CALIBRATION OF LANGLEY 16-FOOT TRANSONIC TUNNEL

By

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MEMORANDUM  For Research Files

Subject:  Calibration of Langley 16-foot transonic tunnel

References:  (a) NACA RM L8J06, NACA Transonic Wind-Tunnel Test Sections by Ray H. Wright and Vernon G. Ward, Oct. 1948
(b) NACA RM L5OB14, An NACA Transonic Test Section with Tapered Slots Tested at Mach Numbers to 1.26 by Vernon G. Ward, Charles F. Whitcomb, and Merwin D. Pearson, March 1950
(c) Memo. for 16-Foot Tunnel Files, JTR LEC JMH

1. Data from initial calibration tests in the redesigned and repowered Langley 16-foot high-speed wind tunnel, henceforth referred to in this memorandum as the 16-foot transonic tunnel, are included herein. These data include: (1) the effect of six slot plan form configurations upon the center line and wall Mach number distributions in the test region; (2) the effect of wall divergence upon similar center line and wall Mach number distributions, upon the pressures over the revised effuser bell, and on the variation of required horsepower for given Mach numbers; (3) the effect of two effuser bell configurations upon wall pressure distributions, and upon required horsepower for given Mach numbers; (4) a comparison of pressures over the revised effuser bell with the pressures along the center line of the flat; (5) an indication of flow angularity for several Mach numbers; and (6) comparisons of total pressure measurements in the slot mixing region at several Mach numbers and at three longitudinal stations for certain air exchange intake and exit vane openings.

2. Figure 1 presents a general schematic view of the 16-foot transonic tunnel, together with pertinent survey instrumentation. Two major portions of the original 16-foot tunnel were redesigned: the section between stations 42 and 179 which includes the entrance and test regions and a portion of the diffuser; and the section from stations 285 through the first set of turning vanes, the power section, and the second set of turning vanes to station 285 in the return passage. In addition, the intake and exit vane louvers were redesigned such that each set of vanes may be manually adjusted as a unit in place of the individual manual vane adjustment previously required for the 36 vanes of each set. This manual adjustment presently limits
changes in vane opening to delays between runs. Further modification will eventually provide remote control for variation of vane opening at any time during a run. Other modifications had little or no aerodynamic influence.

3. Figure 2 is a more detailed sketch of the test section and associated calibration instrumentation. The test section is designed to operate on the principle of essentially zero tunnel wall interference as described in reference (a), and is similar in geometry to the test section described in reference (b). The main components of the test section are the slots, flats and effuser bell; with the entire test section enclosed in a sealed tank. The test section is octagonal in shape with the slots located at the corners. The geometry of the slot can be altered by inserts with various contours. The sides of the octagon are referred to as flats or walls. The upstream two-thirds portion of these flats is a straight section, and the divergence in the test section can be varied remotely by changing the downstream slope of this straight portion of the flats. Divergences are referred to a zero position where diametrically opposite flats are parallel. The effuser bell is located in the slot at the downstream end of the test section. Its purpose is to return to the main stream the low energy air in the slot efficiently, thereby conserving power.

Two effuser bells of different geometry were used for these series of tests (see figure 2). Number 1, the original effuser bell, extends from station 142 where it intersects the tank wall to station 154 where its surface is tangent to a plane intersecting the edges of adjacent flats. The upstream portion of the bell is a plane surface of 45° slope which becomes tangent to the surface of an arc of a cylinder at approximately station 146. The surface of the cylinder becomes tangent to a plane intersecting the edges of adjacent flats at station 154. The revised effuser bell, or effuser bell number 2, extends from station 139 downstream to station 146. The slot is closed from station 146 to station 154. The portion of the bell from station 141.5 to station 146 consists of arcs of two cylinders, whose centers are diametrically opposite. The upper arc is tangent to a plane intersecting the edges of adjacent flats at station 146, and is tangent to the lower arc at approximately station 143.75. The lower arc is tangent to a plane that is parallel to the tunnel axis at station 141.5. This plane that is parallel to the tunnel axis is the upper surface of a wedge whose apex is at station 139 and whose nose radius is approximately 3/8 of an inch. The lower surface of this wedge extends back to station 144 where it is tangent to an arc of a cylinder which is a transition surface between the original bell and the revised bell.
Figure 2 also shows the location of the calibration instrumentation in the test section. On flat number 1 from station 107.5 to station 153.5, 93 static orifices are spaced six inches apart and are located five inches off the center line of the flat. There are also 23 static orifices spaced six inches apart and located six inches off the center line of number 1 flat between station 95.5 and station 106.75. On the revised effuser bell, between flats 1 and 2 and between station 139.1 and station 145.2, 39 static orifices are located, most of which are spaced six inches apart. Twenty one of these orifices are located on the upper surface of the bell, and the remainder are on the lower surface. Static pressures along the center of the test section are obtained on a long axial survey tube four inches in diameter, which extends from station 74.5 downstream to station 141.5 where it is inserted into the support strut. The front of the tube is supported by eight wire cables in tension. The deflection due to the weight of the tube produced a maximum slope of the tube axis which did not exceed $\pm 1$ degree. There are 54 static orifices on the tube spaced nine inches apart and located between station 100.25 and station 140. The tube is mounted with the line of orifices opposite flat number 2, so that the aerodynamic effects due to tube deflection will be minimized. A rake of 34 total head tubes can be mounted radially in the slot between flats 1 and 8, and can be moved to various longitudinal positions along the test section.

4. Figures 3 and 4 are photographs of the test section with the axial tube and the support strut mounted in the tunnel.

5. Figure 5 is a contour line drawing of the various slot entrance plan forms which were investigated in the attempt to obtain uniform Mach number distributions along the center line and wall of the test region. There is included a table of coordinates for the various slot plan forms. Slot plan forms numbered 1, 9, and 11 correspond, with slight modification, to slot shapes tested in the 8-foot transonic tunnel having the same numbers. The three additional slot shapes tested were arbitrarily numbered 16, 17, and 18.

6. Figures 6 through 11 are plots of wall and center line Mach number distributions for various slot entrance plan forms. All other test section components remain the same for these tests, except for variations in test-section wall divergence which are indicated on each figure. The stream Mach number, $M$, is the average of the maximum and the minimum Mach number on the center line of the stream over a one-tunnel diameter length between station 122 and station 138, and the Mach number differential, $\Delta M$, is one-half the difference between the maximum and the minimum Mach number over this same length.

Figure 6 presents the tunnel Mach number distributions obtained with slot entrance plan form number 1. This plan form originates at a point and diverges linearly for 1-1/4 tunnel diameters. The point
origin is at station 110, and the taper ends at station 130.5, beyond which nearly constant slot width is maintained (the flat width is maintained constant) such that approximately one-eighth of the total periphery remains open. The Mach number distributions developed by this slot entrance are uniform within ±0.005 in the subsonic and transonic range to a tunnel Mach number of approximately 1.034. At a higher Mach number of 1.077, the Mach number differential becomes ±0.010 M. This Mach number was obtained with the maximum available horsepower and a wall divergence angle of 0°5'. At this same power, a Mach number of 1.096 was obtained by increasing the wall divergence to 0°10', and the Mach number differential increased to ±0.018 ΔM. A specific indication as to the cause of the increase in Mach number differential cannot be stated because of the simultaneous variation of two parameters - wall divergence and tunnel Mach number.

Figure 7 shows the tunnel Mach number distributions obtained with slot entrance plan form number 11. This slot entrance begins with a point origin at station 110 and has an initial contour slope equal to the linear taper of slot entrance number 1. At approximately station 111.5 the contour slope begins to decrease until station 115, where the slope becomes constant and is approximately 1/2 of that utilized in slot plan form number 1. The rate of slope begins to increase at station 118.5 and becomes steeper than that of slot entrance number 1, but at station 125.5 the rate of slope begins to decrease and fairs in smoothly to the flat edge at station 130.5, from which station the slot is the same as plan form number 1. The Mach number distributions developed by this slot entrance are uniform in the subsonic range and also in the supersonic range to a tunnel Mach number of 1.072, which is obtained at the maximum horsepower condition for the five-minute wall divergence. In the subsonic range the Mach number differential is slightly greater than for slot entrance number 1, but the difference is in the order of the accuracy of the measurements. At comparative Mach numbers of approximately 1.075, the Mach number differential is reduced one-half by slot entrance number 11. At the same power condition, the stream Mach number increased from 1.072 to 1.090 when the wall divergence angle was increased to 0°10', causing an increase in Mach number differential of 0.011, or a total Mach number differential of ±0.016. Mach number 1.119 was obtained with an excess of power over that which is normally available for the tunnel. Increasing the top Mach number by increasing the power indicates that, for a constant wall divergence of ten minutes, the Mach number differential apparently does not increase. This fact may indicate that if more power were available to extend the Mach number range, the Mach number differential for the 0°5' wall divergent position would not greatly exceed its existing value, which is within an acceptable tolerance.
Although slot entrance plan form number 11 indicates satisfactory Mach number distributions throughout the subsonic range and in the supersonic range up to the top Mach number 1.072, for the 0°5' wall divergent position, emphasis was directed toward obtaining a satisfactory distribution at the higher Mach numbers which were developed by further increasing the wall divergence. It was believed that a redesign of the slot entrance to reduce the initial rate of development of the flow might produce satisfactory Mach number distributions at higher wall divergences. Slot entrance plan form number 9 was designed with its point origin at station 110 and with its initial contour shape one-half of the slope of slot entrance number 1 between station 110 and station 119.5. At station 119.5, the slope increases, and the contour finally fairs in to slot entrance number 11 at station 125. Slot plan form number 9 and all subsequent plan forms maintain slot plan form number 11 beyond station 125 for simplified mounting requirements.

Figure 8 presents the Mach number distributions for slot entrance plan form number 9. The subsonic distributions developed by this entrance with a 0°10' wall divergence are uniform within acceptable values of Mach number differential. The supersonic distributions indicate an increasing Mach number differential as the tunnel Mach number is increased from 1.036 to 1.103. The magnitudes of these differentials are larger than desired, being ±0.018 ΔM for 1.103 Mach number.

The design of slot entrance plan form number 16 is further in the direction of decreasing rate of initial development of the flow. It was believed that the initial width of slot entrance number 9 might still be too great, and therefore the initial contour slope of slot entrance number 16 was reduced to 1/4 the initial slope of slot entrance number 9. This initial contour slope extended from the point origin at station 110 to station 119.5, at which point the rate of slope was increased, until it faired into slot entrance number 11 at station 125 (see figure 5). Figure 9 presents the Mach number distributions for slot entrance number 16. The wall divergence was 0°10' for all Mach numbers except for the maximum Mach number indicated which was obtained by diverging the walls to 0°20' at the point of maximum available horsepower. The subsonic distributions are uniform and within acceptable tolerances of Mach number differential. All of the supersonic distributions indicate some non-uniformity greater than desired, and do not show any improvement over the supersonic distributions developed by slot entrance plan form number 9, even though the rate of initial development of the flow is appreciably reduced.

Although the non-uniformity of the flow for slot plan form number 16 was greater than previously experienced on slot entrance
number 11 at 0°5' wall divergence, slot entrance number 17 was modified only slightly in comparison to slot plan form number 16 in an attempt to further study the effect of slot plan form at the higher test Mach numbers attained with 0°10' wall divergence. The contour slope was increased from station 117.5 to station 122 in comparison to slot entrance number 16 in order to give a wider slot plan form between these stations and to reduce somewhat the abruptness of change in slope in this region. No change was made ahead of station 117.5 nor beyond station 125. Figure 10 presents the Mach number distributions for slot entrance plan form number 17. These distributions were obtained with a wall divergence of 0°5', except for the maximum Mach number indicated, which was obtained by diverging the walls to 0°20' at the point of maximum available horsepower. The subsonic distributions are uniform and within acceptable values of Mach number differential. The supersonic distributions, from a Mach number of 1.049 up to the maximum Mach number of 1.087 for five minutes wall divergence, indicate a slight decrease in the magnitude of the Mach number differentials over those obtained with slot shape number 16 with ten-minute wall divergence. The Mach number differential for the 0°20' wall divergent condition indicates about the same magnitude of differential as that shown for slot entrance number 16.

Several general observations may be noted from the preceding data: (1) As the width of the slot entrance plan form is decreased, no apparent improvement in flow uniformity is evident at relatively high angles of wall divergence. (2) The supersonic distributions for slot entrance plan form number 17, at five minutes wall divergence, are less uniform than the same distributions for slot entrance plan forms which have wider slot entrances. (3) Slot entrance plan form number 11 developed the most uniform flow in the supersonic range to a Mach number of 1.072 with 0°5' wall divergence. (4) The other slot plan forms developed flows which were not as uniform in this same Mach number range, for either the 0°5' or 0°10' wall divergences. Consideration of these observations led to a further attempt to produce a more uniform flow at the 0°5' wall divergence position, with the possibility of improving the flow uniformity at the higher Mach numbers attainable with 0°10' wall divergence.

These considerations led to compromise slot shape number 18 whose contour was similar to slot shape number 11 over the upstream portion of the slot entrance, and similar to slot shape number 16 over the downstream portion. In addition, the location of the origin of slot plan form number 18 was moved upstream from station 110 to station 107.5. This upstream position of the slot origin, in a region of nearly constant Mach number and of physically constant area, was established in an effort to increase the slot entrance length without altering appreciably other tunnel characteristics.
The initial contour slope of slot entrance plan form number 18 is slightly greater than the initial contour slope of slot entrance numbers 1 and 11. At station 108.5 the slope becomes less than that of 1 and 11, and continues to decrease until at station 115 the slope becomes equal to the initial slope of plan form number 16, or 1/8 of the initial slope of plan form number 1. This slope is maintained until station 119.5, at which point the slope begins to increase and finally falls into the contour of slot entrance number 9 at station 122.75. Figure 11 presents the Mach number distributions for slot entrance plan form number 18 at 0°5' wall divergence. The distributions are uniform throughout the Mach number range, and the Mach number differentials are within acceptable values. The maximum available horsepower gave a tunnel Mach number of 1.075 with the five minutes wall divergence. The Mach number differential for this point is ±0.006. Mach number differentials for 0°10' wall divergence are of the same order as slot shapes numbers 16 and 17. It is noted that although slot entrance plan form number 11 was appreciably different than slot plan form number 18, it developed as uniform a flow over the same Mach number range (figure 7) and with the same wall divergence, as did slot entrance plan form number 18. Attempts to further decrease the longitudinal Mach number variation or to successfully operate with wall divergences other than 0°5' were discontinued.

7. Additional characteristics of the flow are noted in figures 6 through 11. A characteristic of the portion of the entrance cone which was surveyed, is that the local Mach number in the center of the stream is somewhat lower than that measured at the wall for a particular station. This difference in local Mach number, which is evident in all preceding distributions, tends to decrease as the flow approaches the minimum area at station 107, and is extremely small for low subsonic tunnel Mach numbers. Another characteristic of the entrance region is the tendency for the slope of the Mach number distribution curve to approach zero upstream of station 107 and then increase again as the flow enters the effective nozzle portion. This condition becomes more apparent at supersonic Mach numbers. The range of tunnel stations over which near zero slope occurs increases slightly as the initial width of the slot entrance plan form decreases. The range of this near-zero slope condition decreases when the slot origin is located at station 107.5, slot entrance plan form number 18.

The effective nozzle portion of the test section has been arbitrarily designated as the region in which the supersonic flow is developed. In this region there is satisfactory agreement between the wall and center line local Mach number, except for
a few isolated cases in the supersonic range. The slope of the Mach number distribution in this region is a function of the slot entrance plan form to a certain extent. As the width of the slot decreases, for a constant wall divergence and tunnel Mach number, the slope of the Mach number distribution curve decreases. Increasing the divergence of the tunnel walls at constant power causes an increase in the slope of the Mach number distributions in the effective nozzle region and also an increase in the indicated tunnel Mach number (see figures 9 and 10).

The slotted diffuser is the portion of the test section from the end of the test region, station 138, to the station where the effuser bell is tangent to the surface of the closed diffuser. A local apparent Mach number peak along the tunnel wall occurs in the upstream portion of this region, both subsonically and supersonically as well as along the center line supersonically. The center line distributions, subsonically, decrease in Mach number in this region.

The downstream portion of the test section is included in the closed diffuser. It may be noted in preceding figures 6 through 11 that a near duplication of local Mach number distribution occurs in this closed region of the diffuser when a variation in wall divergence is made at a constant horsepower condition.

8. Figure 12 presents similar wall and center line longitudinal Mach number distribution comparisons for wall divergence angles of 0°, 0°5', and 0°10' for Mach numbers of 0.95 and 1.05. The tunnel configuration utilized slot plan form number 18 and the revised effuser bell. It may be noted that a slightly positive Mach number gradient exists in the test region for both the subsonic and supersonic Mach numbers at 0° wall divergence, while a slightly negative Mach number gradient exists for the 0°10' wall divergent position. Although these gradients are in the order of only 0.01 M, the 0°5' wall divergence angle appears to compromise between the 0° and the 0°10' positions, indicating little or no gradient either subsonically or supersonically. It may also be noted that the 0°10' wall divergence condition indicates a compression region following the initial expansion to 1.05 Mach number. Also shown in this figure is the gradual reduction of the localized apparent Mach number increase over the short faired region between the test region and the slotted diffuser, station 138 to station 140, as the wall divergence increases from 0°0' to 0°10'.

9. The variation of the Mach number distribution along the center line of the flow for several wall divergence positions from 0° to 0°20' by four-minute increments and at a top horsepower condition of 62,000, is shown in figure 13. The Mach number scale is 2-1/2 times that
previously presented. Discounting local irregularities thus magnified, it may be noted that as the wall divergence increases from 0°0' to 0°20', the uniformity of the flow decreases until variations in the order of 0.05M are shown for the 0°20' divergent position. This non-uniformity exists in the form of a gradual compression and reexpansion and occurs over a length of approximately 3/4 effective tunnel diameters. Ahead of this region, the flow appears to have expanded normally in the effective nozzle to produce a nearly uniform flow over a region of approximately 3/8 effective tunnel diameters where the local Mach number agrees very nearly to the Mach number corresponding to the static pressure in the tank. This fact is pointed out because reference (b) indicates, as does most experience with slotted wind tunnels, that the flow usually over-expands initially and is then followed by a quite similar compression and reexpansion region, where the tank pressure assumes a nearly average value of this non-uniformity. Although the distribution for 0°0' wall divergence tends to indicate a slightly positive Mach number gradient with the apparent absence of a compression region for the 1.05 Mach number shown, it is not known whether similar non-uniformities would occur for higher Mach numbers at this 0°0' divergent position.

10. Figure 14 presents the average stream Mach number along the center line of the test section between station 131 and 137 as calibrated against the Mach number corresponding to the static pressure in the tank. This method allows a nearly straight-line fairing which approaches a 45° slope. The maximum derivation from such a faired line is ±0.002M for all test Mach numbers.

11. Comparisons of the Mach number distributions along flat number 1 for the original and revised effuser bell configurations are shown for a Mach number of 0.7 and 0.92 in figure 15. Comparison at higher Mach numbers are not available, but a distribution for the revised effuser bell configuration is presented for 1.02 Mach number. The revised bell configuration has a slightly favorable effect upon the distributions, indicating that a small positive Mach number gradient between stations 134 to 138 is favorably reduced as is also the local apparent Mach number rise which occurs over the faired transition from slotted test regions to slotted diffuser, stations 138 to 140. This figure also indicates, that with the installation of the revised effuser bell, an increase in the static pressure recovery is attained over the region between station 138 and 154. The increase in static pressure recovery at station 154 is approximately 0.9 percent for an indicated test section Mach number of 0.7, and approximately 3.6 percent for an indicated test section Mach number of 0.92. This increase in static pressure recovery for the revised effuser bell configuration indicates a stream Mach number increase from about 0.93 to 1.02 when the static pressure at station 153.5 is about equal for both bell configurations.
A comparison of pressures over the revised effuser bell with pressures at similar longitudinal locations along the center line of the flat are presented for several stream Mach numbers in figure 16. The pressures in the tank are also included for comparison. The faired line with symbols represents the static pressures on the revised effuser bell and the corresponding faired line without symbols represents the center line pressures over one adjacent flat. The tailed symbols indicate lower surface of the bell. It is also noted that pressures over the upper surface of the bell entrance between approximately stations 139.5 to 140.5 are missing for these data. The fairing is, therefore, based upon previous similar measurements, which were limited to stream Mach numbers less than 1.03. It may be seen that the tank pressure, which corresponds nearly to the stream Mach number, is approximately the same value as the under surface of the bell. The pressures on the upper surface of the bell appear to increase rapidly from this tank pressure until reaching a peak value near station 143, and then to decrease rapidly to station 145. This local pressure reversal appears primarily over the reverse curve portion of the bell. The pressure along the center line of the flat, while continuously increasing through the slotted portion of the diffuser, tends in the direction of the local flow over the reverse curve portion of the bell, and thereafter matches nearly the bell pressure in the closed portion of the diffuser from station 147 to 154. This trend appears true for all Mach numbers both subsonic and supersonic. The general pressure patterns, both over the bell and on the center line of the flat, appear to progress continuously through the sonic range to the top Mach number of 1.08.

Figure 17 presents a similar comparison of pressures over the revised effuser bell for wall divergence angles of 0°, 0°5', and 0°10' for stream Mach numbers near 0.95 and 1.05. The effuser bell remains fixed and the flats diverge as illustrated in the sketch included in the figure. The general pressure pattern, previously described for figure 16, is evident for the three wall divergence angles. It is recalled from previous figures that the indicated stream Mach number increases with increasing wall divergence for constant power. Figure 17 illustrates the same effect by indicating an increasing pressure at station 153 as the wall divergence increases from 0° to 0°10' for a given Mach number. The only apparent increase in the rate of pressure rise for increasing wall divergence from 0° to 0°10' occurs in the region of the straight portion of the bell entrance between stations 139 and 141.5. It is believed that these data included in figures 16 and 17 indicate that the revised effuser bell configuration is not necessarily the ultimate configuration either in its local pressure distribution or in its effect upon power reduction. The fact that this revised effuser bell configuration did allow stream Mach numbers up to 1.08 to be obtained with existing power facilities, prompted immediate model tests with this revised bell, and delayed further modification until a future date.
12. Figure 18 indicates the indicated free stream angle of flow in the vertical plane of the test region relative to the longitudinal axis of the test section for stream Mach numbers of 0.6, 0.95, and 1.075. These data are averaged from several sets of duplicate orifices over the nose portion of a 33-1/3-inch drop body. Check points with a similar 120-inch drop body, and with a one-inch angle-of-attack free floating vane are noted at 0.6 Mach number. No further data for flow angularity in the vertical plane is available from these latter two configurations. A straight dashed line fairing indicates an upflow angle of about 0.35° at 0.6 Mach number, which decreases to approximately one-half of this angle near a Mach number of 1.1. The scatter of the data from which these averages were obtained is of the order of ±0.15 degrees. Although not shown on the figure, the angle-of-attack free floating vane indicated 0° yaw angle in the horizontal plane at a Mach number of 0.6. No other yaw angularity measurements are available.

13. Figure 19 presents total pressure measurements at station 126.9' radially through the center line of the slot between flats numbers 1 and 2 as a function of the stagnation total pressure in the quiescent chamber for several Mach numbers in the 16-foot transonic tunnel with an air exchange intake and exit vane opening of 12 inches. The slot shape is number 18. The static pressure ratio in the tank is shown for comparison. The total pressure distributions radially through the slot are generally symmetrical about the intersection line of the flats for all Mach numbers. No correction for shock loss in the 1.07 Mach number distribution (H₁/H₀ correction is 0.0004 for normal shock) is made. The stagnation total head of the stream appears to be maintained until a point about 12 inches from the intersection of the flats, except for the two highest Mach numbers of 0.983 and 1.070 where a loss of about 0.001 H₁/H₀ appears between radial stations 32 and 12 inches. The tank pressure appears to nearly correspond, for all distributions, to the total pressure ratio about 12 to 14 inches below the intersection of the flats, except for the highest Mach number of 1.07 for which such station is about 22 inches.

A similar plot with all conditions remaining fixed, except for an increase of the air exchange intake and exit vane opening to 36 inches, the widest opening now possible, is shown in figure 20. The total head distributions are themselves similar to those in figure 19 except for losses in total pressure from radial station 12 inches toward the center line of stream. Stagnation temperature measurements made for identical test conditions (including or simulating those reported in reference (c)), indicate that a relatively cold layer of air, as induced by the air exchange intake vanes, proceeds through the test region without complete mixing and that the thickness of this cold layer is associated with the amount of vane opening. Further consideration of these measurements indicates that conditions representing 100 percent or more relative humidity exist several feet toward the center line of the stream from the intersection of the
flats. Such consideration, together with visible condensation in the vicinity of the slots, tends to correlate with the aforementioned total head losses shown in this figure. The lack of data and the uncertainty of existing temperature data in this super saturated region makes further analysis doubtful. A comparison of the top Mach number distributions from figures 19 and 20 is shown in figure 21 for vane openings of 12 and 36 inches. The total head loss here shown and believed to be associated with the aforementioned problem of condensation, is in the order of 0.013 $\frac{H_1}{H_0}$ at radial station 10 inches and decreases gradually to 0.005 $\frac{H_1}{H_0}$ at station 48 inches for a vane opening of 36 inches. The 12-inch vane opening indicates a loss of about 0.001 $\frac{H_1}{H_0}$ at radial station 10 inches and decreases to 0.0 $\frac{H_1}{H_0}$ at station 36 inches.

The total head measurements presented thus far have been shown only for tunnel longitudinal station 126.9'. Figure 22 presents for a Mach number of about 1.07, similar data for stations 107.5', 126.9', and station 136.9' for an air exchange intake and exit vane opening of 30 inches. Included also are measurements radially from the center line of one of the flats for the 107.5' station only. It is noted that station 107.5' is the entrance of slot number 18, the configuration used for these measurements. The data at the center line of flat and at the intersection of flats for station 107.5' were obtained simultaneously but at different radial planes. These data at station 107.5' were not obtained simultaneously or in the same radial planes as the data at stations 126.9' and 136.9'. The data at stations 126.9' and 136.9' were obtained in the same radial plane but were obtained simultaneously. These conditions therefore limit direct comparison. It may be noted from the figure, however, that the depth of the mixing region increases with increasing longitudinal station in the downstream direction, extending to approximately 16 inches inside the intersection of the flats and 22 inches outside of this intersection for station 136.9'. It is also noted that the local total pressure ratio at the intersection of the flats is nearly the same value at all longitudinal stations, and that it also approaches the total pressure ratio at the surface of the flat.

14. A comparison of corrected horsepower versus Mach number for the original and revised effuser bell configurations is shown in figure 23. All horsepower values are corrected to a stagnation pressure of 2120 lbs/sq ft and to an average stagnation temperature curve which is based on all calibration runs. These data were obtained with slot plan form number 1 in the test section, and are limited to horsepowers below the 60,000 design maximum by performance limitations of the early tests. It may be noted that at a horsepower of 50,000, the revised effuser bell increased the stream Mach number from 0.92 to 0.99, corresponding to approximately a 17-percent decrease in required horsepower in this Mach number range.
Figure 24 presents a similar horsepower comparison for wall divergences of 0°, 0°5', and 0°10' for slot shape number 18. Although an indicated increase in Mach number of about 0.02 per five minute increase in wall divergence angle is shown for Mach numbers above one, it is recalled from figure 13, that the variations in uniformity of flow also increased with increasing wall divergences above about 0°5'. The 0°5' wall divergence position is therefore presently utilized, and Mach numbers up to approximately 1.08 are attained for a horsepower of about 62,000.

15. These data indicate satisfactorily uniform test Mach number distributions for stream Mach numbers up to approximately 1.08. These data also indicate further investigation in regard to the following: (1) modification of effuser bell configuration in order to improve both local pressure distributions and power requirements; (2) modification of slot configuration if Mach numbers above 1.08 are attainable either by future decreases in required power or by increased availability of power; (3) reduction or elimination of the local apparent Mach number increase at the rear of the test region; and (4) modifications to the air exchange system to insure more complete mixing of the relatively cool inlet air with the recirculated warm air in an attempt to eliminate local super saturated conditions in the flow.

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FIGURE I.—GENERAL SCHEMATIC VIEW OF 16-FOOT TRANSONIC TUNNEL, TOGETHER WITH PERTINENT CALIBRATION INSTRUMENTATION.
Figure 2 — Schematic Sketch of 16-Foot Transonic Tunnel Test Section with Calibration Instrumentation Installed.
Figure 2.- Diagram of the 100" wing-fuselage model in the 16-foot transonic tunnel, showing details of the angle-of-attack mechanism.
Figure 3.— Upstream view of axial survey tube mounted in test section of 16-foot transonic tunnel. Slot shape number 18.
Figure 4.— Downstream view of axial survey tube mounted in test section of 16-foot transonic tunnel. Slot shape number 18.
COORDINATES FROM CENTER LINE OF SLOT FOR VARIOUS SLOT
WEIRS USED IN 16-FOOT TRANSSONIC TUNNEL
CALIBRATION RUNS (FEB 195)

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SLOT PLANFORM NO. 1

TUNNEL LONGITUDINAL STATION, FEET

FIGURE 5.—TABLE OF COORDINATES AND LINE DRAWING OF SLOT PLANFORMS TESTED IN 16-FOOT TRANSSONIC TUNNEL.
Figure 7: Longitudinal Mach number distributions along wall (6 inches from centerline of flat number 1) and centerline of 16 foot transonic test section for slot planform number II: wall divergence as noted. Axial tube mounted in tunnel with effuser bell number 2.
NOTE: SYMBOLS WITH TAILS INDICATE CENTERLINE DISTRIBUTIONS.

FIGURE 8 - LONGITUDINAL MACH NUMBER DISTRIBUTION ALONG WALL (6 INCHES FROM CENTERLINE OF FLAT NUMBER 11) AND CENTERLINE OF 16 FT. TRANSonic TEST SECTION FOR SLOT PLANFORM NUMBER 9. (WALL DIVERGENCE IS 50 MINUTES). AXIAL TUBE IS MOUNTED IN TUNNEL WITH EFFUSER BELL NUMBER 2.
Figure 11: Longitudinal Mach Number Distribution along wall (6 inches from centerline of flat No. 1) and centerline of 16-foot transonic test section for slot planform number 18. Wall divergence is 5 minutes. Axial tube mounted in tunnel with effuser bell number 2.

Note: Symbols with tails indicate centerline distributions.
Figure 12 — Longitudinal Mach number distributions along centerline and tunnel wall (6 inches from centerline of flat No. 1) of 16-foot transonic test section with walls at divergence 8°, 0°, 5°, 10°, at subsonic and supersonic Mach numbers.
Figure 13 — Comparison of Mach number distributions along centerline of 16 foot transonic tunnel for various wall divergences at top horsepower conditions (HP = 62,000), slot planform no. 18, revised effuser bell.
Figure 14. Calibration of Mach number corresponding to tank pressure, $M_{(tank)}$, with the stream Mach number, $M$, which is based on the average pressures as measured on axial tube between stations 131 to 137. Slot shape number 18, wall divergence 3°.0.5°.
FIGURE 15 — COMPARISONS OF LONGITUDINAL MACH NUMBER DISTRIBUTIONS ALONG WALL (6 INCHES FROM CENTERLINE OF FLAT NUMBER 1) OF 16 FOOT TRANSONIC TEST SECTION FOR THE TWO EFFUSER BELL CONFIGURATIONS. WALL DIVERGENCE IS ZERO DEGREES AND SLOT PLANFORM IS NUMBER 1.
Figure 16 — Comparison of static pressure along 4/3 of upper and lower surface of revised effuser bell with corresponding pressures along 4/3 of flat for several Mach numbers in 16-foot Transonic Tunnel: Wall divergence, 2°-0.5°.
FIGURE 17.—COMPARISON OF PRESSURE RATIO ALONG UPPER AND LOWER SURFACES OF REVISED EFFUSER BELL FOR TUNNEL WALL DIVERGENCES $\delta \cdot 0^\circ, 0^\circ 5', 0^\circ 10'$ AT SIMILAR SUBSONIC AND SUPERSONIC NUMBERS. SLOT PLANFORM IS NO. 17
Figure 18. — Flow angularity in 16 ft transonic tunnel at $M = 0.600$, 0.950, and 1.075 in vertical plane.
FIGURE 19 — TOTAL PRESSURE RATIOS RADIALLLY THROUGH $\xi$ OF SLOT AT STA. 126.9' FOR AIR EXCHANGE INTAKE AND EXIT VANE OPENING OF 12 INCHES IN 16-FOOT TRANSONIC TUNNEL FOR SEVERAL MACH NUMBERS. 120-INCH DROP BODY IN TEST REGION AT $\alpha = 0^\circ$ AND NOSE AT STATION 126'.
FIGURE 20.—TOTAL PRESSURE RATIOS RADIALL THROUGH $\xi$ OF SLOT AT STA. 126.9 FEET FOR AIR EXCHANGE INTAKE AND EXIT VANE OPENING OF 36 INCHES IN 16 FOOT TRANSONIC TUNNEL FOR SEVERAL MACH NUMBERS; 120 INCH DROP BODY IN TEST REGION AT $\alpha = 0^\circ$ AND NOSE AT STATION 126.'
Figure 21. Comparison of total pressure ratios radially through $\xi$ of slot at STA 126.9 for air exchange intake and exit vane openings of 12 inches and 36 inches in 16-foot transonic tunnel with 120 inch drop body at $\alpha = 0^\circ$ and nose at station 126'. $M = 1.071$ and 1.054 respectively.
Figure 22 — Comparison of total pressure ratios through \( \xi \) of slot at stations 107.5', 126.9' and 136.9', together with similar ratios at \( \xi \) of flat at station 107.5', in 16-foot transonic tunnel for a supersonic Mach number near 1.07, tunnel empty; air exchange intake and exit vane opening of 30 inches. Slot shape number 18.
FIGURE 23 — COMPARISON OF CORRECTED HORSEPOWER FOR ORIGINAL AND REVISED EFFUSER BELL CONFIGURATIONS IN 16-FOOT TRANSONIC TUNNEL WITH SLOT SHAPE NO. 1; $H_0 = 2120 \text{ LBS/ SQ FT}; T_o = \text{ AVERAGE STAGNATION TEMPERATURE CURVE FOR CALIBRATION RUNS}; \text{TUNNEL EMPTY}; \text{WALL DIVERGENCE, } 8^\circ$
FIGURE 24.—COMPARISON OF CORRECTED HORSEPOWER FOR WALL DIVERGENCE ANGLES OF 0°, 0°5°, 0°10° IN 16-FOOT TRANSSONIC TUNNEL WITH SLOT SHAPE NO 18; $H_o = 2120$ LBS/SQ FT; $T_o =$ AVERAGE STAGNATION TEMPERATURE CURVE FOR CALIBRATION RUNS.