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Influence of Geometric Parameters on Aerodynamic and Aeroacoustic Performance of Bladeless Fans

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OUTLINE

- Background & Motivation
- Methodology
  - Experiments
  - Numerical Simulations
- Results
- Conclusions

BACKGROUND: FANS IN INDUSTRY

Vehicle Engine

CPU Radiator Fan

Applications

- Cooling system
- Ventilation
- Thermal comfort

HVAC

Cooling Fan

Features

- High flow rate
- Low noise level

BLADELESS FAN

- Bladeless fans launched by Dyson®

Advantages

- The produced wind is softer and more uniform.
- Flow rate at downstream is larger.
- No visible rotating blade is safer for children.

Working mechanism of the bladeless fan

Jafari *et al.* (2015)

AN EXAMPLE OF THE BLADELESS FAN

– UK, Dyson. “Dyson Cool Fans - Air Multiplier Technology Explained - Official Video.” YouTube, YouTube, 5 Mar. 2014, www.youtube.com/watch?v=bUJ-X1rsKV4.

PREVIOUS WORK

Li et al. (2016)

Flow field structure outside the bladeless fan over the center plane

Li et al. (2014)

Pressure distribution near the slit with different Coanda surface curvatures

Jafari et al. (2015)

Streamlines outside the bladeless fan over the center plane

Jafari et al. (2016)

Sound power contour

Jafari et al. (2016)

Effect of the outlet thickness and outlet angle on volume flow rate at downstream

OBJECTIVE & RESEARCH STRATEGY

- Characterize the aerodynamic and aeroacoustic performances of the bladeless fan by a combined 3D numerical and experimental study
- Investigate the influence of geometric parameters of the wind channel on bladeless fan's performance

METHODOLOGY: VELOCITY MEASUREMENT AT FAR FIELD

3D ultrasonic anemometer

Measurement in Herrick PBE Lab

- Measurement position: 837
- Measurement duration at each position: 30s
- Sampling rate: 1s
- Accuracy: $\pm(2\%+0.03\text{m/s}$ of indicated values)

**X velocity contour
@x = 1.5m**

METHODOLOGY: SOUND PRESSURE MEASUREMENT AT RECEIVERS

Measurement in Herrick anechoic chamber

B&K intensity probe

Sound pressure level
@ two receivers

PROTOTYPE OF THE BLADELESS FAN

$d=2\text{mm}$, $H=3\text{cm}$, $c=12\text{cm}$, $x_0/c=10\%$
Cross-section of the wind channel

Wind channel

Computational domain

Temperature: $25^{\circ}\text{C} \sim 30^{\circ}\text{C}$

Reynolds number at the intake and the slit:

$$\text{Re}_{\text{intake}} = 6723, \text{Re}_{\text{slit}} = 3000 \sim 4100$$

Simulation Set-up

- The number of grids: **6,320,000**
- Steady RANS: $k - \varepsilon$ model
- LES: Smagorinsky-Lilly model
- Time step: $1 \times 10^{-4}\text{s}$
- Flow solver: SIMPLE

MESH GENERATION OF THE BLADELESS FAN

- Mesh for the computational domain

- Mesh for the cross-section of the wind channel

– Mesh independency test

METHODOLOGY: DATA POSTPROCESSING

RESULTS: INSTANTANEOUS FLOW FIELD

- X velocity over Z planes
- LES, $t = 5s$ to $15s$

AERODYNAMIC CHARACTERISTICS: MEAN FLOW

@ the center plane of the bladeless fan

@ $z = 0.8\text{m}$

@ $X=1.5\text{ m}$

LES, time-averaged
($t = 4\text{s}$ to 15s)

RANS

Exp.

AERODYNAMIC CHARACTERISTICS: MEAN PRESSURE

- Pressure over Z planes
- LES, averaged from $t=4s$ to $15s$

EFFECT OF THE SLIT WIDTH

LES, time averaged for $t = 4s$ to $15s$, @ $x = 1.5 m$

X velocity component (m/s)

@ $z = 0.8m$

EFFECT OF THE CROSS-SECTION HEIGHT

EFFECT OF THE SLIT LOCATION

@ $z = 0.8$ m

LES, time averaged for $t = 4$ s to 15 s, @ $x = 1.5$ m

X velocity component (m/s)

Color scale: 0 0.2 0.4 0.6 0.8 1 1.2 1.4 1.6 1.8 2 2.2 2.4 2.6 2.8 3 3.2 3.4

$x_0/c = 5\%$

$x_0/c = 10\%$ (baseline)

$x_0/c = 15\%$

$x_0/c = 20\%$

— $x_0/c = 5\%$
 — $x_0/c = 10\%$
 — $x_0/c = 15\%$
 — $x_0/c = 20\%$

EFFECT OF THE PROFILE OF CROSS-SECTION

RATIO OF MASS FLOW RATE

Effect of slit width

Effect of cross-section height

Effect of slit location

Effect of profile of the cross-section

$$M_1 = \frac{Q_{total}}{Q_{inlet}}$$

$$M_2 = \frac{Q_{back}}{Q_{inlet}}$$

AEROACOUSTIC CHARACTERISTICS

- Acoustic model: FW – H model
- Density: 1.225kg/m^3
- Sound speed: 340m/s
- Reference acoustic pressure: $20\mu\text{Pa}$
- Noise source: Bladeless fan

Sound pressure level

@ $x = 0.1\text{m}$

@ $x = 1.5\text{m}$

EFFECT OF THE GEOMETRIC PARAMETERS ON AEROACOUSTIC PERFORMANCE

$d=2\text{mm}$, $H=3\text{cm}$, $c=12\text{cm}$, $x_0/c=10\%$

Effect of slit width

Effect of cross-section height

Effect of slit location

Effect of profile of the cross-section

CONCLUSIONS

- When the wind produced by the bladeless fan becomes more **powerful**, the aerodynamic noise is **louder**.
- With the **decrease** of the slit width, the wind strength becomes more **powerful**. The generated noise **increases** at the same time.
- The bladeless fan with the cross-section of **4cm** has the best aerodynamic performance, but the generated noise is the loudest.
- With the slit **moves away from the leading edge**, both wind strength and noise level **increase**.
- The profile of the cross-section affect the shape of the influence zone, but has insignificant effect on outflow mass flow rate and the generated noise.

ONGOING EFFORT

- Investigate the performance of the bladeless fan prototype with the impeller in the base
- Identify the main noise source
- Analyze the noise directivity of the bladeless fan
- Come up with a general criteria to evaluate the aerodynamic performance of the bladeless fan (i.e. strength, uniformity and steadiness of the wind)
- Propose a criteria to evaluate the compromise between the aerodynamic and aeroacoustic performance
- Apply the results to optimize the design of the new-generation bladeless fan.

ACKNOWLEDGEMENT

- Thanks to the financial support and professional feedback provided by Midea Global Innovation Center

*Thank
you*

A black and gold fountain pen, shown from the side, with its nib pointing towards the right, positioned as if it has just finished writing the 'Thank you' text.