DEFINITION OF SEPARATION

Taneda, Sadatoshi
Research Institute for Applied Mechanics, Kyushu University : Professor

https://doi.org/10.5109/6776456

出版情報：Reports of Research Institute for Applied Mechanics. 28 (89), pp.73-81, 1980-12. 九州大学応用力学研究所
バージョン：
権利関係：

Reports of Research Institute for Applied Mechanics
Vol. XXVIII, No. 89, 1980

NOTE

DEFINITION OF SEPARATION

By Sadatoshi TANEDA*

The vanishing of the wall shear is not the appropriate criterion for separation in unsteady flows. I propose the shedding of fluid particles from the wall as the definition of separation.

Key words: Flow visualization, Unsteady flows, Definition of separation

1. Introduction

As was pointed out by Moore[1], by Rott[2], by Sears[3], and by Telionis[4], the Prandtl condition, or the vanishing of the wall shear, is not the appropriate criterion for separation in unsteady flows. It appears that the definition of separation that is meaningful for all kinds of unsteady flows has not been established.

The definition which has a physical meaning should be independent of the reference frame. As for the flow separation, there are two physical quantities which are independent of the reference frame. They are the fluid particle and the vorticity. However, it is impossible to see the vorticity. Therefore, the fluid particle is thought to be the only physical quantity that is meaningful for defining the flow separation.

2. Results and discussion

Figure 1 shows the streamline pattern of the steady flow around a circular cylinder at Reynolds number 26. The flow is made visible by means of the aluminum dust method. As is well known, in the case of two-dimensional steady flow the separation points can be definitely determined using the Prandtl criterion. The Prandtl separation point is the point at which the wall shear vanishes.

Figure 2 shows an example of the streakline pattern. Since the streaklines coincide with the streamlines in steady flows, the streakline separ-

* Professor, Research Institute for Applied Mechanics, Kyushu University.

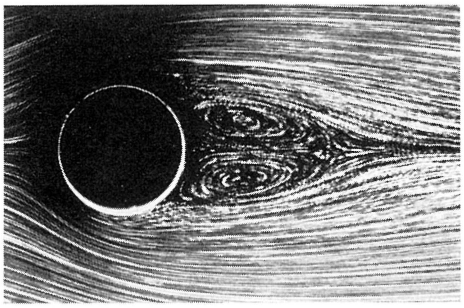


Fig. 1 Streamline pattern in the steady flow past a circular cylinder at R=26 (R is the Reynolds number).

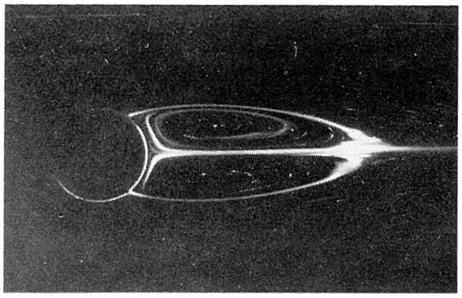


Fig. 2 Streakline pattern in the steady flow past a circular cylinder at R=41.

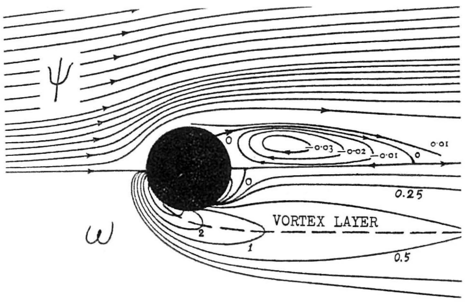


Fig. 3 Streamlines (upper half of figure) and lines of constant vorticity (lower half) at R=40, calculated by Apelt (1961).

ation points coincide with the streamline separation points. In other words, when the flow is steady the point at which fluid particles are shed from the wall coincides with the point of vanishing wall shear.

Figure 3 shows the streamlines and the lines of constant vorticity around a circular cylinder calculated by Apelt[5] using the numerical method. The flow is steady, and the Reynolds number is 40. It may be seen that the vorticity is zero at the separation point, but the separated streamline does not coincide with the line of zero vorticity, and with the vortex layer (the ridge of vorticity).

Figure 4 shows the streamline pattern around two circular cylinders at a very small Reynolds number. The Reynolds number is 0.009, and the flow is steady. At such small Reynolds numbers, no boundary layer is formed on the cylinders. However, as is seen from the photograph, flow separation clearly exists between the two cylinders. This indicates that there is no relation between flow separation and the boundary layer.

Figure 5 shows the flow pattern behind a circular cylinder at Reynolds number 100. The wake is oscillating, and a Karman vortex street is formed. The aluminum dust method and the electrolytic precipitation method[6] are used at the same time for flow visualization. The aluminum dust shows the streamline pattern, and the white dye generated by means of the electrolytic precipitation method shows the integrated streaksheets. The

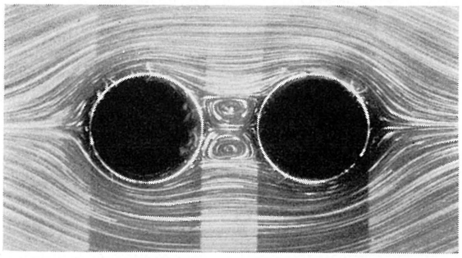


Fig. 4 Streamline pattern around two circlar cylinders at R=0.009.

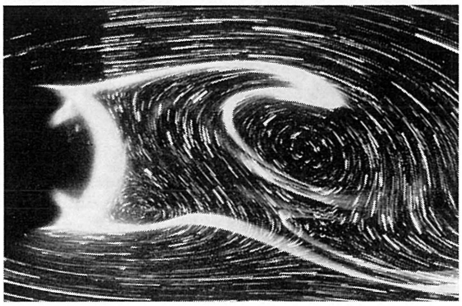
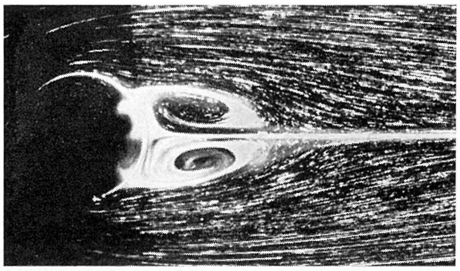


Fig. 5 Streamline and integrated-streakline patterns behind a circular cylinder at R=100.

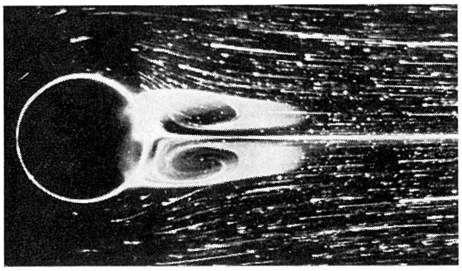
integrated streaksheet is the instantaneous loci of all fluid particles which have been detached from the whole surface of the body. As will be seen from this picture, when the flow is unsteady, the integrated streaksheets do not coincide with the streamlines. The vortex centres and saddle points in the streamline pattern are not located on the integrated streaksheets. This is due to the fact that the streamline pattern depends on the reference frame, while the integrated-streaksheet pattern is invariant.

Figure 6 shows an example of the case when the streamline separation point does not coincide with the integrated-streakline separation point. Figure 6(a) shows the streamlines and the integrated streaklines of the steady flow around a circular cylinder at Reynolds number 21.5. As may be seen from this photograph, when the flow is steady the streamline pattern and the integrated-streakline pattern are identical. Just after the cylinder has been accelerated, however, the streamline separation points disappear, while the integrated-streakline separation points remain unchanged (see Figure 6(b)). This clearly shows that the streamline separation points do not coincide with the integrated-streakline separation points.

Figure 7 shows the relation between the streamline pattern and the



(a)



(b)

Fig. 6 Stremline and integrated-streakline patterns around a circular cylinder accelerated abruptly.
(a) before acceleration (steady flow, R=21.5),
(b) after acceleration (unsteady flow, R=149).

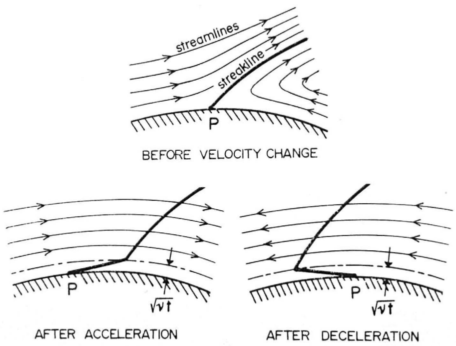


Fig. 7 Relation between streamlines and integrated-streakline in the case of abrupt velocity change.

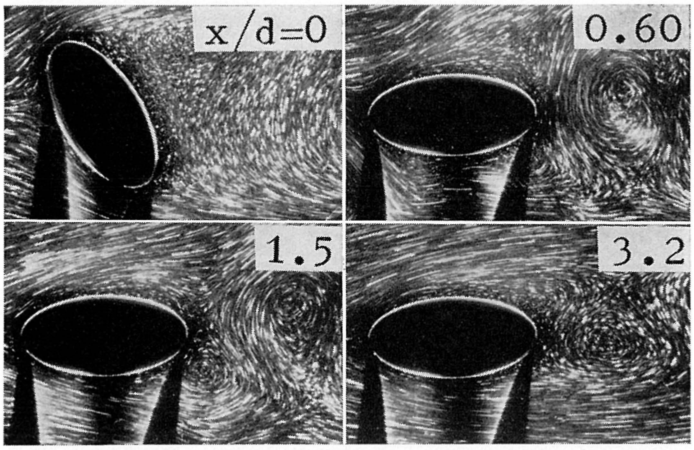


Fig. 8 Streamlines around a 2:1 elliptic cylinder whose angle of incidence has been abruptly decreased from 60° to 0°.

streakline pattern in the case when the fluid velocity has been increased or decreased abruptly[7]. As is well known, at small times after the velocity change, the flow consists of the superposition of the primary velocity field and the irrotational velocity field. Therefore, outside the very thin secondary boundary layer, the primary streakline is shifted downstream or upstream by the irrotational flow. Since the secondary boundary layer is very thin at small times, it is very difficult to determine the integrated-streakline separation point.

The following pictures show some examples of streamline patterns and the corresponding integrated-streakline patterns of unsteady flows. Figure 8 shows the streamline patterns around a 2:1 elliptic cylinder after the angle of incidence has been abruptly decreased from 60° to 0°. The Reynolds number is 152, and the axis of rotation is at the centre of the elliptic cylinder. Figure 9 is the corresponding integrated-streakline patterns. It is seen that the white dye is shed from many points on the surface of the cylinder just after the angle of incidence has been changed, and that it is very difficult to determine the integrated-streakline separation points.

Figure 10 shows the streamline patterns around a 2:1 elliptic cylinder

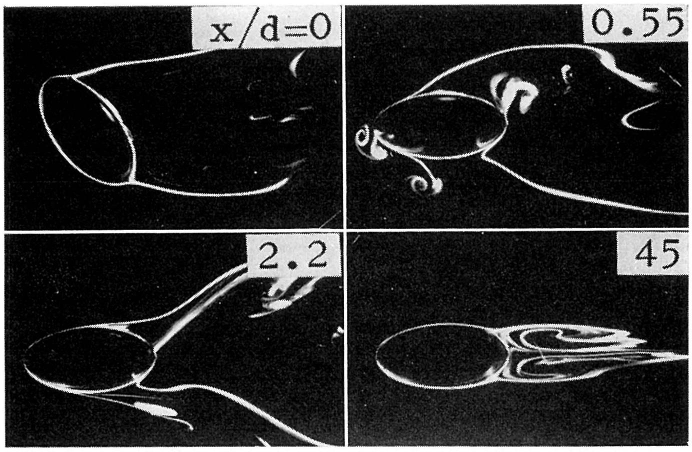


Fig. 9 Corresponding integrated-streaklins.

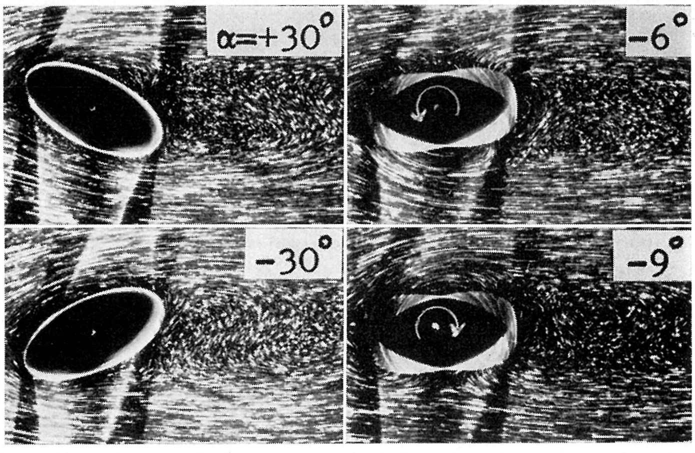


Fig. 10 Streamlines around a 2:1 elliptic cylinder performing a rotatory oscillation about its centre at R=138 and Strouhal number 0.99.

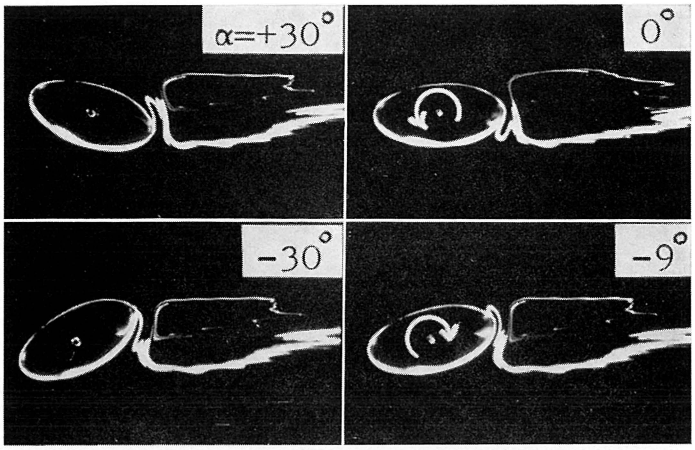


Fig. 11 Corresponding integrated-streaklines.

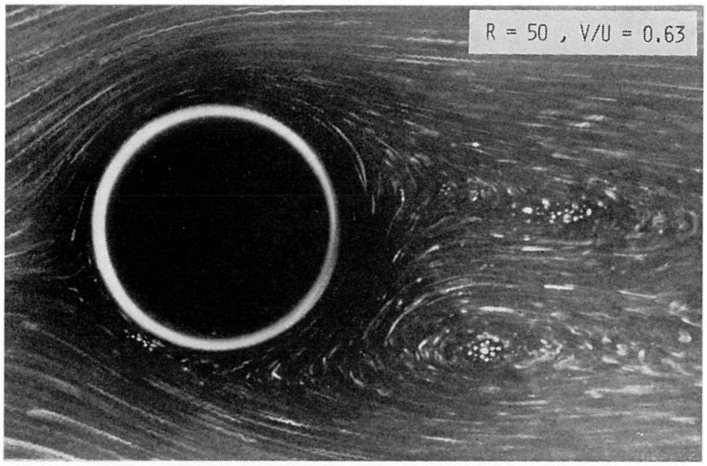


Fig. 12 Streamlines around a circular cylinder which is rotating about its axis in a uniform flow at $R=50$ and $V/U=0.63$.

performing a rotatory oscillation about its centre in a uniform flow. The Reynolds number is 138, the Strouhal number is 0.99, and the angular amplitude is 30°. We can see a large dead water region behind the cylinder.

Figure 11 is the corresponding inintegrated-streakline patterns. What is interesting is that the dye is shed only from one point on the surface, and an isolated permanent dead-water region is formed some distance downstream.

Figure 12 shows the streamline pattern in the flow past a circular cylinder

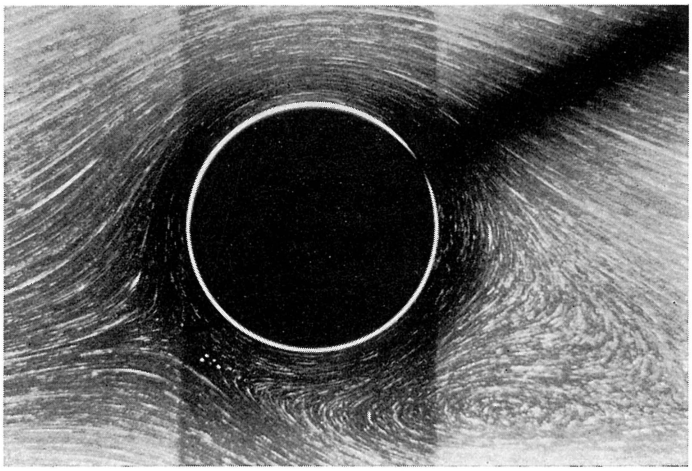


Fig. 13 Streamlines at R=68 and V/U=2.1.

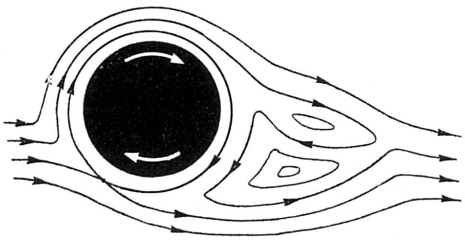


Fig. 14 Sketch of the streamlines.

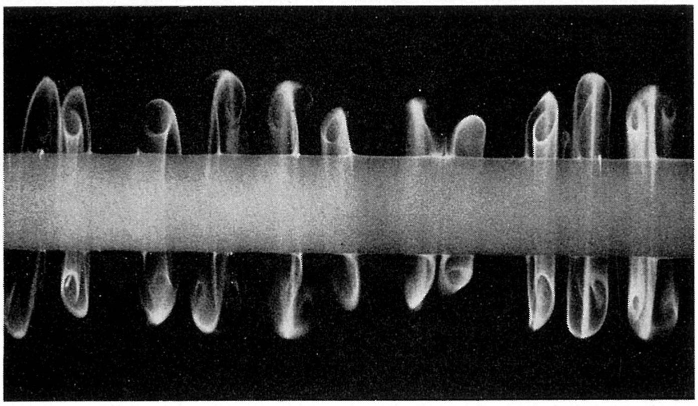


Fig. 15 Integrated-streaksheets around a circular cylinder which is rotating about its axis in still water. The diameter of the cylinder is 1 cm and the angular velocity 1 rps. The photograph was taken 6s after the start.

which is rotating in a uniform flow. The Reynolds number is 50, and V/U equals 0.63, where V is the circumferential velocity and U the velocity of the undisturbed flow. It should be noted here that in this reference frame the flow is steady, but the surface is moving. As will be seen, there is no stagnation point on the surface, and there exists only one saddle point near the surface. Figure 13 shows the streamline pattern at Reynolds number 68 and $V/U=2.1$. It will be seen that the distance between the saddle point and the surface of the cylinder increases as the circumferential velocity is increased. The sketch shown in Fig. 14 illustrates that at least as far as the flow is two-dimensional the integrated-streakline separation point does not exist.

Figure 15 shows the integrated streaksheets around a circular cylinder which has been impulsively started to rotate in still water. The integrated streaksheets are shed from many lines spaced regularly on the surface of the cylinder, and form a series of ring-shaped vortices. This photograph indicates that the flow around a rotating circular cylinder can separate only three-dimensionally.

3. Conclusions

(1) The shedding of fluid particles from the wall is the meaningful definition of separation for all kinds of flows.

(2) The new definition coincides with the Prandtl criterion in the case of steady two-dimensional flow over a fixed wall.

(3) The flow separation can be detected only by observing the integrated streaksheet.

(4) When the flow is highly unsteady, it is very difficult to determine the separation point.

Acknowledgements

I would like to express my sincere thanks to Mr. H. Amamoto, Mr. K. Ishi-i and Mrs. K. Ishimura for their much help.

This work was supported by the Grant-in-Aid for Scientific Research from the Ministry of Education, Science and Culture.

References

1) Moore, F.K.: *Boundary Layer Research*, ed. Görtler (Springer, 1958) 296.
2) Rott, N.: Quarterly J. Appl. Math. **13** (1956) 441.
3) Sears, W.R.: J. Aeronautical Sciences **23** (1956) 490.
4) Telionis, D.P.: J. Fluids Engineering **101** (1979) 29.
5) Apelt, C.J.: A.R.C. Rep. Mem. No. 3175 (1961).
6) Taneda, S., Honji, H. and Tatsuno, M.: International Symposium on Flow Visualization, Tokyo (1977) 133.
7) Taneda, S.: Progress in Aerospace Sciences **17** (1977) 287.

(Received September 26, 1980)