Scondary Current In a Two-Dimensional Shear Flow

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ABSTRACT

This paper deals with the investigation of secondary current produced by the presence of protubarance on the flow surfaces. For the purpose of simulation an isolated solid element was placed in fully developed turbulent pipe flow to monitor the nature and extent of disturbance the element created in the flow and to investigate the presence of secondary current thus developed. Similar experiments were also carried out by putting the isolated element on a flat plate ; this was done to find out whether secondary current of the similar kind was developed on the flat surfaces in a two dimensional flow. The secondary current thus formed has been compared with a proposed Hodograph Model for the purpose of prediction.

SYMBOLS

A,B	Constants
h	height of the isolated element (circular cylinder)
R	Pipe radius
r	Radius of the circular cylinder
U	Local Mean velocity
Uc	Centreline Velocity
U	Free Stream velocity
W	Tangential velocity (cross) component
pi,qi	Hodograph model family
x,y	Co-ordinates
α	Angle of rotation
δ	Boundary layer thickness.

Introduction

Investigation of secondary flow has attracted the mind of the researchers in the field of boundary layers because of the secondary flow effects in many engineering applications such as turbines, compressors, swept wings etc. Flow cases that are apparently two-dimensional (e.g. flow over shiphull and other marine surfaces) also develop sizeable three-dimensional flow spots due to the presence of protuberances (joints, rivet heads etc) on the flow surfaces which create localised secondary current. The calculation of total drag forces on the above surfaces will remain substantially incomplete and somewhat incorrect unless the contributions due to this secondary current are taken into consideration. Francis

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& Pierce (1) Shanebrook & Hatch (2) Okamoto etal (3) worked on this kind of problems. Das (4) also worked on similar topic by using pipe flow technique unlike the previous authors who used wind tunnels or water flumes. In the present paper an attempt has been made to look for the similarities of results obtained by the above two techniques. A model for prediction has also been suggested.

Experimental Set-up

The pipe used for the purpose was made of glass fibre. The isolated element used to disturb the flow was a right circular cylinder of aspect ratio (r/h) of unity (fig.1). The pipe radius to height-of-the element ratio (R/h) was 2.635. This ratio was arbitrarily chosen keeping in mind that the blockage area is insignificant (about 3%). A number of velocity profiles were taken across the radius at different angular positions starting from the vertical reference radius. The right circular cylinder was then shifted to a different position (changing x/h ratio) and similar measurements were made.

The right circular cylinder of the same aspect ratio as above was also used to act as the isolated element while carrying out experiments on the flat plate. The element was fixed on the smooth bottom plate of the wind tunnel working section. Care was taken to maintain the freestream velocity same as that of the centre line velocity of the pipe. A grid locating some stations (fig.3) were made and velocity profiles were measured at all those stations In both cases pitot tube was used to monitor the data using a sensitive inclined-tube manometer.

Presentation and Discussion of Results

All the mean velocity profiles measured downstream of the right circular cylinder in the pipe flow experiment were compared with undisturbed profiles to appraise the distortion thus caused. It was noticed that the flow,

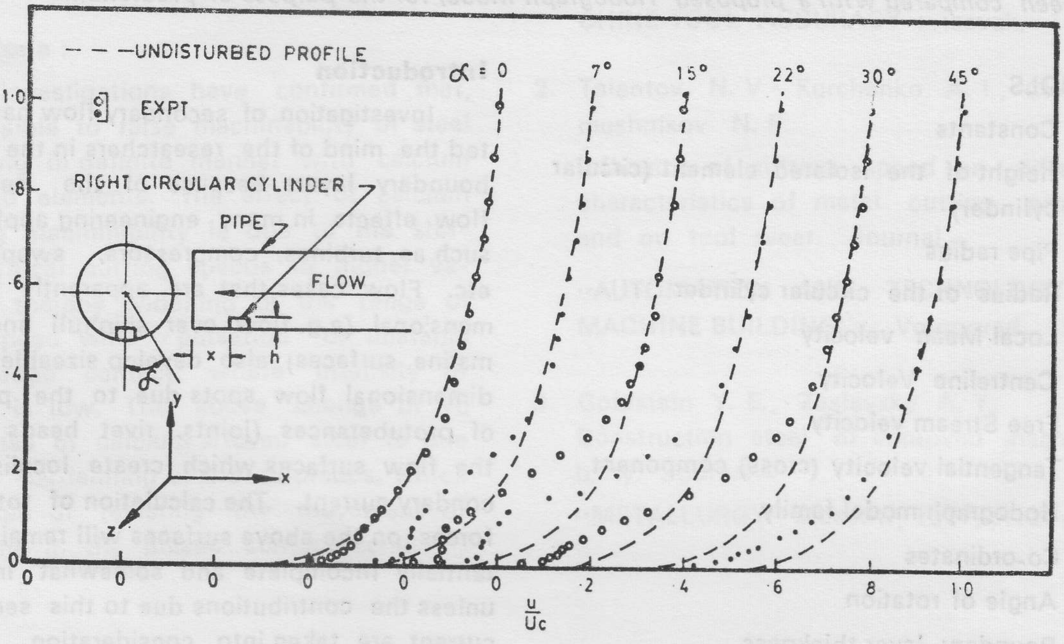

Fig. 1 Mean velocity distribution at x/h = 4 (Pipe Flow Experiment)

especially in the inner region ($\alpha = 45°$), was vigorously distorted at $x/h = 4$ (fig.1). Further down stream at position $x/h = 12$ (fig.2), the profile assumed a very different type of distortion and so they did in the inner region. At earlier stations the flow was found to be retarded but here the flow velocity increased compared with the undisturbed flow velocity. This trend appeared to indicate a negative wake effect. The changing behaviour of the flow downstream of the isolated element from station to station strongly evidenced the existence of a secondary current.

In the flat plate experiment, the velocity profiles at grid points L2,M2,R2 (i.e. x/h 3, fig. 3) showed a combination of flow retardation, at M2 i.e. in the inner region, and negative wake effect, at L2,R2 i.e. in the outer region. But further downstream at grid points, L4,M4,R4 (fig.4) negative wake effect was clear, again indicating the existence of secondary current.

In both the cases (pipe flow and flat-plate experiments) immediately after the obstruction flow retardation occured but showly at a further downstream position negative wake effect started showing up giving rise to secondary flow.

The secondary current was monitored by a two tube Yawmeter which actually detected the direction of flow ; the tangential component (z-component) of the mean velocity was thus calculated The secondary flow or cross flow profiles thus obtained (fig. 5 & 6) assumed the from of 'S' better known as cross over profile. In both the cases, pipe flow and flat plate flow, the profiles of the secondary current are almost alike, thus eliminating the confusion, if any, regarding the existence and form of secondary flow in two-dimensional turbulent flow over surfaces offering any obstacles to the straight flow.

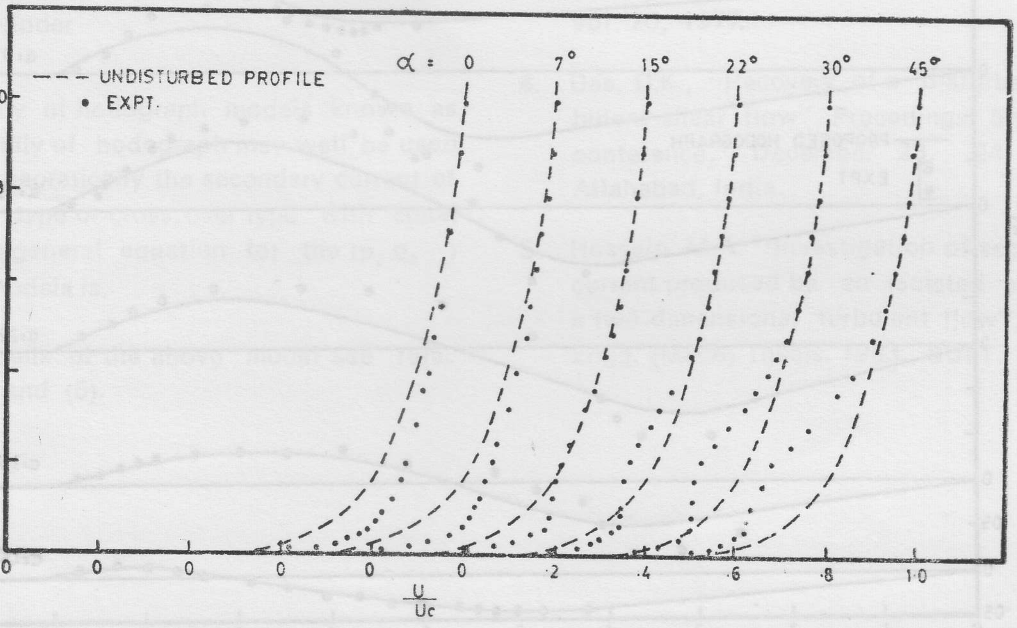

Fig. 2 Mean velocity distribution at $x/h = 12$ (pipe flow experiment)

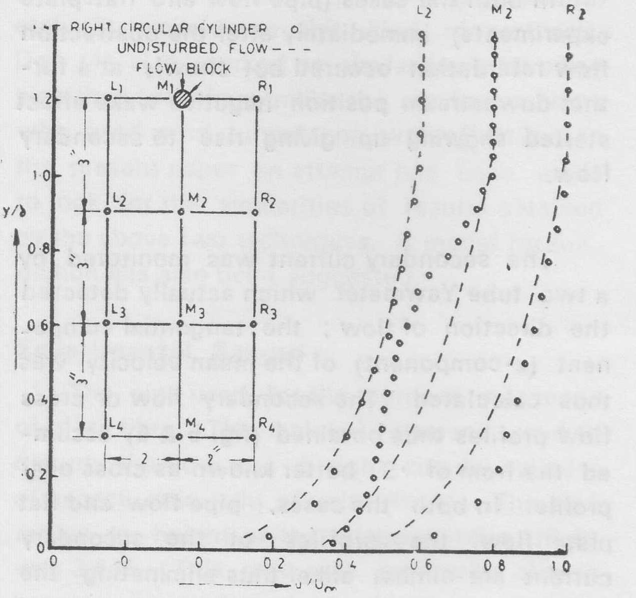

Fig. 3 Mean velocity profiles (flat plate experiment)

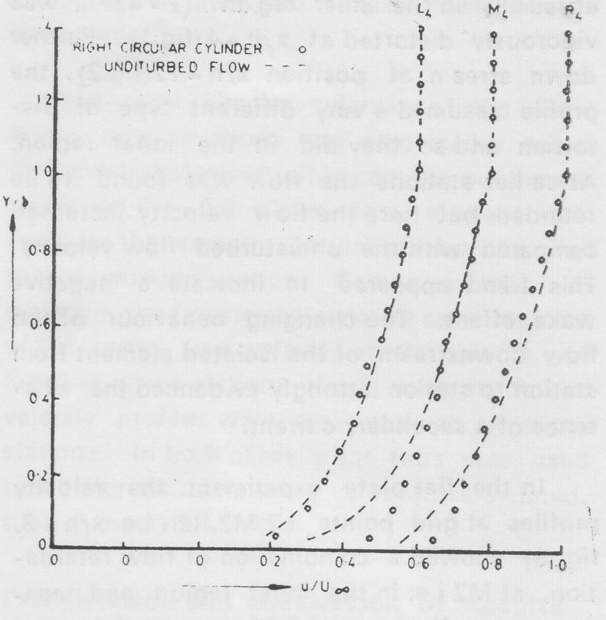

Fig. 4 Mean velocity profiles (flat Plate experiment)

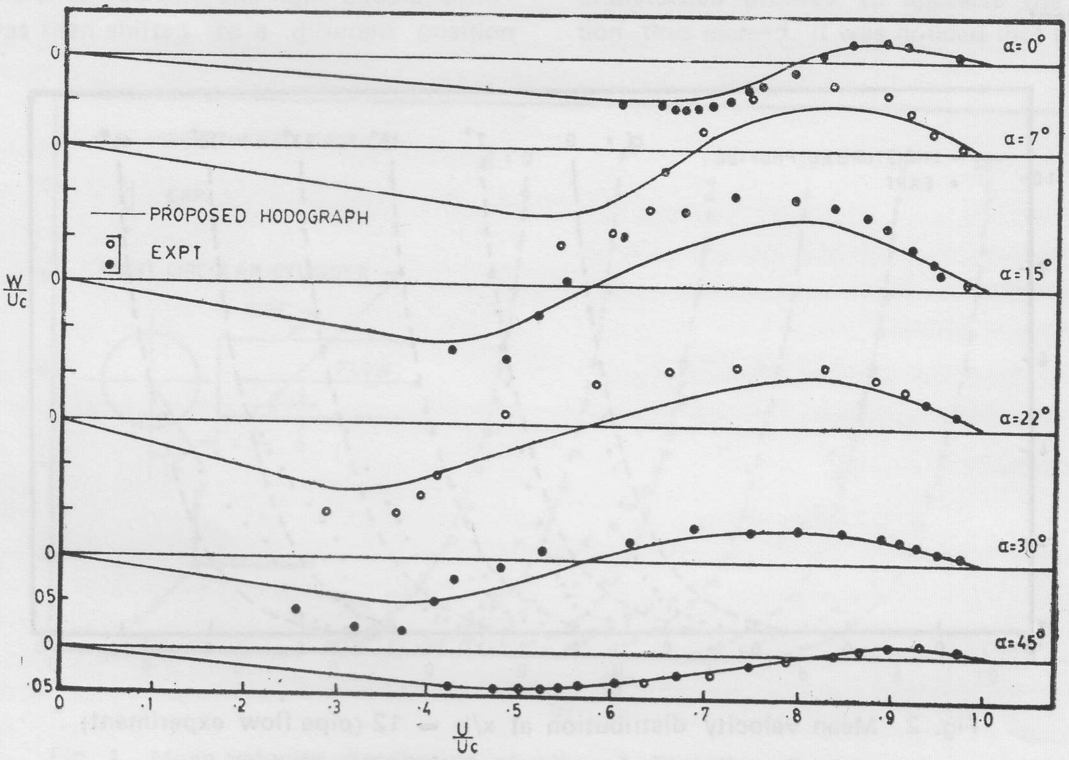

Fig. 5 Hodograph plot at x/h = 4 (pipe flow Experiment)

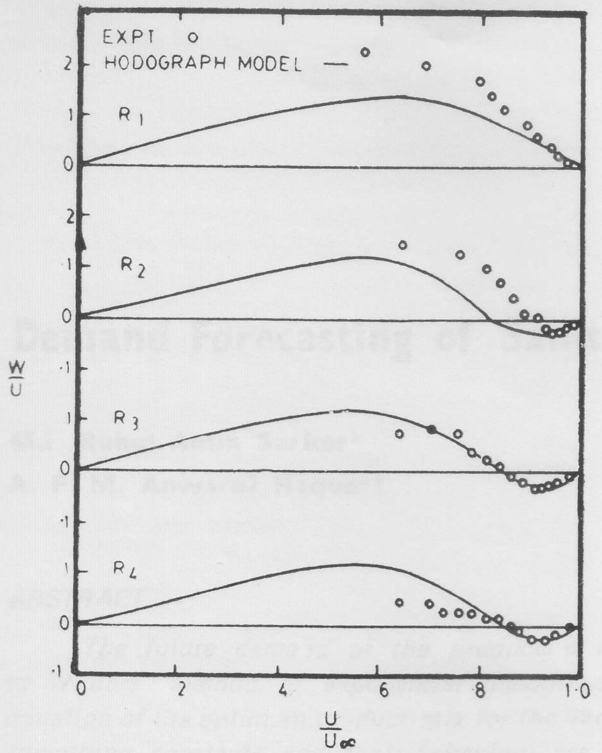

Fig. 6 Hodograph for the right circular cylinder

A family of hodograph models known as (pi, qi) family of hodograph may well be used to define theoretically the secondary current of cross-flow type or cross-over type with equal case. The general equation for the $(p_2\ q_2)$ family of models is.

For details of the above model see references (4) and (5).

Conclusions :

A two-dimensional turbulent shear flow when obstructed in its straight flow by an isolated obstacle or by other means, a secondary current develops. This has been established by experiments by both pipe flow technique and wind tunnel flow technique. The secondary flow in most cases will be of cross-over flow type.

References

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