Further Studies on the Asymmetrical Flow Past Yawed Cylinders

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ABSTRACT

The study of the flow around a yawed cylinder between parallel walls is a way to understand some fundamental aspects of fluid dynamics and not only a particular case of application.

First of all the eventual alternate vortex street is steady and it is much more easy to study it with respect to the unsteady case by experiments.

Second, it is possible to achive fully turbulent regime and have a transition-free experiment in order to study the effect of the other possible instabilities.

The present paper will resume a set of experimental results and fundamental considerations on this kind of flows.

Notation

X,Y,Z Coordinates - u,v,w velocity comp.

Λ -Yaw angle

Γ -Circulation

Θ -Angle around the cylinder

INTRODUCTION

In this research the flow on a yawed cylinder was initially studied to describe some fundamental aspect of the flow separation on yawed bodies, in order to understand some typical effect of the stalling of yawed wings. Going on with this research, it became clear that the flow had some very interesting properties and it could give a lot of significant information.

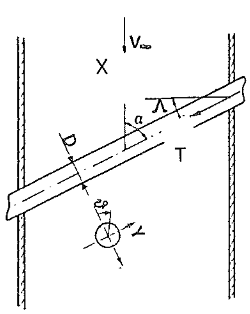


Fig 1 Sketch of the experimental configuration and coordinate system

It was soon realized (Abbà, Baron , De Ponte, (1))that the flow was antisymmetrical in the same way as the one of pointed bodies, and this feature could extend to a wider range of flow situations the knowledge about the alternate vortex street.

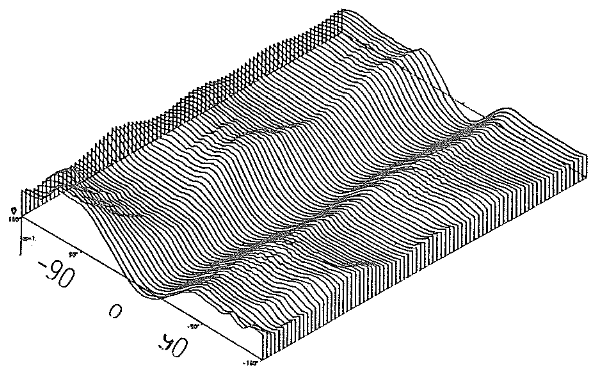


Fig 2 Pressure distributions on the yawed cylinder.

But another interesting aspect was the observation that the initial asymmetry was triggered by something on the upstream wall intersection and not by some imperfection of the nose. It was therefore possible to rotate the body and its instrumentation around the revolution axis *without changing the triggering mechanism of asymmetry*, thus allowing an accurate flowfield survey without a very complex instrumentation.

Furthermore, the flow was rather stable in time and repeatible allowing a more systematic investigation.

A lot of questions arose from the first investigations, among them the following:

-is there any "true" periodic behaviour of the flow beyond a certain aspect ratio?

-what is the upstream influence of the wake on the body flowfield, observing that any alternate wake disappears as sonic conditions are reached?

-how do the transitional instabilities affect the flow, observing that tha maximum asymmetry on nosed bodies happens in transitional conditions?

-how is the roll-up of the vortex sheed affected by the Kelvin-Helmholtz instability?

It appeared that an overview of existing data was not sufficient to answer to the questions and some new *insights into the phenomena* were required.

Without discarding the theoretical and numerical approaches, due to the difficulties of a correct simulation, the experimental approach was preferred, at least to compare the obtained data to the results of other approaches.

Three sets of experiments were planned, while one of them was insuccesful. This latter was an attempt to build a model with an aspect ratio exceding 50, in order to check the possibility of reaching an appreciable periodic stage of the vortex shedding in space. It was impossible to avoid eccessive vibrations and deformations of a model which was an extension of the tested 20 aspect ratio one.

The other two experiments were an attempt to measure the vortex roll-up by wake survays and a measurement of the wall-shearing stresses on the body itself. This last was suggested by the observation that, on simple bodies of revolution (Iuso- Oggiano - De Ponte (2)) the asymmetry of tangential stresses was much more remarkable than the one of pressures.

1) <u>TESTS ON WALL STRESSES</u>

The test on wall stresses was primarily intended to investigate the effects of transition and the case of trension-free flow.

It is well known that, beyond a certain Reynolds Number, *attachement line contamination* takes place on yawed leading edges and the *whole boundary* layer becomes turbulent.

In this case there is no transition on the body and the instabilities leading to transition, being absent, cannot interfere *on* the flow developement.

It is therefore possible to separate the effects of transitional instabilities from the vortex sheet instability in the wake, observing the differences between flow in such conditions and the one on nosed cylinders.

The starting idea is the observation that, on nosed cylinders, when the boundary layer upstream the separation line becomes transitional, the prerssure asymmetry is quite larger (Hartman (3))

It is impossible to obtain transition-free flows on nosed cylinders, while it is possible if there is an upstream body-wall intersection and the boundary layer on the wall is fully turbulent because the Reynolds Number is large enough.

A test was planned, first measuring pressure distributions and shearing stresses on a "large" model (.21 m diameter) tested in tha wind tunnel of Politecnico di Torino, putting two artificial parallel walls into the round tunneland testing a model with the same aspect ratio of about 20 as the previous tests in the small Reynolds Number regime.

The shearing stresses were measured by means of 24 triangular pressure probes as described by Ashhill(Welsh - Ashill (4)) The probes were placed along a cylinder generator with a 1/4 diameter spacing, as suggested by the previous pressure tests and by the need of limiting the interference, as by the limits of the available Scanivalves.

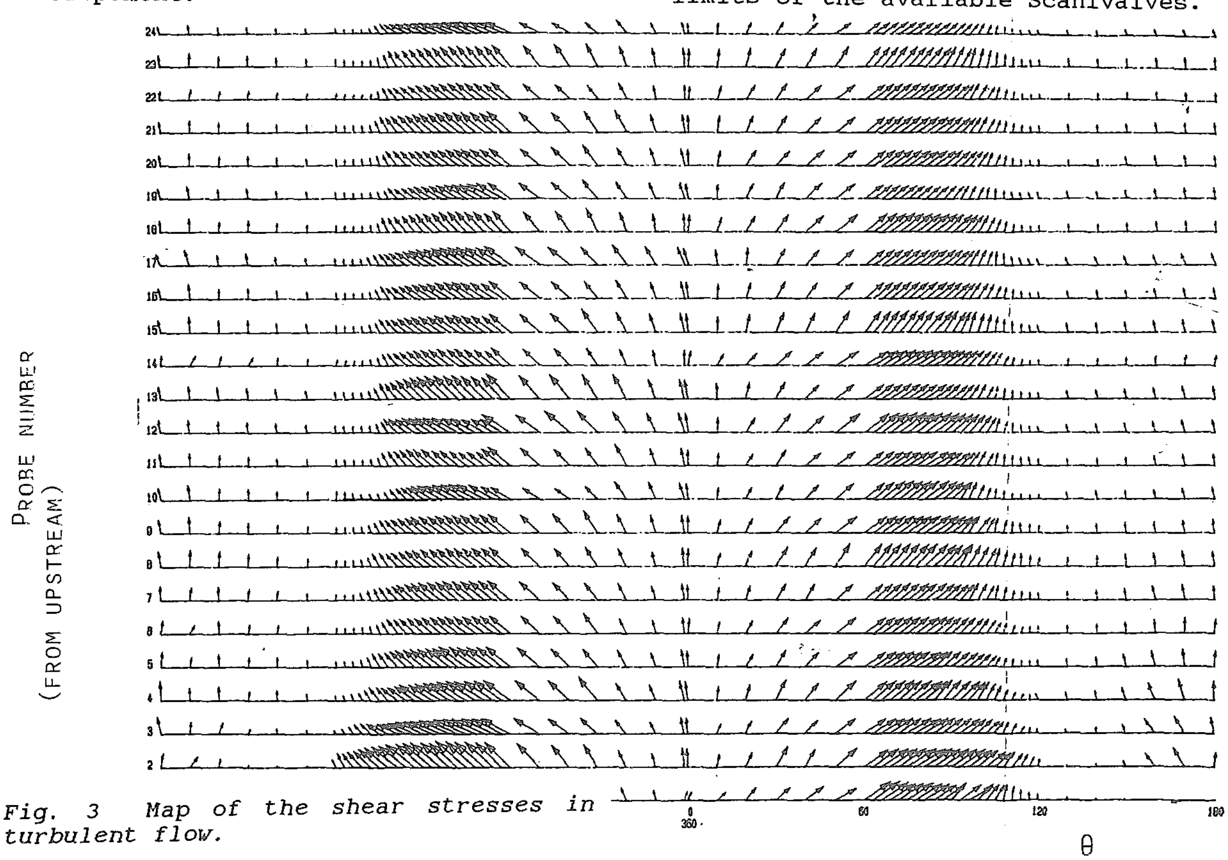


Fig. 3 Map of the shear stresses in turbulent flow.

The probes are someway protruding into the flow, but being the whole boundary layer turbulent, they do not affect too much its developement: in any case they *do not anticipate transition.*

A first attempt of doing so, based on usual instability criteria, was unsuccesful because probably the turbulent flow was not fully developed (De Ponte -Iuso-Gibertini (5)). The measured pressures were antisymmetrical while different from those observed at lower Reynolds Numbers.

In a second attempt the tunnel velocity was pushed up sufficiently to get the significant result that the flow was almost symmetrical and at least a period of pressure weawyness was smaller than the period of antisymmetry.

In this case, which is the object of a separate paper, the shear stresses were measured on the wall showing the complex structure of the separation lines in the transitional regime and the simpler topological aspect in the fully turbulent flow.

As an example three maps of the shearing stresses are shown in the following three figures.

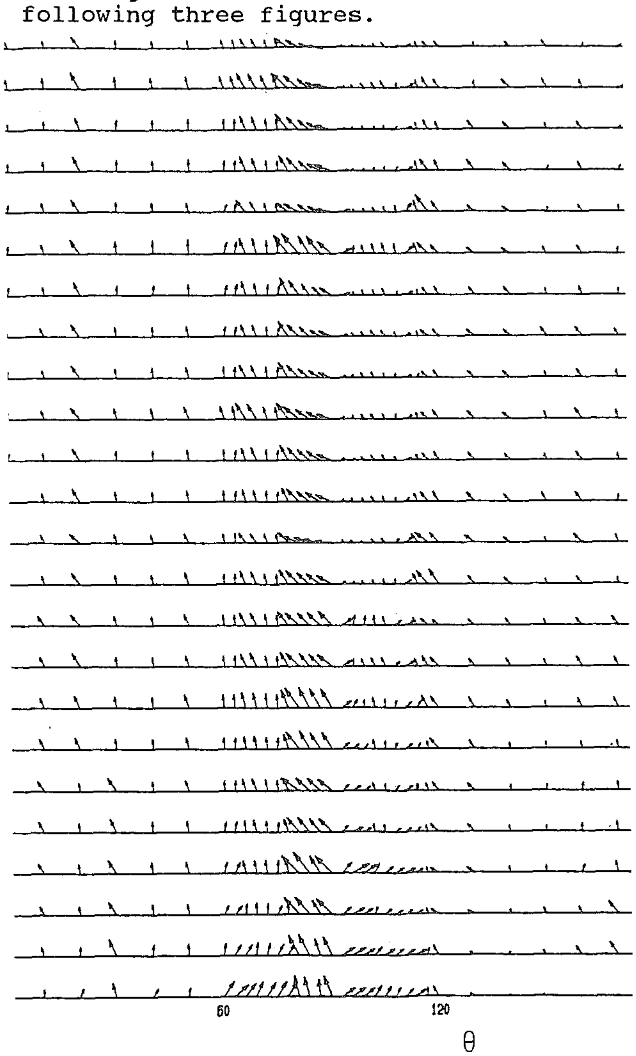


Fig. 4 Map of the shear stresses in laminar flow.

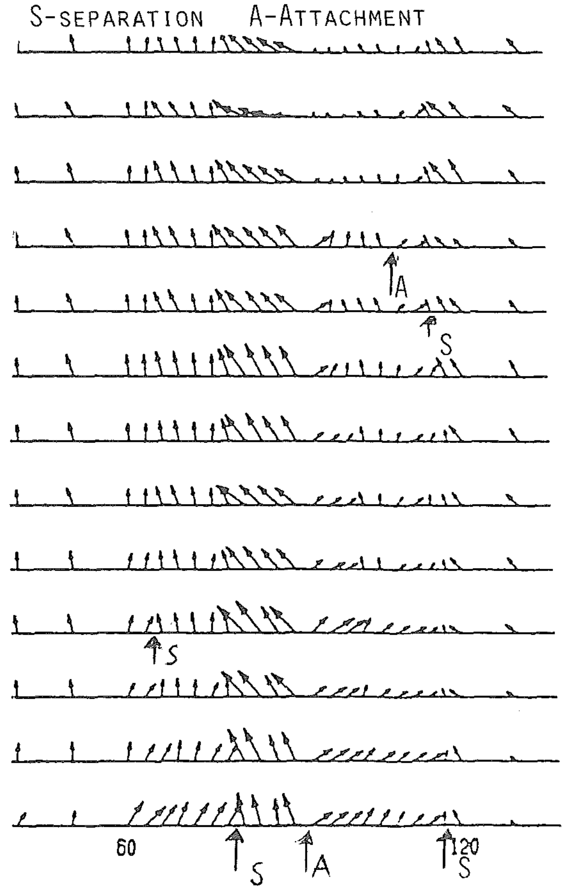


Fig. 5 A detail of multiple separations in laminar flow.

It is remarkable that, at the highest Reynolds Number the separation line is almost straight and not weawy.

It does not mean that there is no alternate vortex street, but only that the vortex street does not influence too much the separation mechanism.

If one looks at the pressure distribution, as reported in the following figure, one can see thet also the pressure field is completely different from the one of figure 2.

Of course, the next question is about the roll-up mechanism.

<u>TESTS IN THE WAKE</u>

A first wake surway is presented in Icas in Jerusalem (Abbà-Borsa-De Ponte (6)) and from the first wake measurement it might be suspected that the vortex structure could be much more complex than a simple pair of vortex sheets issuing from the main separation lines and rolling up into discrete vortices. It could be presumed that the roll-up would start with a shorter wave length than tha final vortex spacing.

In fact, the circulation had shown some "step" meaning that, at the measuring station, the vorticity was distributed in some complex way.

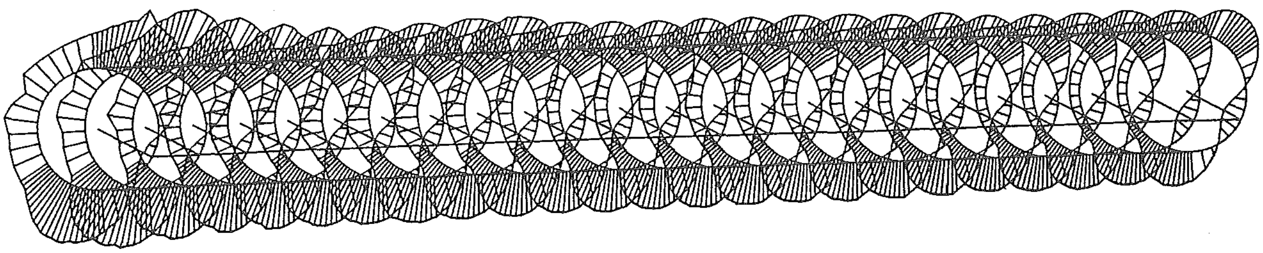


Fig. 6 Pressure distribution in turbulent flow

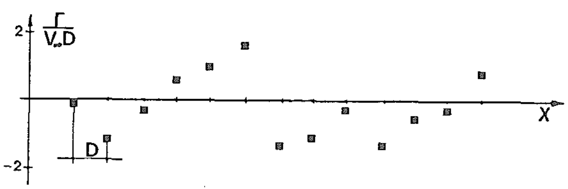


Fig. 7 Vorticity in the wake

A figure publised by Van Dyke was very interesting (Van Dyke.(7)) In his "Album of Fluid Motion", in fig: 48 at page 31, for a limiting Reynolds Number when a slight upstream influence is expected, it is possible to observe that the collapsing of the vortex sheets into the alternate vortex street happens after a weawiness which is probably a Kelvin-Helmholtz instability. If this happens in a plane, unstesdy flow it might be possible that the same happens in three-dimensional steady flow.

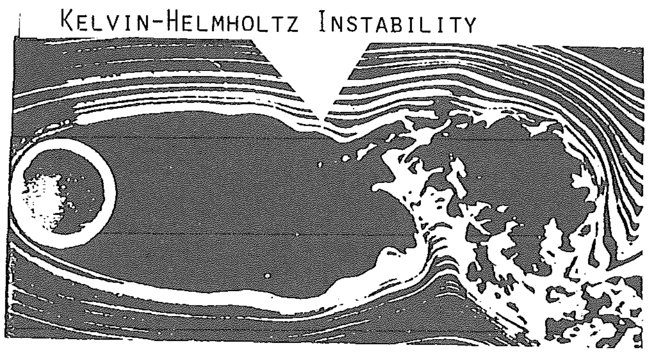


Fig 8 A visualization of a vortex street.

It might be possible that the first rull-up of the vortex sheet could be governed by the wawe length of the Kelvin-Helmholtz instability while the stability of the alternate vortex street will later preveal.

On the basis of those considerations and on the results of shear stress measurement a second set of tests in the wake were undertaken in the small Wind tunnel of the Politecnico di Milano only for the case of laminar separation, as the tests published in Jerusalem (De Ponte, Abbà, Borsa, (6)).

EXPERIMENTAL SETUP

The experimental setup is the same as described in the previous paper (Abba-Borsa-De Ponte ,(6)) and consisted in a .5 by .7 m wind tunnel with a cylinder of .062 m diameter spanning the tunnel at a yaw angle of 60°.

A 5-hole pressure probe was chosen as a good compromise between accuracy and general test economy.

A limit in the previous tests were the fact that only the total pressure and not the local velocity could be measured. Adding a further pressure measurement with respect to the prtevious test, it was possible to evaluate also the velocity of the flow.

Particular care was taken in the calibration of the pressure probe and in the procedure for data reduction for obtaining significant measurements in a rather wide range of flow directions.

Of course a pressure probe could produce a bursting in the vortex core, so that the vorticity measurement close to the vortex centerline could not be reliable, but all the other data should be correct. This might be a limit of the measuring technique, but also other techniques are not suitable for vortex cores.

Pressure probe holes were connected to a system of Scanivalves and pressure transducers arranged to minimize measuring errors. In this way it was possible to have a suitable pressure transducer for each pressure range, from small pressure differences for evaluating flow directioins to the range of the dynamic pressure for the velocity.

The pressure probe was connected to a transversing gear spanning the tunnel.

A coordinate system for the location of measuring points, based on a non orthogonal reference, although seems to be rather confusing, is very useful for representing the main features of the flow.

It is based on a reference frame with respect to the onset flow -X axis- and the cylinder axis -t axis-, the y axis being normal to X and t in a standard way.

A second, orthogonal coordinate system has the same X axis, the Y axis and the Z axis aligned with the tunnel walls and normal to the onset flow with the standard conventions, Y and y being coincident. In this reference frame the velocity components *u,v,*and *w* are referrred.

The displacing gear which moves the probe has two degrees of freedom, in *t* and y directions, while it was displaced by hand at different, *fixed* X locations.

Therefore the probe si displaced in planes parallel to the cylinder axis (t-y planes) and the probe axis is kept aligned with the onset flow.

Maps of the velocity components *normal to the onset flow* (*v* and *w*) are represented as function of the distance of the measuring plane from the cylinder axis in the onset flow (X) direction.

DESCRIPTION OF THE RESULTS

From the shown figures, it is clear that, although the vortex street is alternate in its overall shape, there are significant differences in the flow pattern around the vortex cores.

It is therefore confirmed the idea that the vortex sheets issuing from the primary separation lines have a complex history before collapsing into the main alternate streeet.

In the two figures it is represented projection of the velocity field in the Y-Z plane in the most upstrteam and downstream t-y planes.

In the most upstream, although a first rolling-up is clear, it might be noted that there are almost two sepatate vortex sheets issuing from the cylinder, while in the most downstream position the rolling-up is almost completed.

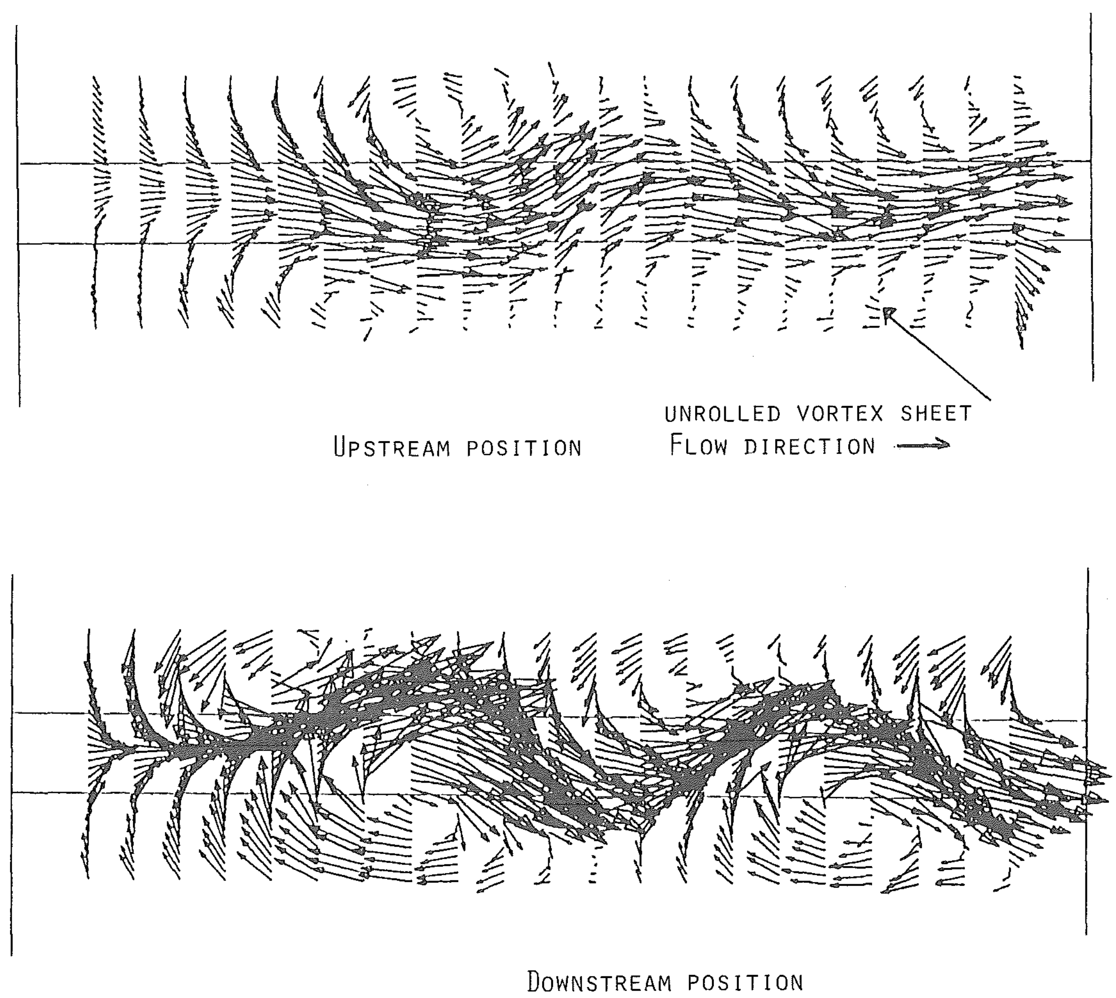
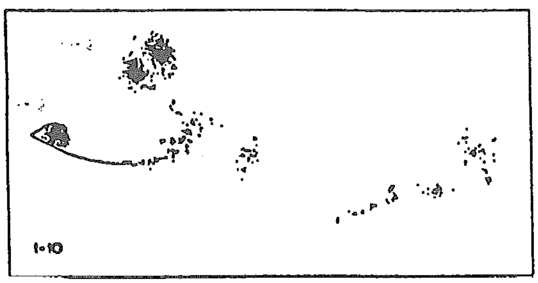


Fig. 9 Flowfield in the wake

While in the most downstream position four main vortex cores are quite clear, in the most upstream , at least on the uppre side many separate vortex cores are still noticeable and it might be concluded that the roll-up mechanism takes effectively place in different, small-size vortices, then collapsing into the main vortices of the alternate street.

This all is in agreement with the behaviour of the plane, unsteady wake.

Recent numerical experiments (De Ponte - Gibertini - Sartorelli,(8))have also shown the fundamental effect of secindary separation on the developement of the vortex rolling-up in two dimensional wakes. It might be seen from a comparison between the numerical simulation without secondary separation and with a very rough secondary separation model in fig. 9 from ref (7) that the flowfield is quite different and flows with no secondary separation are quite unrealistic.



- Unrealistic wake for α=25°.

SIMULATED SECONDARY SEPARATION

Fig. 10 Two numerical simulations of impulsively started plate, with and without secondary separation effects

Observations of the complex pattern of the shear-stress lines in the "large"" cylinder experiments lead to the idea that not only the Kelvin-Helmholtz instability but other complex phenomena may influence the rolling-up mechanisms, specially at low Reynolds numbers.

Flow visualizations by means of a surface paint have shown some detail of a sinuous first separation line and a secondary separatioin, possibly merging with the primary one at some place along the body. This is topologically inconsistent and some small structure shoud be not cleared enough by the visualization.

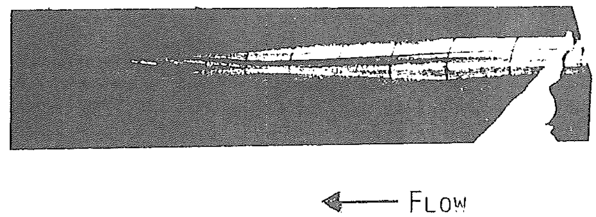


Fig. 11 Visualization of separation on the yawed cylinder, as seen from the upstream side.

Also in the turbulent regime on the "large" model the spatial resolution of the pressure probes for wall shear stresses is of the order of one centimeter on a diameter of 22 cm, so it is not sufficient to describe the small structures and the possible merging of separation lines.

So the set of new results allows a better insight into the problem but is not sufficient up to now to answer the whole set of questions.

CONCLUSIONS

It is possible to conclude that the flow is rather complex in the details although the large features are quite simple and undestood.

From completely different source of information, based on numerical simulation of plane flows, the roll-up mechanism seems to be related roughhly only of the vortex dynamics neglecting a detailed description of the viscous and small-scale turbulent diffusions, so that a numerical approach by means of vortex dynamics should be one of the next steps for investigation. But a true three-dimensional numerical simulation is probably very expensive in terms of computer size and computing time, so that an improved experimental approach still remains a main requirement, at least for preliminary code validation.

The experimental approach has shown the advantages and the limits of the instrumentation.

The advantages of a pressure-probe system is the reliability, simplicity and accuracy of measurements, while the main limit is the poor spatial resolution, expecially for the shearing stresses.

From the experiments it is possible to observe the disappearance of the weaviness of the separation line when the fully turbulent regime is reached by means of the attachement-line contamination.

This is a very important result because it confirms the feeling that the antisymmetrical separation is in some connection with the same instabilities that caause transition and further investigatioins should be done in this connection.

The wake surway has shown that the vortex structure is rather different from vortex to vortex although spacing and pitch of the street are in rough agreement to the theoretical values of the von Kaarman street.

It has been shown that the roll-up of the vortex sheets is first dominated by some kind of Kelvin-Helmholtz instability and then by the parameters of the alternate wake, while these and other results show that the pitch-distance ratio is in the rtange of theoretical values but not too close to them

A further significant point is that the stability of the alternate vortex street is prevaling on the Kelvin-Helmholtz instability, in contrast with the simple theory, which gives *neutral first order stability* for the von Karman street. The reasons for this are still to be investigated.

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