PHOTOGRAPHIC STUDY OF VORTEX MOTIONS

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Introduction

The structure of the flow behind an obstacle of revolution has been the subject of many experiments at great values of the Reynolds number, but there is a scarcity of experiments at small Reynolds numbers. The difficulties arising when the attempt is made to work at Reynolds numbers of about 200 are perhaps one reason for this.

In any case the vortex system in the wake of figures of revolution for Reynolds numbers corresponding to the existence of alternate vortices in the two dimensional case is still very poorly known. Some experimenters have already tried to explain the results of their experiments in this case by extending to the three dimensional case the theory of von Karman for the two dimensional case, but until now such attempts have not been completely successful.

This lack suggested the idea of studying more accu--rately how the wake could be modified when going from the two dimensional to the three dimensional case, and it was the first purpose of this work to study the form of the wake behind obstacles such as ellipses with constant major axis and with decreasing minor axis. This kind of experiment can indeed be very helpful for deve--loping the theory of the wake behind figures of revolu--tion.

First, an airflow of uniform velocity had to be obtai--ned. A small smoke tunnel, with square cross section, was used for this. To get a very good laminar flow in this tunnel was the most difficult task in these experiments.

The wakes behind a two dimensional flat plate and behind a flat circular plate were first studied.

REALIZATION OF A SLOW AND UNIFORM AIRFLOW

Experimental apparatus: We had to build a smoke tunnel in which we wished to get a laminar flow, and to obtain this desired flowthe Reynolds number in the tunnel had to be less than the critical Reynolds number, which lies between 1400 and 2000. To be sure of working in the domain of stability, we had to choose a Reynolds number less than 1400.

By définition, the Reynolds number is:

$$R = \frac{vd}{\nu} = \frac{vd\rho}{\mu}$$

where v is the velocity of the fluid

d is a characteristic dimension of the body

ν is the kinematic viscosity of the fluid

ρ is the specific mass of the fluid

μ is the viscosity of the fluid

For dry air, we have:

$$\mu = 1720 \cdot 10^{-7} (1 + 0.003665\, t) \quad \text{c.g.s.}$$

$$\rho = 0.001293 \cdot \frac{p}{760} \cdot \frac{273}{273 + t} \quad \text{c.g.s.}$$

where t is the temperature of the air in degrees centigrade

p is the pressure of the air in millimeters of mercury

For dry air, at 0 degree centigrade and normal pressure (760 mms of mercury) we get:

$$\mu_0 = 1720 \cdot 10^{-7} \quad \text{c.g.s.}$$

$$\rho_0 = 0.001293 \quad \text{c.g.s.}$$

Then: $\nu_0 = \frac{\mu_0}{\rho_0} = 0.133$ c.g.s.

The condition for the laminar flow is:

$$R = \frac{vd}{\nu_0} < 1400$$

or:

$$vd < 1400 \times \nu_0 = 1400 \times 0.133 = 186$$

$$v < \frac{186}{d} \quad \text{c.g.s.}$$

or: $$v_{lim.} = \frac{186}{d} \quad \text{c.g.s.}$$

In his experiments in Strasbourg, Mr. Sadron had used a horizontal tunnel of square cross section the side of which was 5 cms. He suggested that we use a similar tunnel but with a side of 15 cms. However since experience has shown that symmetrical steady motion in a channel is more easily obtained when the motion is vertical instead of horizontal, we used a vertical tunnel.

Tunnel of 15 cms: The cross section was square. We have for this tunnel:

$$d = 15 \text{ cms}$$

Therefore: $v_{lim.} = \frac{186}{15} = 12.4$ cms/sec.

The entrance of the tunnel was streamlined. It proved experimentally, however, that this tunnel did not give a laminar and uniform airflow. It was first believed that the big pipe leading the air into the upper box and pla--ced just the entrance to the tunnel itself was the cause of the disturbance, but this did not disappear when a screen was placed inside the upper box before the big pipe. Other possible causes were investigated, but, finally, it appeared certain that the disturbances depended on the tunnel itself whose dimensions were too large.

Furthermore, we are restricted to a range of velocity in which the maximum velocity is determined by the critical Reynolds number and the minimum determined by the properties of the $TiCl_4$ smoke which we observed can not be worked reasonably well below a velocity of about 12 or

13 cms/sec. That is to say we have to work between two well defined limits: a maximum velocity corresponding to the critical Reynolds number and a minimum velocity of about 13 cms/sec. below which a special phenomenon occurs that forbids us to work in this region.

Therefore, due to these two conditions, we had to change the dimensions of the tunnel.

Tunnel of 8 cms: We built a tunnel similar to the former one but with a side of only about 8 cms. The tunnel was formed of 4 glass plates, 5 mms thick, as sides, the oppo--site plates being parallel. The section was practically square (dimensions: 7.7 cms x 7.8 cms). The entrance was not streamlined but the glasses were 8 cms too long so that the tunnel began 8 cms above the bottom of the upper box as shown in figure 1.

We have for this tunnel:

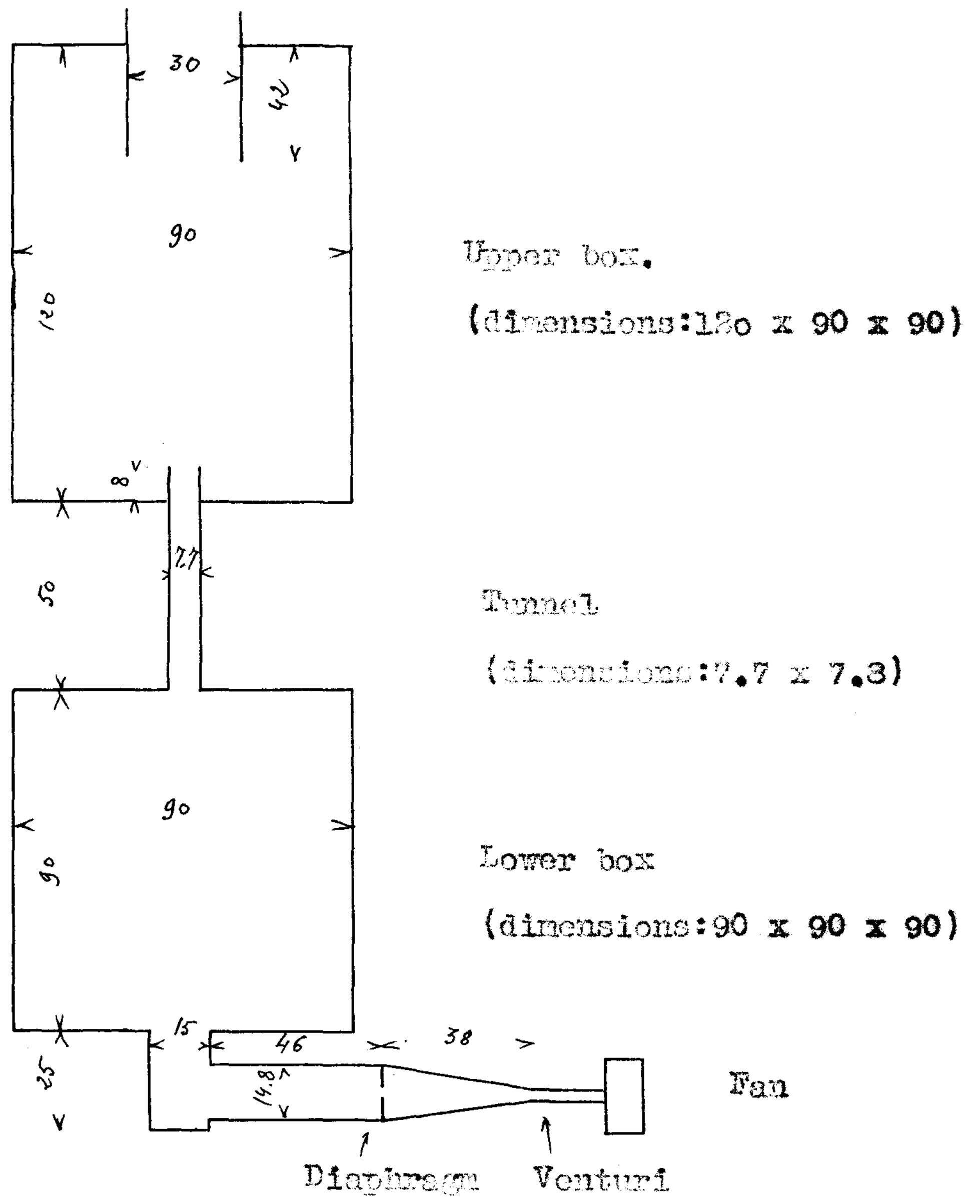
$$v_{lim.} = \frac{186}{7.8} = 23.9 \text{ cms/sec.}$$

Upper box: The air comes into the tunnel from a box placed coaxial to and above the tunnel and open to the atmosphere by a circular orifice in which was set a big pipe. The dimensions of this box can be seen in figure 1.

Consequently, the air flowing in the tunnel can be assumed to come directly from an atmosphere practically at rest. All the parasite motions of the outside air have time to disappear or to be damped almost completely while the air is in the upper box.

Lower box: A similar box was put at the other end of the tunnel between it and the fan in order to avoid possible disturbances due to the presence of the latter.

Smoke generation: We used titanium tetrachloride($TiCl_4$)



Experimental apparatus: Smoke tunnel of 8 cms.

Dimensions in cms.

Figure 1

giving abundant white smoke of TiO_2 .The titanium tetrachloride which is contained in a small bottle is blown out through a very sharp glass needle.A drop arrives at the extremity of the needle and gives a smoke line,very white and more or less abundant.

Velocity: 1) Uniformity of the velocity in the tunnel:

Referring to the work of Mr. Sadron who determined the velocity distribution in a cross section of the smoke tunnel he used in Strasbourg,we can assume that the velocity of the fluid in the tunnel is constant in a central region about 6 cms square,since the velocity is less than 25 cms/sec.,and whose length is the length of the tunnel itself.If we choose obstacles of about 2 cms in width,we can assume with sufficient accuracy that the wake is the same as if it was in a fluid extending to infinity and flowing with constant velocity. We did not investigate experimentally the velocity distribution in a cross section of the tunnel,ourselves.

2) Velocity measurement: For the tunnel of 15 cms we chose a Venturi tube of 30 mms in diameter in order to control the velocity,to keep it constant,and to know its approximate value,but it could not be used for the smaller,8 cms tunnel,its indication being inappreciable for the velocities used.We chose then a diaphragm that we put in the air circuit as indicated on the figure 1. The difference of static pressure between the two sides of the diaphragm is measured by an alcohol manometer with which it is possible to control the velocity of the air and to keep it constant during the experiments. Moreover,if we assume the value 0.6 for the coefficient

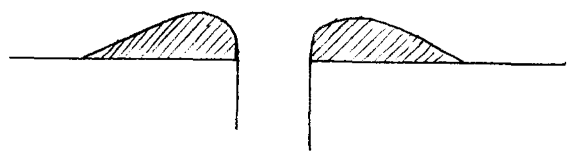


Figure 2: Streamlined entrance for a tunnel

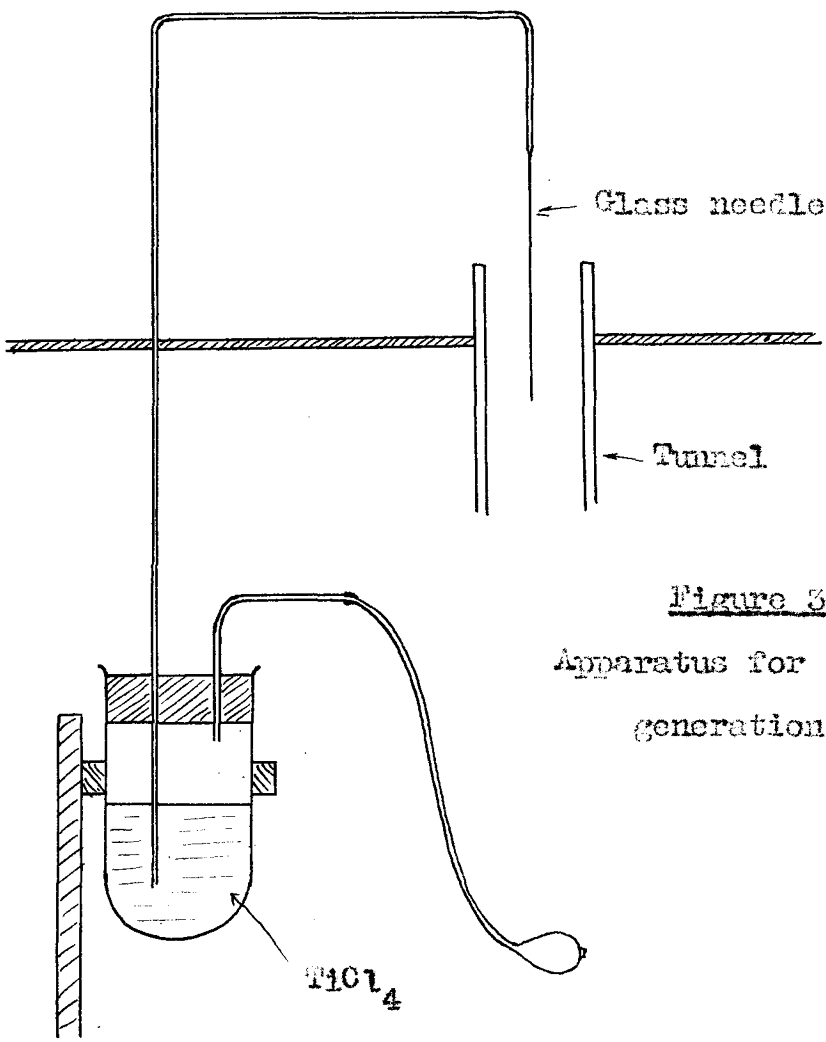


Figure 3 :
Apparatus for smoke generation

of the diaphragm, a value which is approximately exact within a few % , we can calculate roughly the value of the velocity of the fluid in the tunnel.

At the same time, this diaphragm created in the cir--cuit a loss of energy which let the fan run at suitable speed. The relation giving the velocity of the air through the orifice of the diaphragm is:

$$v_1 = K\sqrt{\frac{2\Delta p}{\rho}} \qquad (1)$$

where Δp is the difference of pressure between the two sides of the diaphragm

ρ is the specific mass of the air. As the variations of temperature and pressure of the atmosphere are rather small, we shall take a constant value for ρ :

$$\rho = 0.0012 \quad grs/cm^3.$$

K is a correction factor generally taken near 0.6 and which can be considered constant when the velocity varies. We shall take K = 0.6 .

The formula (1) with the assumed values of K and ρ gives a good idea of the velocity in the tunnel. If the value 0.6 we assume for K is not exact, the true values of the velocity will be proportional to the values using K = 0.6 .

We can, from the formula (1), calculate the mean value of the velocity of the air in the tunnel:

$$v = v_1 \times \frac{S_1}{S}$$

where S is the section of the tunnel

S_1 is the section of the diaphragm

We have:

$$S_1 = \frac{\pi d^2}{4} = \frac{\pi (1.5)^2}{4} = 1.765$$

$$S = 7.8 \times 7.7 = 60$$

Then: $$v = K \frac{S_1}{S} \sqrt{\frac{2 \Delta p}{\rho}}$$

Relation between v and the manometer reading h:

We can write:

$$\Delta p = hg\gamma$$

where h is the manometer reading

γ is the specific mass of the manometric fluid.

We use alcohol for which $\gamma = 0.808$ grs/cm^3.

Then:

$$v = K \frac{S_1}{S} \sqrt{2gh\frac{\gamma}{\rho}} = K \frac{S_1}{S} \sqrt{2g\frac{\gamma}{\rho}} \sqrt{h} = K' \sqrt{h} \text{ c.g.s.}$$

If we measure h in mms, say h', we get:

$$h = \frac{h'}{10}$$

and: $$v = \frac{K'}{\sqrt{10}} \sqrt{h'} = K'' \sqrt{h'} \text{ cms/sec. (h' in mms)}$$

$$v = K'' \sqrt{h'}$$

Value of K'':

$$K'' = \frac{K'}{\sqrt{10}} \frac{K}{\sqrt{10}} \frac{S_1}{S} \sqrt{2g\frac{\gamma}{\rho}} = \frac{0.6}{\sqrt{10}} \cdot \frac{1.765}{60} \sqrt{\frac{2 \times 981 \times 0.808}{0.0012}}$$

$$K'' = 6.425$$

Then: $$v = 6.425 \sqrt{h} \text{ cms/sec. (h in mms)}$$

or: $$h = \frac{v^2}{41.3}$$

Special case: In the region of low velocities(i.e.velocities less than 13 cms/sec.),we can observe a phenomenon already observed by Mr. Sadron in his horizontal tunnel.

The smoke line which was steady and rectilinear at higher velocities begins to divide into drops regularly spaced which fall as drops of a liquid in an immiscible medium.All these smoke drops form a kind of chaplet.

We determined the velocity below which this pheno--menon,probably caused by the high density of the smoke of $TiCl_4$,occurred.We found that in order to avoid the appearance of this phenomenon,we had to work at veloci--ties above 13 cms/sec.

Remarks: To have a steady flow in the tunnel,experience has shown it is necessary:

1) to place the tunnel in a,room where the air is as calm as possible for it is imperative that there be no internal motion in the air in the reservoir supplying the stream
2) to avoid leaks at the apparatus itself
3) to eliminate as much as possible temperature influ--ences because small differences in the temperature create régional parasite convection currents.

It is very important to realize these conditions for without them it is really not possible to get the wanted steady flow in the low velocity range here consi--dered.

Photographic apparatus: The pictures of the wake were taken with a Leica camera,the light was provided by a Photoflood lamp of 250 watts,and superpanchromatic films were used,no other film being suitable.

The lamp was switched on for as short an interval as possible, just long enough for taking the picture, in order to avoid parasite currents due to temperature.

N.B. All Reynolds numbers were calculated with ν_0 = 0.133 c.g.s.

WAKE OF A FLAT PLATE IN TWO DIMENSIONAL FLOW

Theory: Let us consider a fluid extending to infinity and flowing with an uniform velocity U in rectilinear motion. If we put now in this fluid an infinitely long flat plate of constant width perpendicular to the di--rection of motion, we shall observe behind the plate a wake whose form changes with the velocity of the fluid.

The classical potential flow of a perfect fluid past a bluff body is not a satisfactory representation of the actual flow except in the limiting cases of very slow motion of small bodies or of very high fluid vis--cosity i.e. for very low Reynolds numbers. ($R < 5$)

In the case we are considering, the flow will be the same in all planes normal to the long axis of the plate. In this case it is found experimentally that surfaces of discontinuity of velocity spring from the two sides of the body and enclose a dead region behind it. These surfaces of discontinuity of velocity are essentially vortex sheets and can be considered as a succession of roller bearings between the dead region and the general stream. But as it can be shown in a quite general way and observed directly, such sheets are unstable. Owing to this fact these vortex sheets rapidly disintegrate and observation shows that they have a tendency to roll themselves up i.e. there is a concentration around some points of the sheet originally between them. Finally there is a succession of independent vortices which pass downstream in the form of a double vortex row or vortex street.This happens for Reynolds numbers greater than IOO or so.Observation shows that betweenthe regionsof potential flow and of the periodic discharge of vortices there is a region where the wake behind the obstacle remains the same.

The possible existence of isolated vortex filaments which can be considered as the final product of decompo--sed vortex sheets was first considered and solved by von Karman in 1912.von Karman investigated the question whether or not two parallel rows of rectilinear infinite vortices of equal strength but rotating in opposite di--rections can be so arranged that the whole system, while maintaining an invariable configuration,will have a uniform translation and be stable at the same time. It can easily be shown that there are only two possible arrangements for which two parallel vortex rows,such as those considered,can move with a uniform and rectilinear velocity:the vortices may be placed one opposite the other(figure 5,a) or the vortices of one row may be placed opposite the middle points of the spacing of the vortices of the other row(figure 5,b).Indeed,in order that the vortices retain their positions on the two parallel lines,the induced velocity at any vortex must be parallel to the lines.This condition will be satis--fied if any vortex of one row is exactly opposite to a vortex of the other row or if it is opposite the mid-point between two vortices of the other row.For any other arrangement than the two former ones,the induced velocity has a component perpendicular to the vortex row;then the configurationwill not be maintained.

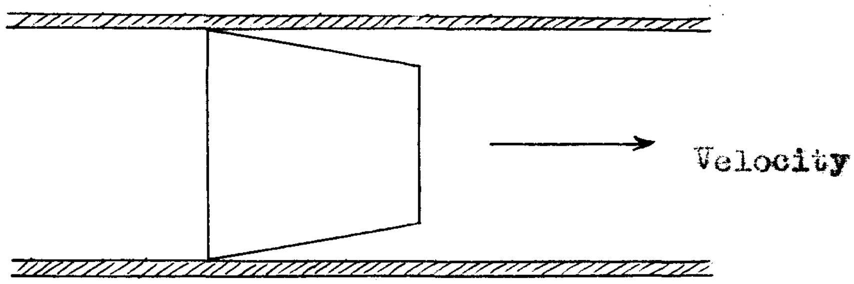
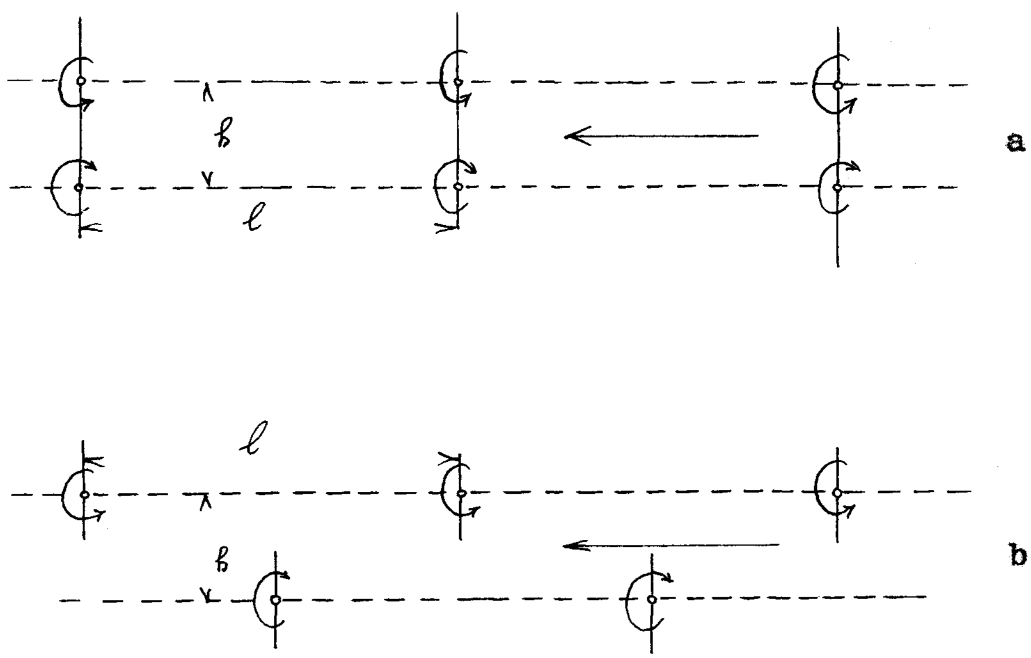


Figure 4: Approximate velocity distribution in the tunnel



Figures 5.a and 5.b .

Referring to stability considerations, von Karman establiſhed that the first configuration with the vorti--ces in pairs was unstable, but he shew that for the arrangement with alternate vortices there exists a value of the ratio h/l for which the system is stable (h is the distance between the two rows, l is the distance between the vortices in the row). The necessary condition of stability for this second configuration was found to be:

$$h/l = \frac{1}{\pi} \cosh^{-1} \sqrt{2} = 0.281$$

A double vortex row of this stable type is called a "Karman vortex street".

By aid of the formula found for the complex potential of this flow, the flow picture could be drawn. The veloci--ty u of the vortex street is smaller than the velocity U of the fluid.

The origin of the vortex system remains unanswered, although the viscosity seems to be responsible for the formation of the vortices. According to Jaffé there is much greater cause for the formation of vortices when there are discontinuities in the external forces or in the velocity of the fluid. Such discontinuities exist in the vicinity of the plate.

Experiments: Experiments were made in the smoke tunnel formerly described with thin flat plates of 1 or 2 cms width respectively. With these dimensions and the exis--ting velocity distribution, the central part of the pla--te was entirely in a region of uniform velocity and we can assume with good approximation that the flow around it is two dimensional.

The glass needle providing the indicator fluid $TiCl_4$ was put immediately above the plate and by pressing on the rubber bulb $TiCl_4$ was shed on the plate, causing the wake to be entirely filled with smoke. Very good vortices springing alternatively from each side of the plate appeared immediately behind it, but as it can be seen on the pictures they disappeared quite rapidly and only three or four of them were visible.

WAKE OF FLAT CIRCULAR PLATES IN THREE DIMENSIONAL FLOW

Theory: We consider a fluid extending to infinity and flowing with a uniform velocity U in rectilinear motion. Let us put a flat circular plate perpendicular to the direction of motion and we ask what is the behaviour of the wake when the velocity of the fluid is increa--sing.Many experiments have led to the following results:

At small Reynolds numbers i.e. for very low veloci--ties up to a vaguely defined limit that we will call the lower limit(for R = about 5),the motion is of streamline form.

At speeds above this lower limit but below an upper limit corresponding to R = about 100,a permanent vor--tex ring is observable behind the obstacle.The exis--tence of a vortex ring at the back of a circular plate was first pointed out by Osborne Reynolds in 1877.The radius of the ring,always greater than that of the disc, grows slowly and the thickness more rapidly with increa--sing Reynolds numbers.The surface of the vortex ring is a surface of discontinuity.The circulation of the fluid in the vortex ring can be seen.

When the Reynolds number exceeds that of the upper limit,an oscillating disturbance of the vortex ring becomes apparent,and the vortex ring opens up and forms a sheath of discontinuity the substance of which is discharged downstream in a series of rings of vorticity of definite pitch and periodicity.The exact form of this discharge has been the subject of continued inves-

-tigation but no measure of agreement has been reached so far.

The transition from the two dimensional case to the three dimensional one has been attempted by a generali-sation of the two dimensional work of von Karman. The scheme proposed by Mr. Sadron in his work is one example of this extension of the two dimensional theory of von Karman to the wake behind an obstacle of revolution. This scheme does not satisfy Mr. Sadron any more and I personally believe that it does not correspond to a good representation of the real phenomenon.

But the two cases, the two dimensional and the three dimensional, are very different. Indeed in the two dimen-sional case all the vorticity is produced about a well defined direction. There is no such simplification in the three dimensional case. It was first believed as a uni-spiral discharge of vorticity down the wake, but this would imply a circulation about a contour surroun-ding the wake drawn in a plane parallel to the disc. A wake composed of helical vortices the sum of whose strengths is zero would meet this difficulty. But it was shown by Jeffreys (Roy. Soc. Proc. A. Vol. 128, p. 376 1930) that the bi-spiral discharge, one helix having positive vorticity and the other negative, was also im-possible because if the helices are imagined wound round an imaginary cylinder in opposite directions, they are bound to intersect and produce big disturbances at the points of intersection and then disrupt themselves; and if they are imagined wound round the cylinder in the same direction, then this means that on the average there is no generation of vorticity at a point of the obstacle,which is impossible.Moreover,the bi-spiral discharge does not in general form a steady motion,for the helices do not tend to follow each other round the surface of the imaginary cylinder,but they tend to come together and to neutralise each other.

The question rises to determine which are the possible forms of steady motion of three dimensional vorticity that satisfy the circulation condition and to determine whether they are stable or not.The only possible forms of steady motion are:

1) The sheath of discontinuity

2) A system of circular rings of vorticity

which are both unstable.From this fact,Rosenhead derived a model of the wake:

The motion is of streamline form when the velocity is very small.

Between the lower and the upper limits,vorticity is shed and arranges itself symmetrically.This gives rise to a vortex ring which diffuses vorticity in the rear, but being continually supplied with vorticity from the plate it remains at uniform strength and keeps its posi--tion.There is such an equilibrium state for each Reynolds number,the thickness of the vortex adjusting itself properly.

If the velocity is increased above the upper limit the supply of vorticity to the vortex ring exceeds the amount which is diffused away and the surface alters its shape.The result is a sheath of vorticity which is unstable and breaks up.Considering the surface of discontinuity as a series of elemental vortex rings, packed closely together, which are generated at the edge of the plate, let us suppose that one of these elemental vortex rings is slightly distorted. This distortion will be increased owing the own influence of the vortex ring considered and to that of neighbouring rings. Neighbouring rings will be similarly affected, and we will expect to see a series of corrugations travelling down the surface of discontinuity.

Experiments: Experiments were made with discs of 8 mms, 10 mms, 15 mms, 20 mms in diameter, dimensions such that they can be considered as being completely in the region of uniform velocity and that interference with the tunnel walls is not yet appreciable. Due to the fact that the titanium tetrachloride smoke is rather heavy, we could not observe very well the formation of the permanent vortex ring below the upper limit, the velocity of the airstream being too slow. The smoke fell in the flow by its own weight and the wake was completely disturbed.

On the other hand, we could observe very well the periodic discharge of long shaped vortex rings, especial-ly for the discs of 8, 10 and 15 mms, but for the disc of 20 mms, the influence of the walls is already sensible, and it was more difficult to get rings in this case.

Some experimenters have observed in water a wake formed by the periodic discharge downstream of symmetri-cal rings of vorticity. This would correspond in two dimensions, to a double row of vortices placed one opposite the other, an unstable configuration. I observed something similar to this with a disc of 55 mms in diameter but in this case, interference with the walls seemed to be the cause of the phenomenon.

It seems that a simple photographic study, although giving already a good idea of the phenomenon, is not enough and that a, cinematographic study would be more useful.

WAKE OF FLAT ELLIPTIC PLATES IN THREE DIMENSIONAL FLOW

The study of such a wake will probably give in the future more precise information about the possible generalisation of the two dimensional law of von Karman to the three dimensional case of flat circular plates.

The purpose of the experiments was to try in the smoke tunnel ellipses of decreasing minor axis and of constant major axis so determined as to avoid any sensible interference with the walls of the tunnel. We chose ellipses with a major axis of 16 mms. We tried also one ellipse with a major axis of 32 mms and a minor axis of 4 mms.

Experiments on ellipses were not numerous enough to enable us to draw valuable conclusions from them. A study of the wake in two directions at right angles is absolutely necessary before drawing any conclusions. However, we observed the following things:

We consider ellipses with a ratio $\frac{\text{minor axis}}{\text{major axis}}$ = about 1/8. When looking at such an ellipse in the direction of the major axis, we see alternate vortices, similar to those we get in two dimensional flow, springing from the long sides. On the other hand, whenwe look at the ellipse in the direction of the minor axis, we see that these vortices open themselves up slightly, giving long shaped vortices, similar to those we get for the discs.

In this case, there is therefore a combination of the wakes we observed for two dimensional obstacles and for obstacles of revolution. Our conclusions can not actually go further.

CONCLUSIONS

The greatest difficulty of these experiments is, undoubtedly, to get a steady uniform laminar airflow in the tunnel. Bearing this in mind, it was a poor idea to increase the dimensions of the tunnel's cross section; even the tunnel of 8 cms is not as satisfactory as desired. The best course of action to follow seems to reduce further still the tunnel size and to return to the tunnel of 5 cms in width with which Mr. Sadron had already worked in Strasbourg. Moreover, too many precau--tions can not be taken to avoid disturbances in the flow; we should suggest for example to have streamlined entrance even for the tunnel of 5 cms. It is also very important to avoid any kind of parasite aircurrents which would disturb easily the airflow and consequently the studied wake.

The smoke used, that is the smoke provided by the decomposition in the air of the titanium tetrachloride, has its only advantage in that it is produced in great abundance and is very visible. On the other hand, it is, first, too heavy forbidding operation at low velocities; second, the reaction produces heat causing a disturbance whose effect must be made negligible by working at velocities higher than desired.

In the cases of flat circular and elliptic plates, it is advisable to take pictures at right angles. Cinematography of the phenomena would be very helpful too.

The smoke tunnel seems to be a good mean of inves-

-tigation for studying phenomena at low velocities, but it needs to be perfected in order to give the results that we can expect of its use.

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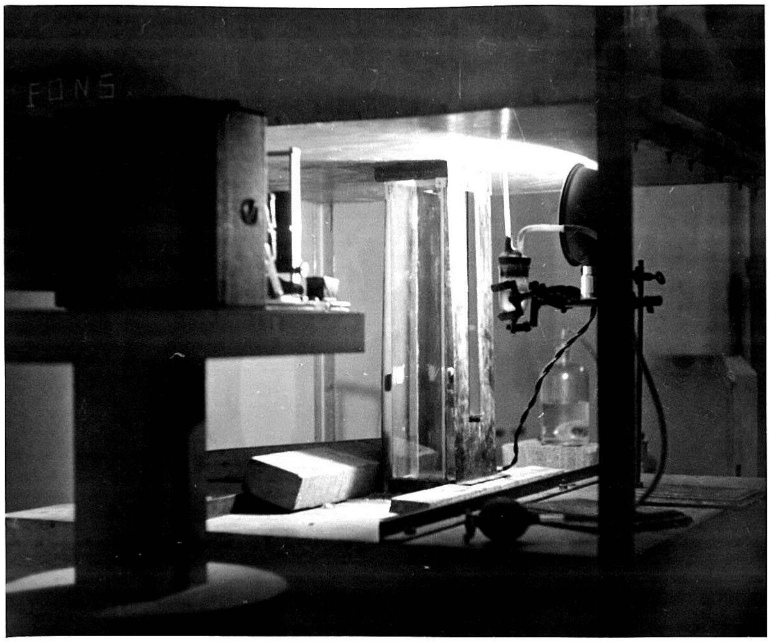
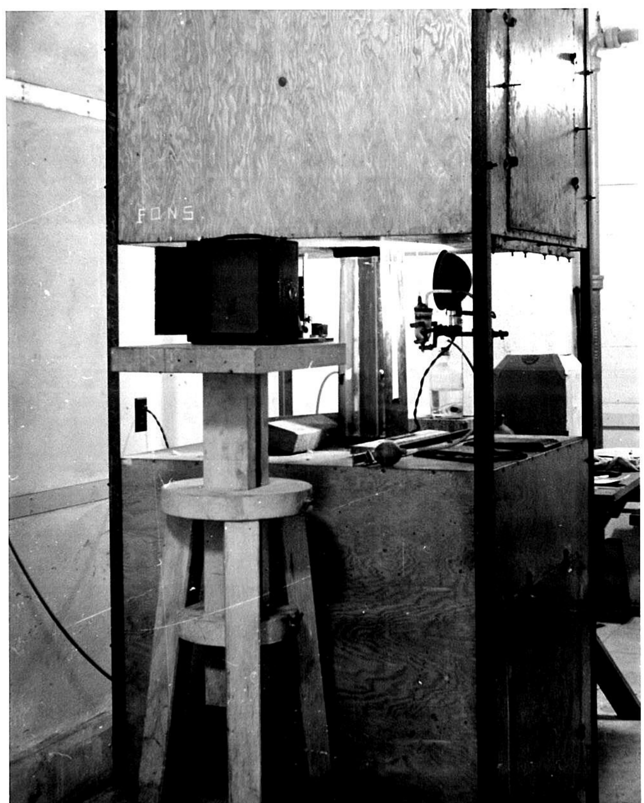


The smoke tunnel of 8 cms



Experimental apparatus

Photo No. A,1. - 10 mms disc.-Velocity:20.7 cms/sec.
Reynolds number = 156

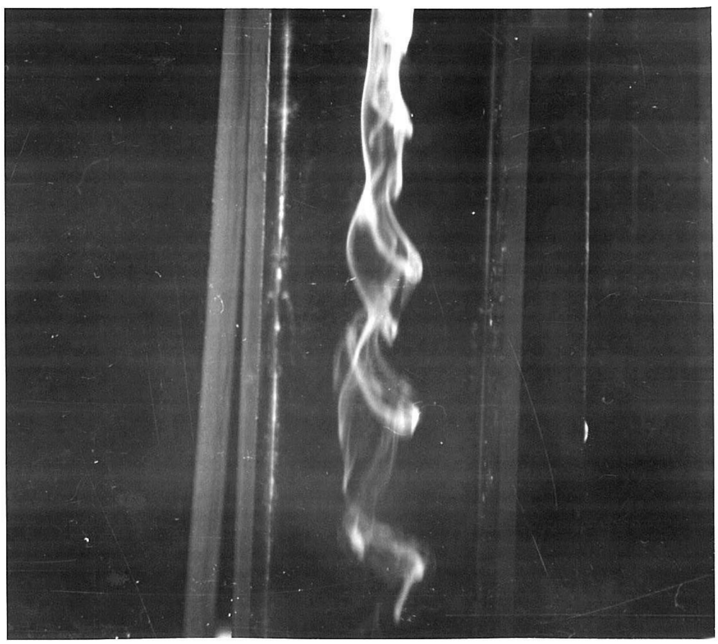


Photo No.A,3.-10 mms disc.-Velocity:22.4 cms/sec.
Reynolds number = 169

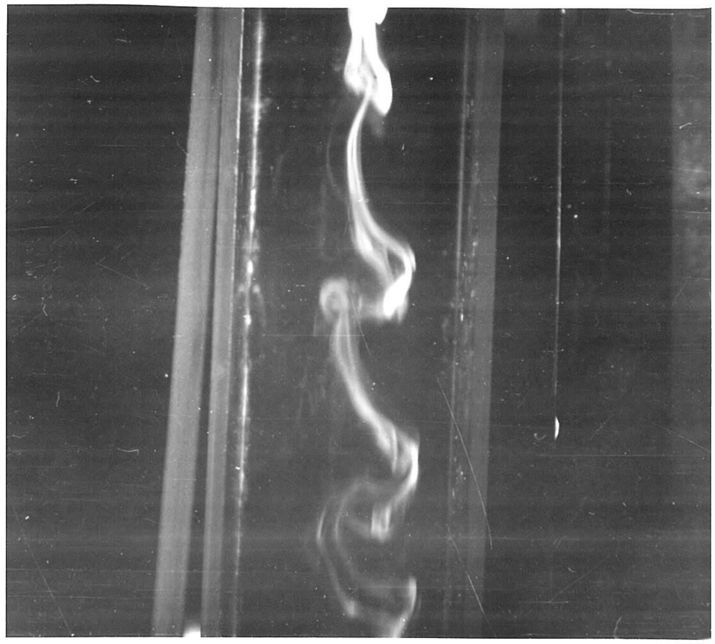


Photo No. A,4. - IO mms disc.-Velocity:22.2 cms/sec.
Reynolds number = 167

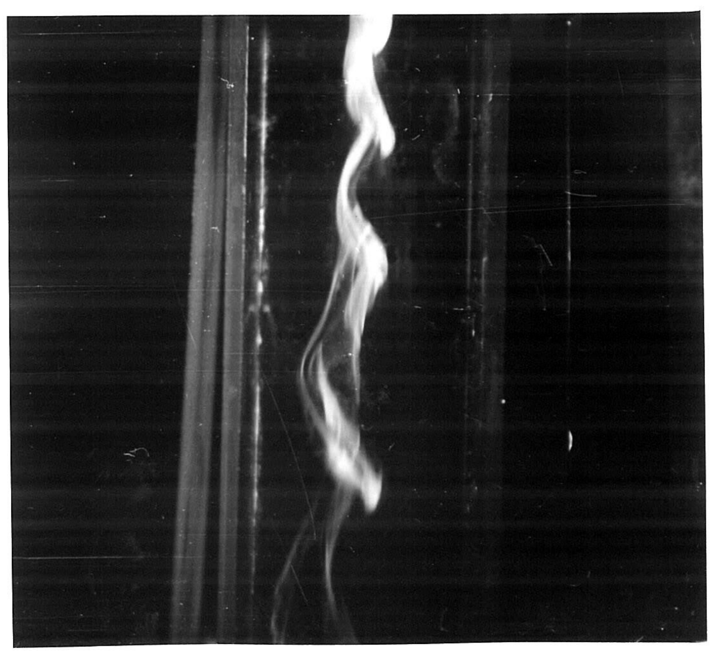


Photo No. A,7. - IO mms disc.-Velocity:22.6 cms/sec.
Reynolds number = 170

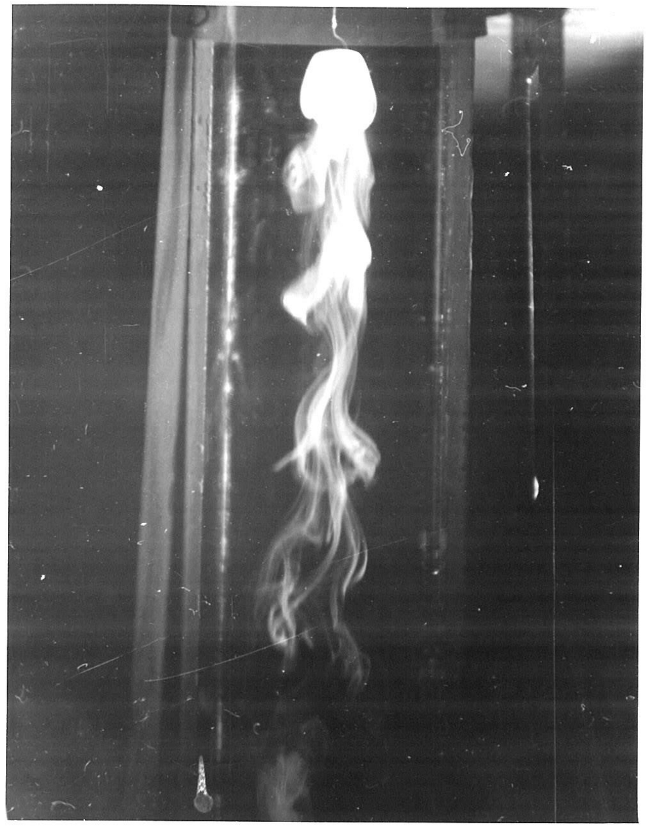


Photo No. B,4. - 15 mms disc.-Velocity:20.4 cms/sec.
Reynolds number: 230

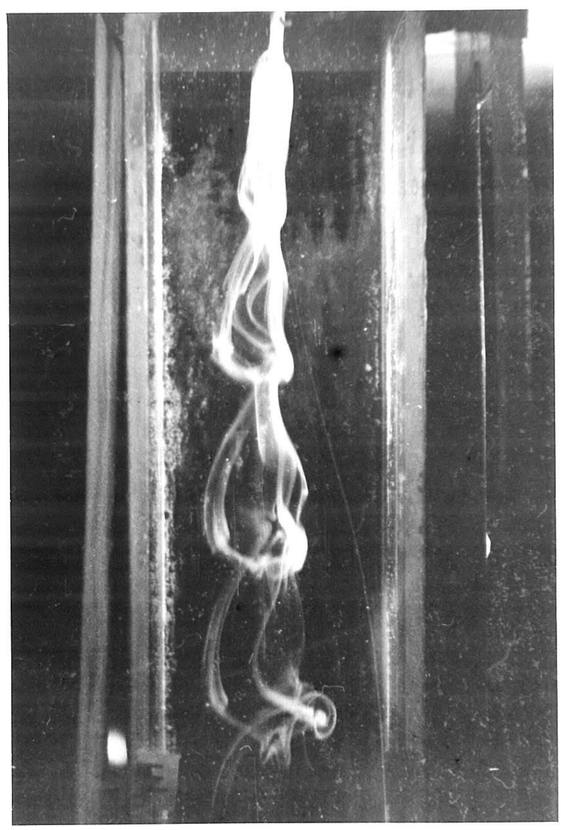


Photo No. E,4. - 7.5 mms disc.-Velocity:32.2 cms/sec.
Reynolds number = 182

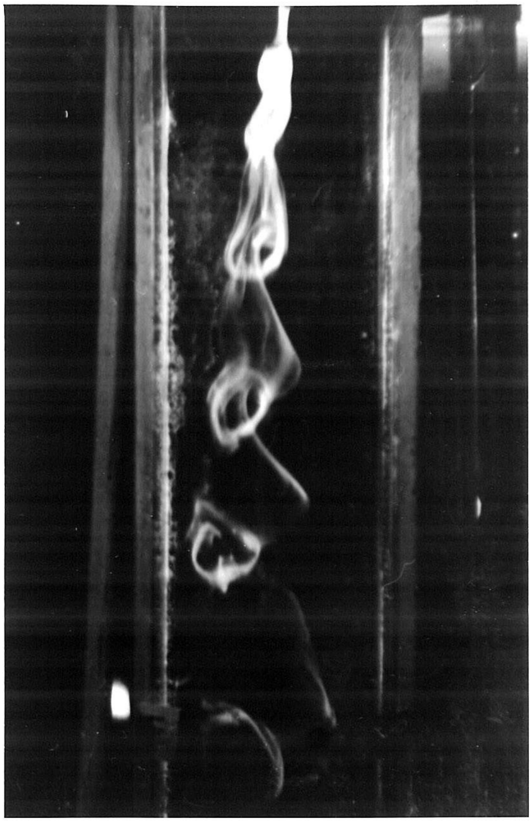


Photo No. E,4. - 7.5 mms disc.-Velocity:27.8 cms/sec.
Reynolds number = 157

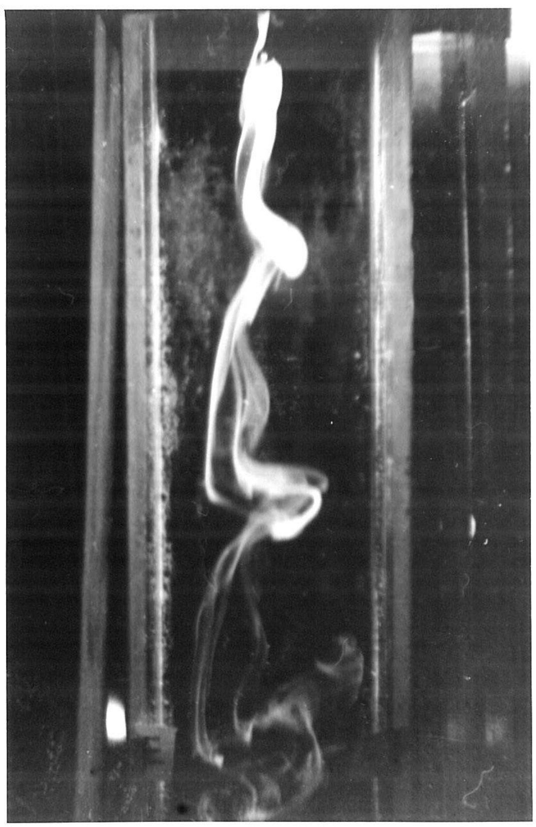


Photo No. E,4. - 7.5 mms disc.-Velocity:32.2 cms/sec.
Reynolds number = 182

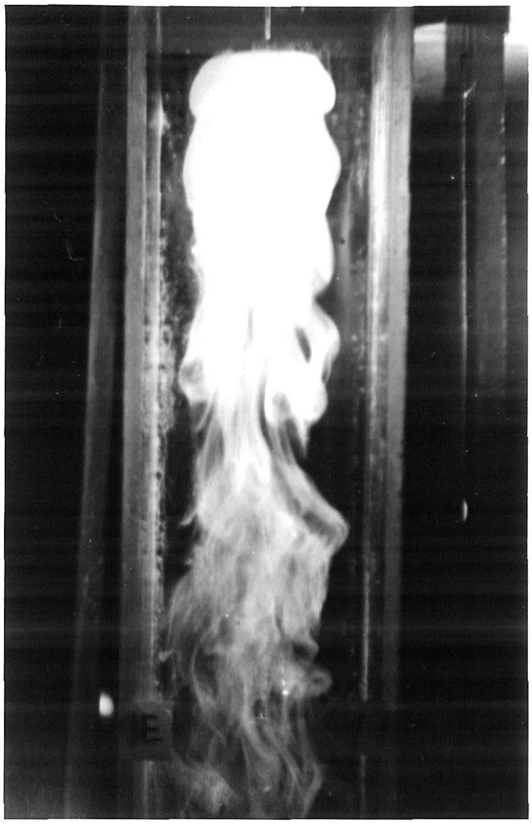


Photo No. D,0. - 35 mms disc.-Velocity:24.2 cms/sec.
Reynolds number = 637

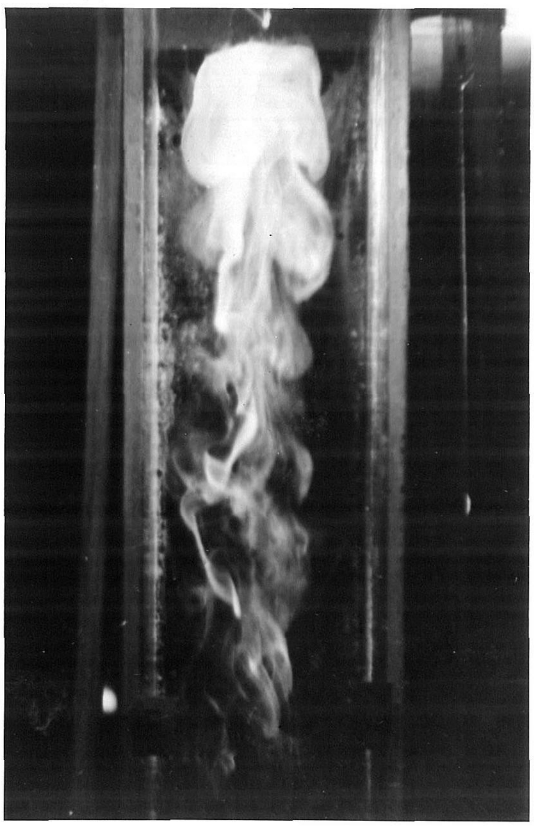


Photo No. E,2. - 35 mms disc.-Velocity:17.2 cms/sec.
Reynolds number = 453

Photo No. A,0. -Two dimensional flow picture.
Rectangular plate,1 cm wide.
Velocity:15.7 cms/sec.Reynolds number=118

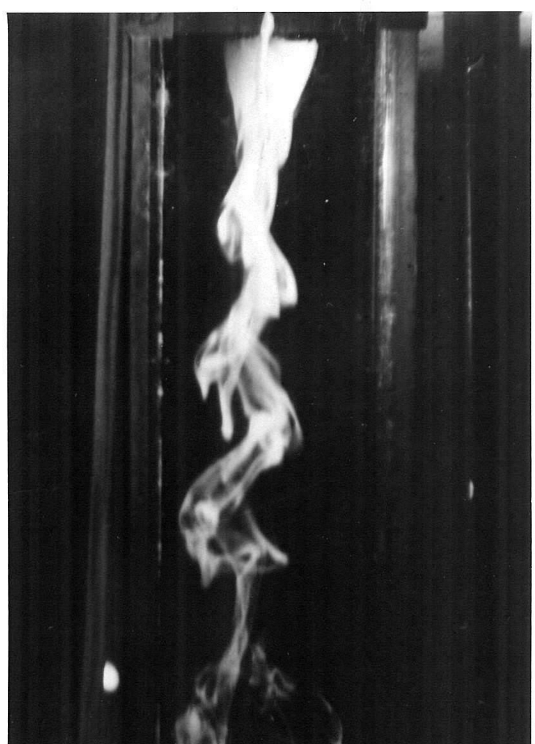


Photo No. D,8. -Elliptic plate(major axis=32 mms;minor axis=4 mms;ratio of the axes = 1/8),looking at it in the direction of the minor axis.Velocity:20.6 cms/sec.R.N.=496

Photo No. D,8. - Elliptic plate(major axis=32 mms;minor axis=4 mms;ratio of the axes=1/8),looking at it in the direction of the minor axis.Velocity:20.6 cms/sec.R.N.=496

Photo No. D,7. - Elliptic plate(major axis=32 mms;minor axis=4 mms;ratio of the axes=1/8),looking at it in the direction of the minor axis.Velocity:27.4 cms/sec.R.N.=660

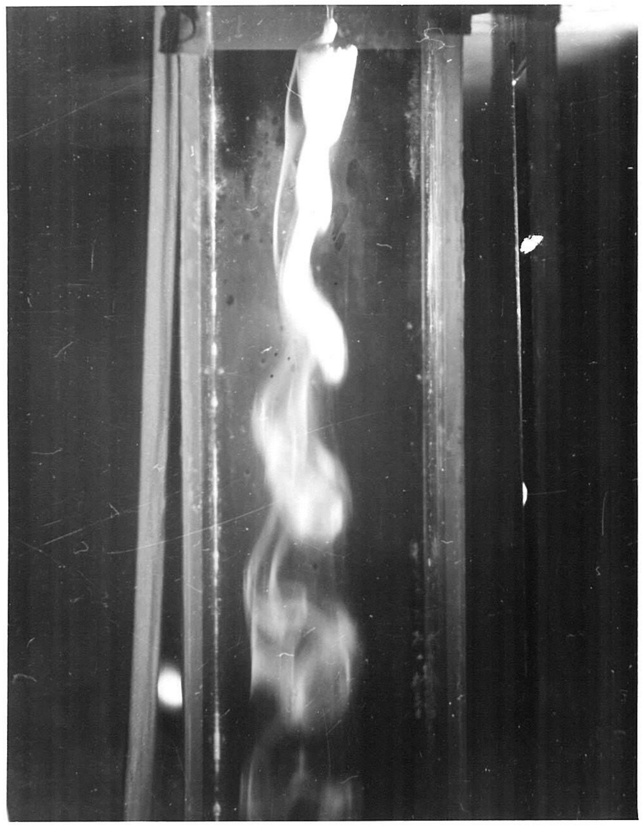


Photo No. D,4. - Elliptic plate(major axis=16 mms;minor axis=4 mms;ratio of the axes=1/4),looking at it in the direction of the minor axis.Velocity:22.1 cms/sec.R.N.=266

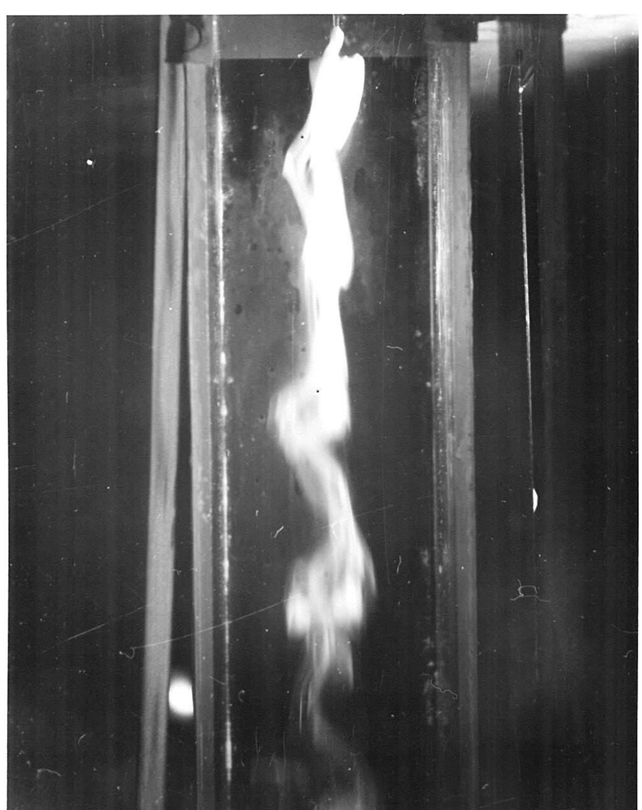


Photo No. D,4. - Elliptic plate(major axis=16 mms;minor axis=4 mms;ratio of the axes=1/4),looking at it in the direction of the minor axis.Velocity:22.1 cms/sec.R.N.=266