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RESEARCH MEMORANDUM

AN INVESTIGATION OF THE DOWNWASH AT THE PROBABLE TAIL LOCATION BEHIND A HIGH-ASPECT-RATIO WING IN THE LANGLEY 8-FOOT HIGH-SPEED TUNNEL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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AN INVESTIGATION OF THE DOWNWASH AT THE PROBABLE TAIL LOCATION BEHIND A HIGH-ASPECT-RATIO WING IN THE LANGLEY 8-FOOT HIGH-SPEED TUNNEL

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SUMMARY

Downwash angles have been measured behind a model of a high-aspect-ratio wing at points near the probable tail location at Mach numbers up to 0.89 in the Langley 8-foot high-speed tunnel. The model has an NACA 65-210 section, an aspect ratio of 9.0, a taper ratio of 2.5:1, no twist, dihedral, or sweepback. The results indicate that the variations of downwash angle with normal-force coefficient are approximately the same at Mach numbers up to the highest test value for normal-force coefficients up to the stall condition, and that the downwash angle for a given normal-force coefficient varies only slightly at Mach numbers up to approximately 0.83 but decreases by approximately 0.4° when the Mach number is increased from 0.83 to the highest test value.

The downwash angle at the position of the tail behind a wing similar to that tested, that is an untwisted wing with a high-aspect ratio and a constant section across the span, at Mach numbers appreciably above the critical values may be predicted with fair accuracy using presently available equations or charts with or without a correction for compressibility.

INTRODUCTION

The Langley 8-foot high-speed tunnel staff has conducted a series of tests on models of a high-aspect-ratio wing and typical tail at Mach numbers up to 0.925. The aerodynamic characteristics of the wing are presented in reference 1, and those of the tail are presented in reference 2. In order to use the results of these tests in the determination of the stability and trim characteristics of a complete airplane, the downwash angles behind the wing at the tail position for flight conditions are required. Methods that can be used to predict the downwash at subcritical Mach numbers with sufficient accuracy are available (references 3 and 4); however, the applicability of these methods for predicting the downwash at supercritical Mach numbers is unknown.

In order to obtain reliable downwash angle values for supercritical Mach numbers the downwash angles have been measured at Mach numbers up to 0.89 at the probable tail locations behind the high-aspect-ratio wing. These probable locations are relatively high in comparison to tail locations used at present since the tail must be placed outside the region of flow fluctuations as described in reference 5. In order to obtain an indication of the exact applicability of the methods to predict downwash at all Mach numbers behind a wing similar to that tested, the measured results have been compared with downwash angles calculated using these methods.

The results presented are not directly applicable to the prediction of the exact downwash angles that may be present behind a wing on an airplane since the test configurations did not include a fuselage; the results do indicate, however, changes in the downwash angles with Mach number that may occur behind such a wing.

SYMBOLS

b span of model, feet

c section chord, feet

c_r root chord, feet

c_n section normal-force coefficient

C_N wing normal-force coefficient

h vertical distance from wing chord line extended to point of measurement, feet

M Mach number, corrected for tunnel-wall interference

S area of model, square feet

TEST APPARATUS AND METHODS

Apparatus

The Langley 8-foot high-speed tunnel, in which the tests were conducted, is of the single-return, closed-throat type. The Mach number at the throat is continuously controllable. The air-stream turbulence in the tunnel is small but slightly higher than in free air.

The wing used in this investigation is described in reference 1. The wing has an NACA 65-210 section, an aspect ratio of 9.0, a taper ratio of 2.5 to 1.0, no sweepback, twist or dihedral. The effective span of the model is 37.8 inches, the root chord is 6 inches, and the tip chord is 2.4 inches. The model was supported in the tunnel by means of a vertical plate as described in reference 1.

The downwash behind the wing was measured by a small yaw head which was placed 2.82-root-chord lengths behind the 25-percent-chord station of the model and 0.25 semispan from the plate. The yaw head was held in place by means of an arc-shaped strut which was fastened to the side of the support plate as shown in figure 1. The vertical position of the yaw head was adjusted by changing the position of the arc-shaped strut on the plate. Total-pressure measurements were made at the points at which downwash measurements were made by means of the rake described in reference 1.

Tests and Reduction of Data

The yaw head was calibrated at the test Mach numbers by measuring the pressures at the open end of the tubes with the yaw head rotated at various angles with respect to the support and tunnel. Yaw head measurements were made with the yaw head 0-, 0.25-, 0.50-, and 1.0-root-chord lengths above the center of rotation of the wing at uncorrected Mach numbers of 0.4, 0.6, 0.76, 0.80, 0.85, and 0.883 for angles of attack of 0°, 2°, 4°, and 7°. Total-pressure measurements were made at the same Mach numbers and angles of attack. The pressures measured at each of the open ends of the yaw head were corrected for the difference between the measured and the free-stream values of total pressure at the positions of these open ends, and the downwash angles were obtained from these corrected pressure values. Downwash angles for positions 0.5- and 0.7-root-chord lengths above the wing chord line extended have been determined from interpolation of these results. An analysis of possible sources of error indicates that the maximum error of the downwash angles presented is approximately 0.1°.

The Mach numbers have been corrected for the effects of the tunnel wall by the method described in reference 1. The downwash angles have been corrected using the equations presented in reference 4. The downwash corrections applied at Mach numbers of 0.40 and 0.89 were approximately 5 and 7 percent of the measured values, respectively.

Calculations of Downwash Angles

The results of numerous tests (reference 3) indicate that the downwash angle behind an airfoil at low speeds may be calculated with sufficient accuracy by use of the theoretical span load distribution presented in reference 6 and the methods given in reference 3 which are based on Biot-Savart equation and the lifting-line concept. Even more satisfactory results might be obtained by the use of these equations and the measured span load distributions. An analysis presented in reference 4 indicates that the downwash angle at any point behind a wing at Mach numbers M up to the critical value may be determined by the methods of reference 3 if computations are made for a point which is at a distance of $\frac{1}{\sqrt{1 - M^2}}$ times the tail length from the line of reference.

Using the theoretical span load distribution shown in figure 2 and the equations of reference 3, the downwash angles have been calculated for a Mach number of 0.40 for the stations for which experimental data are presented. Using the same load distributions and equations and the correction for compressibility, the downwash angles have been calculated for Mach numbers from 0.40 to 0.90 for the upper station for which experimental data are presented. Using measured span load distributions similar to those shown in figure 2 in place of the theoretical distributions, similar calculations have been made for the same station and Mach number range. Downwash angles determined by use of these theoretical span load distributions and methods of reference 3 for a point in the plane of symmetry of the wing or average downwash angle value for tail position may be obtained with very little effort using the charts presented in reference 7. The equations of reference 3 rather than the charts have been used for all the calculations since the calculated values for the off-center points of measurement were desired.

RESULTS AND DISCUSSION

Experimental Results

The variations of the downwash angles with normal-force coefficient for the various Mach numbers and for the two measurement stations are presented in figure 3. The variations of the downwash angles with Mach number for normal-force coefficients of 0.2, 0.4, and 0.7 are presented in figure 4. The normal-force coefficients measured are very nearly equal to the lift coefficients for the same conditions; the variations of the downwash angle with normal-force coefficient are therefore very nearly the same as the variations with lift coefficient for the same conditions. Any discrepancy is less than the probable maximum error in the measured angles.

For all Mach numbers the variations of downwash angle with normal-force coefficient are approximately the same up to the stalled condition (fig. 3).

Figures 3 and 4 indicate that the downwash angles for a given normal-force coefficient do not vary appreciably when the Mach number is increased up to approximately 0.83, a value which is approximately 0.1 greater than the critical Mach number at the design angle of attack for the wing (reference 1). The results presented in reference 8 show that the changes in the downwash angles behind other wings for given lift coefficients are small at Mach numbers up to the critical value.

At Mach numbers greater than 0.83 the downwash angle for a given normal-force coefficient decreases slightly. The changes are approximately the same for all normal-force coefficients at both of the vertical stations and in most cases are less than 0.4° at a Mach number of 0.89.

Comparison of Experimental and Calculated Results

The downwash angles calculated by the use of the theoretical span load distributions of reference 6 and the method of reference 3 but with no correction for compressibility are approximately the same as the measured downwash angles at Mach numbers up to the highest test value. The maximum variation between the calculated values and measured values is approximately 0.2°.

At Mach numbers up to approximately 0.75, the correction for compressibility does not significantly affect the agreement between the calculated and measured values. At Mach numbers between approximately 0.75 and 0.87 the correction for compressibility increases the disagreement. The divergence of the measured downwash angles and those calculated using the correction for compressibility at these Mach numbers may be attributed to the increase in the intensity and extent of the wake which occurs at these Mach numbers due to separation on the wing. The flow behind the wing tends to move into the more intense wake as described in reference 3 and as a result the downwash above the wake increases while that below the wake decreases.

When the Mach number is increased beyond approximately 0.83 the differences between the measured downwash angles and those calculated using the correction for compressibility are reduced. This reduction may be attributed to the presence of the large region of supersonic flow at these Mach numbers but the exact explanation of how the presence of this flow changes the downwash is not known. Because of this reduction, at Mach numbers greater than approximately 0.87, use of the compressibility correction improves the agreement between calculated and measured values for the lower normal-force coefficients. At these Mach numbers and normal-force coefficients, the maximum variation between the measured values and those calculated using the correction for compressibility is about 0.1°.

Use of the actual measured span load distribution in place of the theoretical gives values of downwash angles which are slightly closer to the measured values at all Mach numbers.

These comparisons indicate that the downwash at the tail position behind a wing similar to that tested, that is an untwisted wing with a high-aspect ratio and a constant section across the span, at Mach numbers appreciably above the critical Mach number may be predicted with fair accuracy using the theoretical span load distribution and the methods of reference 3 or the charts of reference 7. The correction for compressibility does not significantly affect the agreement between the measured and calculated values.

CONCLUDING REMARKS

The results of downwash angle measurements made near the tail location behind a high-aspect ratio wing with an NACA 65-210 airfoil section, an aspect ratio of 9.0, and a taper ratio of 2.5:1 at Mach numbers up to 0.89 indicate the following:

1. For each Mach number up to the highest test value the variations of the downwash angles with normal-force coefficient were approximately the same up to the stalled condition.

2. The downwash angle for a given normal-force coefficient varied only slightly with Mach numbers up to approximately 0.83 but decreased by about 0.4° when the Mach number was increased from 0.83 to the highest test value obtained.

3. The downwash angle at the position of the tail behind a wing similar to that tested at Mach numbers appreciably above the critical values may be predicted with fair accuracy using presently available equations or charts with or without a correction for compressibility.

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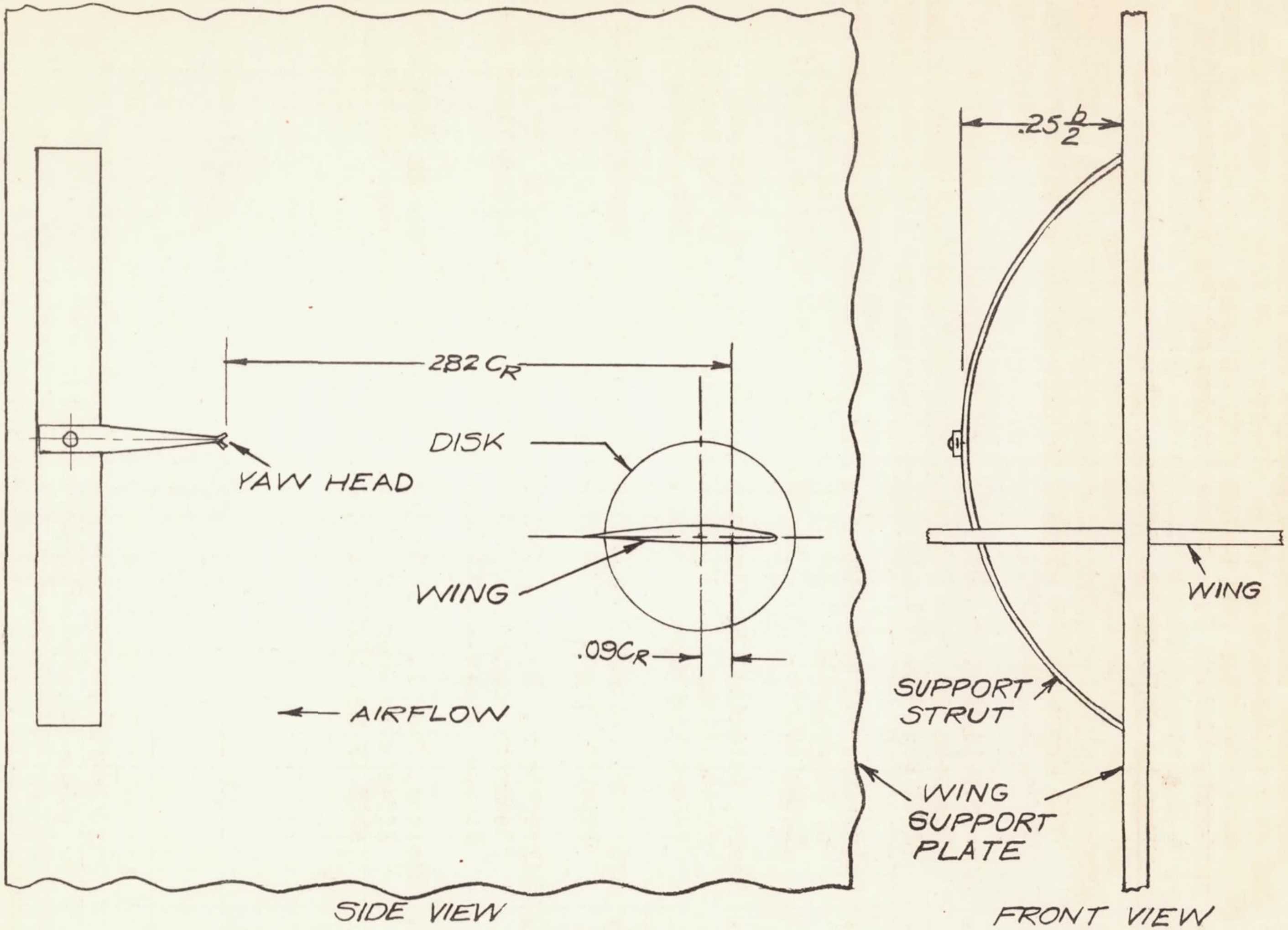

FIGURE 1.- TEST APPARATUS.

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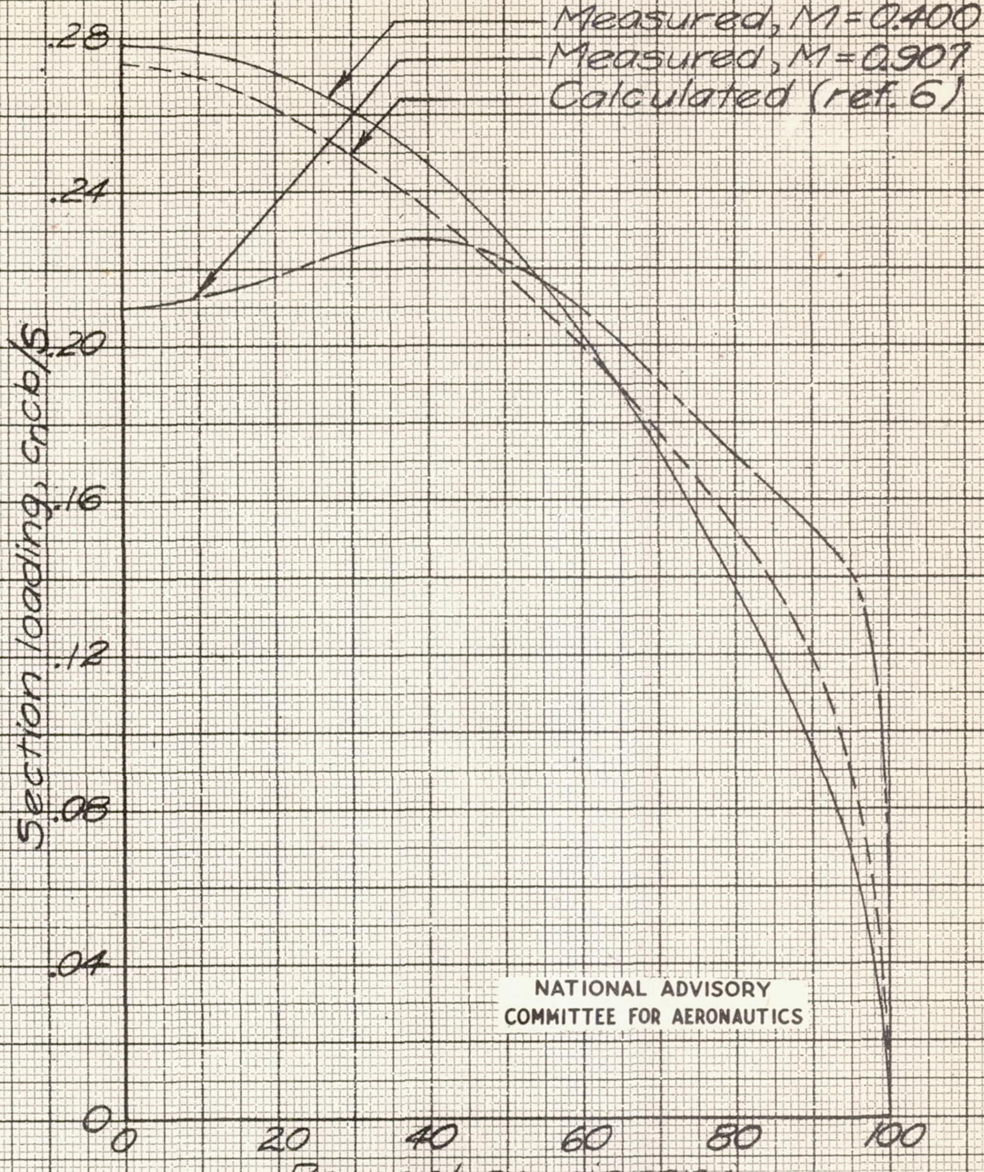

Figure 2.- Measured and calculated spanwise load distributions. $C_N = 0.2$.

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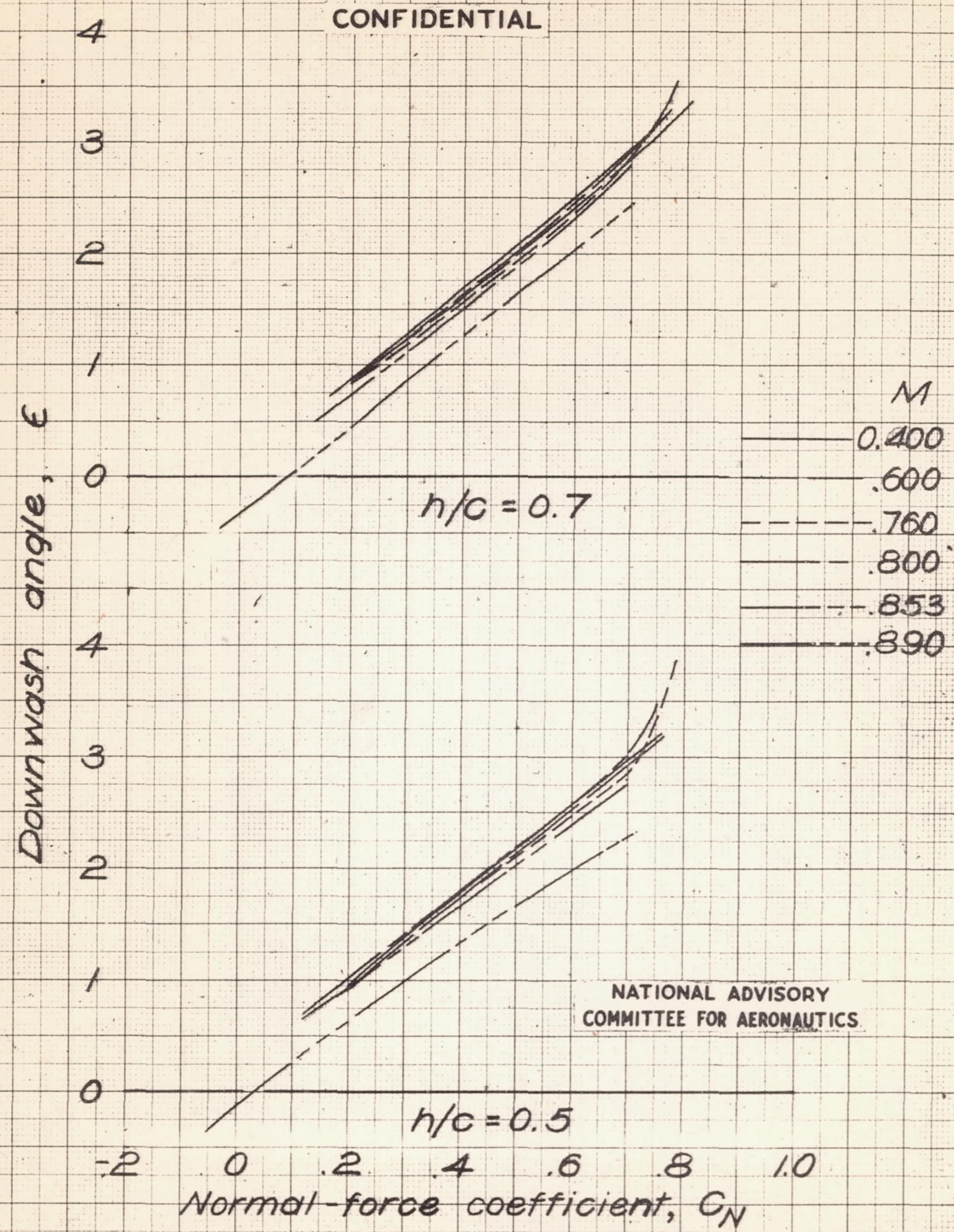

Figure 3 .- Variation of downwash angle with normal-force coefficient at two distances above wing-chord line extended.

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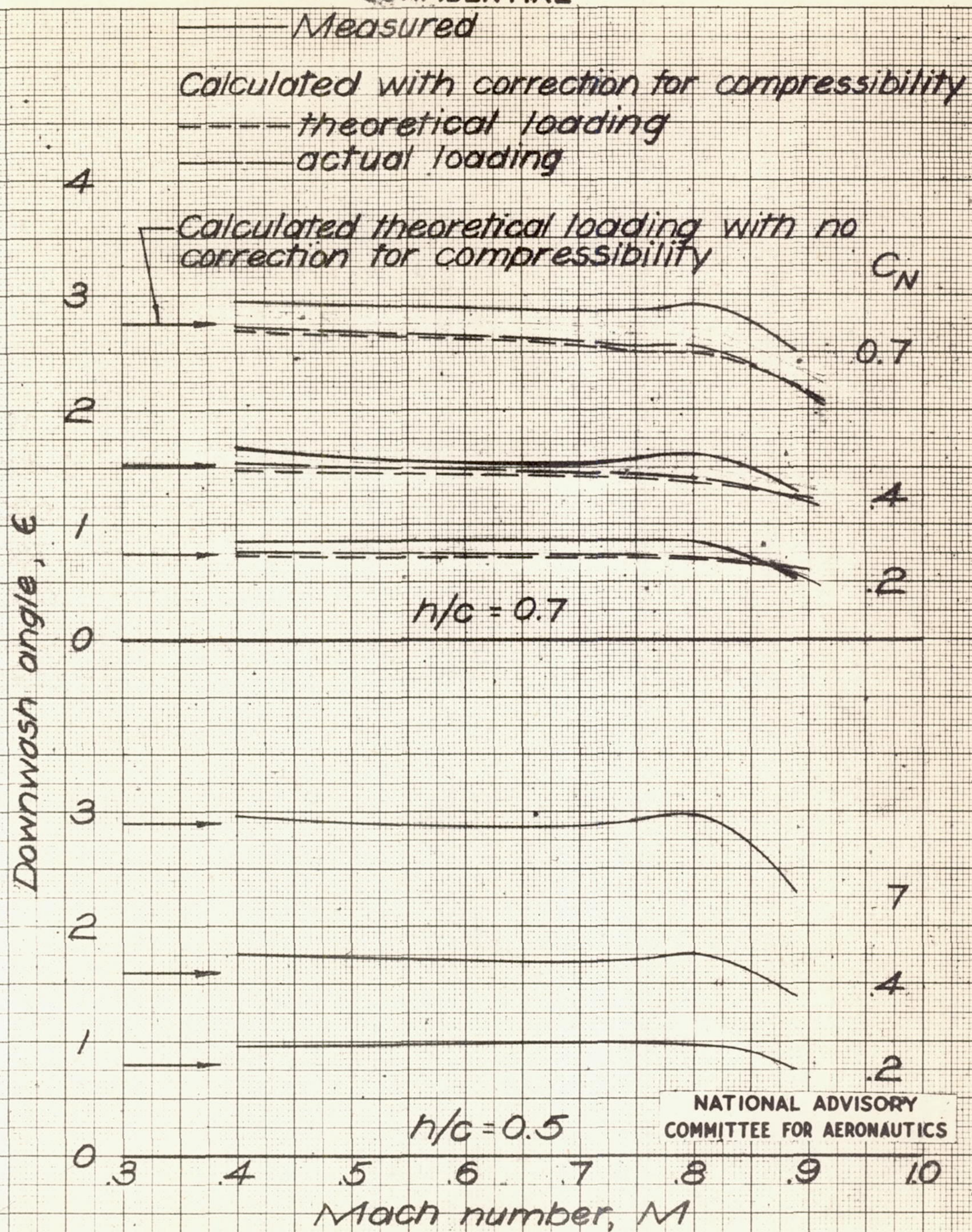

Figure 4.– Variation of downwash angle with Mach number at two distances above wing-chord line extended.