unclassified
~~RESTRICTED~~

Copy No. 122

RM No. A7F12

A7F12

6929

RESEARCH MEMORANDUM

HIGH-SPEED WIND-TUNNEL INVESTIGATION OF THE EFFECTS OF COMPRESSIBILITY ON A PITOT-STATIC TUBE

By

Louis S. Stivers, Jr., and
Charles N. Adams, Jr.

Ames Aeronautical Laboratory
Moffett Field, Calif.

CLASSIFIED DOCUMENT

This document contains classified information affecting the National Defense of the United States within the meaning of the Espionage Act, USC 50:31 and 32. Its transmission or the revelation of its contents in any manner to an unauthorized person is prohibited by law. Information so classified may be imparted only to persons in the military and naval services of the United States, appropriate civilian officers and employees of the Federal Government who have a legitimate interest therein, and to United States citizens of known loyalty and discretion who of necessity must be informed thereof.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

August 4, 1947

unclassified
~~RESTRICTED~~

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

HIGH-SPEED WIND-TUNNEL INVESTIGATION OF THE EFFECTS OF COMPRESSIBILITY ON A PITOT-STATIC TUBE

By Louis S. Stivers, Jr., and
Charles N. Adams, Jr.

SUMMARY

A high-speed wind-tunnel investigation has been made of a pitot-static tube having the Federal Standard Stock Catalog No. 88-T-2950 to provide information on the effects of compressibility upon the pressure indications of a representative airspeed head at high subsonic speeds. The calibration factor for the instrument has been evaluated for several small angles of pitch and yaw throughout a Mach number range from 0.30 to approximately 0.925.

The results indicate that the calibration factor for each combination of pitch and yaw angles tested is, in most cases practically constant with Mach number up to a Mach number of approximately 0.8. A greater variation in the calibration factor exists for changes in yaw angle than for changes in pitch angle, and only slightly more variation for changes in positive pitch angle than for changes in negative pitch angle. At zero pitch and zero yaw the error in the differences of the total and static pressures given by the pitot-static tube is never greater than 1.6 percent for speeds up to a Mach number of 0.925.

INTRODUCTION

The need for additional information concerning the practicability of pitot-static tubes for indicating airspeeds near the speed of sound becomes increasingly apparent as the operating speeds of aircraft approach this velocity more and more closely. Wind-tunnel investigations of several standard service pitot-static tubes at speeds up to approximately 0.8 Mach number have been reported in references 1 and 2. Each pitot-static tube was tested at zero pitch and zero yaw; one pitot-static tube of reference 2 was also tested at small angles of pitch.

To supplement the existing information on this subject, the present investigation was undertaken in the Ames 1- by 3-1/2-foot high-speed wind tunnel to evaluate the effects of compressibility on the velocity indications of a high-speed-type service pitot-static tube at speeds up to approximately 0.925 Mach number. The tests were extended to include several small angles of pitch and yaw.

SYMBOLS

The following symbols are used in this report:

p	free-stream static pressure
p_T	static pressure given by pitot-static tube
q	free-stream dynamic pressure $(\frac{1}{2}\rho V^2)$
M	free-stream Mach number
$1 + \eta$	compressibility factor $\left(1 + \frac{M^2}{4} + \frac{M^4}{40} + \frac{M^6}{1600} + \ldots\right)$
H	free-stream total pressure $[p + (1 + \eta)q]$
H_T	total pressure given by pitot-static tube
θ	angle of pitch
ψ	angle of yaw
β	arc tan (θ/ψ)
Ω	angle of inclination to free stream (approx. $\sqrt{\theta^2 + \psi^2}$ for small angles)
$\frac{p - p_T}{H - p}$	error in static pressure
$\frac{H - H_T}{H - p}$	error in total pressure

$\dfrac{H - p}{H_T - p_T}$ calibration factor

APPARATUS AND TESTS

The present tests were conducted in the Ames 1- by 3-1/2-foot high-speed wind tunnel, a low-turbulence closed-throat wind tunnel powered by two 1000-horsepower motors.

A pitot static tube having the Federal Standard Stock Catalog No. 88-T-2950 (Navy Aviation Supply Office Stock No. R88-T-2950), shown in figure 1, was used in the present tests. The static-pressure orifices in this tube were located only on the top and bottom of the tube approximately six tube diameters behind the nose. Throughout the entire investigation the pitot tube drain hole was sealed. The pitot-static tube was attached by flush head screws to a tube 44-1/2 inches long and 1-1/2 inches in diameter (fig. 2). This supporting tube, in turn, was attached to a heavier tube held in place by steel cables anchored at the tunnel walls in the diffuser. It was necessary that this heavier tube be located far enough downstream in the diffuser to avoid tunnel blocking. A sketch of the mounting is shown in figure 3, and a photograph of the entire assembly is shown in figure 4. This assembly was positioned in the tunnel such that the static-pressure orifices of the pitot-static tube were located at a position where the free-stream static pressures were accurately known. This position was approximately 3 feet downstream of the normal test position for airfoil models. (The Ames 1- by 3-1/2-foot wind tunnel has a test section 10 feet long.) The free-stream static pressures at the pitot-static tube test position had been previously determined in a manner similar to that described in reference 2, but the true total pressures at this same position were assumed to be those indicated by the pitot tube at zero pitch and zero yaw. This assumption is valid since the pitot-tube drain hole was sealed for the entire investigation.

Measurements of the total and static pressures of the pitot-static tube were obtained throughout a speed range from a Mach number of 0.3 to approximately 0.925. These measurements were obtained for the following combinations of angles of pitch and yaw:

Pitch, deg	Yaw, deg
0	0
0	±3.6
±3.6	0
±7.4	0
±2.5	±2.5
±5.2	±5.2

In order to determine the care required in the installation of the pitot-static tube, tests were initially made at angles of zero pitch with zero yaw and zero pitch with ±3.6° yaw in which the support screw holes were both unfilled (fig. 2(a)) and filled (fig. 2(b)).

RESULTS AND DISCUSSION

The pitot-static-tube data obtained in the present tests have been corrected for tunnel-blockage effects, including the effects of compressibility, using linear perturbation theory. The magnitude of this correction to the calibration factor and to the error in static pressure is shown in figure 5 for the case of zero pitch and zero yaw.

The test results are presented in figure 6 in a form similar to that of reference 2 giving the errors in static and total pressures and the calibration factors as a function of Mach number for the several configurations of pitch and yaw.

No appreciable differences in pressure measurements were discernible for the tests with the screw holes of the pitot-static tube support unfilled and filled, as shown in figures 6(a) and 6(b), so the remaining portion of the tests were made with the screw holes unfilled.

Check tests of the pitot-static-tube pressure readings for equal angles of positive and negative yaw showed substantially identical values. These readings would have been expected to be the same since the static-pressure orifices are symmetrically located with respect to a vertical plane through the axis of the pitot-static tube. The data obtained for positive angles of yaw, therefore, are presented in figure 6 as the values for both positive and negative angles of yaw. Tests made for equal positive and negative pitch angles show almost identical total-pressure readings but different static-pressure readings (cf. figs. 6(d) and (e), 6(f) and (g), 6(h) and (i), and 6(j) and (k)). These differences in static-pressure readings can be attributed only to the fact that the static pressure orifices on the bottom of the tube cover a greater length of the tube periphery than those on the top.

In general, the data of figure 6 show that the error in measuring free-stream total pressures with the pitot-static tube is very small and almost negligible at small angles of pitch and yaw, while the error in measuring free-stream static pressures constitutes the larger part of the total error of the pitot-static tube. For each combination of pitch and yaw angles investigated the calibration factor is, in most cases, almost constant with Mach number up to a Mach number of approximately 0.8, and increases somewhat for higher Mach numbers. Figure 6(a) shows that for Mach numbers up to 0.925, the error in measuring $H - p$ with the pitot-static tube at zero pitch and zero yaw is never greater than 1.6 percent.

Over the range of Mach numbers where the calibration factors are nearly constant, average values were obtained from figure 6 for each combination of pitch and yaw angles tested, and were used in the preparation of figure 7. Each combination of these angles determines the angles β and Ω, and a specific quadrant of figure 7. In this figure the intersection of the radial line defined by an angle β in the proper quadrant and the contour for an angle Ω defines a calibration factor. For zero pitch β equals zero, and Ω is the absolute value of the angle of yaw; whereas, for zero yaw β equals positive or negative 90° (depending upon whether the pitch is positive or negative), and Ω is the absolute value of the angle of pitch. For zero pitch and zero yaw Ω is zero and β may be any angle. Figure 7 shows a larger variation in the calibration factor for changes in yaw angle than for changes in pitch angle, and only slightly more variation for changes in positive pitch than for changes in negative pitch angle. The calibration factors obtained from this figure may be used for speeds up to a Mach number of 0.925 with reasonable accuracy, since the errors in the factors given by this figure for any combination of pitch and yaw angle tested are no greater than 1 percent at this Mach number.

CONCLUSIONS

The following conclusions are obtained from the results of the high-speed wind-tunnel tests of a pitot-static tube having the Federal Standard Stock Catalog No. 88-T-2950:

1. The calibration factor of the pitot-static tube for each combination of pitch and yaw angles investigated is, in most cases, practically constant with Mach number up to a Mach number of approximately 0.8.

2. There is more variation in the calibration factor for changes in yaw angle than for changes in pitch angle, and only slightly more variation for changes in positive pitch angle than for changes in negative pitch angle.

3. At zero pitch and zero yaw the error in the differences in the total and static pressures given by the pitot-static tube is never greater than 1.6 percent for speeds up to a Mach number of 0.925.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

REFERENCES

1. Look, C.N.H., and Hilton, W.F.: Calibration of Standard Pitot-Static Heads in the High-Speed Tunnel. R. & M. No. 1752, British ARC, 1936.

2. Hensley, Reece V.: Calibrations of Pitot-Static Tubes at High Speeds. NACA ACR, July 1942.

Figure 1.- Pitot-static tube having Federal Standard Stock Catalog No. 88-T-2950.

(a) Support screw holes unfilled.

(b) Support screw holes filled.

Figure 2.- View of tube mounting showing the attachment of the tube to the support.

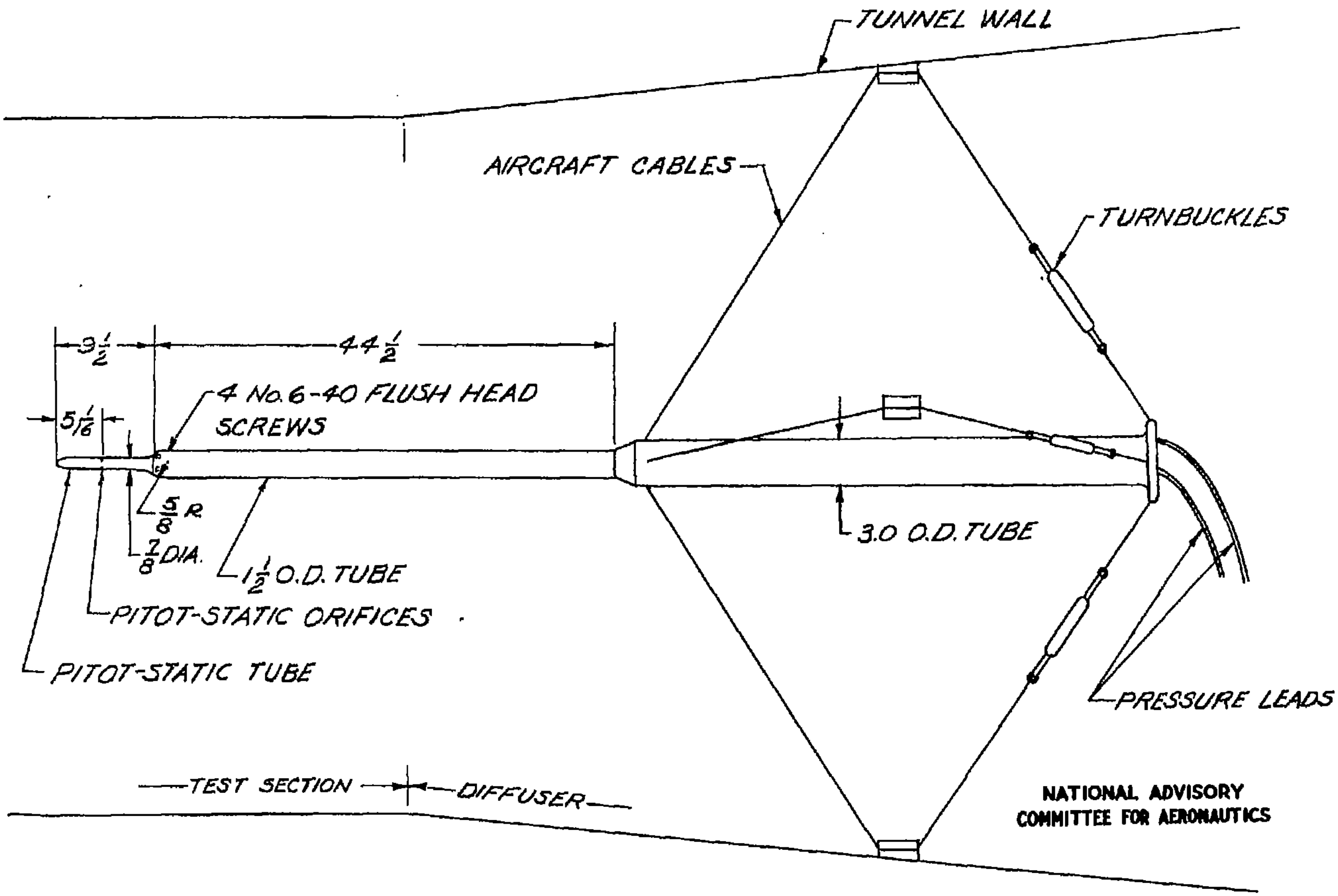


FIGURE 3.- MOUNTING OF THE PITOT-STATIC TUBE IN THE WIND-TUNNEL.

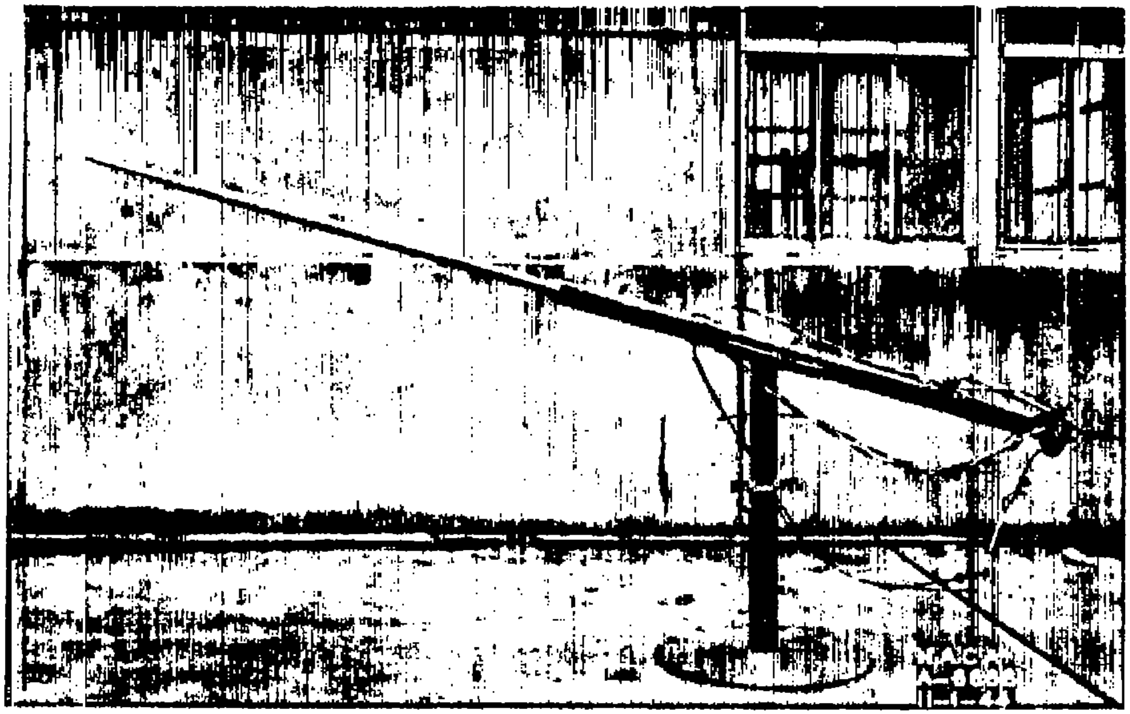


Figure 4.- Side view of mounting of pitot-static tube for Ames 1- by $3\frac{1}{2}$-foot wind tunnel.

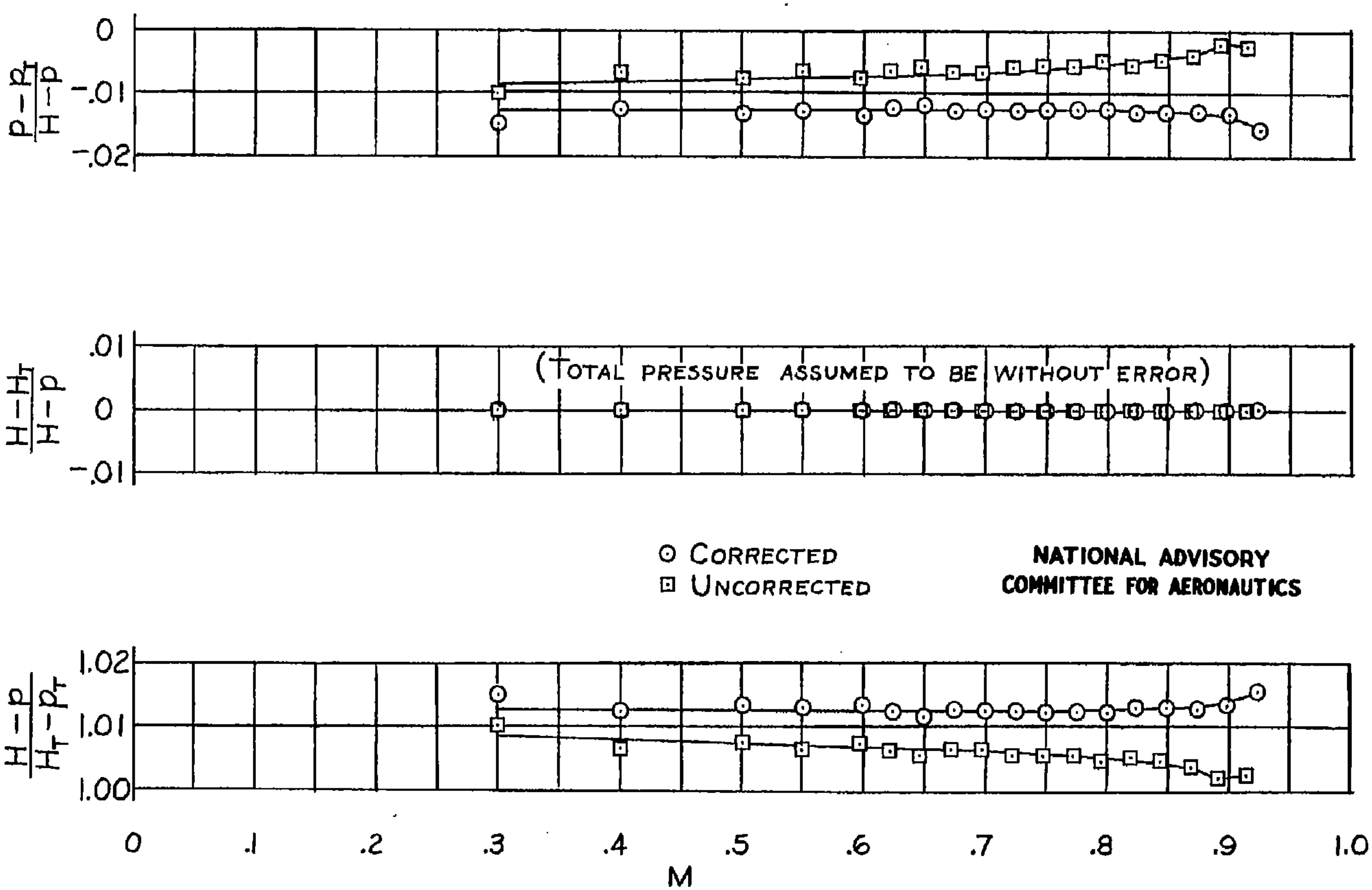
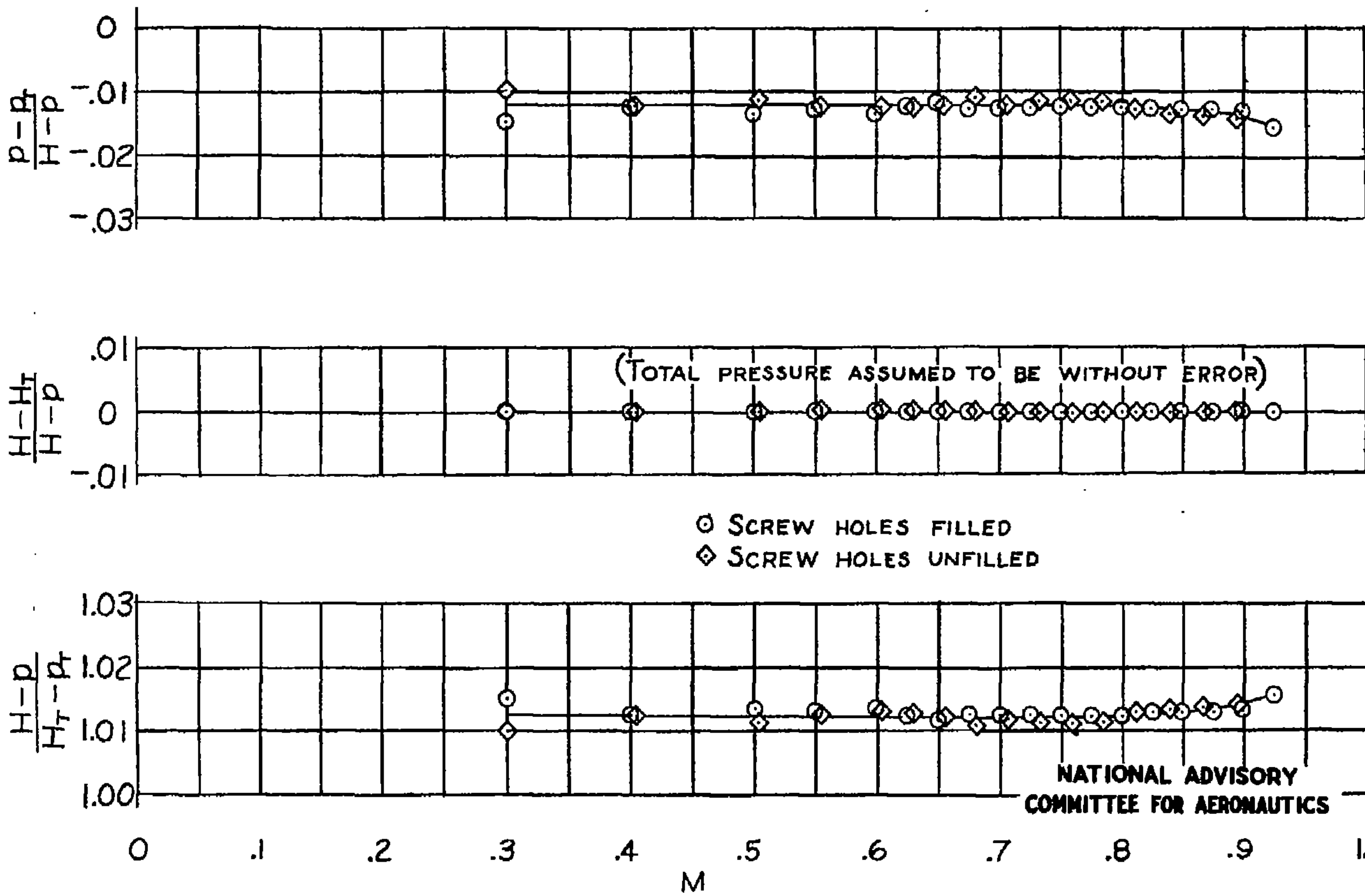
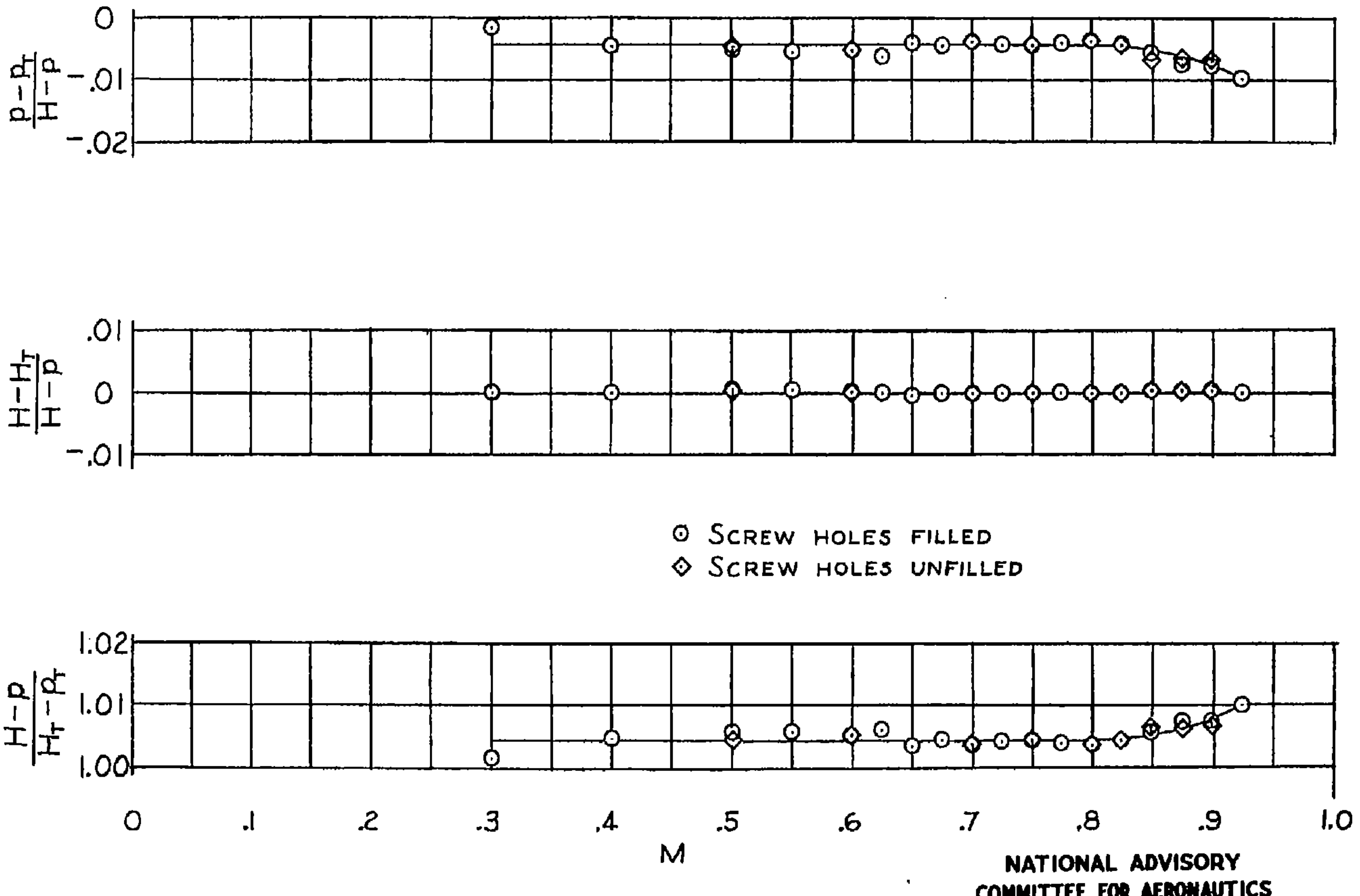


Figure 5. – The variation with Mach number of the magnitude of the tunnel-wall correction to the error in static pressure and to the calibration factor of the pitot-static tube at zero pitch and zero yaw.



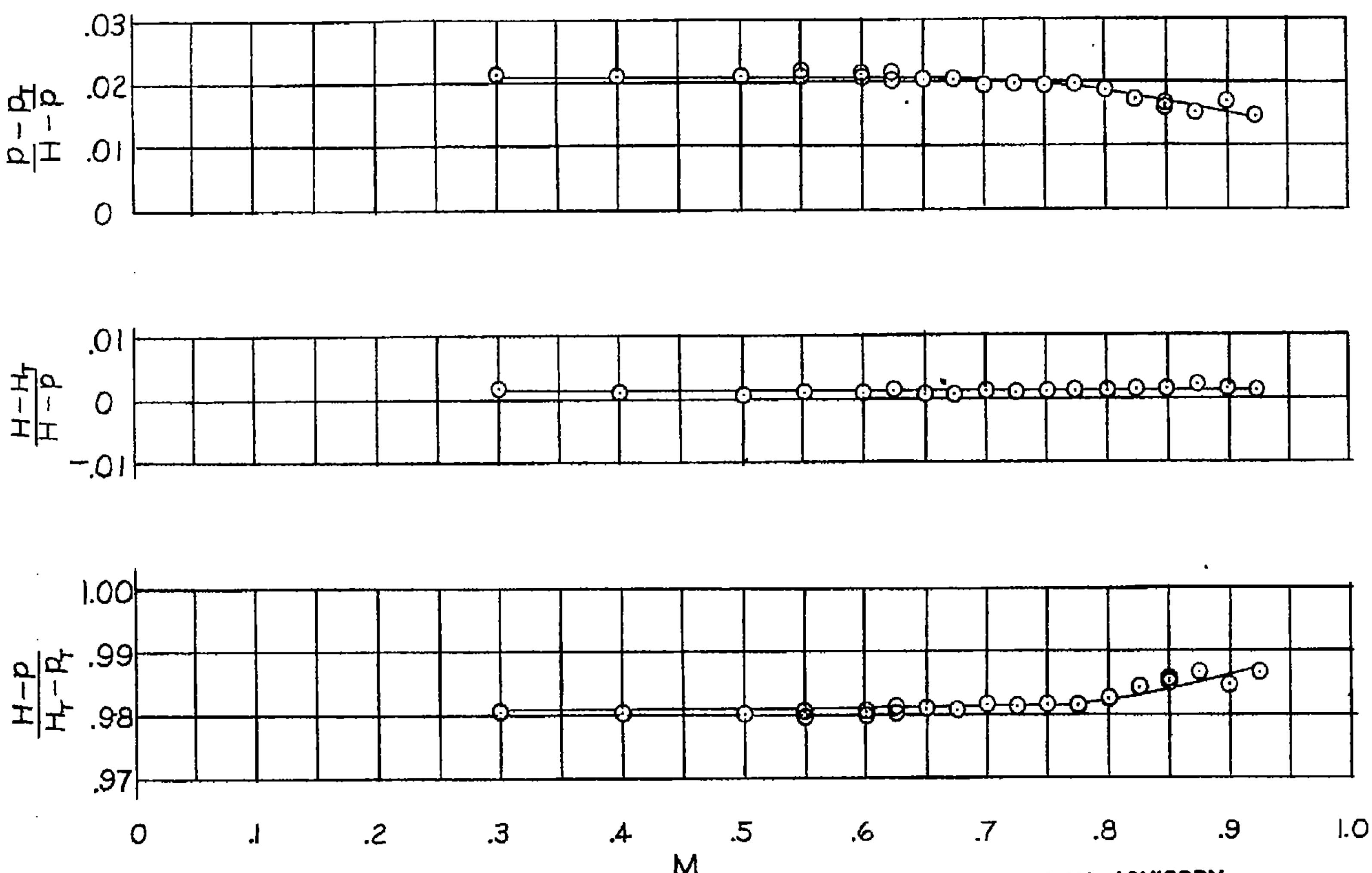
(a) Pitch, 0°; yaw, 0°.

Figure 6.— The variation with Mach number of the calibration factor, and the errors in the total and static pressure for the pitot-static tube.



(b) PITCH, 0°; YAW ± 3.6°

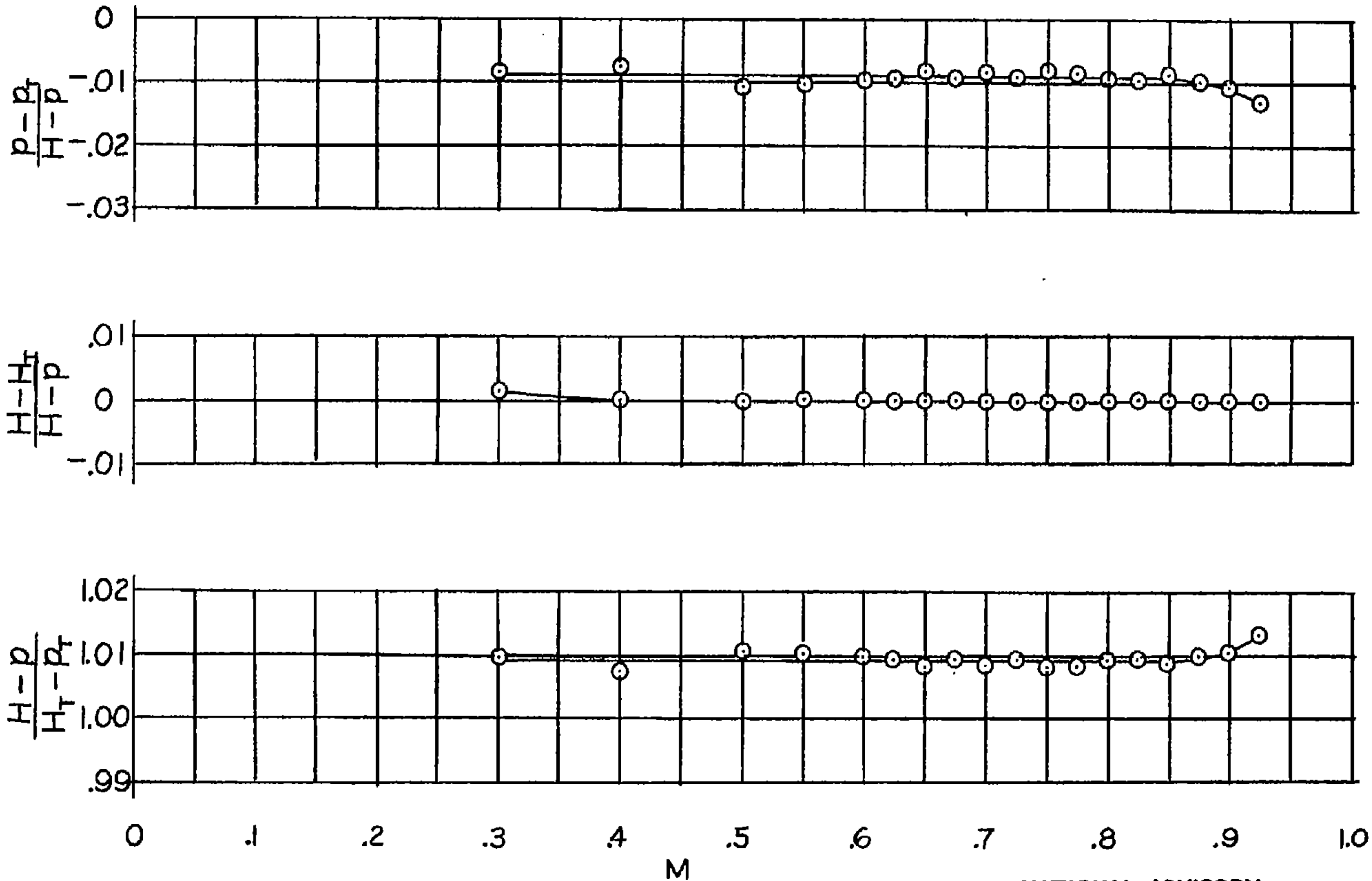
FIGURE 6. — CONTINUED.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(c) Pitch, 0°; yaw, ± 7.4°.

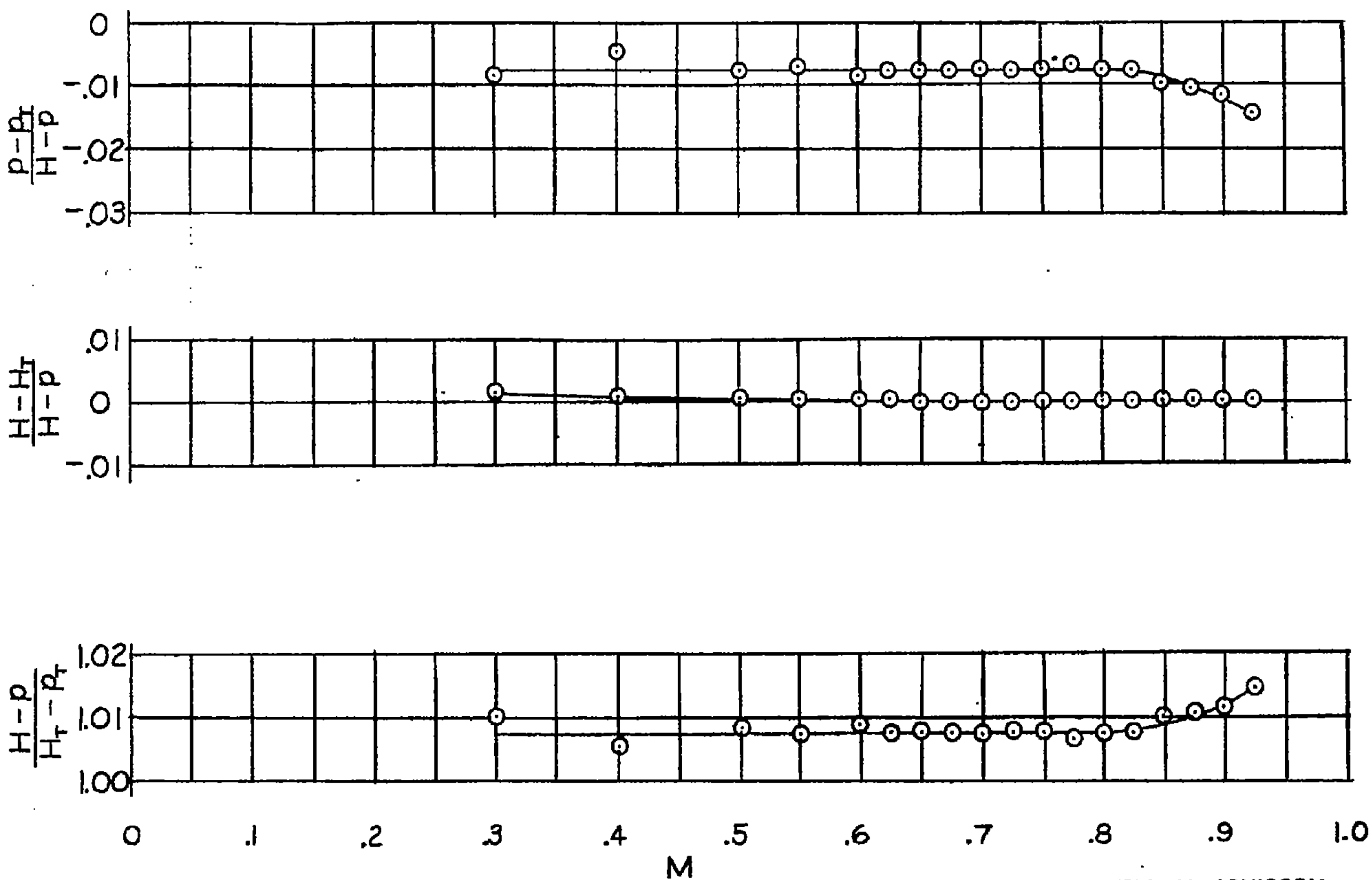
Figure 6.— Continued.



(d) Pitch, 2.5°; yaw, ± 2.5°.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

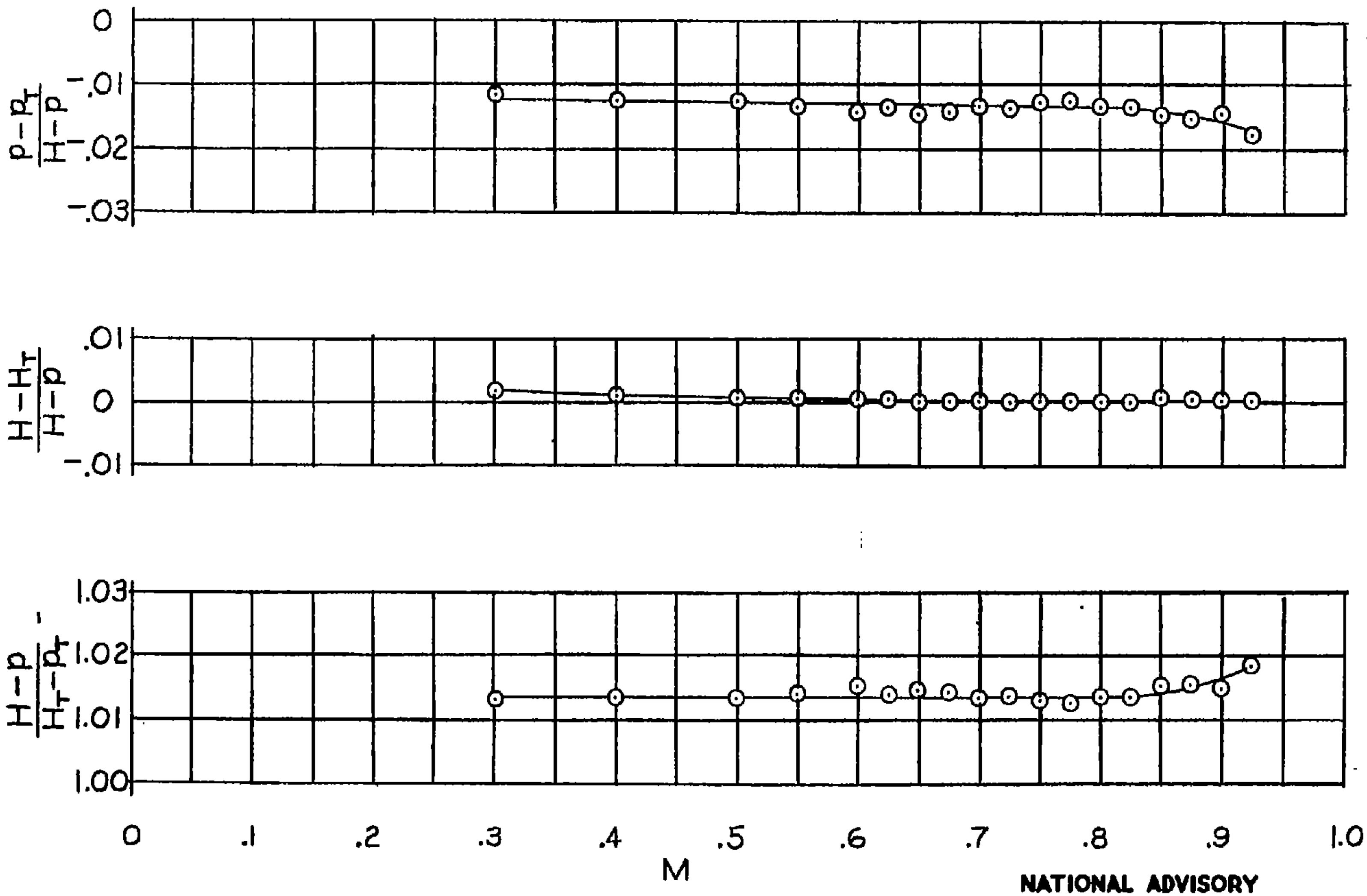
Figure 6.- Continued.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(e) Pitch, −2.5°; yaw, ± 2.5°.

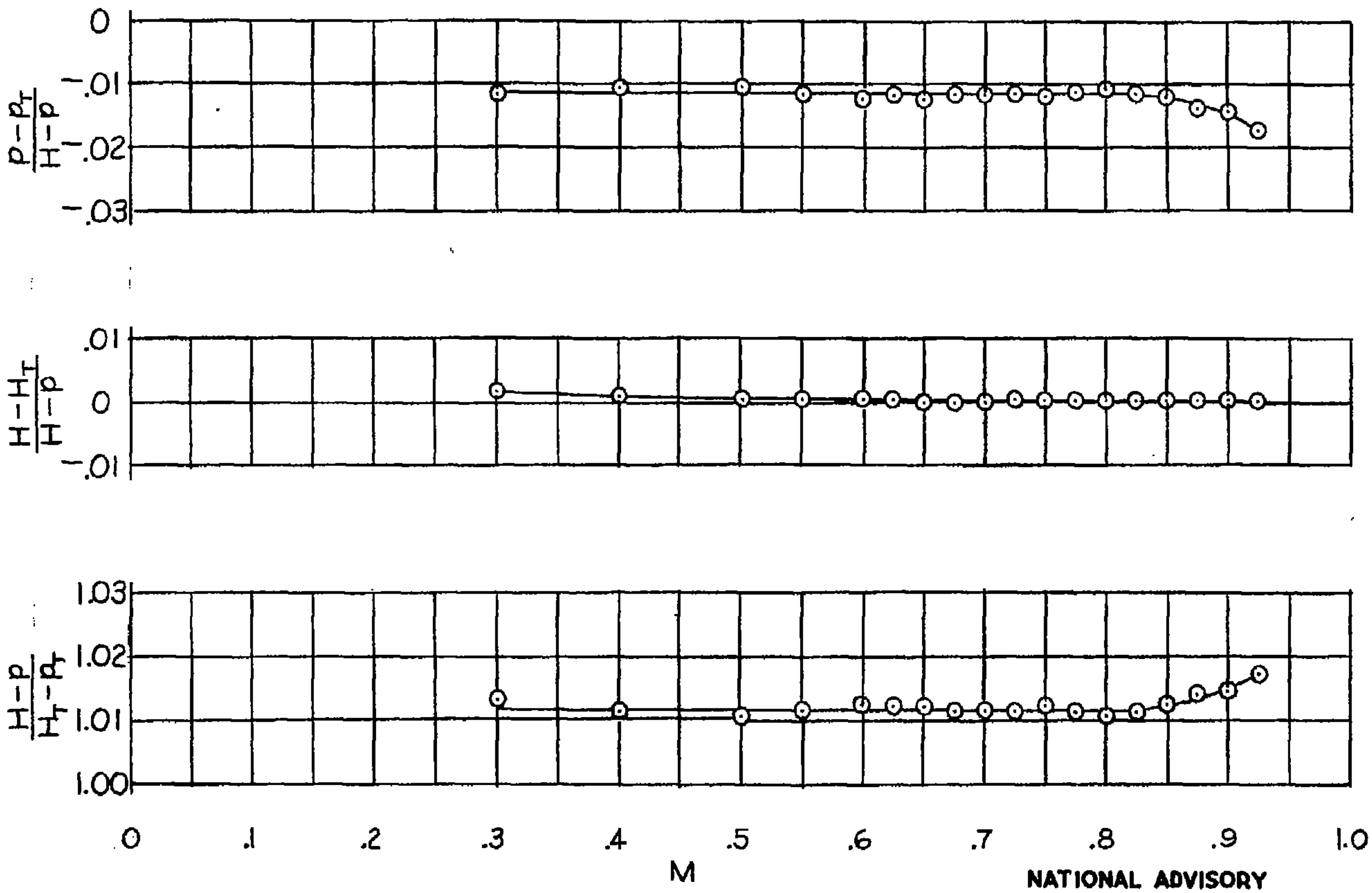
Figure 6. – Continued.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(f) Pitch, 3.6°; yaw, 0°.

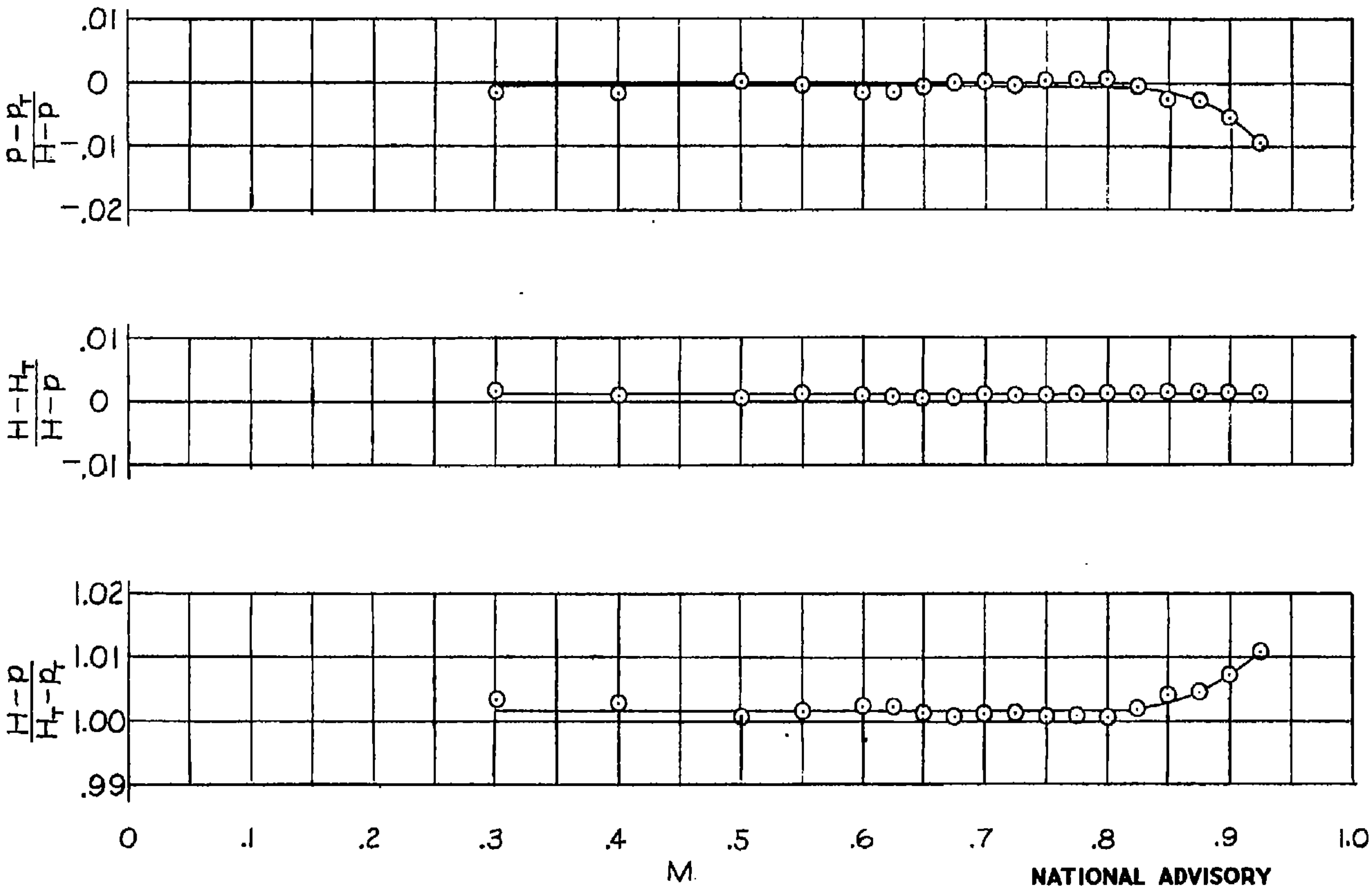
Figure 6. – Continued.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(g) Pitch, −3.6°; yaw, 0°.

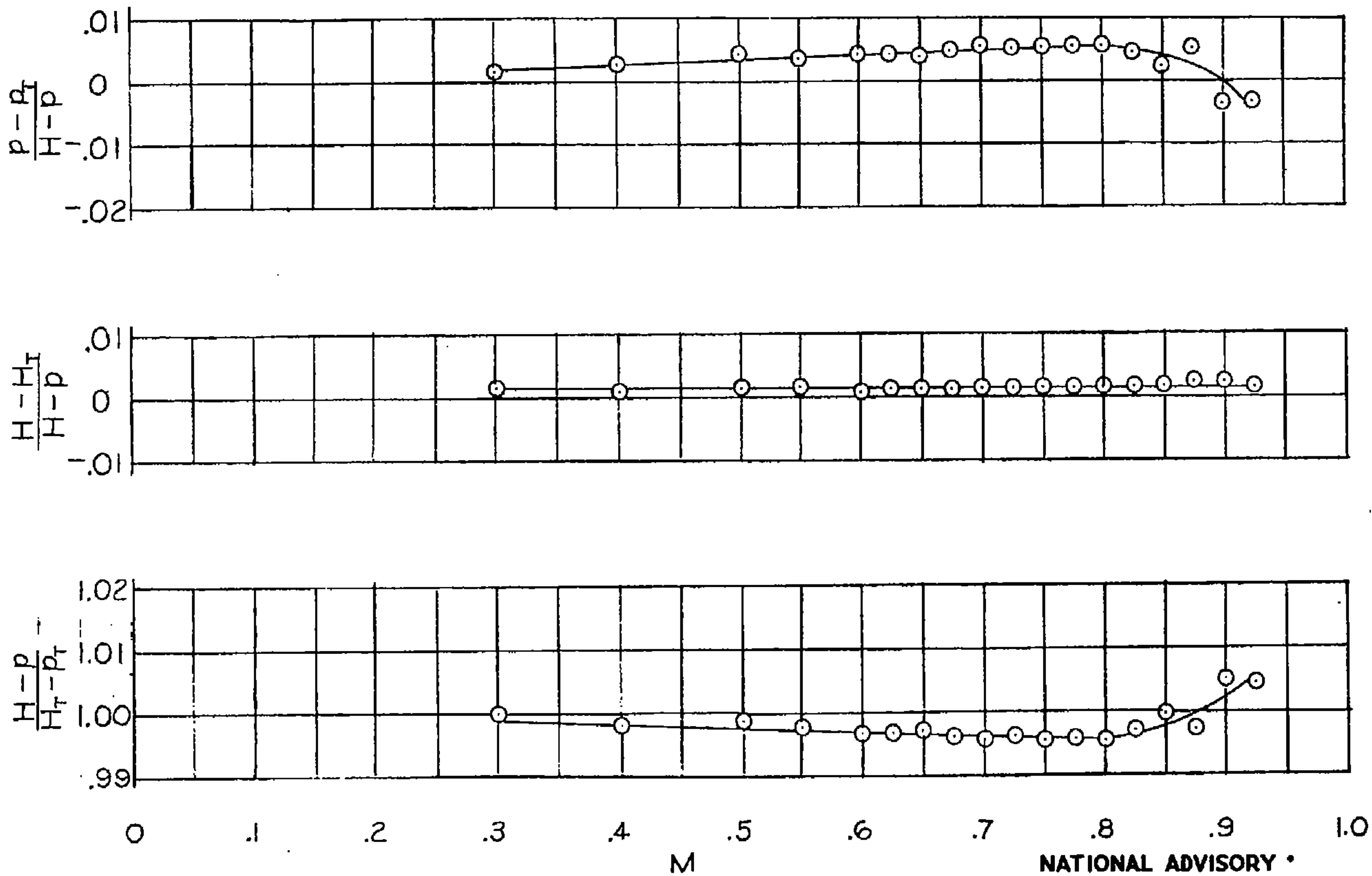
Figure 6.— Continued.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(h) PITCH, 5.2°; YAW ± 5.2°.

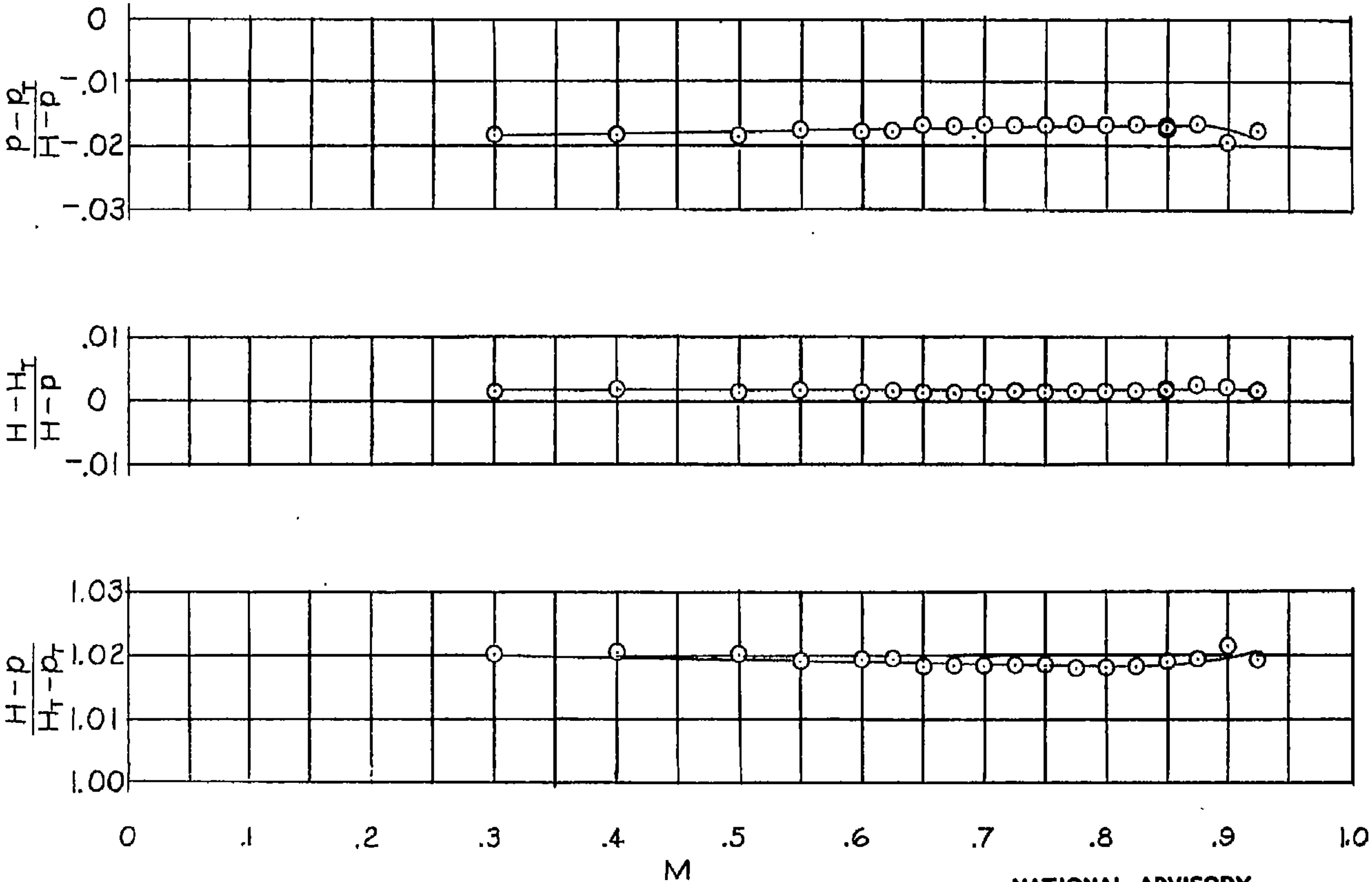
FIGURE 6.– CONTINUED.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(*i*) Pitch, −5.2°; yaw, ± 5.2°.

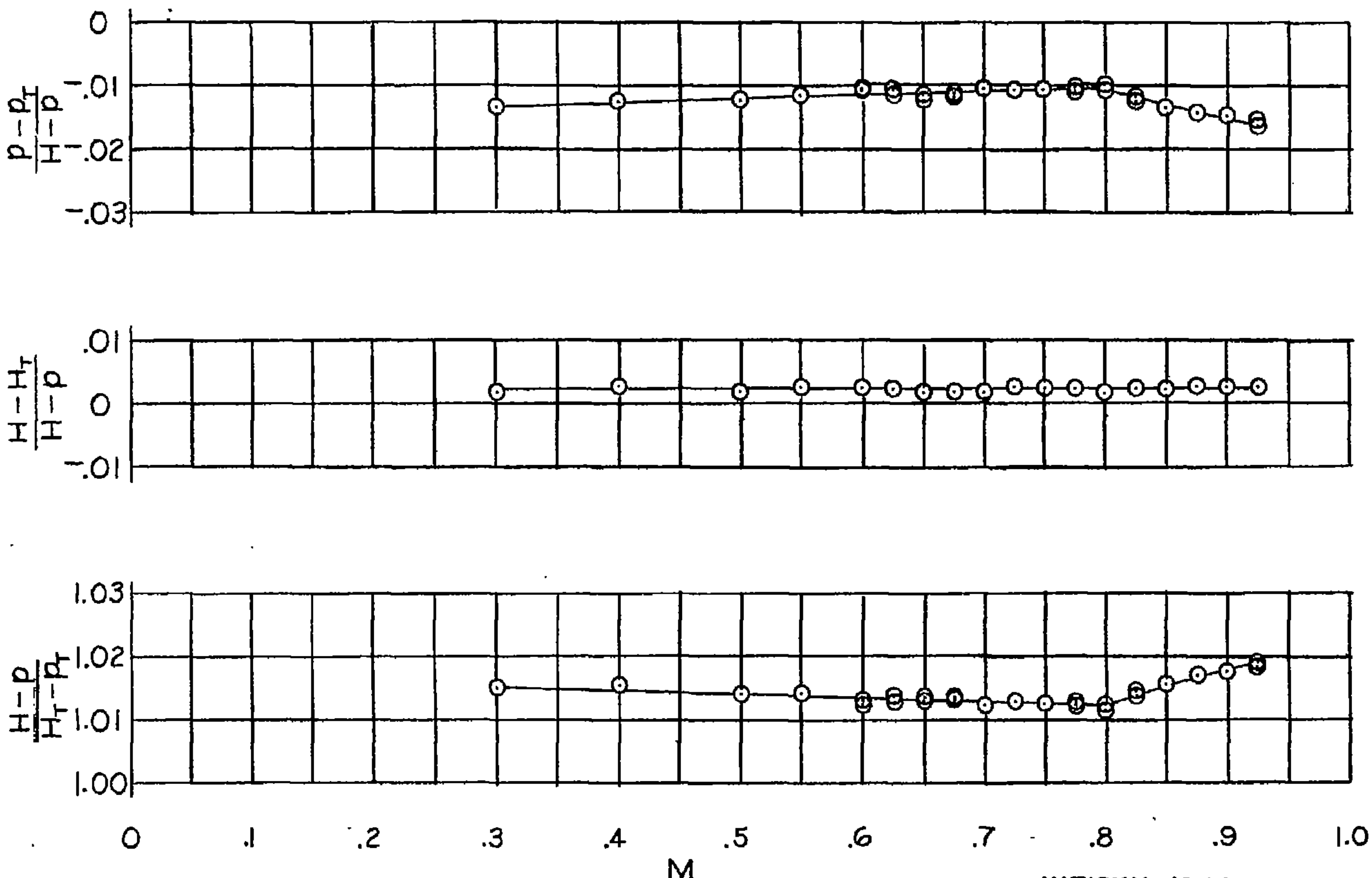
Figure 6. – Continued.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(j) Pitch, 7.4°; yaw, 0.

Figure 6.– Continued.



NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

(k) Pitch, −7.4°; yaw, 0°.

Figure 6.– Concluded.

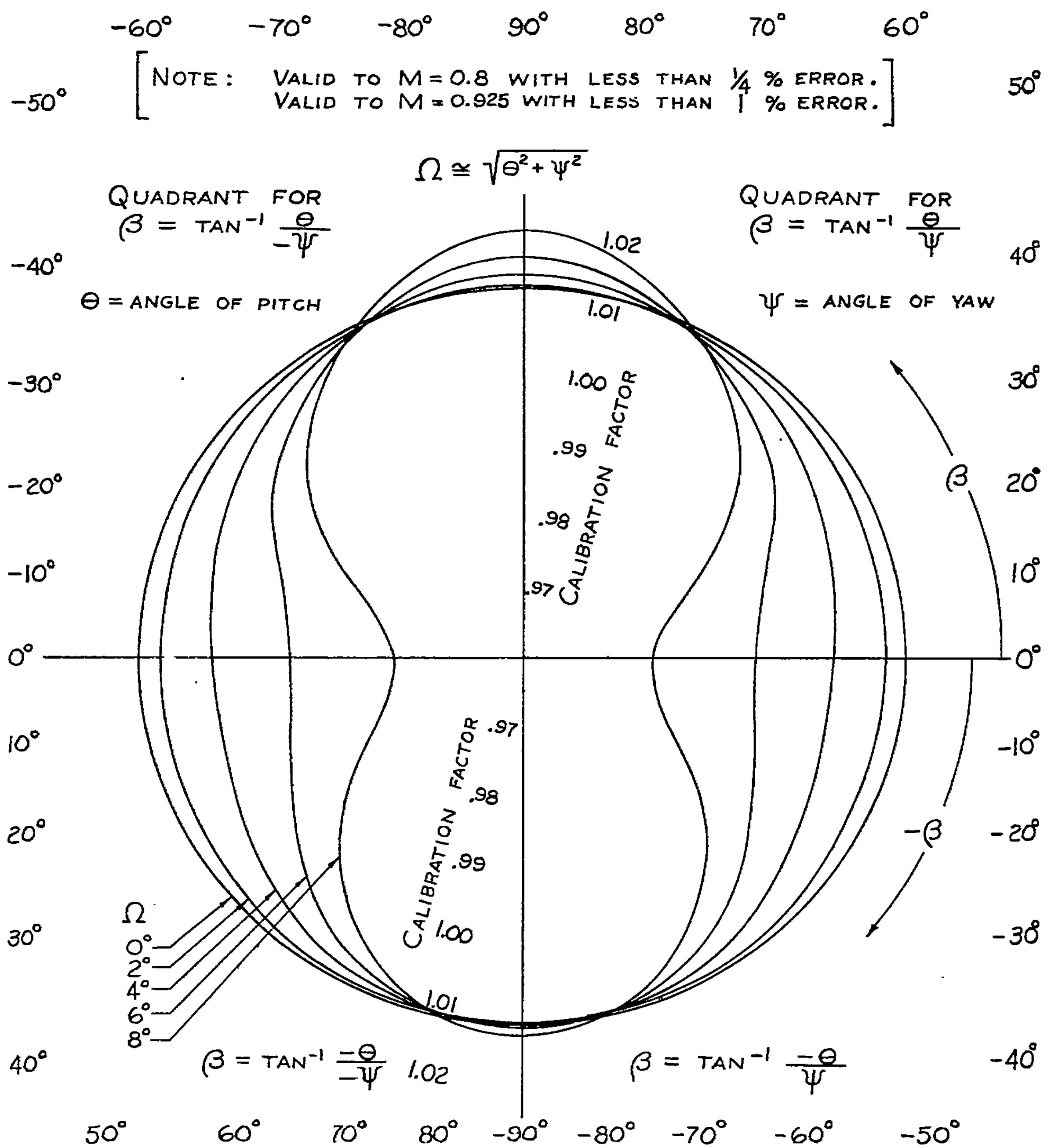


FIGURE 7. – THE VARIATION OF AVERAGE VALUES OF THE CALIBRATION FACTOR WITH β AND Ω FOR MACH NUMBERS UP TO 0.925.

NATIONAL ADVISORY
COMMITTEE FOR AERONAUTICS