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Inflow Treatment for Small Scale Axial Fans Under Unfavorable Inflow Conditions

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Motivation

• Unfavorable inflow example from video projector

• Literature
Experimental Study

- Test design
  - Choice of the specimen fan
    - Drawing based on US TOYO Fan Corporation, USTF12038 series
    - 120 mm × 120 mm axial
    - 3-D print with Object Eden350
    - 12V DC brushless motor
    - Optimal rotational speed: 2250 RPM
  - Inflow disturbance
    - Blockage: 120 mm × 120 mm plate
    - Parameter: distance from the inlet plane of axial fan, 15, 20, 25 and 30 mm

- Axial fan performance test
  - Conducted by Sony, Japan, using dedicated fan tester
  - Iso-RPM curves at 2250 RPM
Inflow Diffuser

- Inflow diffuser
  - Duocel® Aluminum Foam Metal
    - Pore size: 10 ppi
    - Volume density: 6-8%
    - Material: Alloy 6101-T6
    - Size: 120 mm × 120 mm × 5 mm
  - Installed at the inlet plane
    - Limited space
    - If not tightly installed, does not function as a diffuser

- Effect of inflow diffuser
  - 25% less flow rate at zero pressure condition
  - 100% pressure improvement at zero flow condition
  - Stable volume flow rate with system resistance
Acoustic Measurement

- ISO 10302 standard
  - Mylar plenum
    - Most of parts are made of mylar sheet
    - Applies pressure load on the fan by adjusting the slider
  - Microphone array
    - Ten microphone array on hemispherical structure
    - Sound power measurement in anechoic chamber with hard floor

- Sound power spectra

\[ L_w = \bar{L}_p + 10 \log_{10} \frac{S}{S_{ref}} \]

  - Where \( \bar{L}_p \) averaged sound power level re 2.0E-5 Pa
  - \( S \) surface area of hemisphere
  - \( S_{ref} \) reference area, 1 m²
Acoustic Measurement

- Foam suppresses tonal noise and removes stall noise
- But introduces high frequency tones
Numerical Study

- Detailed flow information is desired to explain Inflow diffuser effect
- URANS model with sliding mesh for rotor region
- 8 layers of mesh applied to the tip clearance
- Mesh refinement study indicated little dependence on mesh for stable flow, but unstable performance conditions are still sensitive to mesh structure
- The foam structure is modeled as a porous media with a momentum sink term in the N-S equation
Porous Screen Modeling

- The porous screen acts as a source (sink) term in the momentum equation.
- The screen is assumed to be homogeneous.
- The source term for the $i$th momentum equation $S_i$

$$S_i = - \left( \frac{\mu}{\alpha} v_i + C \frac{1}{2} \rho v_{mag} v_i \right)$$

**Total momentum loss = viscous loss + inertial loss**

- Here, $\alpha$ is permeability and $C$ is the inertial resistance factor which can be found empirically.
- $p$-$v$ test using a simple tube

$$\Delta p = 1.1567 v^2 + 0.54223 v$$

$$1.1567 = C \frac{1}{2} \rho \Delta n \quad C = 377.702$$

$$0.54223 = \frac{\mu}{\alpha} \Delta n \quad \frac{1}{\alpha} = 6060486$$
Measured vs. Predicted Performance Curves

- The pressure boundary condition was assigned at the inlet and exit surface of the domain
- Solve the transient model until steady state
- The resultant flow rate of the CFD result decides the performance point

- Unstable behavior shown in CFD result
- The “crossing-over” feature in CFD result
Axial Velocity [m/s]

- bare
- foam
Circumferential Velocity [m/s]

bare

foam
Vorticity Magnitude [1/s]

- Bare
  - Foam

- Blockage
  - Foam
Pressure Contour [Pa]

- **tip** (5 cm)
- **mid** (4 cm)
- **hub** (3 cm)

Comparing pressure contours between a **bare** and a **foam** surface.
Acoustic Modeling (FLUENT)

- The Ffowcs Williams and Hawkings Model
  - Dipole source on the surface is considered for tonal noise prediction

\[
\frac{1}{a_0^2} \frac{\partial^2 p'}{\partial t^2} - \nabla^2 p' = \frac{\partial}{\partial t} \left\{ [\rho_0 v_n + \rho (u_n - v_n)] \delta(f) \right\} \quad \text{monopole}
\]

\[- \frac{\partial}{\partial x_i} \left\{ [P_{ij} n_j + \rho u_i (u_n - v_n)] \delta(f) \right\} \quad \text{dipole}
\]

\[+ \frac{\partial^2}{\partial x_i \partial x_j} \{T_{ij} H(f)\} \quad \text{quadrupole}
\]

  (ignored in FLUENT)

- Free field acoustic pressure was obtained at the receiver location of ISO standard

- The sound power was calculated using 20 reception (microphone) locations on a 1 m radius sphere
Prediction vs. Measurement

- Free flow (0Pa) condition with different RPMs

![](image1)

- 10 dB under prediction for BPF
- Tones grow and shift in the same manner comparing to measurement
- The broadband base does not show up with URANS-FWH model
- Foam structure couldn’t be included in the model
dP/dt RMS Contours

$\Delta P = 10$ Pa, Blockage @ 25 mm: Foam screen improves performance
Conclusions

• Aerodynamically, the inlet diffuser improves the performance of axial fans by changing the axial fan to generate more stable flow rate for given pressure condition with any outer pressure disturbance when the inflow condition is distorted by some blockages.

• In terms of noise generation, the inlet diffuser was effective in suppressing the blade passing frequency tone and instability noise, but introduced high frequency tones.

• The combined URANS simulation and FWH aeroacoustic analogy model was able to predict the tonal noise generated from the fan-shroud surfaces. Proper model for the foam structure is needed for acoustic prediction of foamed fan.

• The simulated flow information in the impeller region showed: the inflow diffuser helped to redistribute the inflow pressure and avoid reverse flow that degraded the aerodynamic performance of the axial fan.

• The diffuser also suppressed the unnecessary circumferential momentum at the inlet of an axial fan and helped to increase more useful static pressure at the inlet.