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Numerical Study of Planar Diffuser Flows at Very Low Reynolds numbers

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ABSTRACT

This paper presents flow regime maps of two-dimensional, planar diffusers with constant-area ducts at very low Reynolds numbers. They are obtained from numerical calculations using the commercial CFD program CFD-ACE+. The Reynolds numbers considered are 63, 105, and 210. For each Reynolds number, a wide range of geometric parameters of dimensionless diffuser length, which is a ratio of diffuser length to throat width, $1<L/W_1<40$ and divergence half angle $1°<\phi<50°$ are selected to obtain steady-state solutions. These maps can be served as a guideline to designers for very low Reynolds number diffuser flows.

Key Words: Planar Diffuser, Very Low Reynolds Number Flow, CFD

1. Introduction

A diffuser is widely used fluidic device to recover static pressure by decelerating the passing fluid. In diffusing process, the flow experiences adverse pressure gradients in the flow direction. Severe adverse pressure gradients cause large flow separation regions along the wall and they block the flow. This can result in low pressure recovery, and cause severe flow asymmetry, severe unsteadiness, or both. Since these flow phenomena are so complicated to predict theoretically, the diffuser researchers have been heavily relied on experimental works.

Kline et al [1,2] reported data on performance and flow regimes for incompressible, turbulent flows in two-dimensional straight-walled diffusers. The performance data were correlated to the flow regimes and the four flow regimes were established.

Recent interests of small scale fluidic apparatus require the performance characteristics of small scale diffusers. In this flow regime, the flow is fully laminar and the results of the turbulent flows may not be applicable. Also the experiments of diffuser flows at the low Reynolds numbers of less than 300 are difficult due to the nature of very low Reynolds number flows. This motivates the study of diffuser flows at very low Reynolds numbers to resort to numerical solutions as a first attempt. Since the flow is fully laminar, the mathematical model is not hassled by the turbulence closure problem encountered in the turbulent flows. Thus the numerical solution can be more reliable.

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2. Flow Regimes

A schematic of two-dimensional, planar diffuser with constant-area duct is shown in Fig. 1, where W_1 is the diffuser throat width, W_2 the diffuser exit width, ϕ the divergence half angle, L_u the length of constant-area duct upstream of diffuser, L the diffuser length, and L_d the length of constant-area duct downstream of diffuser. A dimensionless diffuser length of L/W_1 ranges from 1 to 40 and a divergence half angle of ϕ from 1° to 50° as long as the solution converges.

The flow regimes are known to be closely related to the performance and their map can provide diffuser designers with concepts of a geometry depending on their design interests such as flow patterns and optimum performance. The flow regime maps for Re=65, 105, and 210 are presented in Figs. 2, 3, and 4, respectively. The geometric parameters of dimensionless diffuser length, L/W_1, and area ratio, which is a ratio of diffuser exit width to throat width, AR, are used as coordinates of the flow regime map. Five flow regimes are observed in this study and each flow regime is defined as follows:

No Appreciable Stall Regime

In this regime, the flow is well behaved and attached to both diffuser walls. It is located below the line a-a in Figs. 2-4. The pressure and velocity profiles are eseentially symmetrical about the center plane.

Appreciable Stall Regime

In this regime, the flow is well behaved and symmetric like the 'no appreciable stall regime,' but the stall width is greater than one-fifth of the diffuser exit width at the diffuser exit. It is located in the region of line c-f-a-a in Figs. 2-4. This regime takes most of the region between the line a-a and line b-b at which the symmetric and asymmetric flows border, except the small region of symmetric jet flow (b-f-c). As L/W_1 increases, the gap between the line a-a and line b-b becomes smaller. For high L/W_1, the lines a-a and b-b almost coincide and this flow regime seems to disappear.

Two-Dimensional Stall Regime

In this regime, the flow is separated from the one diverging wall, forming one large stall, and completely attached to the other diverging wall. It is located in the region of line d-d-b in Figs. 2-4. The flow becomes severely asymmetric, and the one large stall blocks a significant fraction of the available flow area and degrades the diffuser performance. As the area ratio (or half angle) is further increased, a secondary stall appears on the opposite wall and just downstream of the large first stall. The asymmetric velocity and pressure profiles become flattened downstream of the second stall.

Jet Flow Regime

In this regime, the flow is separated from both diverging walls very near the throat. It is located above the line c-c in Figs. 2-4. In the present study, the jet flow is defined when the flow separation occurs more than four-fifth of each diverging wall. The most region of jet flow regime is asymmetric, but at very low L/W_1 the jet flow is symmetric and the symmetric jet flow regime becomes smaller with increasing Reynolds number. Also the secondary stall appears with increasing the area ratio (or half angle).

Transition Regime among Appreciable Stall, 2-D Stall, and Jet Flow

In this regime, the flow has pattern that can't be defined as one of the appreciable stall, two-dimensional stall, and jet flow. It is located in the region of line c-f-d-d in Figs. 2-4. In the low L/W_1, the flow in 'appreciable stall regime' goes to 'jet flow regime' through this transition regime. The symmetric stall becomes asymmetric with one large stall and the other small stall. The large stall separates very near the throat, but the small stall is not separated enough near the throat to become jet flow. In the transition from 2-D stall to jet flow at high L/W_1, the flow attached to the diffuser wall begins to separate near the throat first and then at the corner. Two stalls grow bigger, merge to one large stall as the area ratio (or half angle) increases, and the flow finally becomes jet flow. Descriptions of flow regimes on Figures 2-4 are shown in Table 1.

3. Conclusions

The planar, two-dimensional diffuser flows with constant-area ducts at very low Reynolds numbers are numerically studied for a wide range of geometric parameters of dimensionless diffuser length and divergence angle. The following features are observed:

1. The transition regime among appreciable stall, two-dimensional stall, and jet flow regimes exists at L/W_1 =3-4.
2. The two-dimensional stall regime is not observed for L/W_1 < 4.

References

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2. L. R. Reneau, J. P. Johnson, and S. J. Kline, "Performance and Design of Straight, Two-Dimensional Diffusers," Journal of Basic Engineering, vol. 89, March 1967, pp. 141-150

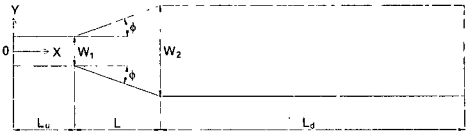


Fig. 1 A schematic of two-dimensional diffuser with constant-area duct

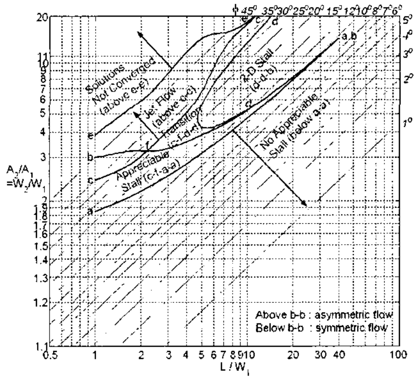


Fig. 2 Flow Regime Map for Re=63

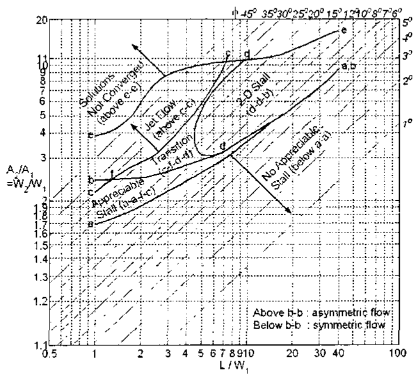


Fig. 3 Flow Regime Map for Re=105

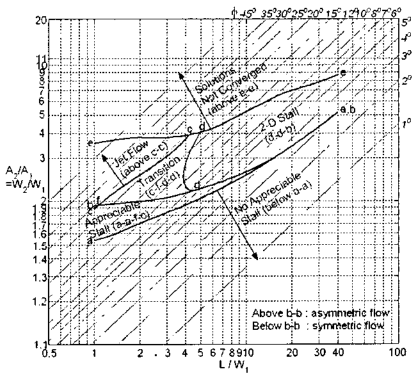
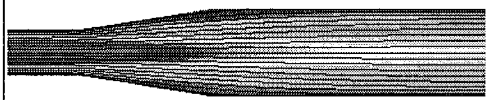
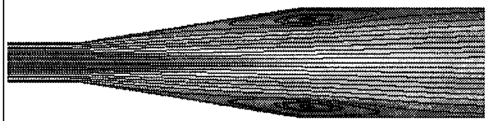
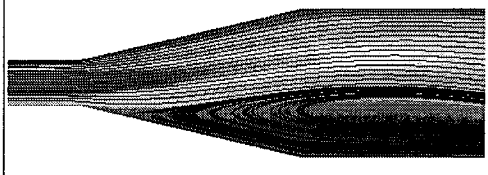
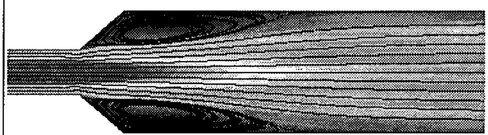


Fig. 4 Flow Regime Map for Re=210

Table 1 Descriptions of Flow Regimes on Figures 2-4

Flow Regime	Description of flow patterns	Flow patterns
No appreciable stall (below a-a)	Flow attached on both walls except for geometries close to a-a when small separated areas may appear in the diffuser corners.	
Appreciable stall (a-a-f-c)	Symmetric flow separation from both diverging walls.	
2-D stall (between d-c and d-b)	Flow separated stably from one diverging wall.	
Jet Flow (above c-c)	Flow stably separated from both diverging walls. (asymmetric and symmetric jet flows)	 
Transition among Jet flow, 2-D stall, and appreciable stall	Asymmetric flow separation from both walls, but smaller flow separation is not enough to be jet flow.