N 62 70324

NASA MEMO 5-10-59L

NASA MEMO 5-10-59L

/N-02

344396

# NASA

# MEMORANDUM

# REVIEW OF AIRCRAFT ALTITUDE ERRORS DUE TO STATIC-PRESSURE SOURCE AND DESCRIPTION OF NOSE-BOOM INSTALLATIONS FOR AERODYNAMIC COMPENSATION OF ERROR

By William Gracey and Virgil S. Ritchie

Langley Research Center
Langley Field, Va.

NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION
WASHINGTON
June 1959

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

MEMORANDUM 5-10-59L

# REVIEW OF AIRCRAFT ALTITUDE ERRORS DUE TO STATIC-PRESSURE SOURCE AND DESCRIPTION OF NOSE-BOOM INSTALLATIONS FOR AERODYNAMIC COMPENSATION OF ERROR

By William Gracey and Virgil S. Ritchie

## SUMMARY

A brief review of airplane altitude errors due to typical pressure installations at the fuselage nose, the wing tip, and the vertical fins is presented. A static-pressure tube designed to compensate for the position errors of fuselage-nose installations in the subsonic speed range is described. This type of tube has an ogival nose shape with the static-pressure orifices located in the low-pressure region near the tip. The results of wind-tunnel tests of these compensated tubes at two distances ahead of a model of an aircraft showed the position errors to be compensated to within 1/2 percent of the static pressure through a Mach number range up to about 1.0. This accuracy of sensing free-stream static pressure was extended up to a Mach number of about 1.15 by use of an orifice arrangement for producing approximate free-stream pressures at supersonic speeds and induced pressures for compensation of error at subsonic speeds.

## INTRODUCTION

As the cruise speeds of transport aircraft are extended into the transonic and supersonic speed ranges, the altitude errors due to the static-pressure source will, in general, become very much larger than those for subsonic speeds. This will be particularly true for fuselage-nose installations, the errors of which can reach enormous proportions just prior to the passage of the fuselage bow wave. The fuselage-nose installation, on the other hand, is most desirable for supersonic operation because, once the fuselage bow wave has moved to the rear of the static-pressure tube, the tube becomes isolated from the flow field of the aircraft. In order to realize the advantages of the fuselage-nose installation at supersonic speeds, the Langley Research Center has recently investigated a method for aerodynamic compensation of position errors ahead of fuselage noses at subsonic and near-sonic speeds (ref. 1). Some results of this investigation will be discussed following a review of some aspects of the altitude-measuring problem.

## SYMBOLS

| | |
|---|---|
| $\Delta h_{30,000}$ | altitude error at 30,000 ft |
| $p$ | static pressure |
| $M$ | Mach number |
| $x$ | distance from nose of tube to orifice |
| $d$ | maximum diameter of tube |
| $D$ | maximum diameter of body |
| $\alpha$ | angle of attack |

## DISCUSSION

Figure 1 shows the allowable tolerances for the altitude errors due to the static-pressure source as specified for civil and military aircraft. In this figure the altitude error $\Delta h$ at an altitude of 30,000 feet is plotted as a function of Mach number $M$. At a Mach number of 0.9, the Mach number range where the new jet transports will be operating, the tolerance for civil aircraft is ±900 feet and that for military aircraft is ±230 feet. When these errors are compared with the vertical separation minimums which, for reciprocal headings, are 1,000 feet for altitudes up to 29,000 feet and 2,000 feet for the altitude range above 29,000 feet, it will be apparent that the civilian aircraft allowance is too large for both 1,000-foot and 2,000-foot minimums and that the military aircraft allowance is probably too large for 1,000-foot minimums, especially when it is considered that this is only one of the errors that determine the accuracy of the altitude measurement. In view of this situation, the International Civil Aviation Organization (ICAO) has recommended a tolerance of ±50 feet for all speeds and altitudes. This tolerance represents a degree of accuracy which would be difficult to achieve with present-day instrumentation and techniques. A more realistic value, for the present time, would be a tolerance of ±1/2 percent of the static pressure. This value corresponds to an altitude error of 140 feet at sea level, 110 feet at 30,000 feet, and about 100 feet at 60,000 feet.

Figure 2 shows the calibrations of representative static-pressure-tube installations on the fuselage nose, the wing tip, and the vertical fin. Again, the altitude errors at 30,000 feet are plotted as a function of Mach number. For each of the three installations, the errors increase rapidly in the high subsonic speed range and reach peak values just prior to the passage of the bow waves. When the bow waves are sufficiently far downstream of the pressure-sensing orifices, the error of the fuselage-nose installation becomes that of the isolated tube, which for this case is assumed to be zero. The errors of the wing and fin installations, on the other hand, continue to vary by large amounts in the supersonic speed range. The large increase for the wing installation is due to the rearward bending of the fuselage bow wave; once this bow wave has moved to the rear of the static-pressure tube, the error of the wing installation becomes that of the isolated tube, which is again assumed to be zero.

As an aircraft would not be expected to cruise for any length of time in the Mach number range around 1.0, it is believed that, from the standpoint of vertical separation, the aircraft operator will be mainly concerned with the altitude errors in the Mach number range up to 0.9 and in the Mach number range above 1.1. On this basis, the errors of these installations at a Mach number of 0.9 are 100 feet for the fin installation, 400 feet for the wing installation, and 1,000 feet for the fuselage-nose installation. In the Mach number range beyond 1.1, the error of the nose installation is again assumed to be zero. The errors for this particular fin installation reach values of about 600 feet and the errors for the wing installation reach values of about 2,800 feet.

Figure 3 shows the calibrations of a number of fuselage-vent installations. These calibrations were chosen to show that the altitude errors of vent installations at subsonic speeds may be either positive or negative, this result being in contrast to the errors of the static-pressure-tube installations (fig. 2) which, at subsonic speeds, are in all cases negative. At a Mach number of 0.9, the errors range from -300 feet to 700 feet, and in the Mach number range beyond 1.1 the errors are about 1,300 feet and 1,700 feet.

It is apparent from the magnitudes of the errors of these installations that some means must be found to reduce the static-pressure errors if altitude errors on the order of 100 feet are to be achieved. The static-pressure errors may be minimized in any one of a number of ways: (1) by the use of an electro-mechanical compensator which computes the error and applies a correction before the altitude indication is displayed, (2) by the use of two static-pressure installations (for example, it would be possible to use a fin installation up to a Mach number of 0.9 and then, at supersonic speeds, to switch to a fuselage-nose boom which, in this case, could be relatively short), and (3) by the use of aerodynamic compensation whereby induced pressures are utilized to approximately cancel the static-pressure errors.

As shown on figure 4, the last method can be applied to fuselage-nose installations by the use of a novel form of a static-pressure tube.

This tube has an ogival nose shape with the static-pressure orifices located in the low-pressure region near the tip. The two curves on this figure represent the position-error variations, as determined by wind-tunnel tests, at two positions ahead of a model of an aircraft configuration. The position error $\Delta p$ is presented as a fraction of the static pressure and is plotted as a function of Mach number. By the proper combination of nose shape and orifice location, it is possible to produce a static-pressure-error variation with Mach number which will be a mirror image of the position-error variation at a given position ahead of the fuselage. The results of the tests of the two tubes at distances of 0.27 and 0.95 fuselage diameters ahead of the fuselage nose are shown by the symbols along the zero-error line. These results show that, even for positions as short as 0.27 fuselage diameter, the position errors of the fuselage can be compensated to within 1/2 percent of the static pressure throughout the subsonic speed range. It should be noted that the error indicated by the long-nose tube at a Mach number of about 1.03 is due to the location of the fuselage bow wave downstream of the pressure-sensing orifices.

Figure 5 presents typical pressure distributions along the long-nose tube of figure 4 at subsonic and supersonic speeds. On this figure the static-pressure coefficient $\Delta p/p$ is plotted as a function of the distance $x/d$ along the tube. For the position of the orifices on the tube shown in figure 4, the local pressure coefficient at subsonic speeds is negative (as is required for compensation) and the pressure coefficient at supersonic speeds (which would be that of the isolated tube) is also negative. If the orifices had been located at a position of about 2.6d, the pressure coefficient at subsonic speeds would have about the same negative value as at $x/d = 4.95$ and the coefficient at supersonic speeds would be near zero. Although a tube with the orifices at 2.6d was not tested on a fuselage-nose installation during this investigation, the long-nose tube shown in figure 4 was altered by locating three sets of orifices in the region near $x/d = 2.4$; thus, the positive pressure at these orifices would balance the negative pressure of the rear set of orifices ($x/d = 4.95$) and would produce a near-zero error at supersonic speeds.

The results of tests of this tube are shown in figure 6. The curve in this figure represents the position-error variation at a distance of about 1 fuselage diameter ahead of the model aircraft. The results of the tests of this tube, as shown by the symbols along the zero-error line, show the position errors to be compensated for throughout the subsonic speed range and, at supersonic speeds, the error of the isolated tube to be within 1/2 percent of the static pressure for Mach numbers up to about 1.15.

The effect of angle of attack on the errors of these static-pressure tubes is shown in figure 7. For this case the plotted values of $\Delta p/p$ represent the error due solely to tube inclination, complete compensation of error due to position being assumed ($\Delta p/p = 0$ for $\alpha = 0^\circ$); no effects of position-error variation with angle of attack are included. The lower curve shows the effect of angle of attack, at $M = 0.6$, for a tube with the orifices encircling the tube. For an angle-of-attack change from 0° to 4° (the variation which would be expected for a level-flight cruise of about 3,000 miles), the additional error due to angle of attack is about 1/4 percent of the static pressure at a Mach number of 0.6. Although this error increases to about 1/2 percent at transonic speeds, it may be reduced by approximately one-half by deliberately undercompensating the position error at $\alpha = 0^\circ$ in order to allow for negative-pressure error due to increased angle of attack. For large angles of attack, up to at least 15.5°, the error due to angle of attack can be aerodynamically reduced to negligibly small proportions by use of orifices located 37.5° from the bottom of the tube (see unfaired data near zero-error line in fig. 7); this insensitivity of orifices at the 37.5° circumferential location to angle-of-attack changes applied at transonic and supersonic as well as at subsonic speeds.

## CONCLUDING REMARKS

Aircraft altitude errors due to static-pressure source are shown to be large, especially at transonic speeds, for typical pressure-sensor installations. Such errors can be aerodynamically compensated by use of a comparatively simple form of a static-pressure tube installed on a relatively short nose boom.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Field, Va., November 6, 1958.

## REFERENCE

1. Ritchie, Virgil S.: Several Methods for Aerodynamic Reduction of Static-Pressure Sensing Errors for Aircraft at Subsonic, Near-Sonic, and Low Supersonic Speeds. NASA REPORT 18, 1959.

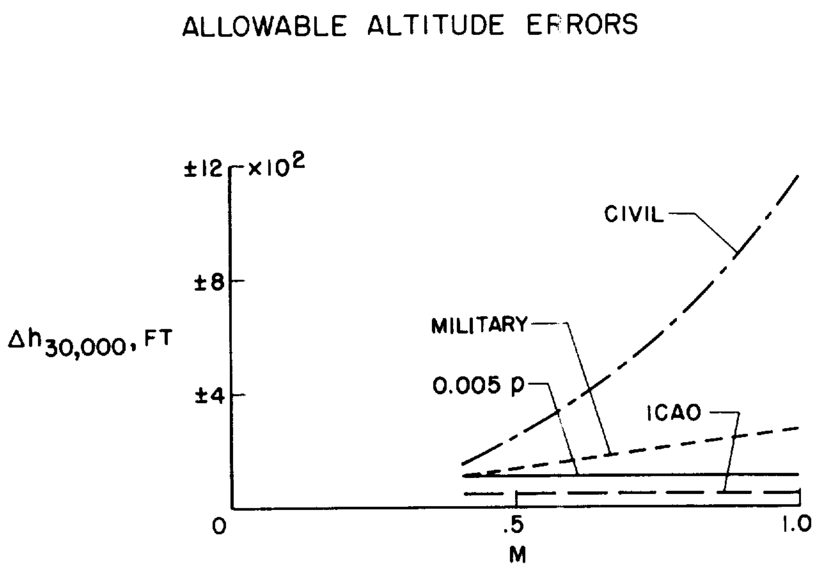


Figure 1

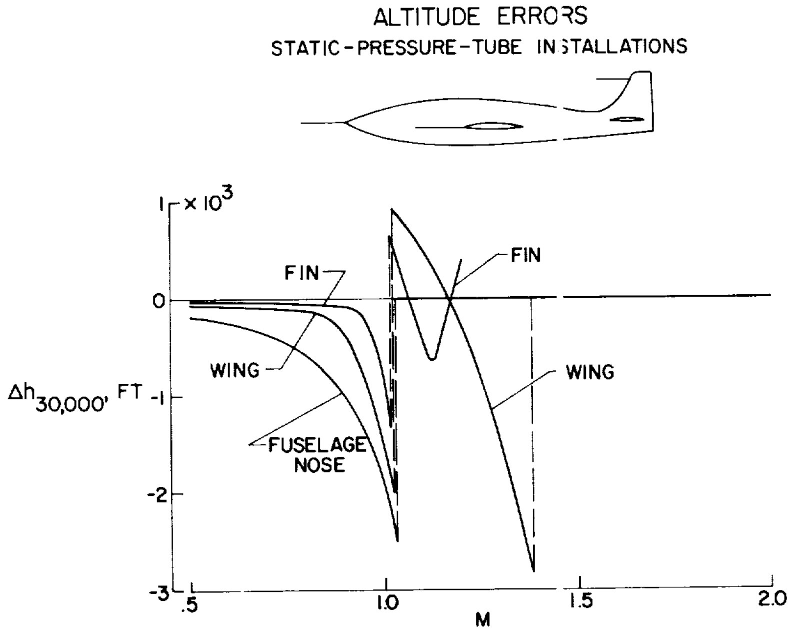
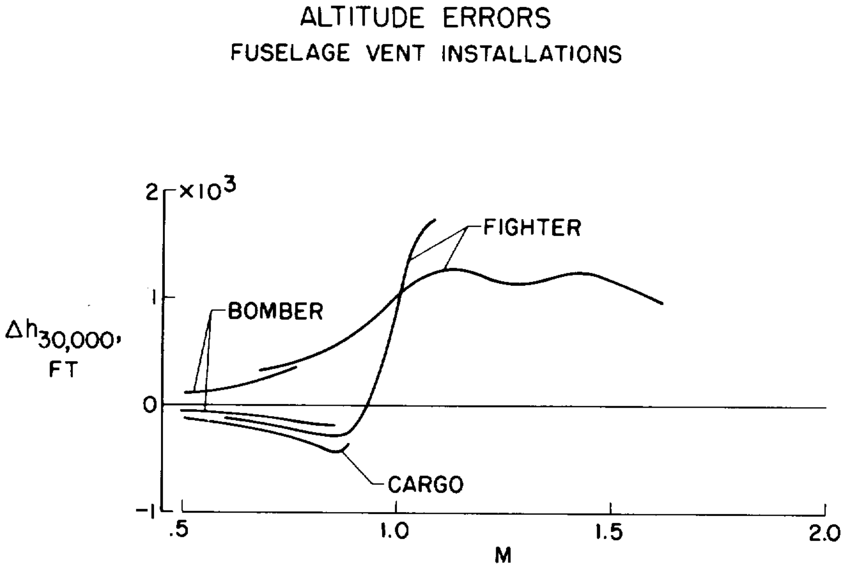


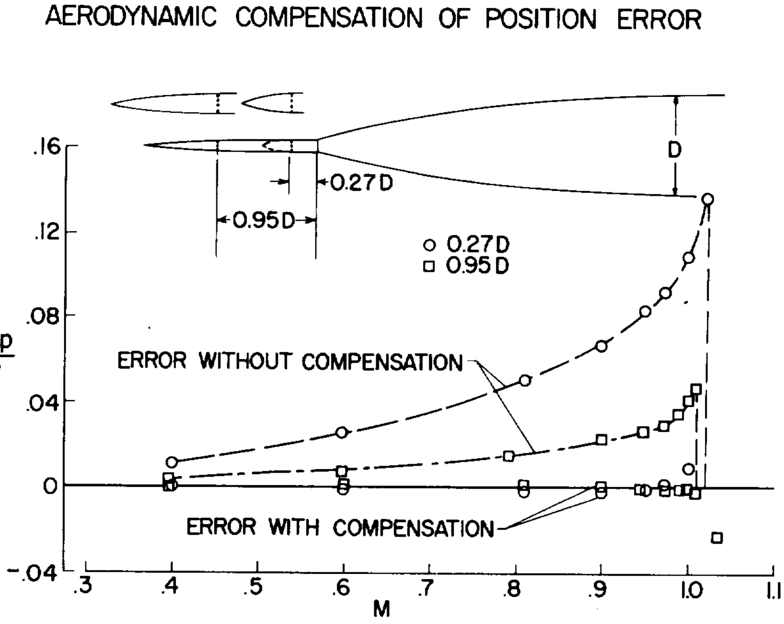
Figure 2



ALTITUDE ERRORS

FUSELAGE VENT INSTALLATIONS

Figure 3



AERODYNAMIC COMPENSATION OF POSITION ERROR

Figure 4

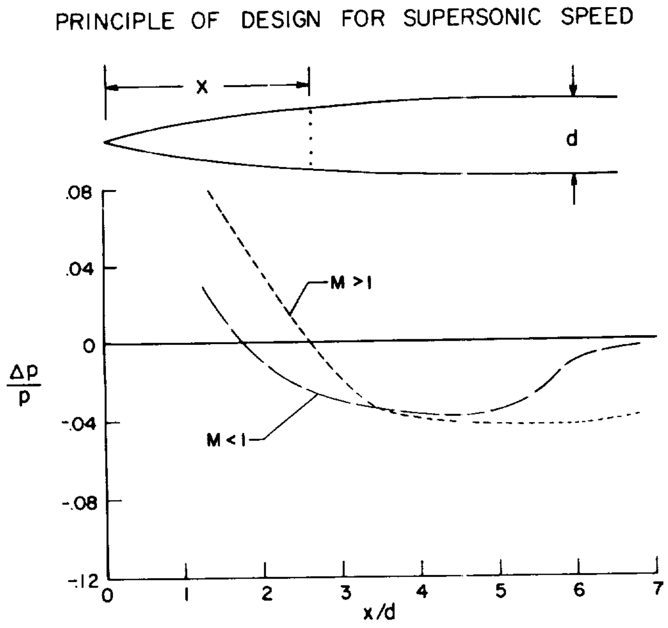


Figure 5

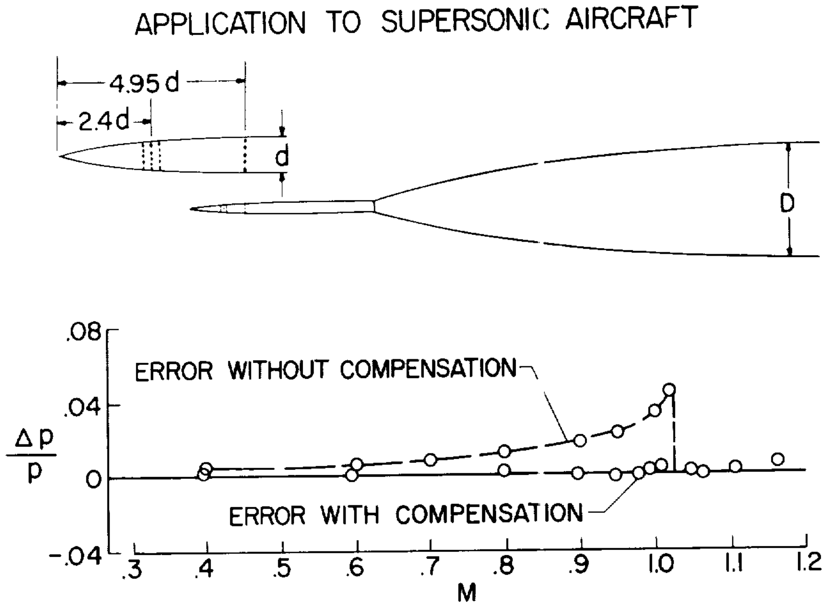


Figure 6

AERODYNAMIC-COMPENSATION TUBES AT ANGLES OF ATTACK

M = 0.6

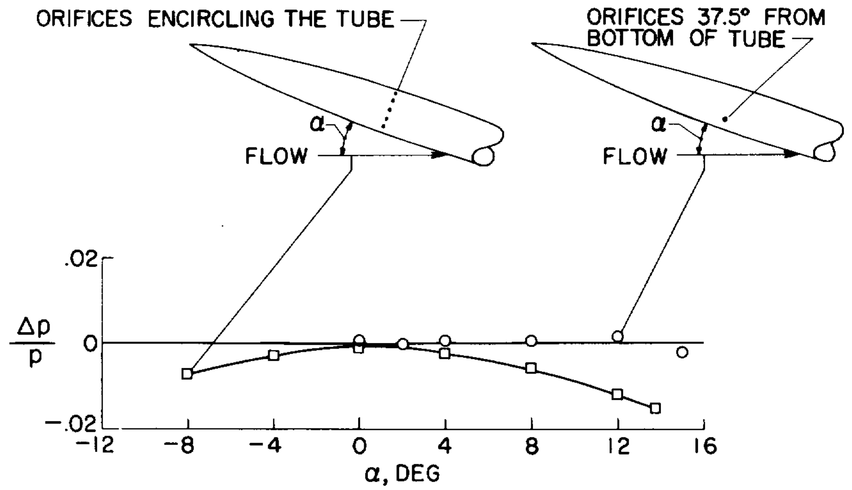


Figure 7

NASA - Langley Field, Va. L-441