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A DRY-SURFACE COATING METHOD

FOR VISUALIZATION OF SEPARATION

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A DRY-SURFACE COATING METHOD FOR VISUALIZATION OF SEPARATION

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A simple and reasonably accurate dry-surface coating method for the visualization of the separation line on a bluff body is described. This method is not restricted to any particular Reynolds-number range and it supplies a clear permanent record of good photographic quality. Examination of this technique in visualizing the separation angle on a circular cylinder indicated that it is accurate within about ±4 percent.

Introduction

An indispensable aspect of any investigation of flow about a bluff body is the visualization of the separation since it supplies an immediate physical insight into the overall flow structure. Methods of visualization of the separation on a bluff body are useful when they: (1) apply over a wide range of Reynolds numbers and for incident laminar and/or turbulent streams; (2) produce an accurate trace of the separation line within a reasonable time period; and, (3) generate a permanent record available after the removal of the oncoming flow.

The most common methods used at the present time to visualize the separation line on a bluff body placed in a wind-tunnel airflow involve smoke, tufts and a variety of wet-surface coatings. None of these visualization techniques meets all the necessary criteria. Smoke is limited by a maximum useful velocity, by the turbulence level in the incident airflow and within the boundary layer due to its dispersion tendency. Tufts are insensitive at low velocity because of their stiffness and gravity effect [1]. Neither of these two methods can, moreover, generate a permanent record. Wet-surface coating techniques provide a permanent record but they are generally prone to earlier indication of separation on a bluff body [2]. This is due to the flow of the film sheet beneath the boundary layer induced by the airstream and, particularly, gravity. The dust method [3] is also

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afflicted by the same problems since the body is initially smeared with a thin oil film to which the powder particles eventually adhere owing to the reverse flow within the wake. Similar errors are present when dust introduced in the wake deposits on an untreated surface as in the case of paraffin wax particles [4]. The error induced by the film motion becomes more critical with increasing bluffness of the body and it is the largest in the case of a circular cylinder. In tests conducted in crossflow around a circular cylinder it was learned, for example, that the error due to the film motion in approximating the separation angle by a wet-surface coating method can be as high as 25 percent. In the light of the limitations imposed by the available techniques, a simple and relatively accurate dry-surface coating method for visualization of the separation on a circular cylinder or on any bluff body was developed. The main features of this method along with its testing in locating the separation angle on a circular cylinder in a crossflow are briefly examined herein.

Method Description

The dry-surface coating method for the visualization of the separation on a bluff body placed in a wind-tunnel flow relies on the color reaction of a pH indicator contained in a thin film. This technique consists of the following basic five steps: (1) application to the surface of the body of an even thin coating composed of a versatile indicator and a paint carrier; (2) complete drying of the film in order to prevent its motion along the bluff body surface induced by the incident airstream and/or by gravity; (3) conditioning of the coating by an acidic solution for ensuring a suitable color reaction; (4) release into the body wake of a gas capable of producing a base as a result of its reaction with the solvent of the conditioning solution; and, (5) color reaction of this base with the film indicator according to its pH. The drying and subsequent conditioning of the coating are executed prior to exposing the body to the wind-tunnel airflow.

To start with, an indicator commonly known as Congo Red (sodium diphenyldiazo-bis-α-naphthylamine-sulfonate) was selected based on its color change over a wide range of pH values. Congo Red is a brownish-red powder whose color changes to either blue or deep red when exposed to a solution of a pH smaller than 3 or greater than 5, respectively [5]. Titanium white acrylic polymer (trade name "Hyplar") water-thinned to the consistency of cream was used as the paint carrier, but any other water soluble latex paint can be employed. Based on numerous trials it was found that a reddish mixture consisting of 1 part by volume of the Congo Red indicator to 30 parts of the paint carrier yields the best coating. In order to avoid permanent coating of the body, it is further desirable to apply the mixture to a thin smooth cardboard sheet. An even thin film is readily obtained by spreading the mixture with a fine foam plastic roller. The complete drying of the film takes 10 minutes at most. Care is to be exercised in snugly wrapping without wrinkling the painted cardboard sheet over the body with its seam along the rear stagnation line.

In view of the initial reddish tint of the film and of the color properties of its Congo Red indicator, conditioning of the coating is necessary for ensuring the realization of two sharply contrasting colored sections on the body under the action of a base (pH > 7 [6]) within the wake. This conditioning consists of spraying the coating with a strong hydrochloric acid solution (HCl) of a pH < 3 that changes its original reddish color to blue. With the completion of this color change and the runoff of excess solution, the coating is enveloped by an extremely thin acidic solution sheath insensitive to both incident airstream and gravity effects. The coating is now ready to be exposed to the airflow.

Ammonia gas (NH_3) is next released in a regulated way along the centerline of the body wake. As the ammonia gas entrained by the recirculating flow comes in contact with the coating of the wake region, it reacts with the solvent of the conditioning solution (i.e., with the water in the sheath of hydrochloric acid solution). Maintenance of a damp surface by applying a water mist furthers this reaction since it counteracts the evaporation of the solvent. The outcome of this reaction is the formation of a very thin film of ammonium hydroxide solution (NH_4OH) which is a base of a pH slightly greater than 11 [6]. Then the coating of the wake region quickly becomes deep red due to the color property of the Congo Red indicator while the rest of the film retains its original blue color.

The release of ammonia gas in the wake is continued until these two strongly contrasting colored regions on the body surface are delineated by a narrow transition band of several millimeters width. Generally, the time required to produce a clearly visible transition band amounts to only several minutes and, moreover, it decreases with increasing Reynolds number. The transition band demarcates the recirculating flow in the separated region from the upstream attached boundary layer and, therefore, it indicates the average location of the separation on the body. One then can view the centerline of this band as the separation line. A clear permanent record of the separation line is obtained since neither the two sharply different colors nor the demarcating transition band are affected by the removal of the airflow. This record is furthermore of consistently good photographic quality due to its color contrast. It is further important to stress that this dry-surface coating method is not restricted to any particular Reynolds-number range and it can be used for either oncoming laminar and/or turbulent crossflow.

Method Testing

The reliability of this dry-surface coating method was tested in visualizing the separation on a circular cylinder in both laminar and turbulent crossflows at subcritical cylinder-diameter Reynolds numbers Re_D ranging from 5×10^4 to 2×10^5. A circular cylinder 16 cm (6-1/4 in) in diameter mounted across a 1.83x1.83x27 m (6x6x88 ft) wind tunnel was used. Freestream turbulence was produced by means of an upwind turbulence-generating grid [7]. The coating was applied to a cardboard sheet 600 μm (23.6 mils) thick of about same surface roughness as the cylinder which, subsequently, was wrapped around it. Smooth entrainment of the ammonia gas by the recirculating flow in the wake was secured by appropriate selection of the diameter of the injection tube (7 mm (9/32 in)) and by its positioning on the wake centerline (9 cm (3-1/2 in) downstream of the rear stagnation point). A transition band from the deep red color in the wake to a plain blue tint in the attached flow region evolved over a time period of at most 10 minutes. Its width varied with the Reynolds number but it never exceeded 7 mm (276 mils). This maximum width corresponds to an arc of 5°. The separation line was approximated by the centerline of the transition band; thus, the absolute error in estimating the separation angle was, at most, ±2.5°.

A sample of the location of the separation line disclosed by this visualization technique is shown in Fig. 1. Four black-and-white still photographs reproduced from a color movie are presented in this figure. The color movies were taken using high-speed color-reversal film with the airflow on and off. Exactly similar images were obtained under both conditions owing to the permanency of the record. In the stills shown in Fig. 1 the dark and light areas represent the blue and red regions on the cylinder, respectively. A scale marking off angles at 5° intervals, with its origin at the forward stagnation point, is incorporated in the still photographs for convenient estimation of the separation angle.

A separation angle of about 80° was consistently revealed by the visualization over the entire Reynolds-number range in the case of incident laminar crossflow as clearly seen in Fig. 1(a). In an oncoming turbulent crossflow, on the other hand, a continuous increase in the separation angle with augmenting Reynolds number was disclosed by the visualization. For instance, separation angles of about 95, 110 and 120° were recorded at Reynolds numbers of 5×10^4, 7.5×10^4 and 1.2×10^5, respectively, as distinctly observed in the stills given in Fig. 1(b), (c) and (d). These results were obtained with the turbulence-generating grid installed at an upwind distance of 10 cylinder diameters (160 cm (63 in)). In order to verify the accuracy of this visualization method, the separation angle was next estimated based on the distribution of the mean wall pressure under exactly similar flow conditions [7]. In each case, the separation angle indicated by the visualization was at most ±3° from its counterpart deduced from the wall pressure distribution. Thus, this visualization method yields results which are within ±4 percent of the measured separation angles. It is thus apparent that the dry-surface coating method supplies a reasonably accurate visual approximation of the separation angle on a bluff body. This method can also be used in visualizing the separation line on a streamline body.

Conclusions

A relatively simple and reasonably accurate dry-surface coating method for visualization of the separation line on a bluff body was devised and successfully tested. This technique is based on the color reaction of a dry film containing a pH indicator with an appropriate gas released in the body wake. The dry-surface coating method is effective at any Reynolds number and for both incident laminar and turbulent flows. It further supplies a colorful permanent record of consistently good photographic quality of the separation line. The effectiveness and accuracy of this technique were tested in visualizing the separation angle on a circular cylinder in both laminar and turbulent crossflows at subcritical Reynolds numbers. Separation angles revealed by the visualization were within ±4 percent of their counterparts deduced from the mean wall pressure distribution.

The work reported here is a part of a research program on the structure of turbulence and the effect of turbulence upon the separation in flow about bluff bodies and aerodynamic surfaces. Sponsoring of this research program by NASA Lewis Research Center is gratefully acknowledged. (NSG-3127)

References

1. W. Merzkirch, Flow Visualization, Academic Press, New York, NY, 17-20, 1979.

2. L. C. Squire, The motion of a thin oil sheet under the boundary layer on a body, P. R. Maltby, ed., Flow Visualization in Wind Tunnel Using Indicators, AGARDograph 70, 7-28, 1962.

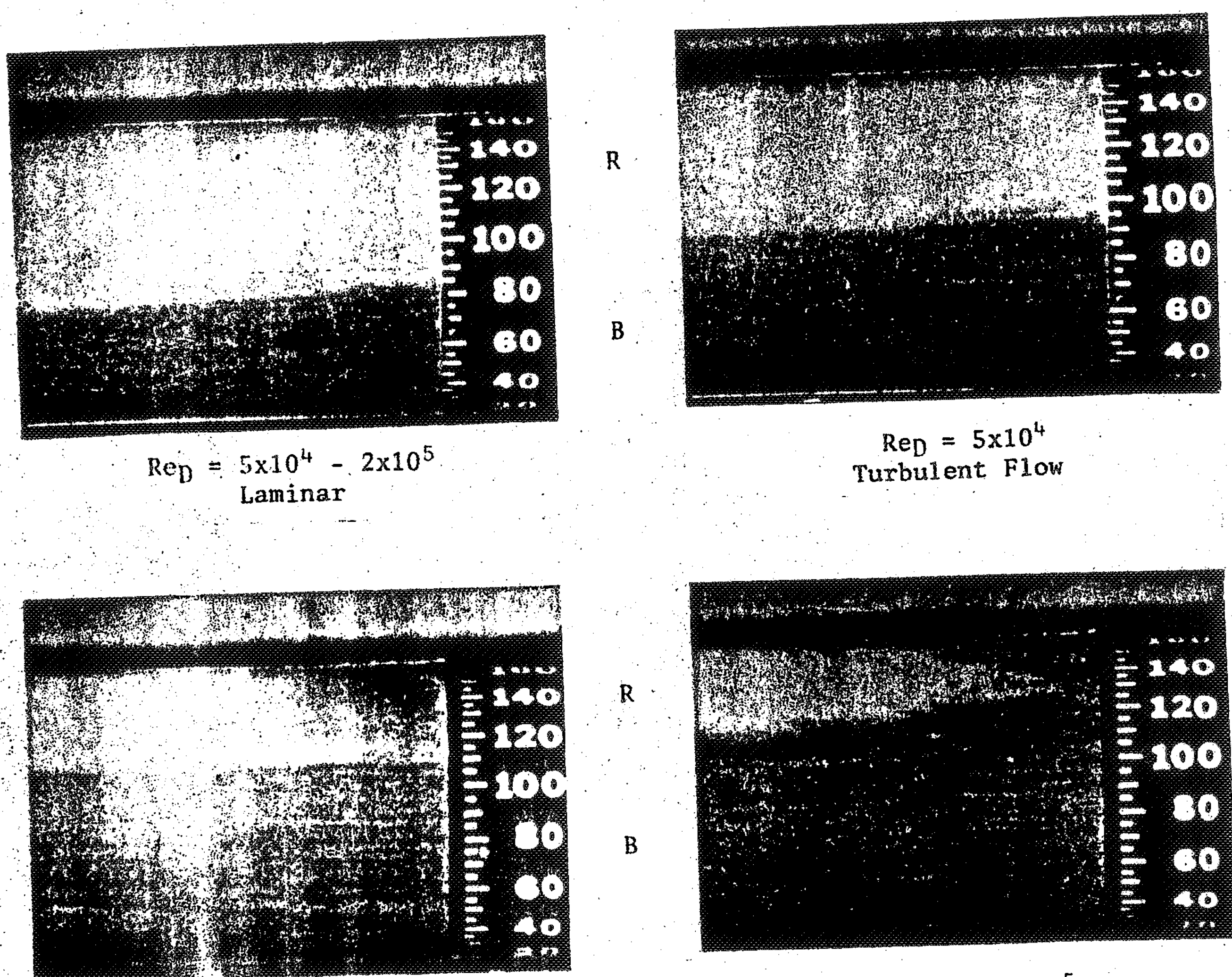
3. A. M. O. Smith, J. S. Murphy, A dust method for locating the separation point. J. Aero. Sci. 22, 4, 273-279, 1955.

4. E. T. Hignett, The use of dust deposition as a means of flow visualization. ARC CP 631, 1962.

5. M. Windholz, ed., The Merck Index, Monograph 2467, 9th ed., Merck & Co., Inc., Rahway, NJ, 321-322, 1976.

6. L. Pauling, General Chemistry, 2nd ed., W. M. Frieman & Co., San Francisco, CA, 435-442, 1956.

7. W. Z. Sadeh, H. J. Brauer, P. P. Sullivan, Freestream turbulence effect on laminar separation on a circular cylinder. AIAA Paper No. 79-1476, AIAA 12th Fluid and Plasma Dynamics Conference, Williamsburg, VA, 24-25 July 1979.



$Re_D = 5x10^4 - 2x10^5$
Laminar

$Re_D = 5x10^4$
Turbulent Flow

$Re_D = 7.5x10^4$
Turbulent Flow

$Re_D = 1.2x10^5$
Turbulent Flow

Fig. 1. View of the separation angle on a circular cylinder in laminar and turbulent crossflow at subcritical Reynolds numbers; B: Blue, attached flow; R: Red, separated