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RESEARCH MEMORANDUM

SUBSONIC INVESTIGATION OF EFFECTS OF BODY INDENTATION ON ZERO-LIFT DRAG CHARACTERISTICS OF A 45° SWEPTBACK WING-BODY COMBINATION WITH NATURAL AND FIXED BOUNDARY-LAYER TRANSITION THROUGH A RANGE OF REYNOLDS NUMBER FROM 1×10^6 TO 8×10^6

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NATIONAL ADVISORY COMMITTEE
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SUBSONIC INVESTIGATION OF EFFECTS OF BODY INDENTATION ON ZERO-LIFT DRAG CHARACTERISTICS OF A 45° SWEPTBACK WING-BODY COMBINATION WITH NATURAL AND FIXED BOUNDARY-LAYER TRANSITION THROUGH A RANGE OF REYNOLDS NUMBER FROM 1×10^6 TO 8×10^6

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SUMMARY

An investigation has been made in the Langley low-turbulence pressure tunnel at low subsonic speed through a range of Reynolds number from approximately 1.0×10^6 to 7.6×10^6 to study the effects of body indentation in accordance with the transonic area rule on the zero-lift drag of a transonic body in combination with a 45° sweptback wing having an aspect ratio of 4, taper ratio of 0.3, and NACA 65A006 airfoil sections. The results indicate that with either natural boundary-layer transition or with transition fixed near the wing leading edge, body indentation had no effect on the zero-lift drag coefficient at subcritical Mach numbers, throughout the test range of Reynolds number. The results also indicate that for a wide range of Reynolds number the ability to maintain extensive regions of laminar flow on a configuration of this type depends on the maintenance of sufficiently smooth surfaces rather than on a dynamic boundary-layer instability due to sweep.

INTRODUCTION

Fuselage indentation in accordance with the transonic area rule (ref. 1) has been shown in numerous investigations to effect reductions in the transonic drag rise of wing-body configurations. Most of these investigations have also indicated small decreases in the drag coefficients at subcritical Mach numbers; however, little significance was placed on these differences inasmuch as they usually were close to or within the limits of experimental accuracy. A recent investigation at high subsonic and transonic speeds of a sweptback wing-fuselage combination in the Langley 8-foot transonic tunnel (ref. 2), however, showed differences in the values of subcritical drag coefficients between the basic- and indented-fuselage configurations that were greater than would be expected from the standpoint of accuracy. The possibility was considered that these differences in subcritical drag coefficients might be a result of an improved pressure distribution over the inboard sections of the wing caused by the body indentation and hence an increased extent of laminar flow. In order to determine whether an increase in Reynolds number might influence the possible difference in laminar run, the same wing-fuselage models were investigated at subsonic speeds in the Langley low-turbulence pressure tunnel through a range of Reynolds number from about 1.0×10^6 to 7.6×10^6 based on the wing mean aerodynamic chord. The models were studied with smooth surfaces and with fixed transition strips on the wing and body. A fluorescent lacquer technique was also used as a visual aid for comparison of the transition positions on the basic and indented configurations.

Model

A plan-form drawing of the models is presented in figure 1 and a photograph of one of the models mounted on a sting support is shown in figure 2. The basic configuration consisted of a 45° sweptback wing having an aspect ratio of 4, taper ratio of 0.3, and NACA 65A006 airfoil sections in the stream direction mounted on a boattailed body of revolution. As shown in figure 1, two bodies were considered - a basic body and a body indented according to the transonic area rule to give an axial cross-sectional area distribution of the wing-body combination equal to that of the basic body alone. The models are the same as those described in detail in reference 2.

Tests and Measurements

The tests were conducted in the Langley low-turbulence pressure tunnel through a Reynolds number range from about 1.0×10^6 to 7.6×10^6 at Mach numbers from 0.2 to 0.4. Zero-lift drag was measured on an internal strain-gage balance and was adjusted to a condition of free-stream static pressure at the base of the model. The accuracy of the drag coefficients based on balance sensitivity, scatter, and repeatability of the data is estimated to be within ± 0.0004. All data were corrected for tunnel blockage effects.

The fluorescent lacquer technique, described in reference 3, was used at a Reynolds number of 2×10^6 to give a visual indication of the position of boundary-layer transition on the configurations with smooth surfaces. In brief, this technique consists of spraying a lacquer containing a phosphorous pigment on the model surfaces. The lacquer dries more rapidly in the turbulent regions and becomes fluorescent in the presence of an ultraviolet light.

The models were also investigated with transition strips, 1/8 inch wide, located at the 10-percent-chord station on the upper and lower wing surfaces and around the fuselage 1/4 inch ahead of the maximum diameter. These strips were composed of carborundum grains blown on a thin layer of shellac. Two grain sizes were investigated, 0.003 to 0.005 inch diameter and 0.010 to 0.012 inch diameter, which are herein referred to as small-grain and large-grain roughness, respectively. In one instance, the roughness was placed on the wings only.

RESULTS AND DISCUSSION

The zero-lift drag coefficients for the various test configurations are shown for the range of Reynolds number investigated in figure 3. The drag coefficients of the basic and indented wing-body configurations with smooth surfaces were found to be equal throughout the entire test Reynolds number range indicating that body indentation did not extend the region of laminar flow. The gradual increase in drag coefficient with increasing Reynolds number is a result of a forward movement of transition.

Addition of the fine grain roughness to the wings and fuselage with an associated forward movement in position of transition increased the drag coefficient from a value of 0.0084 to about 0.0128 at a Reynolds number of 1.8×10^6 for both wing-body configurations. This higher value of drag coefficient is approximately the same as that measured initially at subcritical speeds in the tests of reference 2 for the basic configuration at the same Reynolds number and indicates that the differences in drag coefficient at subcritical speeds measured between the basic and indented wing-body configurations were most likely a result of premature transition on the basic configuration. A retest of this configuration at high subsonic speeds did, in fact, result in drag coefficients at subcritical Mach numbers for the basic configuration equal to the values obtained with the indented configuration, thus showing that the initial differences in drag coefficient were probably caused by almost unnoticeable surface irregularities.

A further indication of the sensitivity of laminar flow to small surface disturbances was obtained during the present investigation when an attempt was made to improve the photographic background of the model for the visual boundary-layer observations. A light coat of zinc chromate, which had been sprayed on the model for the fluorescent lacquer tests, became slightly soft when a solvent was used to remove the fluorescent lacquer previous to measurement of the model drag. Although the surface condition appeared smooth to both the touch and eye, there were evidently sufficient disturbances to move the position of transition somewhat forward as indicated by the small increase in drag coefficient shown by the curve in figure 3 designated by the diamond symbols.

Additional tests were made for the basic wing-fuselage configuration with the large-grain roughness on the wings and around the fuselage. As indicated in figure 3, doubling the grain size at a low Reynolds number increased the drag coefficient by about 0.003. The question may, therefore, be asked as to whether the small-grain roughness actually moved transition completely forward to the roughness strips or only part way forward. The effect of surface roughness on the position of boundary-layer transition for a given Reynolds number depends primarily upon the relative size of the surface disturbance to the boundary-layer thickness. A four-fold increase in Reynolds number from 2×10^6 to 8×10^6 for the small-grain roughness tests would produce the same change in relative size of the roughness to the boundary-layer thickness as the two-fold increase in grain size at the low Reynolds number. If transition was located downstream of the small-grain roughness strips at the low values of the Reynolds number, an increase in Reynolds number, then, would move the position of transition farther forward and the drag coefficient would approach the value obtained with the large-grain roughness. Inasmuch as the drag coefficient for the small-grain roughness actually decreases with Reynolds number, which is characteristic of the decrease in turbulent skin-friction coefficient, it is apparent that transition was located at the small-grain roughness strips and that the difference in drag coefficient between the two sizes of roughness is due to an increased drag of the larger roughness itself.

A visual indication of the natural position of transition at a Reynolds number of 2×10^6 is presented in figure 4, which is a typical photograph for either the basic or indented wing-body configurations in the smooth condition. Laminar flow, indicated by the dark areas, extends to about 65 percent of the wing chord. The wedge-shaped turbulent areas (light areas) are effected by the rolling up of the wet fluorescent lacquer at some points as the air flows over the wing and are not necessarily indicative of any premature transition during the drag tests which were made with the lacquer removed from the surfaces. The light area near the wing leading edges does not denote turbulent flow but is rather due to rapid drying of the lacquer where the velocity gradient in the laminar boundary layer is steep. The position of transition on the fuselage is seen in the photograph to be well forward of the wing location. This is verified by the fact that drag measurements made on the indented wing-fuselage configuration with small-grain roughness strips applied to the wings but not to the fuselage indicated that the presence of the roughness strip around the fuselage just ahead of the leading edge of the wing-fuselage intersection had no measurable effect on the drag coefficient. (See fig. 3.)

The attainment of extensive regions of laminar flow on the smooth sweptback wing-fuselage models investigated prompted a comparison of these results with some British studies of the effects of sweepback on laminar boundary-layer stability. (For example, see ref. 4.) The British work indicates that a dynamic type of laminar boundary-layer instability is introduced by wing sweep and that this instability is primarily dependent upon the amount of sweep and a Reynolds number based on the value of the wing leading-edge radius. For a given sweep angle, then, there exists a critical value of the Reynolds number based on the leading-edge radius above which boundary-layer transition will move rapidly forward to the vicinity of the wing leading edge. For the present wing-fuselage configuration, the maximum test Reynolds number was found to be well below the critical for dynamic instability. In fact, a Reynolds number of approximately 30×10^6, based on the wing mean aerodynamic chord and free-stream velocity, would be required, according to the results of reference 4, to move the transition position to the leading edge because of dynamic instability. It appears, therefore, that for a wide range of Reynolds number, attainment of extensive regions of laminar flow on a configuration of the type considered for the present investigation is dependent upon the ability to maintain sufficiently smooth wing surfaces rather than on a dynamic boundary-layer instability due to sweep.

CONCLUDING REMARKS

A low subsonic speed investigation was made of a 45° sweptback wing of aspect ratio 4, taper ratio 0.3, and 6 percent thickness, in combination with a basic body and a body indented in accordance with the transonic area rule. The results indicate that with either natural boundary-layer transition or with transition fixed near the wing leading edge, body indentation had no effect on the zero-lift drag coefficient at subcritical Mach numbers throughout the test range of Reynolds number from about 1.0×10^6 to 7.6×10^6. The results also indicate that for a wide range of Reynolds number the ability to maintain extensive regions of laminar flow on a configuration of this type depends on the maintenance of sufficiently smooth surfaces rather than on a dynamic boundary-layer instability due to sweep.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., February 8, 1954.

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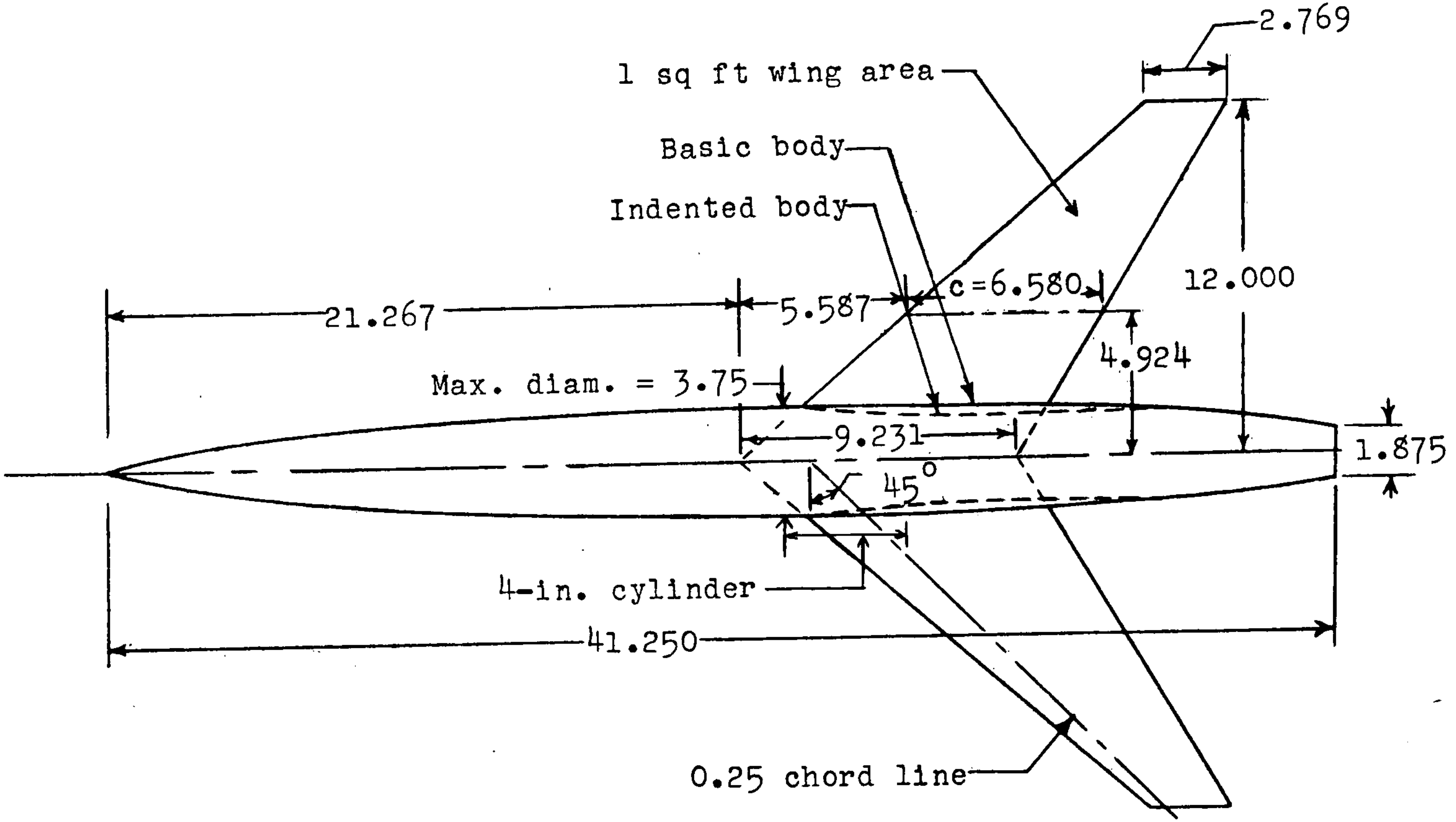

Figure 1.- Plan view of 45° sweptback wing-body combination having aspect ratio of 4, taper ratio of 0.3, and NACA 65A006 airfoil sections. All dimensions are in inches.

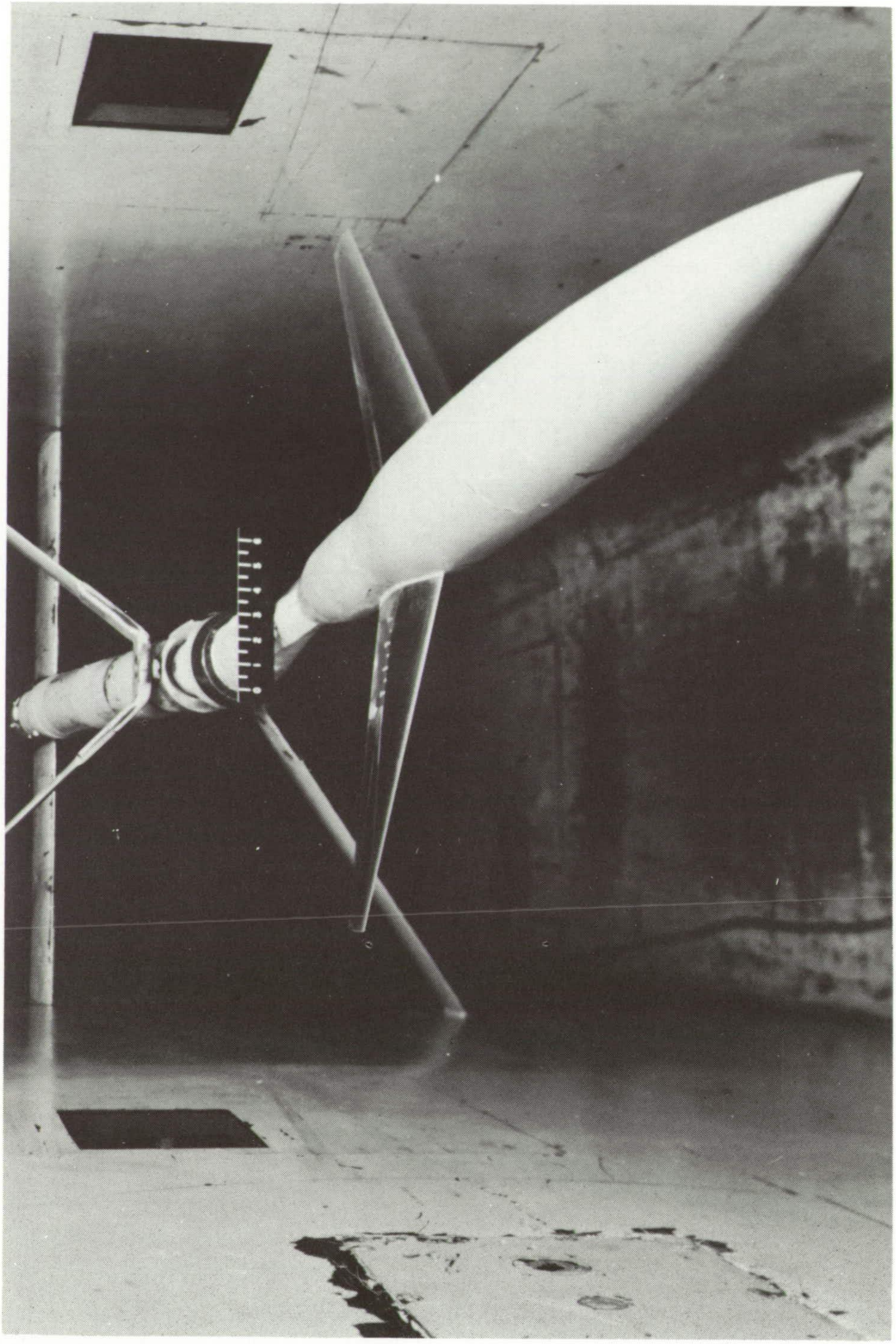

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Figure 2.- Photograph of indented wing-body configuration mounted on sting support in Langley low-turbulence pressure tunnel.

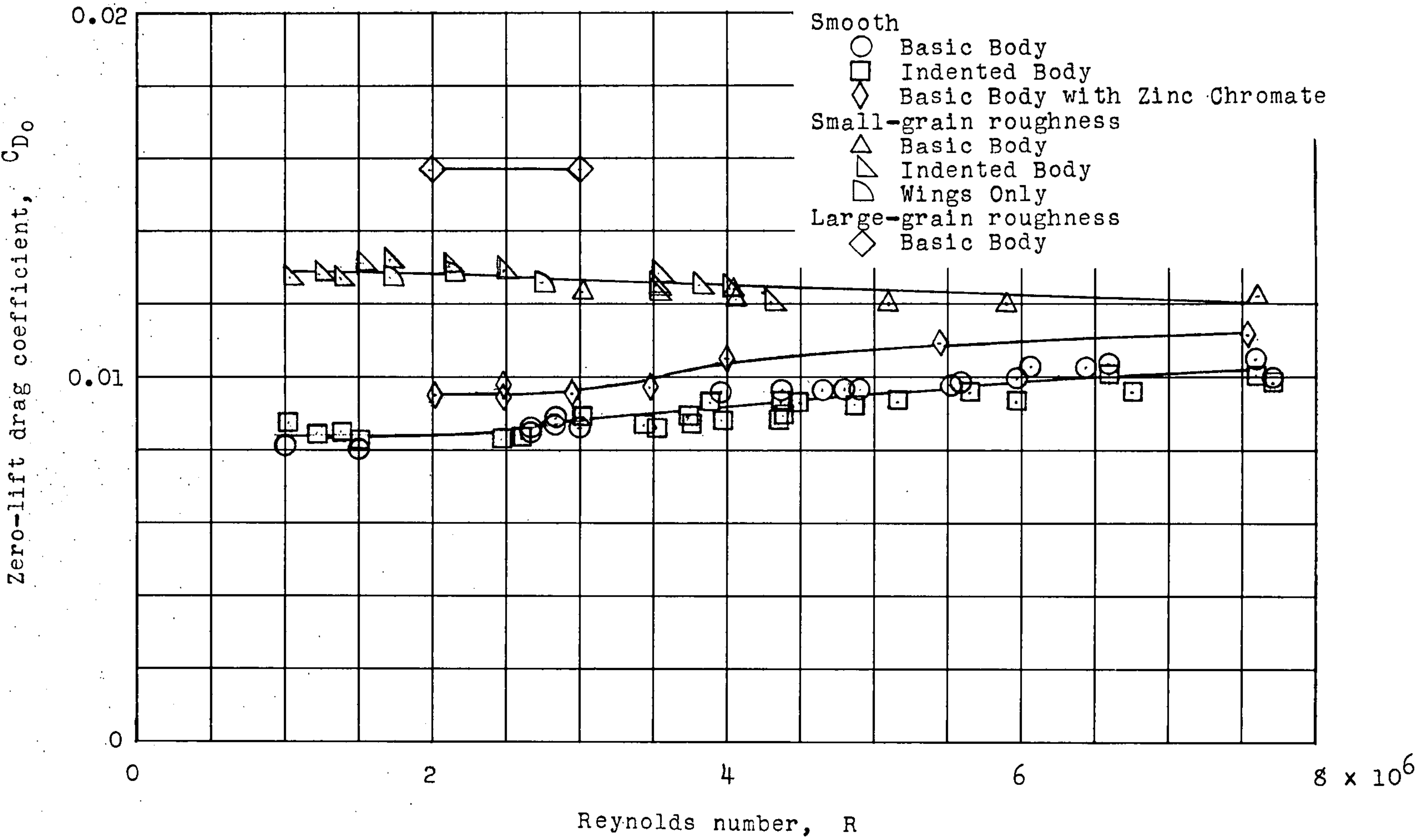

Figure 3.- Effect of Reynolds number on the zero-lift drag coefficient of the basic and indented wing-body combination with natural and fixed boundary-layer transition.

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Figure 4.- View of basic model with fluorescent lacquer showing regions of laminar and turbulent boundary-layer flow.