PERIODIC FLOW PHENOMENA IN DIFFUSERS

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Experiments were performed on a water table to determine the occurrence of periodic or nearly periodic repetitive flow phenomena in step diffusers. Flow rate and width ratio could be varied, and both fully developed and not fully developed channel flow could be obtained at the inlet to the step diffuser. Several repeating patterns of eddy generation were observed. The Strouhal number of the average frequency of generation of major eddies depended on the Reynolds number based on the inlet width; for not fully developed inlet flow the dependence of the flow on Reynolds number based on entry length was stronger. The latter is an indication of the state of the wall layers and, hence, of the shear layers which enters into the diffuser.

METHODS

A step diffuser configuration was set up on a water table. The flow was generally two-dimensional flow at a depth of approximately two inches over a glass plate, at rates from about one inch per second on upward. The step diffuser was formed by straight side walls which could be moved to various width ratios. Experiments were run open, as well as with a top plate to avoid free surface effects at more extreme velocity ratios. A number of rounded contour sections were tried at the entrance of the diffuser.

The flow was visualized by dye placed in the stream with a hypodermic needle, by dye placed on the wall upstream of the diffuser, by hydrogen bubbles generated by a cathodic wire stretched across the entrance to the diffuser, and, for open flows, by aluminum powder sprinkled onto the surface.

Velocities were established by timing the passage of an aluminum particle, dye streak, or bubble line over a measured distance. Thus velocities could be observed at different depths and locations.

The validity of assuming the flow to be two-dimensional was tested by observing the thickness of the bottom boundary layer, and the similarity of flows at different depths. Although specific minor secondary flow patterns were observed, the flow was two-dimensional in all important respects over the range of parameters investigated. The depth was small enough for the major eddies to be coherent over the full depth.

In addition to observation of the major flow patterns, the rates of shedding major eddies were noted for different flow conditions. These were related to the non-dimensional parameters describing the flow: entry-length Reynolds number to indicate the degree of development of the incoming channel flow, inlet-width Reynolds number to indicate the inlet flow velocity, and width ratio to indicate the flow area increase.

Hot-wire measurements were also made on the identical geometry in the wind-tunnel, but this method proved to be inconvenient for obtaining the pattern of eddy development.

RESULTS

The flow patterns observed can be broken up into three main regions: the central main stream; the region on either side, including a stationary vortex producing back-flow in each corner of the step; the shear region between the main stream and each side region. This shear region was seen to contain more or less distinct traveling vortices, depending on the flow conditions.

Under some low Reynolds number conditions, the main stream curved towards one wall, attached to it, and tended to stay there. This was more common for a rounded corner than a square corner step diffuser. If the inlet was symmetrical, the flow would stay attached to either wall once it had been made to flow that way by means of a short period of stirring.

Under conditions which favored the formation of pronounced traveling vortices, adequate Reynolds number and square corners, the eddies would form alternately on each side of the diffuser, and were large and regular enough to give the main stream the appearance of a sinuous flow undulating from side to side.

Under some conditions, the eddies would form in pairs; they would not travel onward in a stable configuration, however, but one or the other would speed up or slow down. As a result they would again approach a somewhat irregularly alternating pair of rows of vortices further downstream, and the flow would be seen to undulate back and forth.

Under high Reynolds number conditions, the regularity of eddies was no longer evident, and only general turbulence could be visualized.

The formation of a vortex was seen to begin with the formation of a bulge in the side of the main stream, either on the outside of the main stream when it was curving after a previous vortex or simultaneously on both sides. The bulge became larger and sharper in its contour until a swirl broke away into an eddy which then traveled on downstream until it dissipated.

Irregular eddies were generally not as large and long-lived as regular eddies.

The overall results for the rate of eddy shedding were:

1. Irregular vortex formation at inlet-width Reynolds numbers low enough to preclude fully developed flow.
2. Scattered inlet-width Strouhal numbers from about 0.3 to 0.55, averaging 0.45, without any strong dependence on any of the other parameters (such as Strouhal or Reynolds numbers based on other thicknesses), where fully developed inlet flow existed.
3. Failure of the visualization methods at very high Reynolds numbers and, hence, no conclusions.

The most interesting aspect of these results is the observation of some near-periodic phenomena in a confined jet flow in the absence of external excitation. Future work will pursue this further by different means.

DISCUSSION

The observations are in substantial agreement with those of Flügel (1) in ejectors and Davey (2) in shear layers as far as vortex formation is concerned, Beavers and Wilson (3) in free jets, and Abbott and Kline (4) for backward-facing steps as far as the flow fields are concerned. Sato (5) and others have attempted to find characteristic frequencies in jets, but generally have been forced to introduce external noise and observe the response of the jet in order to get clear results.

The present work shows some of the parameters which may influence the rate of vortex shedding and the approximate scale of these vortices. Hence it has applications to situations where a flow goes through an increase in flow area and produces flow disturbances which may cause flow-induced vibrations (6).

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