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Performance of conical diffusers in incompressible flow

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(Continued on inside back cover)

PERFORMANCE OF CONICAL DIFFUSERS IN INCOMPRESSIBLE FLOW

CONTENTS

	Page
1. NOTATION AND UNITS	1
2. INTRODUCTION	3
3. FLOW REGIMES	4
4. STATIC-PRESSURE RECOVERY	5
4.1 Diffusers without Tailpipes	5
4.2 Diffusers with Tailpipes	5
4.3 Optimum Pressure Recovery Lines	6
4.4 Effect of Variation in Reynolds Number	6
4.5 Effect of Increasing Mach Number	6
4.6 Other Factors Influencing Diffuser Pressure Recovery	6
4.6.1 Junction with inlet duct	7
4.6.2 Surface roughness	7
4.6.3 Inlet flow turbulence and velocity profile	7
5. TOTAL-PRESSURE LOSS	8
5.1 Diffusers with Tailpipes	8
5.2 Diffusers without Tailpipes	8
5.3 Factors Influencing Total-pressure Loss	8
6. EXAMPLE	9
7. DERIVATION	11
8. TABLES	13
TABLE 8.1 DESCRIPTION OF FLOW REGIMES INDICATED ON FIGURE 1	13
TABLE 8.2 AVERAGE INLET-FLOW KINETIC-ENERGY COEFFICIENT, α_1	13
FIGURES 1 to 10	14 to 23

PERFORMANCE OF CONICAL DIFFUSERS IN INCOMPRESSIBLE FLOW

1. NOTATION AND UNITS

Three coherent systems of units are given below.

		SI	British	
A	cross-sectional area of duct	m^2	ft^2	ft^2
C_{pr}	static-pressure recovery coefficient (see Equation (2.2))	—	—	—
D	diameter of duct, $2R$	m	ft	ft
K_t	total-pressure loss coefficient (see Equation (2.3))	—	—	—
L	axial length of diffuser (see Sketch 2.1)	m	ft	ft
L_d	length of tailpipe (see Sketch 2.1)	m	ft	ft
L_u	length of parallel duct upstream of diffuser (see Sketch 2.1)	m	ft	ft
Ma	Mach number	—	—	—
m	mass flow rate	kg/s	lb/s	$slug/s$
p	static pressure	N/m^2	pdl/ft^2	lbf/ft^2
p_t	total pressure (see Equation (2.4))	N/m^2	pdl/ft^2	lbf/ft^2
R	radius of duct	m	ft	ft
Re	Reynolds number, $\bar{V}_1 D_1 / \nu_1$	—	—	—
V	local axial flow velocity	m/s	ft/s	ft/s
$\bar{V}$	area-averaged flow velocity, $m/\rho A$	m/s	ft/s	ft/s
α	kinetic energy coefficient, $[1/(\bar{V}^3 A)] \int_A V^3 dA$	—	—	—
ν	fluid kinematic viscosity	m^2/s	ft^2/s	ft^2/s
ρ	fluid density	kg/m^3	lb/ft^3	$slug/ft^3$
ϕ	half divergence angle of diffuser (<i>i.e.</i> total divergence angle = 2ϕ)	degrees	degrees	degrees

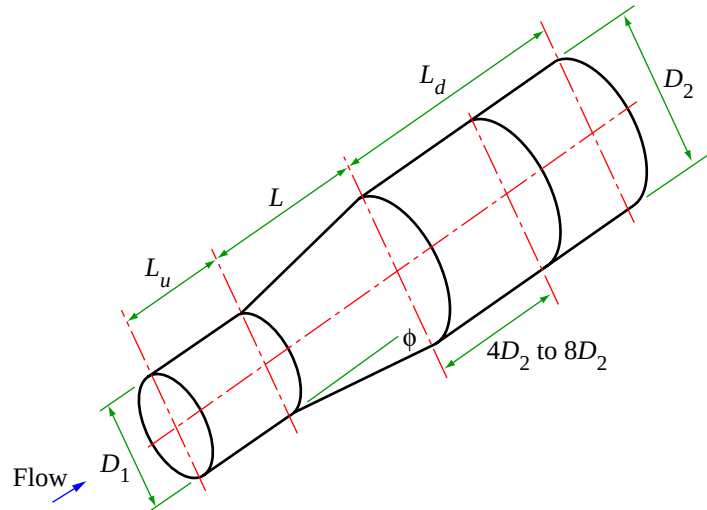
Suffixes

- | | |
|---|--|
| 1 | refers to conditions at diffuser entry |
| 2 | refers to conditions at diffuser exit |
| 3 | refers to conditions at tailpipe reference point |

2. INTRODUCTION

This Data Item presents information on static-pressure recovery, total-pressure loss and overall flow pattern for flow through straight-axis conical diffusers. The effects of various geometrical and flow parameters on the diffuser performance are discussed.

The geometry of a typical diffuser and its associated ductwork is shown in Sketch 2.1. For the case of a diffuser with free discharge the diffuser exit plane 2 forms the end of the system.



Sketch 2.1 Geometry of typical diffuser

The principal geometrical parameters are related by the equation

$$\frac{A_2}{A_1} = \left(1 + \frac{L}{R_1} \tan \phi\right)^2, \quad (2.1)$$

and the data in this Item are presented in the form of contours of constant C_{pr} or K_t on a grid of area ratio, A_2/A_1 , and ratio of diffuser length to inlet duct radius, L/R_1 , with lines of constant diffuser half-angle, ϕ , as an auxiliary scale.

The static-pressure recovery coefficient is defined by

$$C_{pr} = \frac{p_e - p_1}{\frac{1}{2} \rho \bar{V}_1^2}, \quad (2.2)$$

and the total-pressure loss coefficient by

$$K_t = \frac{p_{t1} - p_{te}}{\frac{1}{2} \rho \bar{V}_1^2} \quad (2.3)$$

where the suffix e is taken as 2 or 3 according to whether the diffuser has free discharge or tailpipe outlet conditions. The static pressure is assumed constant across sections 1 and 2 or 3 and the total pressure is defined as

$$p_t = p + \alpha \frac{1}{2} \rho \bar{V}^2. \quad (2.4)$$

3. FLOW REGIMES

The overall flow pattern in conical diffusers falls essentially into one of the three main types described in Table 8.1. The boundaries between the regimes, shown in Figure 1, depend on diffuser geometry and, to a smaller extent, on entry flow conditions. Since the experimental assessment of these boundaries is very subjective, only an approximate indication of their location can be given. If the regime of operation is important then the diffuser geometry should be chosen to lie outside the hatched bands of Figure 1.

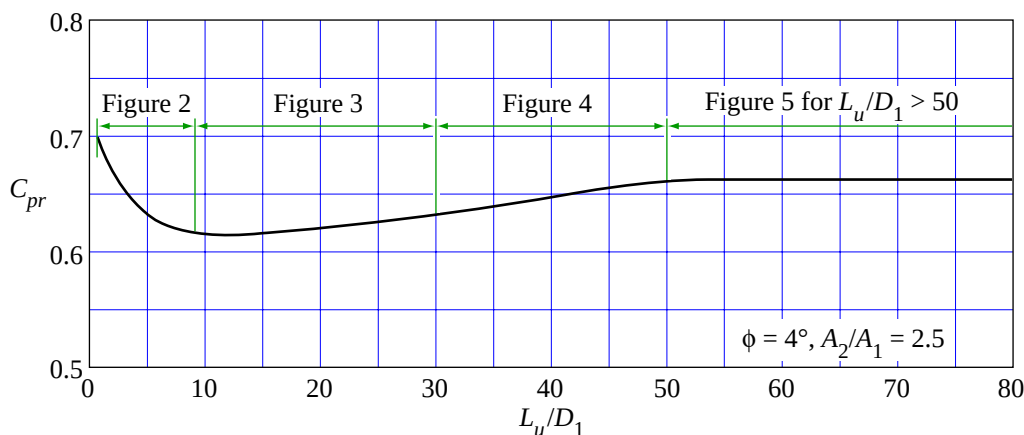
The boundaries of the regimes for thin, naturally-developing inlet boundary layers tend to lie in the upper part of the hatched bands shown in Figure 1. The line of onset of appreciable transitory separation is based on data from Derivations 16, 22 and 25 but the jet flow boundary is based on that for plane-walled diffusers as no data were found for conical diffusers. Since this boundary lies in a primarily “angle-dependent” region of performance, equivalence of the diffuser half-angles and of L/R_1 to length/inlet width of the corresponding plane-walled diffusers has been assumed. For fully-developed inlet flows, data from Derivation 25 suggest that the boundaries lie below those for thin inlet boundary layers, in the lower part of the hatched bands.

4. STATIC-PRESSURE RECOVERY

Static-pressure recovery coefficients are presented in Figures 2 to 5 for diffusers without tailpipes and with varying lengths of duct upstream. Figure 6 presents the coefficients for diffusers with tailpipes. These Figures apply basically for incompressible ($Ma < 0.2$), naturally-developing inlet flows at $Re \approx 10^5$.

4.1 Diffusers without Tailpipes

The performance of diffusers without tailpipes (free-discharge exit condition) is influenced by the condition of the inlet flow. For naturally-developing inlet flow this is primarily dependent on the entry duct length, L_u/D_1 , which determines the boundary layer development. Thus C_{pr} varies with L_u/D_1 as shown by a typical curve in Sketch 4.1, the exact shape of the curve depending on the diffuser geometry.



Sketch 4.1 Static pressure recovery

Figures 2 to 5 show contours of constant C_{pr} for values averaged over the four ranges of L_u/D_1 indicated on Sketch 4.1. For fully-developed flow ($L_u/D_1 \geq 50$, Figure 5), C_{pr} does not vary with L_u/D_1 . For Figures 2 to 4, the value of C_{pr} at any L_u/D_1 within each range is generally within ± 10 per cent of the averaged value given by the contours but for very short inlet ducts, say 1 to 2 diameters long, C_{pr} may be up to 15 per cent higher than the averaged values from Figure 2.

The data of Figures 2 to 5 are estimated to be accurate within ± 0.05 in C_{pr} , except in the regions of extrapolated data where the accuracy cannot be assessed. Figure 2 is based on data from Derivations 3, 8-10, 12, 13, 15, 16, 18, 21, 24 and 27, Figure 3 on data from Derivations 10, 15, 21, 24 and 27 and Figures 4 and 5 are based on data from Derivations 12, 15, 21 and 27.

4.2 Diffusers with Tailpipes

When a diffuser is fitted with a tailpipe the effect of variations in inlet conditions is considerably reduced, provided that the tailpipe is long enough for more or less complete pressure recovery to take place. In general, for diffusers with naturally-developing inlet flow, a tailpipe length, L_d , of $4D_2$ will allow full pressure recovery but for some geometries in the upper part of the transitory separation regime longer tailpipes may be required. The incomplete recovery will tend to be more noticeable in irregularities in the outlet velocity profile than in a reduction in C_{pr} .

Figure 6 presents pressure-recovery coefficient contours for diffuser-tailpipe combinations with L_d/D_2 in the range 4 to 8. Within this range of L_d/D_2 the available data show no significant trends in the variation of C_{pr} with either L_d/D_2 or L_u/D_1 and the data may be taken to apply for all naturally-developing inlet

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flows. Figure 6 is based on data from Derivations 1 to 5, 7, 14, 15, 22 and 24. The data in the regions defined by solid lines are assessed to be accurate to within ± 0.05 in C_{pr} but the extrapolated data should be used with caution, especially in the transitory separation regime (see Figure 1). For tailpipes longer than $8D_2$ the value of C_{pr} at the end of the tailpipe is given approximately by*,

$$C_{pr} = C_{pr}(\text{Figure 6}) - 4f \frac{L_d - 8D_2}{D_2} \left(\frac{A_1}{A_2} \right)^2. \quad (4.1)$$

For tailpipes shorter than $4D_2$, a linear interpolation between the curve with a $4D_2$ tailpipe and the appropriate curve without a tailpipe gives a good approximation to C_{pr} , i.e.

$$C_{pr}[\text{short tailpipe}] \approx C_{pr} \left[\begin{array}{c} \text{no tailpipe} \\ \text{Figures 2-5} \end{array} \right] + \frac{L_d}{4D_2} \left(C_{pr} \left[\begin{array}{c} \text{with } 4D_2 \text{ to } 8D_2 \\ \text{tailpipe (Figure 6)} \end{array} \right] - C_{pr} \left[\begin{array}{c} \text{no tailpipe} \\ \text{Figures 2-5} \end{array} \right] \right). \quad (4.2)$$

4.3 Optimum Pressure Recovery Lines

Two optimum lines may be determined from the contour maps, the C_{pr}^* line which is the locus of geometries for which C_{pr} is a maximum for a given diffuser length and the C_{pr}^{**} line which is the locus of geometries for which C_{pr} is a maximum for a given area ratio. The C_{pr}^* line is defined clearly on all four maps but the C_{pr}^{**} line cannot be uniquely defined at low area ratios on Figure 6 for diffusers with tailpipes. The location of the optimum lines was found to be independent of inlet conditions (for naturally-developing inlet flow) for diffusers without tailpipes, but the actual pressure recovery achieved for a given optimum geometry does depend on inlet conditions.

4.4 Effect of Variation in Reynolds Number

The contours shown in Figures 2 to 5 are derived for an inlet Reynolds number of about 10^5 . Within the accuracy of the data, variations in Reynolds number above 5×10^4 have been assumed to have negligible effect on C_{pr} . However, two sources (Derivations 21 and 24) do show a systematic increase in C_{pr} of about 5 per cent for Re increasing from 10^5 to 10^6 when the diffuser operates in the transitory separation regime. For low Reynolds numbers no systematic data were found but C_{pr} is generally much reduced, especially in laminar flow when separation occurs at much lower adverse pressure gradients. For $Re < 10^4$, C_{pr} is unlikely to exceed about 0.4 and will generally be lower.

4.5 Effect of Increasing Mach Number

The data presented are for incompressible flow ($Ma < 0.2$). However, for Mach numbers up to about 0.5 the effect of compressibility on C_{pr} is small (Derivations 19 and 20). For higher Mach numbers more significant effects occur culminating in a sudden fall in C_{pr} when choking occurs at the diffuser throat. The shape of the junction between the inlet pipe and the diffuser becomes particularly important in compressible flow and sharp edges should be avoided.

4.6 Other Factors Influencing Diffuser Pressure Recovery

Few data were found for diffusers other than for smooth, carefully-made diffusers isolated from other components and operating with naturally-developing entry flows. It is therefore only possible to give general guidance on the trends of effects of departures from these idealised experimental conditions.

* Note that the area ratio term is required since f , the friction factor, (from, for example, ESDU 66027) is derived on the basis of velocity $\bar{V}_2$ whereas C_{pr} is based on velocity $\bar{V}_1$.