Journal of Applied Mechanics and Technical Physics, Vol. 35, No. 1, 1994

TWO FORMS OF LIQUID SEPARATION FROM A SMOOTH SURFACE

S. K. Betyaev, A. M. Gaifullin, and S. V. Gordeev

UDC 532.527

Experimental studies indicate that separation formations exist in a diversity of forms [1]. Even in the case of a flow past bodies of uncomplicated configuration the structure of the separation formation has not yet been studied sufficiently and so a priori systems of separating flow must be used in numerical calculations. The experimental study of this problem, therefore, is applied as well as cognitive importance.

In a water tunnel with a throat measuring 150 × 150 mm we studied the flow past a model consisting of two plates, connected so that the plane passing through the trailing edge of the first plate and the leading edge of the second was perpendicular to plane of the first (Fig. 1). The plates were separated by a gap. The first plate, set up along the flow, was flat and the second was curved along a circular arc. The leading edge of the second plate was profiled to eliminate breakaways. Drainage tubes with a dye to visualize the flow were connected to the trailing edge of the first plate and the leading edge of the second. The second plate was 85 mm long and its radius of curvature was 55 mm.

Our aim here is to study the interaction of the boundary layers formed on the two plates. A typical pattern of this interaction is shown in Fig. 2. This interaction evidently should model the flow in the vicinity of the gap between a wing and a flap. The flow past such a configuration in a particular range of Reynolds numbers Re leads to an isolated separation [2].

The flow has two characteristic scales: l is the length of the first plate, which was 100 mm in the given case, and $h \ll l$ is the distance between the plates. The entire region of flow can thus be divided into two subregions: an external subregion associated with the total flow past the model and an internal subregion associated with the flow around the gap.

The flow in the external region has a characteristic Reynolds number of the order of 10^3. A Blasius boundary layer forms on the front plate and its thickness δ varies with the distance from the leading edge x by the law [3]

$$\delta(x) \approx 5\sqrt{\frac{\nu x}{u_\infty}}, \tag{1}$$

where u_∞ is the velocity of the mainstream: ν is the kinematic viscosity coefficient.

In the wake of the first plate this boundary layer enters the region of unfavorable pressure gradient and, furthermore, interacts with the boundary layer formed on the second plate.

The flow in the internal region has a characteristic Reynolds number Re_1 that is substantially different from Re. Let us determine in. Since a fairly thick boundary layer forms at the end of the first plate, we can assume that the flow reaches the second plate with an almost linear velocity distribution along the height. For such a flow

$$Re_1 = \frac{h^2\, \partial u/\partial y}{\nu} \tag{2}$$

(y is the coordinate along the normal to the first plate).

The linearity of the velocity profile implies that

$$\frac{\partial u}{\partial y} \sim \frac{u_\infty}{\delta(l)}. \tag{3}$$

Zhukovskii. Translated from Prikladnaya Mekhanika i Tekhnicheskaya Fizika, No. 1, pp. 66-68, January-February, 1994. Original article submitted March 25, 1993.

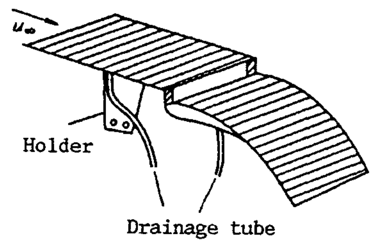

Fig. 1

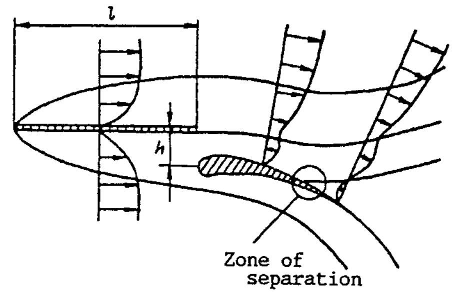

Fig. 2

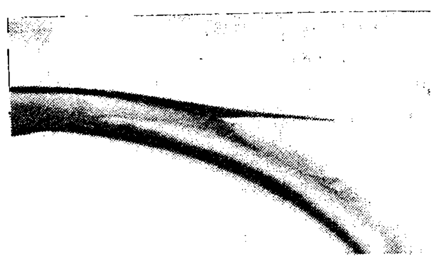

Fig. 3

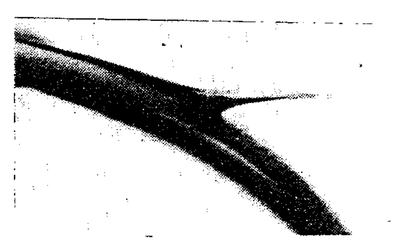

Fig. 4

Equations (1)-(3) give the relation between Re_1 and Re:

$$Re_1 \sim \frac{1}{5}\left(\frac{h}{l}\right)^2 Re^{3/2}.$$

Let us evaluate Re_1. For example, for h = 3 mm and Re = 10^3 we get Re_1 = 5.7. Each of the two regions, therefore, is characterized by substantially different Reynolds numbers.

In the region of unfavorable pressure gradient for Re $\gtrsim 10^3$ the boundary layer on the second plate separates. It has been determined experimentally that the geometry of the flow in the vicinity of the point of separation is different and depends on Re and Re_1. The following flow regimes exist in the Re, h/l parametric plane: 1) Re $\lesssim 10^3$ — attached flow, 2) $10^3 \lesssim$ Re $\lesssim 3\cdot10^3$, $h/l \lesssim 0.025$, and $h/l \gtrsim 0.05$ — ordinary separation, 3) $10^3 \lesssim$ Re $\lesssim 3\cdot10^3$, $0.025 \lesssim h/l \lesssim 0.05$ — λ separation, and 4) Re $\gtrsim 3\cdot10^3$ — turbulent flow. Regime 2 (Fig. 3) has one point of separation and regime 3 (Fig. 4) has two points of separation (A and B Fig. 5). A stagnation zone, in which the velocity of the liquid is low in comparison with that outside the region. The size of the gap corresponding to the given range of Re_1 values is such that the most retarded part of the boundary layer, meeting the trailing edge of the first plate, separates from the surface of the first plate. Since the point of separation is not known in advance, no device was provided for feeding dye into the stagnation zone. The dye was fed into the stagnation zone by means of specially organized unsteady perturbations, attack-angle oscillations. A steady state was established some time after the oscillations ceased.

For $h/l \lesssim 0.025$ the gap has only a slight effect and ordinary separation of the boundary layer from the surface of the second plate is observed. For $h/l \gtrsim 0.05$ the gap becomes fairly large and the outer part of the boundary layer, meeting the first plate, comes to the second plate; ordinary separation of the boundary layer is also observed here.

The boundary layer can thus also separate from a smooth surface, at least in two ways: an ordinary separation and a λ separation (λ separation was observed earlier in [4, 5], but there it was generated by the interaction of the boundary layer with an external viscous flow). In this experiment it arose as a result of the interaction of two boundary layers.

Isolated separation was not detected in the range of Re values studied.

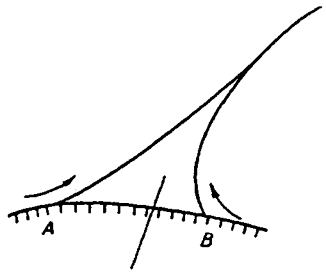

Fig. 5

REFERENCES

1. M. Van Dyke, An Album of Fluid Motion. The Parabolic Press, Stanford, CA (1982).
2. A. V. Petrov, "Some types of separating flow past slotted airfoils," Uchen. Zap. TsAGI, **8**, No. 2 (1977).
3. H. Schlichting, Boundary Layer Theory, 7th edn., McGraw-Hill, New York (1979).
4. D. I. Pullin and A. E. Perry, "Some flow visualization experiments on starting vortex," J. Fluid. Mech., **97**, Part 2 (1980).
5. V. H. Arakeri, "Viscous effect on the position of cavitation separation from smooth bodies," J. Fluid. Mech., **68**, Part 4 (1975).