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RESEARCH MEMORANDUM

PRESSURE MEASUREMENTS ON A BODY OF REVOLUTION IN THE
LANGLEY 16-FOOT TRANSONIC TUNNEL AND A
COMPARISON WITH FREE-FALL DATA

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

The repowered Langley 16-foot tunnel, equipped with a transonic test section, permits the investigation of relatively large-scale models at transonic speeds. As an initial investigation in this facility, a series of tests was conducted which would enable the best possible correlation with pressure measurements which had been made on a body of revolution at transonic speeds by means of the free-fall technique. A body was built to the same dimensions as the free-fall body, which was 10 feet long, and tests were conducted at Mach numbers from 0.74 to 1.09 at essentially the same Reynolds number as the free-fall tests.

At Mach numbers from 0.74 up to and including 1.00, generally good agreement in shape between pressure distributions on the wind-tunnel model and on the free-fall model was obtained. There was a small but consistent displacement in over-all level between the two sets of data, which appears to result from an incorrect reference level for the free-fall data. For Mach numbers from 1.02 to 1.09 increased differences, due to wind-tunnel wall interference, were apparent.

INTRODUCTION

Until recently, pressure data in the transonic speed range were almost nonexistent. The basic reason for this lack of data, of course, has been the inability of conventional wind tunnels to operate in the transonic speed range without severe interference problems. Various research techniques have been developed to avoid these difficulties and have been widely used to obtain such data as do exist. Most of these methods, however, suffer from other limitations such as very small-scale, nonuniform flow field or limited instrumentation. One such special method which permits interference-free investigation at large scale is exemplified in reference 1. In this investigation the drag and pressure distribution on a slender body of revolution dropped from an airplane at high altitude are reported.

The repowered Langley 16-foot tunnel, equipped with a transonic test section of the type described in reference 2, permits the investigation of relatively large-scale models at transonic speeds. In order to verify the ability of this new facility to provide accurate data, the initial tunnel investigation consisted of series of tests which would enable the best possible correlation with the results reported in reference 1. A body was built to the same dimensions as the free-fall body and was sting-mounted in such a way as to give the smallest possible difference in configuration at the rear end of the body. The model was made larger than would have been dictated by the usual blockage considerations of closed-throat high-speed wind tunnels, being large enough to eliminate by area considerations alone the Mach number range from 0.94 to 1.06 in a closed throat of the same size. In addition to correlation with free-fall data, the investigation was extended to include an angle-of-attack range and to observe any wall-interference effects. The present report covers the first phase of this work, that is, the correlation of wind-tunnel pressure data with free-fall pressure data.

APPARATUS AND METHODS

Test conditions.- The range of Mach number covered in this investigation was 0.74 to 1.09. All data were obtained at approximately zero angle of attack. The Reynolds number based on model length was restricted to the relatively narrow range of about 33×10^6 to 41×10^6. Figure 1 shows the Reynolds number for the tests in the 16-foot transonic tunnel and for the free-fall test reported in reference 1. It will be noted that the curves intersect at a Mach number slightly above the sonic value. The free-stream relative humidity was at all times below the saturation point, generally varying from about 80 percent at the lower speeds to less than 30 percent at the maximum speeds attained.

Model dimensions.- The shape of the model is that of the fuselage used in an NACA transonic research program. A sketch of the model is shown in figure 2, along with a sketch of the free-fall test body (from reference 1), which is included to emphasize the similarities of the two test configurations. A list of ordinates is included in the figure. The body is 120 inches long, with a 10-inch maximum diameter 60 inches from the nose. At the aft end the body is faired into a 2-inch-diameter cylindrical section, which in turn is faired into a cone-shaped sting having a half-angle of 5°.

A nose boom was installed for one test run. This boom duplicated the dimensions of the airspeed head of the free-fall body but was not instrumented for pressure measurement. For another test run, a transition strip was installed around the body 9 percent of the length from the nose, as shown in figure 2. This strip consisted of No. 60 carborundum grains imbedded in a $\frac{3}{8}$-inch-wide band of dope.

Model construction.- The all-metal body is made up of several sections, and the longitudinal locations of the joints between sections are tabulated in figure 2. The joints are well fitted and tight, however, and the model was maintained at all times in a clean and fair condition.

Following the investigation, the ordinates of the body were measured at stations every 1.25 percent of the length from $\frac{x}{l} = 0.0375$ to $\frac{x}{l} = 0.9000$ and compared with the ordinates of a curve faired smoothly through the design ordinates $\left(\text{which were given at intervals of } \frac{x}{l} = 0.05 \text{ over most of the body}\right)$. The results of this comparison are shown in figure 3 as $\Delta y/l$ (the average deviation of the body surface at each station from the faired curve, expressed as a fraction of body length) plotted against longitudinal location.

Support strut.- Figure 4 is a sketch of the support configuration used in these tests. The main support is a vertical cantilever strut of circular-arc section, capped with a 14-inch-diameter cylindrical body. The cone-shaped sting behind the model is faired into this body.

Instrumentation and accuracy of measurement.- The pressure orifices are arranged in five rows of 21 orifices each, with the rows distributed over one side of the model as sketched in figure 2. The pressure tubes from these orifices were conducted through the sting and strut, and thence to multiple-tube manometers. The estimated accuracy of the pressure coefficients is ±0.005, where pressure coefficient is defined as

$$\frac{\text{Local pressure - Free-stream static pressure}}{\text{Free-stream dynamic pressure}}$$

The accuracy with which the model was alined with the tunnel air stream for these tests is not known, since at the time of the tests no data on stream alinement in the test section were available. The first eight pairs of the 0° and 180° orifices were connected to alcohol U-tubes, and at each Mach number the model angle of attack was adjusted to obtain the smallest possible difference between upper- and lower-surface pressures. The model angle at which the smallest difference was obtained varied between +0.1° and +0.4° from the horizontal, the angle being measured to an accuracy of ±0.1° with the aid of cathetometers directed at targets on the model.

The stream Mach number was determined on the basis of a calibration which related the stream static pressure to the pressure measured in the forward end of the tank surrounding the test section. Stream static pressure was measured along the surface of a cylindrical tube located on the axial center line of the test section. The largest variations in local Mach number along the test-section axis found in this calibration were ±0.003 for the region of the body. Mach numbers in this report are considered accurate to ±0.005.

No corrections have been applied to the data. For wind tunnels of this type operating at subsonic speed, the need for tunnel-wall corrections has not been established. For supersonic conditions, no method exists as yet which enables the interference corrections to be calculated.

RESULTS

Repeatability of results.- No difficulty was experienced in repeating data during the tests. The last test runs gave data which were in every way comparable with those of the first runs, indicating that the model was maintained in a sufficiently clean condition to avoid pressure-measurement errors due to changes in surface conditions. In addition, the agreement of the measured pressures at the five rows of orifices was excellent. This is illustrated by figure 5, in which the pressures measured on the five rows of orifices are superimposed on a single plot. The agreement at this speed (Mach number = 0.97) is typical of all speeds.

Configuration modifications.- Two minor changes were made in the wind-tunnel model during the test program. These changes were intended to establish the major effects of two possible differences between the wind-tunnel model and the free-fall body. The first of these was a change of body roughness, which was simulated by the installation of a transition strip as shown in figure 2. A run was made through the Mach number range, but the only observable effect was a small increase in the pressure recorded at the orifice immediately behind the transition strip. The result at Mach number 1.0, shown in figure 6, was typical of the results at other Mach numbers. A second modification, also shown in figure 2, consisted of the addition of a nose boom to the model. The object of this installation was to determine whether the presence of the airspeed head on the free-fall model affected the pressure distributions in any way. The results again indicated local effects only; the first orifice on the model, and at higher speeds the second orifice also, indicated slightly higher pressures than before the nose boom was installed. Figure 7 shows a typical comparison, again at Mach number 1.0.

Comparison with free-fall results.- Figure 8 shows plots at several Mach numbers of pressure coefficient along the body as obtained in the 16-foot transonic tunnel and as obtained in the free-fall tests reported in reference 1. The wind-tunnel data points in this figure are from tests of the body without transition strip and without nose boom. The values are the average of the 0° and 180° orifice pressure measurements. This averaging was done to eliminate the effects of stream misalinement, although figure 5 indicates that these effects, if present, were small. The tunnel data curves were faired to include all points. The free-fall data shown were obtained from reference 1, and in this case each point represents a single orifice. The curves again were faired to include all points.

The most apparent feature of the comparison is the marked similarity in shape detail at most speeds, accompanied by a consistent displacement between the data obtained in the tunnel tests and those obtained by the free-fall technique. For the speeds tested from Mach number 0.74 up to and including 1.00, agreement in shape was generally good except over the aft 15 percent of the body length, and at most points on the body the free-fall pressure coefficients are displaced 0.02 or 0.03 in the positive direction from the wind-tunnel data. Local sonic velocity first occurred at about 70 percent of the body length at a stream Mach number of about 0.95. At slightly higher speeds the pressures in this area formed a distinct negative peak, followed by the sharp increase in pressures generally indicative of a shock wave. In the vicinity of Mach number 1.0 the position of this shock wave appears to be very sensitive to small speed changes, so that two distributions near Mach number 1.0 have been presented (figs. 8(g) and 8(h)). At the supersonic speeds the agreement was not as good as at the subsonic speeds, although general agreement in shape continued, again except over the rearmost portions of the body. At these speeds differences up to 0.08 in pressure coefficient were measured, although at the highest speeds the agreement over the forward portion of the body was at least as good as at the subsonic speeds.

DISCUSSION

Surface irregularities.- In comparing the wind-tunnel and free-fall pressure distributions, one noticeable peculiarity is the roughness of the forward part of the pressure distributions, particularly for the wind-tunnel model in the region of 10 to 30 percent of the length. This irregularity is in evidence at all Mach numbers but becomes most prominent for speeds near the sonic value. Similar irregularities have been noted previously in the pressure distributions measured on slender bodies and have been considered by some authors to be an aerodynamic characteristic of slender bodies of revolution (reference 3). In the present case, however, certain surface irregularities are believed to be a contributing, if not the major, cause of the irregularities in the pressure distribution on the model used for these wind-tunnel tests. Figure 3 shows that at points between 10 and 15 percent of the body length the actual body surface averages as much as $0.00013l$ (or about 0.016 inch) below the faired curve, resulting in a somewhat flattened profile. Between 15 and 20 percent of the length the surface averages as much as $0.00006l$ (or about 0.007 inch) above the faired curve, resulting in greater curvature than desired. These surface irregularities correspond closely in position to the waviness of the pressure distribution on the forward part of the wind-tunnel model. Since the two are probably related, the importance of obtaining a smooth and fair surface curve when constructing such a body is emphasized.

For the free-fall body a similar though much less prominent irregularity occurs in the pressure distribution at about the same point on the body, but the smaller number of orifices prevents a good definition of the curve. The ordinates given for construction were the same for both bodies, and are those shown in figure 2. The number of these ordinates is probably insufficient to insure a better faired surface than was obtained, if normal shop procedures are used.

Limitations of the correlation.- At a Mach number of 0.75 the free-fall pressure coefficients are accurate to ±0.04, and in this speed range the differences between the free-fall and wind-tunnel data are of this same order. As the speed increases, the estimated accuracy of the free-fall pressure coefficients improves, being ±0.02 at Mach number 1.0, or slightly better than the differences observed. However, it is indicated in reference 1 that a type of error may exist in the free-fall data which would cause an over-all shift in the positive direction, particularly at the supersonic speeds. Such an error could account for some of the differences observed at the higher speeds.

With regard to the large differences observed in the region of 85 to 95 percent of the length at most speeds, it should be remembered that this is the portion of the body where the differences in the aft configuration would be expected to affect the comparison. However, the configuration differences are such that the more positive pressures would be expected in the wind-tunnel data, rather than in the free-fall data where they are shown. Only a single free-fall test of the body alone equipped for pressure measurements was made, so that no direct verification of the original measurements is available. However, later free-fall tests of two similar bodies with wings in different positions, as yet unreported, indicate that the orifices at 85 and 95 percent of the length may not have been operating properly during the test of the body alone reported in reference 1. The later tests record pressures in substantial agreement with the wind-tunnel data, but the presence of the wings on the free-fall models obviates a definite conclusion concerning errors in the original data.

Wind-tunnel wall interference.- Another important source of discrepancy in the comparison is wall interference in the case of the wind-tunnel data. Although the test section is designed to minimize subsonic interference, it was expected that at supersonic speeds the bow wave would be reflected back to the model. At Mach number 1.09, for example, the comparison shows the two sets of data to be in very good agreement, except for a small displacement, over the entire forward half of the model. At 50 percent of the length of the wind-tunnel model an abrupt positive increase in pressures occurred, however, and behind this point all pressures were low as compared with the free-fall data. At Mach number 1.07 the comparison is similar except that the point of positive increase moved up to 37 percent of the length, and the region of more negative pressures moved forward a corresponding amount. These peculiarities are interpreted as the effects of the wall-reflected disturbances on the body pressures, as described in references 4 and 5. The pressures ahead of the compression should be free of interference, and the differences between the two sets of data in this area are probably due to the incorrect reference level for the free-fall data which resulted in a small displacement of the curve in the positive direction.

At the lower supersonic Mach numbers similar interference conditions appear to be present, but to a lesser extent. At Mach number 1.05 no abrupt compression is in evidence, but in the region of 13 to 20 percent of the length the pressures on the wind-tunnel model are approximately in coincidence with the free-fall pressures, rather than being more negative as is the case at every other speed. This result is believed to represent a mild interference compression in this region on the wind-tunnel model. Beginning at about 30 percent of the length the pressures are again considerably lower than at the corresponding points on the free-fall model, indicating an interference expansion behind this point on the wind-tunnel model. At Mach number 1.02 the differences between the two sets of data for the forward central section of the body are also believed to be representative of a mild interference expansion of the pressures on the wind-tunnel model. If a compression ahead of this area is present, it is too small to be observed.

For any of the supersonic Mach numbers, the largest differences between the pressures on the free-fall model and those on the wind-tunnel model, except at the extreme rear, do not exceed about 8 percent of the dynamic pressure. Of this amount, it is estimated that about 2 or 3 percent may be due to the incorrect reference level for the flight data, since this is the magnitude of the differences over most of the body at Mach number 1.0 and over the forward interference-free areas at the supersonic speeds. The remaining 5 or 6 percent is attributed to wind-tunnel interference.

CONCLUDING REMARKS

Pressure measurements have been made on a relatively large body of revolution, 10 feet long and of fineness ratio 12, in a 16-foot transonic wind tunnel between Mach numbers of 0.74 and 1.09, and the results have been compared with pressure data obtained by the free-fall method on an identical body at essentially the same Reynolds number. These comparisons indicate that:

1. For the speeds tested from Mach number 0.74 up to and including 1.00, generally good agreement in shape between pressure distributions on the wind-tunnel model and on the free-fall model was obtained. There was a small but consistent displacement in over-all level between the two sets of data of from 2 to 3 percent of dynamic pressure. This displacement appears to result from an incorrect reference level for the free-fall data.

2. For the speeds from Mach number 1.02 to 1.09, the agreement was not quite as good as at the lower speeds. This discrepancy is believed due to the wind-tunnel wall interference. At the lower speeds in this range, the interference is weak but begins well forward on the model. At higher speeds the interference becomes stronger, but begins much farther back on the model. Maximum differences between the free-fall and wind-tunnel data were about 8 percent of dynamic pressure, about one-third of which is believed due to an incorrect reference level for the free-fall data, and two-thirds due to wind-tunnel interference. Over the forward interference-free areas on the model, agreement as good as at the subsonic speeds was obtained.

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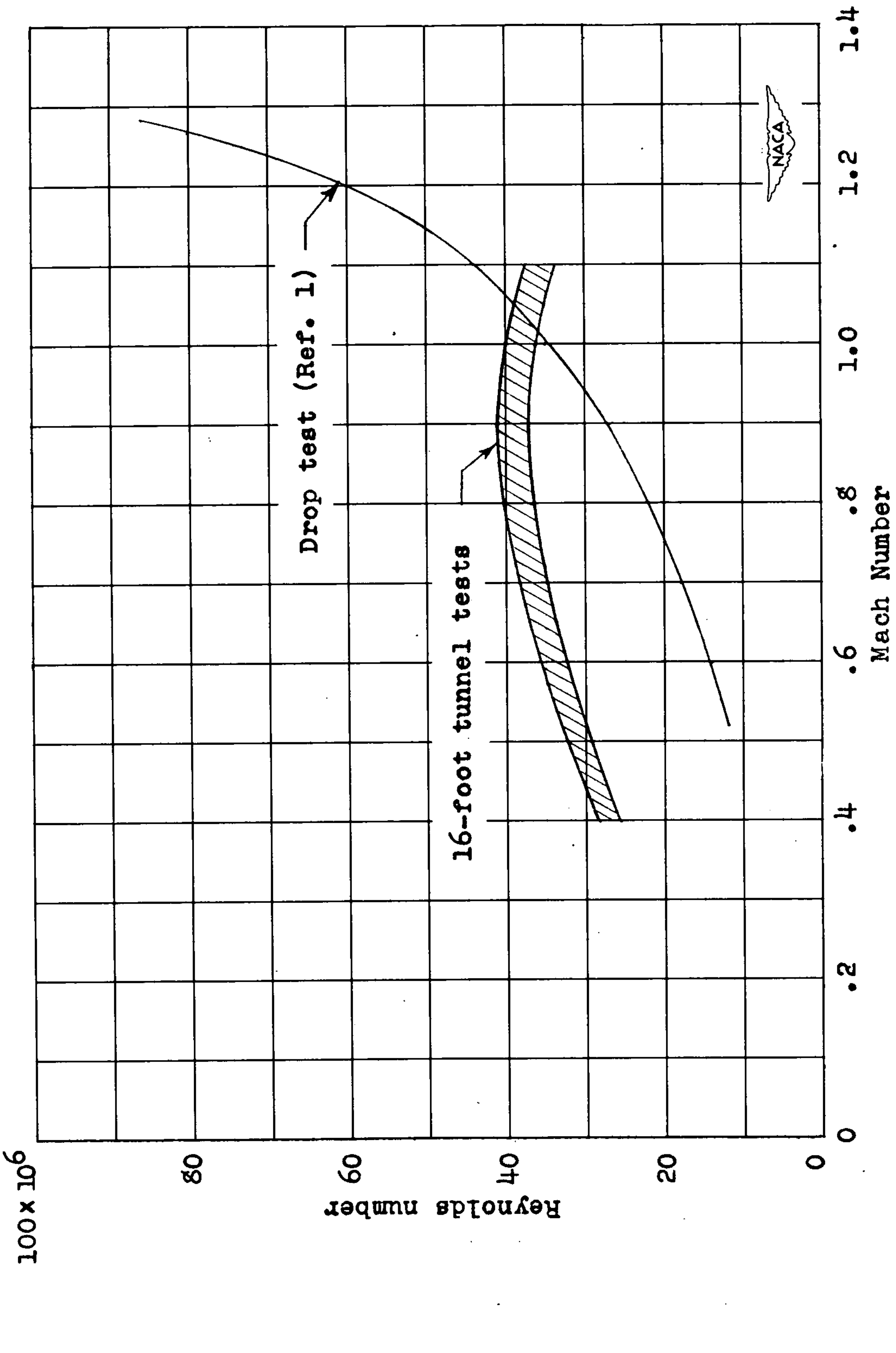
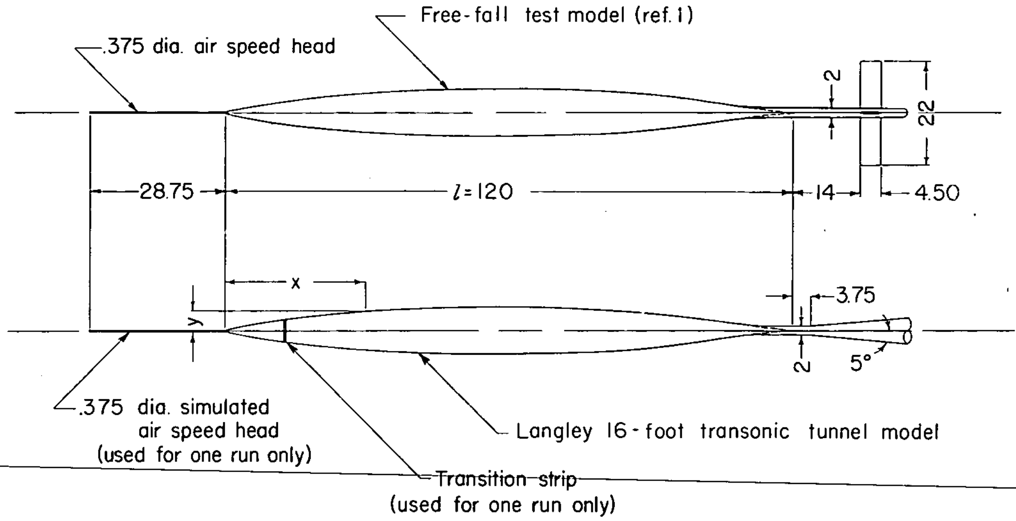


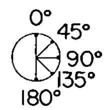
Figure 1.- Reynolds number based on body length for wind-tunnel tests and for drop tests of a 120-inch body of revolution.



Fuselage ordinates (both models)			
x/l	y/l	x/l	y/l
0	0	0.4500	0.04143
0.005	0.00231	.5000	.04167
.0075	.00298	.5500	.04130
.0125	.00428	.6000	.04024
.0250	.00722	.6500	.03842
.0500	.01205	.7000	.03562
.0750	.01613	.7500	.03128
.1000	.01971	.8000	.02526
.1500	.02593	.8333	.02083
.2000	.03090	.8500	.01852
.2500	.03465	.9000	.01125
.3000	.03741	.9500	.00439
.3500	.03933	1.0000	0
.4000	.04063		
Leading-edge radius = 0.0005 l			

Joint locations (tunnel model only) x/l
0.015
.092
.262
.492
.725
.904

Orifice locations (tunnel model only)	
x/l	x/l
0.017	0.567
.033	.633
.067	.700
.100	.733
.133	.767
.167	.800
.233	.833
.300	.867
.367	.900
.433	.933
.500	



Angular positions of orifice rows looking upstream

Figure 2.- Dimensions and details of models investigated in the Langley 16-foot transonic tunnel and in free-fall tests (reference 1). All dimensions are in inches.

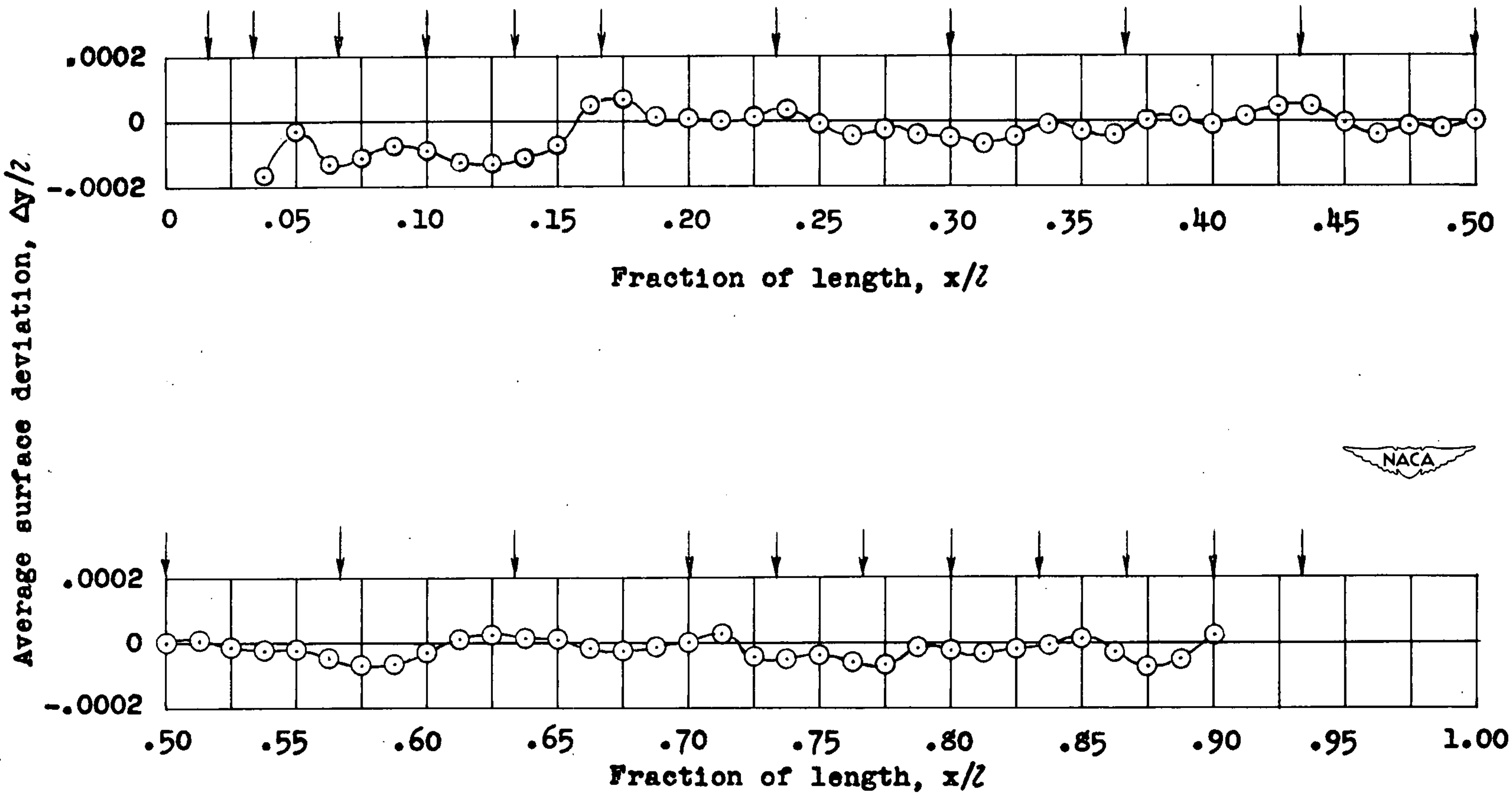


Figure 3.- Average measured surface deviation from a faired curve along the body of the wind-tunnel model. Arrows denote locations of pressure orifices.

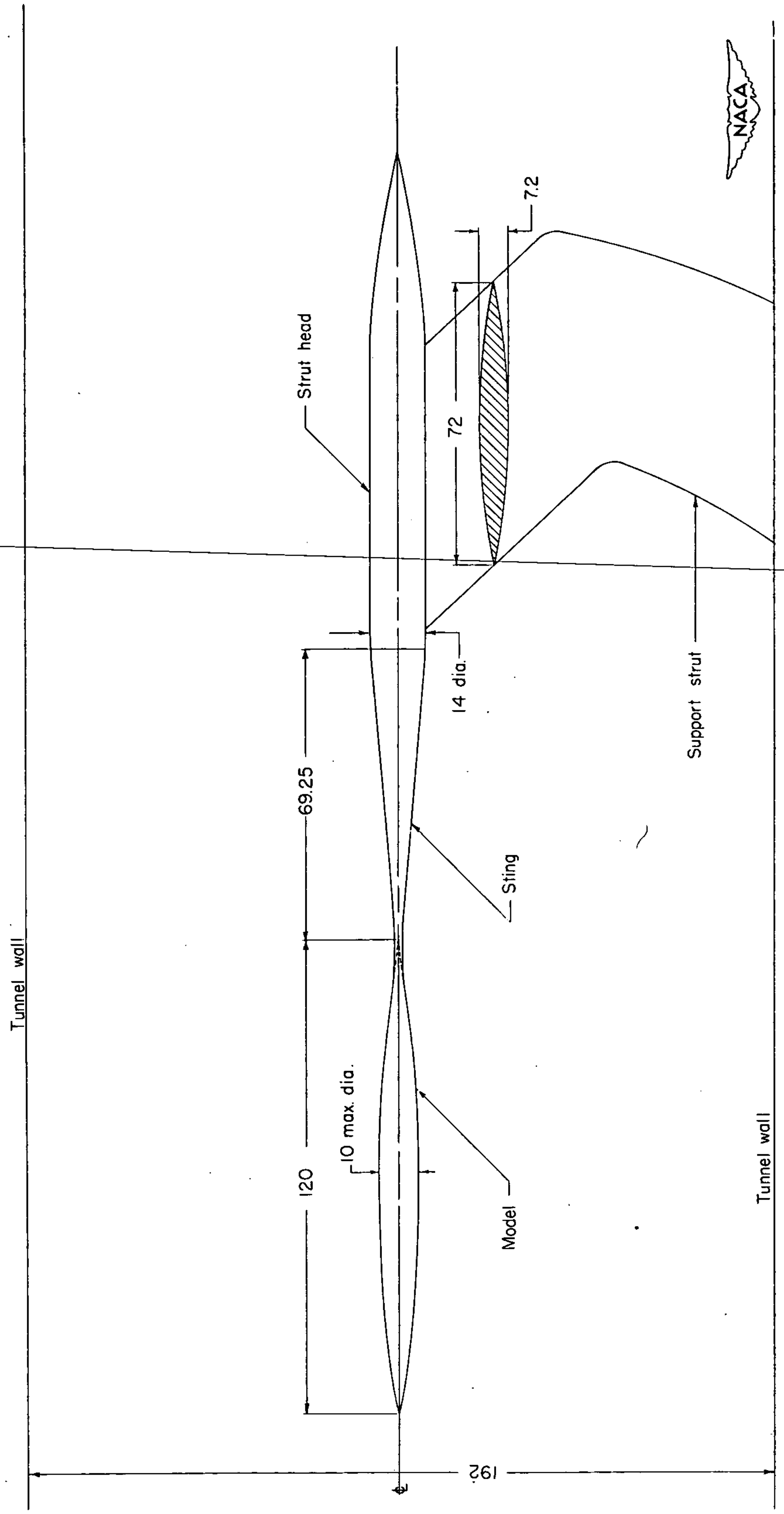


Figure 4.- Support strut and sting used to mount 120-inch body in the Langley 16-foot transonic tunnel. All dimensions are in inches.

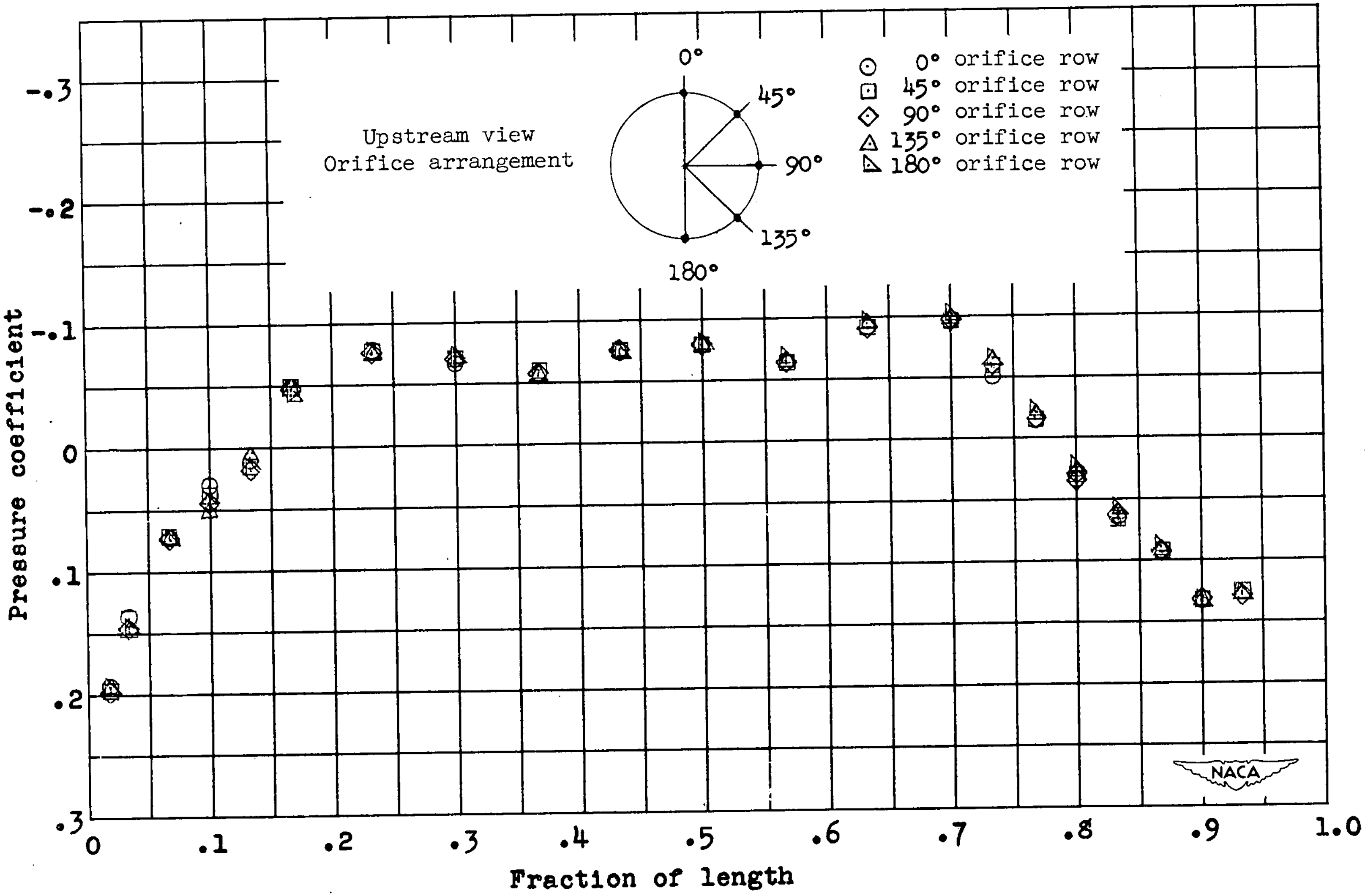


Figure 5.- Pressure distributions obtained on the five rows of orifices at a Mach number of 0.97.

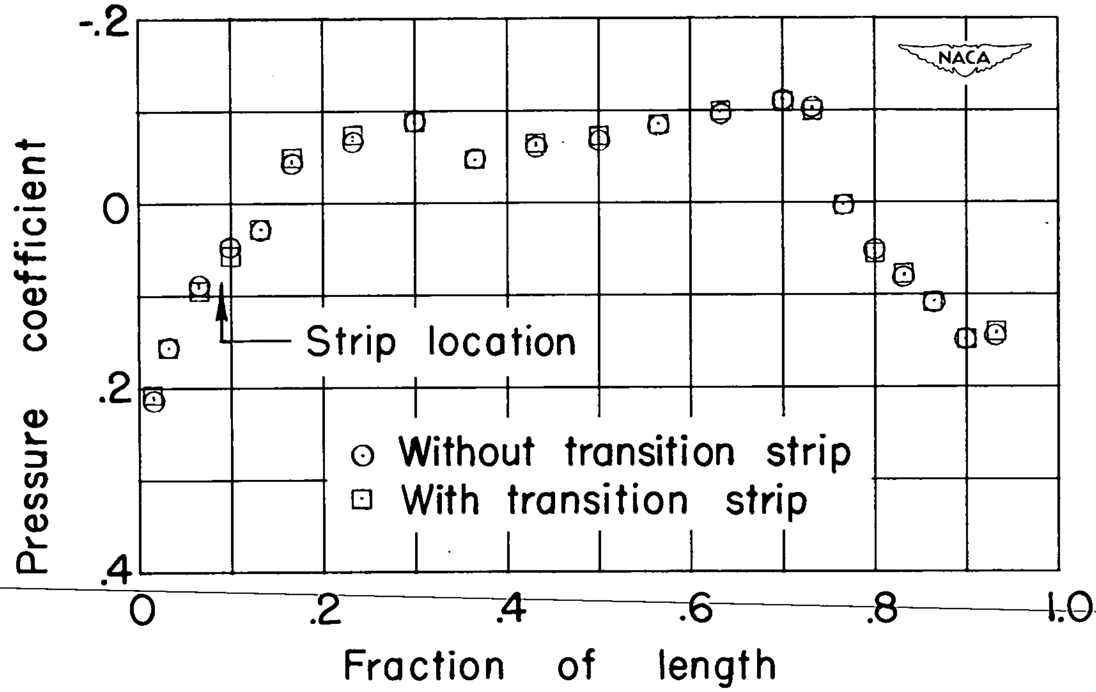


Figure 6.- Effect of addition of a transition strip on the pressure distribution at Mach number 1.0.

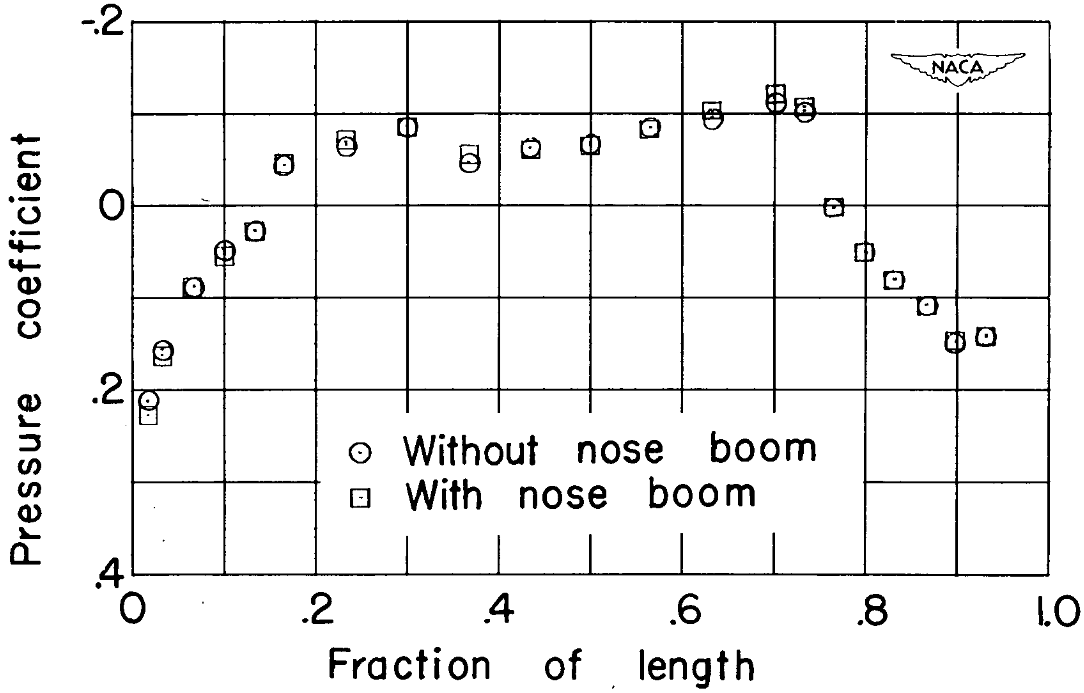


Figure 7.- Effect of addition of a nose boom on the pressure distribution at Mach number 1.0.

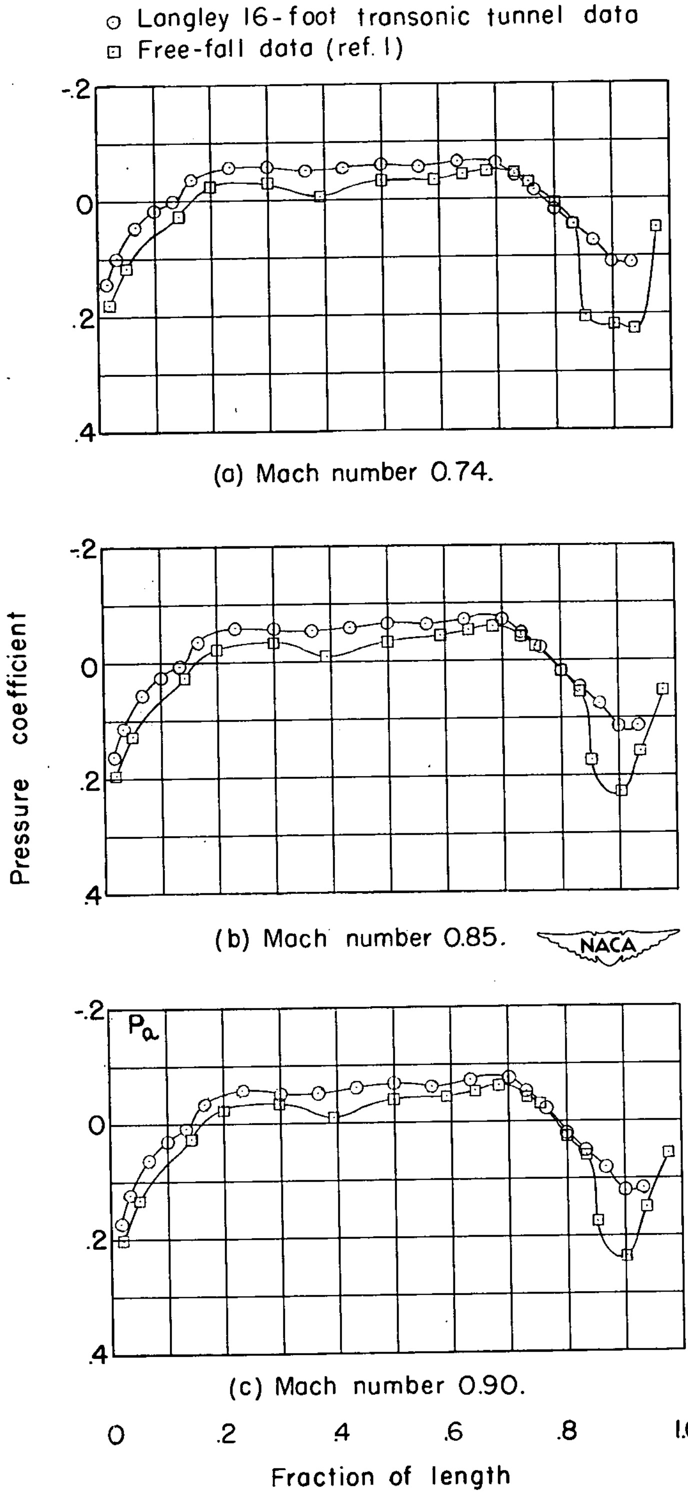


Figure 8.- Comparison of pressure distributions obtained in the wind tunnel and in free-fall drop tests. The pressure coefficient corresponding to local sonic velocity is indicated by P_a.

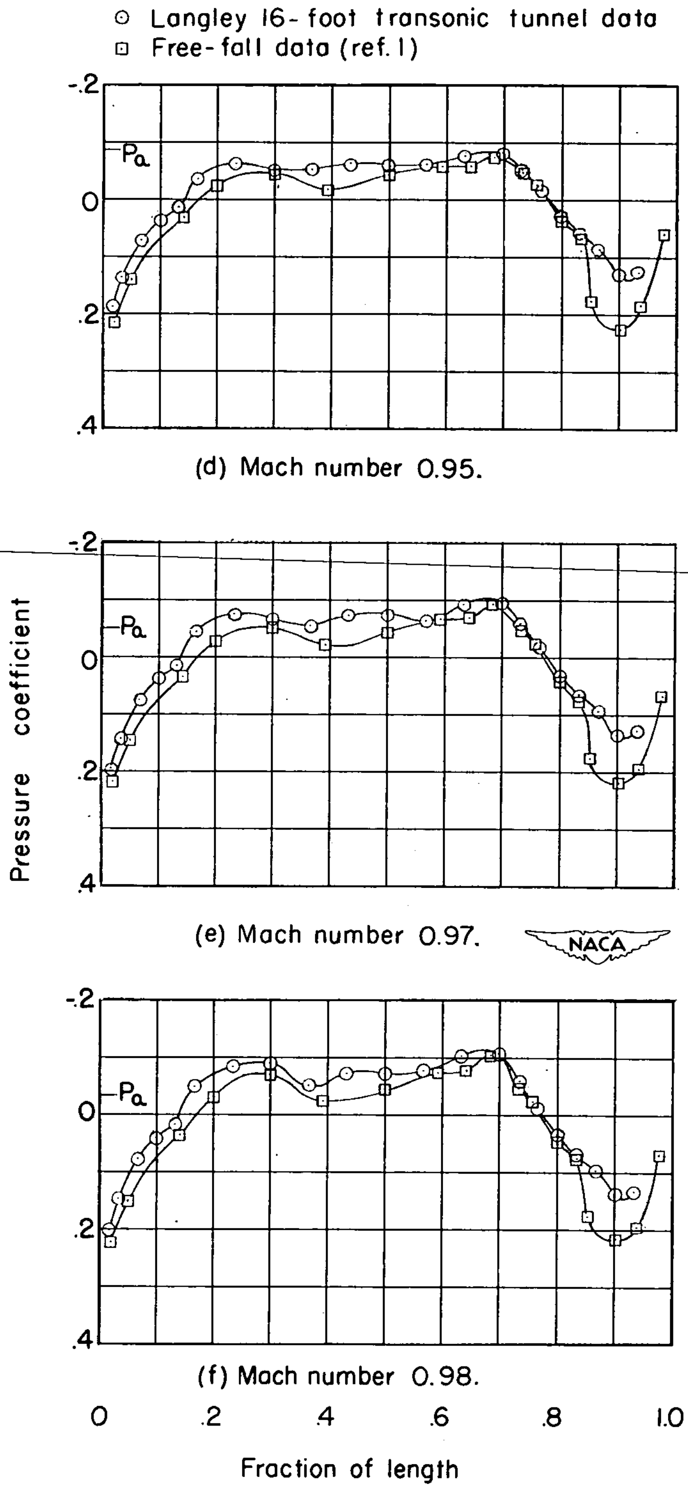


Figure 8.- Continued.

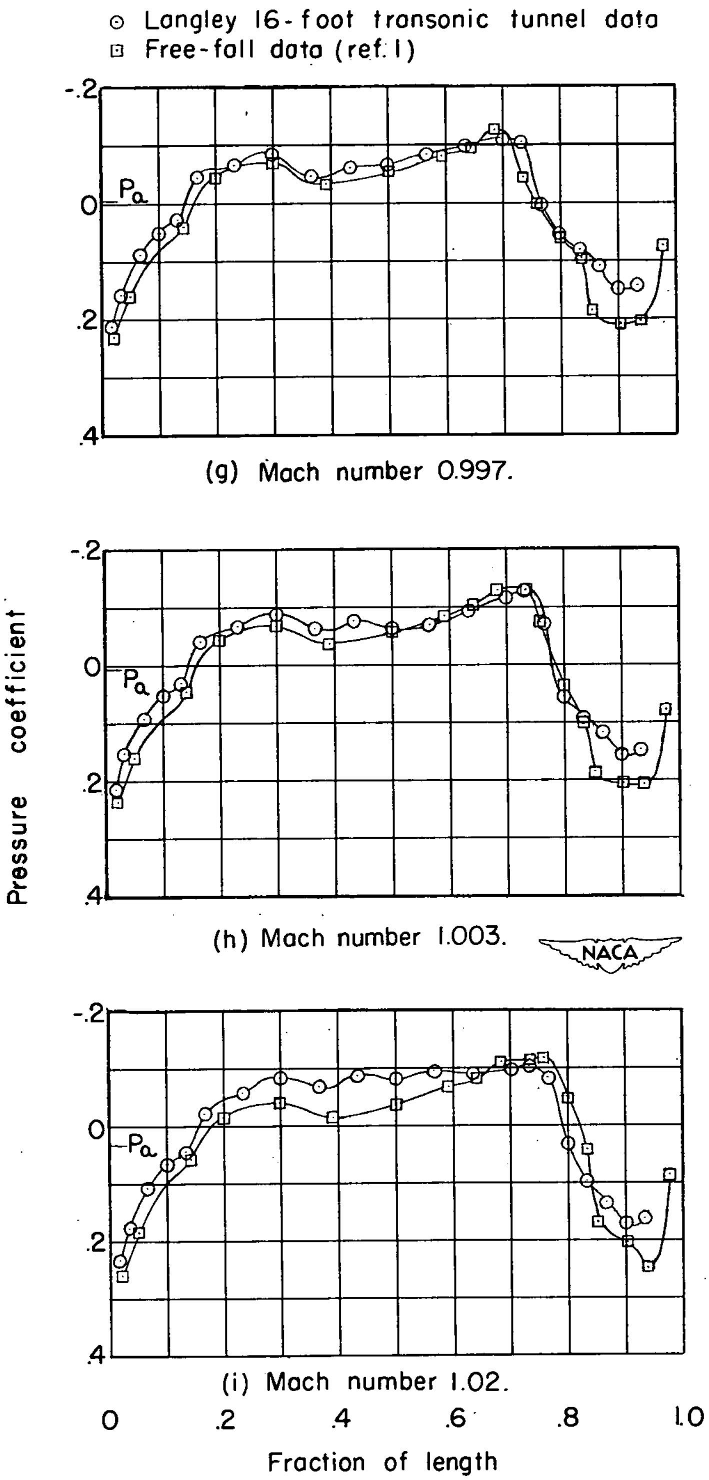
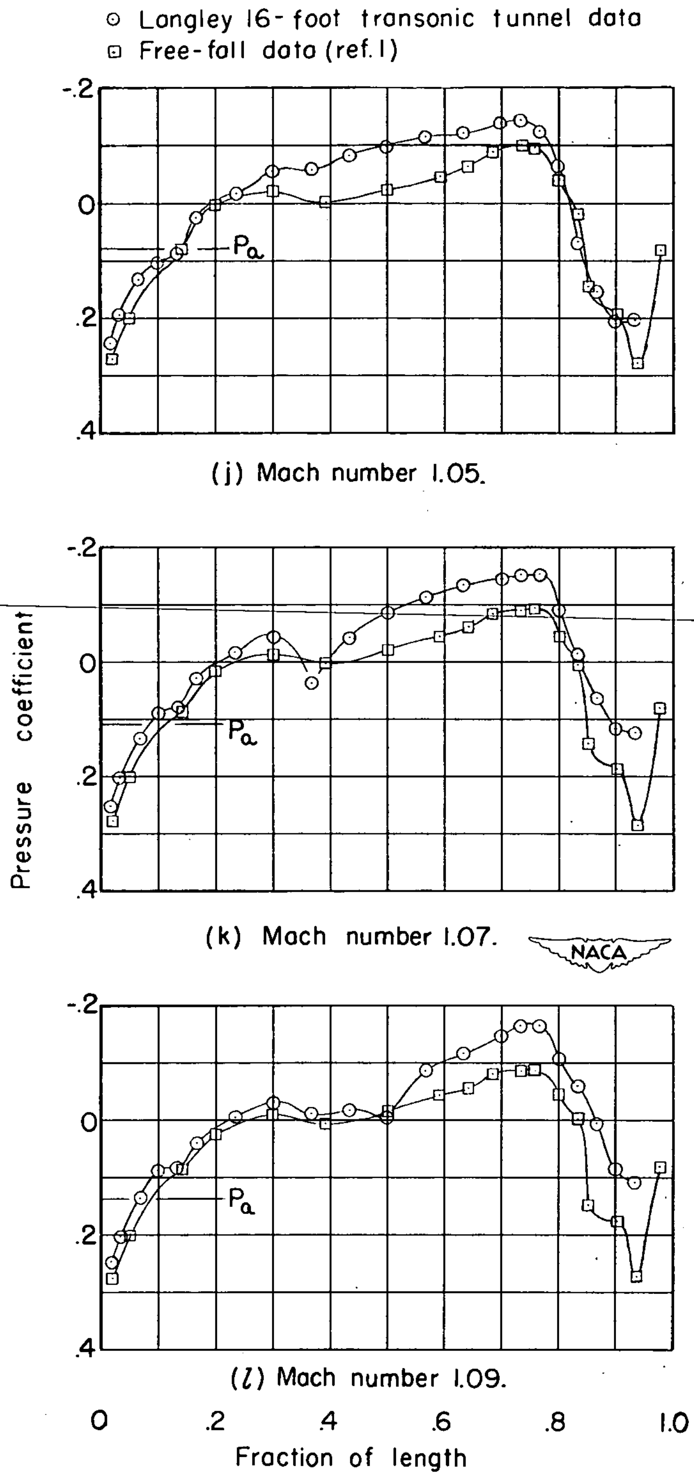


Figure 8.- Continued.



(j) Mach number 1.05.

(k) Mach number 1.07.

(*l*) Mach number 1.09.

Figure 8.- Concluded.