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RESEARCH MEMORANDUM

MEASUREMENTS OF THE EFFECT OF TRAILING-EDGE THICKNESS ON THE ZERO-LIFT DRAG OF THIN LOW-ASPECT-RATIO WINGS

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RESEARCH MEMORANDUM

MEASUREMENTS OF THE EFFECT OF TRAILING-EDGE THICKNESS ON THE ZERO-LIFT DRAG OF THIN LOW-ASPECT-RATIO WINGS

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SUMMARY

Results of an exploratory free-flight investigation at zero lift of several rocket-powered drag-research models having tapered 4-percent-thick wings are presented for a Mach number range of 0.7 to 1.6. Wings having an aspect ratio of 3.11 and trailing-edge thickness of 0, 1/3 maximum thickness, 2/3 maximum thickness, and 3/3 maximum thickness were tested. The sections were identical circular arcs back to the 40-percent-chord station. The remainder of the section was formed by drawing a tangent from the various thickness trailing edges to the extended circular arc. The data obtained indicated that an increase in the ratio of trailing-edge thickness to maximum thickness caused a corresponding increase in wing drag coefficient throughout the Mach number range investigated, which was due to the increased area over which the base suction acts.

By use of the linear theory and base-pressure values measured on a 6-percent-thick blunt-trailing-edge wing, the calculated wing drag coefficients at Mach numbers from 1.3 to 1.5 compared favorably with the test results. Thus the base pressure coefficient of blunt-base airfoil sections appears to be constant with base thickness in the range of thicknesses from 6 to 1.3 percent chord for Mach numbers of 1.3 to 1.5.

INTRODUCTION

Recent experiments indicate that airfoil sections having sharp leading and trailing edges heretofore considered good at supersonic speeds may be inferior to blunt-trailing-edge airfoils when compared on the basis of drag-stiffness ratio and when used as control surfaces.

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References 1 and 2 point out the need for further research and the possibilities of the blunt-trailing-edge airfoil. The design of such wing sections depends to a large degree on the magnitude of the pressures developed over the flat base of the trailing edge.

In view of the scarcity of data on wings having blunt bases, the NACA has conducted a rocket-powered-model flight test at its Pilotless Aircraft Research Station at Wallops Island, Va., to determine the effect of various thickness wing bases on the drag of a thin tapered wing. An additional purpose was to obtain a comparison of the calculated wing drag coefficient, by use of the linear theory and measured base-pressure-coefficient values of reference 2, with the experimental wing drag coefficient. The results obtained with the four models used in this investigation are presented herein.

The wing drag presented in this paper includes the mutual interference drag between wings, body, and stabilizing fins. Results are presented for a Mach number range of 0.7 to 1.6 corresponding to a Reynolds number range of 3.5×10^6 to 10.2×10^6 based on wing mean aerodynamic chord.

SYMBOLS

C_D drag coefficient based on exposed wing area of 2.072 square feet

M Mach number

A aspect ratio $\left(b^2/S_T\right)$

S_T total wing area, 2.582 square feet to center line of model

S exposed wing area (2.072 sq ft)

b wing span (2.833 ft)

R Reynolds number based on M.A.C.

W weight of the test vehicle, powder expended, pounds

a measured acceleration, feet per second per second

g acceleration of gravity (32.194 ft/sec/sec)

θ angle between model center line and horizontal, degrees

ρ density of air, slugs per cubic foot

V measured velocity, feet per second

T temperature of air, $^{\circ}F$ absolute

MODELS

The general arrangement of the drag-research vehicles used in this investigation is shown in figures 1 and 2. The models were wooden cylinders with pointed wooden ogival noses and were stabilized with four thin metal fins located near the base. The location of the 4-percent-thick wings of 3.11 aspect ratio and 0.423 taper ratio is shown in figure 2. Four models with different wing sections were tested. The trailing-edge thickness of the various sections was 0, 1/3 maximum thickness, 2/3 maximum thickness, and 3/3 maximum thickness. The wing sections of the models were identical circular arcs back to maximum thickness at the 0.4-chord station. From the trailing edge of the wing a line is drawn tangent to the extended circular arc to form the rear portion of the various trailing-edge-thickness airfoils. The center of gravity of the models was located such that the models were stable throughout the test flight. The two stage models were propelled by 3.25-inch aircraft rocket motors contained within the fuselage and were boosted by 5-inch HVAR rocket motors.

TESTS

The models were flown at the Pilotless Aircraft Research Station at Wallops Island, Va. The test technique consists essentially of measuring the straight-line distance from the launching site to the model, ascertaining the flight path of the model, and obtaining an atmospheric survey at the time of firing. The data from these three sources are used in the equations below to determine the drag coefficient C_D and Mach number M for a given model.

$$C_D = \frac{-2W(a + g \sin \theta)}{g\rho S V^2}$$

$$M = \frac{V}{49.2\sqrt{T}}$$

The atmospheric quantities ρ and T are measured with respect to altitude by radiosonde and are tied into the flight history of the model by altitude-time measurements taken from the SCR 584 radar tracking unit. The angle θ is determined from the trajectory described by the SCR 584 unit by assuming the model to be flying at zero lift. The velocity and acceleration time histories are reduced from measurements taken from the CW Doppler radar velocimeter unit. The Doppler unit furnishes a time history of the straight-line distance between the model and the launching site. Velocity is obtained from the first derivative of the distance-time variation and acceleration is obtained from the second derivative corrected for flight-path curvature. The method by which these two differentiations are obtained has been analytically developed to its present state of precision, which generally results in a maximum possible velocity error of less than 0.5 foot per second and possible acceleration error less than 3 feet per second per second. The probable inaccuracy in the values of wing drag coefficient is approximately ±0.002 except at the extreme ends of the Mach number range. The Mach number is believed to be accurate to within ±0.01.

The average Reynolds number of the four models based on M.A.C. of 0.962 foot varied from 3.5×10^6 at a Mach number of 0.7 to 10.2×10^6 at a Mach number of 1.6. A plot of Reynolds number against Mach number is shown in figure 3.

RESULTS AND DISCUSSION

The total-drag-coefficient curve plotted against Mach number for each of the models investigated is given in figure 4. A curve for a wingless model (reference 2) is also shown in figure 4 in order that the wing drag coefficient may be found. A comparison of the wing drag coefficients (fig. 5) shows that an increase in base thickness causes an increase in wing drag coefficient which is due to the increased area over which the base suction acts.

Also shown in figure 5 are calculated wing drag coefficients for each of the four profiles, computed at three Mach numbers by use of base pressure coefficients measured on a 6-percent-thick blunt-base airfoil (reference 2). The calculated points agree reasonably well with the experimental results, this agreement indicating that, for a given Mach number, the base pressure coefficient appeared to be constant from the range of base thicknesses from 6 percent to 1.3 percent chord over the Mach number range from 1.3 to 1.5 and in the Reynolds number range of the tests. This result is in agreement with reference 1 and other data from the Ames 1- by 3-foot supersonic tunnel.

Figure 6 shows the computed drag-coefficient components for a Mach number of 1.4 plotted against the ratio of wing base thickness to maximum thickness. The base drag component was calculated from the base-pressure-coefficient curve of a 6-percent-thick blunt-base airfoil presented in reference 2. The wave drag component was calculated by the linearized theory as presented in reference 3. The friction drag component was estimated to be 0.006 based on exposed plan-form area. Also shown in figure 6 are experimental points for the four different configurations.

CONCLUDING REMARKS

An exploratory rocket-powered flight investigation of drag-research models has been conducted at zero lift for a Mach number range from 0.7 to 1.6. The data obtained indicate that an increase in the ratio of wing base thickness to maximum thickness causes a corresponding increase in wing drag which is due to the increased area over which the base suction acts. By use of the linear theory and base pressure values measured on a 6-percent-thick wing, the calculated wing drag coefficient at Mach numbers from 1.3 to 1.5 compared favorably with the test results. Thus, the base pressure coefficients of blunt-base airfoil sections appear to be constant with base thickness in the range of thicknesses from 6 to 1.3 percent chord for Mach numbers of 1.3 to 1.5. The pointed trailing-edge airfoil had the lowest drag throughout the Mach number range investigated, and the section with base thickness equal to maximum thickness had the highest drag throughout the Mach number range.

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National Advisory Committee for Aeronautics
Langley Air Force Base, Va.

REFERENCES

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2. Morrow, John D., and Katz, Ellis: Flight Investigation at Mach Numbers from 0.6 to 1.7 to Determine Drag and Base Pressure on a Blunt-Trailing-Edge Airfoil and Drag of Diamond and Circular-Arc Airfoils at Zero Lift. NACA RM L50E19a, 1950.

3. Bonney, E. Arthur: Aerodynamic Characteristics of Rectangular Wings at Supersonic Speeds. Jour. Aero. Sci., vol. 14, no. 2, Feb. 1947, pp. 110-116.

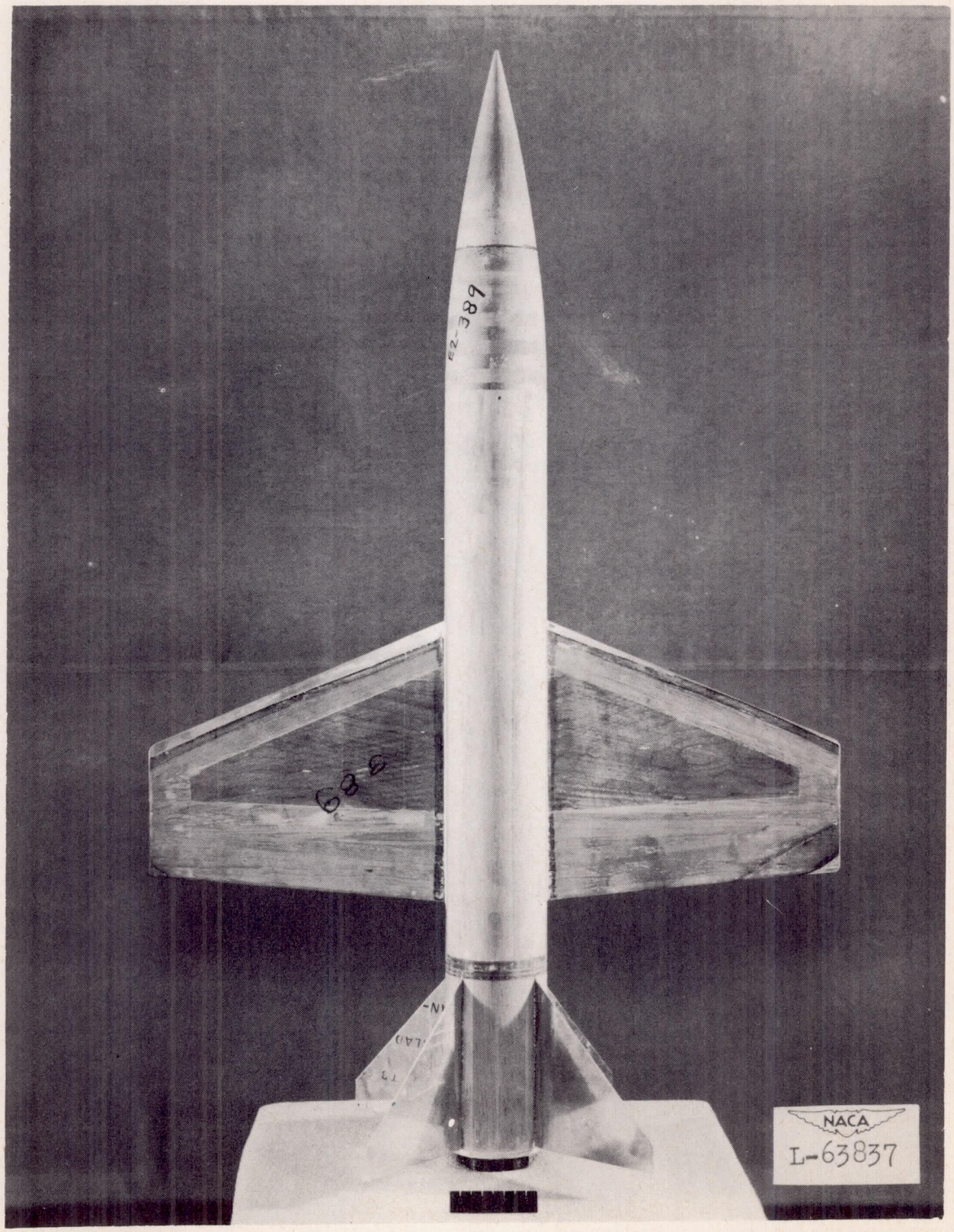
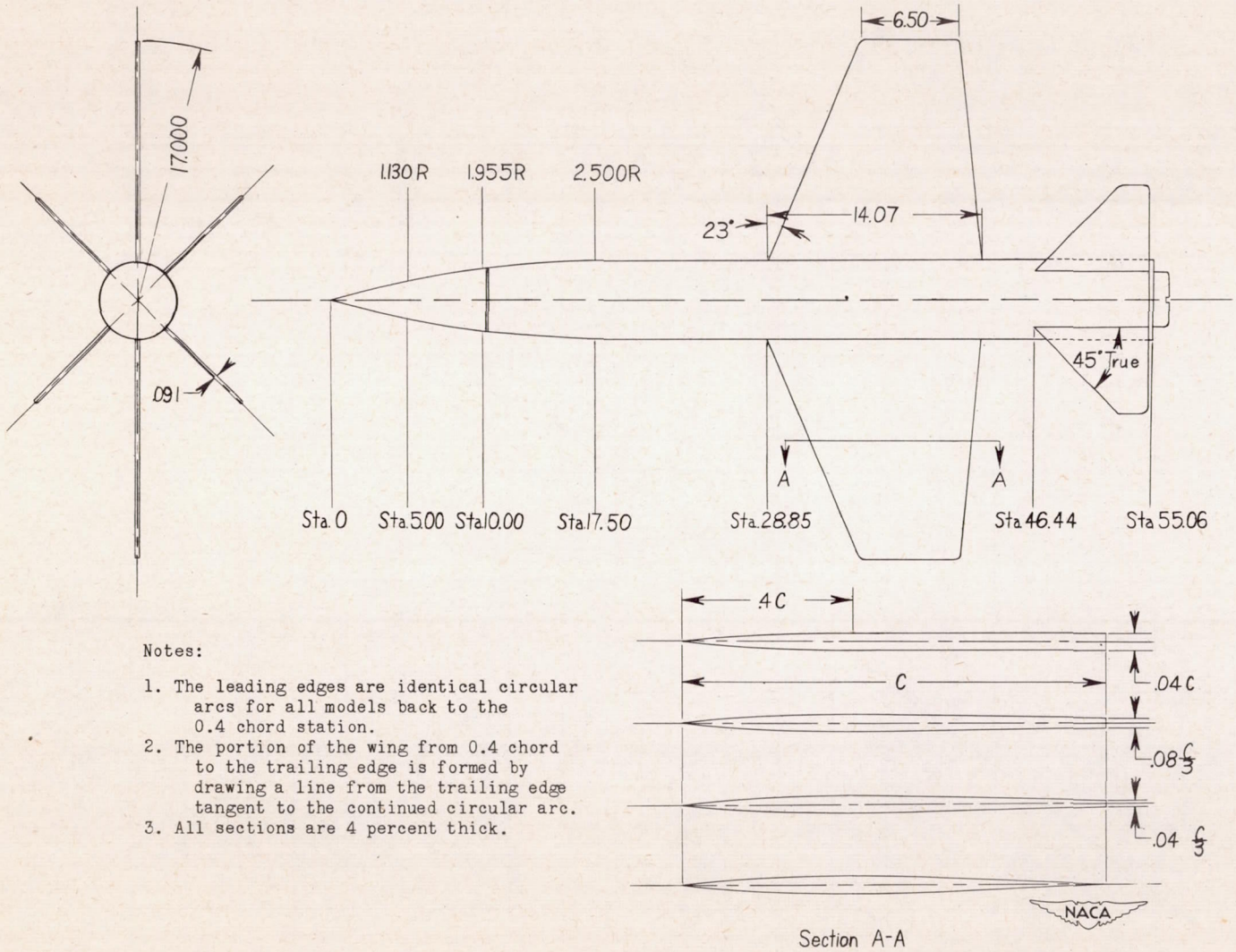


Figure 1.- Typical wing plan form for the configurations tested.



Notes:

1. The leading edges are identical circular arcs for all models back to the 0.4 chord station.
2. The portion of the wing from 0.4 chord to the trailing edge is formed by drawing a line from the trailing edge tangent to the continued circular arc.
3. All sections are 4 percent thick.

Figure 2.- General arrangement of vehicle showing each airfoil section investigated.

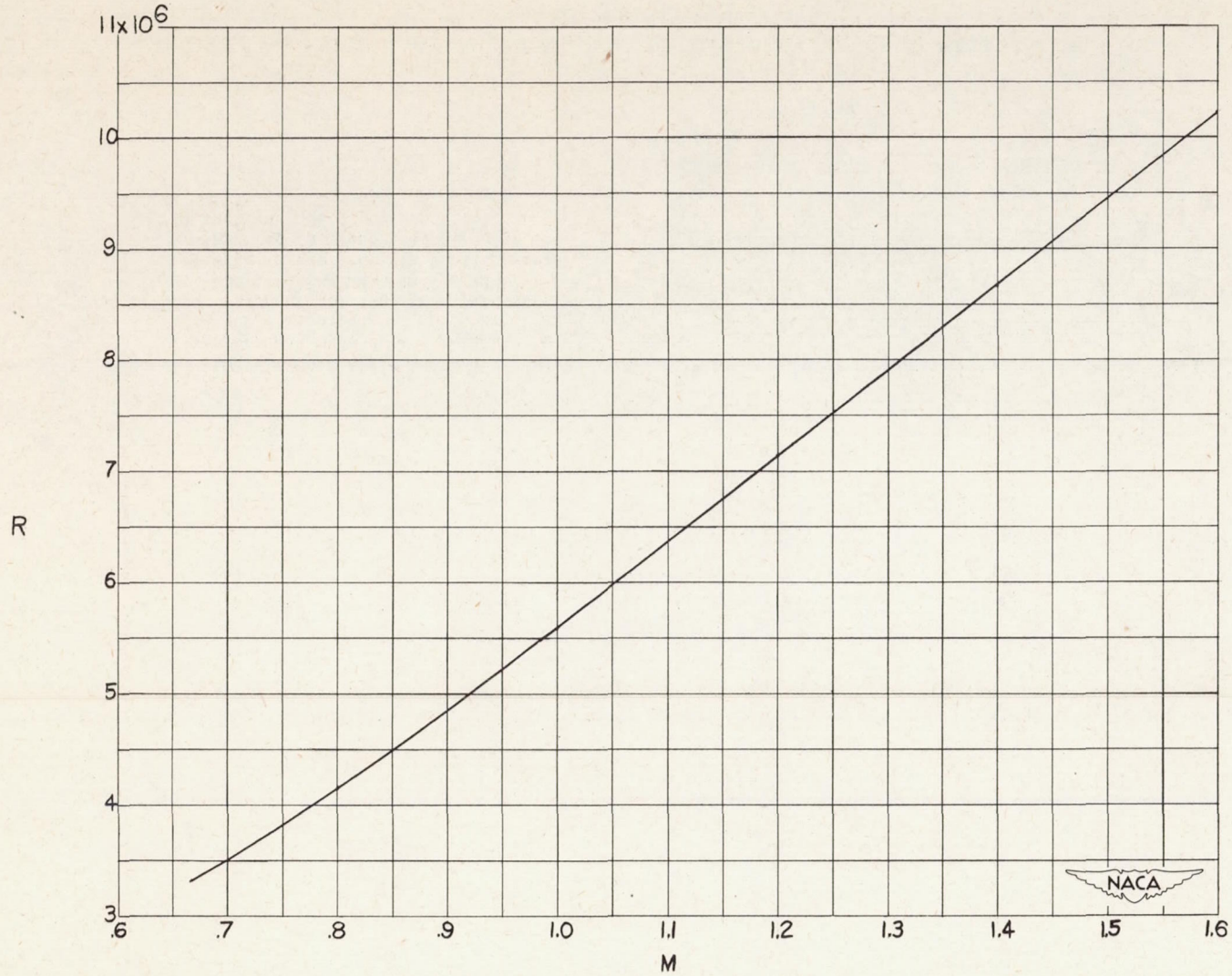


Figure 3.- Reynolds number based on mean aerodynamic chord of 0.962 foot plotted against Mach number.

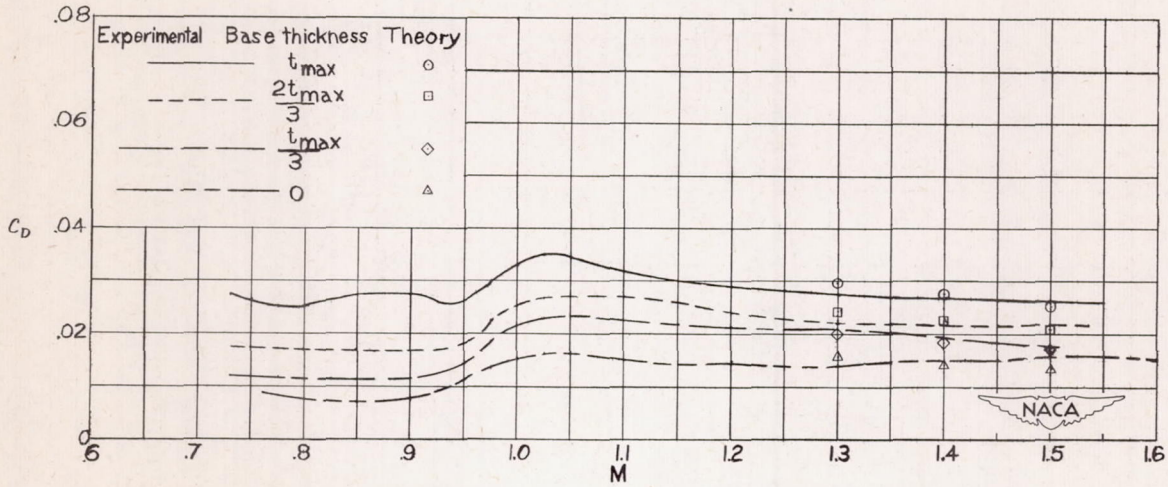


Figure 5.- Comparison of experimental and calculated wing-alone drag coefficients for the four sections plotted against Mach number. The wing drag coefficients are based on exposed wing area of 2.07 square feet.

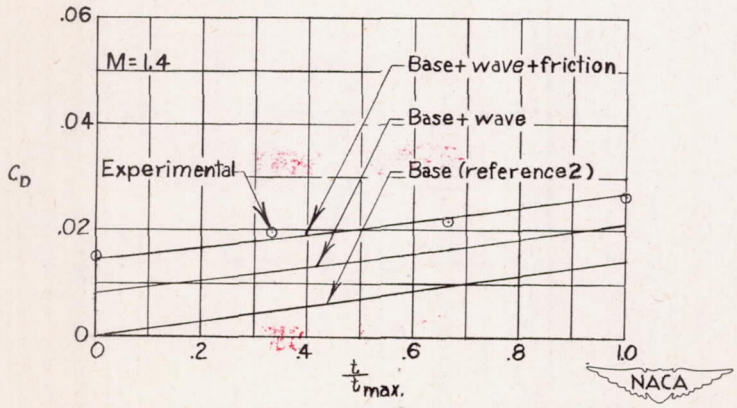


Figure 6.- Drag-coefficient components calculated at M = 1.4 plotted against the ratio of wing base thickness to maximum thickness.

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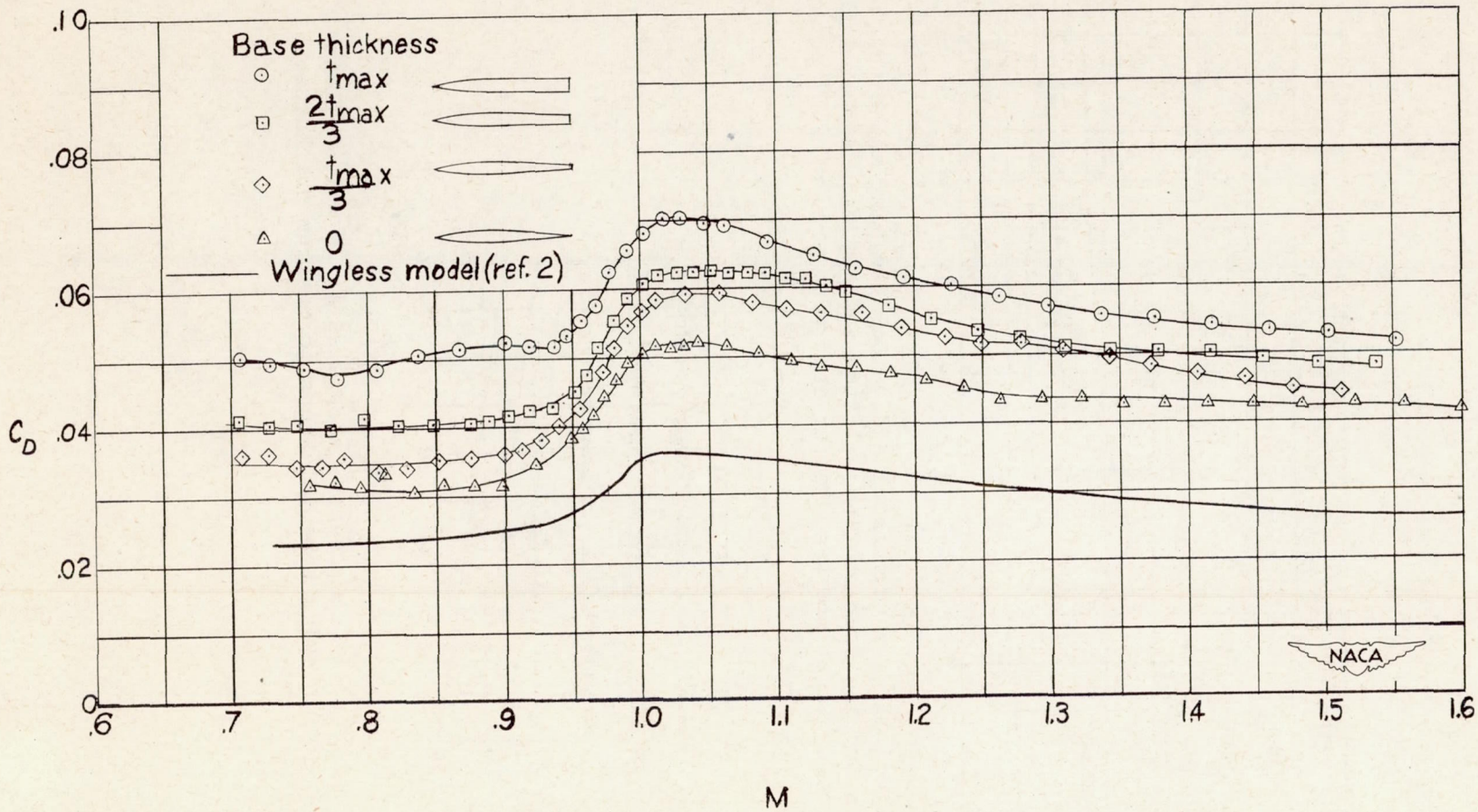

Figure 4.- Total-drag coefficient plotted against Mach number for the four different winged configurations and a wingless configuration. The total-drag coefficient is based on exposed wing area of 2.07 square feet.

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