[redacted]

12323

209

~~CONFIDENTIAL~~

Copy
RM L54G22

NACA RM L54G22

NACA

RESEARCH MEMORANDUM

EFFECT OF YAW AND ANGLE OF ATTACK ON PRESSURE RECOVERY AND MASS-FLOW CHARACTERISTICS OF A RECTANGULAR SUPERSONIC SCOOP INLET AT A MACH NUMBER OF 2.71

By Raymond J. Comenzo and Ernest A. Mackley

Langley Aeronautical Laboratory
Langley Field, Va.

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
WASHINGTON
September 10, 1954

~~CONFIDENTIAL~~

[redacted]

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

EFFECT OF YAW AND ANGLE OF ATTACK ON PRESSURE RECOVERY AND MASS-FLOW CHARACTERISTICS OF A RECTANGULAR SUPERSONIC SCOOP INLET AT A MACH NUMBER OF 2.71

By Raymond J. Comenzo and Ernest A. Mackley

SUMMARY

An investigation has been conducted of the effect of yaw and angle of attack on the total-pressure recovery and mass-flow characteristics of a rectangular supersonic scoop inlet designed to have low external drag at a Mach number of 2.7 and an angle of attack of 0°. Total-pressure recovery and mass-flow data are presented for a Mach number of 2.71 at angles of yaw of 0°, 2.5°, and 5° and angles of attack of 0° and 5°. Total-pressure recovery, static pressure, and Mach number distributions at the subsonic diffuser exit are presented.

An increase in angle of yaw caused small decreases in maximum total-pressure recovery at both angles of attack tested. At an angle of attack of 0° and angles of yaw of 0°, 2.5°, and 5°, the maximum total-pressure recoveries obtained were 0.76, 0.71, and 0.68, respectively. The mass-flow ratio of the inlet for both angles of attack at maximum total-pressure recovery increased for a yaw angle of 2.5° and then decreased slightly upon increasing the angle of yaw to 5°. The total-pressure and static-pressure distributions at maximum average total-pressure recovery were generally uniform for all angles of yaw and attack. The small variations in total pressure which did exist, however, caused fairly large variations in local Mach number at the rake station.

INTRODUCTION

A rectangular supersonic scoop inlet designed for low drag at an angle of attack of 0° and a Mach number of 2.7 and reported in reference 1 was found to give high total-pressure recovery. Applications of this type of inlet will obviously require operation at angles of pitch and yaw; therefore, it was considered important to obtain experimental results of the effects of these variables on the mass-flow and total-pressure-recovery characteristics of the inlet.

This investigation was performed in a blow-down jet at a Mach number of 2.71 for angles of attack of 0° and 5° and angles of yaw of 0°, 2.5°, and 5°. A simulated fuselage of semicircular cross section having a diameter equal to the inlet width was used in conjunction with the inlet. In reference 1, the highest value of pressure recovery was obtained with this inlet-fuselage configuration. Mach number and total-pressure distributions as well as the mass-flow and total-pressure-recovery characteristics are presented for the conditions mentioned.

SYMBOLS

M_o	free-stream Mach number
M_1	subsonic diffuser exit Mach number
$\left(P/P_o\right)_{av}$	ratio of integrated average total pressure at exit of subsonic diffuser to free-stream total pressure (the pressure-recovery ratio was calculated on a weighted mass-flow basis)
$\left(P/P_o\right)_L$	ratio of local or point value of total pressure at exit of subsonic diffuser to free-stream total pressure
$\left(p/P_o\right)_{av}$	ratio of average static pressure at subsonic diffuser exit to free-stream total pressure
$\left(p/P_o\right)_L$	ratio of local static pressure at subsonic diffuser exit to free-stream total pressure
m_m/m_o	ratio of measured mass flow to mass flow through a $M_o = 2.71$ free-stream tube of cross-sectional area equal to inlet frontal area
α	angle of attack, deg
ψ	angle of yaw, deg

MODEL AND TESTS

The investigation was conducted at $M = 2.71$ in a blow-down jet using low-humidity air from large pressurized tanks. The Reynolds number of this investigation was 2.55×10^6 per inch.

Model.- The model tested was the circular-fuselage configuration of reference 1 and is shown in figure 1. For this configuration, the fuselage diameter is the same as the inlet width (2 inches) which, although not generally representative of the relative fuselage-inlet size in an actual configuration, does simulate a local shape which may be used to prevent the boundary layer from entering at the inlet upper lip. The subsonic diffuser consisted of a 3-inch constant-area minimum section followed by a diverging section having an 8° included angle. Only the upper and lower surfaces of the inlet diverged.

Tests.- The test setup (fig. 2) and test procedure were, in general, the same as those of reference 1. In order to obtain the three angles of yaw tested, the flat rear portion of the upper nozzle block was made in replaceable sections. The model and retaining slot (fig. 3) were varied in angle relative to the free-stream direction and translated across the tunnel when necessary to assure starting of the tunnel. The angle-of-attack variation was accomplished by pivoting the model about point A (fig. 2).

Measurements.- The total- and static-pressure distributions in the subsonic diffuser were obtained by 17 total-pressure tubes and 8 static orifices at the diffuser exit or rake station as indicated in figure 4. The mass flow through the model was measured by a calibrated orifice located between the rake station and the throttling valves (fig. 2). Total temperature was measured in the settling chamber and immediately ahead of the orifice plate. Pressures were measured on calibrated gages and were recorded photographically. Instrument error contributed an error of ± 2 percent to the integrated average total-pressure recovery (weighted mass-flow basis, stepwise integration). The mass-flow ratios are also estimated to be accurate within ± 2 percent.

RESULTS AND DISCUSSION

Although the configuration used in these tests may not duplicate actual fuselage-inlet interference, crossflow effects, and other boundary-layer conditions, the results presented herein are considered generally indicative of the effects of yaw and angle of attack on the inlet performance. A good comparison of results between the model and actual configurations could be assured only by the use of a local shape ahead of the inlet upper lip (for boundary-layer control) similar to the fuselage used in the present investigation.

Total-pressure distribution.- The effect of increasing back pressure (moving normal shock nearer minimum section) on the total-pressure distribution along the vertical center line of the duct at the diffuser exit is shown in figure 5 for $\alpha = \psi = 0^\circ$. Because all the rakes (A, B, C, D, E of fig. 4) indicated the same general pressure distribution for each particular test condition, only the values of rake C are presented in figure 5. The arithmetic-average static-pressure ratio $(p/P_o)_{av}$ is used as a measure of the back pressure. For the lowest back pressure, $(p/P_o)_{av} = 0.27$, the total-pressure recovery was highest near the fuselage or inboard side of the subsonic diffuser as a result of separation on the outboard wall; however, upon increasing the back pressure to $(p/P_o)_{av} = 0.44$, the highest values of total-pressure recovery shifted to the opposite or outboard side. For the highest (buzz limited) back pressure obtained for $\alpha = \psi = 0^\circ$, $(p/P_o)_{av} = 0.72$, a condition corresponding to the condition of maximum total-pressure recovery, the total-pressure distribution was more nearly symmetrical about the horizontal center line of the duct. This movement of the high-total-pressure region in the duct with increasing back pressure appears typical of this type of inlet as test results (unpublished data) of a similar inlet indicated like effects.

The total-pressure distribution at the diffuser exit for the condition of maximum average total-pressure recovery (maximum back pressure, buzz limited) is presented in figure 6. In general, the total-pressure distributions at each rake were similar for all angles of yaw and attack. The value of local-total-pressure recovery $(P/P_o)_L$ decreases with increasing angles of yaw for $\alpha = 0^\circ$ (fig. 6(a)). For an angle of attack of 5° (fig. 6(b)), the pressure distributions are similar for $\psi = 0^\circ$ and 2.5°; however, an increase in yaw angle from 2.5° to 5.0° resulted in decreases in local-total-pressure recovery up to 8 percent.

Static-pressure distributions.- The local static pressure around the subsonic diffuser exit for maximum average total-pressure recovery was nearly constant at each condition of yaw and angle of attack (fig. 7). For $\alpha = 0^\circ$, the decrease (approximately 10 percent) in local-static-pressure ratio for the increase in yaw angle from 0° to 2.5° is approximately three times the decrease for the change in yaw angle from 2.5° to 5°. This trend is reversed for $\alpha = 5^\circ$ with almost no change in $(p/P_o)_L$ from 0° to 2.5° yaw angle and a decrease of approximately 5 percent for a change in yaw angle from 2.5° to 5°.

Mach number distributions.- Contour plots of the local subsonic diffuser exit Mach number M_1 for the maximum total-pressure-recovery condition (maximum back pressure, buzz limited) and for each angle of yaw and attack tested are presented in figure 8. The maximum average total-pressure recovery at each test condition is shown below each plot and the maximum point value of M_1 measured is indicated. Although a nearly constant static-pressure distribution was attained (fig. 7) it can be noted that a small variation in local total-pressure recovery (fig. 6) causes a fairly large variation in local Mach number (fig. 8). At $\alpha = \psi = 0^\circ$ (fig. 8(a)) the Mach number distribution at the diffuser exit was nearly symmetrical around the center of the duct. The effect of increasing angle of yaw at both $\alpha = 0^\circ$ and $\alpha = 5^\circ$ was to move the high Mach number portion of the flow from the center of the duct to the right and toward the outboard side. Comparison of figures 8(a) and 8(b) indicate the effect of increased angle of attack was to shift the high Mach number region to the outboard side of the duct at the rake station and to increase the rightward movement in the distribution caused by increasing angle of yaw.

Mass-flow and total-pressure recovery variation.- The average total-pressure recovery increased and the mass-flow ratio decreased slightly with increasing back pressure (fig. 9). The variation of total-pressure recovery relative to the mass-flow ratio was linear at $\psi = 0^\circ$, $\alpha = 0^\circ$, and $\alpha = 5^\circ$, whereas at $\psi = 2.5^\circ$ and $\psi = 5^\circ$ and $\alpha = 0^\circ$ and $\alpha = 5^\circ$, the rate of total-pressure-recovery increase with decreasing mass flow was variable. The slight decrease in mass flow with increasing back pressure is attributed to the spillage allowed by a small amount of boundary-layer separation just ahead of the inlet sidewall-fuselage juncture. The rate of spillage was increased for $\alpha = 5^\circ$ at both $\psi = 2.5^\circ$ and $\psi = 5^\circ$.

The increase of average total-pressure recovery with increasing back pressure is considered to be the result of a decrease in losses in the subsonic diffuser as the internal shock waves were forced upstream toward the inlet upper lip. The maximum total-pressure recovery was obtained just prior to the onset of inlet buzz; the corresponding mass-flow ratio, as indicated by the uppermost points on the individual curves, decreased with increasing angle of attack (fig. 9).

Figure 10 presents the geometric details of the free-stream-tube reference areas, I and II, used in the calculation of mass-flow data of reference 1 and the present report, respectively. In order to make a comparison of the data of reference 1 for the circular-fuselage configuration with the present data, it was necessary that the mass-flow ratios in both cases be based on the same free-stream-tube reference area. In order to accomplish this, the mass-flow data of the reference report were multiplied by the ratio of reference area I to reference area II (0.937). Data from reference 1 are plotted (dashed lines, solid symbols) in figure 9 at $\psi = 0^{\circ}$ for $\alpha = 0^{\circ}$ and $\alpha = 5^{\circ}$ and represent integrated average total-pressure recovery values for rake C only. The near-maximum average total-pressure recovery points, for rake C only (ref. 1), appear to be in good agreement with comparable average values for all rakes. The discrepancies that exist at the low total-pressure recoveries between the data of reference 1 and the present data at $\psi = 0^{\circ}$ may be accounted for by the fact that the greater number of total-pressure tubes at the rake station (present data) gives a more nearly correct value of integrated average (weighted mass-flow basis) total-pressure recovery in the presence of flow separation.

As shown in figure 11, the maximum total-pressure recovery obtained decreased with increasing yaw angle. At $\alpha = 0^{\circ}$, an increase in yaw angle from 0° to 5° resulted in a decrease of approximately 10 percent in maximum total-pressure recovery. For $\alpha = 5^{\circ}$, however, the same increase in yaw angle caused a decrease in maximum total-pressure recovery of 5 percent. The losses in total-pressure recovery for yawed-inlet operation may be attributed to the system of shock and expansion waves originating on the swept sidewalls of the inlet. Although the leading edges of the inlet swept sidewalls were sharp, no separation on the internal portion of the sidewalls was noted at the rake station for any condition investigated.

Inasmuch as an increase in yaw angle causes a decrease in inlet projected frontal area, the entering mass flow was also expected to decrease. However, the mass-flow ratios, corresponding to the maximum pressure recoveries, for angles of attack of 0° and 5°, increase with variation in yaw angle from 0° to 2.5° (fig. 11) and fall off slightly upon increasing the yaw angle from 2.5° to 5.0°. Repetition of tests confirmed these results. The increase in m_m/m_o indicated from $\psi = 0^{\circ}$ to $\psi = 2.5^{\circ}$ may have been a result of the high pressure on one side of the fuselage when the model is yawed. In addition, the crossflow effects may have resulted in some change of the flow conditions at the junction of the inlet sidewalls and fuselage; however, because of the location of the sidewall-fuselage juncture, it was impossible to observe the flow with a schlieren system.

SUMMARY OF RESULTS

An investigation has been made to determine the effect of yaw on the mass-flow and pressure-recovery characteristics of a rectangular supersonic scoop inlet designed to have low external drag and high pressure recovery at a Mach number of 2.7 and angle of attack and yaw of 0°. The inlet was tested at Mach number 2.71 and angles of yaw of 0°, 2.5°, and 5° for angles of attack of 0° and 5°. A simulated fuselage of circular cross section having a diameter (2 inches) equal to the inlet width was utilized in this investigation. The following results were obtained:

(1) The general effect of increasing angle of yaw was to decrease the maximum average total-pressure recovery. For yaw angle of 0°, 2.5°, and 5°, the values of maximum average total-pressure recovery were 0.76, 0.71, and 0.68, respectively, for an angle of attack of 0° and 0.73, 0.72, and 0.69, respectively, for an angle of attack of 5°.

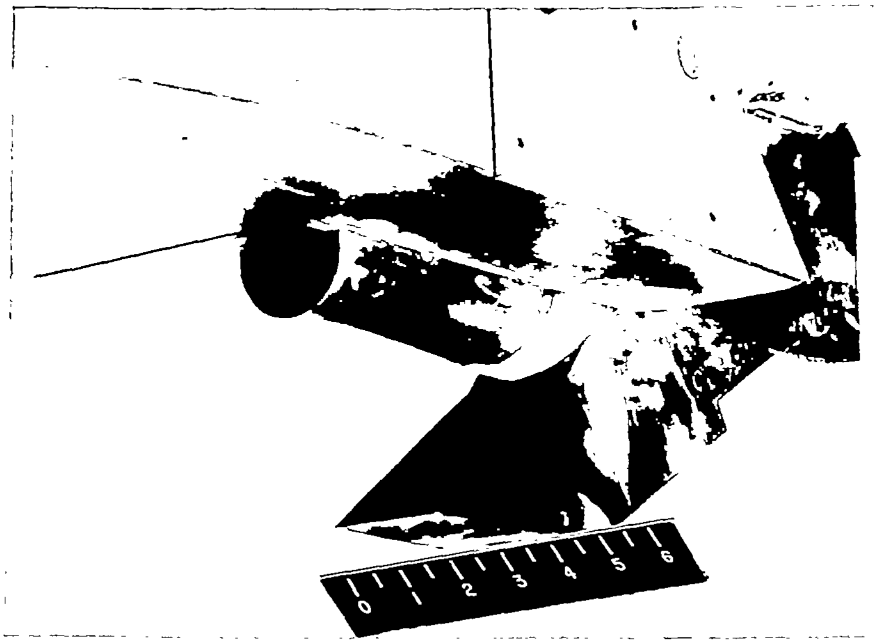
(2) The mass-flow ratios of the inlet corresponding to the maximum pressure-recovery conditions, for the angles of attack tested (0° and 5°), increased upon changing the angle of yaw from 0° to 2.5° and decreased slightly when the angle of yaw varied from 2.5° to 5°. Values of mass-flow ratios (m_m/m_o) corresponding to the maximum average total-pressure-recovery values given above for angles of yaw of 0°, 2.5°, and 5° were 0.85, 0.97, and 0.96, respectively, for an angle of attack of 0° and 0.84, 0.93, and 0.91, respectively, for an angle of attack of 5°.

(3) For each of the three angles of yaw tested, the total pressure distribution at the rake station, for maximum average total-pressure recovery, was generally uniform at angles of attack of 0° and 5°. Although the static-pressure distributions were fairly uniform at angles of attack of 0° and 5° for each angle of yaw, the small variations in total pressure caused large variations in local Mach number at the rake station.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., July 1, 1954.

REFERENCE

1. Comenzo, Raymond J., and Mackley, Ernest A.: Preliminary Investigation of a Rectangular Supersonic Scoop Inlet With Swept Sides Designed for Low Drag at a Mach Number of 2.7. NACA RM L52J02, 1952.



L-76080

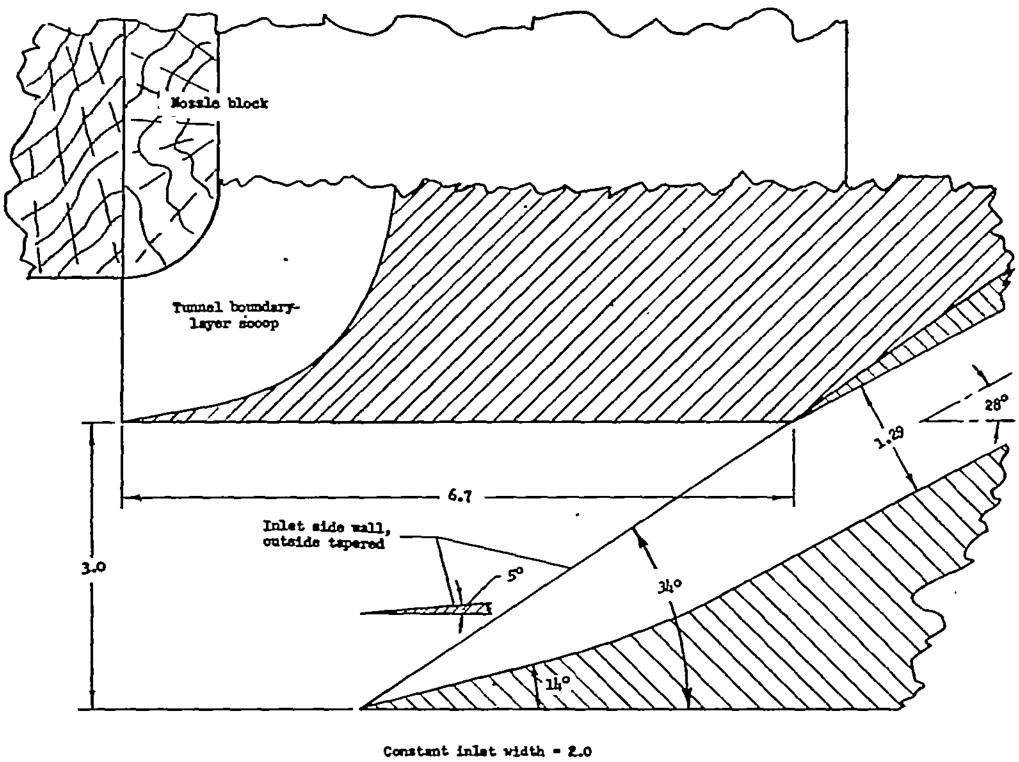


Figure 1.- Details of model with circular fuselage. All dimensions are in inches.

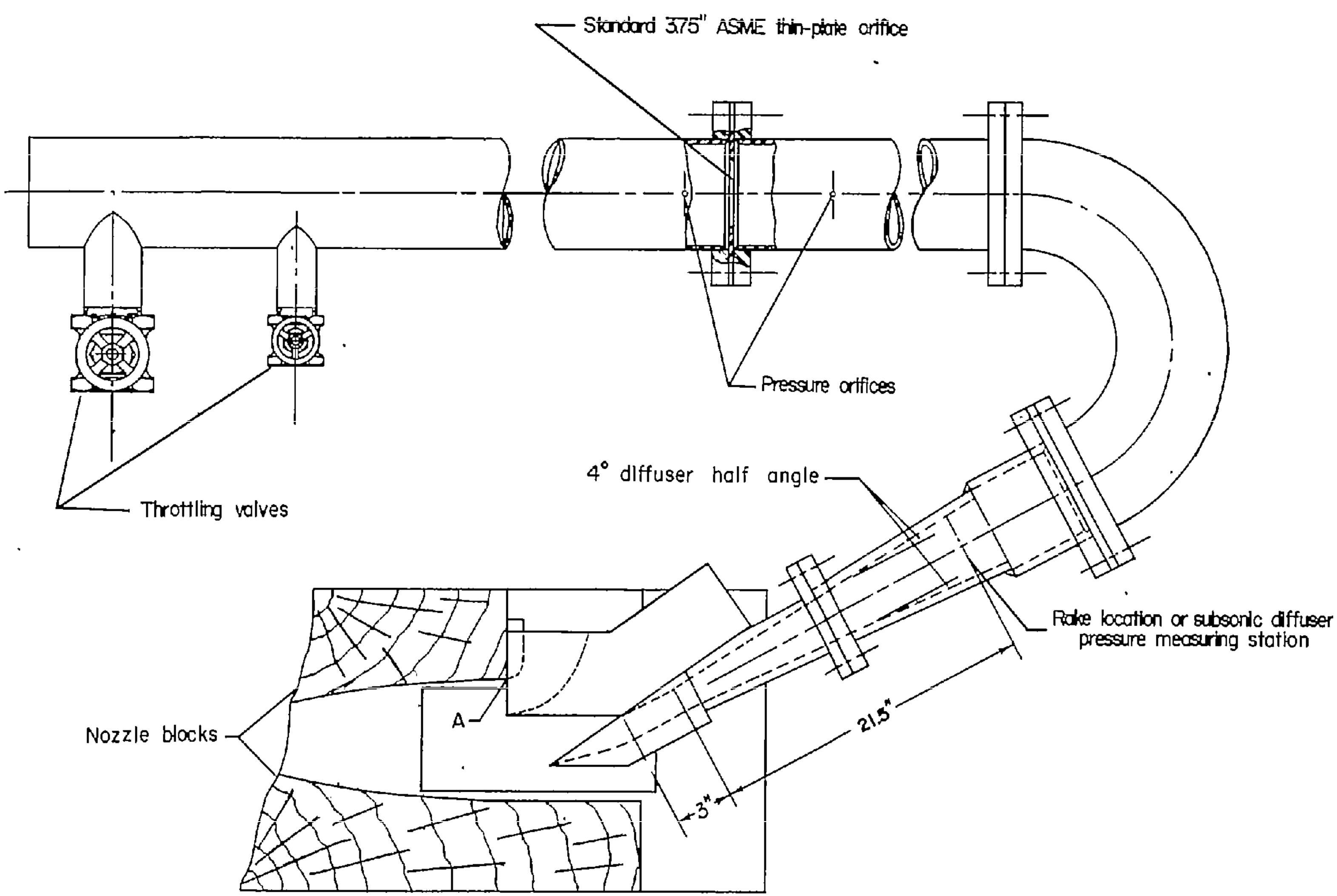


Figure 2.- Schematic drawing of test installation. All dimensions are in inches.

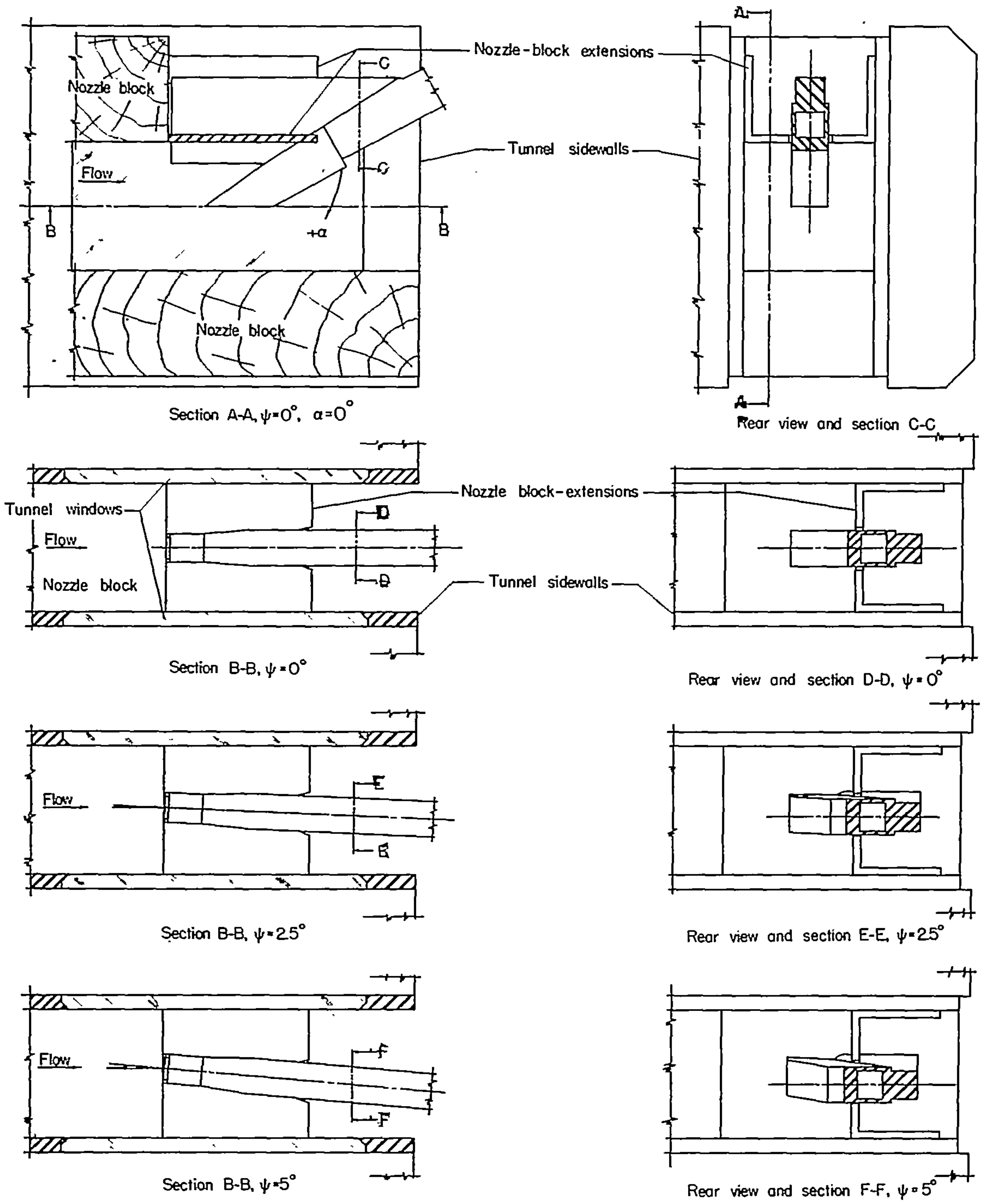


Figure 3.- Schematic drawing of the method of yaw-angle variation.

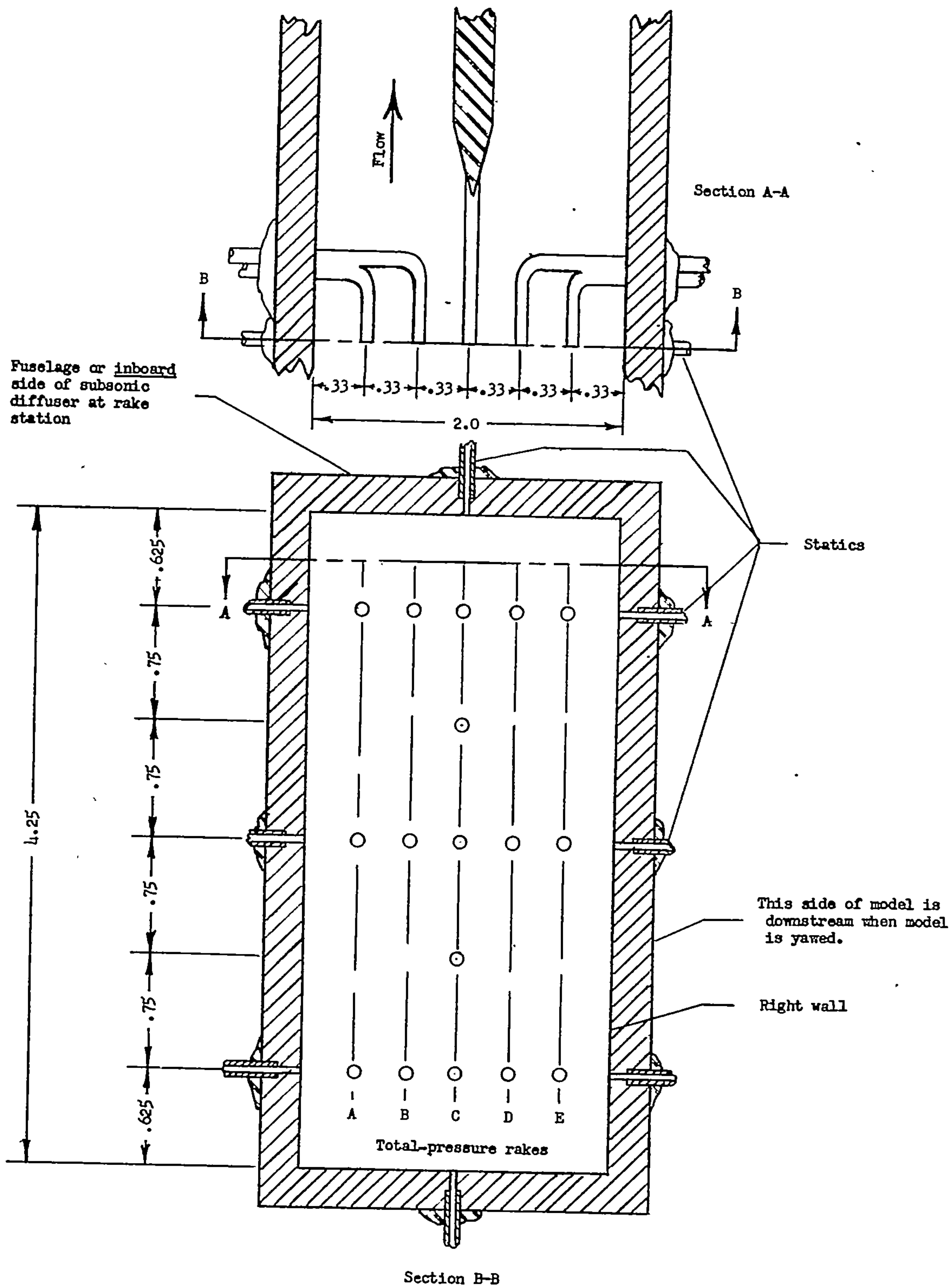


Figure 4.- Rake-tube and static-orifice location in subsonic diffuser. All dimensions are in inches.

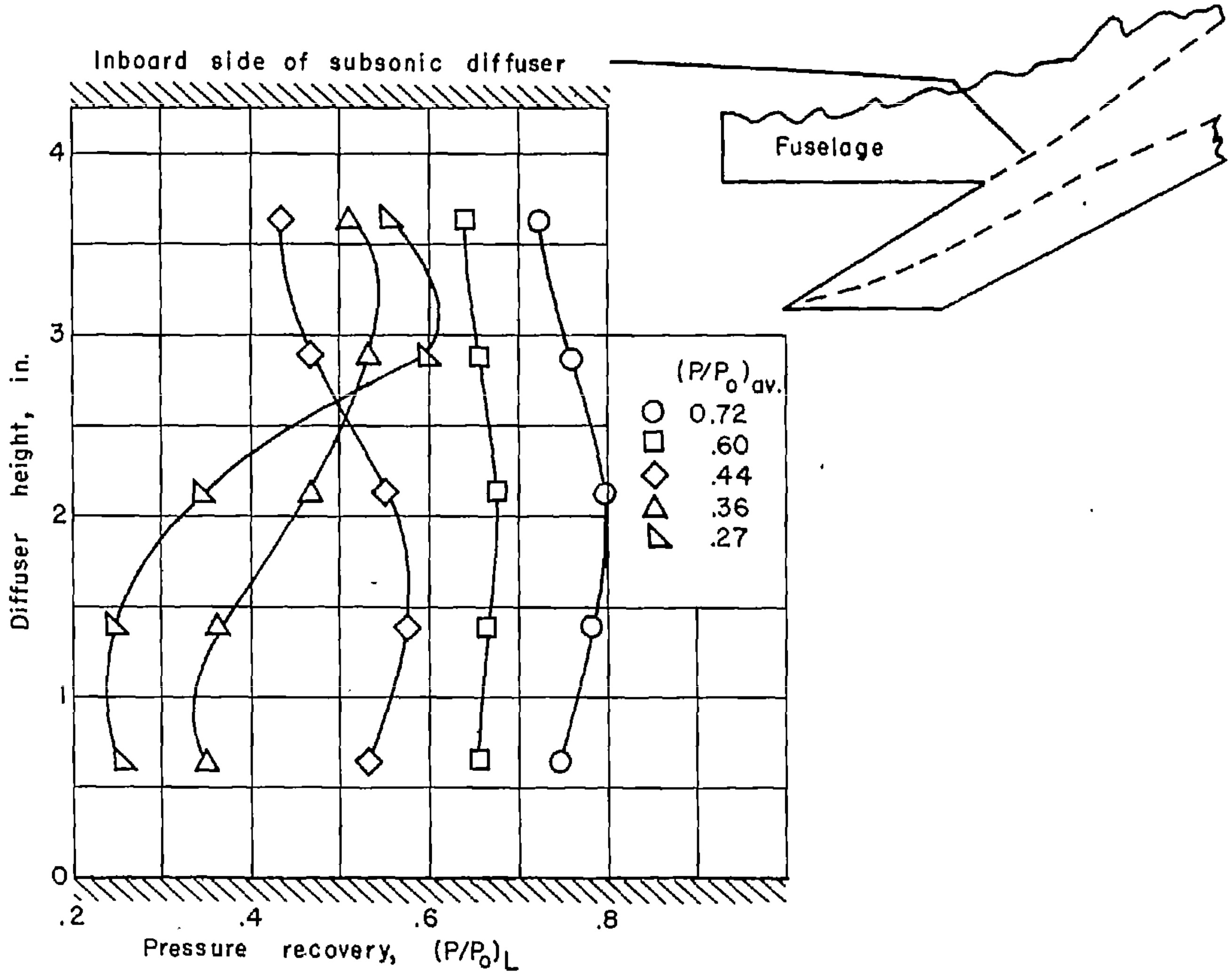
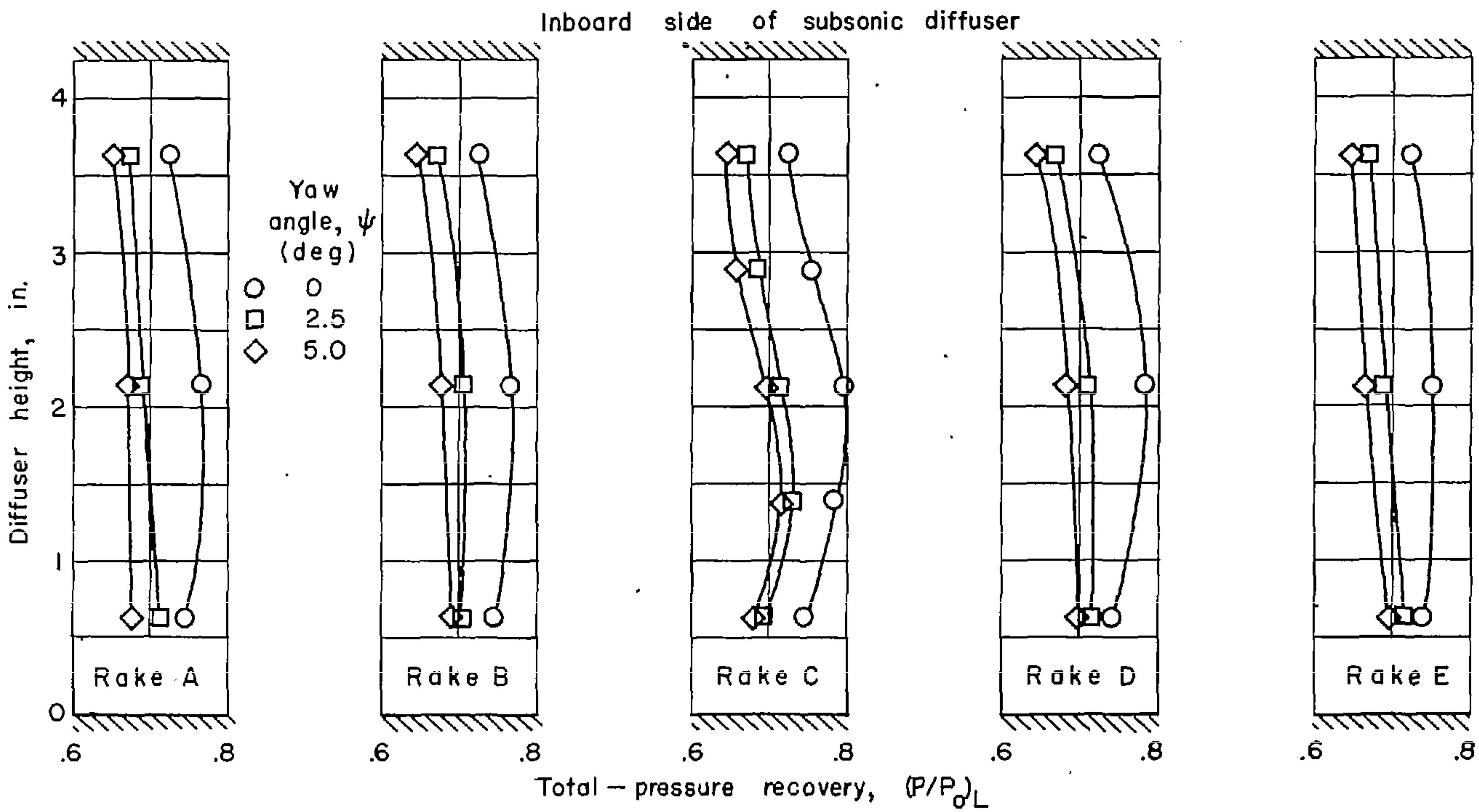
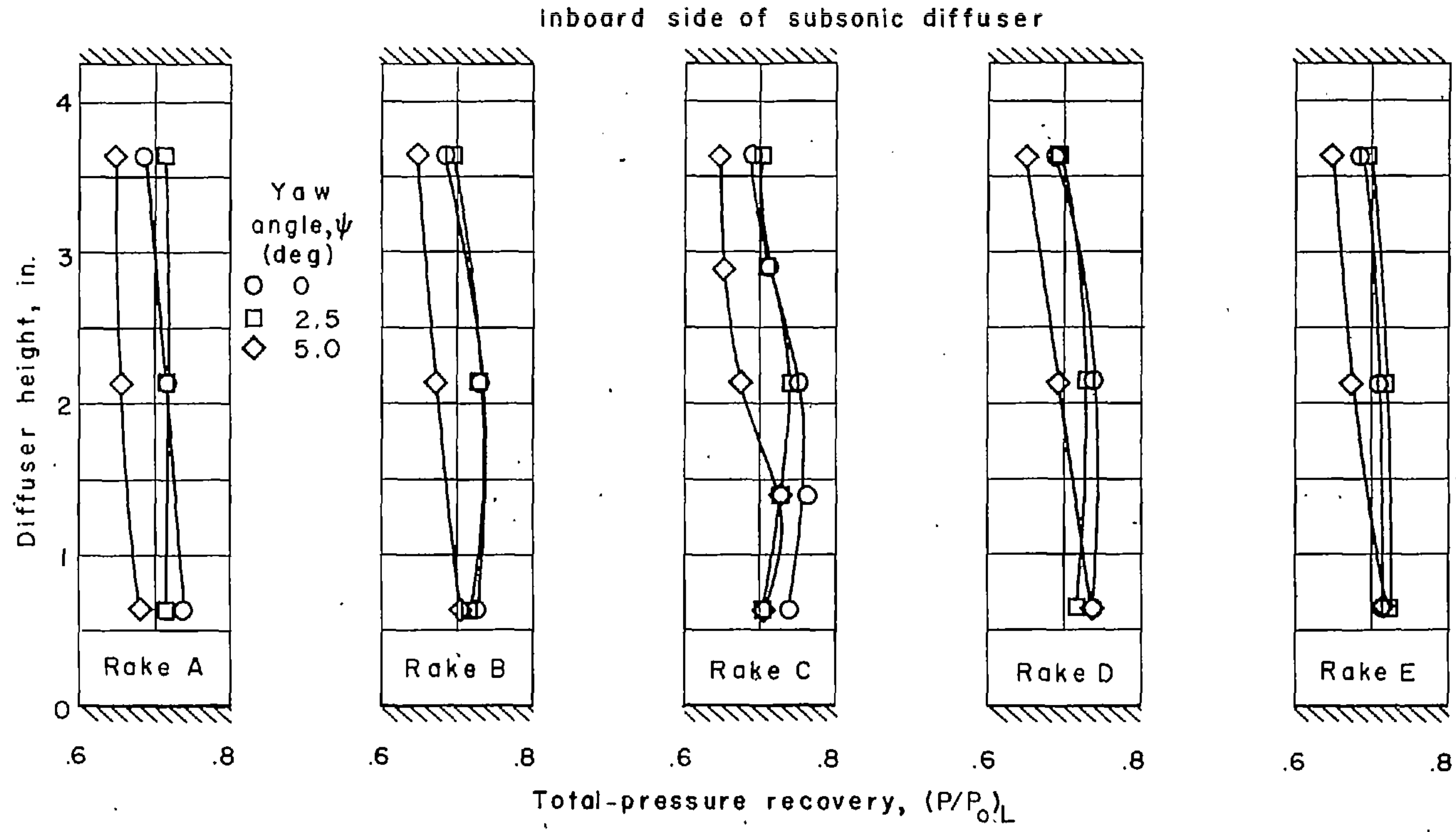


Figure 5.- Effect of back pressure on local total-pressure distribution. Rake C: $\alpha = 0^\circ$; $\psi = 0^\circ$; $M_o = 2.71$.



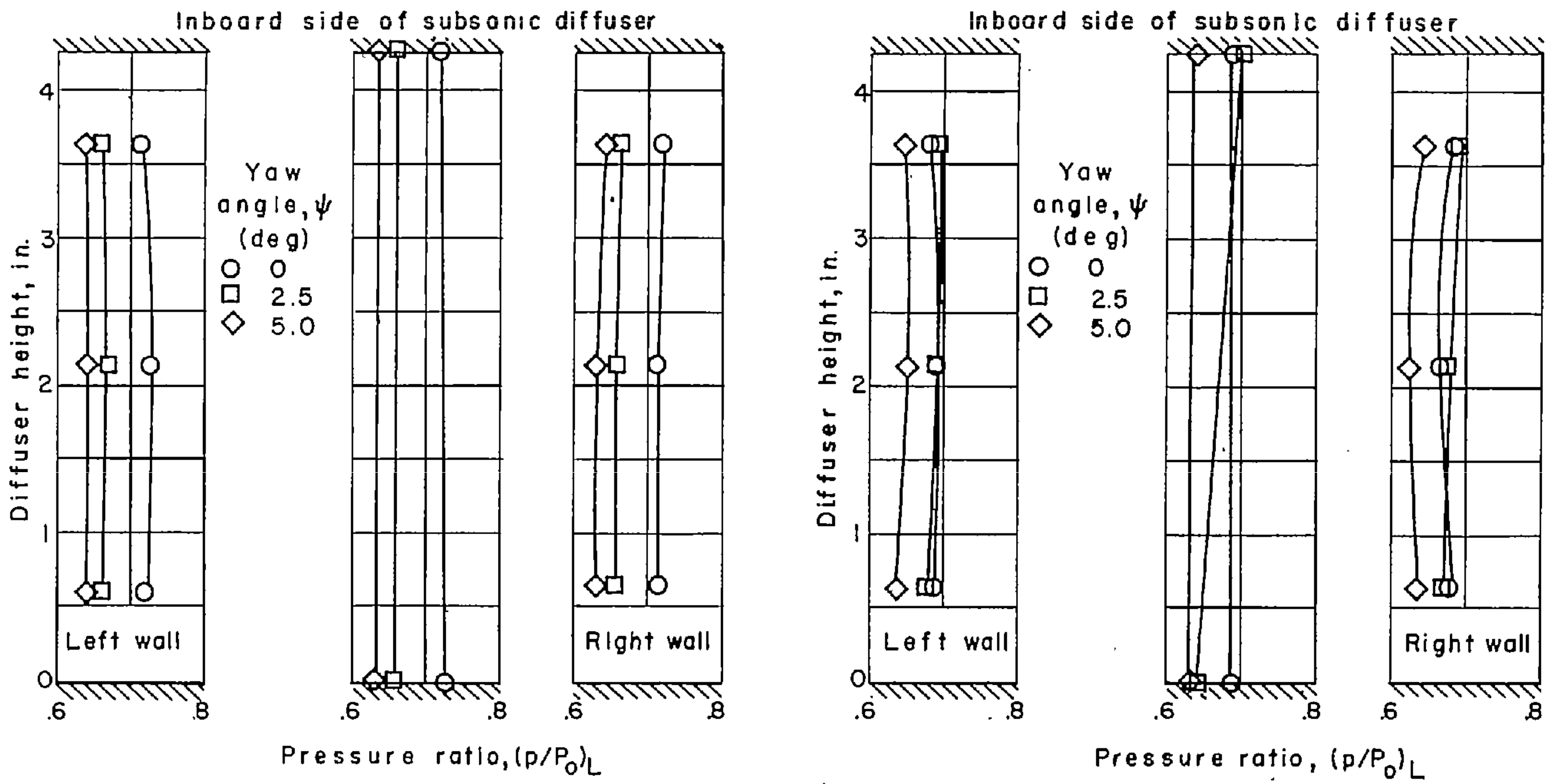
(a) $\alpha = 0^{\circ}$.

Figure 6.- Local total-pressure distribution at rake station in subsonic diffuser at maximum $(P/P_o)_{av}$ for yaw angles of 0°, 2.5°, and 5°. $M_o = 2.71$.



(b) $\alpha = 5^{\circ}$.

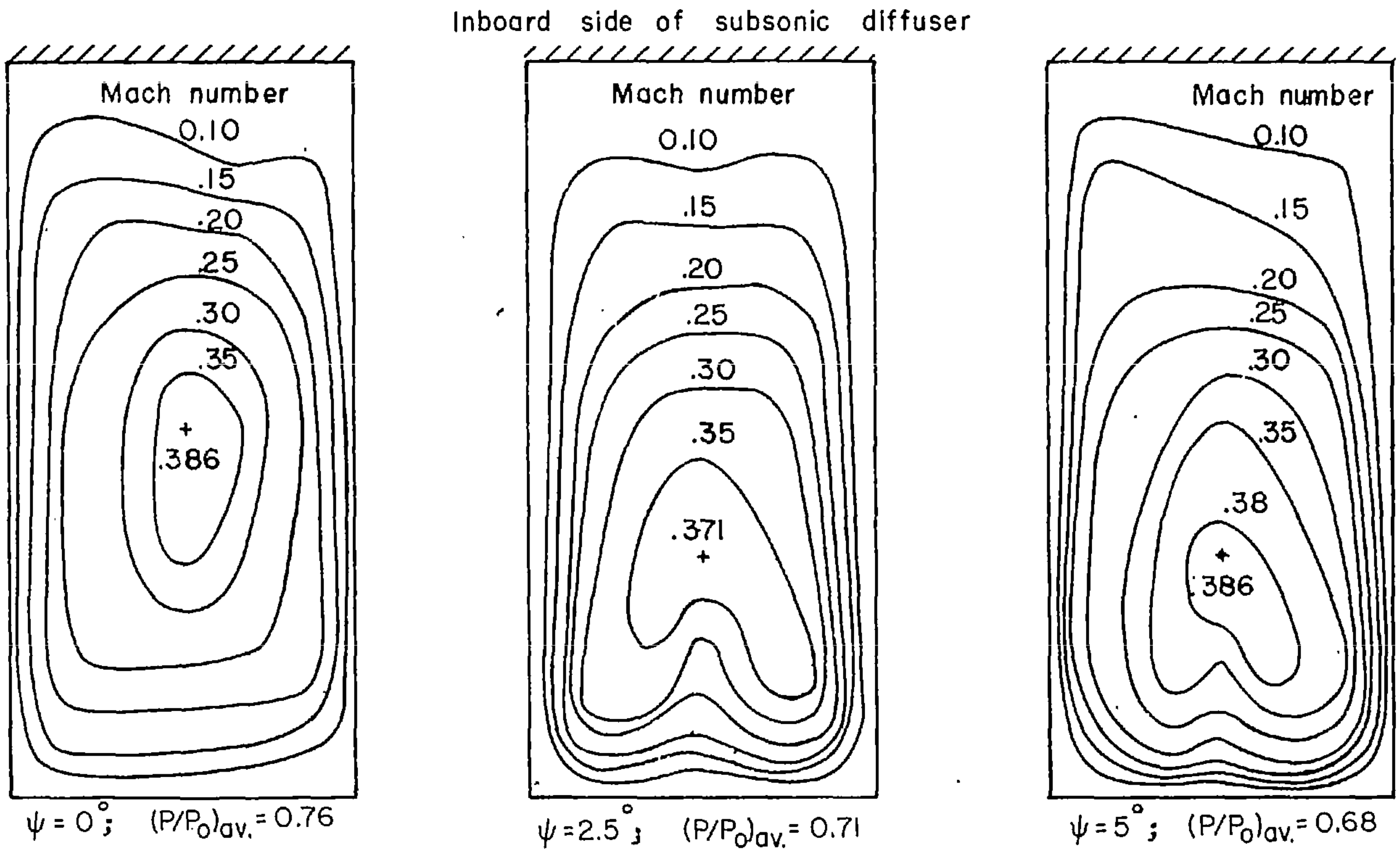
Figure 6.- Concluded.



(a) $\alpha = 0^{\circ}$.

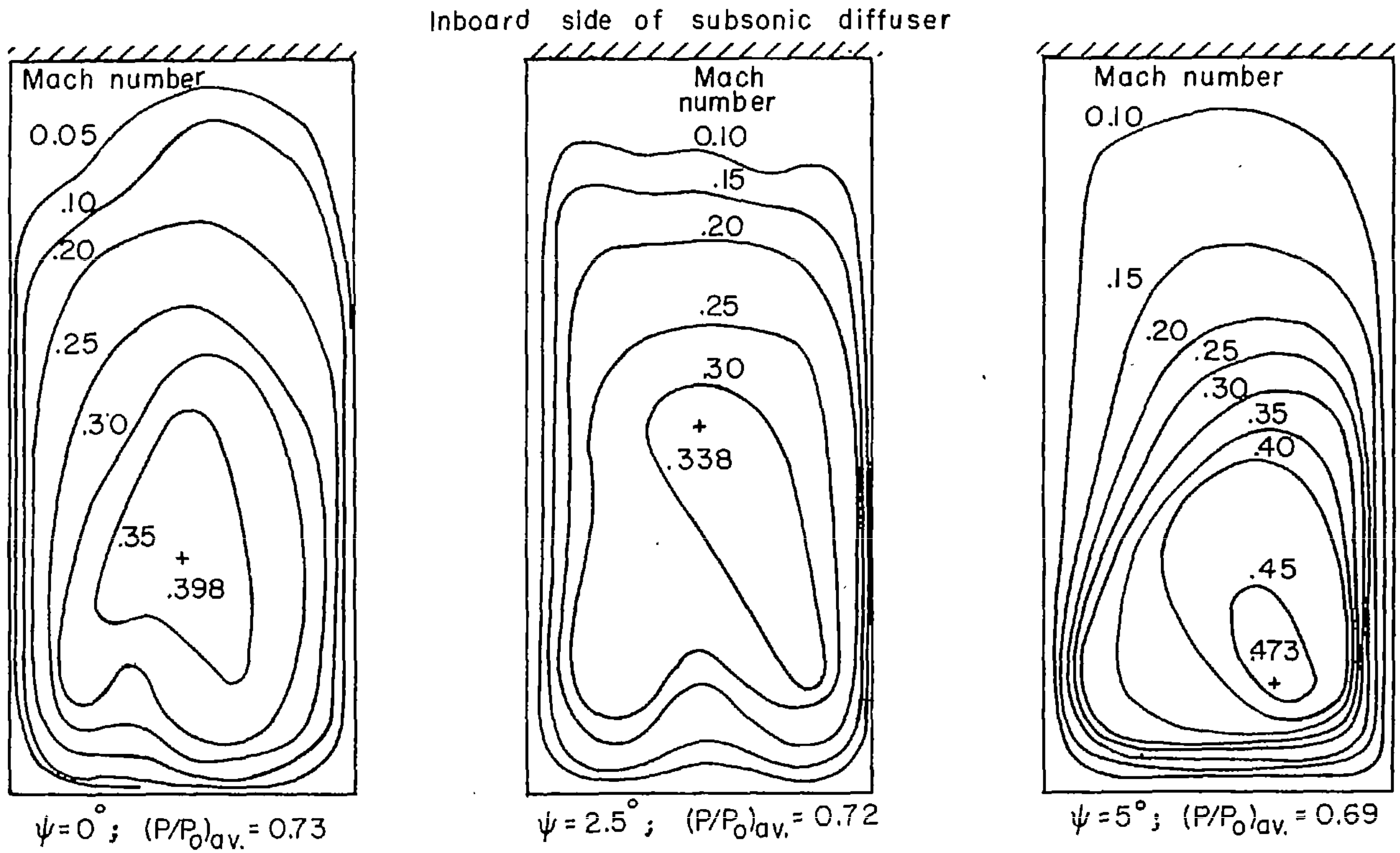
(b) $\alpha = 5^{\circ}$.

Figure 7.- Variation of the ratio of the static pressure to free-stream total pressure with diffuser height at the rake station for maximum $(P/P_o)_{av}$ and for angles of yaw of 0°, 2.5°, and 5°. $M_o = 2.71$.



(a) $\alpha = 0°$.

Figure 8.- Contour plots of the Mach number M_1 at the subsonic diffuser exit at maximum total-pressure recovery for angles of yaw of 0°, 2.5°, and 5°. $M_o = 2.71$.



(b) $\alpha = 5^\circ$.

Figure 8.- Concluded.

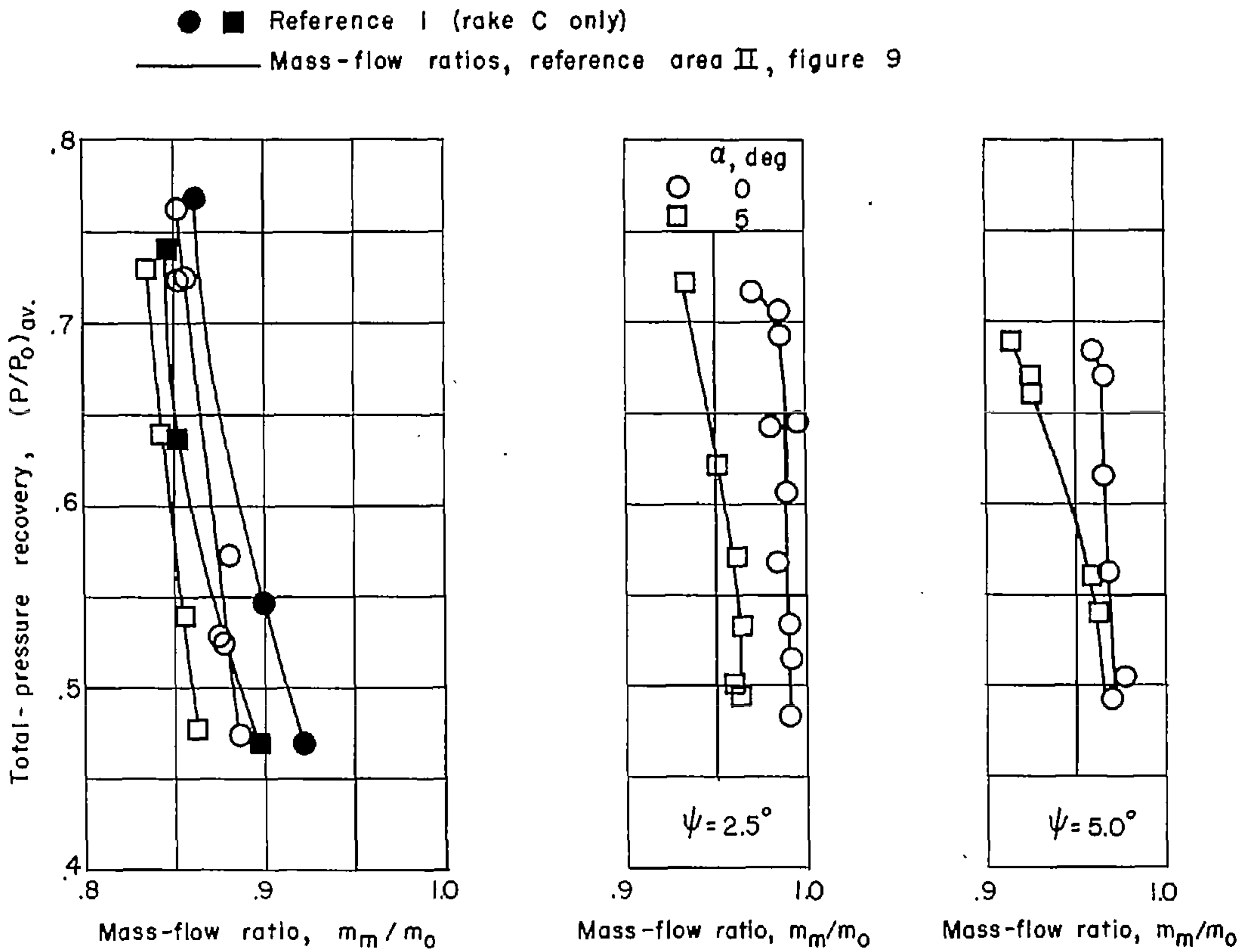
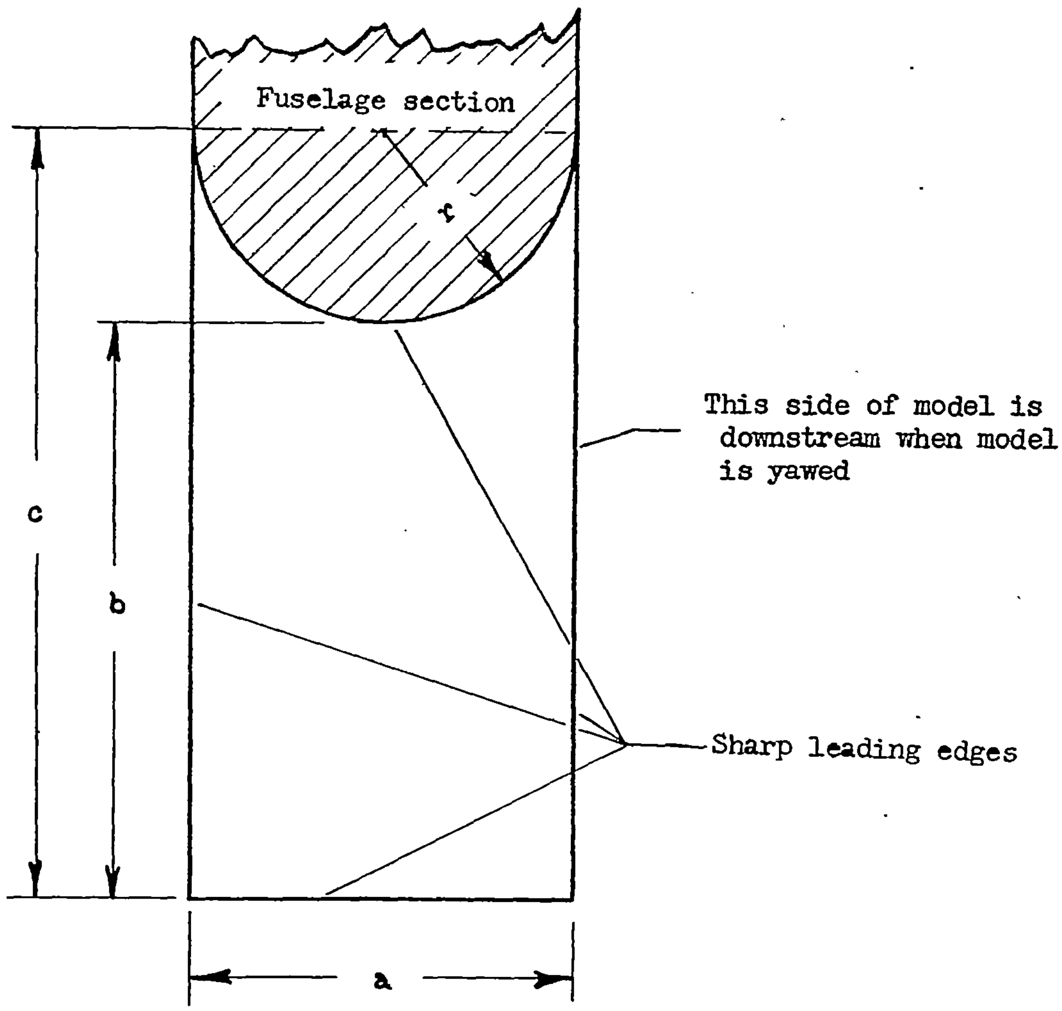


Figure 9.- Variation of total-pressure recovery with mass-flow ratio for various angles of attack and yaw and comparison with data of reference 1. $M_o = 2.71$.



Reference area I = ab

Reference area II = ac - $\frac{1}{2}\pi r^2$

$$\frac{\text{Reference area I}}{\text{Reference area II}} = 0.937$$

Figure 10.- Front view of inlet showing inlet frontal reference areas.

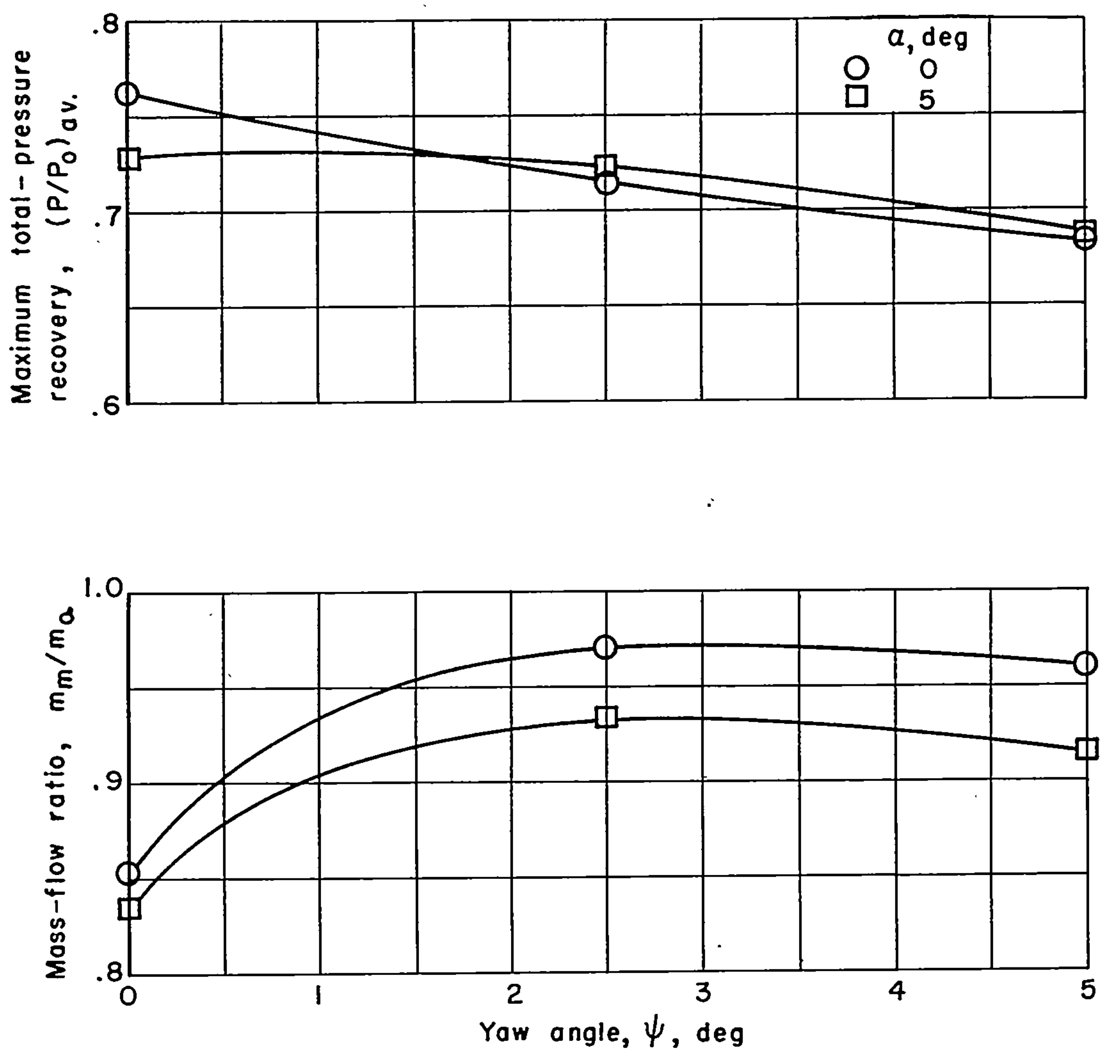


Figure 11.- Effect of yaw angle on the maximum total-pressure recovery and the corresponding mass-flow ratios. $M_o = 2.71$.

NACA-Langley - 9-10-54 - 350