoustic and aerodynamic tests
- Acoustic results are available for the isolated fan and the fan with a simple inlet duct (80 mm length)
- Aerodynamic results are available for the isolated fan

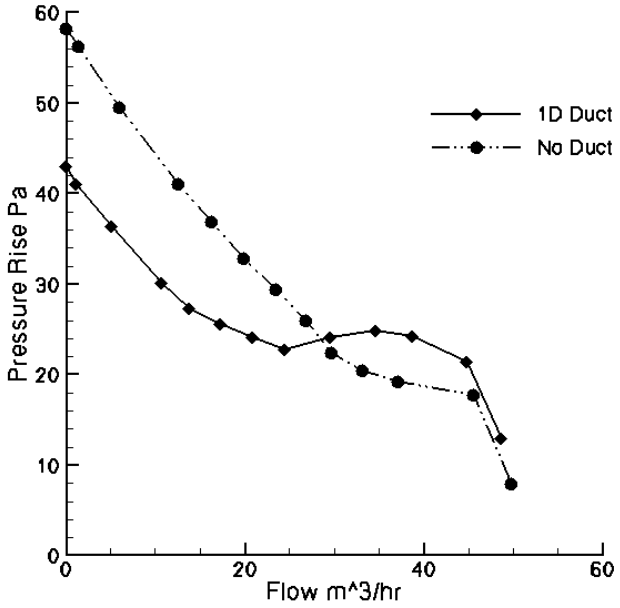
Results and Recommendations

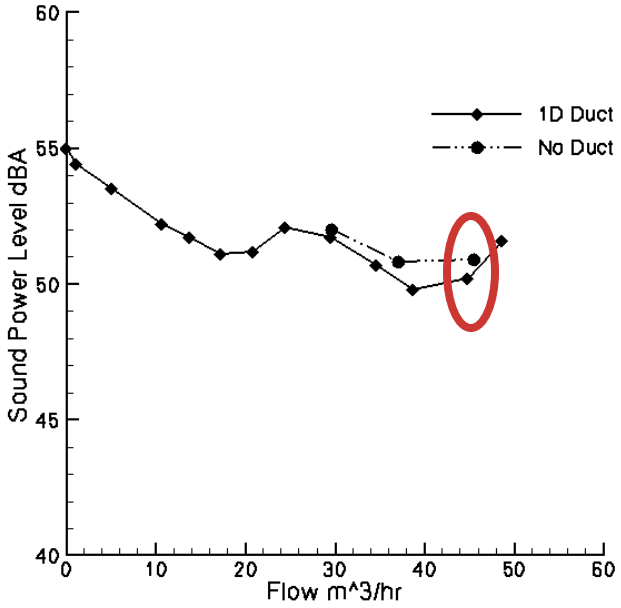


NASA Glenn Acoustical Testing Laboratory

- Hemi/full anechoic chamber, working area 21’ x 17’ x 17’
  - 100 Hz low frequency cut-off

Results and Recommendations





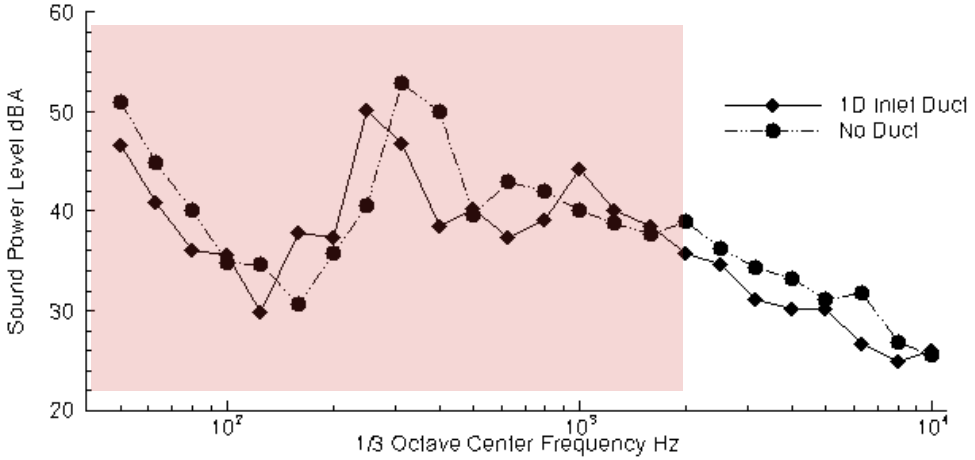
Results: Pressure rise and overall Sound Power Level was measured as a function of flowrate with and without a simple inlet duct 80 mm in length

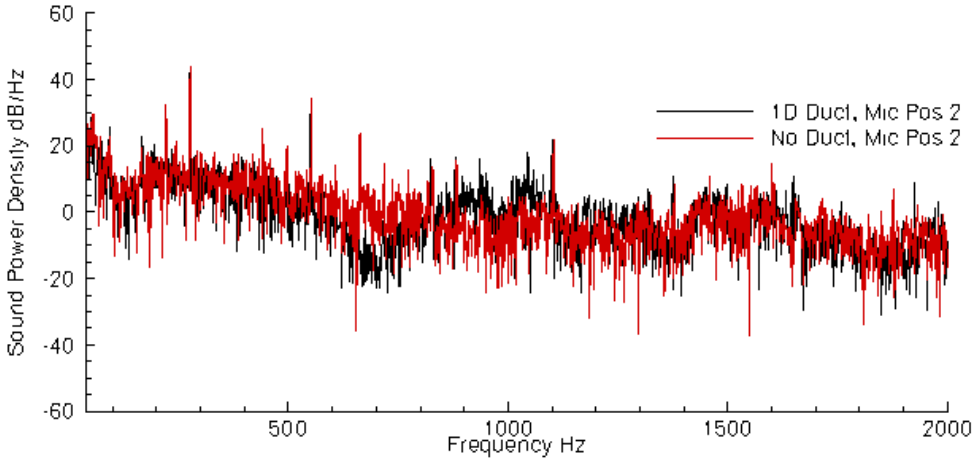
Recommendations: Both maps are needed for conceptual design work; presence of the simple duct suggest that better conditioning the flow ingested by the fan can improve both aero and acoustic performance

Results and Recommendations

Results: One-third Octave and Narrowband spectra were recorded and plotted; tones can be seen at BPF and rotational harmonics

Recommendations: Narrowband sound pressure levels ought to be recorded synchronously with the rotor rotational speed so that averaging schemes can be used to better understand the relative contribution of tone vs. broadband noise generation mechanisms.

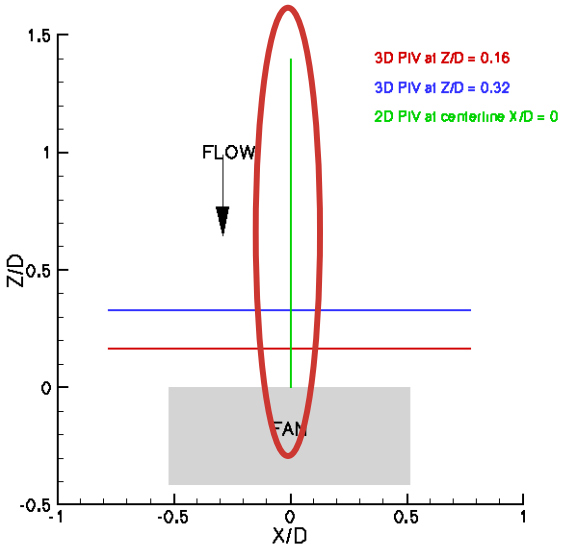


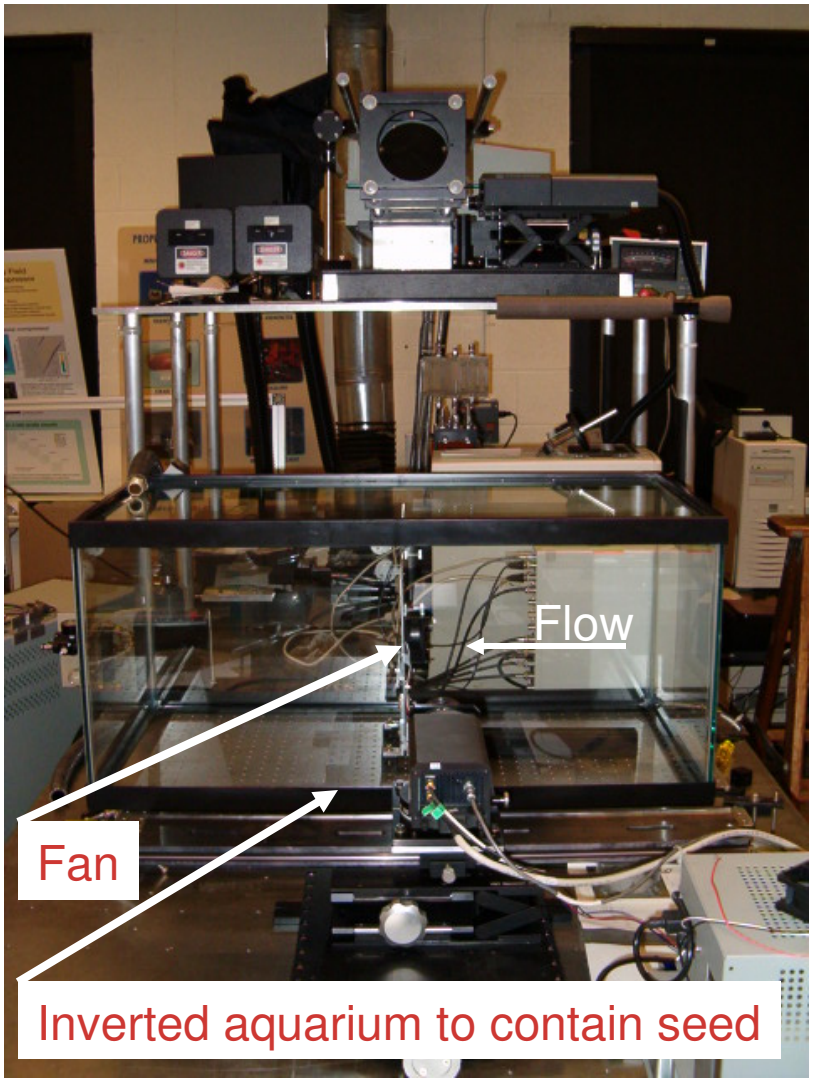


Results and Recommendations

2D and 3D Particle Image Velocimetry (PIV) used to map velocity fields at the fan inlet and exit regions

Fan tested without inlet duct



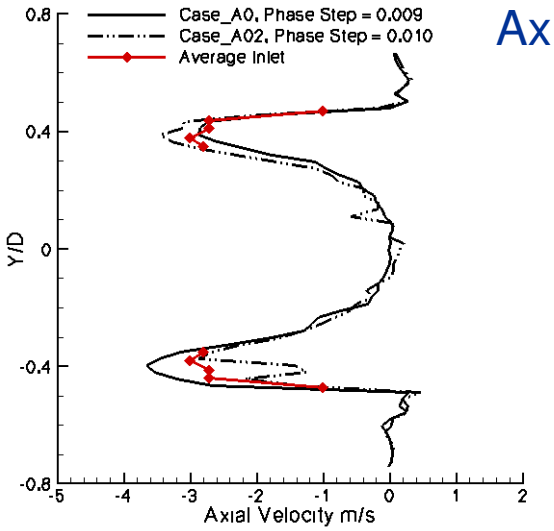


Results and Recommendations

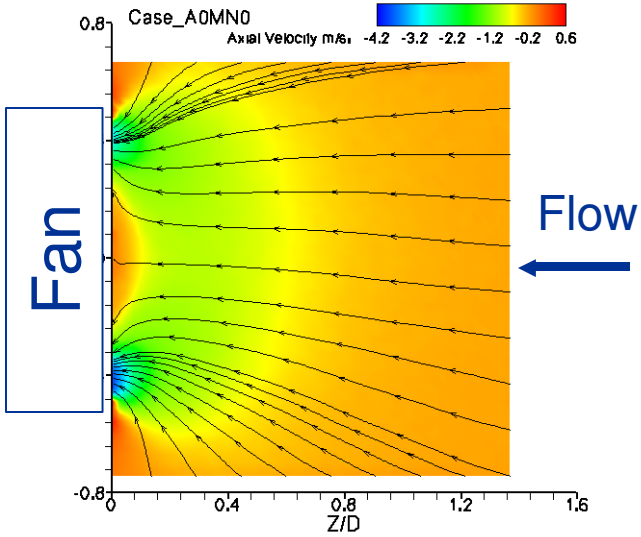
Results: 2D PIV measurements in a plane perpendicular to the fan face indicate significant radial velocities

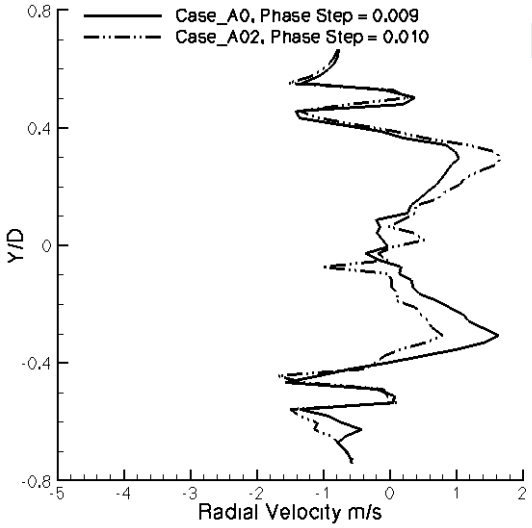
Recommendations:

- Inlet flow conditioning could improve performance, as well as the match with noise prediction schemes;
- Fixture needed to acquire PIV measurements of a throttled, ducted fan



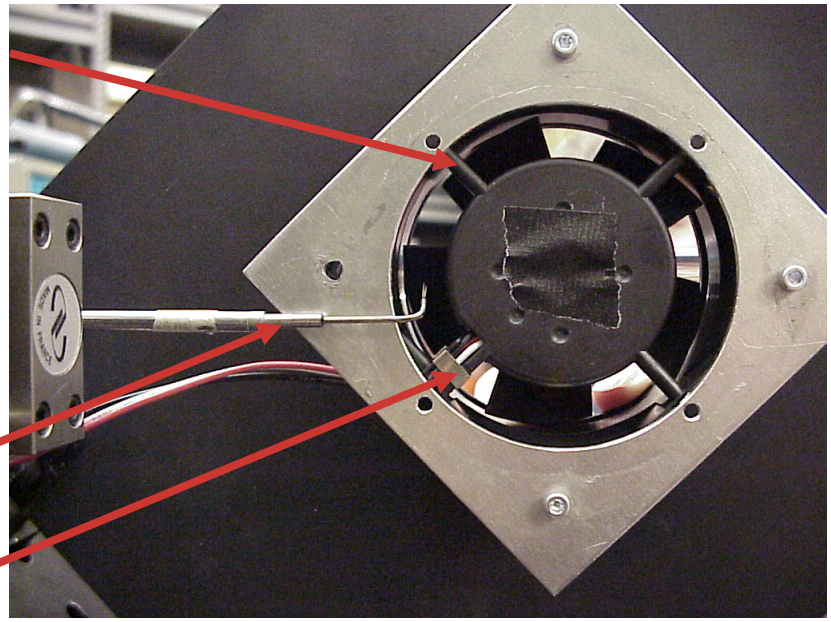
Axial Velocities at fan inlet plane





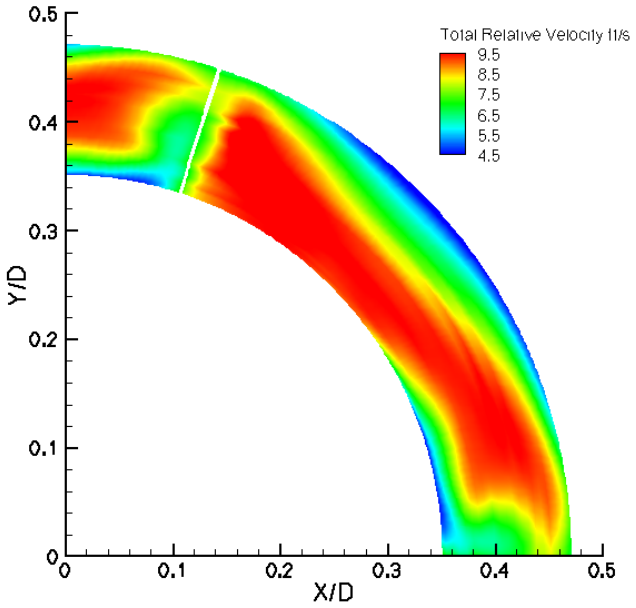
Radial Velocities at fan inlet plane

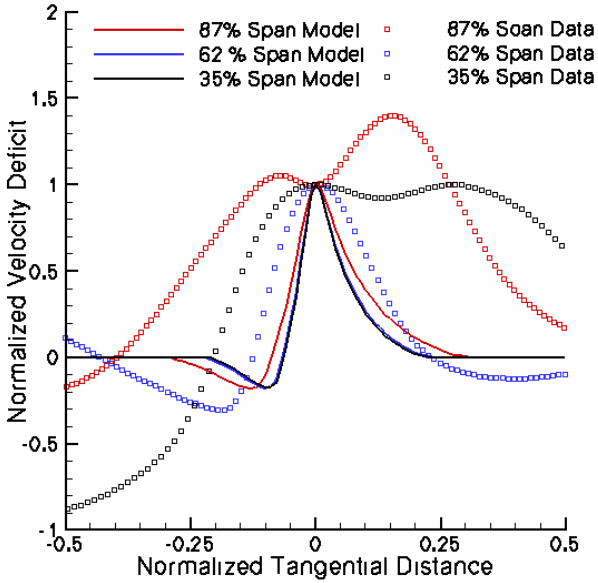
Results and Recommendations



- Axial and tangential components of velocity measured with a two wire hotwire probe traversed radially at one circumferential location
- Un-ducted fan tested at free delivery, 3300 rpm

Results and Recommendations





Results: 2 component hotwire probe measurements indicate wakes impinging on motor struts vary significantly across the blade span and do match a wake model in an existing rotor wake/stator interaction code well

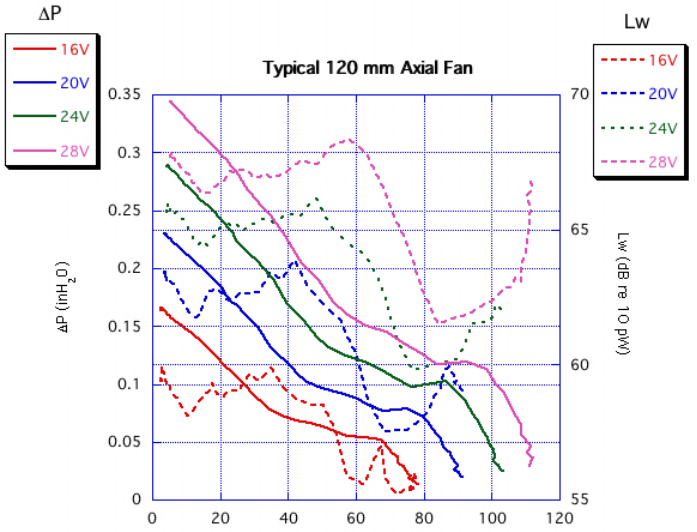
Recommendations:

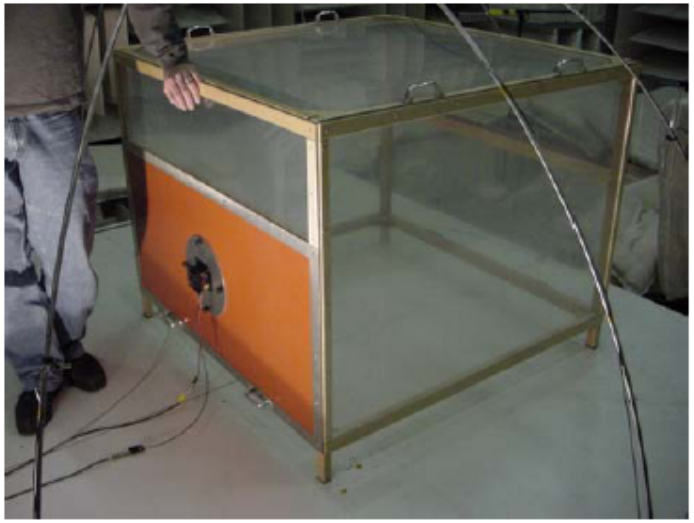
- Attention to design of the blade and shroud may improve the performance of the fan;
- Efforts to develop a noise prediction scheme ought to be guided by more thorough source identification
- Fixture needed to acquire hot wire measurements of a throttled, ducted fan

Suggestions for Future Work

For spaceflight fan system designers and fan noise researchers:

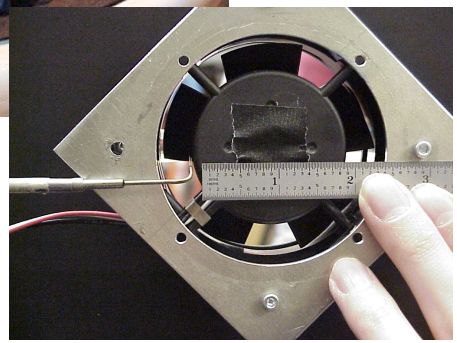
- Overall aerodynamic and acoustic performance maps should be available to system designers.
- Based on the overall performance, a subset of fans could be selected for advanced aero/acoustic diagnostics focused on determining the primary noise generation mechanisms.
- Results of the source identification tests could guide the development of low noise concepts (improved aero designs, active noise control, liners) and the development of noise prediction codes.
- By openly publishing the results of this research, industry would be able to use the geometry and data to validate their own proprietary design tools.





Data and Photo Courtesy NASA Ames

Suggestions for Future Work



Suggestions for future collaborative work have been described in more detail in a separate white paper available from the NASA Glenn Acoustic Branch Website:

http://www.grc.nasa.gov/WWW/Acoustics

Visit our website for links to copies of our recent reports, more information on NASA Glenn facilities and instrumentation, as well as links to noise researchers at other NASA Centers.