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RESEARCH MEMORANDUM

RESULTS OF FLIGHT TESTS TO DETERMINE THE ZERO-LIFT DRAG CHARACTERISTICS OF A 60° DELTA WING WITH NACA 65-006 AIRFOIL SECTION AND VARIOUS DOUBLE-WEDGE SECTIONS AT MACH NUMBERS FROM 0.7 TO 1.6

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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RESULTS OF FLIGHT TESTS TO DETERMINE THE ZERO-LIFT DRAG CHARACTERISTICS OF A 60° DELTA WING WITH NACA 65-006 AIRFOIL SECTION AND VARIOUS DOUBLE-WEDGE SECTIONS AT MACH NUMBERS FROM 0.7 TO 1.6

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SUMMARY

Results of an exploratory free-flight investigation at zero lift of several rocket-powered drag research models equipped with 60° swept-back delta wings are presented for a Mach number range from about 0.70 to 1.60. The airfoil sections tested included the NACA 65-006 and a series of double-wedge sections with various thicknesses and positions of maximum thickness.

The results of tests showed that, of the double-wedge sections with 6-percent thickness ratio, the two sections with positions of maximum thickness at 20 and 50 percent of the chord had drag coefficients approximately equal through the transonic and supersonic Mach number range and had similarly occurring drag rises. The section with position of maximum thickness at 80 percent chord had a drag rise occurring at approximately 0.15 Mach number lower than the drag rise of the other two sections. At M = 1.0, this section had drag coefficients more than twice those of the other two sections; however, this difference decreased with increasing supersonic Mach numbers. The wing drag calculated by the linearized theory was in qualitative agreement with the test results in indicating the effects of varying the position of maximum thickness. The double-wedge section of 3-percent thickness ratio with position of maximum thickness at 50 percent chord had fairly constant drag coefficients throughout the supersonic region, which ranged from about 50 to 80 percent of the drag coefficients for the similar section with twice the thickness ratio. The theoretical wing drag for this section was in very good agreement with the experimental value. The NACA 65-006 section had lower drag coefficients throughout the test region than any of the double-wedge sections of the same thickness ratio, although at the highest Mach numbers covered by these tests, the differences became very small.

INTRODUCTION

As part of the National Advisory Committee for Aeronautics program to determine the drag characteristics at zero lift of various wings at supersonic, transonic, and high-subsonic speeds, tests of a series of 60° delta wings with varying airfoil sections have been made. These tests were conducted at the Pilotless Aircraft Research Station at Wallops Island, Va., with the wings being mounted on rocket-propelled test bodies.

The results are presented as curves of total drag coefficient and wing drag coefficient against Mach number. Curves of theoretical wing drag coefficients are shown, for the double-wedge-section wings, for comparative purposes.

SYMBOLS

R	Reynolds number based on wing mean aerodynamic chord
C_{D_T}	total drag coefficient based on exposed wing area
C_{D_W}	wing plus wing-body interference drag coefficient based on exposed wing area
t/c	wing thickness ratio
t	maximum wing section thickness
c	wing chord measured parallel to center line of body
M	Mach number
m	mass of the test vehicle, propellant expended
dV/dt	rate of change of velocity along flight path
g	acceleration due to gravity, 32.1740 feet per second per second
γ	flight-path angle, measured from horizontal
ρ	mass density of air
S	exposed wing area
V	velocity along flight path

[redacted]

MODELS

The general arrangement of the drag research models used in the present investigation is shown in figure 1 and a typical plan-view photograph is shown in figure 2. The body of the models was cylindrical with a pointed ogival nose and was stabilized with four thin fins, located near the base. The wings investigated were of delta plan form, had 60° sweepback of the leading edge, were of equal size relative to the body, were mounted on the body in the same location, and differed only in airfoil section. The variations of the airfoil sections of the five configurations investigated are indicated in the table shown in figure 1. Three configurations were double-wedge airfoil sections of 6-percent thickness ratio but having the position of maximum thickness of the section located at 20, 50, and 80 percent of the chord. A fourth configuration was a double-wedge, 3-percent-thick section with maximum thickness at 50 percent chord. The last configuration had an NACA 65-006 airfoil section. Models without wings were flown to make possible the determination of the increment in drag produced by addition of the test wings. For convenience, the double-wedge sections with position of maximum thickness at 50 percent chord will be referred to as symmetric sections in the rest of this paper.

The bodies of the models were made of pine and balsa wood, and the wings and fins were made of aluminum. The models were propelled as two-stage rockets. The first stage or booster employed a 5-inch high-velocity aircraft rocket. The models comprised the second stage and were propelled by a 3.25-inch Mark VII aircraft rocket within the model.

TESTS

The models were flown at the Pilotless Aircraft Research Station, Wallops Island, Va. The tests were performed by the usual method. The models were launched at an elevation angle of approximately 70° above the horizontal and drag measurements made during the coasting period of the model down through the Mach number range to subsonic speeds. From the summation of the forces acting upon the model along the direction of the flight path, the drag force may be found and equated to the standard formula for drag involving the drag coefficient, thus giving

$$C_D = \frac{-2m\left(\frac{dV}{dt} + g \sin \gamma\right)}{\rho S V^2}$$

[redacted]

The range, velocity, and acceleration relative to a point on the ground near the launcher were measured from the ground by a continuous-wave Doppler type radar. The trajectory was measured with an SCR-584 radar theodolite. The trajectory measurements provided the flight-path angle γ, the altitude, and the small corrections to the measured velocity and acceleration necessitated by the slight curvature of the portion of the trajectory during which the drag measurements were obtained. The variation of atmospheric pressure and temperature with altitude, which gives the air density ρ, the velocity of sound for determining the Mach number, and the viscosity of air for determining the Reynolds number, was measured by radiosonde at the time of the tests.

The continuous-wave Doppler type radar furnished a time history of the radial distance to the model. Velocity and acceleration were obtained, respectively, as the first and second time derivatives of this time history. The method by which the two differentiations were obtained has been analytically developed to its present state of precision which is less than 0.5 foot per second velocity error and less than 3 feet per second per second acceleration error.

The wing drag coefficients, including wing-body interference, were obtained as the difference between the drag coefficients of winged and wingless models. The tests were performed with the wings mounted on a readily constructed body which had drag coefficients that were well-established from previous tests. The difference between the drag coefficients of the winged and of the wingless models being small relative to the drag of wingless model, particularly at subsonic speeds, causes low accuracy of the determined wing-plus-interference drag coefficients; however, the accuracy is sufficient for displaying the trends sought in this exploratory investigation. Because of the relatively low accuracy required in this exploratory investigation, repetitive tests were performed in only a few cases, so that assurance is not had that, in the single tests, the results do not deviate from the correct values to an extent greater than the amount normally existing in repetitive tests of this type. From a large number of similar previous tests, the probable error in wing drag coefficients is estimated to be ± 0.002 at $M = 0.80$, ± 0.0013 at $M = 1.1$, and 0.0035 and -0.0015 at $M = 1.4$. The probable error in Mach number is estimated to be ± 0.01 at $M = 0.8$ and ± 0.005 at $M = 1.4$.

The average Reynolds number of the ten models tested, based on wing mean aerodynamic chord of 15.25 inches, varied from 3.5×10^6 at $M = 0.61$ to 14.2×10^6 at $M = 1.75$. A plot of Reynolds number against Mach number is shown in figure 3.

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RESULTS AND DISCUSSION

The total drag coefficients C_{D_T} plotted against Mach number M for all the configurations investigated including the basic wingless body are presented in figure 4. Two models were flown for each of the five configurations tested; however, data were obtained for only one model for each of the two symmetrical, double-wedge section configurations. The drag of the wingless body was subtracted from the total drag of each configuration leaving the wing drag plus wing-body interference drag for each. This wing drag coefficient is shown plotted against Mach number M in figures 5 and 6.

Calculated wing drag coefficients are also shown in figures 5 and 6 for the double-wedge sections. The calculated values include a constant viscous drag coefficient, estimated at 0.006, which has been added to the theoretical wave drag coefficients obtained from reference 1.

Of the double-wedge sections with 6-percent thickness ratio, the two sections with positions of maximum thickness at 20 and 50 percent of the chord had drag coefficients approximately equal through the transonic and supersonic Mach number range and had similarly occurring drag rises. The section with position of maximum thickness at 80 percent chord had a drag rise occurring at approximately 0.15 Mach number lower than the drag rise of the other two sections. At M = 1.0, this section had drag coefficients more than twice those of the other two sections; however, this difference decreased with increasing supersonic Mach numbers. The wing drag calculated by the linearized theory was in qualitative agreement with the test results in indicating the effects of varying the position of maximum thickness.

The symmetrical, double-wedge section of 3-percent thickness ratio had fairly constant drag coefficients throughout the supersonic region, which ranged from about 50 to 80 percent of the drag coefficients for the symmetrical, double-wedge section of 6 percent thickness. The theoretical wing drag for this section was in very good agreement with the experimental value.

The NACA 65-006 section had lower drag coefficients throughout the test region than the symmetric double-wedge section of the same thickness ratio. In the region of M = 0.975, the NACA 65-006 section appears to show a favorable wing-body interference drag.

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CONCLUDING REMARKS

Measurements of the effect of airfoil section on the wing plus wing-body interference drag at zero lift of delta-plan-form wings having 60° leading-edge sweepback and tested at high Reynolds numbers over the Mach number range from about 0.7 to 1.6 in free flight on cylindrical, fin-stabilized bodies with pointed nose lead to the following conclusions.

1. Of the double-wedge sections with 6-percent thickness ratio, the two sections with positions of maximum thickness at 20 and 50 percent of the chord had drag coefficients approximately equal through the transonic and supersonic Mach number range and had similarly occurring drag rises. The section with position of maximum thickness at 80 percent chord had a drag rise occurring at approximately 0.15 Mach number lower than the drag rise of the other two sections. At M = 1.0, this section had drag coefficients more than twice those of the other two sections; however, this difference decreased with increasing supersonic Mach numbers. The wing drag calculated by the linearized theory was in qualitative agreement with the test results in indicating the effects of varying the position of maximum thickness.

2. The symmetric, double-wedge section of 3-percent thickness ratio had fairly constant drag coefficient throughout the supersonic region which ranged from about 50 to 80 percent of the drag coefficients for the symmetric, double-wedge section of 6-percent thickness ratio. The theoretical wing drag for this section was in very good agreement with the experimental value.

3. The NACA 65-006 section had lower drag coefficients throughout the investigated transonic and supersonic regions than any of the double-wedge sections of the same thickness ratio, although at the highest Mach numbers reached, the differences became very small.

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REFERENCE

1. Puckett, Allen E. and Stewart, H. J.: Aerodynamic Performance of Delta Wings at Supersonic Speeds. Jour. Aero. Sci., vol. 14, no. 10, Oct. 1947, pp. 567-578.

[redacted]

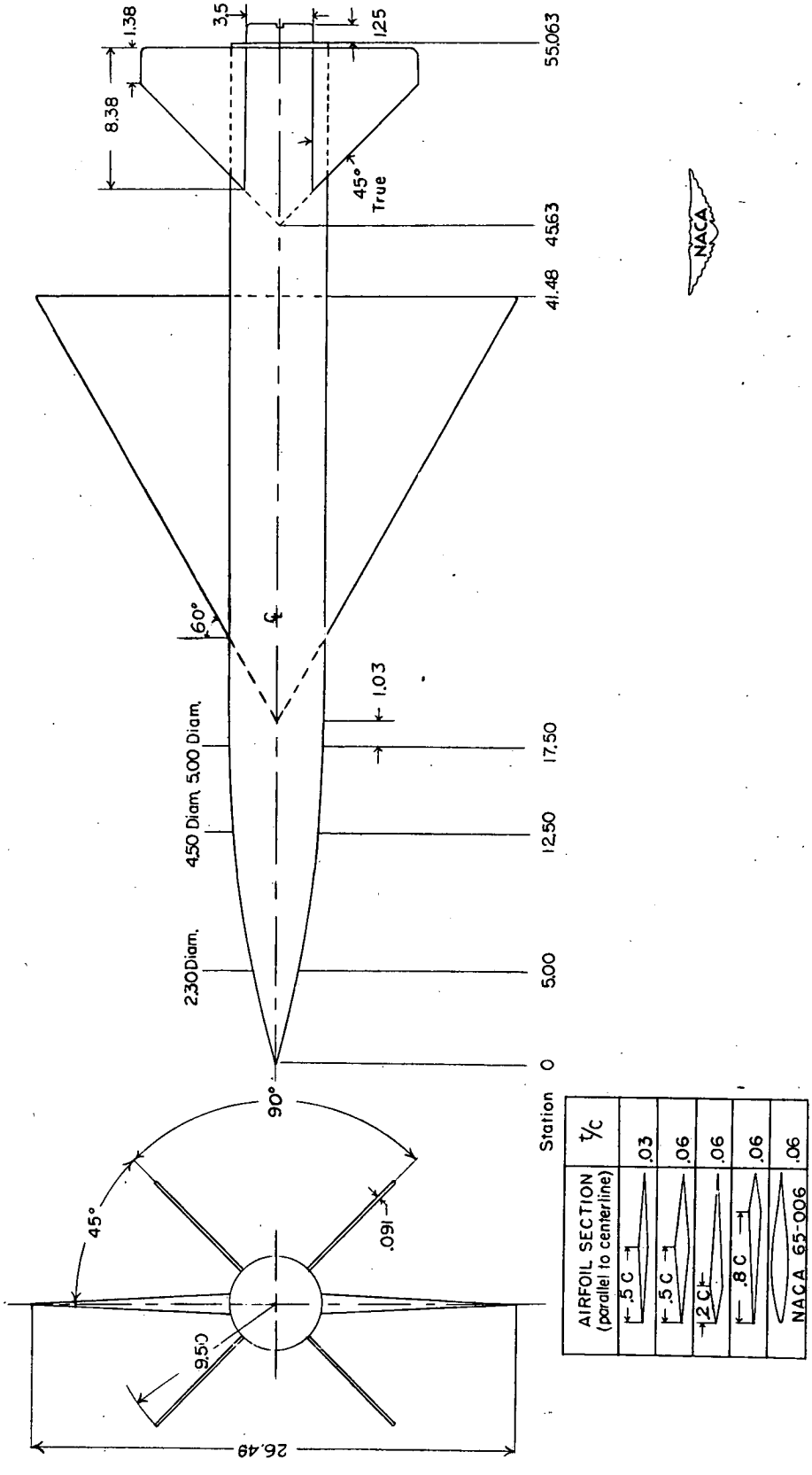

Figure 1.- General arrangement of drag research vehicle with delta wing. Table shows different wing airfoil sections investigated. All linear dimensions are in inches.

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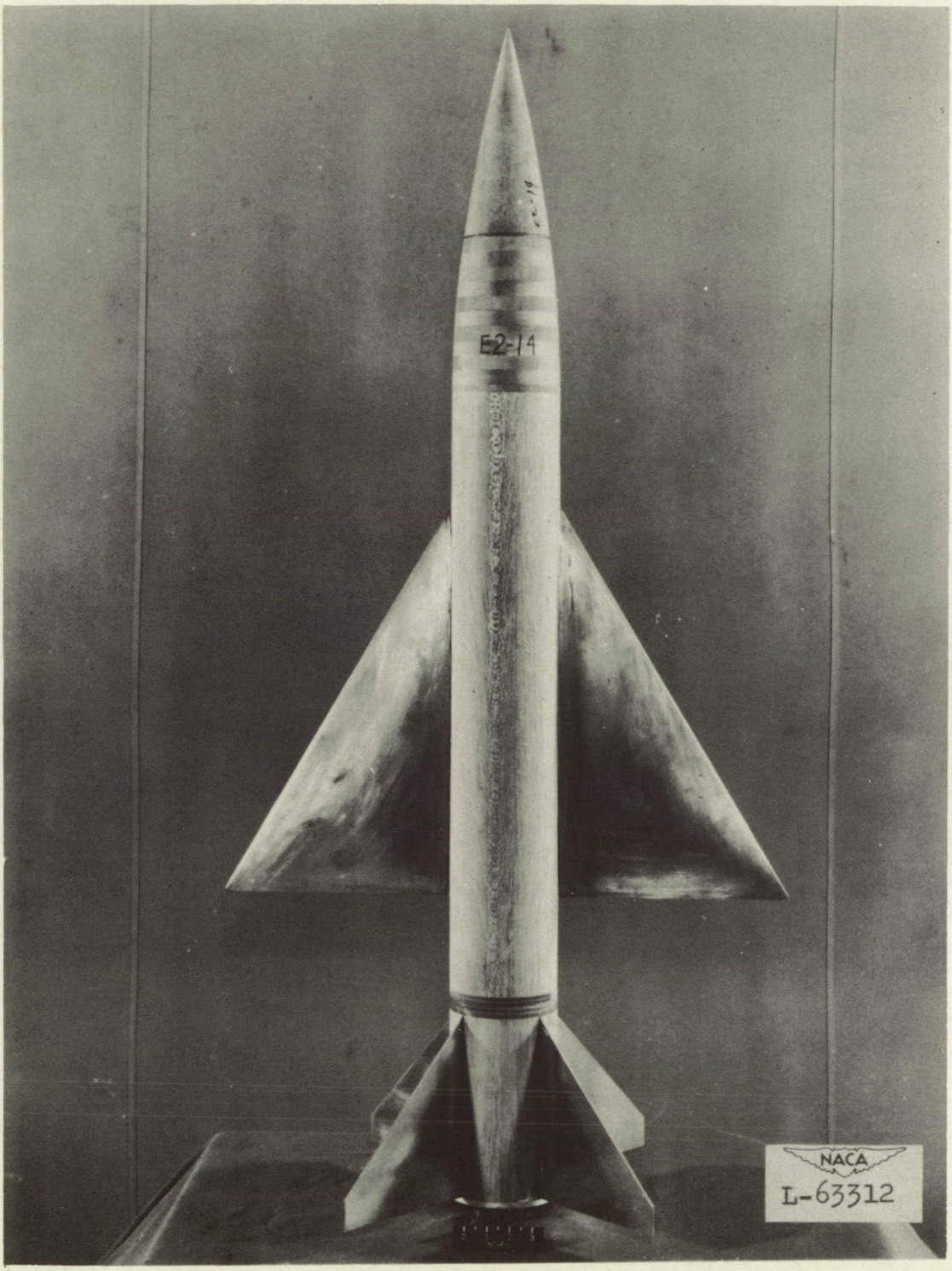

Figure 2.- Test vehicle showing plan view of delta wings investigated.

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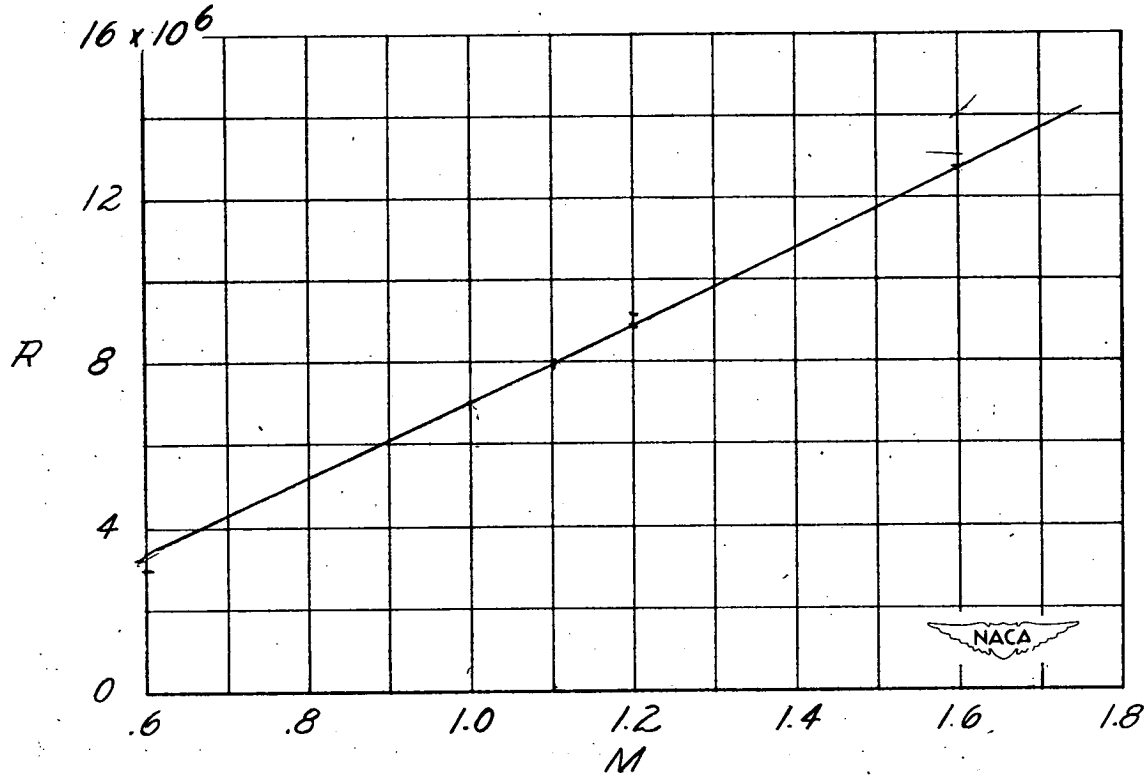

Figure 3.- Average variation of Reynolds number with Mach number for all models tested, based on mean aerodynamic chord of the wing, 15.25 inches.

[redacted]

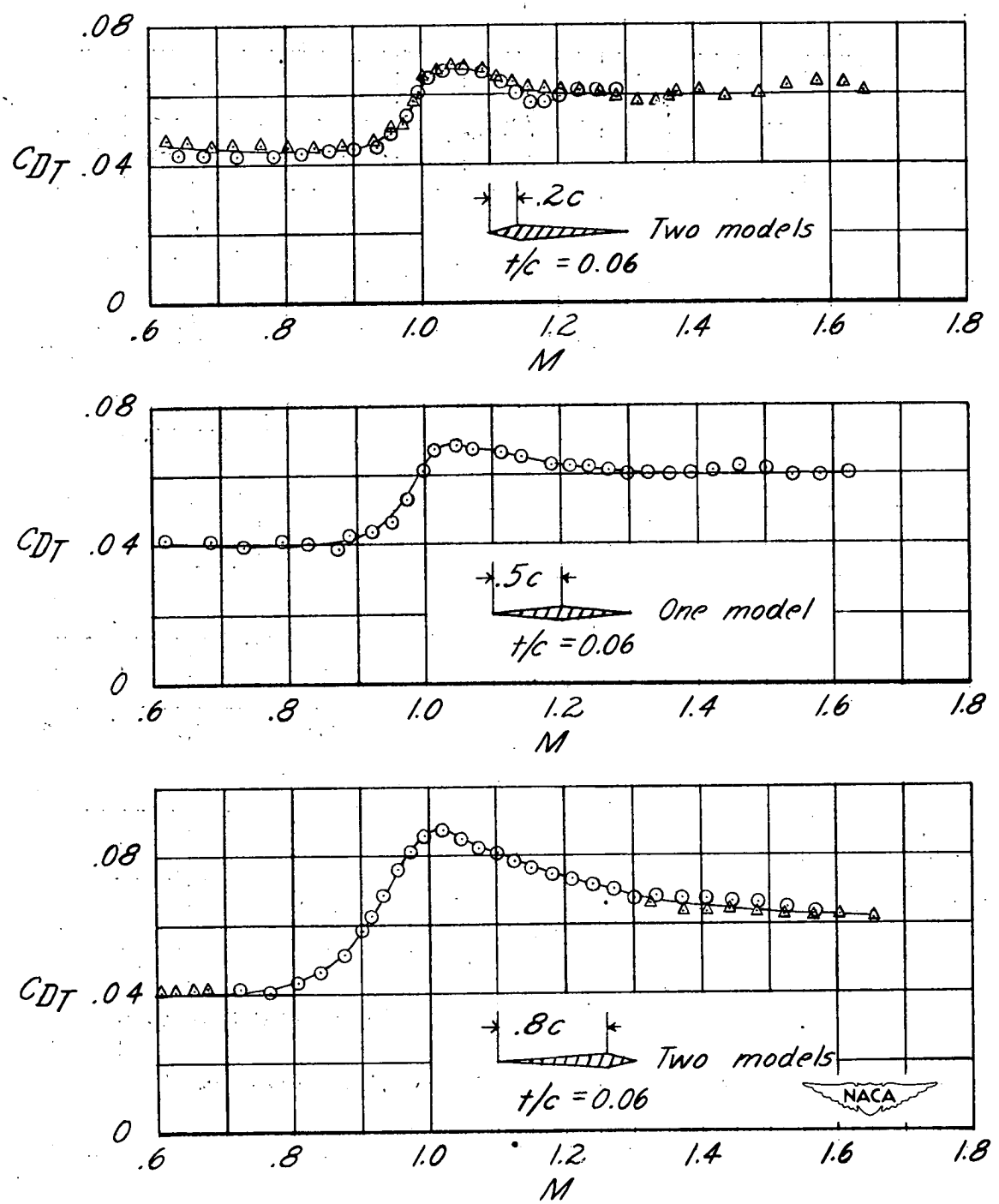

Figure 4.- Variation of total drag coefficient with Mach number. Wing of 200 square inches; aspect ratio, 2.31; sweepback angle of leading edge, 60°.

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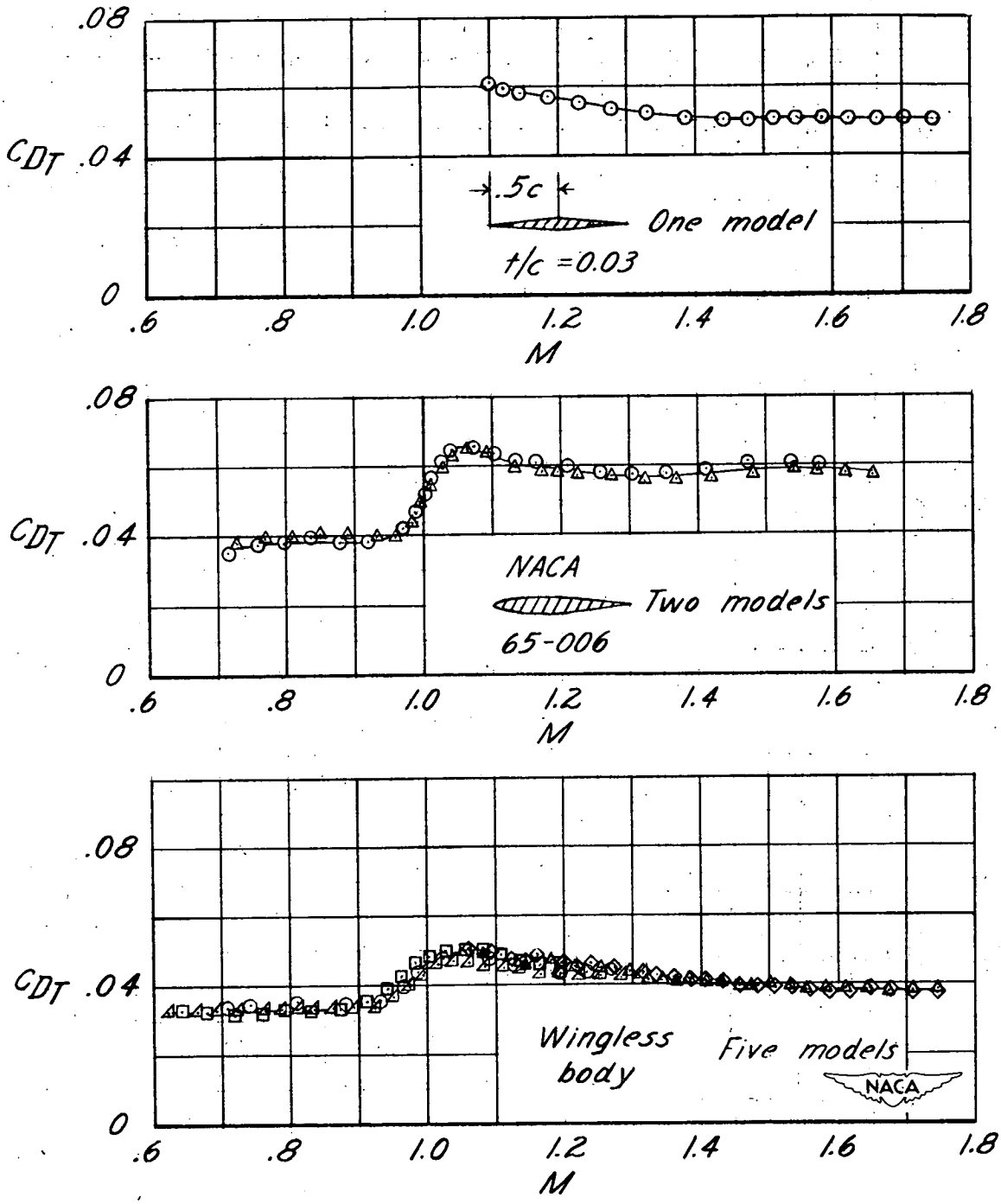
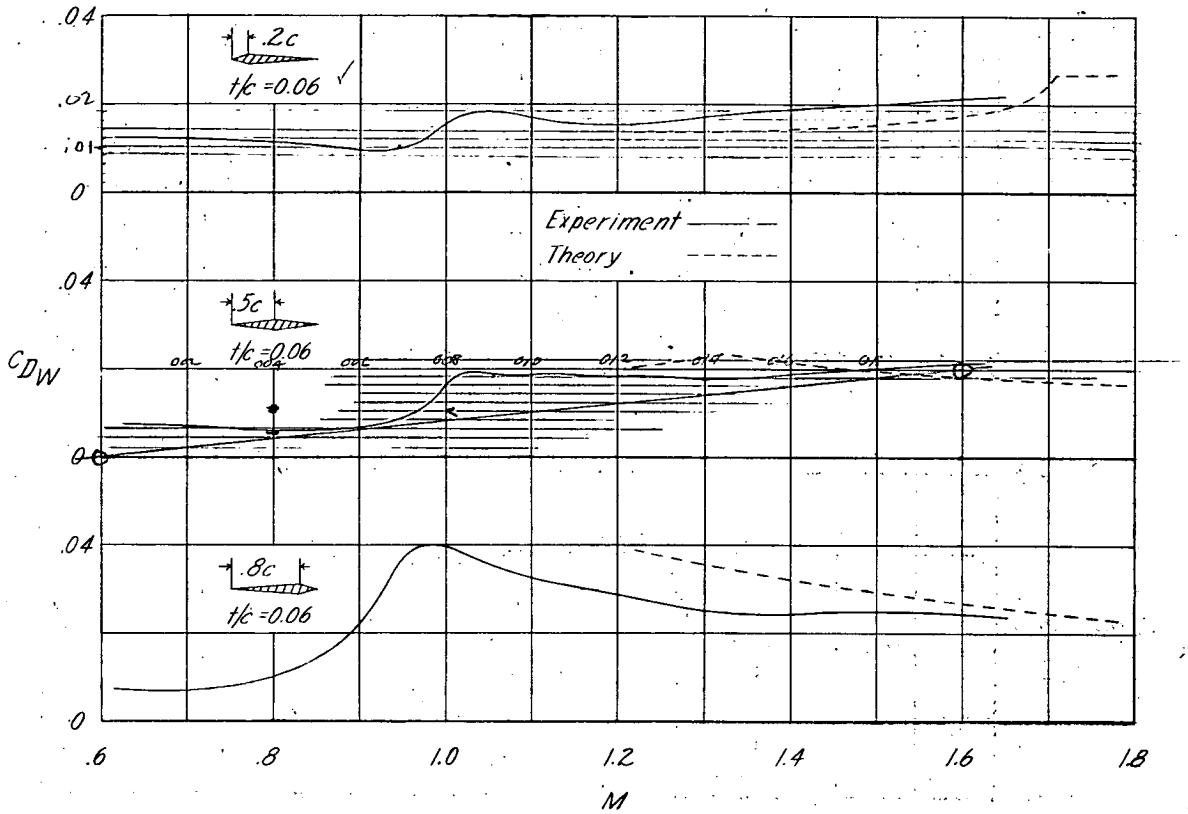
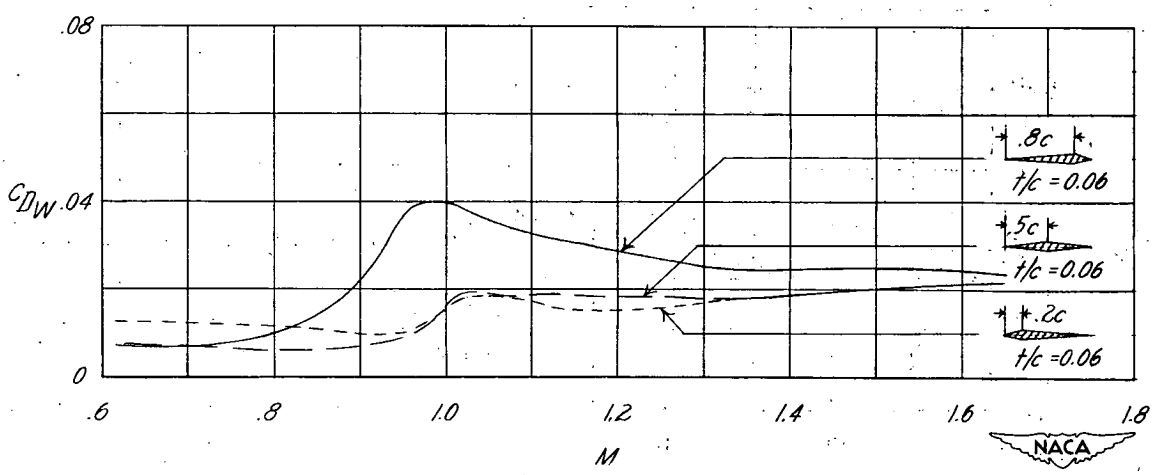


Figure 4.- Concluded.

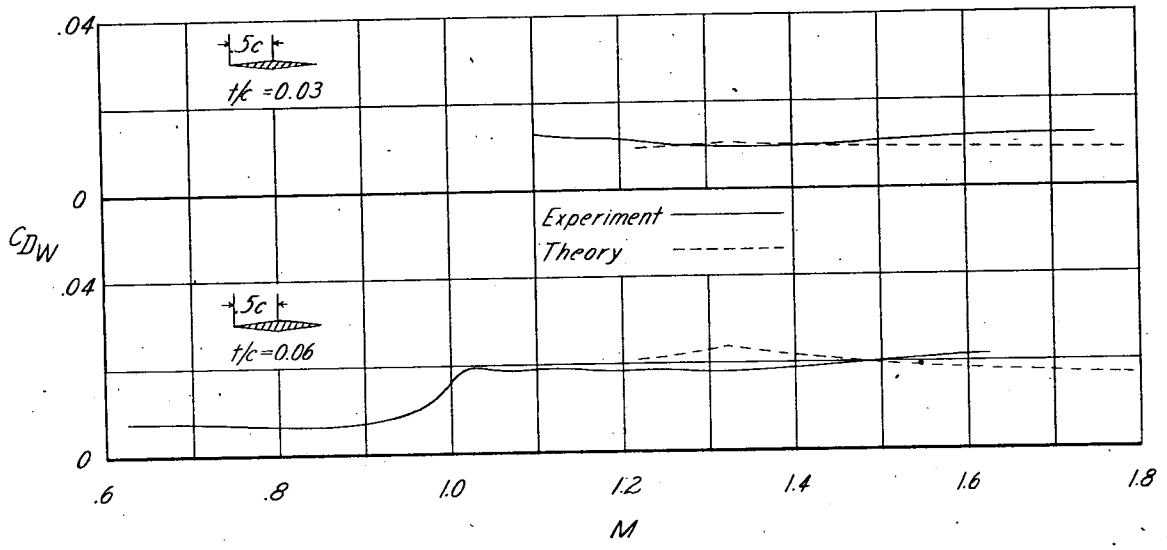


(a) Experimental and theoretical wing drag coefficients.

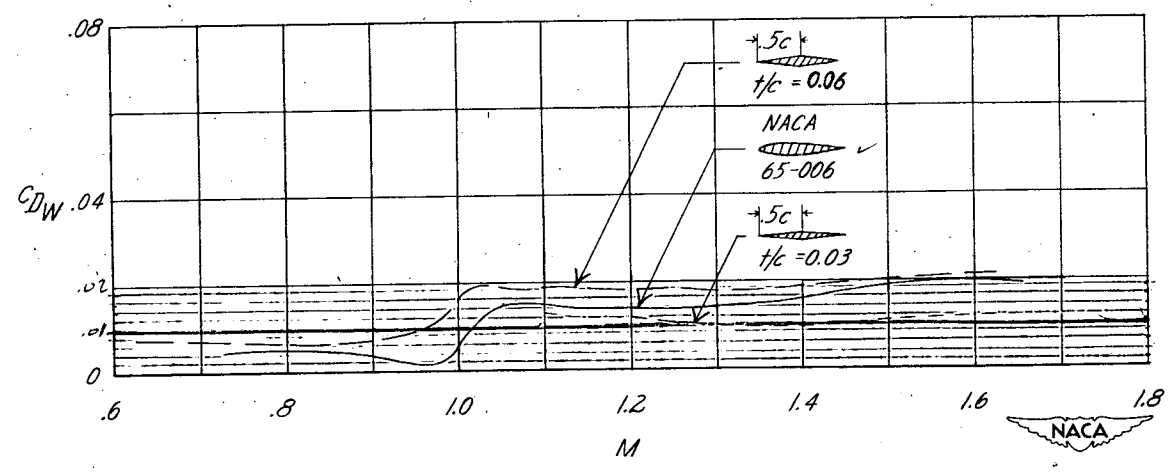


(b) Summary plot of experimental wing drag coefficients.

Figure 5.- Comparison of the wing drag coefficient of the double-wedge sections of 6-percent thickness ratio with varying positions of maximum thickness. The coefficients are based on wing area of 200 square inches.



(a) Experimental and theoretical wing drag coefficients.



(b) Summary plot of experimental wing drag coefficients.

Figure 6.- Comparison of the wing drag coefficients of the NACA 65A006 and two symmetrical double-wedge sections with different thickness ratios. The coefficients are based on wing area of 200 square inches.