Trapping of a Free Vortex by Airfoils with Surface Suction

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Abstract

A FREE vortex may be captured by an airfoil for lift augmentation, but the vortex is unstable to small disturbances at most of its equilibrium positions, except at those in a narrow region above the trailing edge. It is found in the present work that additional stable vortex positions can be created by applying suction through the upper surface of the airfoil. By using the method of surface suction, strong vortices may become stably trapped above the airfoil for generating lift forces that are much higher than that of the original airfoil.

Contents

It has been found in a previous paper[1] that a free vortex may be captured by an airfoil for lift augmentation. However, except in a narrow region above the trailing edge, the captured vortex is unstable in the sense that it will move away from its equilibrium position after being slightly disturbed. In an attempt to stabilize the vortex for more effective utilization of the vortex lift, the present work investigated the effect of upper surface suction on the vortex-trapping ability of a symmetric airfoil.

The airfoil shape is generated by mapping from a circle through a Joukowski transformation. The flow caused by surface suction is simulated by that of a point sink of dimensionless strength $-m$ on the airfoil surface, which is obtained by transformation of a sink of strength $-2m$ placed on the circumference of the circle. The resultant flow is maintained to be still tangent to the circle by adding a source of strength m at the center of the circle and another source of the same strength at infinity. The complex potential of the inviscid and incompressible flow past such an airfoil, in the presence of a vortex of dimensionless strength κ, can be written out by adding the contributions of the sources and sink to the complex potential derived in Ref. 1.

The flowfield analysis in Ref. 2 shows that the lift and drag coefficients of the airfoil are given respectively by

$$C_\ell = \Gamma + \kappa \quad \text{and} \quad C_d = m$$

in which the dimensionless circulation Γ around the airfoil increases with the sink strength for given values of κ and angle of attack α. Thus, the surface suction itself can cause a gain in lift, but at the cost of an increased drag.

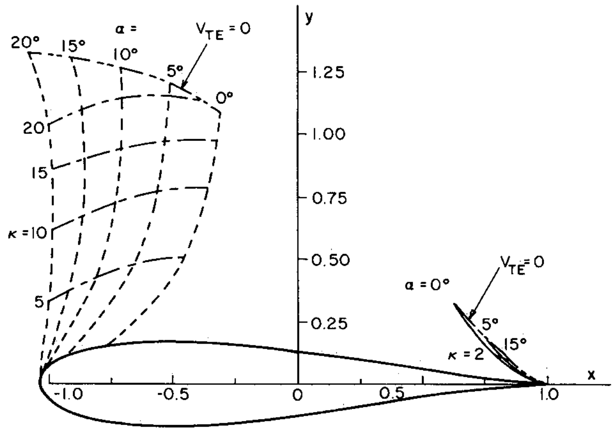

Fig. 1 Equilibrium positions of free vortex captured above a 17% symmetric Joukowski airfoil without surface suction. In this and the following figures, solid and dashed lines are used to denote stable and unstable conditions, respectively.

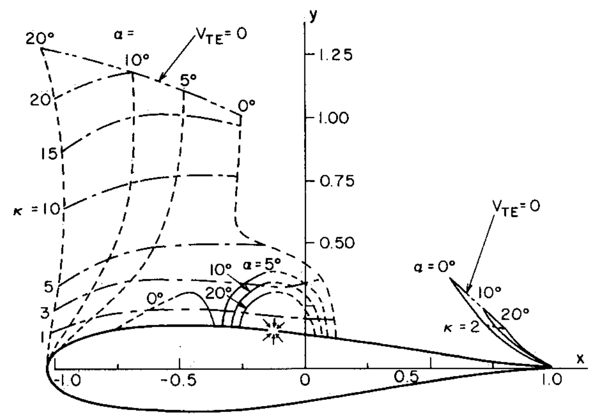

Fig. 2 Equilibrium positions of free vortex for a weak sink with $m=0.05$ placed at a midchord position.

The application of surface suction is found to have a significant influence on the vortex-trapping behavior of the airfoil. To serve as the basis of comparison, the equilibrium positions of trapped vortices in the neighborhood of a 17% thick airfoil are plotted in Fig. 1 for $m=0$. With solid lines representing stable positions, the plot reveals a special feature that in the absence of surface suction, only relatively weak vortices can be trapped stably in a narrow region above the trailing edge. When a weak suction with $m=0.05$ is placed at the 44.4% chord position, new stable vortex positions are created upstream of the suction port, as shown in Fig. 2, and stronger vortices can be captured there. Similar behavior is found when the sink is moved to either the 25% chord or the 77.7% chord position; however, in the latter case, the originally stable positions near the trailing edge all become unstable. When the sink strength is increased to $m=0.2$, stronger vortices may become trapped in an expanded region ahead of the sink,

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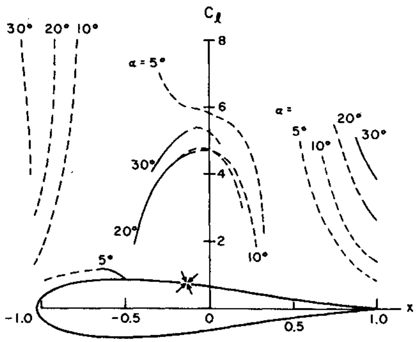

Fig. 3 Airfoil lift coefficient as functions of coordinate of the trapped vortex, for a stronger sink with $m = 0.2$ placed at a midchord position.

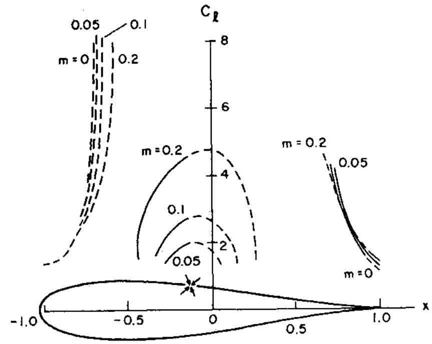

Fig. 5 Variation of airfoil lift coefficient with increasing strength m of a sink placed at the 44.4% chord position.

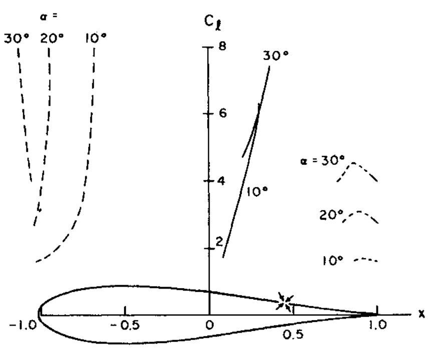

Fig. 4 Airfoil lift coefficient as functions of x coordinate of the trapped vortex, after the sink in Fig. 3 is moved to a trailing-edge position.

while the stable region above the trailing edge shrinks or even disappears when the sink is placed near that region.

The lift of the airfoil increases when a vortex is trapped at its equilibrium position. For a sink with $m = 0.2$ at the 44.4% chord position, the airfoil lift coefficient is plotted in Fig. 3 as functions of the x coordinate of the trapped vortex for various constant angles of attack. The solid lines indicate that, with the application of this surface suction, lift coefficients of magnitudes around five can be achieved by capturing stable vortices. The highest lift coefficient can be pushed further to nearly 8 by moving the sink to the 77.7% chord position, as shown in Fig. 4.

The effect of increasing suction strength m on the lift coefficient of the airfoil is depicted in Fig. 5, plotted for $\alpha = 10$ deg and for a fixed midchord suction position. Generation of tremendous lift forces is possible by capturing strong vortices with the application of a strong surface suction. The vortex trapping ability of the airfoil can be highly improved by shifting the suction port toward the trailing edge.

Acknowledgment

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References

[1]Huang, M.-K. and Chow, C.-Y., "Trapping of a Free Vortex by Joukowski Airfoils," *AIAA Journal*, Vol. 20, March 1982, pp. 292-298.

[2]Chow, C.-Y., Chen, C.-L., and Huang, M.-K., "Trapping of Free Vortex by Airfoils with Surface Suction," AIAA Paper 85-0446, Jan. 1985.