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Wake behind a Sphere Moving in an Electrolyte in the Presence of an Aligned Electric Current

CHUEN-YEN CHOW*
University of Colorado, Boulder, Colo.
AND
RANDOLPH D. BRUNELL†
University of Notre Dame, Notre Dame, Ind.

EXPERIMENTAL results show that the size of the wake behind a copper sphere, moving steadily in an electrolyte, can be reduced significantly by passing an electric current through the fluid in a direction parallel to the body motion. The phenomenon may suggest a method using an aligned electric current to reduce the drag of a body moving in an electrolytic fluid like sea water.

The experiments were performed in an open channel 1.78 m long, 20 cm high, and 15 cm wide made of transparent Plexiglas plates. Above the channel a motor-driven cart could move at controlled speeds on rails aligned with the channel length. An *L*-shaped Plexiglas arm was screwed under the cart in such a way that the cantilever could move close and parallel to the bottom of the channel with the tip in the forward direction. At the end of the cantilever, a rigid plastic sting was installed vertically upward, on top of which a copper sphere of 2.5 cm diam was glued. A downward facing camera was mounted on the cart with the lens right above the sphere. During the experiments the channel was filled with aqueous solution of copper sulfate of specific weight 1.14 to a height of 15 cm, so that the sphere was immersed completely in the liquid. The sphere was situated away from the channel walls and far upstream of the vertical portion of the arm, and the supporting sting was thin compared with the sphere diameter. Under these conditions interferences were assumed negligible. Our arrangement differs from that of Taneda[1] for experiments without an electric field in that his supporting sting was above the sphere and, therefore, was seen by the camera. Furthermore, instead of using milk to show flow patterns, we used fine aluminum powder suspended uniformly in the fluid.

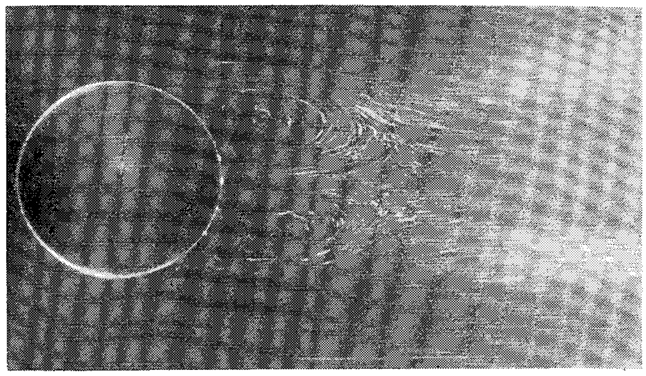

Fig. 1 Flow pattern around a copper sphere 2.5 cm in diameter traveling steadily at 1 cm/sec from right to left, with camera moving with the sphere. There is no current in the fluid.

A d.c. generator supplied electric current in the fluid through two rectangular copper plates placed vertically at the ends of the channel. The horizontal plane passing through the center of the sphere was lighted by concentrated light sources through thin slits on both sides, and the flow patterns described by aluminum particles on the lighted plane were recorded by time lapse photography.

Figure 1 shows the flow around a copper sphere moving steadily at 1 cm/sec without any current in the fluid. As a current of 15 amp was passed along the channel while keeping the same body speed, the size of the separated flow region was significantly reduced as shown in Fig. 2. Pressure is low within the reverse-flow region, thus a form drag results. As the separation point moves rearward, the skin friction must increase, but the reduction in form drag associated with the smaller wake overshadows this contribution.[2] It can be expected that the total drag of the conducting sphere is reduced after the passage of a current through the fluid. When the current was increased to 25 amp, Fig. 3 shows the separated region behind the sphere was further reduced. An interchange of the polarities of electrodes did not seem to alter the flow pattern. Further increase in current caused violent bubbling at the anode and turbulencelike fluid motions were observed throughout the channel, photo-

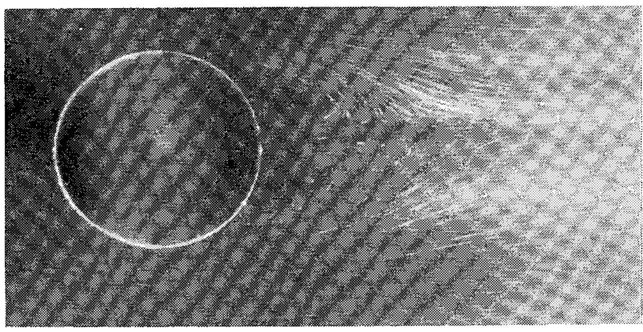

Fig. 2 Flow pattern around the sphere at the same speed with an aligned current of density 0.067 amp/cm² in the fluid far from the body.

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* Associate Professor, Department of Aerospace Engineering Sciences. Member AIAA.

† Graduate Student, Department of Aerospace and Mechanical Engineering; NASA Trainee. Student Member AIAA.

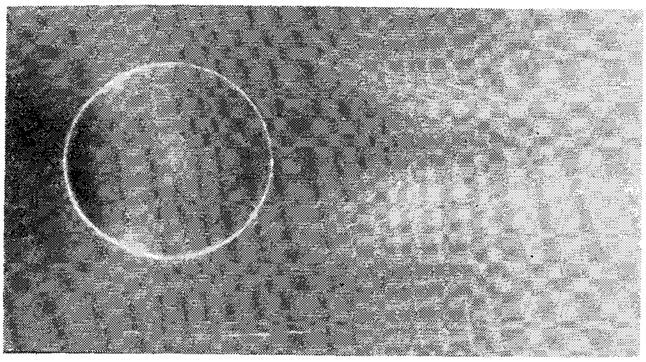

Fig. 3 Flow pattern around the sphere at the same speed when current density is increased to 0.111 amp/cm².

graphs taken under these conditions were not satisfactory. The maximum amount of current which could be passed through the fluid was limited by the kind of electrolytic liquid chosen for the experiment.

Working with a rubber sphere, however, we found that there was no appreciable change in the flow pattern after currents of various amount were passed through the liquid. Because of the limitation of equipment on hand, direct measurement of total drag was not attempted.

It was found analytically that an aligned electric current decreases the drag of a sphere moving in a fluid which is less conducting than the sphere, and increases the drag if the fluid is more conducting, based on a purely hydromagnetic formulation.[3]

The effect of electromagnetic force on flowfield is characterized by the magnetic pressure number R_h. It is the ratio of the magnetic pressure $\mu_e J_o{}^2 a^2/2$ over the dynamic pressure $\rho U_o{}^2/2$, where ρ and μ_e are the density and the magnetic permeability of the fluid, a and U_o are the radius and the velocity of the sphere, and J_o is the uniform current density far from the body. Corresponding to the experimental conditions in Fig. 3 the calculated magnetic pressure number is 0.002, which gives only a negligibly small effect on the flow according to that theory, although the result in the laboratory for a copper sphere agrees qualitatively with what was predicted. It was shown in that theoretical work that appreciable effect appears in the flow if R_h is of the order of 10^{-1}, which is two orders higher than our experimental value.

From these findings it appears that the large change in the wake is not caused by the electromagnetic force $\mathbf{J} \times \mathbf{B}$, and that some other important factors must be included in the analysis when an electrolyte is used as the conducting fluid. One of them could be the electrochemical reactions discussed by Levich,[4] which takes place in a thin diffusion boundary layer along the surface of a conducting body when it moves in a current-carrying electrolytic fluid. This view is supported by the fact that the current which can change the flow around a copper sphere apparently does not affect that around a rubber sphere, at whose surface electrochemical reactions do not occur. The reactions may change the current distribution or may effectively alter the viscosity coefficient of the electrolyte. Exactly how these electrochemical reactions influence the flowfield is not yet clear, and the observed phenomenon still requires an appropriate explanation.

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Measurements of Local Skin Friction Downstream of Grit-Type Boundary-Layer-Transition Trips at $M = 2.17$ and Zero Heat Transfer

James C. Daugherty* and Raymond M. Hicks*
NASA Ames Research Center, Moffett Field, Calif.

Introduction

WIDE use has been made of grit-type boundary-layer transition trips during small-scale-model wind-tunnel drag-evaluation tests to artificially promote boundary-layer transition from laminar to turbulent flow near the leading edges of various model components. Reference 1 shows that for supersonic Mach numbers the minimum grit size required to artificially fix transition near the trip is large relative to the boundary-layer thickness; a grit with diameter approaching the boundary-layer thickness is the minimum requirement at a Mach number of 3, while a grit diameter twice the boundary-layer thickness is indicated for a Mach number of 4. It is pointed out in Ref. 2 that the use of relatively large-sized ("over three times as high as the boundary-layer thickness") grit-type transition trips can either decrease or increase the local skin friction downstream of the trip. The present authors are unaware of any studies of local skin friction behind relatively large-sized grit-type-transition trips which would explicitly justify their use to promote boundary-layer transition. The data presented herein are an initial effort by the authors to validate the use of grit-type boundary-layer transition trips and to determine limitations and interpretive procedures applicable to the technique. Although these data are very preliminary, it is felt that the results will be of interest to researchers conducting wind-tunnel drag evaluations on small-scale aircraft configurations.

Skin-Friction Measurements

Presented herein for various unit Reynolds numbers (R/x, per in.) are local skin-friction coefficients, c_f, measured downstream of several sizes of grit-type boundary-layer-transition trips on a flat plate with zero heat transfer. The measurements were made in the Ames 1- by 3-ft. Supersonic Wind Tunnel at a freestream Mach number of 2.17. The plate had a sharp leading edge and was mounted in the wind tunnel with nominal values of zero sweep and zero incidence. The friction coefficients were determined from direct measurements of local shear forces on a floating element balance manufactured by the Kistler Instrument Corporation. The 0.500-in.-diam floating element of the balance was located 5.875 in. behind the leading edge of the plate and was centered by means of a self-nulling circuit for each measurement. In conformance with manufacturer's specifications, no cooling of the balance jacket was required since tunnel total temperature did not exceed 100°F. Grit-type transition trips were formed by $\frac{1}{8}$-in. wide bands of randomly distributed grit of a specified size located $\frac{1}{4}$ in. behind the leading edge of the plate. Grits were sieved for uniformity and accuracy in sizing. In addition to the grit trips, a trip consisting of 0.0146-in.-high triangular-shaped roughness particles cut from adhesive tape (discussed in Ref. 2) was also tested.

Results and Discussion

The results of these tests, including measurements made with natural transition, are presented in Fig. 1. To aid in interpreting the data, the figure also includes values of skin

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* Research Scientist. Member AIAA.