An assessment of NASA Glenn's aeroacoustic experimental and predictive capabilities for installed cooling fans
Part 1: Aerodynamic performance

Dale E. Van Zante
L. Danielle Koch
Mark P. Wernet
Gary G. Podboy
NASA Glenn Research Center
Cleveland, OH

Internoise 2006, Honolulu, Hawaii

GE90 turbofan engine for the Boeing 777

Objective: to determine if aircraft engine design and analysis techniques for performance and low noise are applicable to cooling fans

Aircraft engine fan design goals:

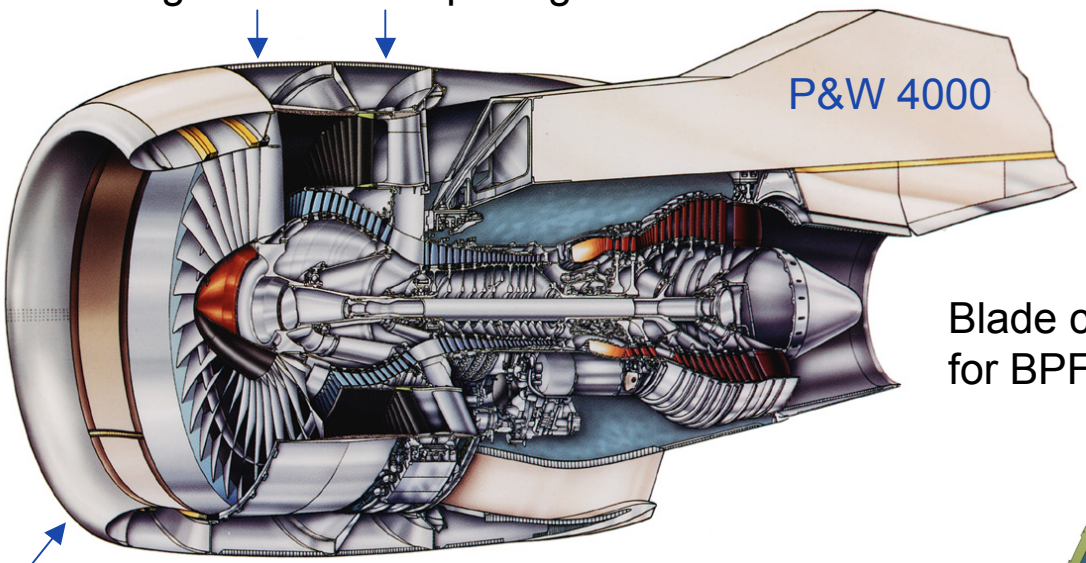
- efficiency
- durability
- low noise
- reduced cost

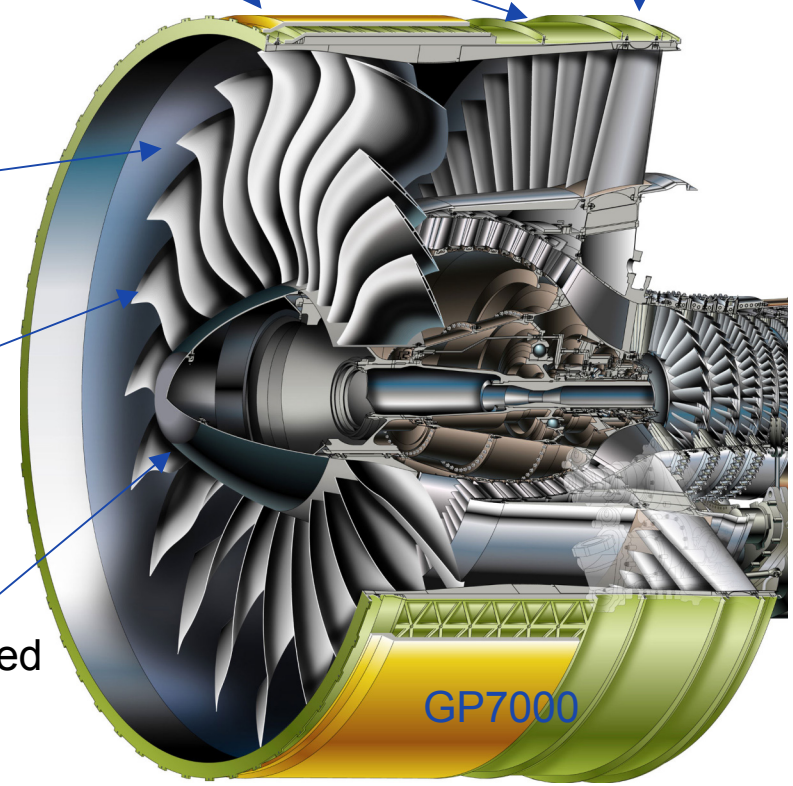
The technological evolution of aircraft engine fans is driven by the use of 3D computational methods and experimental measurements.

What is the design maturity of cooling fans relative to aircraft engine fans?

Rolls-Royce Trent 1000 fan for the A380

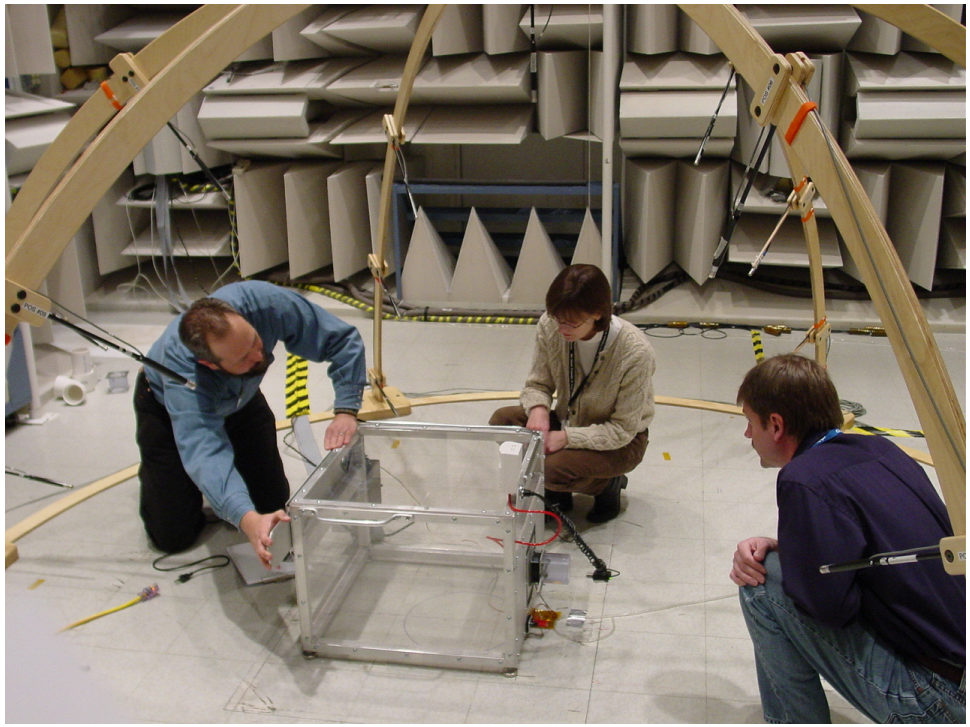
Aircraft engine fan design features for low noise and high efficiency.



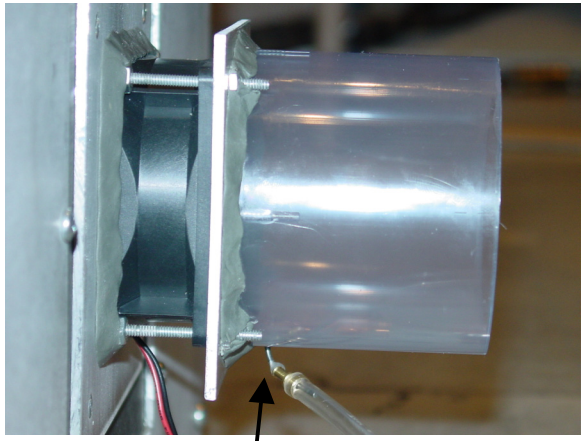


A representative axial fan which was tested for its aeroperformance and acoustic characteristics.

	Cooling Fan	Aircraft Fan Model
Casing radius	38 mm	279.4 mm
Tip radius	37 mm	278.9 mm
Hub radius	26 mm	83.8 mm
Hub/Tip ratio	0.70	0.30
Operating speed	3,300 rpm	12, 657 rpm
Tip speed	12.8 m/s	370 m/s
Clr height	1 mm	0.5 mm
Blade chord	34 mm	94 mm
Clr/chord	2.9%	0.5%
Solidity	0.86	1.7
Rotor blades	5	22
Struts/stators	4	54
Flow	40 m^3/hr	446,000 m^3/hr
Pressure rise	19 Pa	69,000 Pa



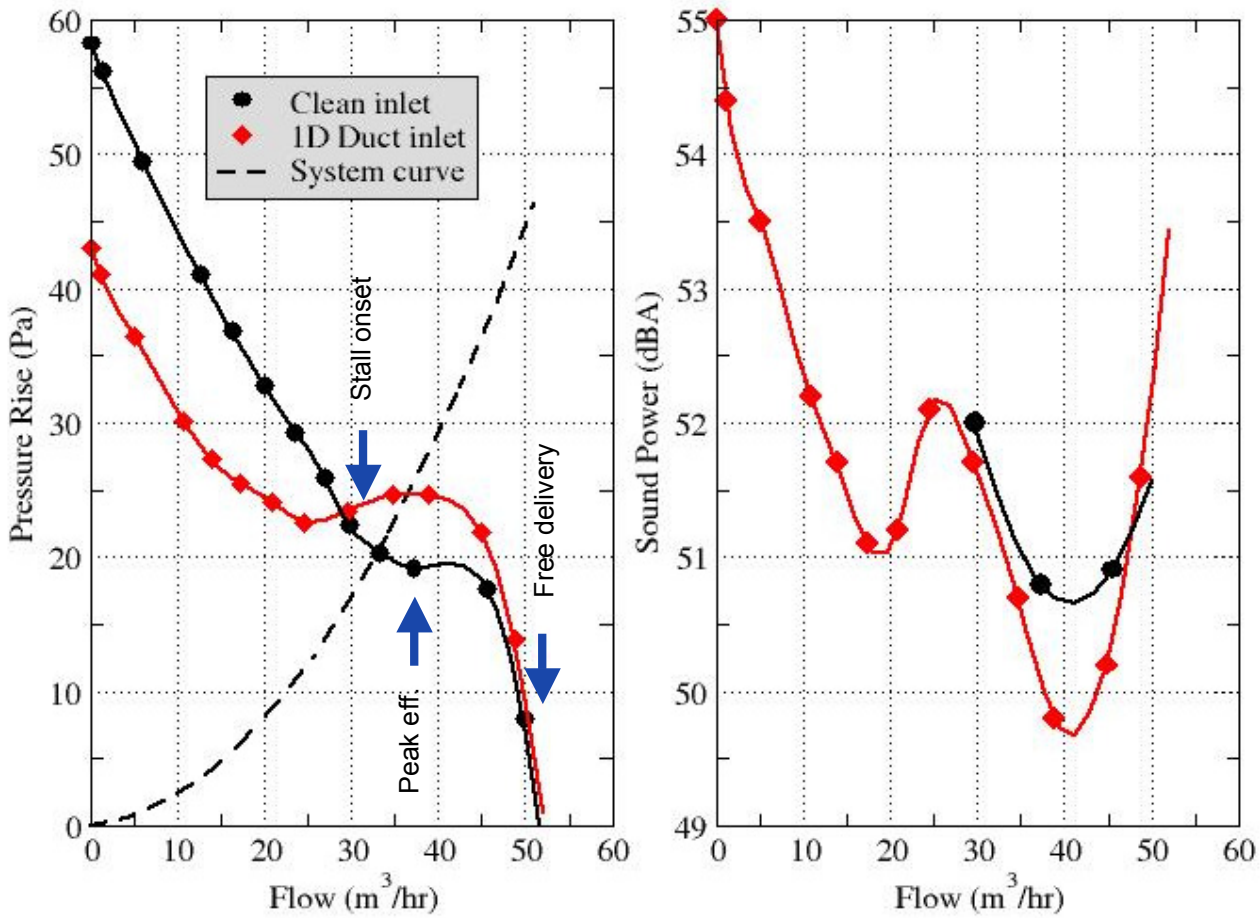
Testing the fan on the automated plenum in the Glenn Acoustic Testing Laboratory (ATL)



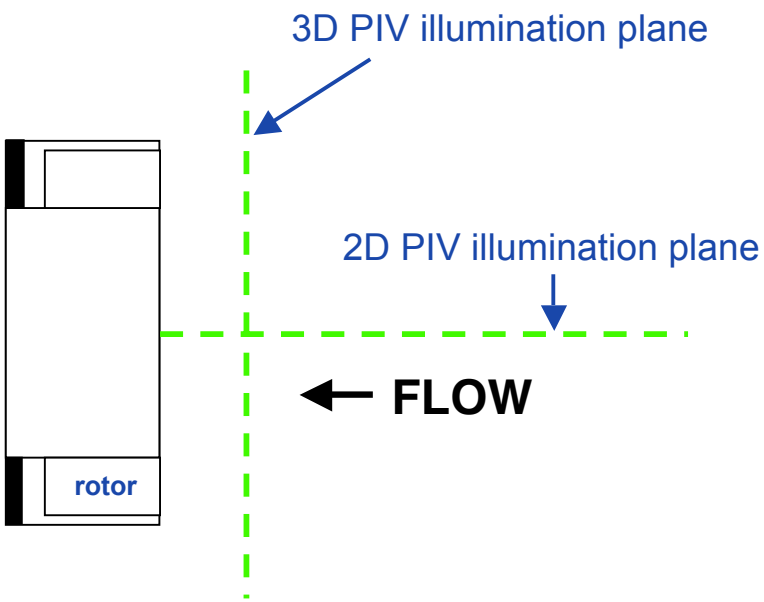
Wall static tap

The fan was tested with and without an inlet duct. The duct contained a wall static tap to determine the fan inlet pressure.

Cooling fan pressure rise and sound power characteristics



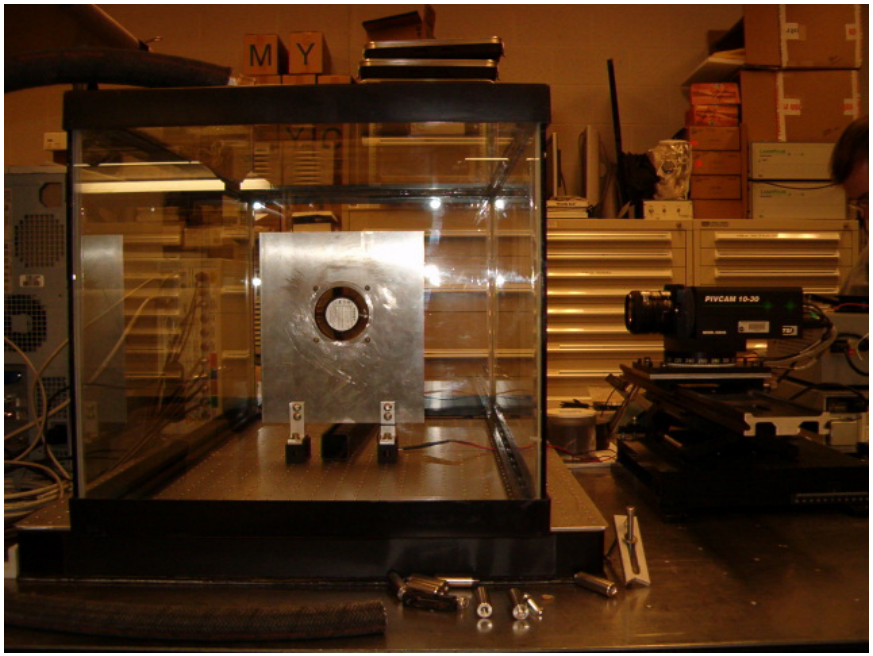
- **the inlet duct increased pressure rise and decreased sound power at the fan peak efficiency operating point**
- **detailed fan flowfield measurements will help explain the performance increase and will also show how the fan flowfield deteriorates at stall onset**

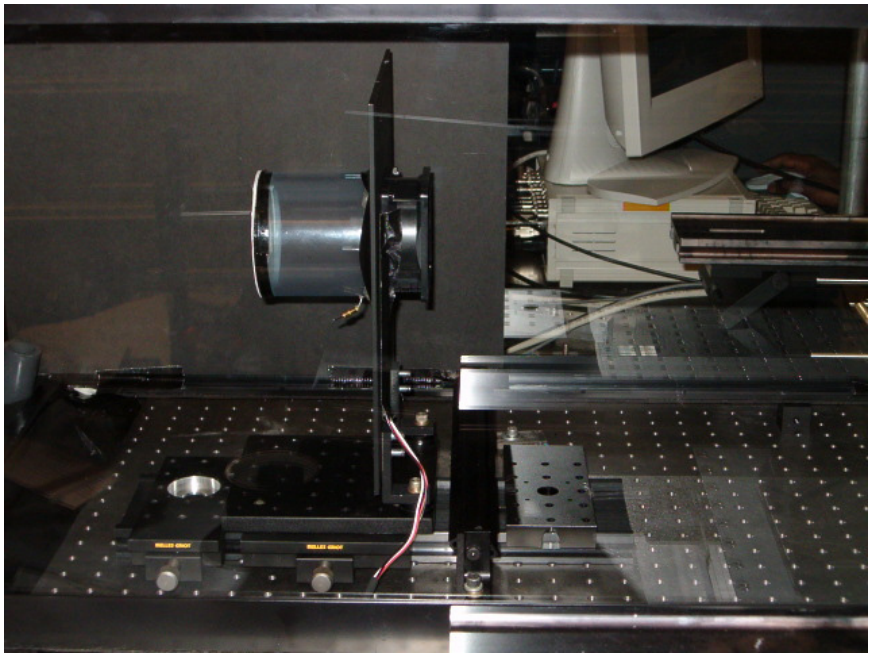


Fan flow field measurements were acquired using Particle Image Velocimetry (PIV)

- flow fields are average of 200 vector maps
- data are phase locked to the rotor using the tach signal
- free delivery and mild stall operating conditions

Fan fixtured for the PIV testing.





• the fan was mounted to a plate to mimic the Maling box installation
• the entire apparatus was enclosed in overturned aquarium which could be flooded with seed material

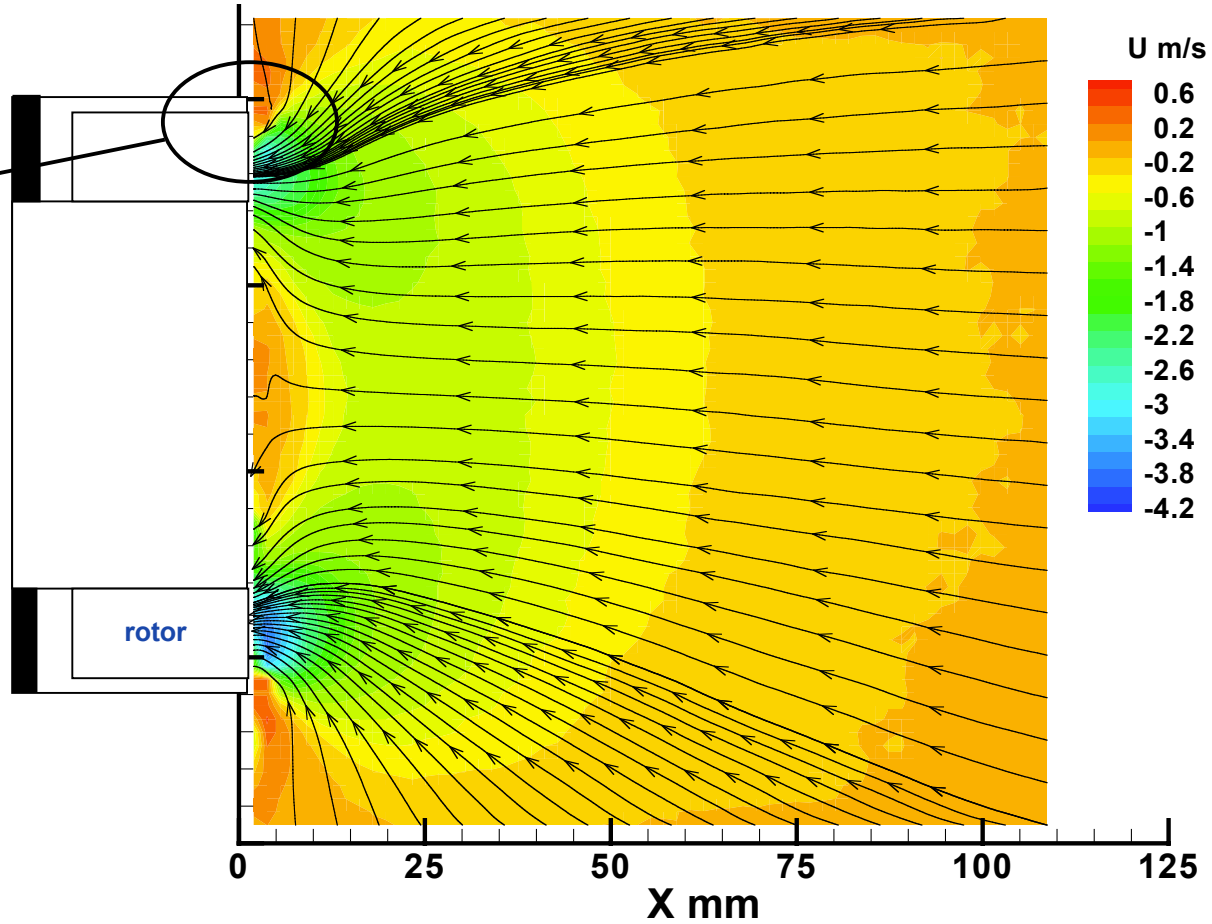
• side view of the fan with the exit duct and orifice attached which throttled the fan into mild stall

Why did the fan pressure rise increase when an inlet duct was added?

Without a duct, the flow is unable to negotiate the sharp inlet lip.

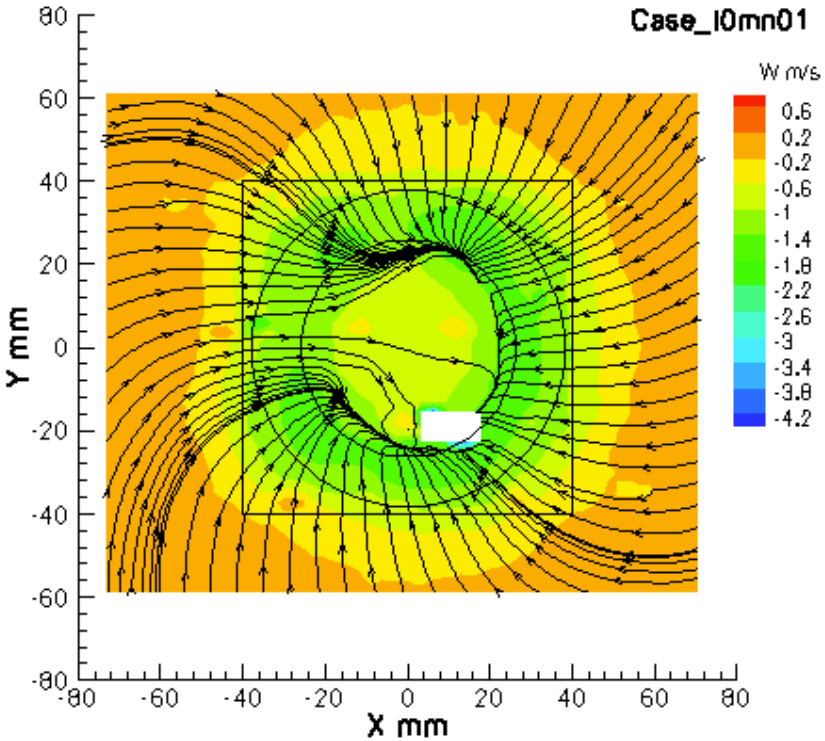
The outer blade spans, where blade speed is highest, are not able to do useful work.

The duct guides flow into the rotor and allows more of the blade span to do useful work, thus the pressure rise is increased.



2D PIV at the fan centerline, free delivery condition.

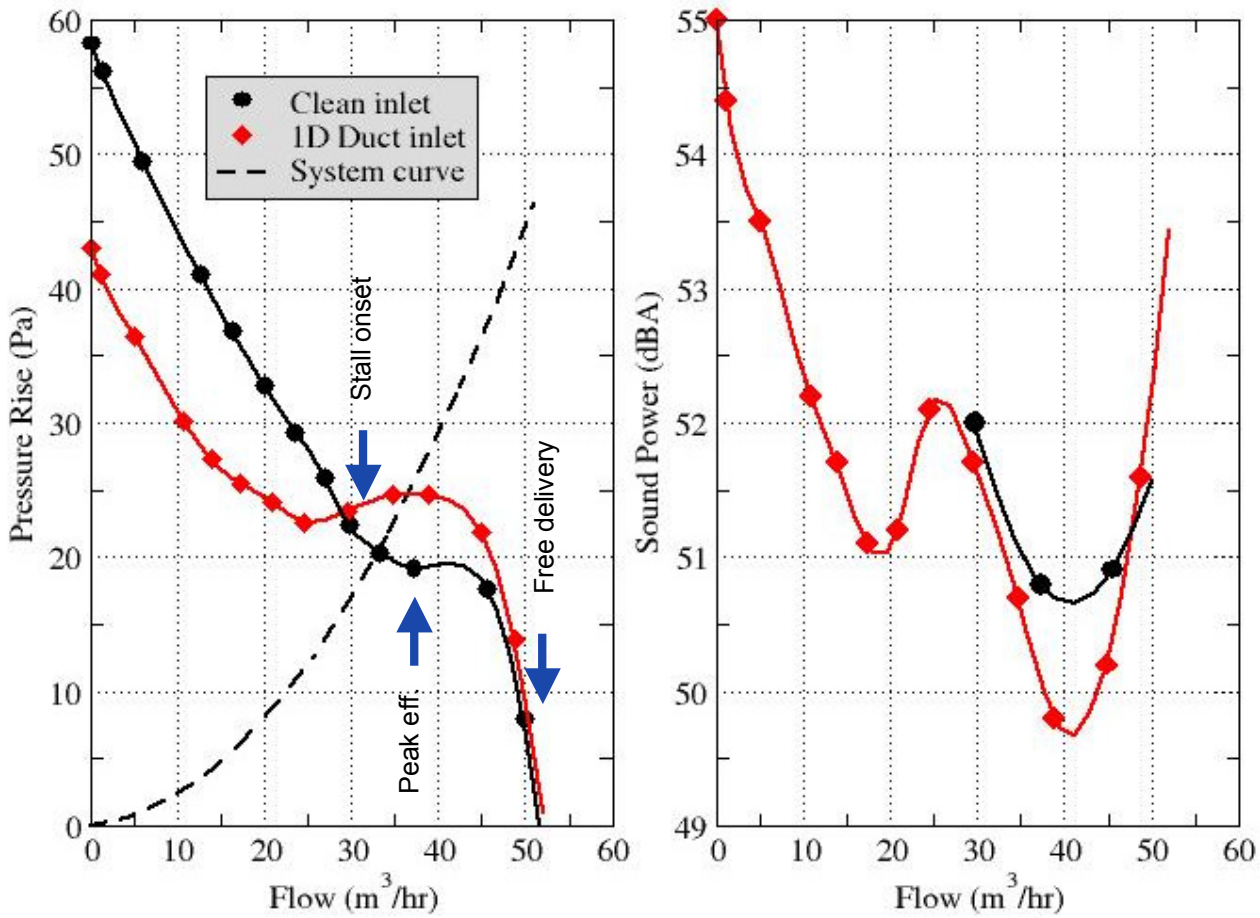
Why did the fan sound power decrease when an inlet duct was added?



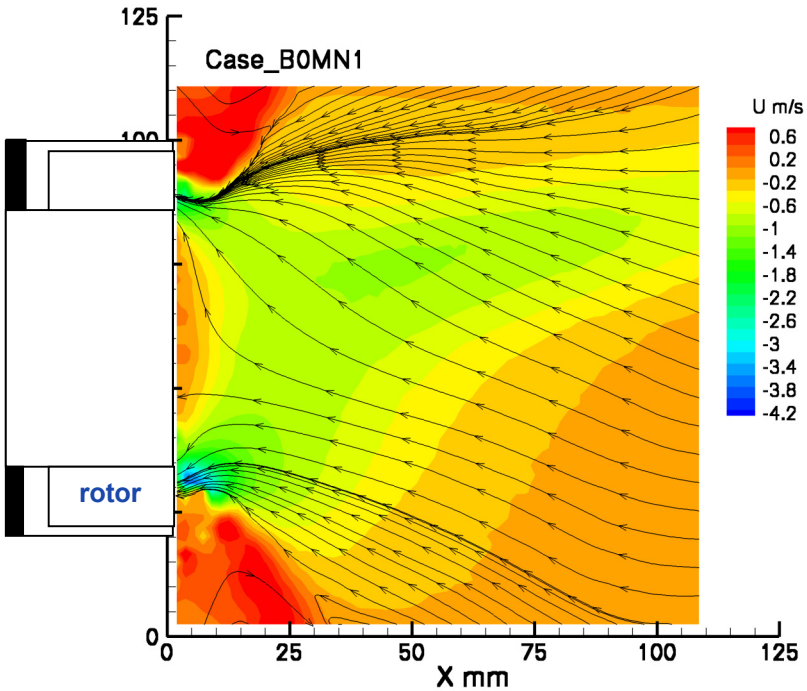
3D PIV on a plane 12.5mm in front of fan, free delivery condition.

- fan inflow shows the 'imprint' of the partial bellmouth in the fan inlet geometry
- the inlet flow distortion is a tone noise source
- the fan inlet duct made the fan inflow more axisymmetric and thus decreased noise

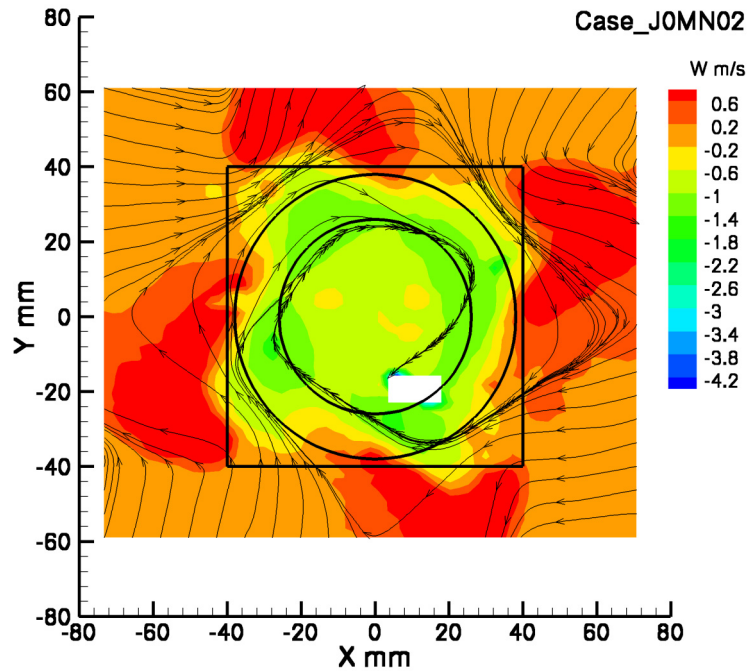
Cooling fan pressure rise and sound power characteristics



What happens if the fan is mismatched to the system and operates in mild stall?



Meridional view, 2D PIV, mild stall.



Fan inlet, 3D PIV, mild stall.

Swirling flow comes OUT of the inlet (red regions in above images) and leaks preferentially at the partial bellmouth cutouts.

Air that the fan is meant to exhaust is recirculated instead.

Discussion

It is unclear as to the origin of certain geometric design features of the cooling fan, although we can speculate that, for example:

- the motor form factor choice results in a large hub/tip ratio
- the drive to low manufacturing cost results in large tip clearance
- the ‘partial bellmouth’ in the fan casing is due to ????

Cooling fans are now expected to be a pressure rise device and more attention to aerodynamics will be necessary to achieve the desired aero performance at acceptable sound power levels.

For example, Wang and Huang (INCE Journal, Jan-Feb. 2006) showed a 2.5 dB decrease in overall sound power when the partial bellmouth was replaced with an axisymmetric inlet on a typical computer cooling fan.

Summary

Aircraft engine systems do provide guidance for low noise, high performance design characteristics.

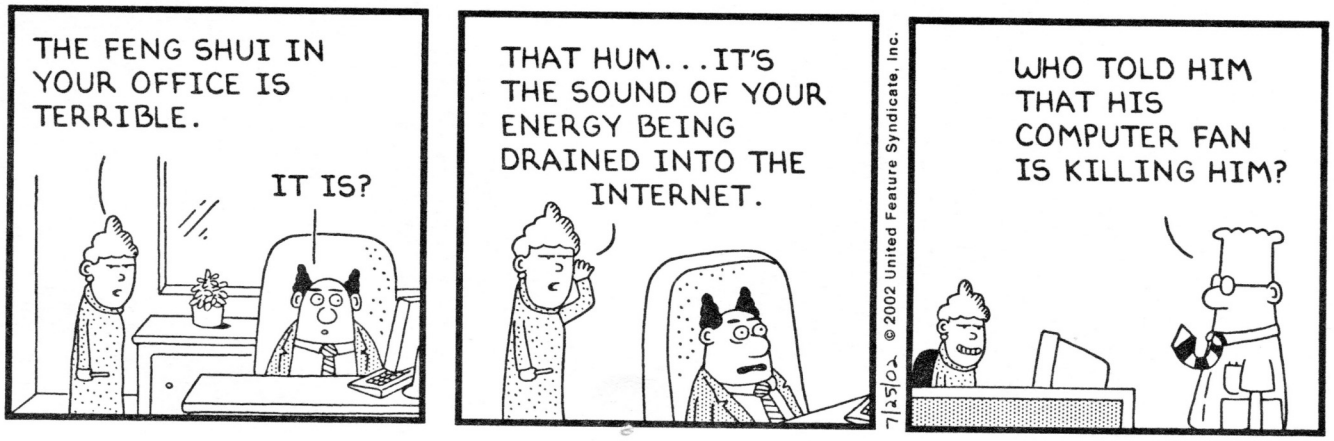
Tools for aircraft fan diagnostics, analysis, and design could help identify noise sources and generally improve the aero and acoustic performance of cooling fans.

We feel that there is significant gains to be made in cooling fan aero design and installation. (For example, a good inlet design could reduce overall sound power by 2.5dB)

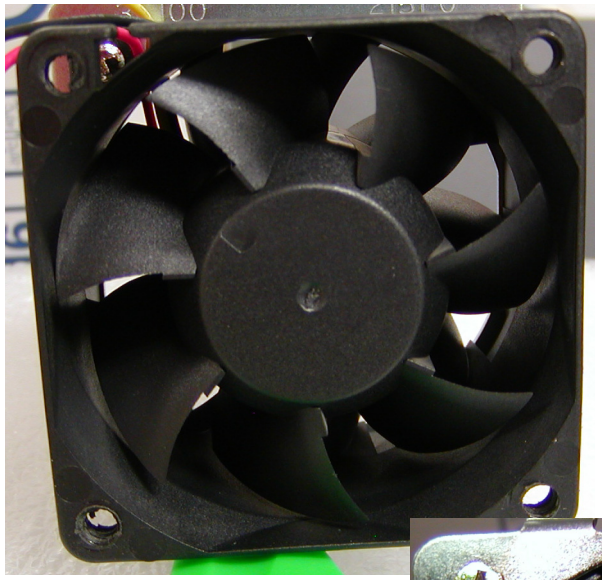
There are some fan manufacturers taking advantage of aircraft engine design tools. The aero performance of these fans is impressive. We would like to investigate the acoustic characteristics of these new fan designs.

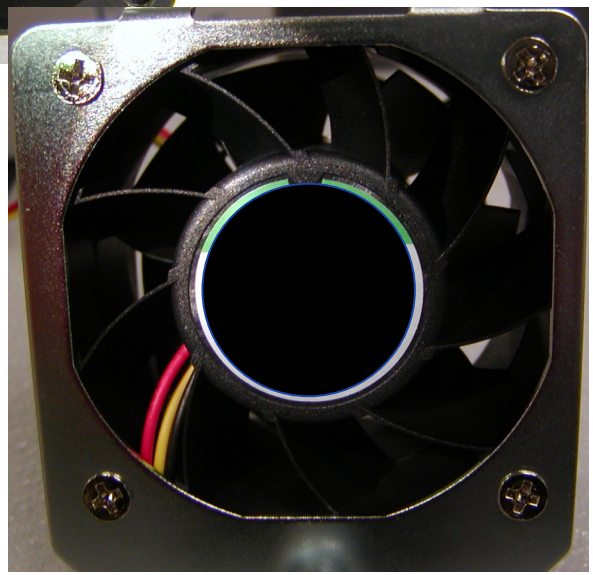
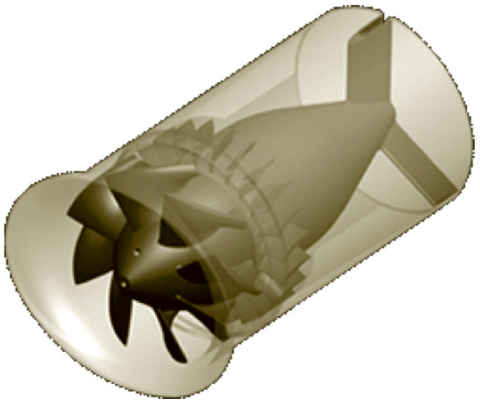
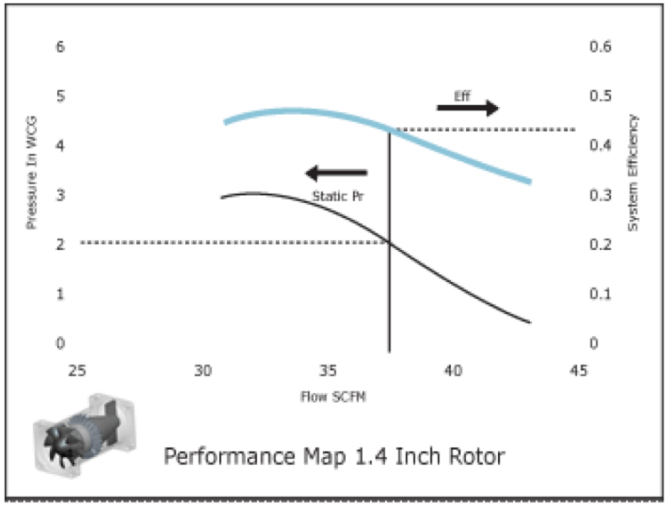
Questions?

http://www.grc.nasa.gov/WWW/Acoustics/collaboration/focusonfans.htm



Examples of improved design practice



Intake

Exhaust