Performance Characteristics of a Fan Using Synthetic Jets

Tomoaki Ishizawa, Kotaro Sato, Koichi Nishibe and Kazuhiko Yokota

Abstract Studies of synthetic jets generated by compact actuators have been conducted for various applications such as drag reduction, boundary layer separation control, and multi-flow mixing. In this paper, a jet fan that utilizes synthetic jets is proposed. The flow patterns inside the jet fan are revealed, and performance curves are drawn. Static pressure distributions in the fan duct are also analyzed to discuss the process of static pressure recovery.

Nomenclature

b_0	Slot width = 10×10^{-3} [m]
C_{pc}	Pressure coefficient for the continuous jet = $(p - p_{in})/0.5\rho U_{c0}^2$ [–]
C_{ps}	Pressure coefficient for the synthetic jet = $(p - p_{in})/0.5\rho U_{sm0}^2$ [–]
D_d	Downstream duct length = 340×10^{-3} [m]
D_u	Upstream duct length = 210×10^{-3} [m]
h	Channel exit height [m]
H	Inlet/outlet channel height of the fan duct = 30×10^{-3} [m]
l_0	Stroke length [m]

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L_0	Non-dimensional stroke length [–]
Δp	Pressure difference between the inlet and outlet [Pa]
Q_t	Total flow rate at the fan outlet [m^3/s]
Re	Reynolds number $= U_0 b_0/\nu = 5300$ [–]
U_{c0}	Representative velocity of the continuous jet [m/s] (see [3])
U_{s0}	Representative velocity of the synthetic jet [m/s] (see [3])
U_{sm0}	$= \sqrt{\frac{1}{T}\int_0^{\frac{T}{2}} u_0^2(t)dt}$ [m/s] (see [5])
W	Width of the duct $= 30 \times 10^{-3}$ [m]
η_c	Efficiency of the continuous jet $= \Delta p Q_t / 0.5\rho U_{c0}^2\, b_0 W U_{c0}$ [–]
η_s	Efficiency of the synthetic jet $= \Delta p Q_t / 0.5\rho U_{sm0}^2\, b_0 W U_{s0}$ [–]
θ_j	Blowing angle = 30 [°]
Φ_s	Flow rate coefficient for the synthetic jet $= Q_t / b_0 W U_{s0}$ [–]
Φ_c	Flow rate coefficient for the continuous jet $= Q_t / b_0 W U_{c0}$ [–]
Ψ_s	Discharge pressure coefficient for the synthetic jet $= \Delta p / 0.5\rho U_{sm0}^2$ [–]
Ψ_c	Discharge pressure coefficient for the continuous jet $= \Delta p / 0.5\rho U_{c0}^2$ [–]

1 Introduction

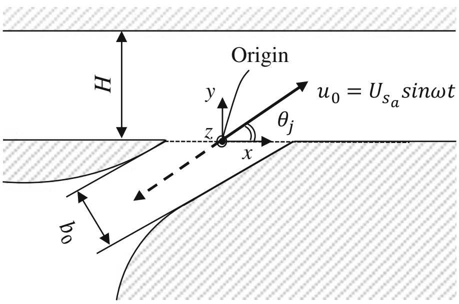
Recently, synthetic jets have received attention as a substitute for continuous jets, and many studies on the flow characteristics of synthetic jets have been conducted to devise means to apply them to active flow control [1]. It has been reported that the flow field of a synthetic jet is governed by two non-dimensional parameters [1], i.e., the Reynolds number and the non-dimensional stroke length $L_0 = l_0/b_0$, where l_0 is the length of the fluid body ejected during the expulsion phase and b_0 is the slot width. An advantage of synthetic jets is that the jet flow can be generated using previously developed actuators that are abundantly available, such as diaphragms, piezoelectric elements [2], speakers [3], and plasma [4]. A magnetic synthetic jet actuator, which can supply energy in a noncontact mode, will be developed in the near future. Because most actuators can function without using rotational parts, synthetic jet technology also facilitates the downsizing, simplifying, and refining of fluid machines, thereby improving their preciseness. However, only few studies have been conducted on fluid machines based on the synthetic jet principle [1–3], and jet pump/fan designs using synthetic jets [5] have not been sufficiently investigated. If pumps or fans that use synthetic jets for energy transformation are developed, they can be used in applications such as air flow production in hermetically sealed aseptic containers, circulation of high-level radiation-contaminated water, and transportation of high-purity chemical liquids.

This study represents fundamental research on jet pump/fan development using a synthetic jet. As the first step, a prototype model of a synthetic jet fan is proposed, and the fan performance characteristics are discussed. In particular, this work is an attempt to experimentally clarify the effect of the jet oscillation characteristics (e.g., the non-dimensional stroke L_0) on the fan performance, the pressure rise mechanism inside the fan duct, and fan efficiency. The experimental data obtained for the synthetic jet is compared with those for the continuous jet.

2 Experimental Setup

Figure 1 depicts the coordinate system and schematic diagram of the proposed synthetic jet fan. This prototype is the first step to utilizing synthetic jets as a fan; however, in the future, this type of fan, which is based on the principle of simple vibration, is expected to be used in various fields mentioned above. The slot width is represented as b_0. The inlet/outlet channel height of the fan duct is H, and the width of the duct is W. The results presented in this paper are obtained for a blowing angle θ_j of 30°. In the blowing process performed using this model, the synthetic jet should flow downstream because of the slot structure. On the other hand, inhalation flow into the slot without momentum, which is similar to a potential-flow sink, is induced in the suction process. Consequently, the flow in the duct is unidirectional, with the time-averaged velocity directed downstream. A schematic representation of the experimental setup used to evaluate the fan performance of a synthetic jet fan model is shown in Fig. 2. The synthetic air jet is generated by a loudspeaker (Diecook DD-15L) driven by a signal generator (MCPLG1100D), which transmits signals through a power amplifier (Classic Pro V3000). The speaker is replaced with a blower (Showa Denki Co., Ltd., U75-2-313) to generate the continuous jet. A sirocco fan (Mitsubishi, BF-16S3) is used to supply the main flow. The slot length is the same as the duct width, $W = 30$ mm, the slot width $b_0 = 10$ mm, representative velocity U_0, and stroke length l_0 can be adjusted by using a power amplifier. The channel height H, which is a geometric parameter, is set depending on some experimental conditions. The channel exit height is h. The velocities of both jets are measured by a hot-wire anemometer (Kanomax, IHW100) using a traverser (Chuo Precision Industrial, ALS-230-C2P). However, the measurement of flow velocity with a hot-wire anemometer is vulnerable to large errors in the regions

Fig. 1 Coordinate system and geometry of slot



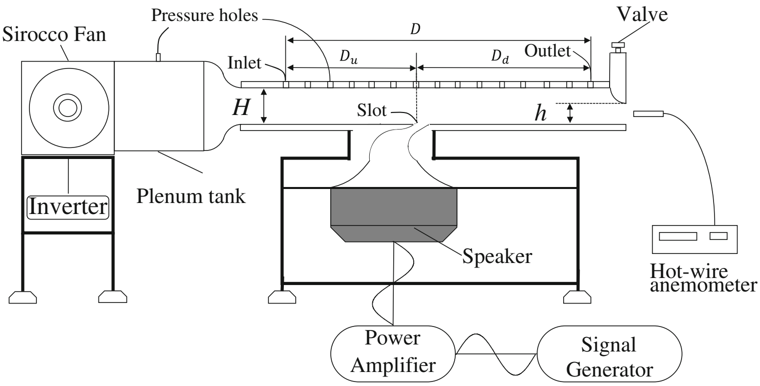


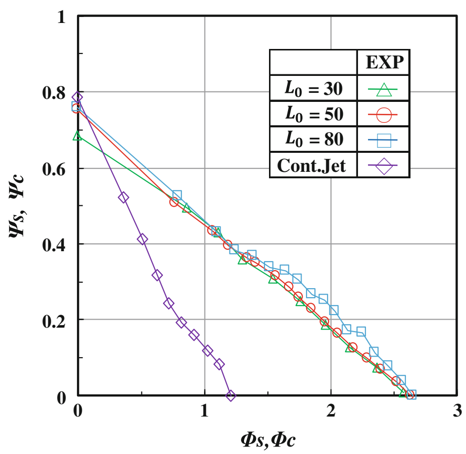
Fig. 2 Schematic diagram of experimental apparatus for synthetic jet

prone to local backflow, such as the complicated flow field near the slot. The static pressure difference between the inlet and outlet of a fan is used to evaluate the fan performance and is measured by a digital manometer (Okano Works, Ltd., DMP301N), and the pressure fluctuations in-side the duct is measured by a pressure transducer.

3 Results and Discussion

Typical fan performance curves for synthetic jets were obtained experimentally for $H/b_0 = 3$ (where the aspect ratio of the duct is $H/W = 1$) and $Re = 5300$, and the results are shown in Fig. 3. The inlet and outlet of the fan are defined as D_u and D_d,

Fig. 3 Typical static pressure–flow-rate performance curves. ($H/b_0 = 3$, $H/W = 1$, $Re = b_0 U_0/v = 5300$) (EXP Experiment)



respectively. The non-dimensional stroke L_0 is varied to obtain different curves. The performance curve for the continuous jet in the case of identical representative velocities is also shown in the same figure for reference. The vertical axis represents the discharge pressure coefficient $\Psi_s = \Delta p/0.5\rho U_{sm0}^2$ ($\Psi_c = \Delta p/0.5\rho U_{c0}^2$ for the continuous jets) based on the kinetic pressure (cf. [2]), where Δp (= $p_{out} - p_{in}$) is the pressure difference between the inlet and outlet. The horizontal axis represents the flow rate coefficient $\Phi_s = Q_t/b_0WU_{s0}$ for the synthetic jet and $\Phi_c = Q_t/b_0WU_{c0}$ for the continuous jets, where Q_t is the blow flow rate from the outlet of the fan. U_{s0} and U_{c0} are representative velocities of the synthetic and continuous jets (cf. [3]), respectively. In all the cases, including the continuous jet, the performance curves are approximately drawn as straight lines and have negative slopes. These results indicate that the continuous jet of the jet fan/pump can be replaced by the synthetic jet. It can also be seen that the performance curves of the synthetic jets do not depend on the non-dimensional stroke L_0 under the present range of conditions. A comparison of the results for the synthetic and continuous jets indicates that the maximum flow rate coefficients for the synthetic jets are roughly twice those for the continuous jet under the present experimental conditions.

Figure 4 presents the static pressure distributions on the upper surface of the duct for various L_0 values for the synthetic jets and the continuous jet in the case of $\Phi = \Phi_{max}/2$, where Φ_{max} represents the maximum flow rate coefficient. The vertical axis represents the pressure coefficient, defined as $C_{ps} = (p - p_{in})/0.5\rho U_{sm0}^2$ for synthetic jets and $C_{pc} = (p - p_{in})/0.5\rho U_{c0}^2$ for the continuous jet. For both the synthetic jets and the continuous jet, it is obvious that the static pressure under any condition drastically increases owing to the momentum of the jet near the slot and reaches the maximum value through pressure recovery at $x/b_0 \approx 20$, except at the singular stagnation point on the duct surface near the slot. Consequently, it is found that the fundamental characteristics of the fan using a synthetic jet are similar to those of the fan using a continuous jet.

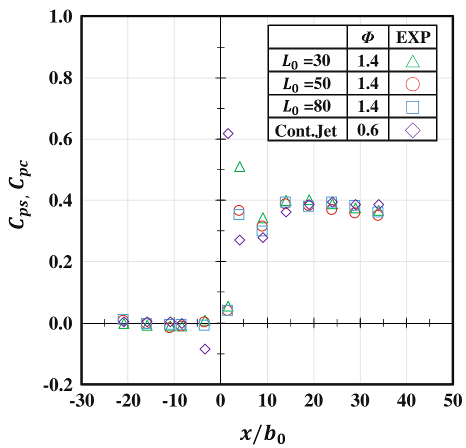


Fig. 4 Static pressure distribution on the upper surface of the duct. ($H/b_0 = 3$, $H/W = 1$, $Re = b_0 U_0/\nu = 5300$, $\Phi = \Phi_{max}/2$) (*EXP* Experiment)

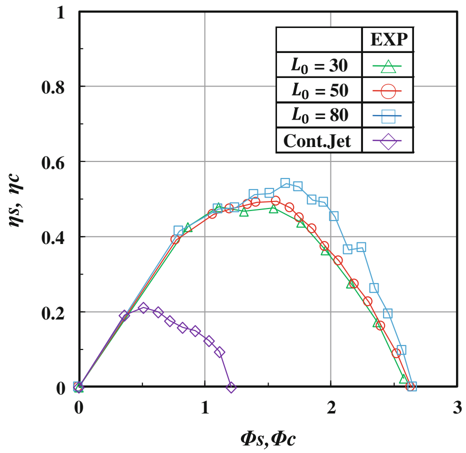


Fig. 5 Typical synthetic jets fan efficiency–flow-rate. ($H/b_0 = 3$, $H/W = 1$, $Re = b_0 U_0/\nu = 5300$) (*EXP* Experiment)

The fan efficiency curves under the same conditions as those considered in previous figures are shown in Fig. 5. The maximum values of the fan efficiency for every non-dimensional stroke of the synthetic jets should be roughly located at $\Phi_{max}/2$ and should reach around $\eta_s = 0.5$. The maximum fan efficiency values for the synthetic jets are greater than twice that for the continuous jet. It seems that the fan efficiency curves for the synthetic jets are almost independent of L_0.

4 Conclusion

In this study, a prototype model of a synthetic jet fan was developed. The fan performance characteristics, pressure distributions on the duct surface, and fan efficiency curves for various non-dimensional stroke values were analyzed.

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