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Turbulator Effects on Heat Transfer in Fan-Driven Flows

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Nomenclature

A	=	heat transfer surface area, cm
D	=	duct hydraulic diameter, cm
H	=	vertical height of the delta-wing turbulator, cm
h	=	convective heat transfer coefficient, $W/(m^2 \cdot K)$
k	=	thermal conductivity of the air, $W/(m \cdot K)$
Nu	=	Nusselt number
Q_{in}	=	power input to the heat transfer surface, W
Q_{loss}	=	conduction and radiation losses, W
T_0	=	air inlet temperature, °C
T_w	=	heat transfer surface temperature, °C
X	=	axial spatial coordinate, cm

Introduction

THIS research effort investigated the effects of delta-wing turbulators on heat transfer in fan-driven swirling flow, and the results were compared with those in uniform flow. The studies of heat transfer augmentation in uniform flow by various types of turbulators, including rib turbulators, arrays of pin fins, wing-type turbulators, shaped roughness elements, arrays of dimples, and so on, have received much attention in the past. For example, Eibeck and Eaton[1] examined the heat transfer effects of a longitudinal vortex embedded in a turbulent boundary layer for various vortex circulations. Tiggelbeck et al.[2] conducted experimental investigations on heat transfer enhancement and induced drag using delta wings, rectangular wings, delta winglets, and rectangular winglets in channel flows. Biswas et al.[3] studied the effects of delta-wing and winglet vortex generators on heat transfer in a channel flow. Ligrani et al.[4] investigated the flow structure and local Nusselt number variations in a channel with a dimpled surface on one wall, both with and without protrusions on the opposite walls. These studies have indicated that turbulators in uniform flow have substantial effects on heat transfer augmentation.

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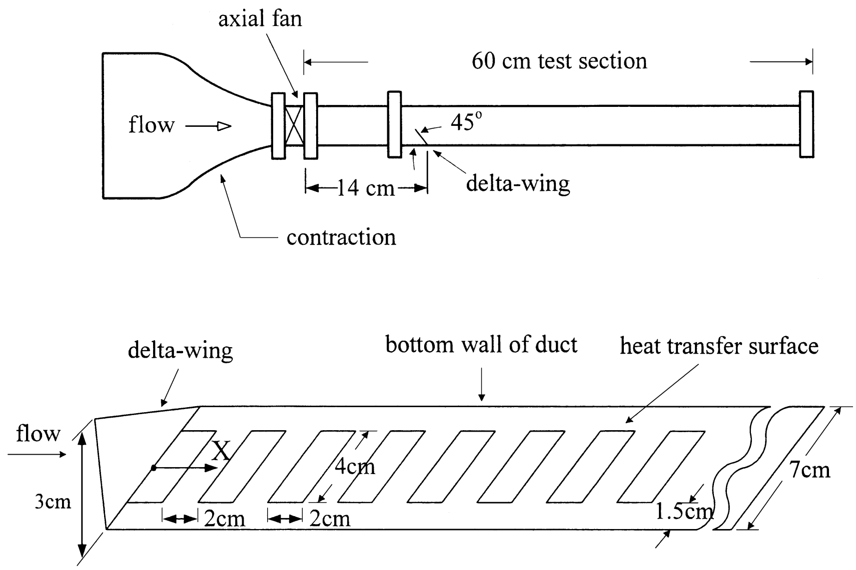

Fig. 1 Schematic of the experimental setup.

Fans have been widely used in electronics as the pumping source to induce flow for heat transfer applications. It is generally known that turbulators in uniform flow generate secondary flowfields, increase the degree of flow turbulence, and change the mean velocity field in velocity boundary layers, which are responsible for the heat transfer augmentation. Fan flow already includes strongly swirling flow. Studies as to whether a turbulator has the effect of disturbing the flow and augmenting heat transfer in this type of fan flowfields have not been seen in the literature, which motivates this research.

In this study, temperature measurements were conducted on heat transfer surfaces in fan and uniform flows with and without a delta-wing turbulator. The Nusselt number distributions were obtained and compared. The turbulator effects on heat transfer augmentation are discussed.

Experimental Setup and Methods

The primary experimental setup utilized in this research is shown in Fig. 1. An axial dc fan, placed between a contraction section and a 60-cm-long test section, was used to develop a flow inside a 7×7 cm^2 square duct. The fan, 7.2 cm in diameter, had seven blades with a maximum airflow rate of 472 cm^3/s and was produced by Yen-Sun Tech, Taiwan, Republic of China. A delta wing was used as a turbulator and placed on the bottom wall of the test section, 14 cm downstream of the fan. The two delta wings, with 45- and 90-deg angles of attack, used in this study have a 7-cm base width and a 3-cm vertical height H. To study the axial variation (X direction) of the heat transfer, eight 4×2 cm^2, 0.2-mm-thick, aluminum plates were equally spaced installed, 2 cm apart, along the bottom wall of the duct between $X/H = 0$ and 10 to serve as independent heat transfer surfaces. The first through the eighth heat transfer surfaces were positioned to give unheated starting lengths of 14–42 cm from the contraction section. The investigations were conducted under constant average flow velocity and constant fan power input conditions. The duct average velocity was 2 m/s under constant average flow velocity conditions with a Reynolds number of 8900 based on the duct hydraulic diameter D. The insertion of turbulators into the flow caused an additional pressure loss. The duct average velocities for the flows with the 45 and 90-deg delta-wing turbulators were reduced to 1.55 m/s under constant fan power input conditions with a Reynolds number of 6900.

The heat transfer coefficient, $h = (Q_{\mathrm{in}} - Q_{\mathrm{loss}})/A(T_w - T_0)$, was measured on the eight heat transfer surfaces. Only one heat transfer surface was heated during each run, with the power input Q_{in} of 2.2 ± 0.08 W. The heat transfer surface area $A = 8 \pm 0.1$ cm^2. The temperatures were obtained using type-T, 0.1-mm-diam thermocouples and read using a TempScan/1100 system produced by IOtech, Inc., with an uncertainty of $\pm 0.5^\circ$C. The reference temperature T_0 was the air inlet temperature. Thermocouples were installed beneath the heat transfer surfaces to obtain the heat transfer surface temperatures T_w and to evaluate the heat losses Q_{loss}. The heat transfer surface temperatures were in the range of 60–95°C with an uncertainty of $\pm 1^\circ$C. Heat conduction losses and radiation losses were estimated to be less than 10% and 4% of the total power input, respectively. Natural convection losses were neglected in the present study. More details on the heat transfer measurements are included in Ref. 5. The total uncertainty in the heat transfer coefficient was estimated to be 7%.

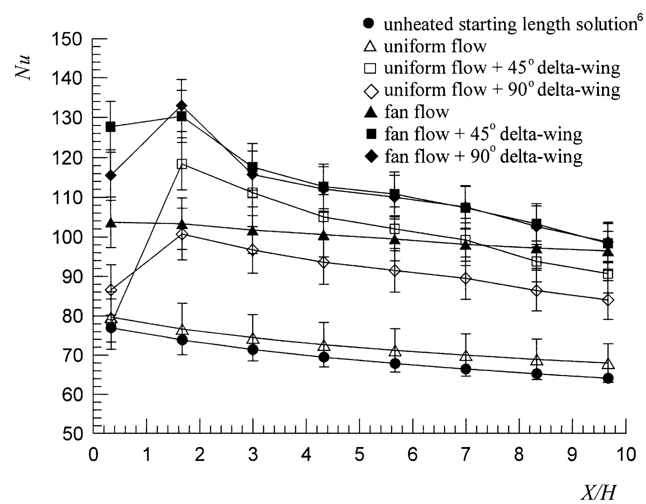

Fig. 2 Nusselt number distribution under constant average flow velocity conditions.

Results and Discussion

The heat transfer data are presented in the form of Nusselt number $Nu = hD/k$, where k was evaluated at the film temperature. Figure 2 shows the Nusselt number distribution as a function of X/H for the investigated flows under constant average flow velocity conditions. The Nusselt numbers for the 2-m/s uniform flow over the 8 independent heat transfer surfaces were also measured and compared with the theoretical unheated starting length solutions presented by Kays and Crawford[6] to check the accuracy of the measured results. These measurements were conducted in a uniform-flow wind-tunnel

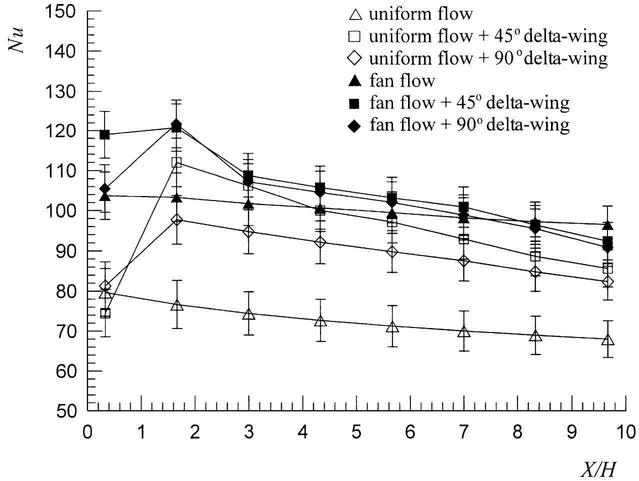

Fig. 3 Nusselt number distribution under constant fan power input conditions.

system using the same contraction and test sections as those in the fan-flow system. Figure 2 shows that the measured Nusselt numbers are approximately 5% higher than the predictions, which is within the expected uncertainty estimate. The Nusselt numbers for the fan and uniform flows without the delta-wing turbulators gradually decrease with X/H, as expected. Because the fan generates vortical flow motion, the fan flow has up to 40% better heat transfer performance than the uniform flow.

The delta-wing turbulators augment heat transfer in fan and uniform flows at most of the investigated X/H stations. The largest heat transfer augmentation occurs at $X/H = 1.667$, which increased 29% and 53% in fan and uniform flows, respectively. The heat transfer augmentation becomes less dramatic as the flows develop downstream and persists approximately to $X/H = 10$ for fan flow. Larger heat transfer augmentation occurs in uniform flow than in fan flow, except in the immediate neighborhood behind the delta wing. Also, the heat transfer augmentation persists farther downstream for uniform flow than for fan flow, which is still up 33% for uniform flow but is less than a 3% increase for fan flow at $X/H = 9.667$. The 45-deg delta-wing turbulator results in larger heat transfer augmentation than the 90-deg delta-wing turbulator in uniform flow, although they generally have the same heat transfer performance in fan flow. The results obtained are reasonable because the fan flow already includes strongly swirling turbulent flow. The fan flow should be less disturbed by the turbulator than the uniform flow is. Also, measurements of turbulator effects on fan flow structures showed that the 45- and 90-deg delta wings cause similar effects on the mean velocity field in velocity boundary layers, the flow turbulence, and the secondary flowfields, which are closely related to heat transfer rate.

The Nusselt number distribution under constant fan power input conditions is presented in Fig. 3, showing qualitatively similar results to those under constant average flow velocity conditions. Because the duct average velocity under constant fan power input conditions (1.55 m/s) is smaller than that under constant average flow velocity conditions (2 m/s), the Nusselt numbers are, accordingly, smaller. The heat transfer is augmented by the delta wings at most of the investigated X/H stations in uniform flow, whereas it shows an effect from $X/H = 0$–8 in fan flow. The maximum increases in the Nusselt number are 46% and 17% in uniform and fan flows, respectively. Figure 3 also shows that the Nusselt numbers for the fan flow with the delta-wing turbulator are smaller than those without the delta-wing turbulator at X/H stations beyond approximately 8.

Conclusions

This paper presents effects of 45- and 90-deg delta-wing turbulators on heat transfer in inherently swirling fan flow and uniform flow for Reynolds numbers of 6900 and 8900. Results show that a delta-wing turbulator in fan flow is effective in heat transfer augmentation, persisting to $X/H = 10$ and 8 under constant average flow velocity and constant fan power input conditions, respectively. However, the delta-wing turbulator effect on heat transfer augmentation in fan flow is not as effective as that in uniform flow. Also, the 45-deg delta-wing turbulator has better heat transfer performance than the 90-deg delta-wing turbulator in uniform flow, although they generally have the same effect on heat transfer augmentation in fan flow.

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