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TECHNICAL NOTE

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EFFECTS OF FINENESS RATIO AND REYNOLDS NUMBER ON THE LOW-SPEED CROSSWIND DRAG CHARACTERISTICS OF CIRCULAR AND MODIFIED-SQUARE CYLINDERS

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EFFECTS OF FINENESS RATIO AND REYNOLDS NUMBER ON THE LOW-SPEED CROSSWIND DRAG CHARACTERISTICS OF CIRCULAR AND MODIFIED-SQUARE CYLINDERS

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SUMMARY

A wind-tunnel investigation has been made on modified-square and circular cylinders to determine the effects of fineness ratio and Reynolds numbers on the crosswind drag characteristics. Fineness ratios from 2 to 14 were investigated over a Reynolds number range from approximately 300,000 to 1,650,000 which corresponded to Mach numbers from 0.057 to 0.377. The results of the investigation show that at supercritical Reynolds numbers the drag coefficient of the circular cylinder increases with increasing Reynolds number for all fineness ratios but at low fineness ratios this effect is considerably less than at higher fineness ratios. For circular cylinders in the high fineness-ratio range there is a reduction in drag as the fineness ratio is decreased except for Reynolds numbers of 900,000 and 1,000,000, whereas at low fineness ratios the opposite trend generally occurs. The addition of hemispherical ends to the circular cylinder gave a substantial decrease in drag at a fineness ratio of 3.27 but the effect was negligible at fineness ratios of 5.27 and 10. The finite-length modified-square cylinder gave a reduction in drag over the two-dimensional modified-square cylinder for the complete range of test Reynolds numbers with the lowest fineness ratio giving the lowest drag at Reynolds numbers above 300,000.

INTRODUCTION

An important consideration in the launching of rocket configurations is the effect of crosswind forces on the early trajectory. This effect is particularly important where the rocket configuration has a large length-to-diameter ratio and where attitude control devices are marginal. In order to calculate these effects it is necessary to know the crosswind drag coefficients as a function of Reynolds number and fineness ratio. The available drag data at low speed for circular cylinders are confined mainly to two-dimensional results and few data are available to show the effect of finite length on the drag coefficients of cylinders at Reynolds numbers above the critical value.

The primary purpose of the present investigation was to determine the effects of Reynolds number and fineness ratio on the drag characteristics of circular cylinders. The investigation was made in the Langley 300-MPH 7- by 10-foot tunnel. The tests covered a range of Reynolds numbers from below the critical to approximately 1,650,000 which corresponded to a Mach number range from approximately 0.057 to 0.377. The cylinders used in this investigation varied in fineness ratio from 2 to 14. In addition to the effects of fineness ratio, the effects of hemispherical ends on the drag characteristics were also obtained.

In addition to being used to make preliminary calculations on rocket configurations, the data presented herein may also be useful in analyzing the characteristics at high angles of attack of airplanes having low-aspect-ratio wings and relatively long noses. (See refs. 1 and 2.) In this connection tests were also made on modified-square cylinders of various fineness ratios since they may be more representative of current noncircular fuselages.

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SYMBOLS

The drag coefficients and Reynolds numbers have been corrected for wind-tunnel wall effects by the method of reference 3. The symbols used in this paper are defined as follows:

C_D drag coefficient, $\dfrac{\text{Drag}}{\dfrac{\rho V^2}{2} S}$

b model span

R Reynolds number based on cylinder diameter or side dimension

M Mach number

S cylinder projected area, normal to air flow

V free-stream velocity, ft/sec

ρ free-stream density, slugs/cu ft

n fineness ratio, b^2/S

APPARATUS AND TESTS

Models

Sketches showing the geometric characteristics of the models used in the investigation are shown in figure 1. All cylinders with the exception of configuration 6 were constructed of mahogany and lacquered to give a smooth finish. Configuration 6 was made from a magnesium tube. The outer surface was polished to give a smooth finish. Configurations 1 and 2 were tested as semispan models with the cylinder extended through the tunnel ceiling and attached to the mechanical balance system which surrounds the test section in such a manner that the length of the model could be easily varied to give the desired fineness ratio. In order to minimize the spanwise flow that might be induced by air leakage through the clearance gaps where the cylinders passed through the ceiling, each model was equipped with a circular end plate attached near the ceiling. (See fig. 2(a).) Configurations 3 to 6 were tested as full-span models supported from the rear by a sting support system as shown in figure 2(b).

Instrumentation

For the semispan models the drag forces on the model were measured by means of a mechanical balance. The drag forces measured were the mean values (the steady component) with the cylinder mounted rigidly to a heavily damped balance. For the full-span models, the drag forces were measured by means of a six-component strain-gage balance mounted in the sting support system. The tunnel stagnation temperature and pressure and test-section static pressure were measured for each run.

Tests

The investigation was made in the Langley 300-MPH 7- by 10-foot tunnel. The procedure used for the tests was to run through a range of Reynolds numbers for a given model configuration. Since the tunnel is an atmospheric tunnel, the test Reynolds numbers were varied by varying the tunnel dynamic pressure. The resulting variations of Mach number with Reynolds number for the various models are shown in figure 3.

RESULTS AND DISCUSSION

Circular Cylinders With Square Ends

Drag data obtained for the circular cylinder with square ends are presented in figure 4 as a function of Reynolds number for the various values of fineness ratio. The two-dimensional data from reference 1 are included for a comparison. Also shown in figure 4 as solid symbols are the values of drag coefficient at a Reynolds number of 88,000 obtained by cross-plotting the data from reference 4. These latter data are useful in defining the probable variations of C_D with Reynolds number (dashed lines) in a range which is inadequately covered by the present investigation. In general, the transition Reynolds numbers are in close agreement with the two-dimensional data. Above the critical Reynolds number there is a general increase in drag coefficient with increase in Reynolds number similar to the two-dimensional results of reference 3. The results of the two-dimensional pressure-distribution investigation of reference 5 show this increase in drag above the critical Reynolds number is the result of the forward movement of the separation point on the cylinder. It would be expected that similar effects might be obtained with the finite-length cylinders particularly those with the greater fineness ratio.

The faired curves of figure 4 have been cross-plotted in figure 5 to show more clearly the effect of fineness ratio. For comparison, the results obtained by Wieselsberger at subcritical Reynolds numbers (ref. 4) are also shown. At Reynolds numbers above the critical, the following effects of fineness ratio are indicated. The drag coefficient increases with increasing Reynolds number for all fineness ratios but the effect at low values of fineness ratios is considerably less than at the higher values. In the high fineness-ratio range, with the exception of Reynolds numbers of 900,000 and 1,000,000 the results indicate a reduction in drag as the fineness ratio is decreased, a trend similar to that shown for cylinders at subcritical Reynolds numbers ($R = 88,000$). At low fineness ratios the opposite trend generally occurs; that is, the drag coefficient increases as the fineness ratio decreases. This is especially true at Reynolds numbers just above the critical where the two-dimensional drag is a minimum. Several factors may contribute to this behavior: first, it may be that the wake-pressure increase associated with inflow from the free ends is minimized because of the relatively high pressure recovery in this Reynolds number range; second, the reduction in local Reynolds number due to the end relief may result in local subcritical conditions; and third, the separation off the sharp corners may tend to give less pressure recovery. The drag associated with the latter two effects would be expected to become an appreciable part of the total at low fineness ratios and at Reynolds numbers corresponding to low two-dimensional drag.

The flat-plate drag data of reference 4 are included in figure 5 to indicate maximum values of C_D that might be expected of a cylinder with a properly fixed separation device. Such a device may have application at high angles of attack to change the pitching or yawing moments contributed by the nose of a relatively long-nose airplane configuration. It was shown in reference 5 that small separation plates attached on the top and bottom surface of a two-dimensional cylinder at the midchord could produce drag coefficients nearly equal to the flat-plate values. Therefore, it is believed that the drag coefficients of plates of finite span may also represent the drag coefficients of cylinders with controlled separation.

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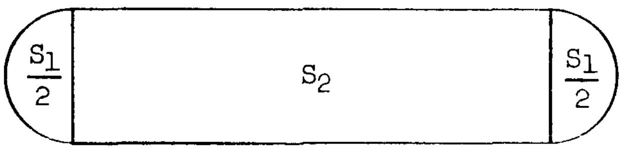
Circular Cylinders With Hemispherical Ends

In an attempt to evaluate the importance of the end separation, tests were made with hemispherical ends attached to the cylinder. The results of these tests are given in figure 6 with the sphere of reference 6 as an end point. No appreciable effect was obtained for fineness ratios of 10 and 5.27. However, at a fineness ratio of 3.27 a substantial decrease in drag coefficient was obtained. This might be expected, in view of the fact that this configuration is approaching a sphere both in area and shape. With this in mind, an estimation was made of the drag of a hemispherical end cylinder by use of the following relation:



$$C_D = C_{D,sphere}\left(\frac{S_1}{S_2 + S_1}\right) + C_{D,cylinder}\left(\frac{S_2}{S_2 + S_1}\right)$$

where $C_{D,cylinder}$ is the drag coefficient of the square-end cylinder. The calculated values of drag coefficient are shown in figure 6 to be in good agreement with the experimental values.

Modified-Square Cylinder

The drag characteristics of a modified-square cylinder with a corner radius of 37 percent of the side dimension measured with a flat side normal to the airflow are shown in figure 7 with a comparison of the two-dimensional value from reference 2. The finite-length cylinders give a reduction in drag over the complete range of Reynolds numbers tested with the lowest fineness ratio giving the lowest drag at Reynolds numbers above 300,000. The variations of drag coefficient with Reynolds number were small for the finite-length modified-square cylinders when compared to the finite-length circular cylinders. This effect is not surprising because the two-dimensional data of the modified-square cylinder show considerably less variation with Reynolds number than the circular cylinder. This reduced variation of C_D with R probably results from the fact that the adverse pressure gradient is more severe and begins at a more rearward position. The movement of the separation point with Reynolds number, which causes the variation of C_D, is less on the modified-square cylinder than on the circular cylinder.

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Attention is directed to the change of transition Reynolds number in going from the two-dimensional data to the finite-length data. The transition Reynolds number appears to have been reduced from 340,000 for the two-dimensional cylinders to a lower value for the finite length. The reason for this change is not apparent.

SUMMARY OF RESULTS

A wind-tunnel investigation has been made to determine the effects of Reynolds number and fineness ratio on the crosswind drag characteristics of a circular and a modified-square cylinder at low speeds. The results are summarized as follows:

1. Above the critical Reynolds number the drag coefficient of the circular cylinder increases with increasing Reynolds number for all fineness ratios but at low values of fineness ratio this increase is considerably less than at higher fineness ratios.

2. For circular cylinders in the high fineness-ratio range there is a reduction in drag coefficient as the fineness ratio is decreased except for Reynolds numbers of 900,000 and 1,000,000, whereas at low fineness ratios the opposite trend generally occurs.

3. The addition of hemispherical ends to the circular cylinder gave a substantial decrease in drag at a fineness ratio of 3.27 but the effect was negligible at fineness ratios of 5.27 and 10.

4. The finite-length modified-square cylinder gave a reduction in drag over the two-dimensional modified-square cylinder for the complete

range of Reynolds numbers tested with the lowest fineness ratio giving the lowest drag at Reynolds numbers above 300,000.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., August 1, 1960.

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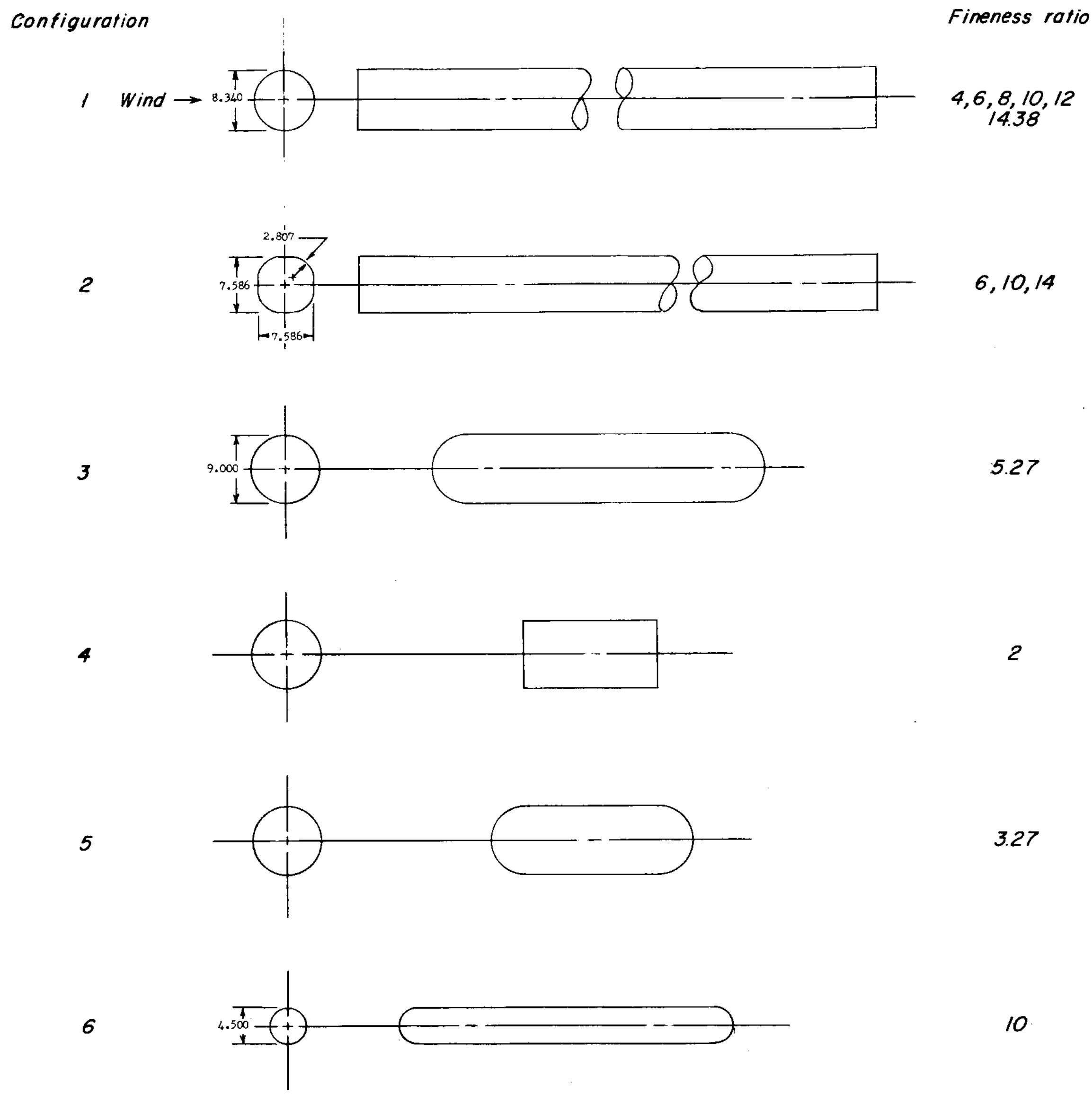
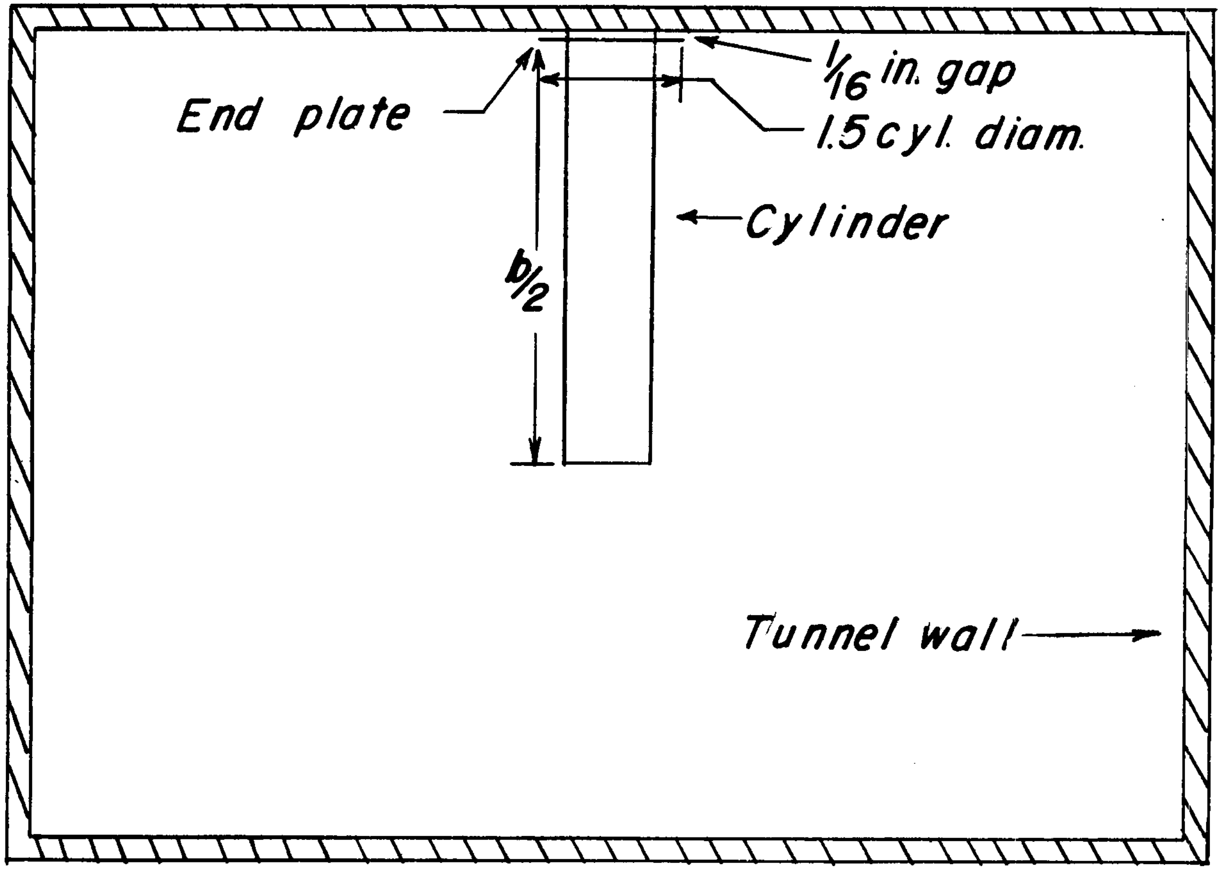
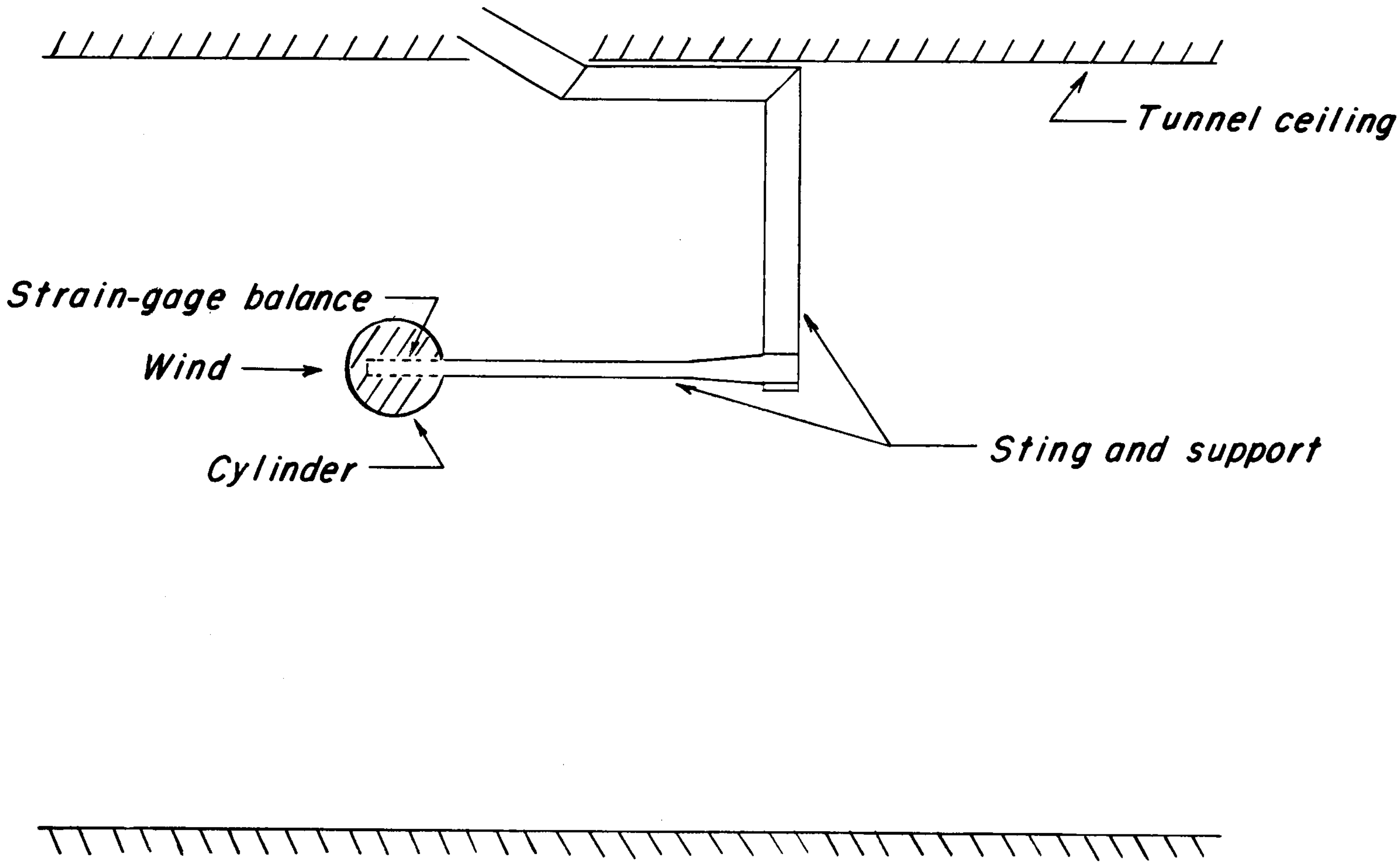


Figure 1.- Sketches showing geometric characteristics of models. All dimensions are in inches.



(a) Semispan model (cross-sectional view).

Figure 2.- Diagram of model-mounting techniques.



(b) Sting-support system (side view).

Figure 2.- Concluded.

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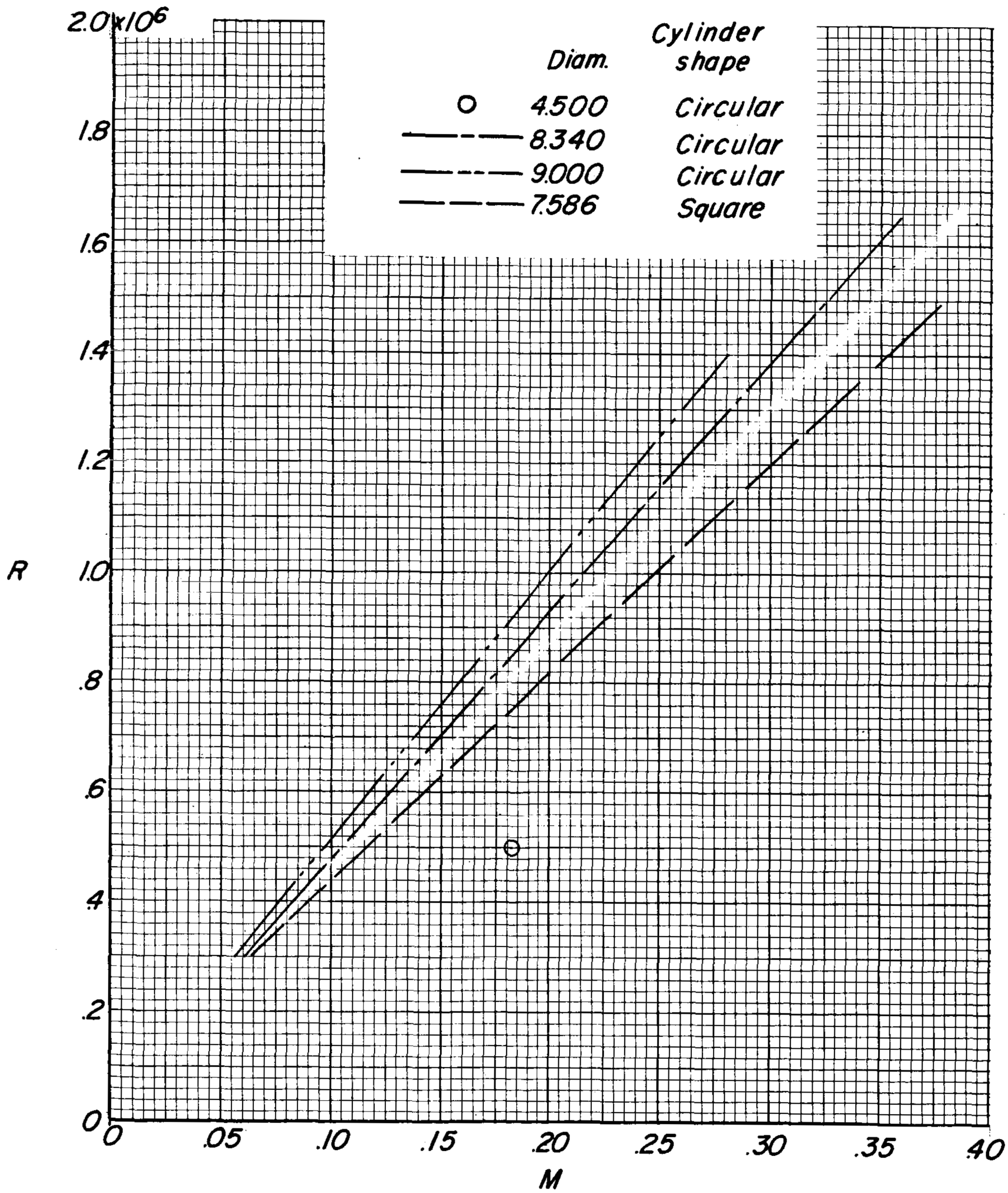

Figure 3.- Variation of Reynolds number with Mach number.

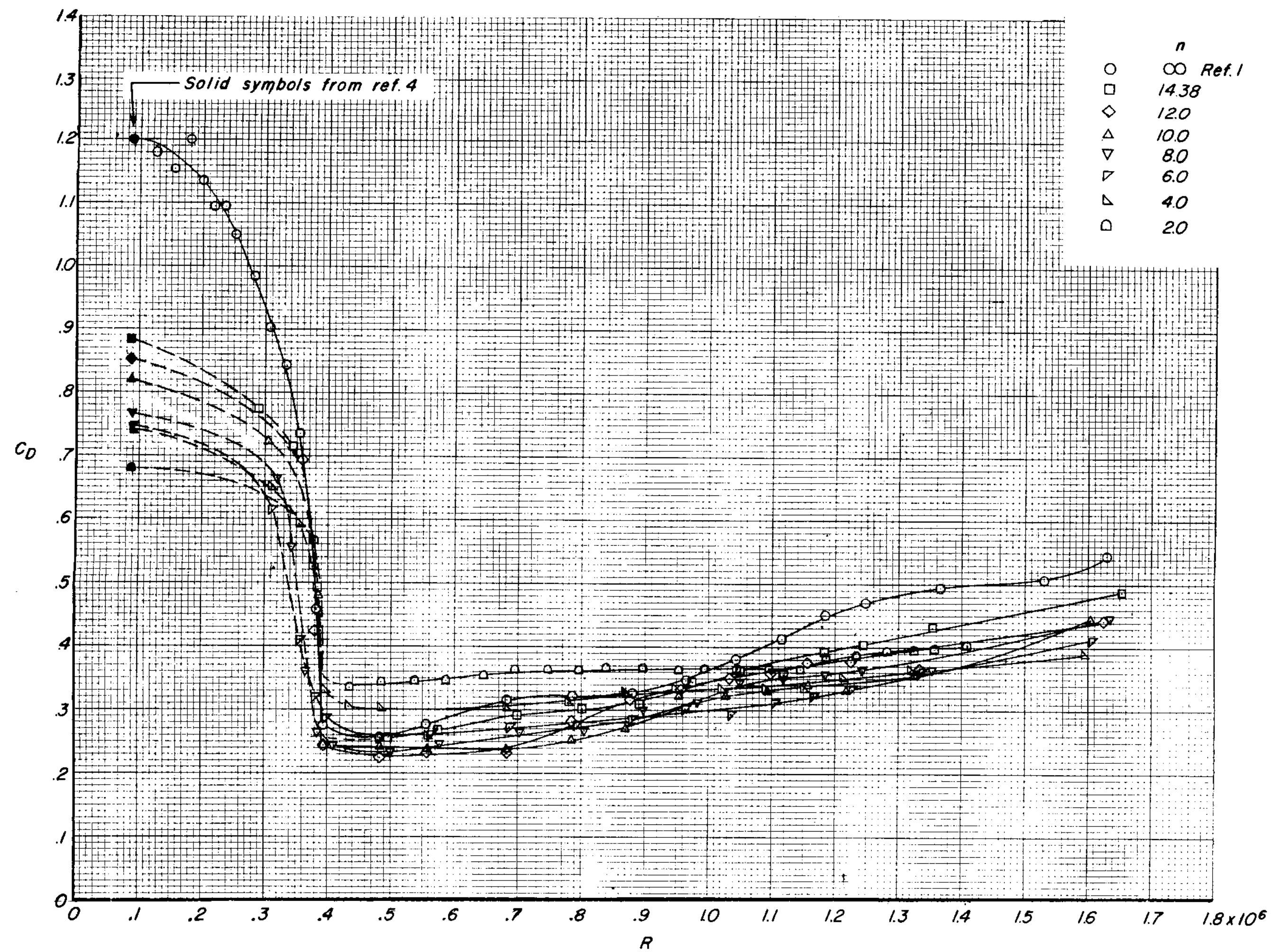

Figure 4.- Variation of drag coefficient with Reynolds number for several fineness ratios of the circular cylinder. Configurations 1 and 4.

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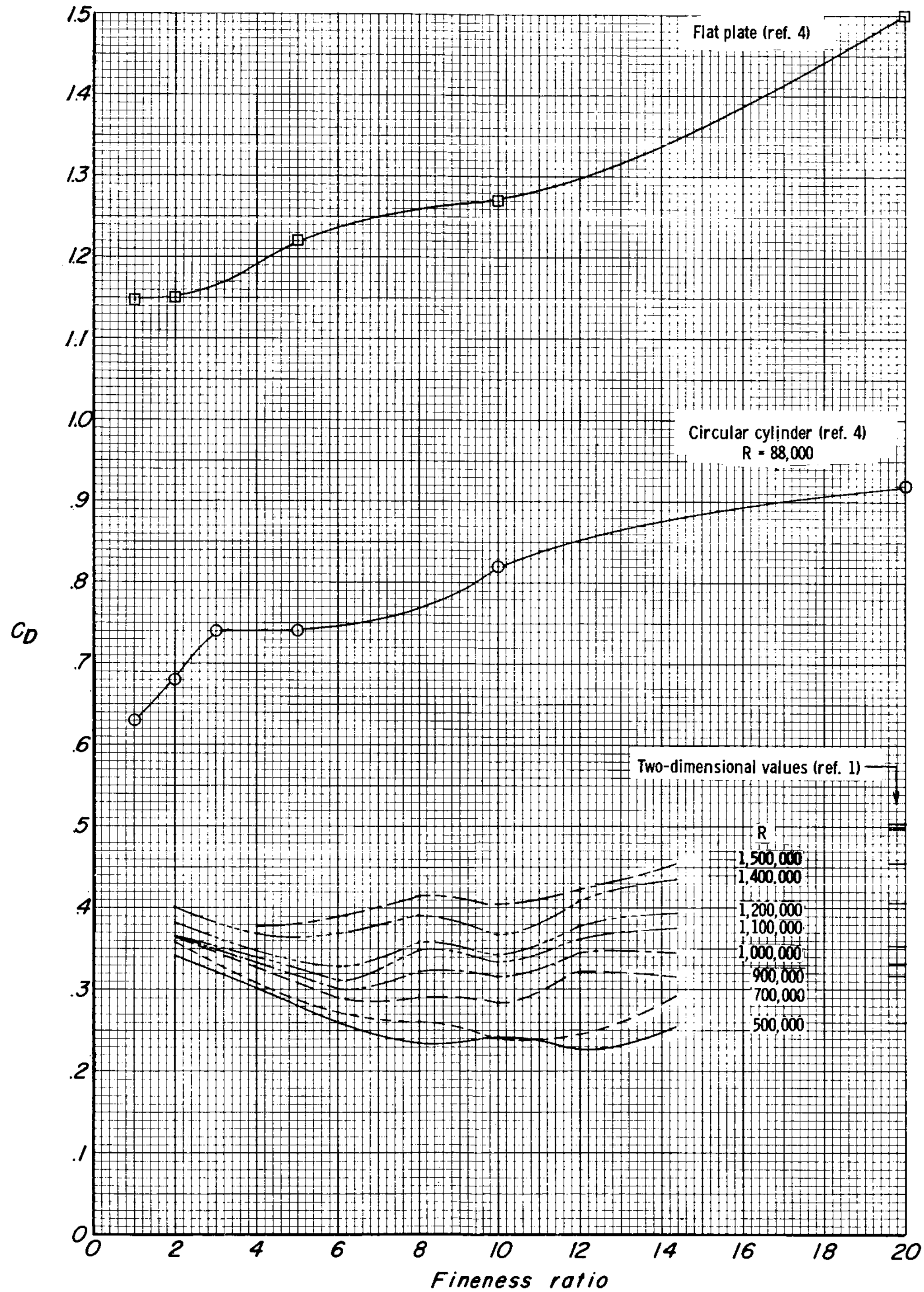

Figure 5.- Effect of fineness ratio on the drag coefficient of a circular cylinder and a flat plate for several Reynolds numbers.

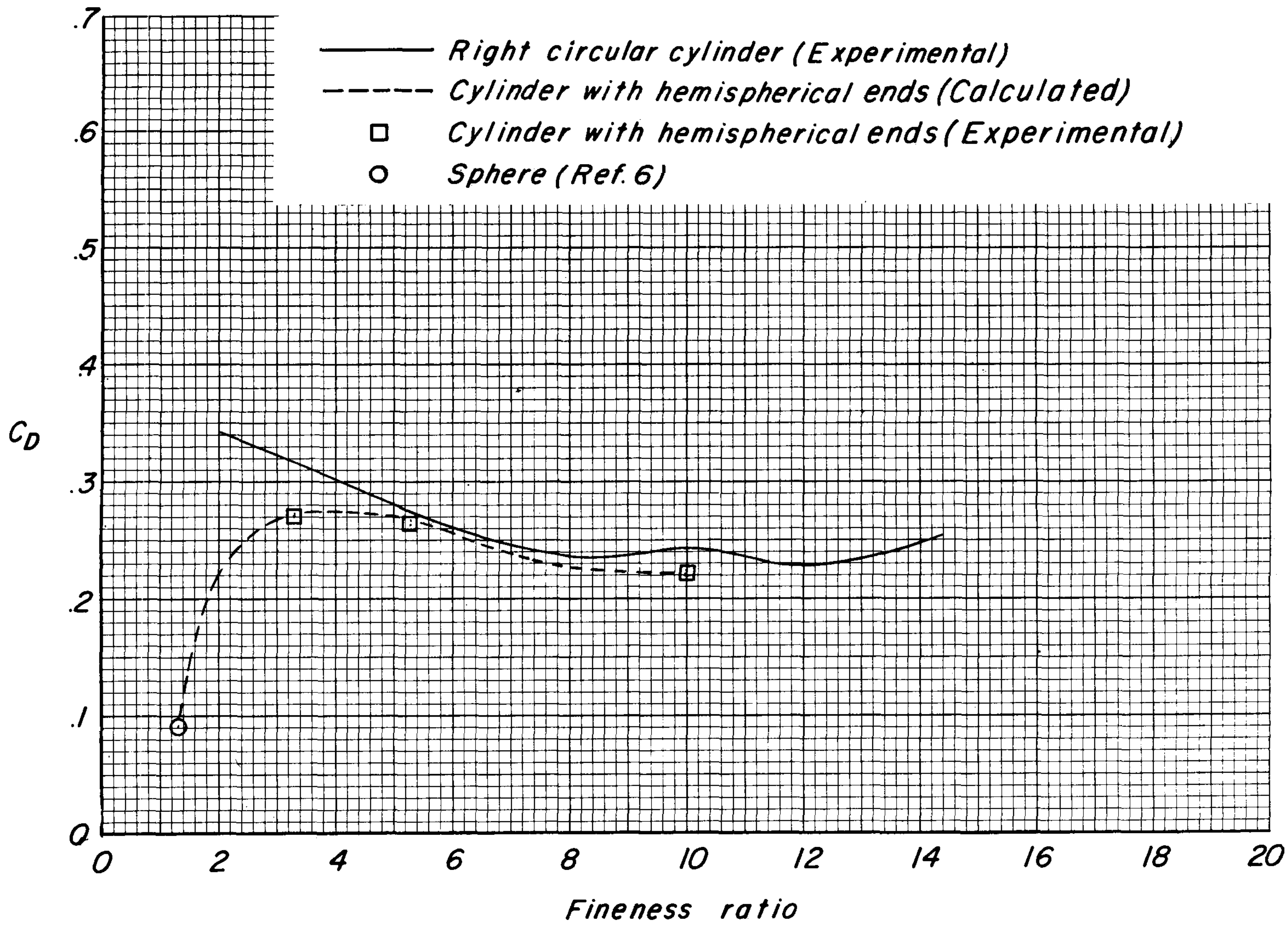

Figure 6.- Effects of hemispherical ends on the drag of a circular cylinder. R = 500,000.

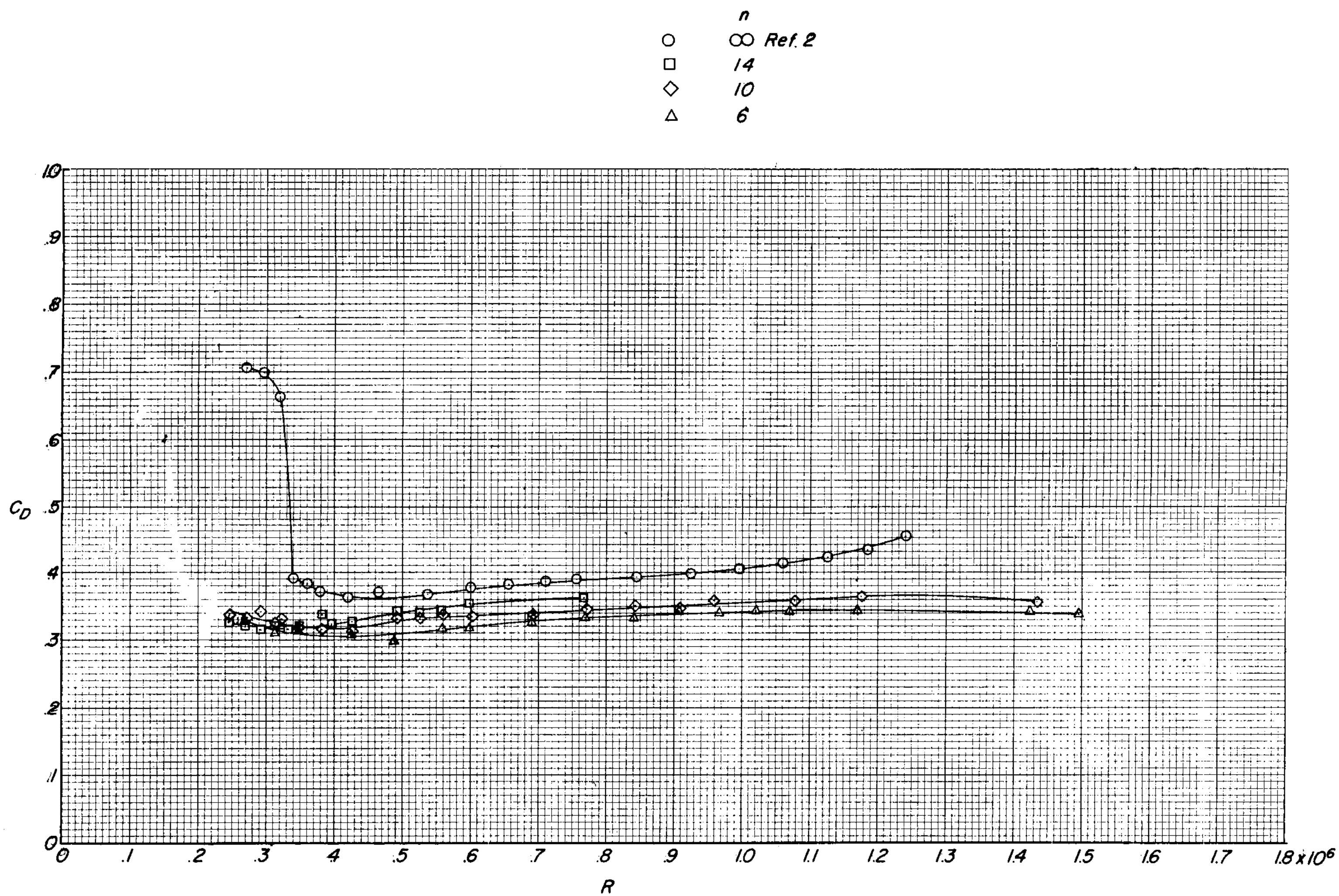

Figure 7.- Variation of drag coefficient with Reynolds number for a modified-square cylinder.

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