NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3081

THE ZERO-LIFT DRAG OF A 60° DELTA-WING—BODY COMBINATION (AGARD MODEL 2) OBTAINED FROM FREE-FLIGHT TESTS BETWEEN MACH NUMBERS OF 0.8 AND 1.7

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SUMMARY

The zero-lift drag of a 60° delta-wing—body combination (designated AGARD model 2) has been determined by free-flight tests of two models between Mach numbers of 0.8 and 1.7. These Mach numbers correspond to Reynolds numbers, based on body length, of 4×10^6 and 12×10^6, respectively. An estimate of the drag of the configuration was made by summing the estimates of the drag of the various components. The agreement between measured and estimated drag is good.

INTRODUCTION

In recent years, many supersonic wind tunnels and free-flight facilities have been developed. Test results from these facilities in some cases have shown a lack of agreement too large to be ignored. Consequently, interest has been expressed in testing, for the purposes of correlation, several configurations in as many supersonic facilities as practical. Such a test program should contribute to the understanding of previously obtained differing results and may lead to the elimination of such discrepancies in the future. During the December 1952 Rome meeting of the Advisory Group for Aeronautical Research and Development (AGARD) of the North Atlantic Treaty Organization, it was decided to encourage such a program of tests in supersonic facilities. The first configuration selected for testing (AGARD model 1) was a slender body of revolution (NACA RM-10 research model). The zero-lift drag of this configuration obtained in flight and by several NACA wind tunnels is presented in reference 1. The second configuration (designated AGARD model 2) was selected primarily for the correlation of data under lifting conditions.

The Langley laboratory has undertaken a program to provide free-flight data on AGARD model 2 at nonlifting and lifting conditions at Mach numbers up to 2. The present paper presents the initial results of the program, namely, the zero-lift drag of the model between Mach numbers of 1.7 and 0.8 corresponding to Reynolds numbers, based on body length, of 12×10^6 and 4×10^6, respectively. The tests were conducted at the Langley Pilotless Aircraft Research Station at Wallops Island, Va., and a helium gun was utilized for propulsion.

SYMBOLS

C_D	drag coefficient, $\frac{\text{Drag}}{\text{Dynamic pressure times total wing area}}$
C_p	nose pressure coefficient
$\bar{c}$	mean aerodynamic chord of exposed wing
D	maximum body diameter
M	Mach number
R	Reynolds number
r	body radius at station x
r_{max}	maximum body radius
x	body station measured from nose point

MODELS

A plan-form sketch of AGARD model 2 is shown in figure 1. This model is 10.625 inches long and has a fineness ratio of 8.5. The body of the model consists of a fineness-ratio-3 nose followed by a cylindrical section with a fineness ratio of 5.5. The lifting surface is a 60° delta wing which has a circular-arc section with a thickness ratio of 0.04 based on the streamwise chord. The nose shape of the model is defined by the following equation:

$$r = \frac{x}{3}\left[1 - \frac{1}{9}\left(\frac{x}{D}\right)^2 + \frac{1}{54}\left(\frac{x}{D}\right)^3\right]$$

which is obtained from the more general equation of reference 2 when a fineness-ratio-3 nose is considered. Ordinates, obtained from this equation, from which the model nose was constructed are presented in table I.

The two models (designated models A and B) flight-tested in the present investigation had, in addition, small vertical fins which were necessary for lateral stabilization in flight. The fins were half-scale exposed wings and are shown on the body in figure 1(b). The models had solid steel noses and steel tubing for the cylindrical section of the body. The brass wings and fins were silver-soldered to the tubing. The base of model A was completely open, whereas model B had a nozzle with a sustainer rocket motor. Details of the internal construction are shown in figure 1.

TESTS

The two models were catapulted from the helium gun. The helium gun makes use of the rapid release of compressed helium to accelerate models to a Mach number of about 1.2. Model B was equipped with a sustainer rocket motor, which was ignited soon after the model left the gun and further accelerated the model to a maximum Mach number of 1.74.

During the coasting period that followed the attainment of peak Mach number, the CW Doppler velocimeter recorded the varying velocity of the model. From this velocity-time record and appropriate atmospheric data obtained by means of a radiosonde, a flight path and the deceleration of the model were calculated. This information in turn was reduced to Mach numbers and drag coefficients based on total wing area.

Errors in the data may arise from limitations of the radar set, methods of data reduction, small physical differences in the models, and the difficulty in ascertaining the absolute weight of model B because of the possibility of unburned rocket particles remaining after rocket burnout. When these sources of error are considered, the drag coefficients and Mach numbers are believed to be accurate to within ±0.001 and ±0.005, respectively. The variation of Reynolds number with Mach number for these tests is presented in figure 2.

RESULTS AND DISCUSSION

The variation of drag coefficient with Mach number for the models is presented in figure 3. The agreement of the test results for the two models is seen to be good, the small differences shown being within the usual accuracy of the data from such tests.

An estimate of the total drag of the configuration has been made and is presented in figure 4. This estimate was obtained by the summation of the estimates of the various drag components which were determined from available theoretical and experimental data. The estimates of these components are also given in figure 4 and a discussion of these values follows.

The work of Van Driest (ref. 3) has been used to estimate the friction drag over the wings and body. A turbulent boundary layer is assumed, although the possibility of a certain amount of laminar flow is realized. The subsonic level of the drag leads to the belief that the amount of laminar flow was small. Total body length was used in calculating the Reynolds number when estimating the friction drag on the body and the mean aerodynamic chord was used in calculating the Reynolds number when estimating the friction drag on the wings.

The estimated pressure drag of the wings and fins was calculated by the method of reference 4. These calculated values are believed to be somewhat higher than the actual wing and fin drag contribution.

The base drag of the model was estimated from information reported in reference 5. Compiled therein are base-pressure measurements obtained in wind tunnels and free flight for finless, cone-cylinder bodies of fineness ratios 5 and 6 over an extensive Mach number range. In addition, data are presented at a Mach number of 1.5 for several fineness ratios from 5 to 9. In order to obtain the present estimate, the data for the bodies with fineness ratios of 5 and 6 were faired between Mach numbers 1.2 and 1.75. The curve thus obtained was then reduced by a constant amount for the effect of fineness ratio as indicated by the data of reference 5 which show the variation of base drag with fineness ratio at a Mach number of 1.5. No allowance was made for the effect of wings or fins on base pressure. The wings are believed to be far enough forward to have a negligible effect. The fins, although in a position to have an effect, are so small that a large effect is unlikely.

Second-order theory as presented in reference 6 was used to predict the nose pressure drag. The calculated pressure coefficients for Mach numbers 1.3, 1.7, and 2.0 are presented in table II. The coefficients were integrated over the nose to obtain the drag from Mach number 1.3 to 1.7. This curve was then extrapolated to the minimum Mach number (1.18) for shock attachment to a cone the apex angle of which is the same as that of the model.

As can be seen in figure 4, the sum of the estimates agrees well with the measured drag. No allowance, however, was made for interference effects among the components.

CONCLUDING REMARKS

The zero-lift drag of a 60° delta-wing—body combination (designated AGARD model 2) has been determined by free-flight tests of two models between Mach numbers of 0.8 and 1.7. The results of the two tests agree well with one another and in turn agree well with an estimate of the drag of the configuration. This estimate was made from available theoretical and experimental data.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 18, 1954.

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2. Roy, Maurice: Tuyères, Trompes, Fusées et Projectiles - Problèmes Divers de Dynamique des Fluides Aux Grandes Vitesses. Pub. No. 203, Pub. Sci. et Tech. du Ministère de l'Air (Paris), 1947.

3. Van Driest, E. R.: Turbulent Boundary Layer in Compressible Fluids. Jour. Aero. Sci., vol. 18, no. 3, Mar. 1951, pp. 145-160, 216.

4. Beane, Beverly: The Characteristics of Supersonic Wings Having Biconvex Sections. Jour. Aero. Sci., vol. 18, no. 1, Jan. 1951, pp. 7-20.

5. Chapman, Dean R.: An Analysis of Base Pressure at Supersonic Velocities and Comparison With Experiment. NACA Rep. 1051, 1951. (Supersedes NACA TN 2137.)

6. Van Dyke, Milton D.: Practical Calculation of Second-Order Supersonic Flow Past Nonlifting Bodies of Revolution. NACA TN 2744, 1952.

TABLE I.- NOSE ORDINATES OF MODELS A AND B

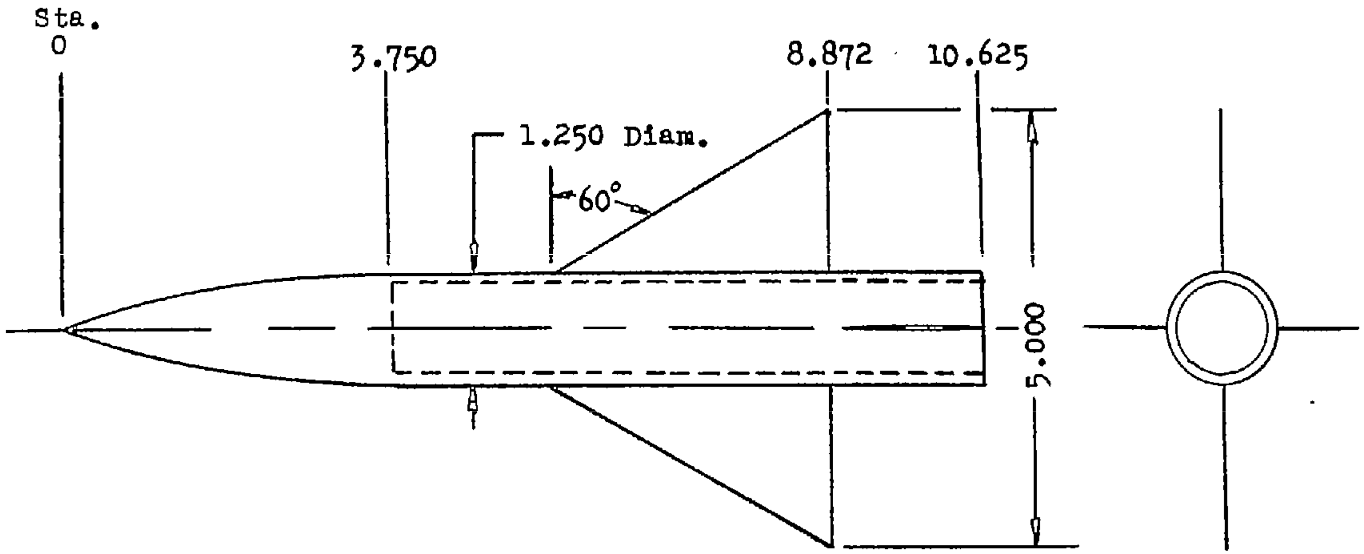
$$\left[r = \frac{x}{3}\left[1 - \frac{1}{9}\left(\frac{x}{D}\right)^2 + \frac{1}{54}\left(\frac{x}{D}\right)^3\right] \quad \text{where} \quad D = 1.25\right]$$

Nose ordinates	
x, in.	r, in.
0	0
.188	.063
.375	.124
.563	.184
.750	.241
.938	.296
1.125	.343
1.313	.394
1.500	.436
1.688	.475
1.875	.508
2.063	.537
2.250	.561
2.438	.580
2.625	.599
2.813	.608
3.000	.616
3.188	.621
3.375	.623
3.563	.624
3.750	.625

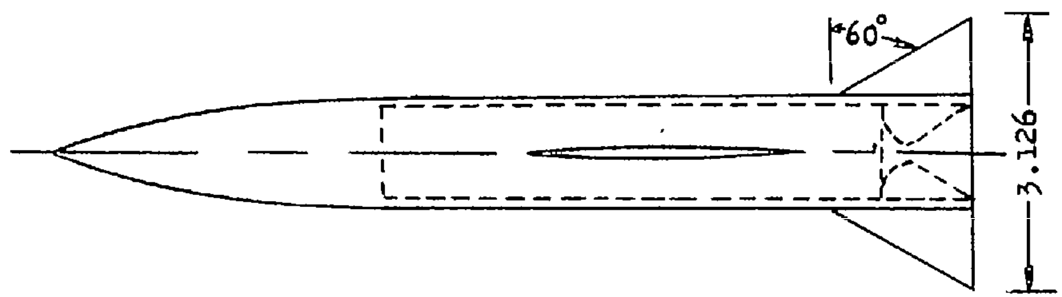
TABLE II.- CALCULATED PRESSURE COEFFICIENTS FOR

SEVERAL MACH NUMBERS

$\frac{x}{r_{max}}$	C_p	$\frac{x}{r_{max}}$	C_p	$\frac{x}{r_{max}}$	C_p
Mach number, 1.3		Mach number, 1.7		Mach number, 2.0	
0	0.4082	0	0.3352	0	0.3146
.3000	.4020	.3000	.3299	.3000	.3092
.4038	.3971	.4176	.3269	.5160	.3029
.5430	.3875	.5808	.3177	.8856	.2791
.7296	.3727	.8070	.3036	1.5120	.2272
.9786	.3467	1.1190	.2775	2.5428	.1215
1.3098	.3052	1.5450	.2346	4.1184	-.0197
1.7460	.2414	2.1174	.1695	6.0000	-.0517
2.3064	.1541	2.8644	.0840		
3.0096	.0507	3.7950	-.0046		
3.8550	-.0464	4.8786	-.0647		
4.8156	-.1072	6.0000	-.0681		
5.8392	-.1063				
6.0000	-.1009				



(a) Plan view, model A.



(b) Side view, model B.

Figure 1.- Sketch of AGARD model 2 as tested in free flight. Dotted lines indicate internal construction of models. All dimensions are in inches unless otherwise noted.

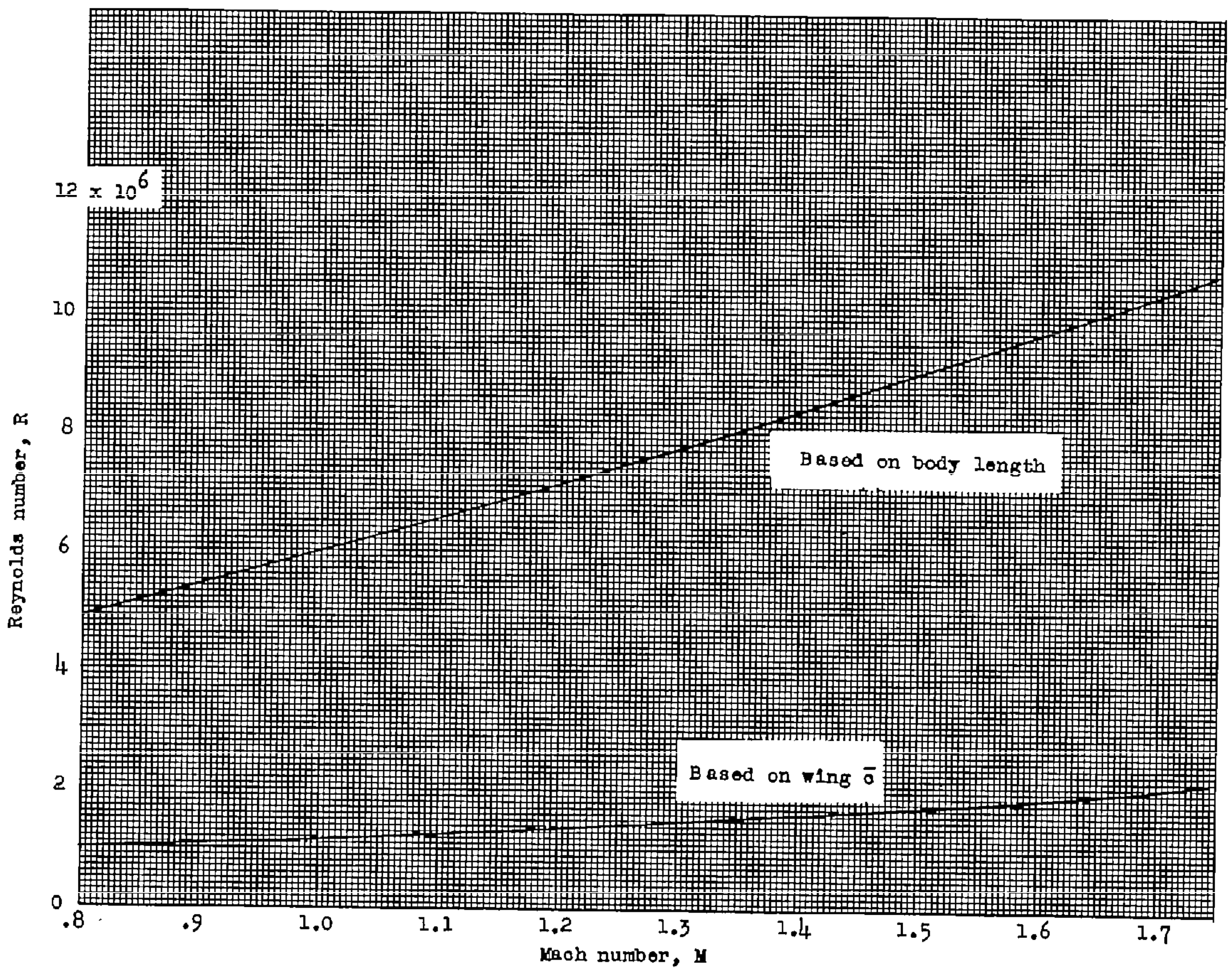


Figure 2.- Test Reynolds numbers.

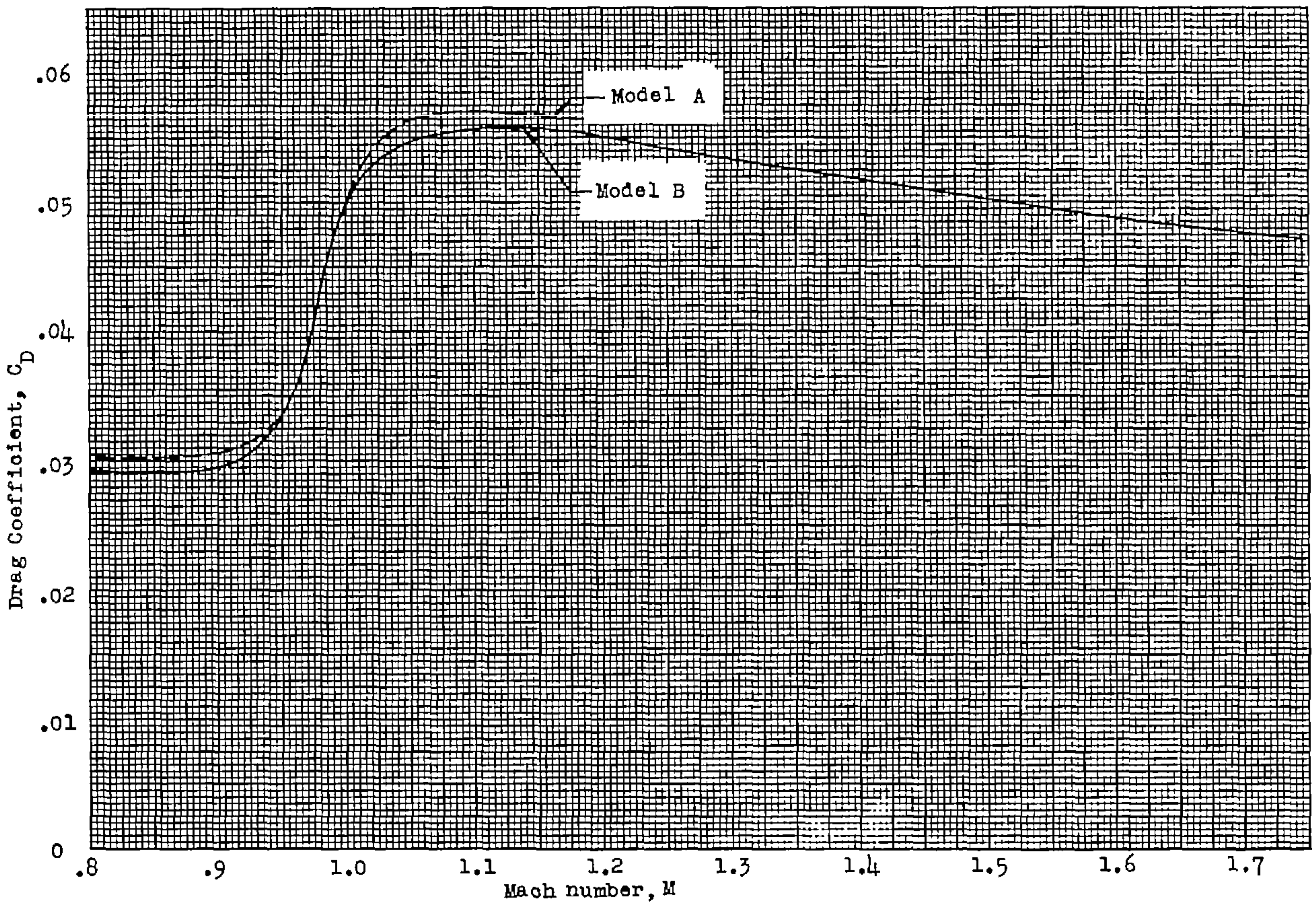


Figure 3.- Drag coefficients of models A and B based on total wing area.

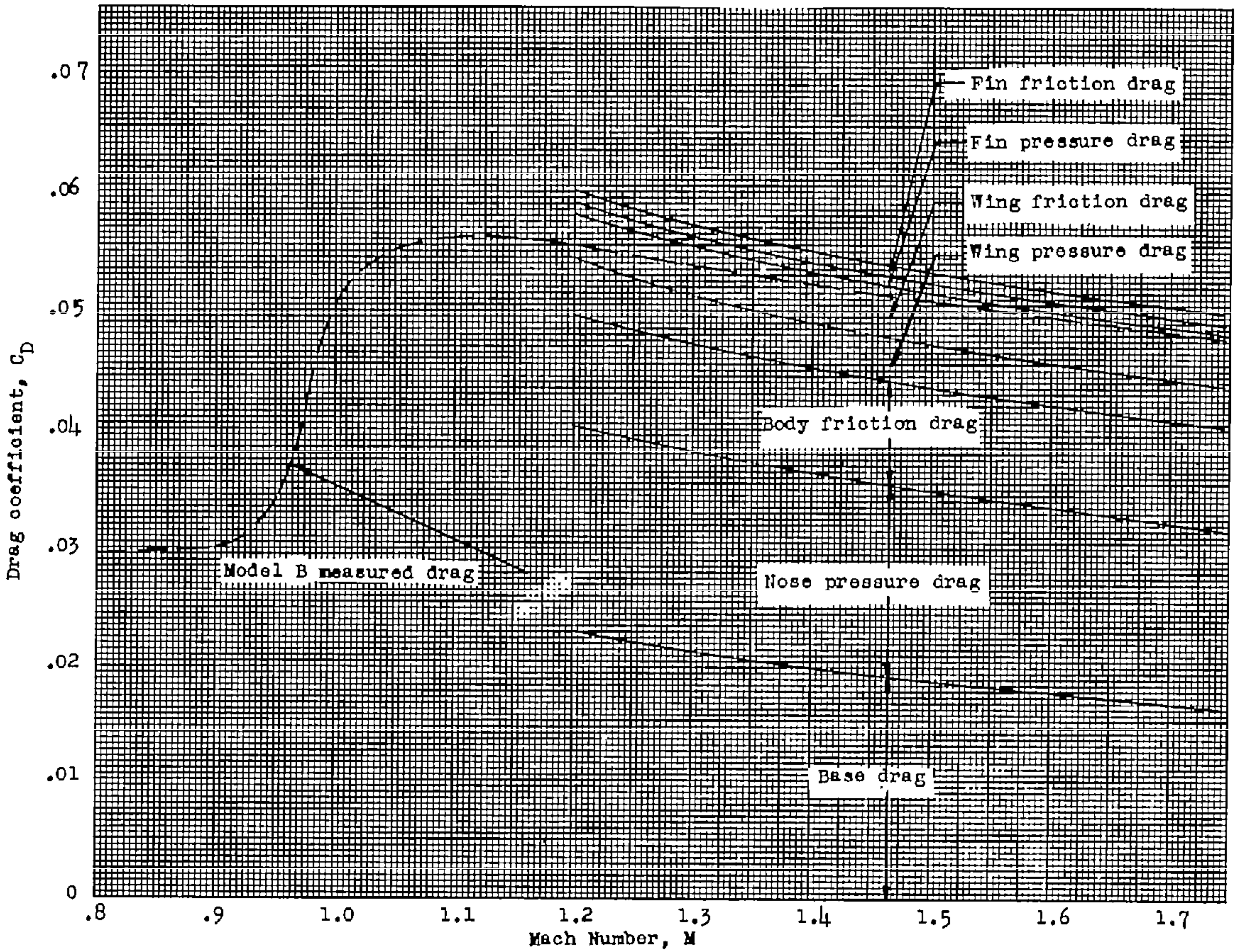


Figure 4.- Estimate of the drag of the configuration.

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