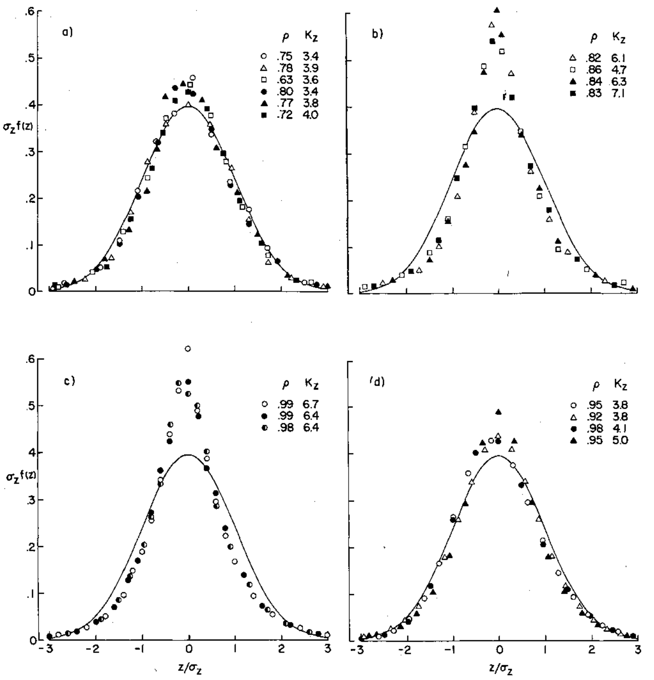

Fig. 2 Normalized probability density functions of Z compared with Gaussian law, where $Z = X(t + \tau) - X(t)$. All notes and symbols are the same as for Fig. 1.

For the cases of HICAT, greater deviations of $f(z)$ and K_z from Gaussian law might be expected if the ρ values were closer to 1, since kurtosis was found to be a smoothly decreasing function of τ when τ is not large.[7] Unfortunately, 0.8 is the highest ρ value available for observation because of the high-flying speed and low-sampling rate used during data acquisition. It is worthy of mentioning again that a ρ value close to 1 is one of the important conditions for arriving at Rice's simple equation. As for the cases of WITT, which have inherently very small turbulence Reynolds numbers, while the first-order distributions exhibit almost perfect Gaussian form the departure from Gaussian law for the second-order distributions is very apparent. The substantial departure indicates that $f(x_1, x_2)$ is strongly non-Gaussian, although the first-order distributions of $X(t)$ appear to be fairly Gaussian.

Conclusions

Joint normality of the second-order probability density is required to insure a successful application of Rice's exceedance statistics to atmospheric turbulence. The experimental results show that, in spite of Gaussian appearance for the first-order densities, the second-order densities invariably turn out to be strongly non-Gaussian. The kurtosis coefficients also depart greatly from 3, the Gaussian value. Thus, even stationary atmospheric turbulence cannot be considered a Gaussian process. And consequently, the application of Rice's equation should be approached with caution.

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Improving Diffuser Performance by Artificial Means

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Introduction

ALTHOUGH a great deal of data on flow in diverging passages has been amassed in the past 115 yr, very little of it has been systematic. An effort was made to review the greater bulk of important diffuser performance results and a detailed investigation was started to understand the flow phenomena in parallel pipe for naturally developing flow and flow with fixed transition, and flow phenomena in conical diffusers. The ultimate aim was to separate out the effects of velocity profile and turbulence intensity on the performance of conical diffusers. Finally it was hoped to correlate diffuser performance with a combination of velocity profile and turbulence structure parameters. The earlier tendency of correlating diffuser performance with velocity profile parameters alone seems to be invalidated by the present results on static pressure rise coefficient.

Apparatus and Tests

Details of the experimental arrangement will be published later. Here only the salient features of the rig design are pointed out very briefly. The closed-circuit experimental rig is run by a 30 h.p. induction motor. The velocity range is 50–300 fps corresponding to Reynolds numbers of 1×10^5 to 4×10^5 (based on duct diameter), respectively. A parallel pipe, which is 150 duct diameters long, is joined to a diffuser, which is connected to the motor through a flexible pipe of 9 in. internal diameter.

A 16:1 area ratio contraction preceding the pipe gives a very flat, low-turbulence, uniform exit profile. The parallel pipe consists of 50 pipe sections each having an internal diameter of 4.06 ± 0.01 in. and length of 1 ft. There are static pressure taps of 0.06 in. diam and 4-in. pitch along three diametric planes at 120° to each other. The diffusers also have similar pressure taps. A heat exchanger is installed in the return circuit between the motor and the breather to keep the temperature of the rig constant, which otherwise tended to rise.

The test diffusers chosen, namely 5° and 15°, represent typically good and bad diffusers. The diffusers were made in four sections to enable the area ratios of 1.5, 2.5, 3.5, and 5.0 to be obtained. The test diffusers at the downstream end were followed by a 3-ft

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9-in.-long parallel pipe. The first section of each diffuser consisted of a 4.06-in.-diam parallel pipe, one diameter long, followed by a sharp entry diverging section giving an over-all area ratio of 1.5. This gives a sharp entry to the diffuser and thereby enables the diffuser inlet station to be determined accurately.

The entire rig was air-tight, and introduction of measuring equipment such as sensors and total head rakes did not introduce any irregularity in the curvature of either the parallel pipe or the diffuser, due to the design of special plugs for the same all along the pipe and the diffusers.

Turbulence generators designed according to Ref. 1 and wire gauzes were used to produce high intensity turbulence along the entire cross section of the flow. Turbulence intensity measurements were conducted with a standard hot wire anemometer, linearizer, correlator, and standard single and cross-wire probes.

Performance Parameter

Static pressure rise coefficient is used in presenting the diffuser performance results. This determines the increase of static pressure between inlet and outlet of the diffuser. It may be defined as

$$C_p = (p_2 - p_1)/\tfrac{1}{2}\rho\bar{U}^2 \tag{1}$$

where C_p—the static pressure rise coefficient represents the internal behavior of the diffuser, p_1 and p_2 are the static pressures at the entry and exit of the diffuser, and $\frac{1}{2}\rho\bar{U}^2$ is the mean dynamic pressure, based on mean flow velocity at entry to the diffuser and defined as

$$\bar{U} = \int U\,dA/\int dA \tag{2}$$

$\bar{U}$ was measured by a 21-probe total-head rake. All the calculations were done on a KDF 9 English Electric Computer and the entire operation was automated.

Experimental Accuracy and Repeatability

At Reynolds number of 1×10^5, the variation in measurement was less than 0.75% as long as the time interval between two readings of C_p was within a week. The variation increased, if the interval was of weeks or months. This higher variation in C_p was believed to be caused by atmospheric changes, such as humidity etc. The variation decreased with increasing diffuser angle and for the 15° diffuser, the variation was less than 0.5% even if the time interval between two readings of C_p at the same condition was more than a week. The same was true at the higher Reynolds number.

Diffuser Performance Tests

Tests were carried out of static pressure rise coefficient at an entrance length station of 8.5, with diffusers of 5° and 15° included angle, of area ratio 2.5 and 5.0, at the Reynolds numbers of 1×10^5 and 4×10^5, for three different inlet turbulence intensity levels. Since at the entrance length station of 8.5, the potential core still exists, the turbulence intensity level of the inlet flow is indicated by the core turbulence intensity. Comparison is made with the results of Sale[2] and Hugh.[3]

Table 1 shows the results of the 5° and 15° diffusers at the Reynolds numbers of 1×10^5 and 4×10^5 for three different core turbulence intensities. C_p is the static pressure rise coefficient for the naturally developing flow, where $\hat{C}_p$ and $\tilde{C}_p$ represent two cases with fixed transition. Also shown are the results of Sale for 5° and 15° diffusers of area ratios 9 and 16, respectively. Hugh's results for the 5° diffuser of area ratio 9 and 12° and 20° diffusers of area ratio 16 at the Reynolds number of 2×10^5 are also given. The extrapolated value for a 15° diffuser at the same Reynolds number is also shown. However, it may be added that Reynolds number does not have a significant effect on the diffuser performance for the naturally developing flow.

Table 1 Pressure recovery for varying inlet turbulence intensity

Author	Reynolds number	$\phi°$	Aspect ratio	C_p	$\hat{C}_p$	$\tilde{C}_p$	I	$\hat{I}$	$\tilde{I}$
Shârân	1×10^5	5	2.5	0.58	0.63	0.635	1.04	4.6	8.1
Shârân	1×10^5	5	5.0	0.72	0.77	0.775	1.04	4.6	8.1
Sale	1×10^5	5	9.0	0.825			1.85		
Hugh	2×10^5	5	9.0	0.8			1.50		
Shârân	4×10^5	5	2.5	0.58	0.705	0.725	0.85	4.8	8.3
Shârân	4×10^5	5	5.0	0.72	0.82	0.855	0.85	4.8	8.3
Sale	4×10^5	5	9.0	0.855			1.7		
Shârân	1×10^5	15	2.5	0.54	0.58	0.585	1.05	4.6	8.1
Shârân	1×10^5	15	5.0	0.62	0.66	0.67	1.05	4.6	8.1
Sale	1×10^5	15	20	0.60			1.85		
Hugh	2×10^5	12	16	0.71			1.50		
Hugh	2×10^5	20	16	0.49			1.50		
Hugh	2×10^5	15	16	0.64			1.50		
Shârân	4×10^5	15	2.5	0.575	0.66	0.68	0.85	4.8	8.3
Shârân	4×10^5	15	5.0	0.645	0.72	0.74	0.85	4.8	8.3
Sale	4×10^5	15	20	0.655			1.7		

Potential core turbulence intensity for the naturally developing flow was of the order of 1% and for flow with fixed transition was 4.6% and 8.3% for the cases marked "^" and "~", respectively. Core turbulence intensity for Sale was 1.7%, and for Hugh it is believed that it was approximately 1.5%.

Discussion of Results

From Table 1 it is obvious that pressure recovery increases by creating a high-intensity inlet turbulence profile. The effect is much greater at higher Reynolds number; the corresponding potential core turbulence intensity at the entry of the diffusers is shown in the last three columns. The turbulence intensity in the case of figures marked "~" is approximately double that for those marked "^". The difference in C_p between these two cases is not very much, being negligible at the lower Reynolds number, increasing to some 3% at the higher Reynolds number. Thus, in these tests, there is an optimum inlet turbulence intensity for improving the static pressure recovery. The area ratio has no effect on the improvement in C_p for high inlet turbulence.

The C_p for a 5° diffuser of area ratio 5 for inlet turbulence level of 8.3% is 0.855, which is equal to the C_p for a 5° diffuser of area ratio 9 with inlet turbulence intensity of 1.7%, as found by Sale. Thus, it is seen that increasing the turbulence intensity has resulted in significant improvement of C_p, and leads to using a diffuser of area ratio 5 instead of 9. This is true for both Reynolds numbers; however, it is noticed that for the 15° diffuser the higher area ratio does *not* lead to any improvement in C_p. Thus, for higher angle diffusers, the only way to attain a significant improvement in C_p is by creating a high-intensity turbulent flow at the entry to the diffuser. It may be added that diffuser performance detoriates with increasing divergence angle, as expected.

Another way to improve the diffuser performance is to introduce suction. Improvement of the order of 12% was obtained in supersonic flow.[4]

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