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FLIGHT INVESTIGATION AT HIGH MACH NUMBERS OF SEVERAL METHODS OF MEASURING STATIC PRESSURE ON AN AIRPLANE WING

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FLIGHT INVESTIGATION AT HIGH MACH NUMBERS OF SEVERAL METHODS OF MEASURING STATIC PRESSURE ON AN AIRPLANE WING

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SUMMARY

A flight investigation was made to compare static pressures in subsonic and supersonic flow over an airplane wing as measured by static-pressure tubes, a static-pressure belt, and orifices flush with the wing surface. The measurements were made on the upper surface of the wing of the P-47D airplane over a range of flight conditions in which local Mach numbers from 0.34 to 1.41 were obtained at the measurement stations. For some of the tests, a total-pressure tube was mounted on the wing surface to determine its characteristics in supersonic flow.

The results indicated that static-pressure measurements obtained with suitably designed and installed flush orifices, static-pressure tubes, and static-pressure belt will be in reasonable agreement for both subsonic and supersonic flow.

The pressures in supersonic flow measured by the total-pressure tube mounted on the wing surface were found to be in close agreement with values predicted by theory.

INTRODUCTION

The installation of static-pressure orifices flush with the surface of some part of an airplane for the measurement of pressure distribution may not always be practicable. Static-pressure tubes and static-pressure belts are two other means that have been used to some extent. The validity of the pressure measurements obtained by these means is questionable, however, because of the possibility of effects due to misalinement with the local air flow and, at high speeds, premature shock formation on the static-pressure tubes and belt.

The purpose of the present investigation was to obtain a comparison of static-pressure measurements made by means of orifices flush with the surface, static-pressure tubes, and a static-pressure belt in subsonic and supersonic flow over the upper surface of an airplane wing. As an incidental phase of the investigation, a comparison was also obtained of the pressure measurements made by means of a total-pressure tube mounted above the wing surface outside the boundary layer with measurements made by means of the total-pressure element of an airspeed head mounted ahead of the airplane wing. Measurements were made in straight flight and in turns at airplane Mach numbers from 0.25 to 0.78 and at lift coefficients from 0.10 to 0.68. A P-47D airplane was used for the tests.

SYMBOLS

p	static pressure
H	total pressure
q_c	local impact pressure outside boundary layer $(H_o - p_f)$
x	distance along chord from leading edge
s	distance along surface from pressure station
c	chord
M	local Mach number determined by q_c and p
g	acceleration of gravity

Subscripts:

o	free stream
f	at flush orifice
b	at belt orifice
t	at static-pressure tube or total-pressure tube
a	at airspeed head

APPARATUS

The investigation was conducted on a section of the left wing of a P-47D airplane at about 63 percent semispan from the plane of symmetry. The wing of the P-47D airplane incorporates Republic S-3 airfoil sections, which have pressure-distribution characteristics similar to those of the NACA 230-series sections. The test section was smoothed and faired by filling and sanding over the forward 35 percent chord on the upper surface and over the forward 10 percent chord on the lower surface. In the first flight, the upper surface developed a crack at the leading edge of the ammunition-compartment door (at 11.5 percent chord) and could not be kept smooth and unbroken in subsequent flights.

The installation and location of the flush orifices, the static-pressure tubes, and the static-pressure belt on the upper surface of the wing are shown in figures 1 and 2. The flush orifices were located at 15.7, 19.4, and 24.8 percent chord along the center line of the test panel. Some tests were made with the surface contour around the orifices at 15.7 percent chord modified slightly by filing down the orifice and the adjacent surface. The change in contour, which extended about $1\frac{3}{4}$ inches inboard and outboard of the orifices, is shown in figure 3. The pressures measured by the flush orifices were referenced to the static pressure measured with an airspeed head mounted 1 chord ahead of the leading edge near the wing tip.

One of the static-pressure tubes tested is shown in combination with a total-pressure tube in figure 4. This combination was designed for use in locating the position of transition from laminar to turbulent flow in the boundary layer. In the present tests, the total-pressure tubes of the combinations were not used. The static-pressure tubes were 1/8 inch in outside diameter and had six orifices equally spaced around the periphery at $1\frac{1}{4}$ inches (10 tube diam) downstream from the hemispherical end and $3\frac{3}{4}$ inches upstream from the first supporting bracket. The static-pressure tubes were stationed so that their orifices were at 15.7, 19.4, and 24.8 percent chord on the upper surface of the test section. The axes of the tubes were raised 1/4 inch above the wing surface except that, for some tests, the tube at 19.4 percent chord was placed in contact with the surface. The upstream or static-pressure tube 1 was $6\frac{3}{4}$ inches inboard of the row of flush orifices and tubes 2 and 3 were $4\frac{1}{4}$ and $1\frac{1}{2}$ inches inboard of the flush orifices, respectively.

The belt, which is shown in cross section in figure 2, was made up of five Saran (vinylidene chloride) tubes 1/8 inch in outside diameter placed side by side and cemented to the wing surface. Filler was used between the adjoining tubes to provide a flat surface and next to the end tubes to fair the belt into the wing surface. A final finish was obtained by cementing fabric over the tubes and over several inches of the wing surface on either side of the belt, applying cement to the outside of the fabric, and then sanding the belt smooth. The belt extended from 15 percent chord on the lower surface, around the leading edge, to 35 percent chord on the upper surface. The center of the belt was $4\frac{1}{2}$ inches outboard of the flush orifices. The orifices in the static-pressure belt were placed at the same chordwise locations as the flush orifices and the orifices in the static-pressure tubes. The arrangement of the belt orifices is shown in figure 2. The pressures measured by the static-pressure belt and the static-pressure tubes were referenced to the pressures measured with the flush orifices at corresponding chordwise locations.

Total-pressure measurements in the flow over the wing were made with the tube shown in figure 5. The tube was made of copper tubing 1/8 inch in outside diameter with a wall thickness of 1/32 inch. For the tests, the total-pressure tube was located at 19.4 percent chord in place of static-pressure tube 2 and, at this location, was set 1 inch above the wing surface in order to clear the boundary layer for all test conditions. Total-pressure measurements were obtained with static-pressure tube 1 in place or removed. The pressure measured by the total-pressure tube was referenced to the total pressure measured by the airspeed head mounted ahead of the wing near the tip.

All pressures were recorded by an NACA multiple recording manometer.

Surface-curvature measurements were made in the vicinity of the static-pressure tubes and the static-pressure orifices in the wing and belt by means of a curvature gage of the type shown in figure 6. The distance between the legs of the curvature gage was $7\frac{1}{2}$ inches. The measurements are presented in figure 7 as a plot of gage deflection against distance ahead of and behind the location of static-pressure orifices in the wing, belt, and static-pressure tubes.

TESTS

Tests were made in straight flight at altitudes from 12,000 to 25,000 feet at indicated airspeeds from 150 to 410 miles per hour. Tests were also made in turns $\left(1\frac{1}{2}g \text{ to } 4\frac{1}{2}g\right)$ at an altitude of 20,000 feet at indicated airspeeds from 310 to 375 miles per hour. The flight Mach numbers ranged from 0.28 to 0.78 and the airplane lift coefficients ranged from 0.10 to 0.68. The local Mach number of the flow over the wing ranged from 0.34 to 1.41 at the chordwise stations where the pressure measurements were made.

PRESENTATION OF RESULTS

The results of the investigation are presented in figures 8 to 10. In figure 8, the difference between the pressure measured by the static-pressure tubes p_t and the pressure measured by the corresponding flush orifices p_f as a fraction of the local impact pressure at the flush orifices outside the boundary layer q_{c_f} is plotted against the local Mach number at the flush orifices M_f. In figure 9, the difference between the pressure measured by the belt orifices p_b and the pressure measured by the corresponding flush orifices p_f is similarly plotted except that for $x/c = 0.157$ in test 1, for which no data were obtained with the flush orifice, the pressure of the static-pressure tube was used as a basis for comparison. The difference between the pressure measured by the total-pressure tube on the wing H_t and the pressure measured by the total-pressure element of the airspeed head H_a as a fraction of q_{c_f} is plotted against M_f in figure 10. The theoretical loss in total pressure, computed by the method in reference 1, is given in figure 10 for comparison.

DISCUSSION OF RESULTS

Static-Pressure Measurements

The results shown in figure 8 indicate that, at subsonic velocities, the pressures measured by the static-pressure tubes were about equal to those measured by the flush orifices at $x/c = 0.157$ and 2 to 3 percent of the local impact pressure higher than the pressures measured by the flush orifices at $x/c = 0.194$ and $x/c = 0.248$. In transition from subsonic to supersonic flow, the pressures measured by the tubes relative to those measured by the corresponding flush orifices appeared to decrease in all cases by 2 to 4 percent of the local impact pressure. For static-pressure tube 1, this decrease occurred at a local Mach number slightly greater than 1. In supersonic flow, the pressures were generally lower for static-pressure tubes 1 and 2 but higher for static-pressure tube 3 than the pressures measured by the corresponding flush orifices. Data at local Mach numbers between 0.97 and 1.20 for tubes 2 and 3 were obtained only as a normal shock wave passed over the chordwise stations where the measurements were made. The position of the normal shock wave varied across the span of the wing, however, with the result that the flush orifices and the static-pressure tubes were in different stages of a steep pressure gradient associated with shock. The data obtained under this condition are not included in figure 8. Some of the values immediately below a local Mach number of 1 in figure 8 were obtained with shock occurring upstream of the measurement station.

The variation with chordwise location of the differences between the pressures measured by the static-pressure tubes and the flush orifices may be due to differences in alinement of the tubes with local air flow, to differences in the surface contour at the flush orifices and the tubes (fig. 7), or to differences in the extent to which the tubes were submerged in the boundary layer. In an attempt to determine the effect of differences in surface contours, a test was made with the surface around flush orifice 1 filed down (figs. 3 and 7). Although the results of this test (fig. 8) were not conclusive, a tendency for the modified orifice to measure higher pressure than the original orifice was indicated. The thickness of the boundary layer at 15.7, 19.4, and 24.8 percent chord was estimated to be about 0.15, 0.25, and 0.35 inch, respectively. These estimates were based on boundary-layer measurements made in other tests at an inboard station and on the assumption that transition from laminar to turbulent flow occurred at the leading edge of the ammunition-compartment door. In order to investigate the effect of the location of a static-pressure tube in the boundary layer on the pressure characteristics of the tube, a test was made with static-pressure tube 2 placed in contact with the surface. The results, which were obtained only in subsonic flow, show that the static pressures measured with the tube in contact with the surface agreed with pressures measured with the tube 1/4 inch above the surface.

A comparison in figure 9 of the static pressures as measured by the static-pressure belt and the flush orifices shows discrepancies in some cases, particularly for inboard belt orifice 1, between different tests made under the same flight conditions. This effect was probably due to the fact that the fabric which formed the surface of the belt was not adequately cemented to the tubes and became detached around the belt orifices during the course of the tests. Only the results obtained with the outboard belt orifice 1 and inboard belt orifice 2, where this condition apparently did not occur, and the results of earlier tests for the other belt orifices should be considered as representative of the characteristics of a suitably constructed belt. For these cases, the difference in pressures measured by the belt and flush orifices was less than 3 percent of the local impact pressure and showed no large change in the transition from subsonic to supersonic flow. The comparison is subject to the same consideration of the effect of surface contour at the belt and flush orifices as in the case of the static-pressure tubes. Data for local Mach numbers between 0.97 and 1.20 are not included in figure 9 for reasons previously discussed.

The results in figures 8 and 9 generally indicate that the pressure measurements obtained by means of the static-pressure tubes and belt, if discrepancies due to faulty belt construction are discounted, were reasonably accurate. The critical Mach number determined by either of these methods, for example, would probably be correct within 2 percent. These results may not apply, however, to arrangements of static-pressure tubes having orifices located at different distances (in tube diam) from the nose and supporting bracket or to static-pressure belts of greater thickness or width in relation to the size of the wing than the belt used in this investigation.

Total-Pressure Measurements

The pressures measured by the total-pressure tube on the upper surface of the wing in subsonic flow were found to agree with the pressure measured by the total-pressure element of the airspeed head, as indicated in figure 10. In supersonic flow over the wing, however, the total-pressure tube on the wing measured a pressure that was lower than the pressure measured by the airspeed head by an amount which increased with local Mach number. This difference in total pressures, due to the formation of a normal shock wave just ahead of the mouth of the tube mounted on the wing, is in close agreement with that computed from the theory of reference 1.

CONCLUSIONS

A flight investigation of several methods of measuring static pressure and of the characteristics of a total-pressure tube in supersonic flow has indicated the following results:

1. The pressures measured by the static-pressure tubes on the upper surface of the wing in subsonic flow agreed within 3 percent of the local impact pressure with the pressures measured by the flush orifices. In transition from subsonic to supersonic flow, the pressures measured by the static-pressure tube relative to those measured by the flush orifices decreased by 2 to 4 percent of the local impact pressure.

2. Some results of the tests with the static-pressure belt were influenced by effects due to faulty construction of the belt. In other cases, however, the pressures measured by the belt agreed within 3 percent of the local impact pressure with the pressures measured by the flush orifices.

3. The total-pressure tube located outside the boundary layer on the upper surface of the wing measured pressures in supersonic flow that were in close accord with the values predicted by theory.

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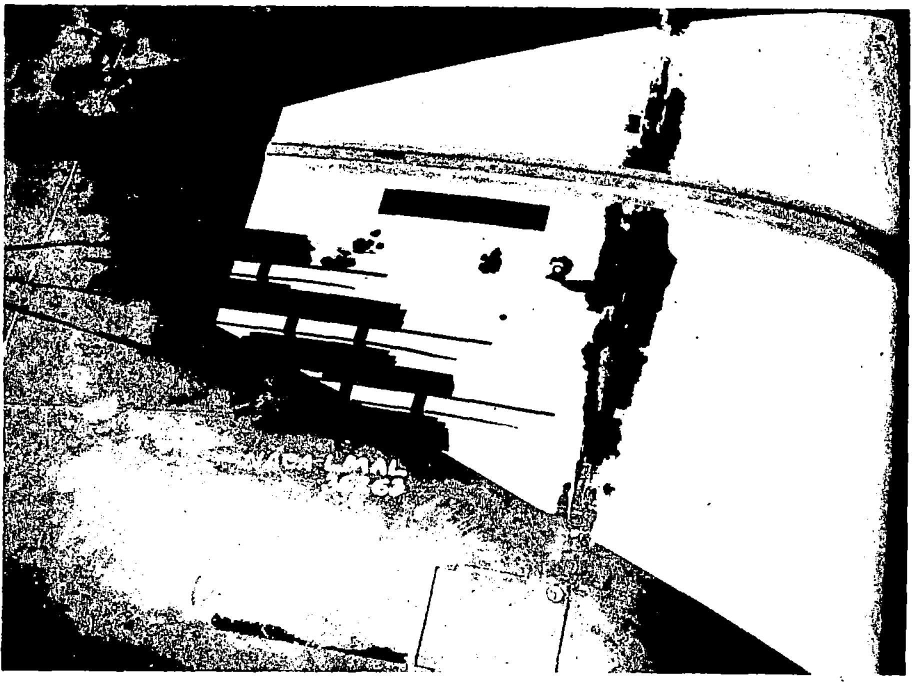

Figure 1.- Installation of static-pressure belt and static-pressure tubes on test panel.

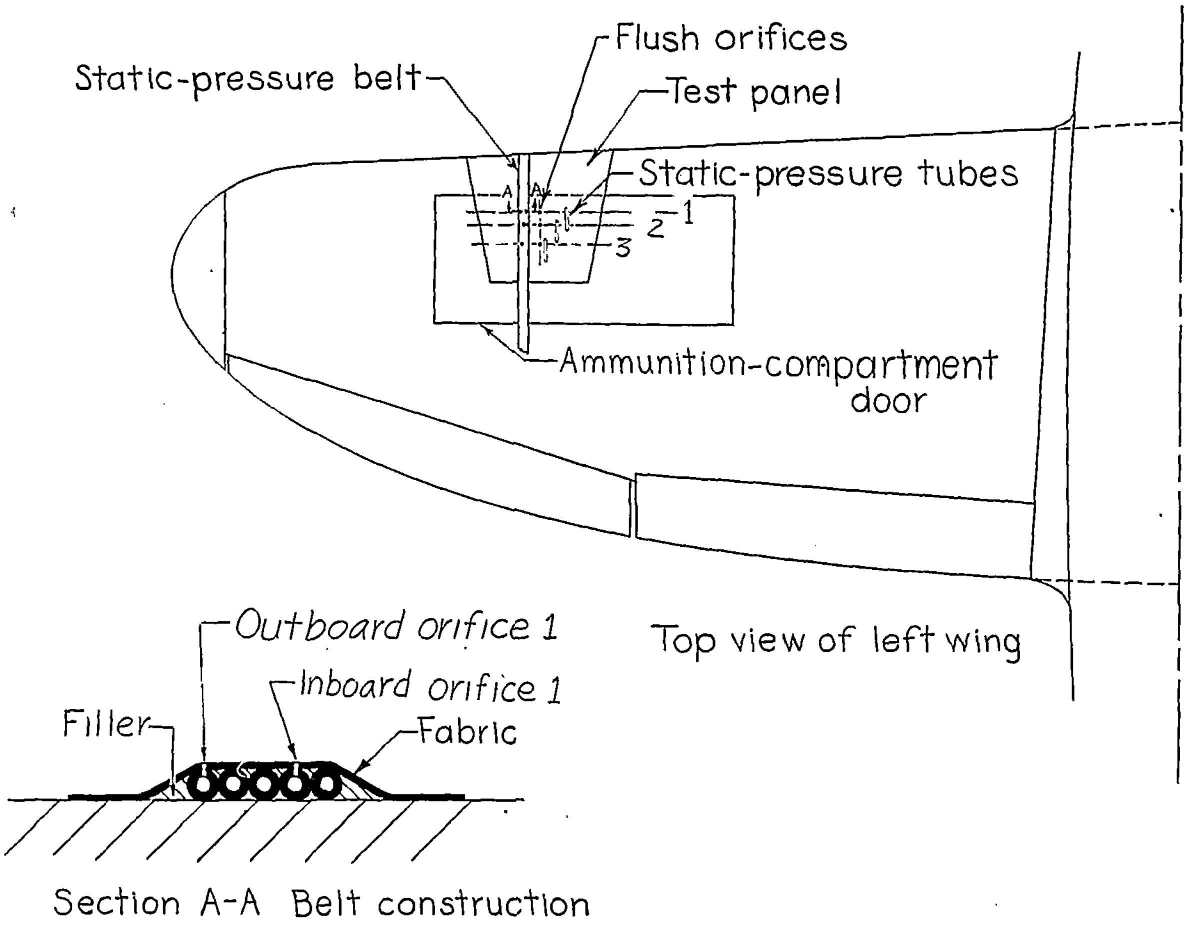

Figure 2.– Location of flush orifices, static-pressure tubes, and static-pressure belt; detail of belt construction.

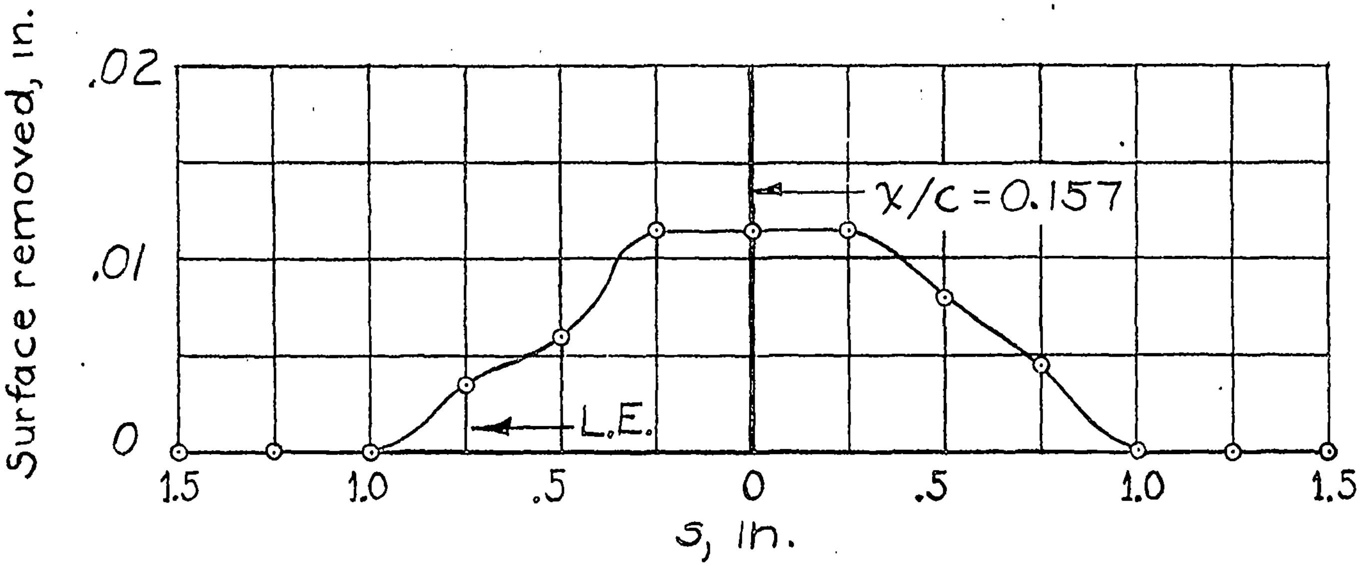

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Figure 3.— Amount of wing surface removed by filing at flush orifice 1.

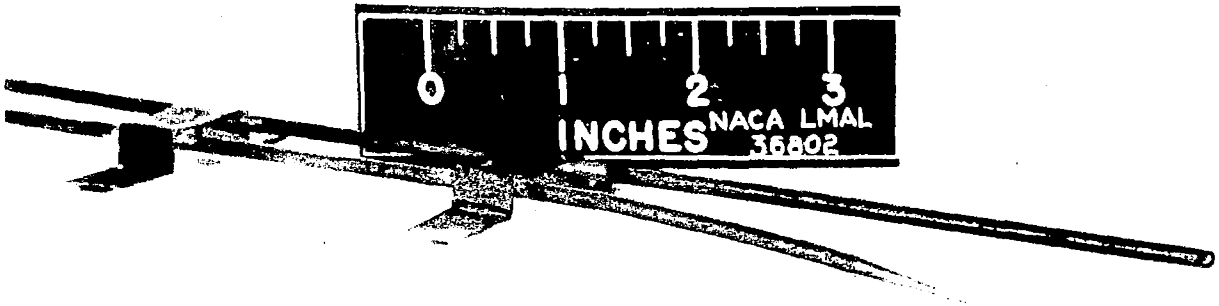

Figure 4.- Static-pressure and total-pressure tubes in combination.

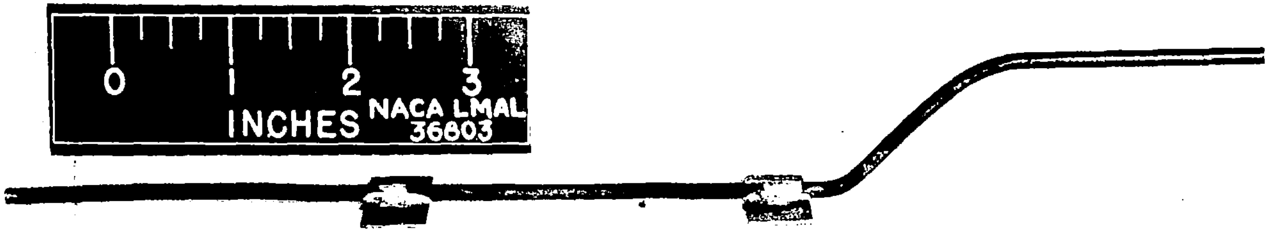

Figure 5.- Total-pressure tube.

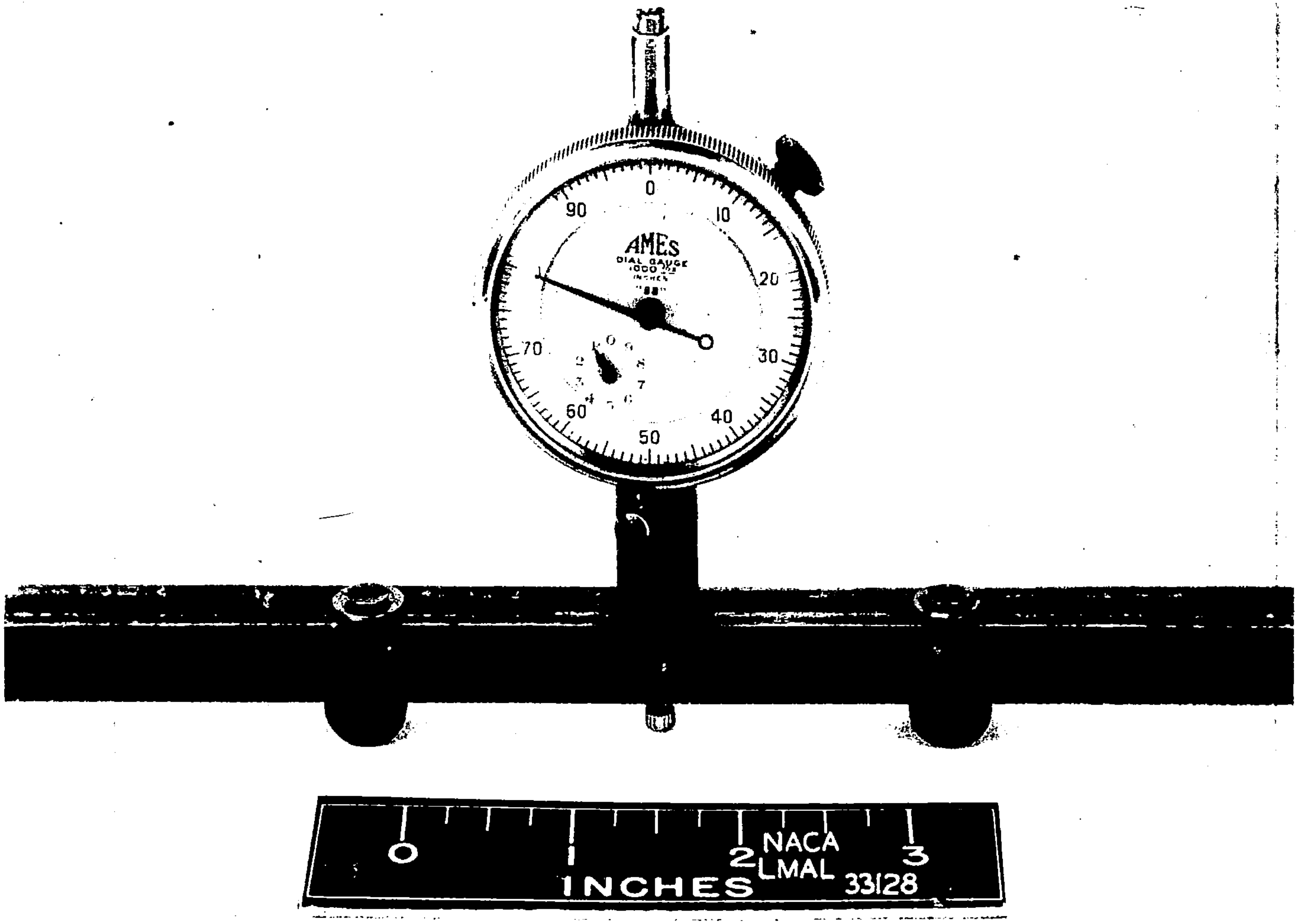

Figure 6.- Curvature gage.

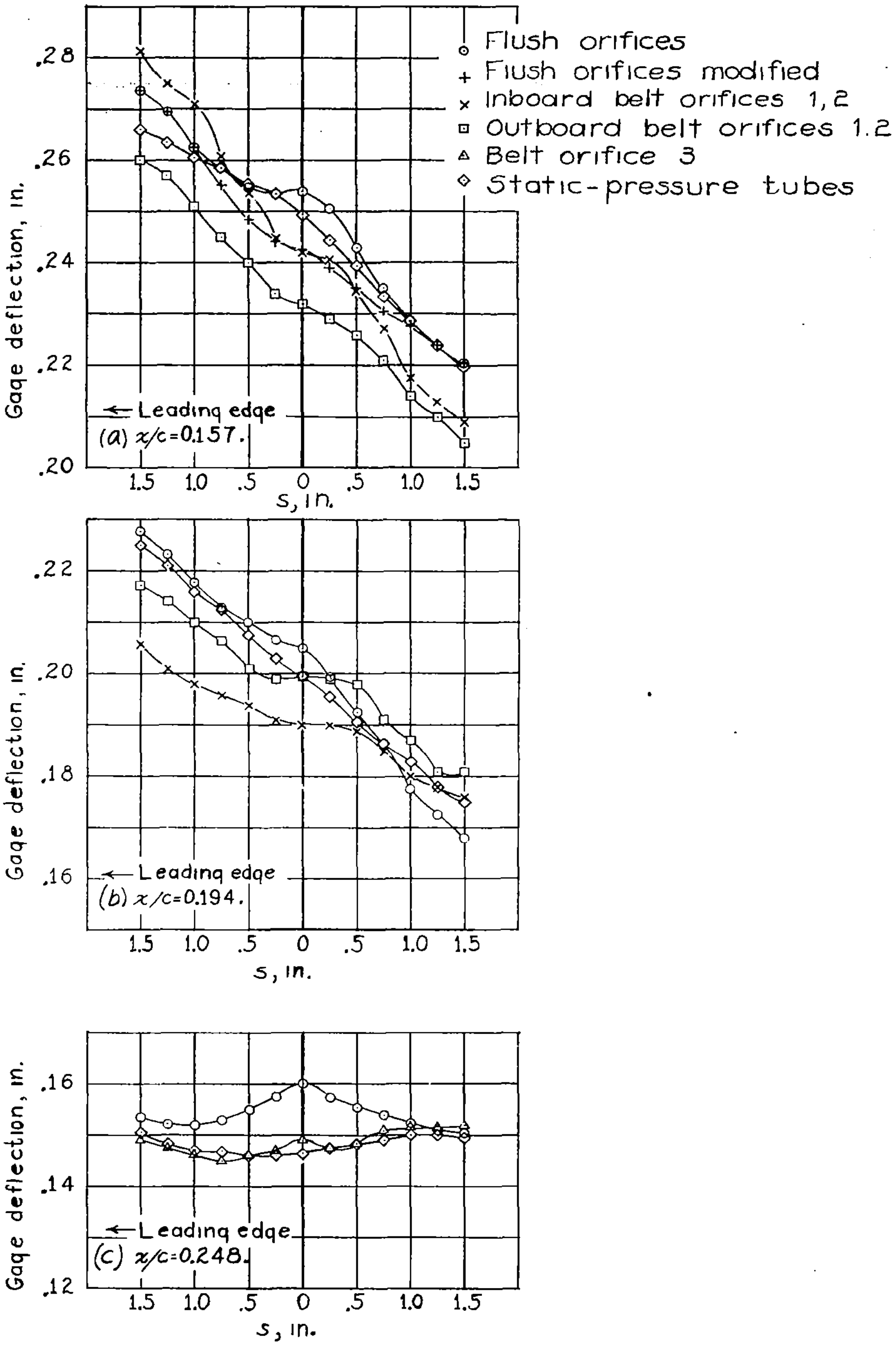

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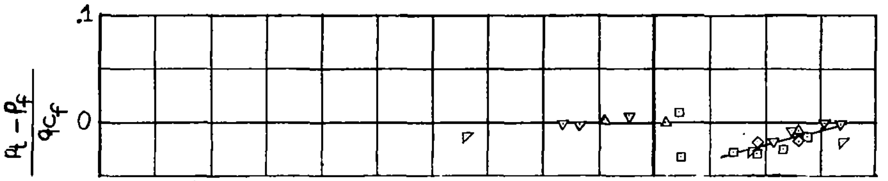
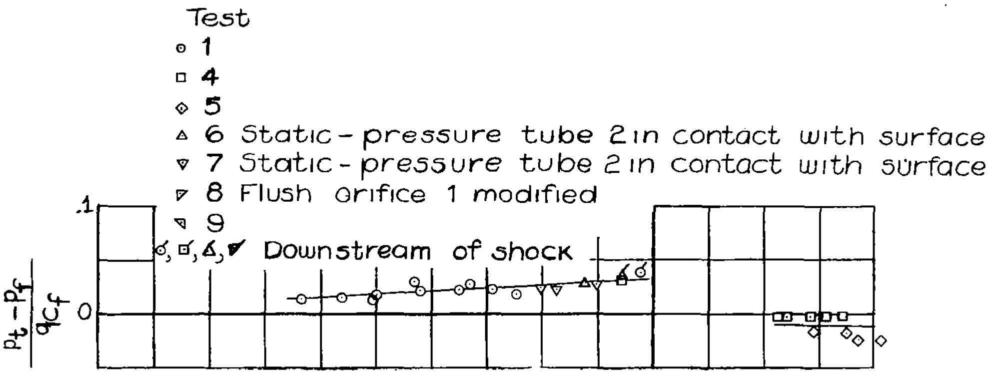
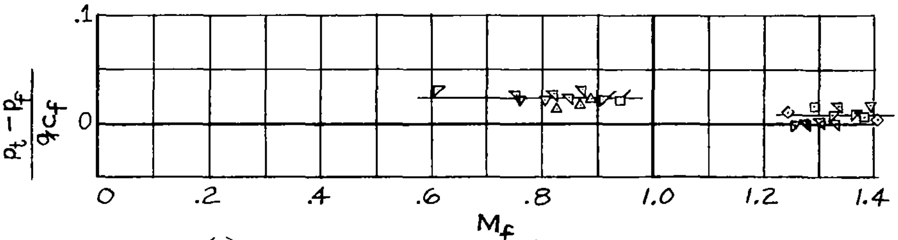
Figure 7.- Surface-curvature measurements near pressure stations.



(a) Static-pressure tube 1; $x/c = 0.157$.



(b) Static-pressure tube 2; $x/c = 0.194$.



(c) Static-pressure tube 3; $x/c = 0.248$.

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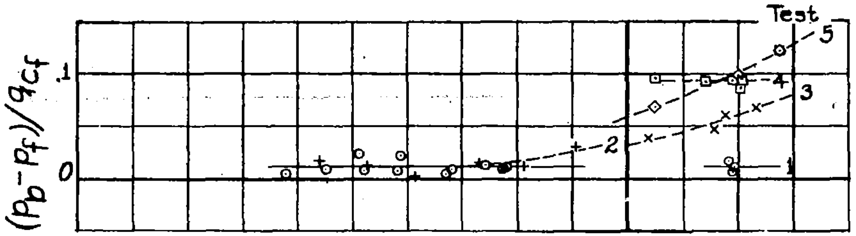
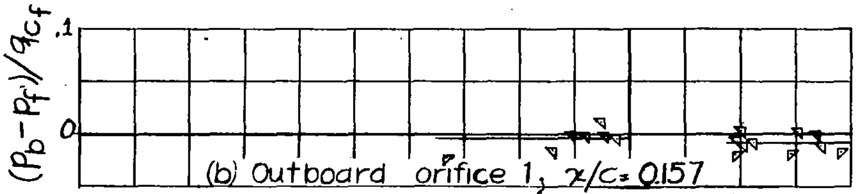
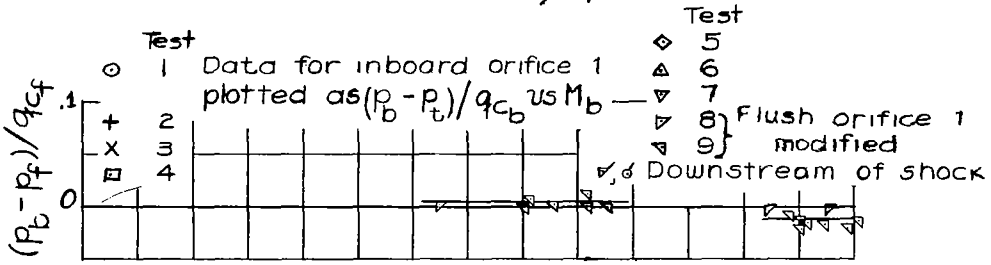
Figure 8.- Comparison of pressures measured by static-pressure tubes and flush orifices.



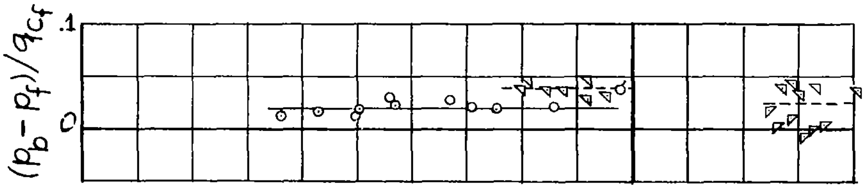
(a) Inboard orifice 1; $x/c = 0.157$.



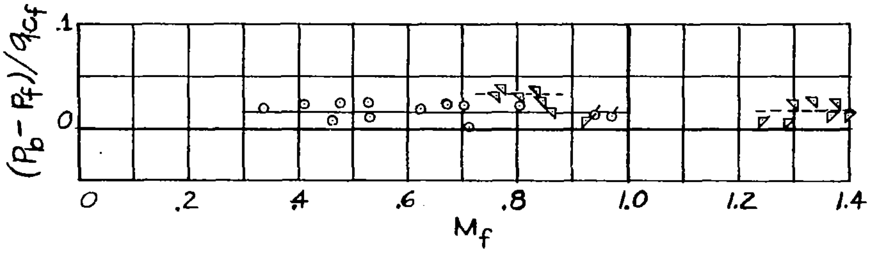
(b) Outboard orifice 1; $x/c = 0.157$



(c) Inboard orifice 2; $x/c = 0.194$



(d) Outboard orifice 2; $x/c = 0.194$.



(e) Orifice 3; $x/c = 0.248$.

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Figure 9.- Comparison of pressures measured by static-pressure belt and flush orifices.

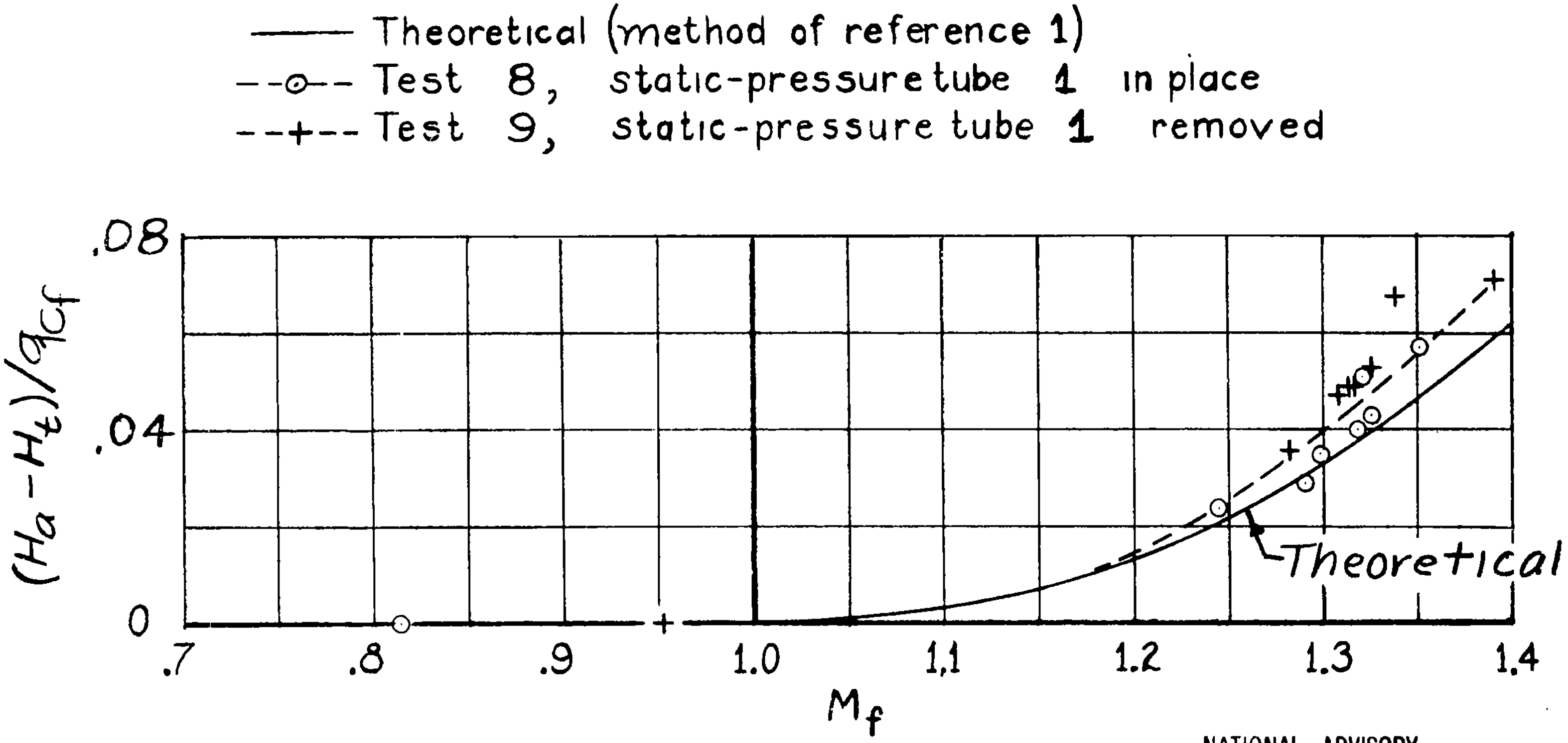

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Figure 10.- Comparison of total pressures measured with total-pressure tube on wing and with total-pressure element of airspeed head mounted ahead of wing

TITLE: Flight Investigation at High Mach Numbers of Several Methods of Measuring Static Pressure on an Airplane Wing

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ABSTRACT:

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