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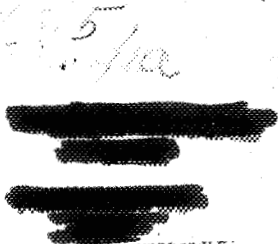
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## NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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## MEMORANDUM REPORT

for the

Bureau of Aeronautics, Navy Department

# AN EXPERIMENTAL INVESTIGATION OF NACA SUBMERGED-DUCT ENTRANCES

By Charles W. Frick, Wallace F. Davis, Lauros Randall,
and Emmet A. Mossman

Ames Aeronautical Laboratory
Moffett Field, Calif.

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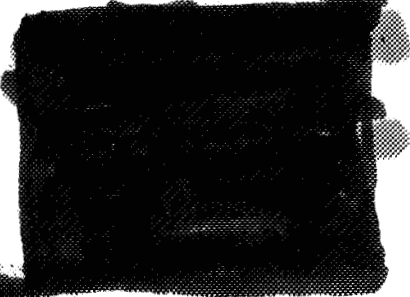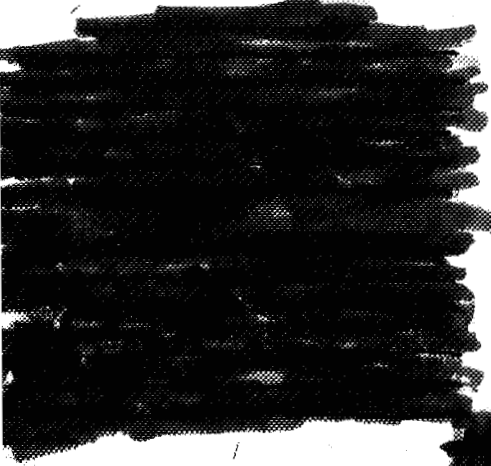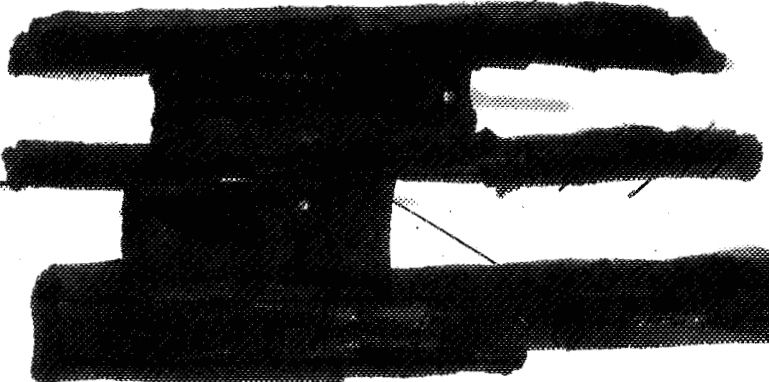
MEMORANDUM REPORT

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AN EXPERIMENTAL INVESTIGATION OF NACA SUBMERGED-

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SUMMARY

The results of an investigation of submerged-duct entrances are presented. It is shown that this type of entrance possesses the following characteristics:

1. Very high-critical-compressibility speeds throughout the range of high-speed inlet-velocity ratios

2. Very low pressure losses for the air entering the duct at all inlet-velocity ratios

3. Low external drag

These characteristics are obtained by the proper shaping of the contour of the upstream approach to the submerged inlets and by proper alinement of the duct lip. Design data are presented and the application of these data to a specific high-speed fighter-airplane design is discussed.

INTRODUCTION

The use of the jet-propulsion motor has greatly

intensified the need for efficient air-induction systems for high-speed aircraft. Although the air quantities used by such motors are not greatly in excess of the over-all air requirements of conventional aircraft engines of equivalent high-speed thrust, the performance of a jet motor is affected to a much greater extent by pressure losses in the air-induction system resulting from poor design. At high speed, a loss in total pressure of 10 percent of the free-stream dynamic pressure for the air supplied to the jet motor of a typical fighter aircraft may result in a loss in thrust equivalent to about one-tenth of the airplane drag. When it is realized that very few of the air-induction systems of existing jet-propelled aircraft have total pressure recoveries of more than 65 percent of the free-stream dynamic pressure, it becomes apparent that there is a great need for improved designs.

The problem of obtaining low pressure losses for the air supplied to the jet motor is made more difficult by the necessity of obtaining these low losses without impairing the critical-compressibility speed or excessively increasing the drag of the basic airplane by protuberances or changes in the basic contour. It is quite possible through the use of large external scoops to obtain very satisfactory internal-air-flow characteristics, but the gain in jet-motor performance may be offset by the high drag resulting from the formation of local shock waves or by the excessive drag of the air scoops themselves.

Consideration of the problem has indicated that the use of air inlets submerged below the basic contour of the aircraft would eliminate the large drag of external air scoops. These submerged openings would also render the attainment of high-critical speed for the air inlets easier. It was anticipated that it would be difficult to obtain low internal-flow losses for the submerged scoop because of the necessity of diverting the air from its path along the surface into the submerged entrance. It was expected, also, that the existence of a boundary layer of low energy air along the surface into which the entrance was placed would make it difficult to attain low pressure losses. The cursory investigation of reference 1 confirmed this conclusion. It was believed, however, that through a proper selection of the contours of the surface upstream from the opening, the flow character-istics of the submerged opening could be improved to an extent which would permit an over-all increase in airplane performance. An experimental investigation was therefore undertaken.

## MODEL AND APPARATUS

The general investigations of the submerged entrances were made in the 1- by 1.5-foot wind channel shown in figure 1. This wind channel is of the open-return type and is powered with a high-capacity centrifugal blower capable of producing a maximum airspeed of 180 miles per hour in the test section.

The air stream itself is very smooth and probably of low turbulence because of the contraction ratio of 13.0 to 1.0.

Measurements of the tunnel air stream indicated an appreciably thick boundary on the walls of the test section. In order to obtain the thinnest boundary layer possible, a false wall was built into the wind-tunnel test section so that the tunnel-wall boundary layer passed between the false and true walls of the tunnel. The model submerged duct was placed in this false wall as shown in figure 1. Air flow into the model duct entrance was controlled through the use of a small centrifugal blower.

The model of the submerged duct entrance was so designed that the contours of the lip, the angle of the entrance ramp (fig. 1), and the divergence of the ramp could be changed without removing the other duct parts. The openings tested were of 4-square-inch area, one of 4- by 1-inch and the other 2- by 2-inch dimension. For all tests the air drawn into the entrance was expanded to a very low velocity in an $8^{\circ}$ conical diffuser of 13.0 to 1.0 area ratio. Sketches of two of the entries tested are shown in figure 2.

A specific application of the results of the general investigation was tested on a 0.25-scale model of a fighter-type aircraft in the 7- by 10-foot wind tunnel. Views of the submerged duct for this model are shown in figures 3(a) and (b).

TESTS AND TEST METHODS

Measurements of the pressure losses of the air flowing into the submerged duct for the tests in the 1- by 1.5-foot wind channel were made both at the entrance and at the end of the diffuser. The placing of the total-pressure tubes and the static-pressure tubes in the entrance is shown in figure 4. Pressure losses at the end of the diffuser were measured with total-pressure tubes. It should be noted that all measurements of the pressure recovery at the end of the diffuser were made while the pressure-measuring tubes were located in the duct inlet. The pressure losses resulting from the drag of these rakes are of considerable magnitude and the data obtained for the diffuser are of comparative value only. This in no way detracts from the value of these measurements since they are used for comparing the effects of various changes to the entrance. Data useful to the designer were obtained with the rakes at the duct entrance. Losses measured with these rakes represent the values obtained with 100-percent diffuser efficiency. Data for other diffuser efficiencies may be computed from these measurements.

Pressure-distribution tests were made over the lip and the ramp of the entrance to permit an estimation of the critical speed. Pressure data obtained with flush orifices were used with reference 2 to obtain values of the critical Mach numbers for various operating conditions.

The effects of removing the boundary layer of the

surface ahead of the submerged duct were determined by testing
suction slots at various locations ahead of the duct entrance.
A small centrifugal blower was used to provide suction.  Air
quantities were measured with a calibrated venturi.  A sketch
of the boundary-layer-control test duct is shown in figure 5.

Nearly all tests were made by holding the tunnel airspeed
constant and varying the air quantity flowing in the duct to
vary the inlet-velocity ratio.  A few tests were made at very
high inlet-velocity ratios by reducing the tunnel airspeed.

Tests of submerged-duct entrances for the 0.25-scale
model of the fighter aircraft were made by drawing the air
flowing into the ducts through a channel in the spar of the
tip-supported model.  The inlet-velocity ratio was held con-
stant while the model angle of attack was varied.  Pressure
losses were measured at the simulated entrance to the Halford
jet motor with a rake of 17 total-pressure-measuring tubes
in each duct.

<div align="center">RESULTS AND DISCUSSION

General Investigation</div>

The investigation of the submerged-duct entrances in the
small wind channel was divided into phases, each concerned
with one particular design variable.  These variables were
as follows:

1. Ramp design

2. Lip design

3.  Entrance shape and aspect ratio

4.  Boundary-layer thickness  ⟶

5.  Boundary-layer control

6.  Drag

*design variables*

The discussion deals with each of these variables separately.
The symbols used throughout this report are defined in the
appendix. *capital showing elements*

Ramp design.- During the preliminary tests of the sub-
merged entrances, the pressure recoveries obtained both at
the end of the diffuser and at the duct entrance were dis-
appointingly low. A maximum value of pressure recovery of
about 57 percent was measured after complete diffusion at an
inlet-velocity ratio of 0.5. The pressure recovery decreased
to zero when the inlet-velocity ratio was increased to a
value of 1.3. The entrance tested consisted of a 1- by 4-inch
opening at the end of a $7^{\circ}$ ramp bounded by straight non-
divergent walls. Since, at inlet-velocity ratios of less than
1.0, more air enters the upstream end of the ramp than flows
into the entrance with resultant spillage over the sides
and, since the streamlines of the flow diverge as the opening
is approached, it was suggested that some improvement might
be obtained by diverging the walls of the ramp to fit the
streamlines more closely. Tests of the first divergent walls
showed a surprising increase in the pressure recovery of 8
to 10 percent at inlet-velocity ratios of less than 1.0. To
investigate this further, tests of various straight divergent

walls and one curved divergent wall as shown in figure 6 and
table I were made. The results of these tests are shown in
figure 7. The best pressure recoveries were obtained with
the curved divergence 4 which gave a maximum pressure recovery
of 73 percent at an inlet-velocity ratio of 0.40. A small
improvement was found at inlet-velocity ratios greater than
unity.

Examination of the pressure-loss data (fig. 8) obtained
in the duct entrance shows that the effect of the divergent
walls is to reduce appreciably the losses suffered by the air
entering the duct. It was noticed, however, that while the
pressure losses were much improved over the entrance as a
whole, higher losses than those obtained with no divergence
were found close to the ends in the upper half of the opening.
This is shown by the data of figure 9 taken for the pressure
rake mounted one-half inch from the end of the opening. Flow
studies indicated that these pressure losses were originating
in a short stalled region along the walls of the ramp. Attempts
made to improve this by rounding the edges of the walls resulted
in even greater losses. It was found that by placing small
ridges or deflectors of a maximum height of one-half inch
along the top of the divergent walls, as shown in figure 10,
an appreciable gain in pressure recovery could be realized.
When these were extended forward along the top of the wall
to near the entrance to the ramp further improvement was
realized at inlet-velocity ratios of less than 0.6. These

data are shown in figure 11. The combination of a curved divergence and the deflectors increased the maximum pressure recovery from 57 percent (fig. 7) to 78 percent (fig. 11) at an inlet-velocity ratio of 0.4 and from 20 percent to 36 percent at an inlet-velocity ratio of unity.

The above results were obtained with a ramp angle of 7°. It was necessary, therefore, to determine the effect of changing the ramp angle on the pressure losses and to find out whether the use of divergence was as efficacious with greater ramp angles as for 7°. The results of figure 12 show that, without diverging walls, an appreciable improvement in the pressure recovery is experienced with increasing ramp angle especially at the inlet-velocity ratios greater than unity. The results of tests of various ramp angles with divergent walls presented in figure 13 show the effectiveness of the divergence in increasing the ramp angle up to 10°. For 15°, a large loss in pressure recovery was experienced. It should be explained that the measure of divergence used in this investigation is the ratio of the width of the entrance of the ramp to the width of the submerged entrance. From the results of the tests, this appears to be a more important parameter than the angle of the walls. From the foregoing, it may be concluded that ramp angles up to 10° may be used without incurring excessive losses. The effectiveness of diverging the walls is the same for all ramp angles up to 10°, even though the pressure gradient along the ramp

floor increases slightly with the ramp angle (fig. 14).

Lip design.- In designing a satisfactory lip for the submerged duct two requirements must be satisfied. First, the lip must have a shape such as to give a high-critical speed at low inlet-velocity ratios as are used in high-speed flight; and second, the lip shape must be such that no stalling of the internal flow will occur at high inlet-velocity ratios or even at infinite inlet-velocity ratio corresponding to the static ground operation of the jet motor. With these criteria in mind, seven lip shapes were tested. Line drawings of these shapes are given in figure 15 and tables II(a) and II(b) give their ordinates. The results of tests of these lip shapes are given in table III. The first lip tested was poor in all respects, especially insofar as the stalling of the internal flow was concerned. Adding curvature to the inner surface (lip 2) improved these stalling tendencies, but the critical speed was still very poor. Adding curvature to the outer surface (lip 3) did not improve the critical speed and made the internal-flow losses much greater. Adding curvature to both the inside and outside surface (lip 4) increased the critical speed and eliminated stalling of the lip except at infinite inlet-velocity ratio. Changing the nose radius (lip 5) did not improve this condition, but an increase in camber and an increase in nose radius resulted in an entirely satisfactory lip (lip 6). A further attempt to improve this lip

by increasing the lip radius still further resulted in decreased critical speeds. It is concluded that, for the duct tested, lip 6 was entirely satisfactory.

It was anticipated that changing the ramp of the submerged entrances might have an appreciable effect on the angle of flow at the lip and thereby on the critical speed. Tests of lip 6 with a ramp angle of $7^\circ$ and divergence 4 showed a decrease in the maximum critical speed from 0.92 to a value of $M_{cr}$ of 0.83 at an inlet-velocity ratio of 0.94. It was surmised that the increased pressure recovery with the divergent wall was increasing the angle of flow at the lip. While the value of $M_{cr}$ of 0.83 is quite high under normal conditions, the fact that these submerged inlets probably will be used on surfaces over which the velocity is greater than free-stream velocity makes the attainment of the highest possible critical speed for the lip necessary for a satisfactory airplane installation.

To counteract the increased angle of flow, the lip of the duct was given $3^\circ$ of down incidence. The effect of this change in incidence may be determined from a comparison of the pressure-distribution data of figures 16 and 17 which show the lip pressure with zero incidence and with $3^\circ$ down incidence. The effect of the change on the critical Mach number is shown in figure 18. The maximum critical speed with $3^\circ$ of down incidence is increased to a value of $M_{cr}$ of 0.92 at an inlet-velocity ratio of 0.85.

It was anticipated further that a change in ramp angle might have an appreciable effect on the critical Mach number of the lip by changing the angle of flow. Data obtained for lip 6 shown in figures 16, 19, and 20 indicate a sizeable effect of ramp-angle change on the pressure distribution over the lip. It is possible to compensate for the change in ramp angle by changing the incidence of the lip. This is believed more desirable than changing the camber of the lip itself since it is possible that the contours of the lip may be changed enough to cause stalling of the internal flow at infinite inlet-velocity ratio.

The original lips used for the submerged ducts, as shown by figure 15(a), protruded slightly above the surface. This effect is not detrimental but it is somewhat easier to fair the ends of the lip and to change its incidence if it is lowered until its upper surface becomes tangent to the surface into which the submerged duct is placed, as shown by figures 2 and 15(b). Tests of this arrangement showed the same characteristics as for the original lip location. Ordinates for the lip so placed are given in table I(b).

Entrance aspect ratio.— A few tests were made to determine the effect of entrance aspect ratio on the pressure-recovery characteristics. Comparative results are shown in figure 21 for the 1- by 4-inch opening (for which most of the research was conducted) and a 2- by 2-inch opening. The effectiveness of diverging the walls for the 2- by 2-inch opening is of

comparable magnitude to that found for the 1- by 4-inch entry.
The maximum pressure recovery which may be realized for the
2- by 2-inch opening is slightly less than for the rectangular
opening.  The data of figure 22 indicate that the loss in
pressure recovery resulting from a thick boundary layer is
somewhat less for the square opening.

Effect of boundary-layer thickness.- All of the tests
discussed above were made with the normal boundary layer of
the false wall of the wind channel noted as boundary layer 1
in figure 23.  In order to ascertain the effect of boundary-
layer thickness and to provide data applicable to submerged-
duct installations far aft on the fuselage of an airplane,
tests were also made with the two other boundary-layer
thicknesses shown in figure 23.  Results of these tests are
shown in figure 24.  As expected, these thicker boundary
layers appreciably reduced the apparent pressure recovery at
the end of the diffuser.

In order to ascertain the effect of the deflectors on
the pressure recovery, tests were made with both normal and
extended deflectors.  (See fig. 10.)  The results of these
tests are shown in figure 25.  It may be seen that for the
thinnest boundary layer, the normal deflectors showed an
appreciable improvement while the extended deflectors  improved
the pressure recovery only for a small range of low inlet-
velocity ratios.  With boundary layer 2, the use of extended
deflectors very appreciably increased the pressure recovery.

With boundary layer 3 the improvement resulting from the use

of deflectors was less, due to the fact that the boundary

layer was very thick.

As will be shown later in this report, tests of a specific

model with a boundary layer thinner than any of those mentioned

in the preceding paragraph  showed a decrease in pressure

recovery resulting from the extension of the deflectors.

Improvement resulted from the use of normal deflectors.  It

may be concluded, therefore, that  for all boundary-layer

thicknesses, the normal deflectors should be used but that the

deflectors should be extended only when the boundary layer

is as thick or thicker than boundary layer 2.  In any specific

application the controlling parameter to be used in applying

the results of this investigation, insofar as the thickness

of boundary layer is concerned, is the ratio of boundary-

layer depth to the depth of the submerged entrance.

Boundary-layer control.- Boundary-layer-control tests

were made with a suction slot located at various positions

along the ramp as shown in figure 5.  The effectiveness of

the boundary-layer control was found to be best when the

slot was located in the ramp near the inlet.  The data

obtained with the best slot (slot 4, fig. 5) are given in

figures 26 and 27.  These data show that, if the flow in the

boundary-layer suction slot is about 20 percent of the flow

into the submerged inlet, the best results are obtained.

However, the improvement obtained by use of boundary-layer

control is no greater than is obtained by extending the deflectors. It is believed that the use of extended deflectors will show an over-all increase in airplane performance greater than for boundary-layer control. It is expected, however, that if the walls of the ramp have no divergence the effectiveness of the boundary-layer control will be much greater.

Drag.- No drag measurements were made in the general investigation in the small 1- by 1.5-foot wind channel. It is impossible to distinguish between the external and internal drag of a submerged inlet in the same manner as for an inlet in the leading edge of a wing or streamline body. Nearly all of the air which suffers a loss in momentum due to the presence of the submerged inlet flows into the entrance of the duct where that loss in momentum appears as a pressure loss. For the basic submerged duct it might be said that the external drag is a negative quantity, since there probably is an improvement of the flow behind the inlet because of the removal of the boundary layer.

It is expected, however, that the use of deflectors will result in some small external drag, but in view of the large increase in pressure recovery resulting from their use, it is believed they will result in a large net gain.

## Application to a Specific Design

As mentioned previously, the results of the general investigation were applied to a specific airplane design and tested on a 0.25-scale model in the 7- by 10-foot wind tunnel. The airplane used for this purpose is a high-speed fighter airplane powered with a Halford jet motor. From the results of the basic research, twin submerged entrances were designed to supply air to the Halford unit at an inlet-velocity ratio of 0.70 at an airspeed of 475 miles per hour at 15,000 feet altitude. The internal ducting was of constant area back to the twin entrances of the jet motor. Pressure losses in the ducting as determined from bench tests were found to be 10 percent of the dynamic pressure of the air flowing in the duct. Views of the submerged inlet are shown in figure 3, and a dimensioned sketch is given in figure 28.

The results of tests made for the basic submerged duct and for the inlet with normal deflectors are shown in figure 29. The use of the deflectors appreciably increased the pressure recovery at the high inlet-velocity ratios. Extending the deflectors had a deleterious effect on the pressure recovery. Since the boundary layer was very thin, these results substantiate the theory that the extended deflectors improve the pressure recovery only if the boundary layer is thick.

The results of tests in which the angle of attack was varied are shown in figure 30. It is interesting to note that the variation of pressure recovery with angle of attack is

small. This represents a considerable improvement in flow
characteristics over those obtained with an inlet in the
leading edge of a wing or streamline body.

The estimated variation of critical Mach number with an
inlet-velocity ratio based on measured pressures is given in
figure 31. The decrease to a maximum $M_{cr}$ of 0.79 at an
inlet-velocity ratio of 0.95 from the value of 0.92 for the
basic lip 6 represents the effect of the addition of the
incremental velocity over the fuselage. The critical speed
of the submerged inlet is much greater than that of other
basic parts of the aircraft. The lip used was given approxi-
mately $2^{\circ}$ of down incidence.

It may be concluded that the application of the results
of the general investigation to a specific design presents
no additional problems. It is considered, however, that the
use of deflectors on the submerged duct for this design was
made even more necessary because the duct was located in a
curved surface. The negative incidence of the lip necessary
for the attainment of high-critical speed was greater than
for the lips tested in the general research because the sur-
face in which the submerged duct was placed had appreciable
curvature in the stream direction.

## Data for Use by a Designer

From the preceding discussion of the research the follow-
ing summary may be given:

1.  Ramp design

    (a)   The use of divergent walls for the ramp improves
          the pressure recovery to such magnitude as to
          make them mandatory for all installations.
          The curved divergence shows the best charac-
          teristics.

    (b)   The ramp angle may be varied up to $10^{\circ}$. For a
          $10^{\circ}$ ramp the pressure losses are slightly
          greater than for lesser ramp angles. If a
          $10^{\circ}$ ramp is used, a lesser divergence should
          be used than for lesser ramp angles.

2.  Lip design

    (a)   Lip shape 6 is entirely satisfactory from the
          standpoint of critical-speed and internal-flow
          losses.

    (b)   The effect of increasing the divergence is to
          increase the angle of attack of the lip at any
          given inlet-velocity ratio. This is
          believed due to increased divergence of the
          streamlines at the entrance resulting from
          increased pressure recovery.

    (c)   The effect of increasing the ramp angle is to
          decrease the angle of attack of the lip.

    (d)   For any ramp angle selected, similar critical-
          speed characteristics may be obtained by
          selecting the proper lip incidence.

(e) The use of a lip submerged below the surface
into which the entrance is placed so that
the lip contour becomes tangent to the
surface at its maximum thickness appears
to be most satisfactory.

3. Entrance aspect ratio

(a) Use of a square entrance in place of a rec-
tangular one of aspect ratio 4.0 shows
slightly greater pressure losses. It is
more desirable to use an aspect ratio of
about 4.0 for the entrance.

4. Boundary-layer thickness

(a) Increasing the boundary-layer thickness
appreciably reduces the pressure recovery.
This loss may be reduced by increasing the
length of the deflectors along the top of
the ramp walls.

5. Boundary-layer control

(a) The use of boundary-layer control does not appear
practicable in view of the improvement in
pressure recovery resulting from the use of
divergent walls and deflectors.

In order to make the results of the research available
in a more convenient form the following design data have
been prepared for the entrance of figure 32, of aspect ratio
4.0 with $7^o$ ramp, divergence 4 and lip 6:

1.  Data showing the expected pressure recovery as a function of inlet-velocity ratio for any diffuser efficiency are presented in figure 33.  Figure 34 presents similar data for the same entrance with normal deflectors.  These data are for boundary layer 1.  For boundary layers 2 and 3, data are presented for the basic ramp with extended deflectors in figures 35 and 36.  These data may be considered to closely approximate the losses for ramp angles up to $10^{\circ}$.

2.  Data showing the necessary alignment of the lip for ramp angles between $5^{\circ}$ and $10^{\circ}$ are shown in figure 37 together with the basic critical speed of the lip.

Design procedure.- The procedure necessary to estimate the characteristics of a submerged entrance designed for the aircraft of figure 38 is outlined below.  This airplane is powered with a 3000-pound-thrust jet motor requiring 31 pounds of air per second at an airspeed of 550 miles per hour at 25,000 feet altitude.  The air enters the jet motor at a velocity of 385 feet per second.

1.  The selection of the inlet position ahead of the wing was made because of the thin boundary layer that exists on the fuselage and because the entrance is out of the velocity field of the wing.  In general, it is believed good practice to locate submerged inlets in a region of relatively low velocity. The attainment of high-critical speed is made easier since the incremental velocities are small and the initial velocity of the air, which is slowed down on entering the duct, is less,

resulting in a less severe pressure gradient and a higher pressure recovery.

2. Twin ducts were used because of the large entrance area required which prohibited the use of a single inlet unless it was placed on the underside of the fuselage. It should be noted that for a twin-duct installation there is danger of flow instability occurring with consequent duct rumble if the inlet-velocity ratio in any flight condition falls below the value for maximum pressure recovery. This flight condition is found usually either in gliding flight with the motor throttled or off. This instability and consequent rumble may be eliminated by closing off one entrance for these flight conditions or by providing spoilers in the internal duct ahead of the juncture of the twin inlet ducting which are actuated when the throttle is closed. It may, also, be eliminated by providing air bleed in these flight conditions. The instability is found only for twin-duct installations and is entirely a function of the positive variation of pressure recovery with inlet-velocity ratio.

3. The boundary-layer thickness was calculated by the method of reference 3 and was found to be less in terms of the duct depth than the thinnest boundary layer tested.

4. It was decided that the entrance should have a $7^\circ$ ramp. Curved divergence 4 and lip 6 with normal deflectors were used. Lip 6 was given $3^\circ$ of down incidence.

5. An inlet-velocity ratio of 0.70 was selected to give

a critical speed of 0.85 for the basic lip.

6.  This inlet-velocity ratio fixed the diffuser expansion at 1.9 to 1.0.  The estimated diffuser efficiency was 85 percent.

7.  The pressure recovery as a function of inlet-velocity ratio was estimated from figure 34.  These data together with an estimate of the critical compressibility speed are given in figure 39.

It should be noted that, if a low inlet-velocity ratio (e.g., 0.5) is selected, there is a possibility that the pressure gradient ahead of the duct entrance may become so severe at high Mach numbers as to cause separation of the flow from the surface similar to that which occurs at low speed at inlet-velocity ratios less than 0.4.  This will result in lower pressure recoveries than estimated.  The use of fairly high inlet-velocity ratios is an essential characteristic of these submerged entrances.  This, of course, intensifies the problem of diffuser design and makes essential the elimination of all bends and rapid expansions in the internal ducting. Fortunately, the submerged inlets may be so placed as to make this problem easier of solution than that for inlets in the leading edge of a wing or a streamline body.

## CONCLUSIONS

As a result of the research conducted on the submerged air inlets the following conclusions may be drawn:

1.  High-pressure recovery at the entrance at inlet-velocity

ratios less than unity (of the duct) may be obtained by diverging the walls of the ramp approaching the submerged entrance.

2. The pressure recovery at high inlet-velocity ratios is improved further by adding small deflectors to the top of the ramp walls.

3. Ramp angles up to 10° may be used without incurring excessive pressure losses. *what is critical M.No. quote*

4. Very high-critical-compressibility speed may be *?* obtained by use of proper lip shape and incidence.

5. The existence of a thick boundary layer on the surface into which the inlet is placed will appreaiably reduce the pressure recovery in terms of free-stream dynamic pressure. This loss may be eliminated to some extent by extending the deflectors forward to the leading edge of the entrance ramp.

6. The use of boundary-layer control is not as effective as the use of extended deflectors.

7. The variation of pressure recovery with angle of attack for a complete model is small, a characteristic which makes submerged inlets more desirable than wing leading-edge inlets.

8. Submerged inlets are well suited for use in supplying air to jet motors especially for those with axial flow compressors which use air at high velocity.

Ames Aeronautical Laboratory,
     National Advisory Committee for Aeronautics,
          Moffett Field, Calif., May 23, 1945.

Charles W. Frick,
Aeronautical Engineer.

Wallace F. Davis,
Aeronautical Engineer.

Emmet A. Mossman,
Mechanical Engineer.

Lauros Randall,
Aeronautical Engineer.

Approved:

Donald H. Wood,
Aeronautical Engineer.

## APPENDIX

### Coefficients and Symbols

H      total pressure, pounds per square foot

p      static pressure, pounds per square foot

V      velocity, feet per second

$\rho$      air density, slugs per cubic foot

q      dynamic pressure $(\frac{1}{2}\rho V^2)$, pounds per square foot

P      pressure coefficient $\left(\dfrac{p_L - p_o}{q_o}\right)$

$\Delta H$      loss in total pressure $(H_L - H_o)$, pounds per square foot

$\eta_D$      diffuser efficiency factor $\left(1 - \dfrac{\Delta H_D}{q_A}\right)$

$M_{cr}$      critical Mach number

$\alpha$      angle of attack of model wing, degrees

Subscripts

A      station at the duct entrance

L      station at which the pressure measurements were made

o      free stream

av      average over duct section

D      diffuser

REFERENCES

1. Rogallo, F.M.: Internal-Flow Systems for Aircraft.
   NACA Rep. No. 713, 1941.

2. von Kármán, Th.: Compressibility Effects in Aerodynamics.
   Jour. Aero. Sci., vol. 8, no. 9, July 1941, pp. 337-
   356.

3. Jacobs, E.N., and Von Doenhoff, A.E.: Formulas for
   Use in Boundary-Layer Calculations on Low-Drag Wings.
   NACA ACR, Aug. 1941.

TABLE I.- ORDINATES FOR DIVERGENT RAMP WALLS

| Y/B X/L | Divergence 0 | Divergence 1 | Divergence 2 | Divergence 3 | Divergence 4 |
|---|---|---|---|---|---|
| 0 | 0.50 | 0.500 | 0.500 | 0.5000 | 0.5000 |
| .5 | .50 | .500 | .500 | .5000 | .4930 |
| .10 | .50 | .500 | .500 | .5000 | .4670 |
| .20 | .50 | .470 | .458 | .4470 | .3870 |
| .30 | .50 | .442 | .415 | .4000 | .3100 |
| .40 | .50 | .418 | .373 | .3500 | .2420 |
| .50 | .50 | .390 | .333 | .3050 | .1950 |
| .60 | .50 | .363 | .290 | .2550 | .1550 |
| .70 | .50 | .335 | .250 | .2080 | .1200 |
| .80 | .50 | .308 | .205 | .1580 | .0750 |
| .90 | .50 | .280 | .165 | .1100 | .0575 |
| 1.00 | .50 | .250 | .125 | .0625 | .0440 |

Note: Reference axes are shown on figure 6.

## TABLE II(a).— LIP ORDINATES GIVEN IN INCHES

| Sta-tion | Lip 1 | | Lip 2 | | Lip 3 | | Lip 4 | | Lip 5 | | Lip 6 | | Lip 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower | Upper | Lower |
| 0 | -0.125 | -0.125 | -0.125 | -0.125 | -0.220 | -0.220 | -0.125 | -0.125 | -0.125 | -0.125 | -0.063 | -0.063 | -0.063 | -0.063 |
| .25 | 0 | -.265 | 0 | -.320 | -.030 | -.360 | .065 | -.310 | .065 | -.280 | .100 | -.275 | .160 | -.280 |
| .50 | 0 | -.296 | 0 | -.380 | 0 | -.390 | .115 | -.370 | .115 | -.350 | .150 | -.350 | .210 | -.360 |
| .75 | 0 | -.336 | 0 | -.415 | 0 | -.421 | .125 | -.410 | .125 | -.395 | .175 | -.410 | .230 | -.410 |
| 1.00 | 0 | -.367 | 0 | -.440 | 0 | -.451 | .120 | -.440 | .120 | -.440 | .187 | -.440 | .250 | -.440 |
| 1.50 | 0 | -.428 | 0 | -.501 | 0 | -.512 | .110 | -.500 | .110 | -.501 | .187 | -.505 | .240 | -.505 |
| 2.00 | 0 | -.488 | 0 | -.563 | 0 | -.574 | .100 | -.560 | .100 | -.562 | .175 | -.570 | .220 | -.570 |
| 2.50 | 0 | -.550 | 0 | -.624 | 0 | -.635 | .085 | -.622 | .085 | -.623 | .150 | -.631 | .180 | -.631 |
| 3.00 | 0 | -.611 | 0 | -.685 | 0 | -.696 | .060 | -.683 | .060 | -.685 | .120 | -.692 | .150 | -.693 |
| 3.50 | 0 | -.673 | 0 | -.746 | 0 | -.757 | .030 | -.745 | .030 | -.746 | .085 | -.753 | .110 | -.754 |
| 4.00 | 0 | -.734 | 0 | -.807 | 0 | -.818 | 0 | -.806 | 0 | -.808 | .055 | -.815 | .060 | -.815 |
| 4.50 | 0 | -.795 | 0 | -.869 | 0 | -.880 | 0 | -.867 | 0 | -.869 | 0 | -.877 | 0 | -.877 |
| | L.E. radius: 0.125 | | L.E. radius: 0.125 | | L.E. radius: 0.125 | | L.E. radius: 0.125 | | L.E. radius: 0.075 | | L.E. radius: 0.125 | | L.E. radius: 0.1875 | |

Note:  For location of reference line, see figure 15(b).

TABLE II(b).- ORDINATES FOR SUBMERGED
LIP 6 IN INCHES

| Station | Outer surface | Inner surface |
|---|---|---|
| 0 | -0.240 | -0.240 |
| .25 | -.087 | -.462 |
| .50 | -.037 | -.537 |
| .75 | -.012 | -.597 |
| 1.00 | 0 | -.627 |
| 1.50 | 0 | -.692 |
| 2.00 | 0 | -.757 |
| 2.50 | 0 | -.819 |
| 3.00 | 0 | -.879 |
| 3.50 | 0 | -.940 |
| 4.00 | 0 | -1.002 |
| 4.50 | 0 | -1.064 |
| Leading-edge radius = 0.125 | | |

Note:  For location of reference line,
       see figure 15(b).

TABLE III.- CRITICAL MACH NUMBERS AND AVERAGE DUCT-ENTRANCE LOSSES FOR
VARIOUS LIP PROFILES THROUGHOUT THE INLET-VELOCITY-RATIO RANGE

| $V_A/V_o$ | Lip 1 | | Lip 2 | | Lip 3 | | Lip 4 | | Lip 5 | | Lip 6 | | Lip 7 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $M_{cr}$ | $\frac{\Delta H_{A_{av}}}{q_A}$ | $M_{cr}$ | $\frac{\Delta H_{A_{av}}}{q_A}$ | $M_{cr}$ | $\frac{\Delta H_{A_{av}}}{q_A}$ | $M_{cr}$ | $\frac{\Delta H_{A_{av}}}{q_A}$ | $M_{cr}$ | $\frac{\Delta H_{A_{av}}}{q_A}$ | $M_{cr}$ | $\frac{\Delta H_{A_{av}}}{q_A}$ | $M_{cr}$ | $\frac{\Delta H_{A_{av}}}{q_A}$ |
| 0 | | ----- | 0.54 | ----- | 0.57 | ----- | 0.56 | ----- | 0.53 | ----- | 0.63 | ----- | 0.54 | ----- |
| .5 | | 0.420 | .64 | 0.542 | .73 | 0.444 | .71 | 0.508 | .69 | 0.650 | .80 | 0.425 | .63 | 0.692 |
| .7 | | .161 | .69 | .127 | .68 | .117 | .77 | .131 | .77 | .135 | .89 | .113 | .69 | .150 |
| .8 | | .086 | .62 | .079 | .69 | .064 | .80 | .075 | .80 | .074 | .93 | .063 | .72 | .085 |
| 1.0 | Below 0.60 | .048 | .45 | .048 | .51 | .032 | .62 | .038 | .72 | .043 | .71 | .036 | .75 | .040 |
| 1.2 | | .028 | .40 | .024 | .44 | .021 | .50 | .023 | .58 | .016 | .57 | .020 | .61 | .023 |
| 1.5 | | .069 | ----- | .015 | ----- | .087 | .36 | .009 | .48 | .012 | .45 | .013 | .50 | .014 |
| 2.0 | | | ----- | .007 | ----- | .190 | ----- | .007 | ----- | .006 | ----- | .004 | ----- | .007 |
| 2.5 | | | ----- | .005 | ----- | .312 | ----- | .004 | ----- | .005 | ----- | .004 | ----- | .006 |
| 3.0 | | Stalled | ----- | .002 | ----- | .433 | ----- | .002 | ----- | .004 | ----- | .003 | ----- | .005 |
| 4.0 | | | ----- | .002 | ----- | .450 | ----- | .001 | ----- | .003 | ----- | .002 | ----- | .005 |
| ∞ | | | ----- | .452 | ----- | .464 | ----- | .425 | ----- | .440 | ----- | .000 | ----- | .000 |

FIGURE LEGENDS

Figure 1.- The 1- by 1½-foot wind channel as arranged for submerged-duct-entrance tests.

Figure 2.- Sketches of submerged duct entrances.

Figure 3.- Submerged-duct installation on a 0.25-scale model of a fighter airplane. (a) View with normal deflectors. (b) View without deflectors.

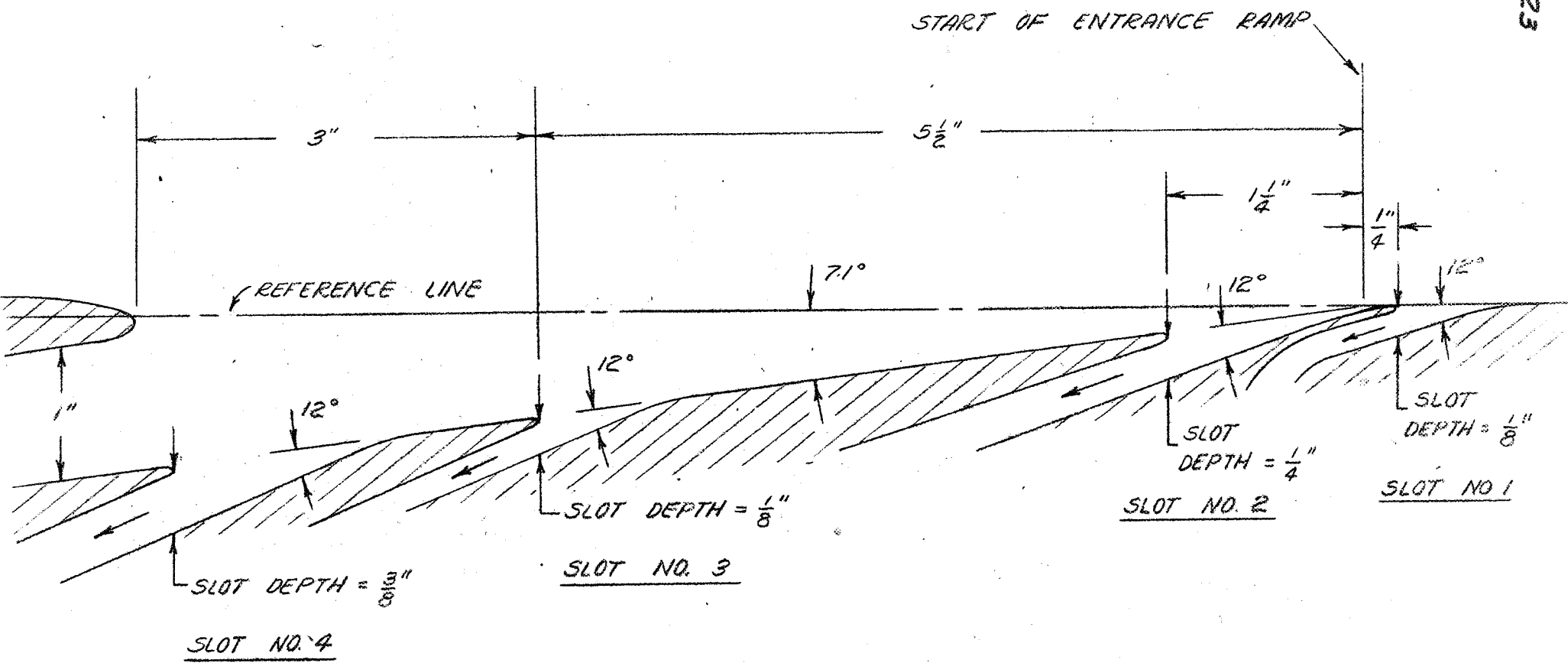Figure 4.- The location of the pressure-survey tubes in the entrance of the submerged duct entry.

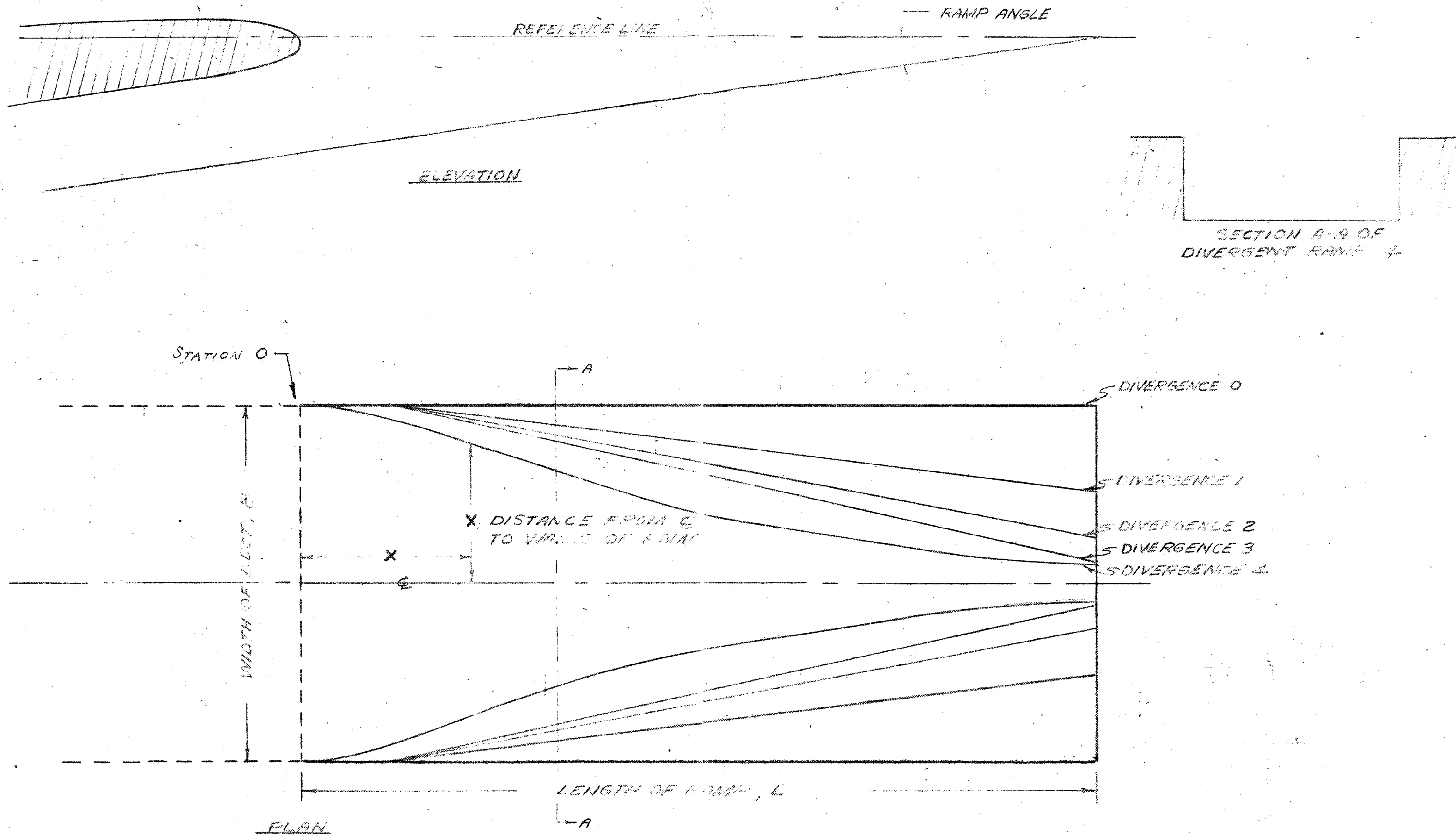Figure 5.- Sectional view of submerged duct entry showing boundary-layer-control slots tested.

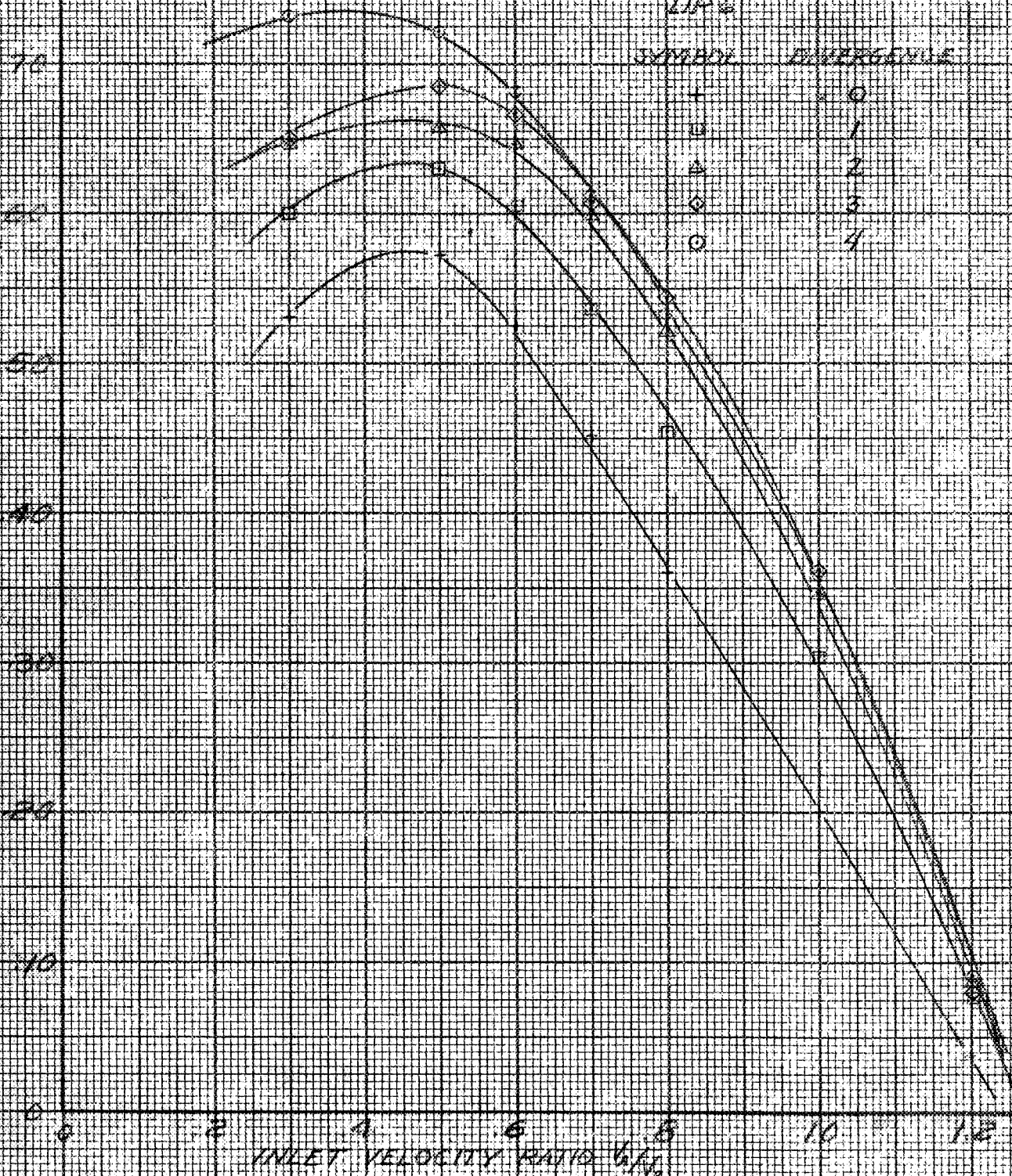Figure 6.- The divergent ramp walls tested with various ramp angles.

Figure 7.- The variation of dynamic-pressure recovery after diffusion with inlet-velocity ratio for diverging ramp walls.
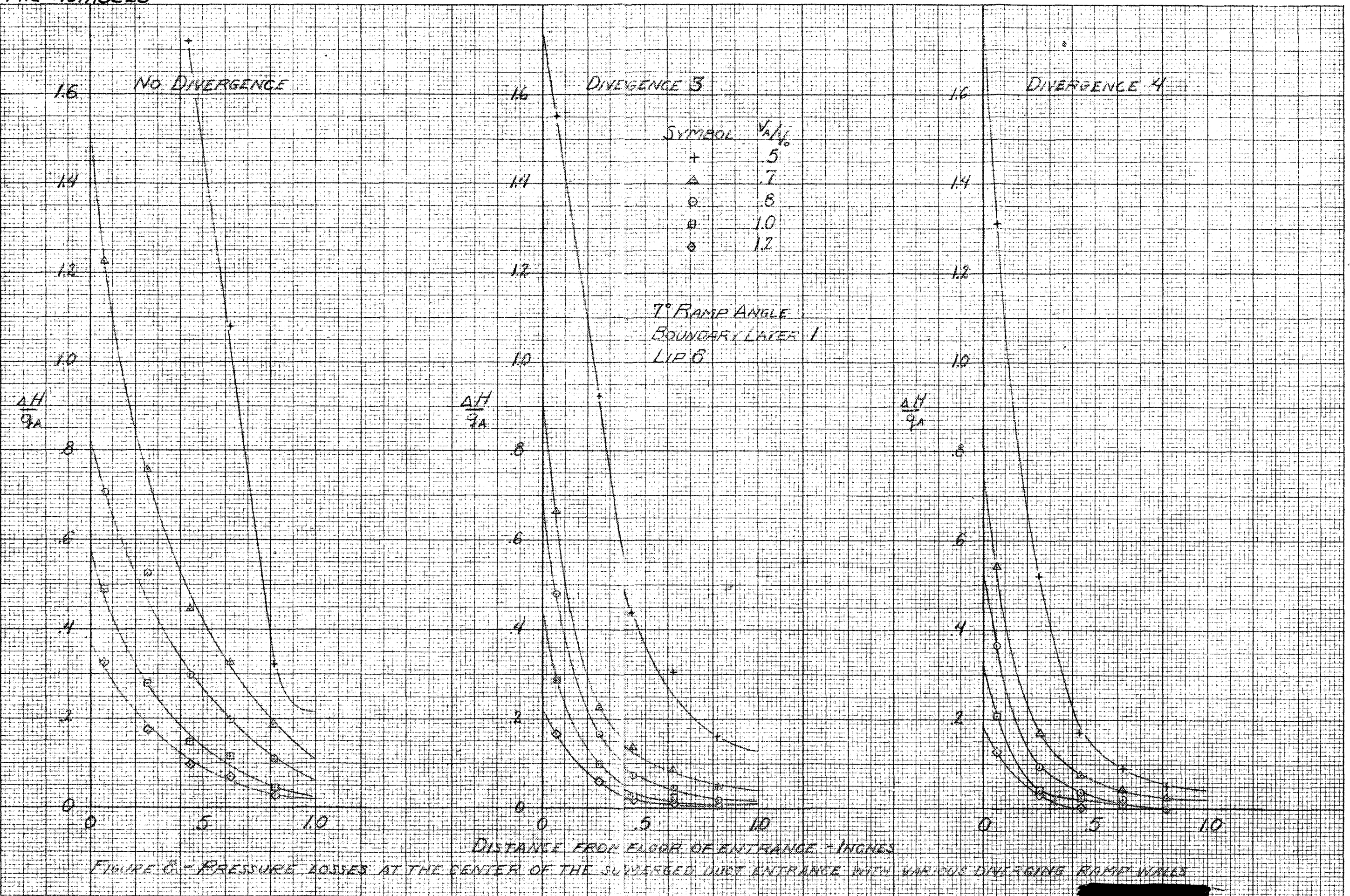
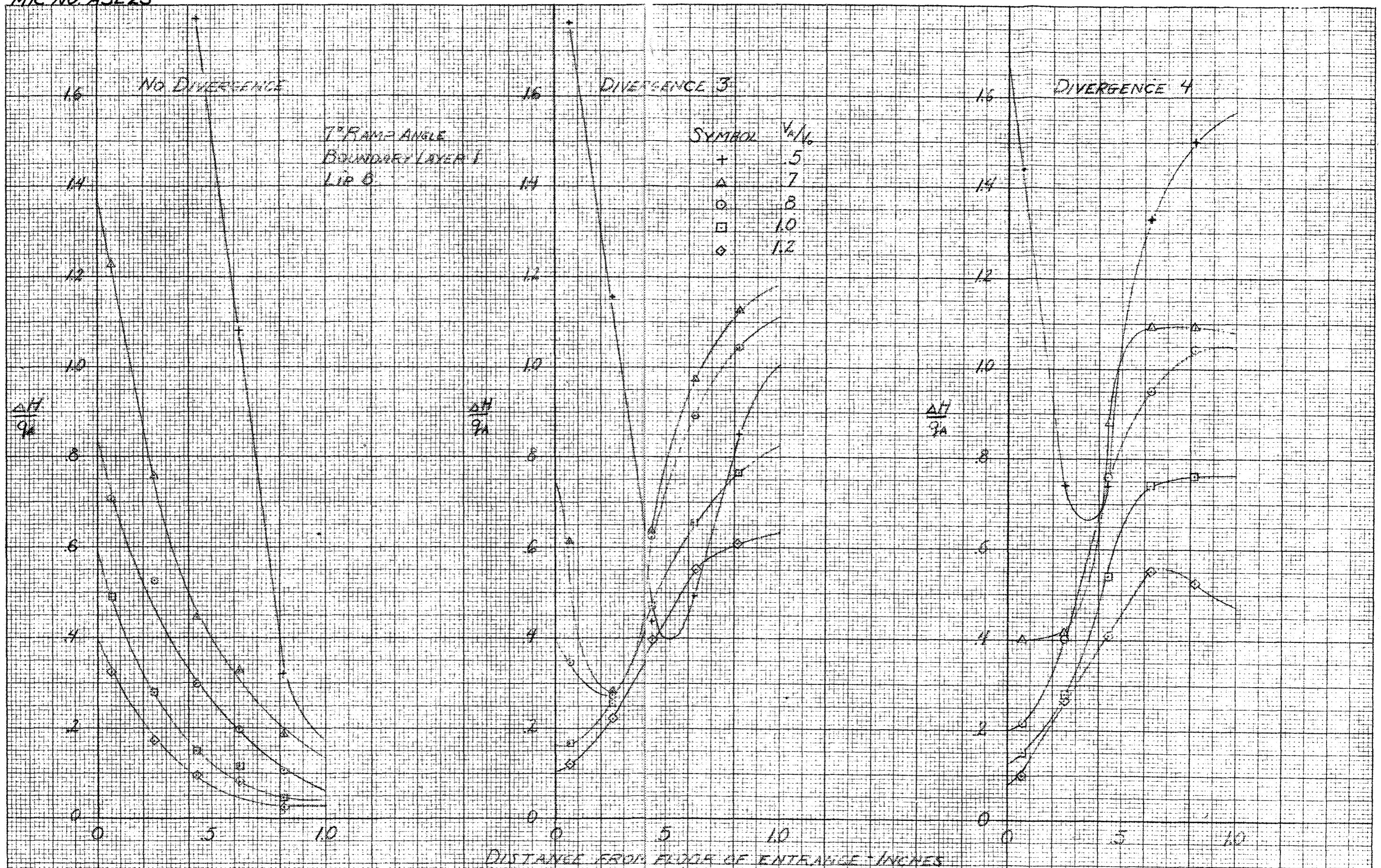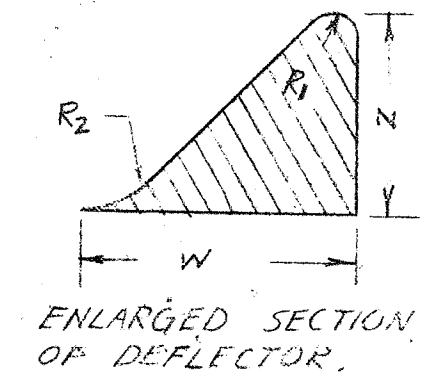Figure 8.- Pressure losses at the center of the submerged duct entrance with various diverging ramp walls.

Figure 9.- Pressure losses at the sides of the submerged duct entrance with various diverging ramp walls.

Figure 10.- Deflectors tested with submerged duct.

Figure 11.- The variation of dynamic-pressure recovery after diffusion with inlet-velocity ratio for various deflectors.

Figure 12.- The variation of dynamic-pressure recovery after diffusion with inlet-velocity ratio for various ramp angles and no divergence.

Figure 13.- The variation of dynamic-pressure recovery after diffusion with inlet-velocity ratio for various ramp angles and diverging walls.

Figure 14.- The pressure gradient along the ramp floor for various ramp angles.

Figure 15.- Lip shapes tested with the submerged duct. (a) Normal lips.

Figure 15.- Lip shapes tested with the submerged duct. (b) Submerged lip.

Figure 16.- Pressure-coefficient distribution for various
inlet-velocity ratios with lip 6 at zero incidence for a
7° ramp angle.

Figure 17.- Pressure-coefficient distribution for various
inlet-velocity ratios with lip 6 at -3° incidence.

Figure 18.- The variation of critical Mach number with
inlet-velocity ratio for lip 6 at 0° and -3° incidence.
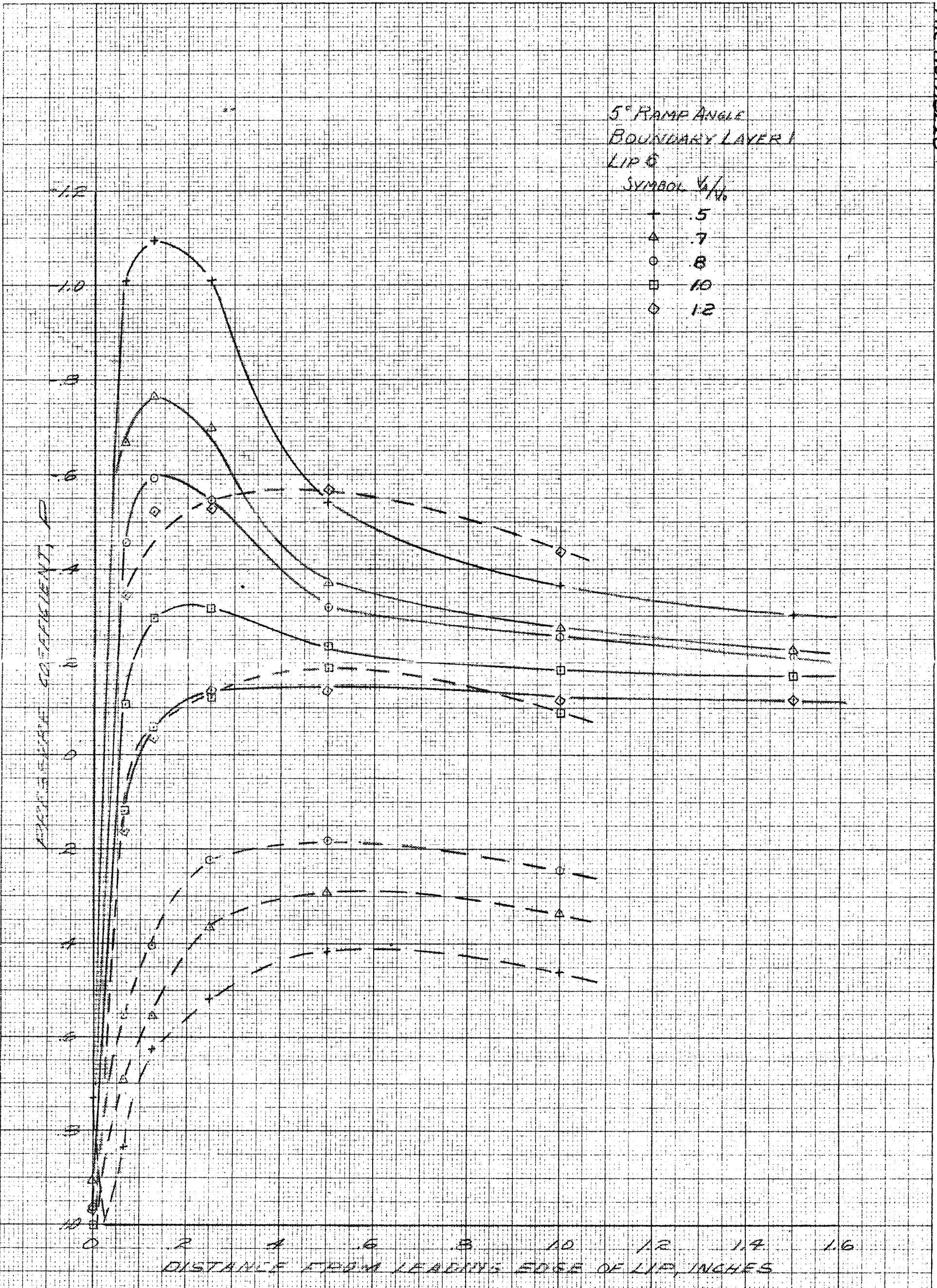
Figure 19.- Pressure-coefficient distribution for various
inlet-velocity ratios with lip 6 at zero incidence for
a 5° ramp angle.
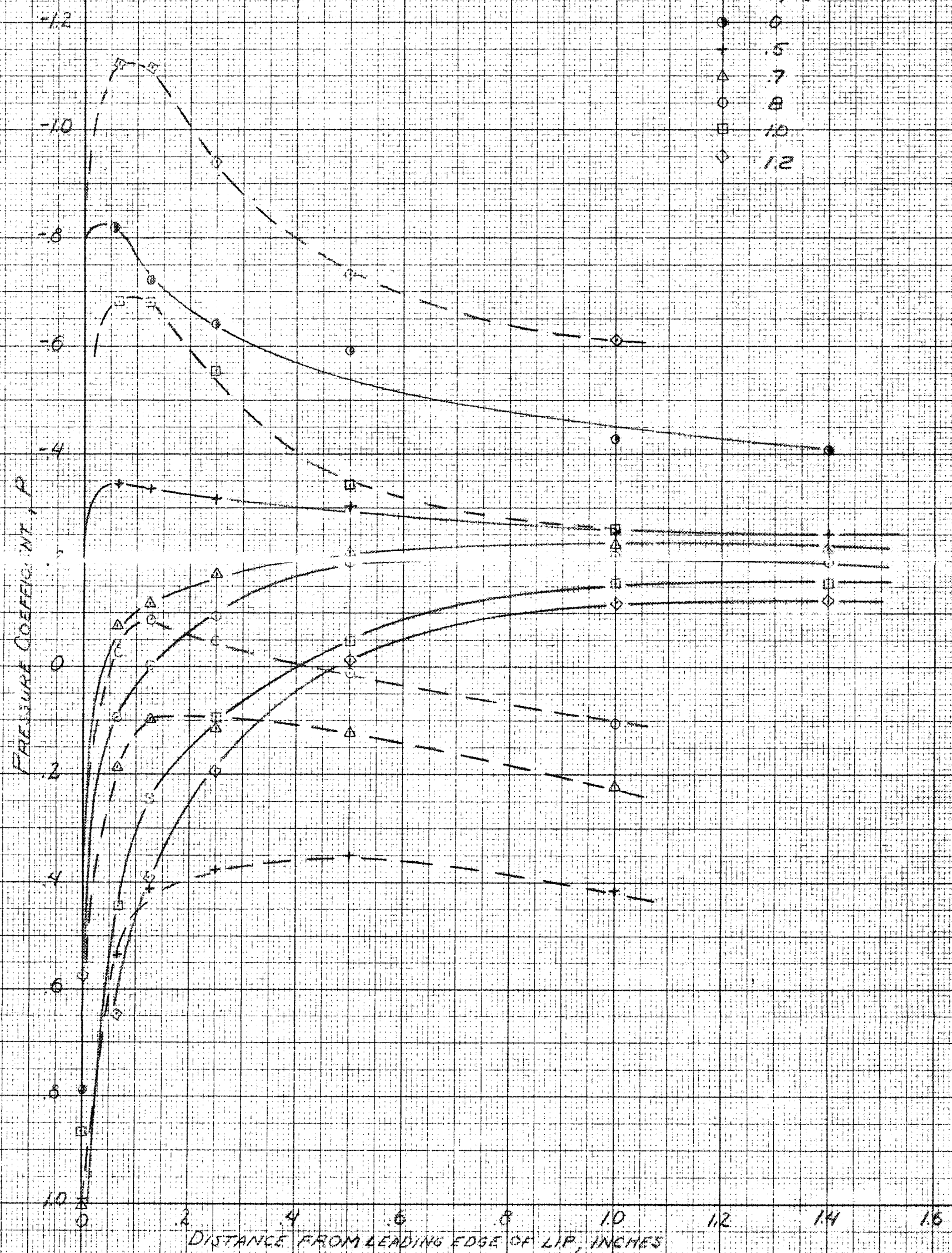
Figure 20.- Pressure-coefficient distribution for various
inlet-velocity ratios with lip 6 at zero incidence for
a 10° ramp angle.

Figure 21.- The variation of dynamic-pressure recovery after
diffusion with inlet-velocity ratio for two entrance
shapes.

Figure 22.- Variation of dynamic-pressure recovery after
diffusion with inlet-velocity ratio for two submerged-
duct-entrance shapes for boundary layer 2.

Figure 23.- Boundary layers for which submerged-duct tests
were made.

Figure 24.- The variation of dynamic-pressure recovery after
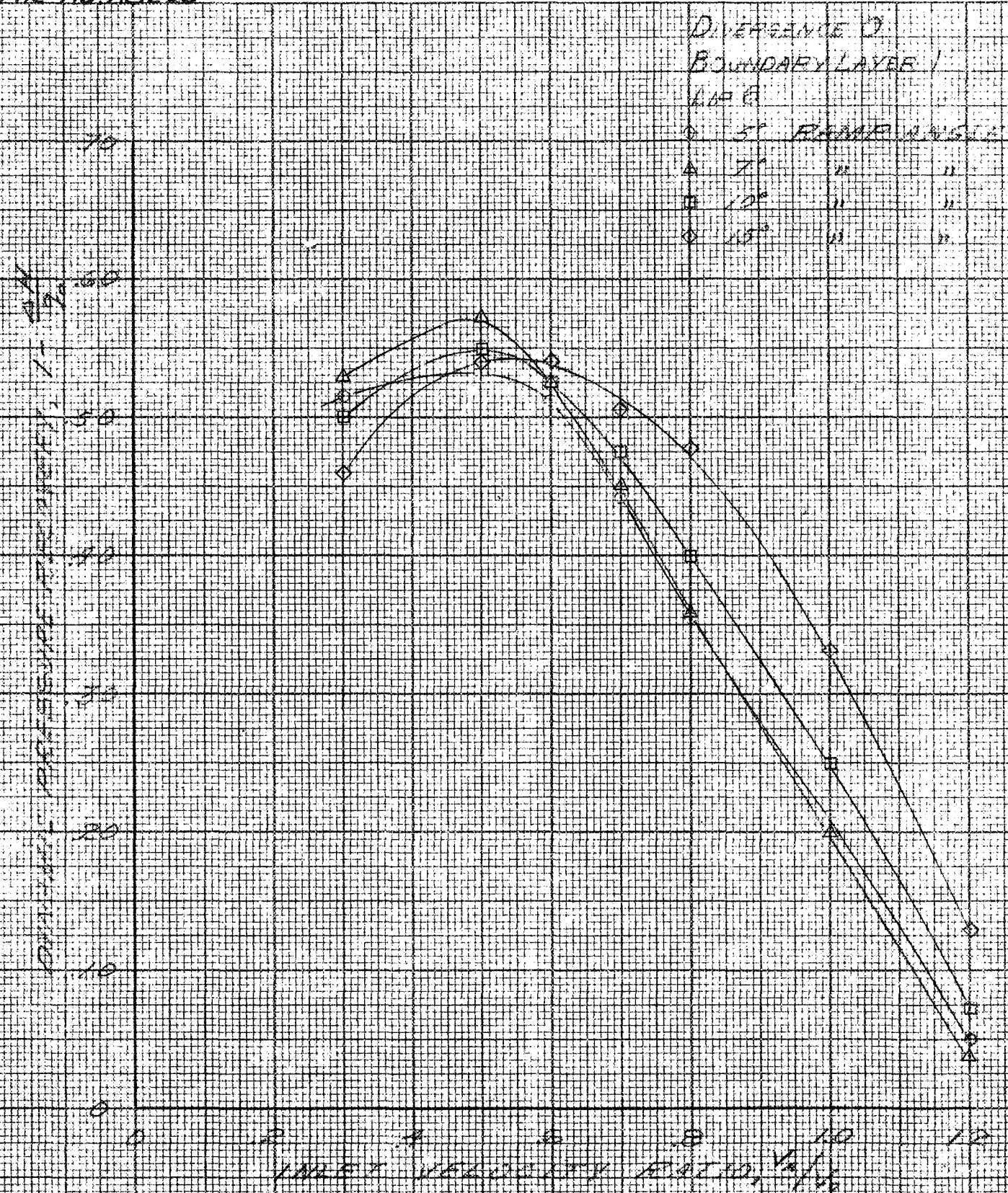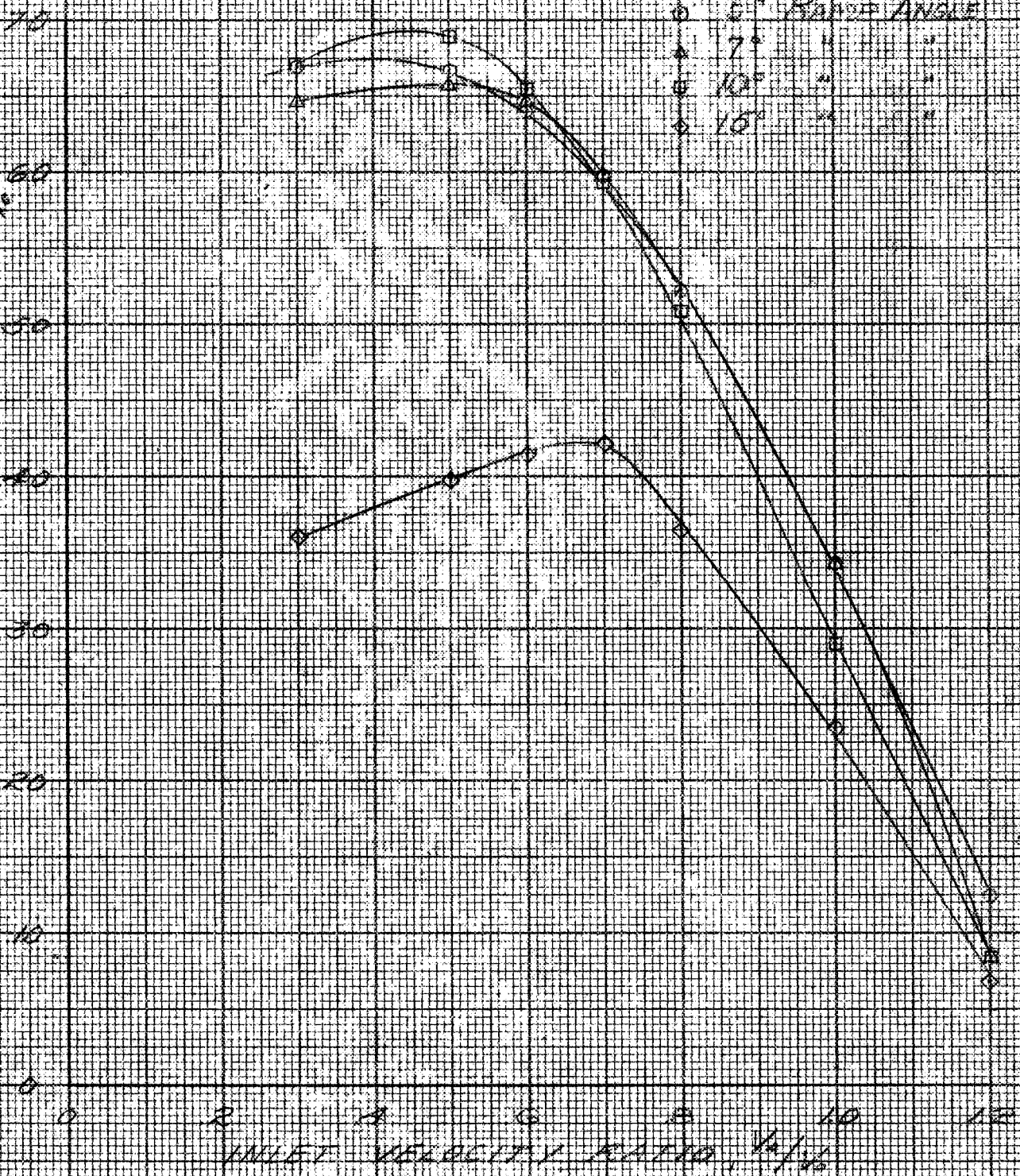diffusion with inlet-velocity ratio for three boundary-
layer thicknesses.

Figure 25.- The variation of dynamic-pressure recovery after
diffusion with inlet-velocity ratio for various boundary
layers and deflectors.

Figure 26.- The variation of dynamic-pressure recovery after
diffusion with quantity of flow through the boundary-layer
slot for various inlet-velocity ratios and boundary layers.

Figure 27.- The variation of dynamic-pressure recovery after
diffusion with inlet-velocity ratio for 20 percent of the
intake air drawn into the boundary layer.

Figure 28.- Sketch of the submerged-duct entrance installed
on the 0.25-scale model of a fighter airplane. No
deflectors.

Figure 29.- Variation of dynamic-pressure recovery with inlet-velocity ratio for various deflector configurations. Submerged-duct installation on a 0.25-scale model of a fighter airplane.

Figure 30.- Dynamic-pressure recovery of the 0.25-scale model of a fighter airplane with submerged-duct entries.

Figure 31.- Variation of critical Mach number with inlet-velocity ratio for the submerged-duct installation on the 0.25-scale model of a fighter airplane. Matched operating conditions.

Figure 32.- Sketch of submerged-duct entry for which design data are given.

Figure 33.- The variation of dynamic-pressure recovery after diffusion with inlet-velocity ratio for various diffuser efficiency factors. No deflectors.

Figure 34.- The variation of dynamic-pressure recovery after diffusion with inlet-velocity ratio for various diffuser efficiency factors. Normal deflectors.

Figure 35.- The variation of dynamic-pressure recovery after diffusion with inlet-velocity ratio for various diffuser efficiency factors. Extended deflectors and boundary layer 2.
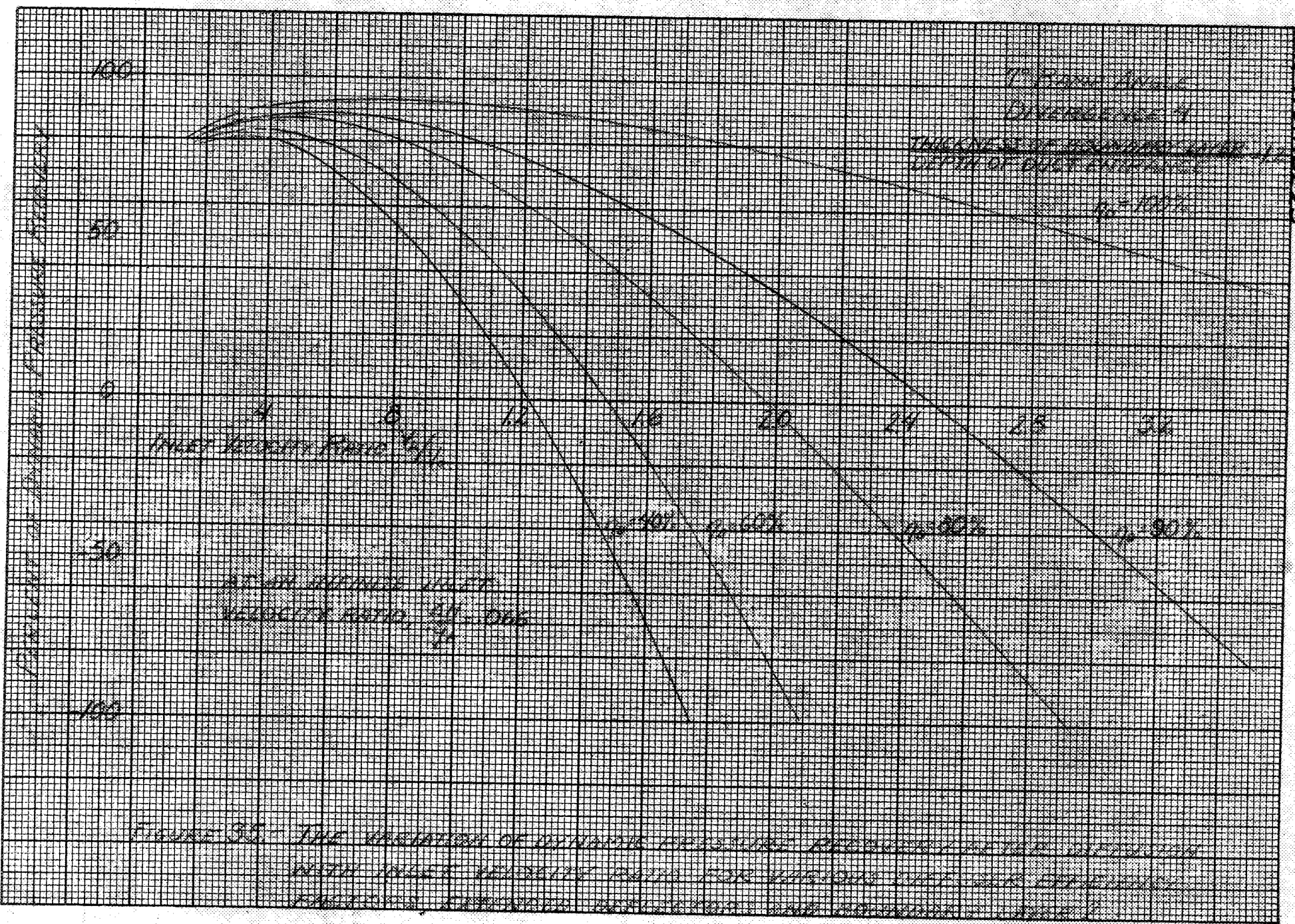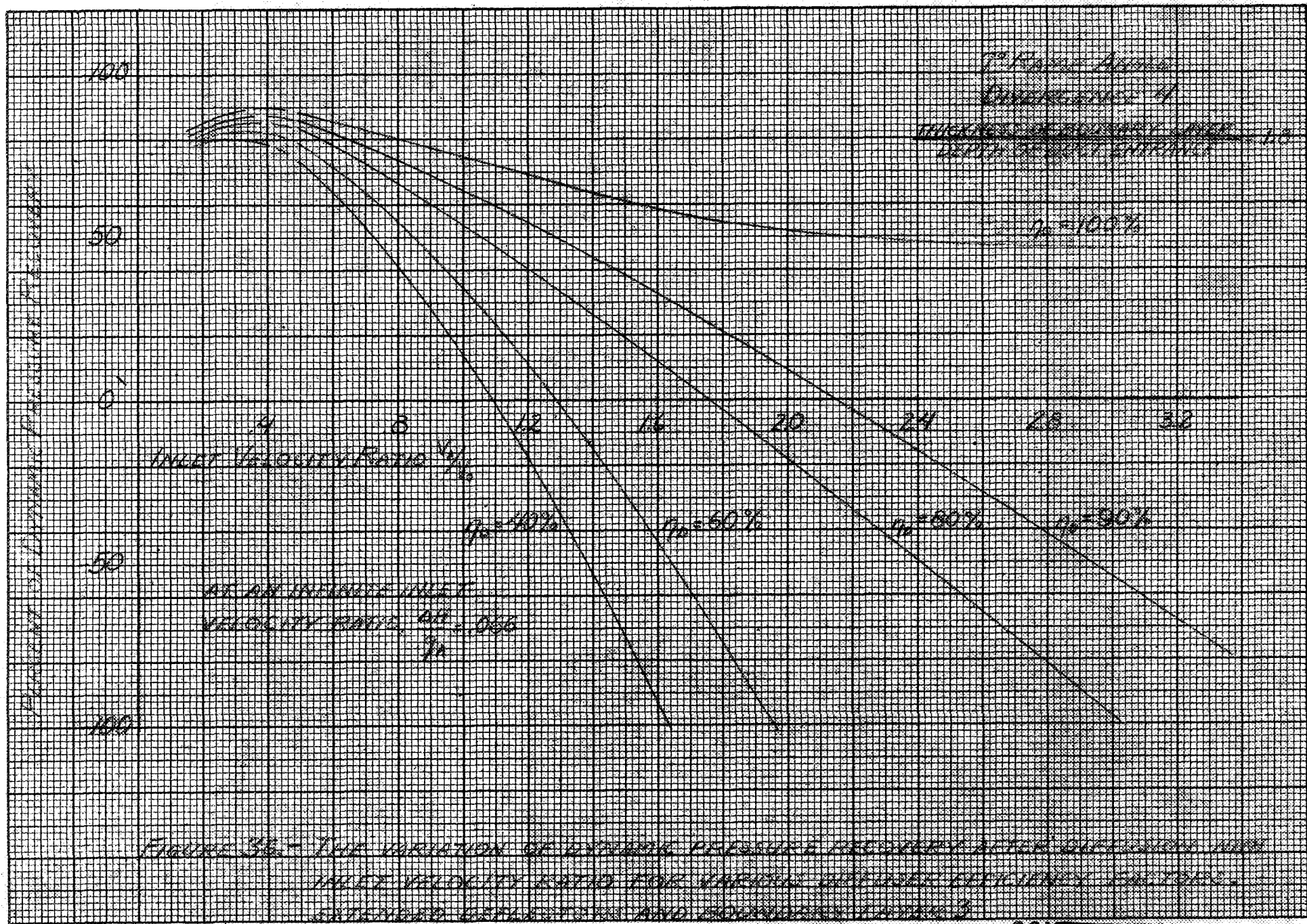
Figure 36.- The variation of dynamic-pressure recovery after diffusion with inlet-velocity ratio for various diffuser efficiency factors. Extended deflectors and boundary layer 3.
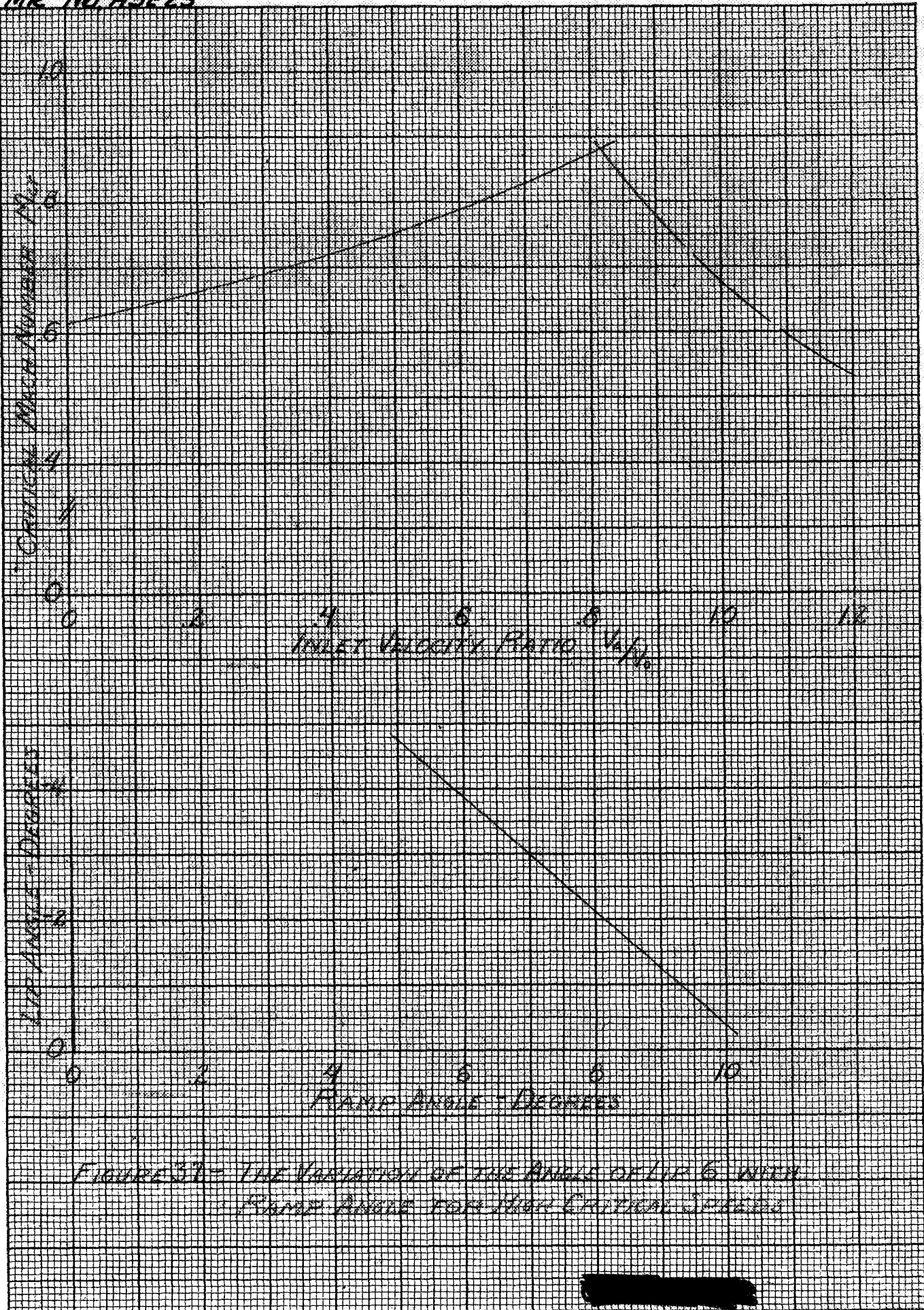
Figure 37.- The variation of the angle of lip 6 with ramp angle for high-critical speeds.

Figure 38.- Three-view drawing of a high-speed jet fighter design.

Figure 39.- The variation of dynamic-pressure recovery after diffusion and critical Mach number with inlet-velocity ratio for a submerged duct entrance on a typical fighter airplane.

1. 75 H.P. BLOWER
2. 15 H.P. BLOWER
3. BUTTERFLY VALVE
4. VENTURY METER
5. INTAKE AIR DUCT
6. ENTRANCE BELL
7. SUBMERGED DUCT ENTRANCE
8. FALSE FLOOR
9. TEST SECTION
10. ENTRANCE RAMP
11. RAKE OF TOTAL PRESSURE TUBES
12. BOUNDARY LAYER SLOT
13. DIFFUSER
14. BOUNDARY LAYER AIR DUCT

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A-7935
5-22-45

L.M.MASTIN
5-22-45

FIGURE 1.  1-BY 1½-FOOT WIND CHANNEL AS ARRANGED FOR SUBMERGED-DUCT-ENTRANCE TESTS.

a) DUCT ENTRANCE OF ASPECT RATIO. 4
WITH 7° RAMP ANGLE DIVERGENCE 4,
SUBMERGED LIP, AND NORMAL DEFLECTORS,

b) DUCT ENTRANCE OF ASPECT
RATIO 4, 7° RAMP ANGLE,
DIVERGENCE 4, AND LIP 6.

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5-20-45

FIGURE 2. SKETCHES OF SUBMERGED DUCT ENTRANCES.

o   TOTAL PRESSURE TUBE

x   STATIC PRESSURE TUBE

SCALE   2" = 1"

NOTE

TUBES WERE LOCATED 1" AFT
OF LEADING EDGE OF LIP

FIGURE 4.- THE LOCATION OF THE PRESSURE-SURVEY TUBES IN THE ENTRANCE
OF THE SUBMERGED DUCT ENTRY.

START OF ENTRANCE RAMP

3"

5½"

1¼"

¼"

REFERENCE LINE

7.1°

12°

12°

12°

12°

12°

12°

1"

SLOT DEPTH = ⅛"
SLOT NO. 1

SLOT DEPTH = ¼"
SLOT NO. 2

SLOT DEPTH = ⅛"
SLOT NO. 3

SLOT DEPTH = ⅜"
SLOT NO. 4

FIGURE 5.- SECTIONAL VIEW OF SUBMERGED DUCT ENTRY SHOWING BOUNDARY LAYER CONTROL SLOTS TESTED

RAMP ANGLE

REFERENCE LINE

ELEVATION

SECTION A-A OF
DIVERGENT RAMP

STATION O

A

DIVERGENCE O

DIVERGENCE 1

DIVERGENCE 2

DIVERGENCE 3

DIVERGENCE 4

X DISTANCE FROM ℄
TO WALLS OF RAMP

X

℄

WIDTH OF DUCT, B

LENGTH OF RAMP, L

PLAN

A

FIGURE 7.- THE VARIATION OF DYNAMIC PRESSURE RECOVERY
AFTER DIFFUSION WITH INLET-VELOCITY RATIO FOR
DIVERGING RAMP WALL

FIGURE 6 - PRESSURE LOSSES AT THE CENTER OF THE SUBMERGED DUCT ENTRANCE WITH VARIOUS DIVERGING RAMP WALLS

FIGURE 9.— PRESSURE LOSSES AT THE SIDES OF THE SUBMERGED DUCT ENTRANCE WITH VARIOUS DIVERGING RAMP WALLS.

DISTANCE FROM EDGE OF ENTRANCE - INCHES

FIGURE 10.— DEFLECTORS TESTED WITH SUBMERGED DUCT.

MR. NO. A5E23

NORMAL DEFLECTOR

EXTENDED DEFLECTORS

11"

1½"

2¼"

½"

6"

.3"

SECTION B-B WITH NORMAL DEFLECTORS

SECTION A-A WITHOUT DEFLECTORS

SECTION A-A WITH DEFLECTORS

SECTION B-B WITH EXTENDED DEFLECTORS

A

B

ENLARGED SECTION OF DEFLECTOR.

$W = 1.5z$
$R_1 = .5z$
$R_2 = .15z$

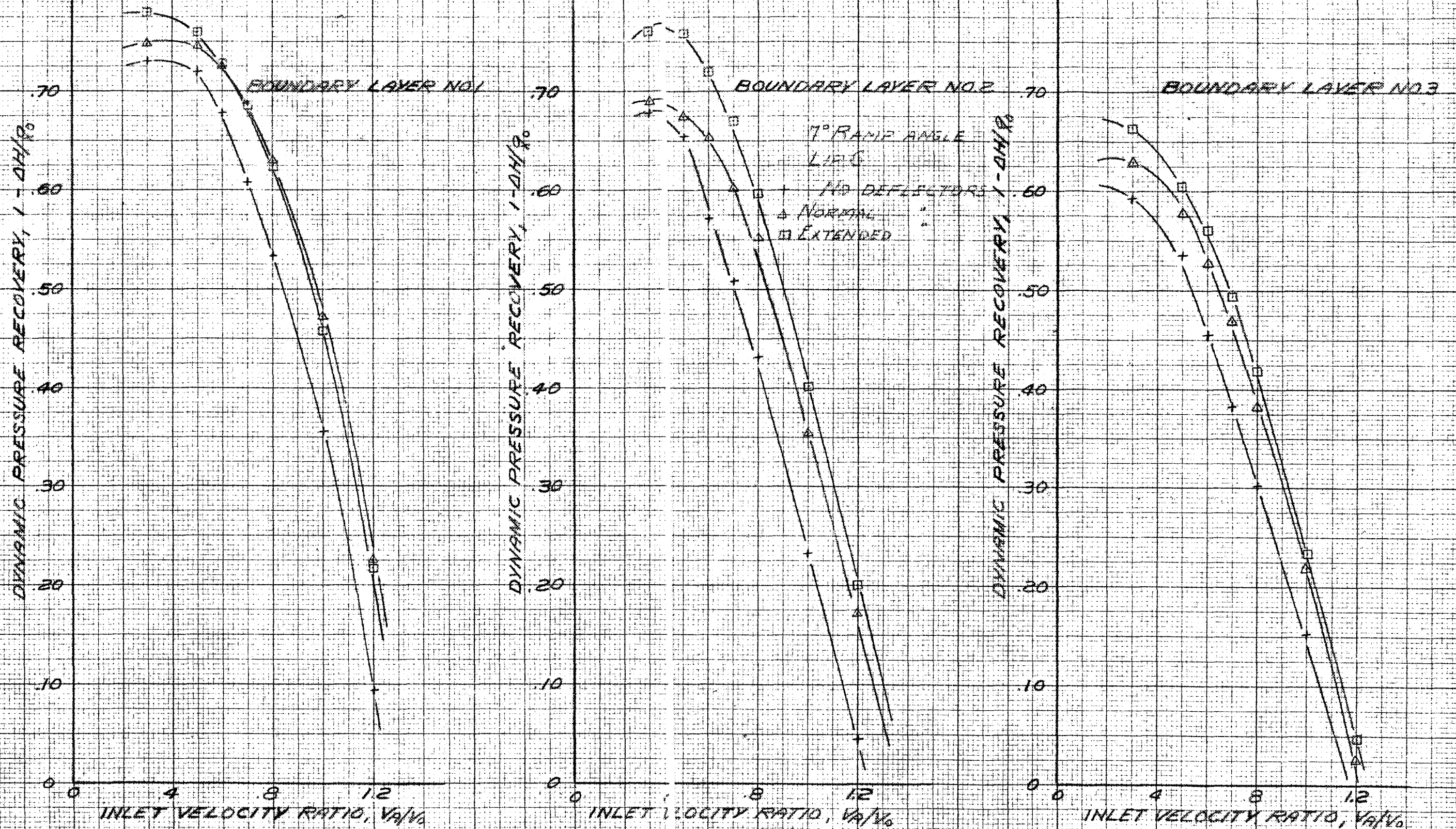FIGURE 11.— THE VARIATION OF DIFFUSER PRESSURE RECOVERY AFTER DIFFUSION WITH INLET-VELOCITY RATIO FOR VARIOUS DEFLECTORS.

FIGURE 12.- THE VARIATION OF DYNAMIC PRESSURE RECOVERY
AFTER DIFFUSION WITH INLET-VELOCITY RATIO
FOR VARIOUS RAMP ANGLES AND NO DIVERGENCE

FIGURE 18 — THE VARIATION OF DYNAMIC PRESSURE RECOVERY
AFTER DIFFUSION WITH INLET-VELOCITY RATIO
FOR VARIOUS RAMP ANGLES AND DIVERGING WALLS

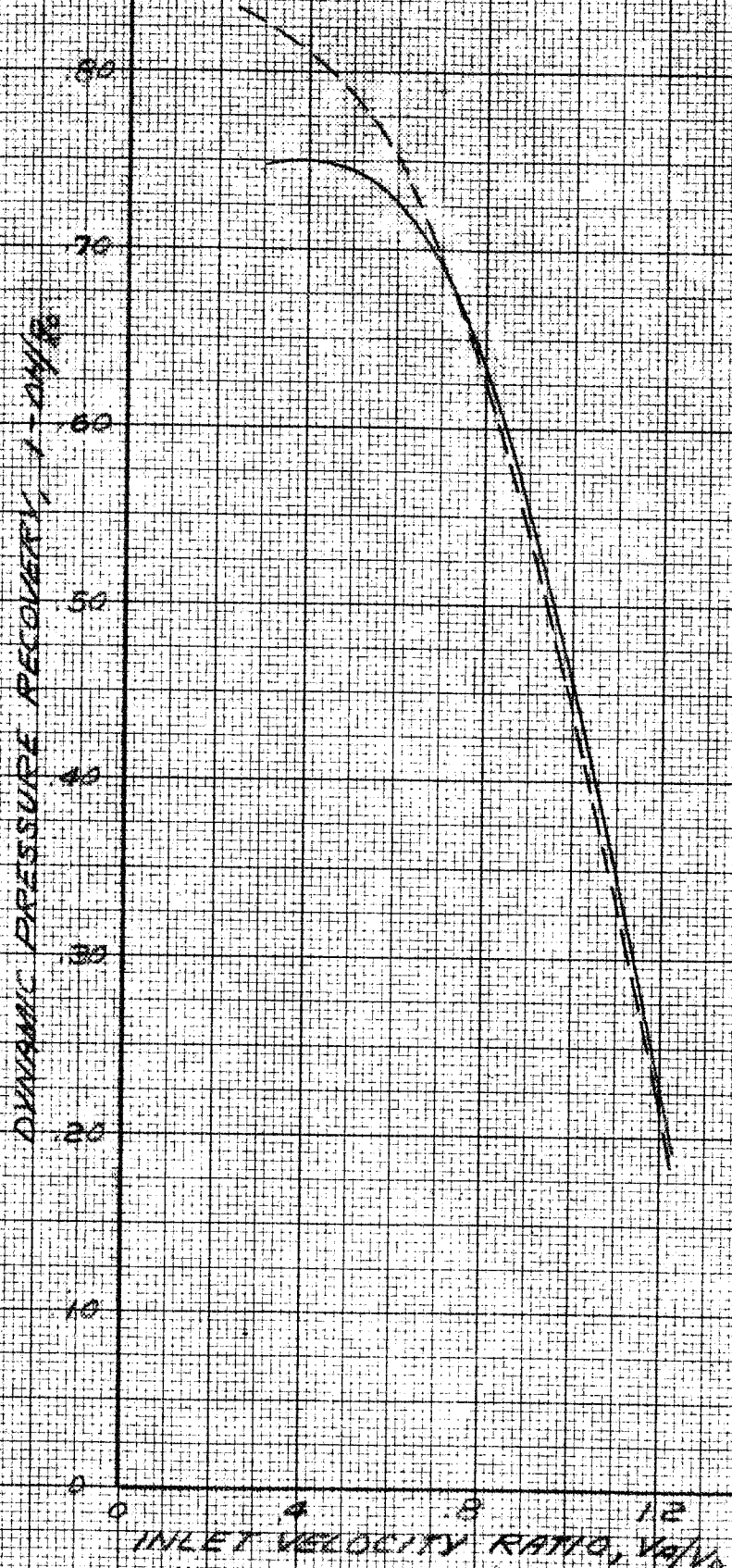FIGURE 14.- THE PRESSURE GRADIENT ALONG THE DUCT ... FLOOR FOR VARIOUS RAMP ANGLES

Lip No. 1

Lip No. 2

Lip No. 3

Lip No. 4

Lip No. 5

Lip No. 6

Lip No. 7

Sta. 0

Surface
Reference Line

(a)   Normal Lips.

Figure 15.-Lip Shapes Tested with the Submerged Duct.

(b.) SUBMERGED LIP

FIGURE 15.- LIP SHAPES TESTED WITH THE SUBMERGED DUCT.

FIGURE 16 - PRESSURE-COEFFICIENT DISTRIBUTION FOR VARIOUS INLET-VELOCITY RATIOS WITH LIP 6 AT ZERO INCIDENCE FOR A 7° RAMP ANGLE

1° RAMP ANGLE
BOUNDARY LAYER 1
LIP 6

| SYMBOL | $V_2/V_0$ |
|--------|-----------|
| ◇ | 0 |
| — | .5 |
| △ | .7 |
| ⊕ | .8 |
| □ | 1.0 |
| ◇ | 1.2 |

DISTANCE FROM LEADING EDGE OF LIP, INCHES

FIGURE 17 - PRESSURE-COEFFICIENT DISTRIBUTION FOR VARIOUS INLET-VELOCITY RATIOS WITH LIP 6 AT -3° INCIDENCE

FIGURE 13.— THE VARIATION OF CRITICAL MACH NUMBER WITH INLET VELOCITY RATIO FOR L/H 6 AT 0° AND -3° INCIDENCE

5° RAMP ANGLE
BOUNDARY LAYER 1
LIP 6

| SYMBOL | $V_1/V_0$ |
|--------|-----------|
| +      | .5        |
| △      | .7        |
| ○      | .8        |
| □      | 1.0       |
| ◇      | 1.2       |

FIGURE 19.— PRESSURE-COEFFICIENT DISTRIBUTION FOR VARIOUS INLET-VELOCITY RATIOS WITH LIP 6 AT ZERO INCIDENCE FOR A 5° RAMP ANGLE

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FIGURE 20. - PRESSURE-COEFFICIENT DISTRIBUTION FOR VARIOUS INLET-VELOCITY RATIOS WITH LIP 6 AT ZERO INCIDENCE FOR A 10° RAMP ANGLE.

FIGURE 21. — THE VARIATION OF PRESSURE RECOVERY IN THE AIR DUCT AFTER DIFFUSION WITH INLET-VELOCITY RATIO FOR TWO DIFFERENT DUCTS.

FIGURE 22 VARIATION OF DUCTED EXHAUST RECOVERY AFTER
DIFFUSION WITH INLET VELOCITY RATIO FOR TWO
SUBMERGED DUCT ENTRANCE SIZES FOR ENGINE
ARTS 2.

FIGURE 18.- BOUNDARY LAYERS FOR WING SUBMERGED-
INLET TESTS CURVE MEASURE

Figure 2A.- The variation of boundary-layer thickness after diffusion with inlet velocity ratio for three boundary-layer thicknesses

FIGURE 26 – THE VARIATION OF DYNAMIC-PRESSURE RECOVERY AFTER DIFFUSION WITH INLET-VELOCITY RATIO FOR VARIOUS BOUNDARY LAYERS AND DEFLECTORS

FIGURE 26.- THE VARIATION OF DYNAMIC PRESSURE RECOVERY AFTER DIFFUSION WITH QUANTITY OF FLOW THROUGH THE BOUNDARY LAYER SLOT FOR VARIOUS INLET VELOCITY RATIOS AND BOUNDARY LAYERS.

FIGURE 27.- THE VARIATION OF DYNAMIC PRESSURE RECOVERY AFTER DIFFUSION WITH INLET VELOCITY RATIO FOR 20% OF THE INTAKE AIR DRAWN INTO THE BOUNDARY LAYER.

FIGURE 28.- SKETCH OF THE SUBMERGED DUCT ENTRANCE INSTALLED ON THE .25-SCALE MODEL OF A FIGHTER AIRPLANE. NO DEFLECTORS.

FIGURE 79 - VARIATION OF DYNAMIC-PRESSURE RECOVERY WITH INLET-
VELOCITY RATIO FOR VARIOUS DESIGN AND CONFIGURATIONS
SUBMERGED-DUCT INSTALLATION ON A 1/4-SCALE MODEL OF A
FIGHTER AIRPLANE.

FIGURE 30.- DYNAMIC-PRESSURE RECOVERY OF THE
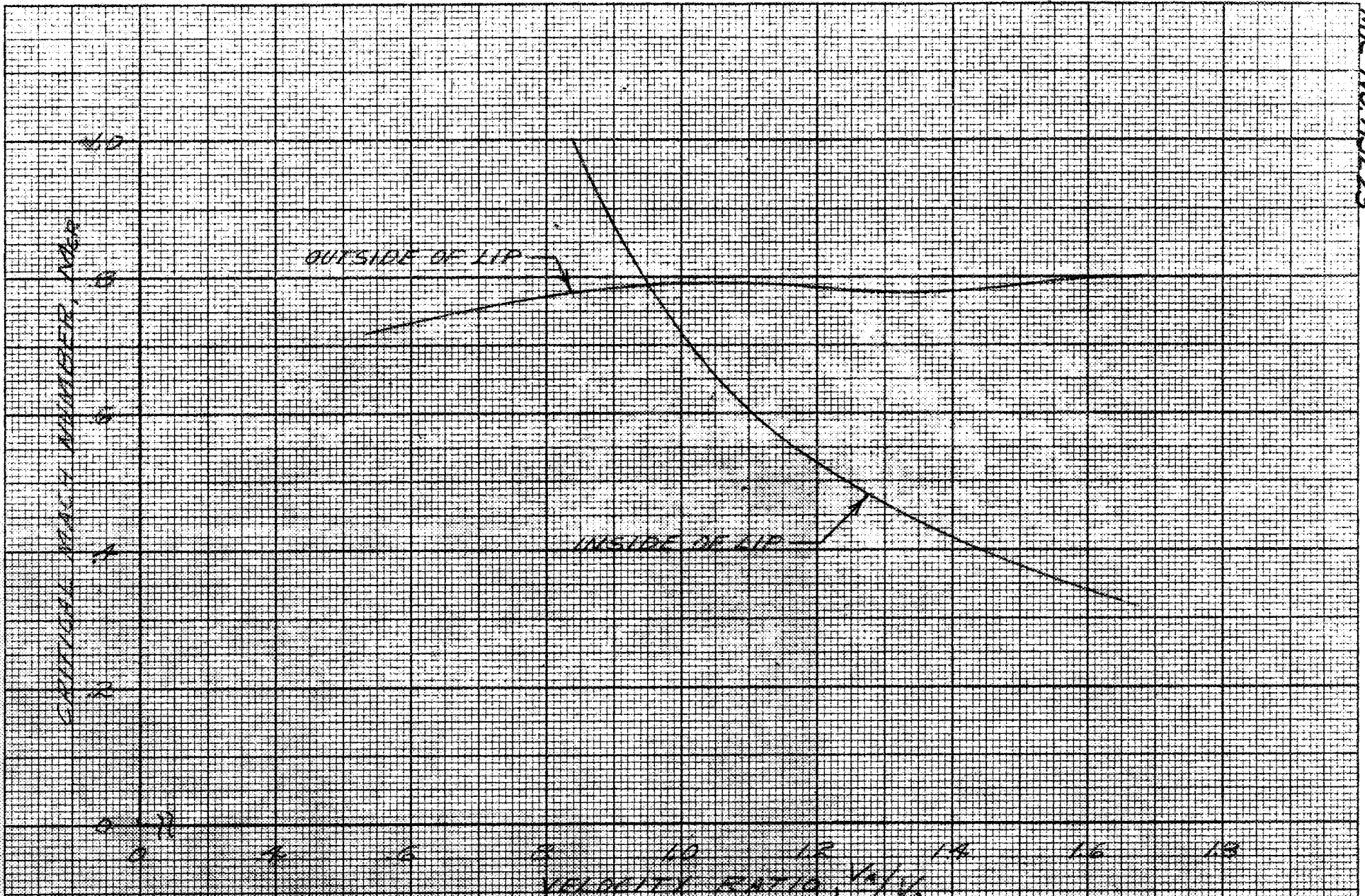1/5-SCALE MODEL OF A FIGHTER AIRPLANE
WITH SUBMERGED DUCT ENTRIES

FIGURE 31.- VARIATION OF CRITICAL MACH NUMBER WITH INLET-VELOCITY RATIO FOR THE SUBMERGED-DUCT INSTALLATION ON THE 25-SCALE MODEL OF A FIGHTER AIRPLANE. MATCHED OPERATING CONDITIONS.
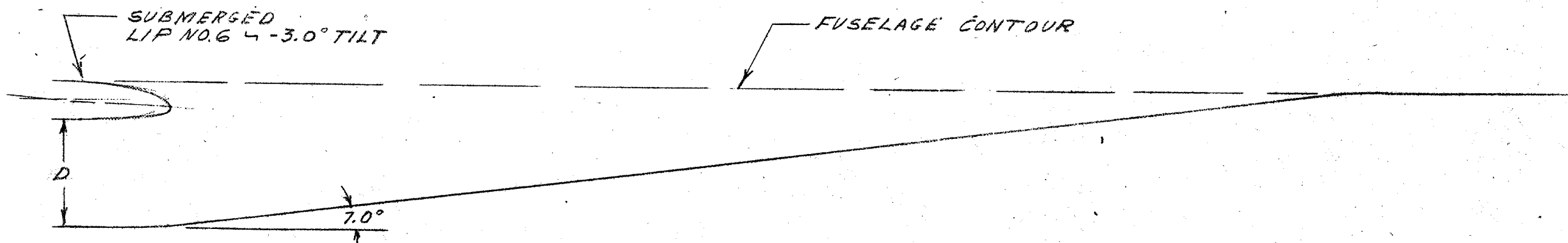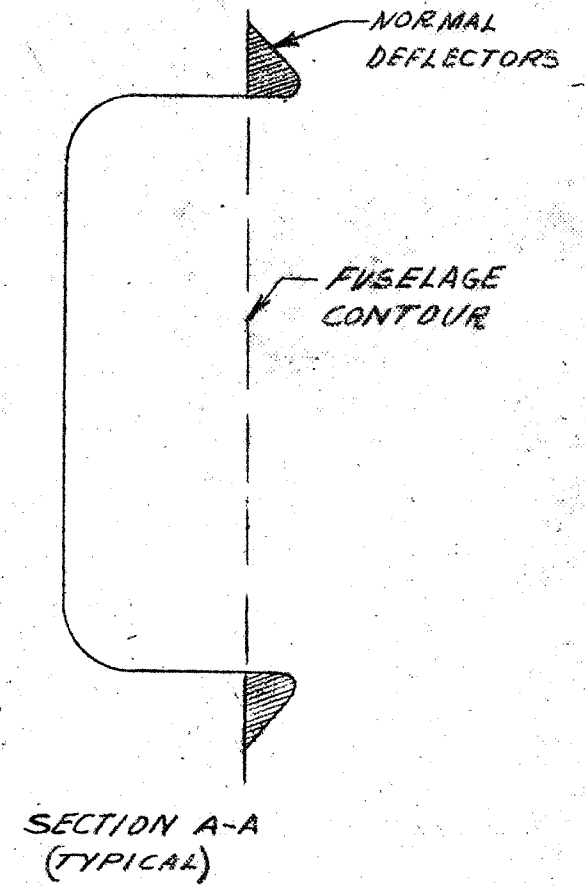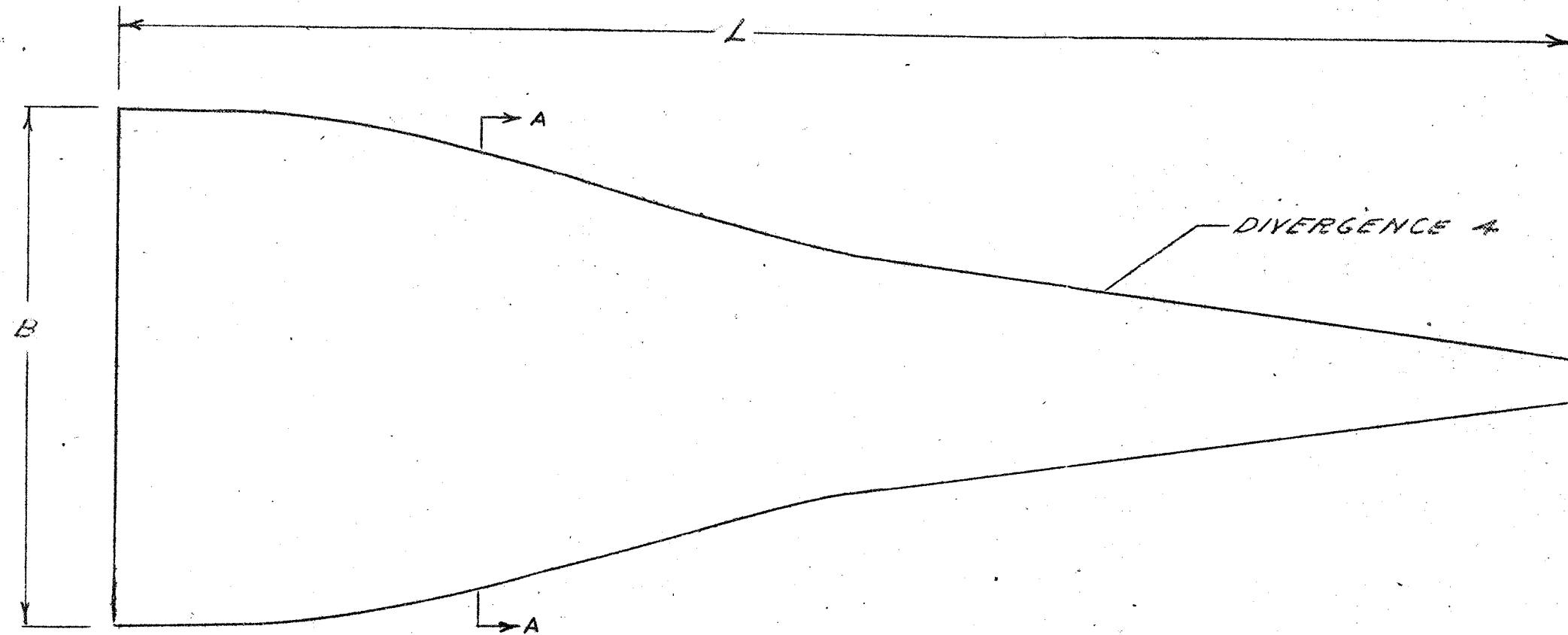
NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

NORMAL
DEFLECTORS

FUSELAGE
CONTOUR

SECTION A-A
(TYPICAL)

L

B

DIVERGENCE 4

A

A

SUBMERGED
LIP NO.6 ↳ -3.0° TILT

FUSELAGE CONTOUR

D

7.0°

FIGURE 32.— SKETCH OF SUBMERGED DUCT ENTRY FOR WHICH
DESIGN DATA ARE GIVEN.

MR NO. A5E23

100

50

0

50

100

4    8    12    16    20    24    28    32

INLET VELOCITY RATIO $V_1/V_0$

1" Base Area
Clearance 4

$q = 100\%$

$q = 40\%$    $q = 60\%$    $q = 80\%$

AT AN INCREMENT INLET
VELOCITY RATIO $\frac{\Delta V}{V_0}$

FIGURE 33. — THE VARIATION OF DYNAMIC PRESSURE RECOVERY AT A GIVEN INLET
INLET VELOCITY RATIO FOR VARIOUS DUCT INLET DEFINING FACTORS

Percent of Dynamic Pressure Recovery $1 - \frac{\Delta H}{q_0}$

96

50

0

-50

-100

$\eta_0 = 100\%$

$\eta_0 = 80\%$

$\eta_0 = 40\%$ $\eta_0 = 60\%$ $\eta_0 = 80\%$

Inlet Velocity Ratio $V_1/V_0$

4 8 12 16 20 24 28 32

7° Total Included
Divergence 2θ
Full Width of Boundary Layer = δ
Depth of Duct Entrance

At an infinite inlet
velocity ratio, $\frac{\Delta H}{q_0}$

Figure 34 – The variation of dynamic pressure recovery with diffuser inlet velocity ratio for various diffuser efficiencies.

Figure 84 — The variation of [minimum pressure coefficient] with [Mach number] for the [airfoil] and [wing]

MR NO. 05E23

INLET VELOCITY RATIO V/Vo

100  50  0  50  100

4   8   12   16   20   24   28   32

$\eta = 100\%$

$\eta = 40\%$   $\eta = 60\%$   $\eta = 80\%$   $\eta = 90\%$

AN ASSUMED INLET
VELOCITY RATIO $\frac{\Delta P}{Vo} = 0.86$

FIGURE 56.- THE VARIATION OF OUTLET PRESSURE RECOVERY ... WITH
INLET VELOCITY RATIO FOR VARIOUS DIFFUSER EFFICIENCY ...

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FIGURE 31 - THE VARIATION OF THE ANGLE OF LIP θ WITH
RAMP ANGLE FOR THE CRITICAL SERIES

| POWER PLANT | 3000 POUND STATIC THRUST |
| --- | --- |
| NORMAL GROSS WEIGHT | 7500 LB |
| MINIMUM SERVICE WEIGHT (¼ FUEL AND NO AMM.) | 5200 LB. |
| WEIGHT EMPTY | 4600 LB |
| OVERLOAD GROSS WEIGHT | 9000 LB |

WING
| AREA | 231 SQ. FT. |
| --- | --- |
| INCIDENCE | 0° |
| GEOMETRIC TWIST | 0° |
| AIRFOIL SECTION (ROOT & TIP) | 65₁–110 |

HORIZONTAL TAIL
| AREA | 46.3 SQ. FT. |
| --- | --- |
| INCIDENCE | +1° |
| AIRFOIL SECTION | 65₁–010 |
| ELEVATOR BALANCE | NOSE RADIUS |
| ELEVATOR THROW | UP 25°, DOWN 15° |

VERTICAL TAIL
| AREA | 23.4 SQ. FT. |
| --- | --- |
| AIRFOIL SECTION | 65₁–010 |
| RUDDER BALANCE | NOSE RADIUS |
| RUDDER THROW | ± 25° |

AILERON-FLAP COMBINATION
| AILERON-FLAP BALANCE | NOSE RADIUS |
| --- | --- |
| AILERON THROW | |
| FLAP DROOP ZERO | ± 12° |
| FLAP DROOP 40° | ± 20° |

FIGURE. 38.- THREE-VIEW OF A HIGH-SPEED JET FIGHTER DESIGN.

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