# NACA

# RESEARCH MEMORANDUM

## INVESTIGATION OF THREE TYPES OF SUPERSONIC DIFFUSER OVER A RANGE OF MACH NUMBERS FROM 1.75 TO 2.74

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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# INVESTIGATION OF THREE TYPES OF SUPERSONIC DIFFUSER OVER A RANGE OF MACH NUMBERS FROM 1.75 TO 2.74

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## SUMMARY

An investigation was conducted in the Lewis 4- by 4-inch variable Mach number tunnel to determine off-design internal performance of three types of supersonic diffuser. Results were obtained at Mach numbers ranging from 1.75 to 2.74 with a normal-shock diffuser, two single-shock spike diffusers designed for Mach numbers 1.75 and 2.40, respectively, and three convergent-divergent perforated diffusers designed for Mach numbers 1.75, 2.10, and 2.50, respectively. The variation of total-pressure recovery with relative mass flow was determined at various Mach numbers in the range. A thrust coefficient based on these measurements was utilized to facilitate interpretation of the results.

With no loss in momentum of the flow spilled through perforations, the perforated diffusers indicated the highest over-all thrust coefficients. With moderate to large losses of the momentum of this flow, however, the spike diffusers gave the highest thrust coefficients. The normal-shock diffuser yielded a thrust coefficient up to 10 percent below that obtained with the spike diffusers. The results also indicated that to maintain the maximum net internal thrust, it is generally desirable to operate with the normal shock in the critical or slightly supercritical region, even at the expense of a small loss in total-pressure recovery.

## INTRODUCTION

Although reports covering extensive investigations of the performance of supersonic diffusers at various design Mach numbers are available, the need exists for further experimental determination of the characteristics of fixed-geometry diffusers operating over a Mach number range. Internal performance data were therefore determined for three types of diffuser operating without combustion within the Mach number range from 1.75 to 2.74. The diffusers studied were a normal-shock diffuser, single-shock spike diffusers, and convergent-divergent perforated diffusers.

## SYMBOLS

The following symbols are used in this report:

| | |
|---|---|
| $A$ | area of cross section |
| $C_{F,n}$ | net internal thrust coefficient |
| $L_{s,b}$ | subsonic diffuser length |
| $L_{s,s}$ | supersonic diffuser length |
| $M$ | Mach number |
| $m$ | mass rate of air flow |
| $P$ | total pressure |
| $q$ | dynamic pressure $(\rho v^2/2)$ |
| $Q_a$ | subsonic flow coefficient, ratio of effective choked area to perforated area |
| $v$ | velocity |
| $\rho$ | density |
| $\tau$ | total-temperature ratio across combustion chamber |

Subscripts:

| | |
|---|---|
| 0 | free-stream conditions |
| 1 | diffuser inlet |
| 2 | diffuser outlet |
| d | design |

s perforations

th diffuser throat

$th^*$ throat at M = 1

## APPARATUS

The investigation was conducted in the NACA Lewis 4- by 4-inch variable Mach number tunnel shown in figure 1(a). A complete description of the tunnel is given in reference 1. The Mach number could be continuously varied in the region of the diffuser inlets. Positions of the movable tunnel wall corresponding to various Mach numbers are shown in the multiple exposure in figure 1(b). The stagnation temperature of the air was maintained at approximately 150° F and the dew point at -10° ±10° F. The Reynolds number per foot varied from $3.45 \times 10^6$ to $2.11 \times 10^6$ over the Mach number range.

Six models were investigated: one normal-shock diffuser, two single-shock spike type diffusers, and three convergent-divergent perforated diffusers (fig. 2). A schematic diagram of the model with the normal-shock diffuser is shown in figure 3.

The spike diffusers (fig. 4) were designed for minimum shock losses without internal contraction and with the conical shock intersecting the inlet lip at design Mach numbers of 1.75 and 2.40, respectively. The inner surface of the cowl lip was machined parallel to the flow streamline behind the conical shock. Formation of a detached shock at the lip of the diffuser designed for Mach number 2.40 was precluded by maintaining a sufficiently small angle between the inner and outer surfaces of the lip. The lip angle (20°) of the Mach number 1.75 diffuser was approximately 1° greater than the maximum for shock attachment.

Three convergent-divergent perforated diffusers (hereafter referred to as perforated diffusers) were designed for Mach numbers 1.75, 2.10, and 2.50 in accordance with the procedure indicated in references 2 and 3. The diffuser contours and the theoretical and actual distributions of perforated-to-throat area ratio are shown in figures 5(a) to 5(c). Principal design parameters are given in the following table.

| Design Mach number $M_d$ | $\frac{A_l}{A_{th}}$ | $\frac{A_s}{A_{th}}$ | $(Q_a)_d$ | $\left(\frac{m_s}{m_0}\right)_d$ | $\frac{L_{s,b}}{d_2}$ | $\frac{L_{s,s}}{d_{th}}$ |
|---|---|---|---|---|---|---|
| 1.75 | 1.473 | 0.680 | 0.4 | 0.059 | 2.03 | 2.50 |
| 2.10 | 2.076 | 1.352 | .5 | .116 | 2.02 | 2.63 |
| 2.50 | 3.274 | 2.900 | .5 | .195 | 1.87 | 3.33 |

Restrictions due to tunnel-test-section size necessitated supersonic diffusers of short length, the result being that the angle between the model axis and the perforated wall varied from 0° to 7° for the diffuser designed for Mach number 1.75 to from 0° to 11.5° for the diffuser designed for Mach number 2.50.

The internal contour of the normal-shock diffuser was arbitrarily given a 5° half-angle of divergence. The subsonic sections of the other diffusers were designed with area distributions resulting in monotonic variations of equivalent cone angles from zero at the throat to between 6° and 8° at axial stations where it became necessary to diverge rapidly due to length limitations. The theoretical Mach numbers corresponding to the initial points of rapid divergence were in the range from 0.27 to 0.35.

The total pressure and Mach number in the region of the inlet were determined by a tunnel calibration. A pitot rake was used to measure the total pressure downstream of the diffuser outlet. The limited number of tubes in this rake appeared to be adequate, as the flat pressure profile (including the wall static pressure) obtained across the diffuser outlet of each model at the peak pressure recovery condition indicated that the instrumentation used was sufficiently accurate.

The flow within each model was directed outside the tunnel wall through a calibrated rotameter and a throttling valve and was discharged into the tunnel downstream of the model. All pressures were measured on a differential tetrabromoethane multiple-tube manometer board and were read to the nearest 0.05 inch.

## RESULTS AND DISCUSSION

### Variation of Pressure Recovery with Relative Mass Flow

The variations of pressure recovery with relative mass flow for the diffusers are shown in figures 6 to 8 for various Mach numbers throughout the range. In the case of the normal-shock diffuser (fig. 6) a slight decrease in pressure recovery with increasing relative mass flow would be expected due to the increase in entrance Mach number resulting from decreased subsonic diffusion ahead of the inlet. The fairly severe decrease just below critical flow at the higher Mach numbers, however, was attributed to a combination of increased shock and boundary-layer losses as a result of observed shock oscillation in and out of the inlet. Whether this oscillation was due to the metering system or to a fundamental characteristic of the normal-shock diffuser was not determined.

As indicated in figures 7(a) and 7(b), the peak pressure recovery for the spike diffusers was, in general, also obtained with slightly subcritical flow. Peak recovery was recorded in all cases with the normal shock in a position of incipient oscillation.

With the perforated diffusers, peak recovery was again obtained with slightly subcritical flow (figs. 8(a) to 8(c)) with the shock configuration located upstream of the throat as observed in reference 3. This shock position presumably reflected a decrease in the subsonic diffuser losses. Observation of the rotameter float oscillation indicated that the flow was generally unstable when the curve slope of the presssure recovery as a function of relative mass flow was positive. The dashed portions of the curves at mass-flow ratios below those corresponding to peak recovery indicate a discontinuity in both pressure recovery and relative mass flow. This characteristic becomes less evident at the higher Mach numbers. In the case of the perforated diffusers designed for Mach numbers 2.10 and 2.50, the data presented for Mach number 1.75 corresponds to operation with the normal shock entirely outside the inlet. Where no data are presented for mass flows below peak pressure recovery for the perforated diffuser designed for Mach number 2.50, flow instability precluded measurements.

### Variation of Performance with Mach Number

Experimental and theoretical variations of performance for the three types of diffuser in terms of pressure recovery and relative mass flow are plotted as functions of free-stream Mach number in figures 9 to 11. Only shock losses were considered when calculating the theoretical variations of peak pressure recovery with Mach number.

In order to facilitate interpretation of diffuser performance, a net internal thrust coefficient is presented. The diffusers were accordingly considered integral with a simulated combustion-chamber-outlet-nozzle configuration wherein an arbitrarily constant total-temperature ratio $\tau$ of 4 existed across the combustion chamber and a choked variable outlet was used. The gas constant $R$ and $\tau$ were assumed constant across the engine, and the mass of fuel was neglected. Internal thrust was defined as the integral of the axial components of the pressure (referenced to ambient) and friction forces acting over the internal surface of the engine (including the spike where present). This thrust could then be conveniently calculated as the change in total momentum of the captured air from free stream to exit conditions (reference 3) less the change in total momentum of this air between the free-stream tube and the inlet. The latter component of the thrust, commonly known as additive drag, was calculated with the aid of references 4 and 5. (In general the exit conditions of the air spilled through the perforations are unknown and must be assumed.) A net internal thrust coefficient $C_{F,n}$ was then expressed as thrust divided by $A_0q_0$, where $A_0$ is the free-stream cross-sectional area of the captured flow that passes through the diffuser outlet. Procedures for calculating design and off-design performance as a function of Mach number for the spike and perforated diffusers are outlined in the appendix.

Normal-shock diffuser. - Results for the normal-shock diffuser (fig. 9) are presented for two conditions: (1) operation corresponding to a subcritical relative mass flow of 0.9, which gives nearly the maximum pressure recovery; and (2) operation with the highest pressure recovery obtainable at maximum relative mass flow (critical flow point). Close agreement was obtained between experimental and theoretical variations of pressure recovery with Mach number for the subcritical flow condition. The small decrement in pressure recovery reflects subsonic diffuser losses. The increased pressure loss in going from the subcritical to the critical flow condition has already been discussed.

That the thrust coefficient is more sensitive to variations in relative mass flow than corresponding variations in pressure recovery is most noticeable at Mach number 2.74, where the effect on net internal thrust coefficient of the 10-percent loss in mass flow corresponding to the subcritical flow condition more than offsets the effect of the sizable gain in pressure recovery recorded for that condition. Thus, from the aspect of the operating conditions and net internal thrust coefficient as defined herein, it is generally preferable to operate a diffuser in the critical or slightly supercritical (minimum additive drag) region, even at the expense of a loss in pressure recovery.

Spike-type diffusers. - The performance curves for the spike diffusers (fig. 10) are also plotted for two conditions: (1) operation at peak pressure recovery with the corresponding relative mass flow; and (2) operation at highest pressure recovery at maximum relative mass flow. The peak pressure recoveries are shown to lie considerably below the theoretical shock losses. Other experimenters with generally similar inlets have observed differences between experimental pressure recoveries and theoretical shock losses of the same order of magnitude (see reference 6). Notable exceptions are the results of reference 7 which indicate appreciably higher pressure recoveries in the Mach number range from 2.45 to 3.30.

The majority of the losses in excess of theoretical shock losses must be attributed to subsonic diffuser losses. Although the difference is almost constant with increasing Mach number for the diffuser design for Mach number 1.75, it reflects progressively less efficient subsonic diffusion by becoming an increasing percentage of the available total pressure after shock losses. A similar trend is noted for the diffuser designed for Mach number 2.40 but with a greater rate of divergence between the theoretical and experimental curves.

As with the normal-shock diffuser the highest thrust coefficients were obtained in the critical flow region where, in general, the pressure recovery was lower than the peak value. The considerable amount of supersonic spillage with the diffuser designed for Mach number 2.40 at 1.75 results in a sizeable decrement in performance as evidenced in the plot of thrust coefficient.

Perforated diffusers. - Performance curves for the perforated diffusers are shown in figures 11(a) to 11(c). At and above the design Mach number the experimental variation of peak pressure recovery with Mach number was found to be displaced from 0.12 to 0.23 below theoretical predictions. Contributing factors to these pressure losses may have included the following: the high rates of angle convergence of the supersonic diffuser sections (compared with those of diffusers of reference 3) may have given rise to internal compression shocks sufficient to cause appreciable total-pressure losses (reference 8). Under contraction of the supersonic flow arising from over-perforation probably caused the strong shock to occur in each diffuser at higher than the design throat Mach number.

The excessive mass flow (when compared with theory) spilled through the perforations at and above the design Mach number of each diffuser was attributed to the high convergence angle of the diffuser, because in each case it permitted expansion of the flow along the external surface of the perforated region to higher than free-stream Mach number. The static pressure outside the perforations was therefore lower than ambient, which resulted in a static-pressure differential across the perforations greater than that calculated according to theory. More than the required mass flow was therefore bled off.

The degree to which the perforated diffusers designed for Mach numbers 2.10 and 2.50 were overperforated (more than required for neutral equilibrium) is also indicated by the variations of peak pressure recovery with Mach number below design Mach number.

At Mach numbers as low as 1.92 and 1.94 with the models designed for Mach numbers 2.10 and 2.50, respectively, it was possible to permit entry of the strong shock to some position downstream of the inlet. This permissable shock entry explains the absence of the sharp discontinuities in pressure recovery and relative mass flow predicted by theory at just below the design Mach numbers. It is thus of interest to note that overperforation, although lowering the performance above the design Mach number, has the favorable effect of eliminating a sharp discontinuity and of increasing the pressure recovery and relative mass flow at Mach numbers below design values.

In determining the operating condition for maximum net internal thrust at any Mach number with a perforated diffuser, the momentum recovery of flow spilled through perforations is of great importance. If peak pressure recovery occurs at a mass flow lower than critical mass flow and if all the free-stream momentum of the spilled air is regained, peak recovery represents the optimum condition. Conversely, if all the momentum of spilled air is lost, the highest net internal thrust coefficient will probably be recorded at the point of critical flow. When the momentum recovery is less than 100 percent, the optimum point is a function of the magnitude of this recovery and falls between peak recovery and the critical flow point. Inasmuch as no reliable method of determining momentum recovery is known, maximum and minimum values of net internal thrust coefficient are presented for each perforated diffuser. Although maximized values of thrust coefficient are independent of relative mass flow, the minimized values strongly reflect the variation in flow spillage. It is thus noted from the plots that the maximized experimental thrust coefficient values are in general agreement with theory, falling below theory at above-design Mach numbers and above theory over most of the below-design Mach number ranges, as would be expected from consideration of the effects of overperforation on the pressure recovery curve. The minimized values represent such poor thrust coefficients as to be ruled impractical.

In determining the design Mach number for a perforated diffuser to be operated over a range of Mach numbers, consideration must be given to the degree of overperforation and to the momentum recovery of the air spilled through the perforations. For example, with no overperforation, designing for the minimum Mach number of the range would give the highest average internal thrust coefficient, but when overperforation exists the best design point will be a function of the momentum recovery of the air bled through the perforations.

Relative performance. - In terms of net internal thrust coefficient, figure 12 reveals that the spike diffuser designed for Mach number 2.40 was most efficient between Mach numbers of 1.75 and approximately 2.15, whereas the spike diffuser designed for Mach number 2.40 gave the highest thrust coefficient values over the remainder of the range (excluding the perforated diffusers). The differences between maximized and minimized thrust coefficient values for the perforated diffusers were of such magnitude as to preclude intelligent comparison between these diffusers and the other types investigated. It should be noted, however, that the maximized thrust coefficients were generally higher than those obtained with the normal-shock and the spike diffusers.

## SUMMARY OF RESULTS

From an investigation conducted without combustion with a normal-shock diffuser, two single-shock spike diffusers designed for Mach numbers 1.75 and 2.40, respectively, and three convergent-divergent perforated diffusers designed for Mach numbers 1.75, 2.10, and 2.50, respectively, within the Mach number range of 1.75 to 2.74, the following observations were made:

1. In general the trends in the performances of the normal-shock and the spike diffusers were in fair agreement with theory. The decrement from shock theory in pressure recovery for the spike diffuser designed for Mach number 2.40 tended to increase with Mach number.

2. In order to maintain the maximum net internal thrust, it is desirable to operate with the normal shock in the critical or slightly supercritical (minimum additive drag) region, even at the expense of a loss in total pressure.

3. If the flow spilled through perforations incurred no momentum losses, the perforated diffusers indicated the highest net internal thrust coefficients. However, with moderate to large losses in the

momentum of this flow, spike diffusers should give a higher net internal thrust coefficient.

4. Values of the net internal thrust coefficient were approximately 10 percent less for the normal-shock diffuser than for the other types of diffuser. 2068

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## APPENDIX

## THEORETICAL PERFORMANCE CALCULATIONS

Single-shock spike diffuser. - The optimum operating condition at any Mach number was assumed to exist when the normal shock intersected the inlet lip, inasmuch as the single-shock spike-type diffuser theoretically performs with the least shock loss and minimum spillage at this condition. In order to determine shock losses at and below the design speed, the Mach number ahead of the normal shock was taken as the unweighted average of the Mach numbers behind the ray intersecting the spike tip and the inlet lip, and along the cone surface. Above the design speed, shock losses were calculated as the weighted average of the losses across the normal shock and the losses across the combination of the oblique and normal shocks. The mass flow spilled at below-design Mach numbers was determined with the aid of reference 5.

Convergent-divergent perforated diffuser. - The theoretical performance of perforated diffusers operating at flight Mach numbers above the design value may be calculated by means of the stepwise integration procedure indicated in reference 3. If, however, design charts of local-to-throat area ratio $A/A_{th}{}^*$ and perforated-to-throat area ratio $A_s/A_{th}{}^*$ plotted as functions of local internal Mach number have been prepared at various free-stream Mach numbers, the following alternate approximate method is convenient.

Consider the diffuser designed for Mach number 1.75 when operating at a Mach number of 2.20. The procedure involves using the aforementioned design charts (figs. 13(a) and 13(b)) to find an "equivalent" diffuser at Mach number 2.20 which will have the same total perforated area as the given diffuser upstream of a cross-sectional area equal to the throat area of the given diffuser. Assuming that these perforations result in the same mass-flow spillage that would be obtained through the perforations of the Mach number 1.75 diffuser operating at Mach number 2.20, the throat Mach number of the subject diffuser may be taken as equal to the local Mach number in the "equivalent" diffuser at the cross-sectional area equal to the throat area of the given diffuser. Theoretical shock losses and mass-flow spillage may then be calculated.

A convergent-divergent perforated diffuser designed according to theory for neutral equilibrium operates with the normal shock ahead of the inlet at below-design Mach numbers. In this range, optimum performance is considered to occur when minimum flow is spilled ahead of the inlet; that is, when the flow through the perforations and the throat is choked. This condition may be expressed as

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$$m_0 = m_s + m_{th}$$

where $m_0$ is the mass flow entering the inlet. Through application of one-dimensional-flow and thermodynamic relations and the assumption of a value for the subsonic flow coefficient ($Q_a = 0.5$ was chosen herein in light of the extensive tests of reference 3), it is possible to calculate the flow spilled around the lip and subsequently the net internal thrust coefficient.

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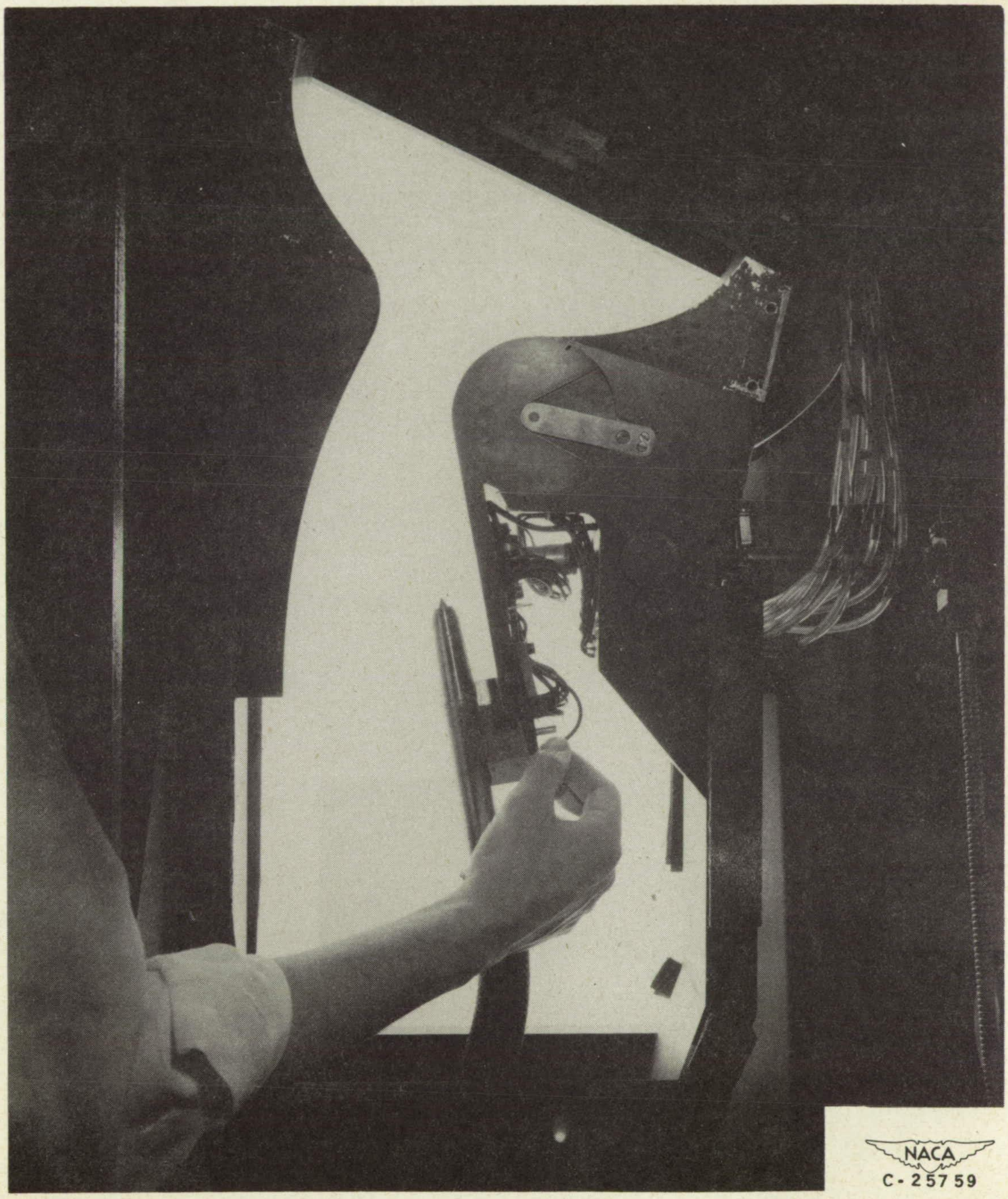

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(a) Photograph of installation.

Figure 1. - Diffuser model in 4- by 4-inch variable Mach number tunnel.

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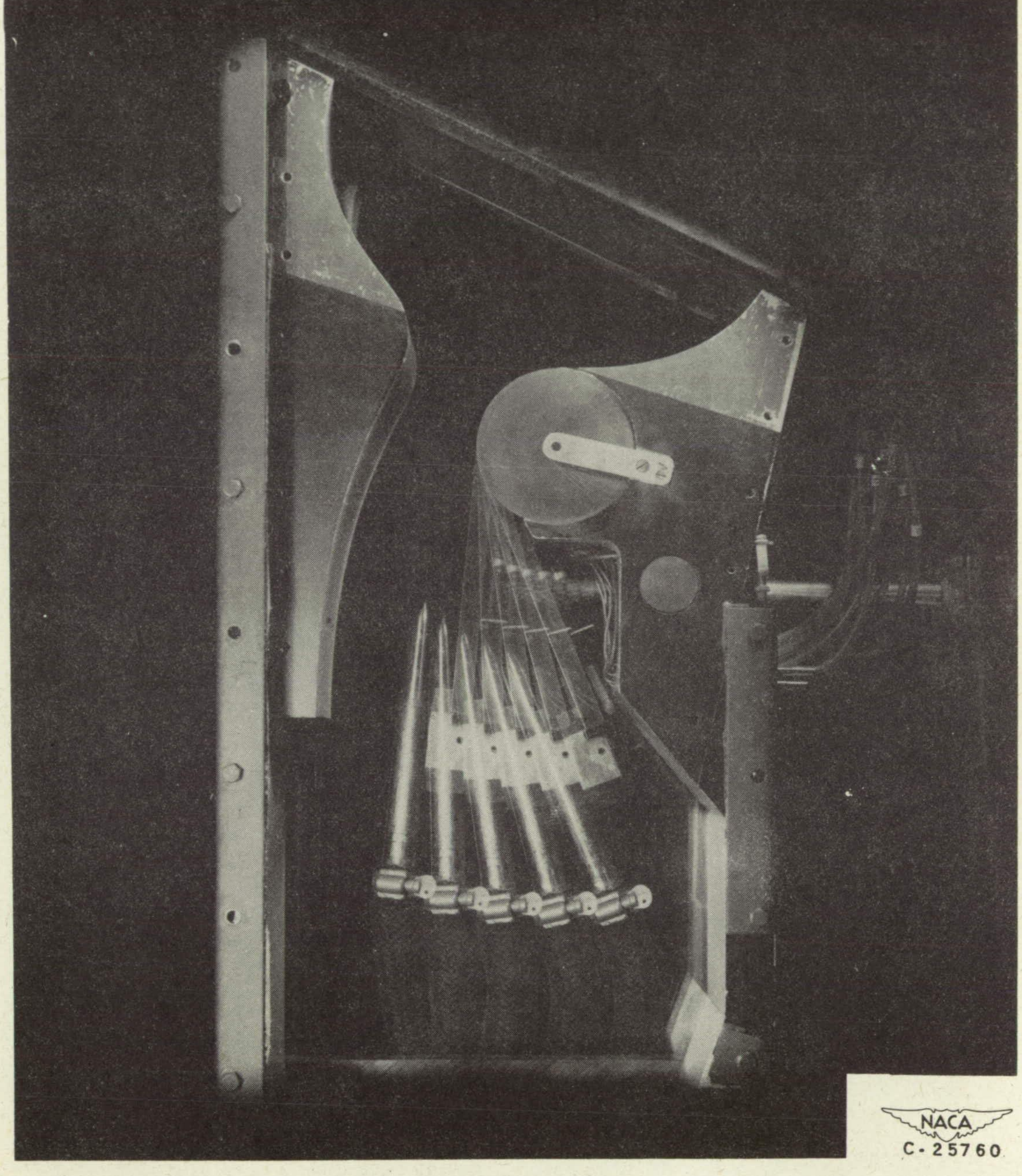


(b) Multiple-exposure photograph indicating Mach number range.

Figure 1. - Concluded. Diffuser model in 4- by 4-inch variable Mach number tunnel.

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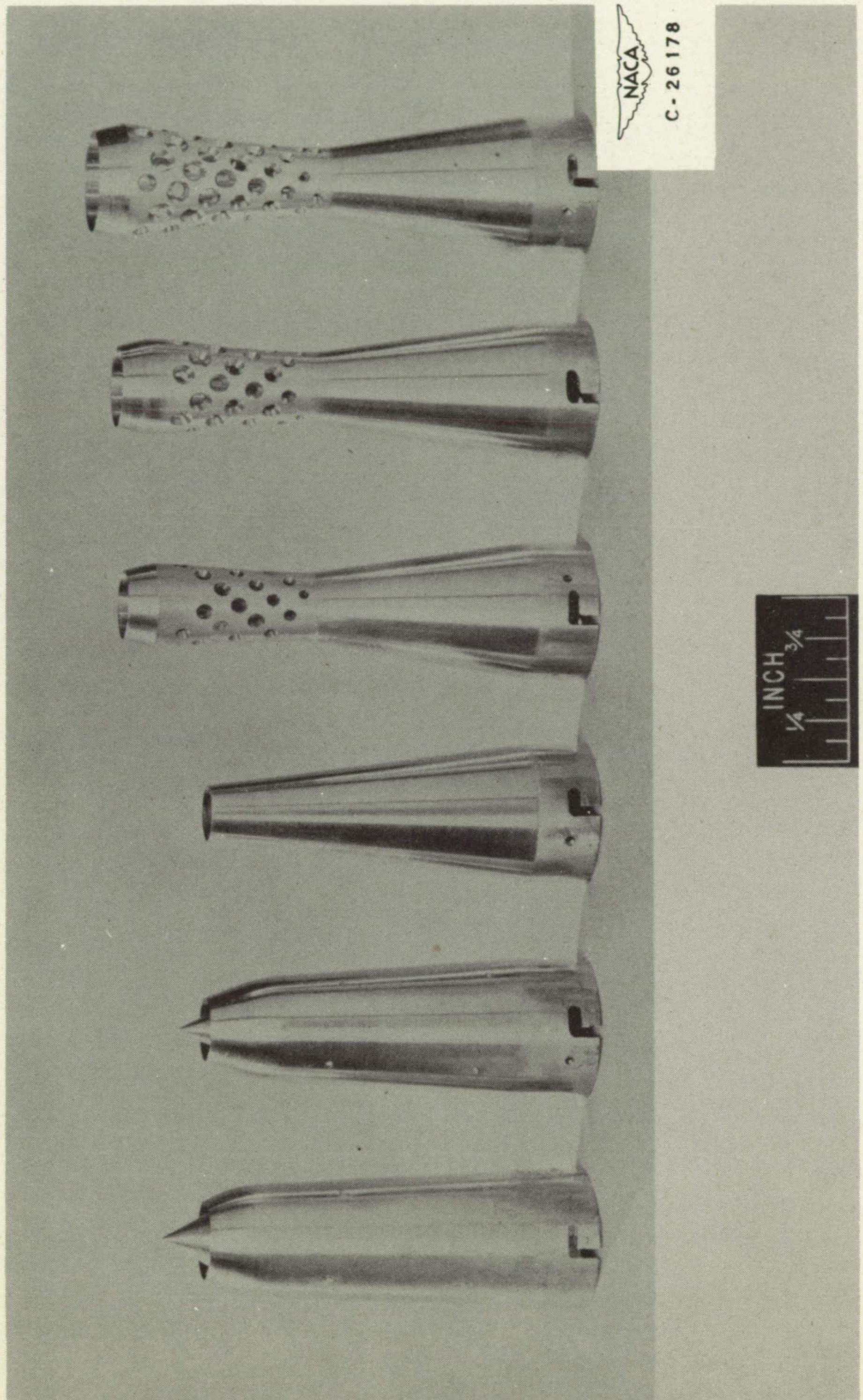


Figure 2. - Six diffuser models; two single-shock spike diffusers designed for Mach numbers 2.40 and 1.75, respectively, one normal-shock diffuser, and three convergent-divergent perforated diffusers designed for Mach numbers 1.75, 2.10, and 2.50 respectively.

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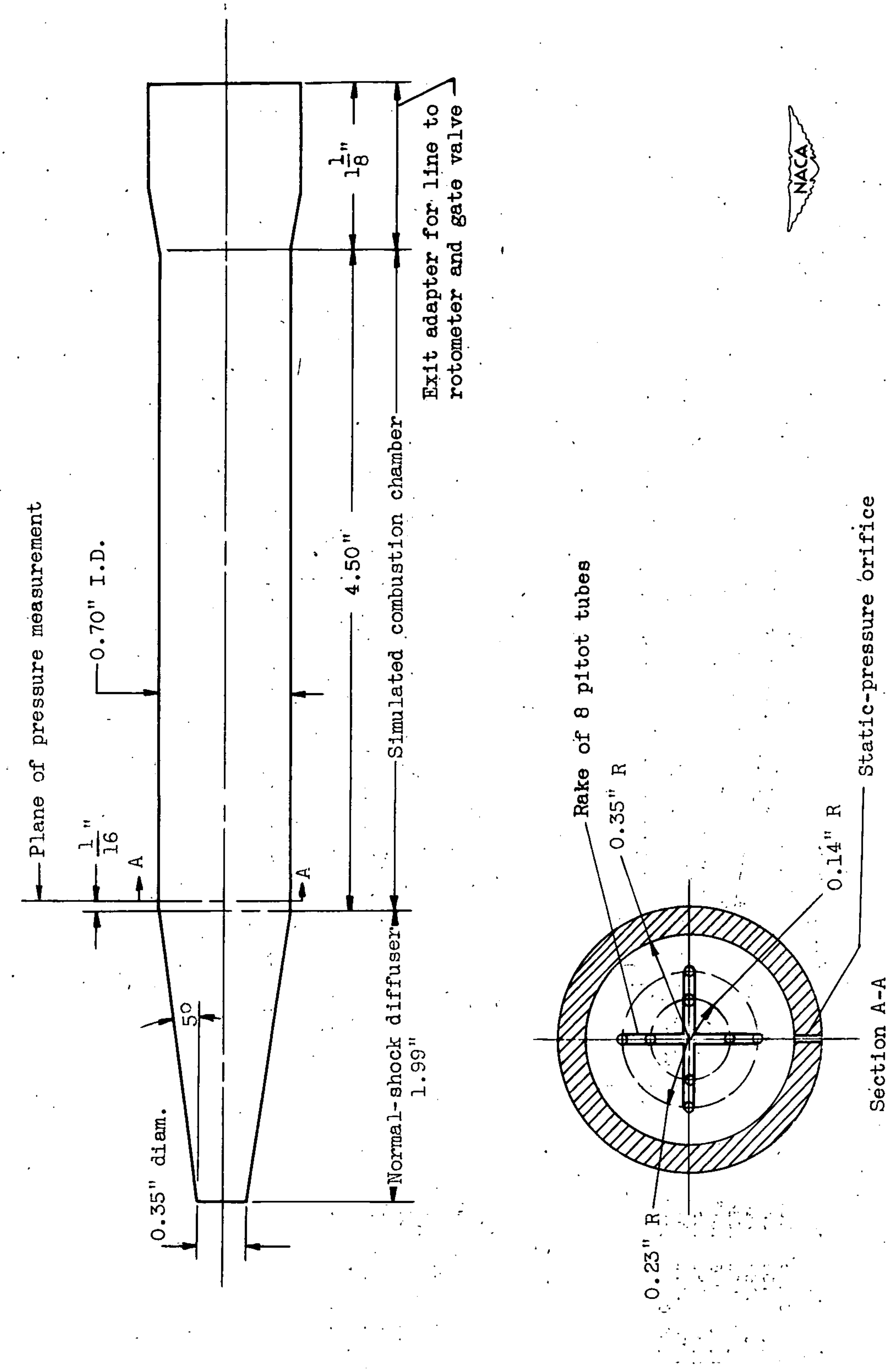
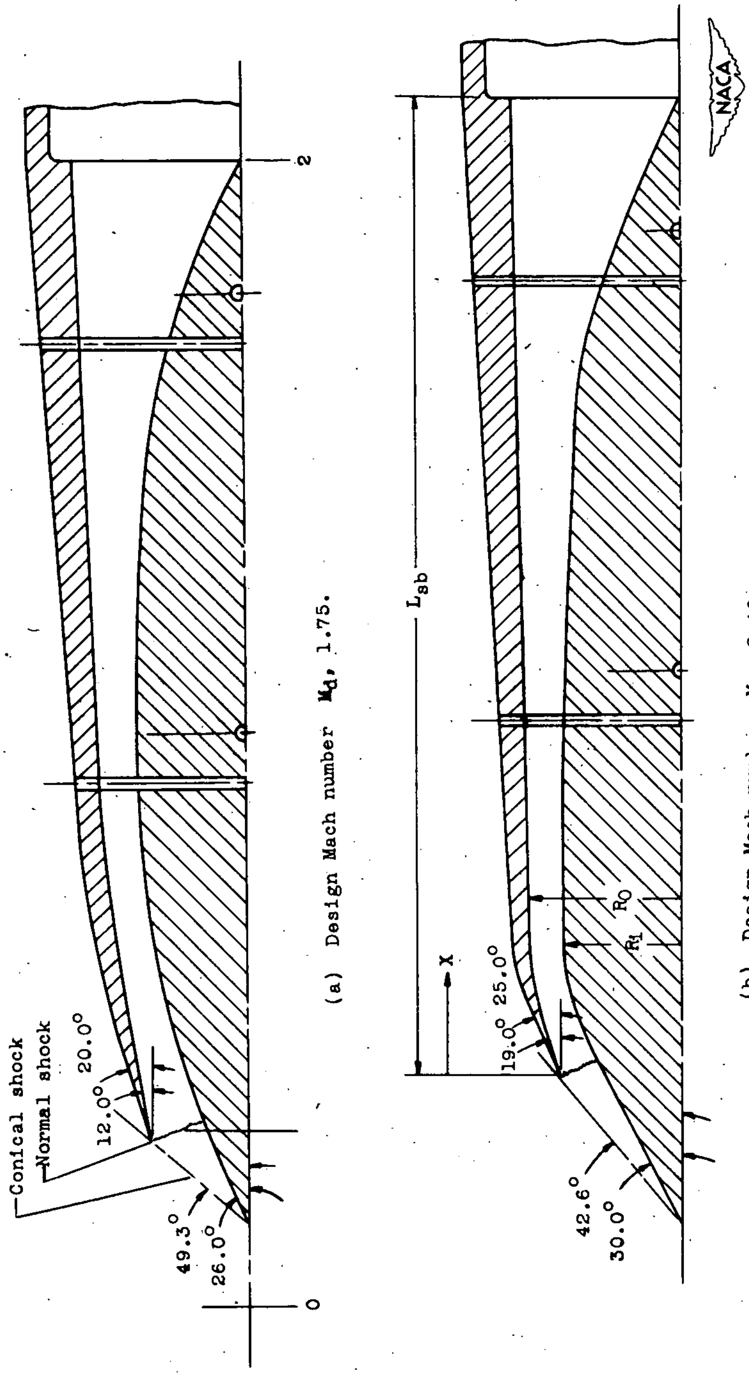



Figure 3. - Schematic diagram of normal-shock diffuser, simulated combustion chamber, and exit adapter.



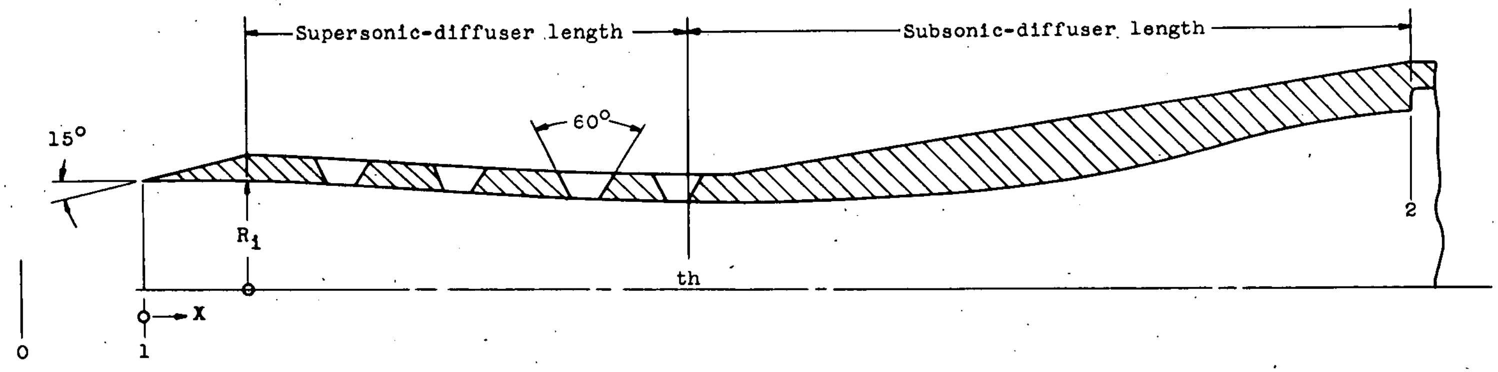

(a) Design Mach number $M_d$, 1.75.

| X | $R_1$ | $R_O$ |
|---|---|---|
| 0 | 0.083 | 0.201 |
| .15 | .136 | .231 |
| .25 | .162 | .248 |
| .50 | .205 | .286 |
| 1.00 | .226 | .316 |
| 1.50 | .188 | .333 |
| 1.75 | .116 | .340 |
| 2.00 | 0 | .350 |

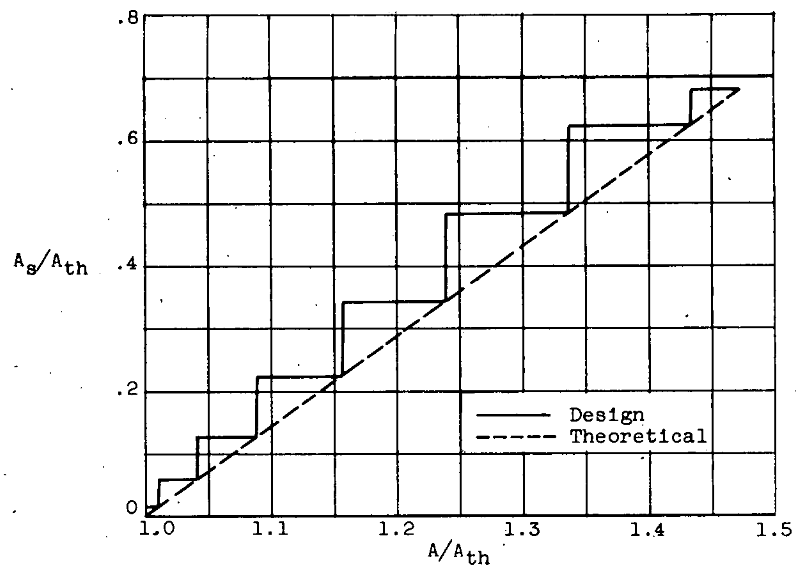
(b) Design Mach number $M_d$, 2.40.

| X | $R_1$ | $R_O$ |
|---|---|---|
| 0 | 0.158 | 0.252 |
| .15 | .230 | .303 |
| .25 | .248 | .317 |
| .50 | .245 | .321 |
| 1.00 | .233 | .330 |
| 1.50 | .198 | .340 |
| 1.75 | .113 | .345 |
| 2.00 | 0 | .350 |

Figure 4. - Cross sections of spike diffusers.



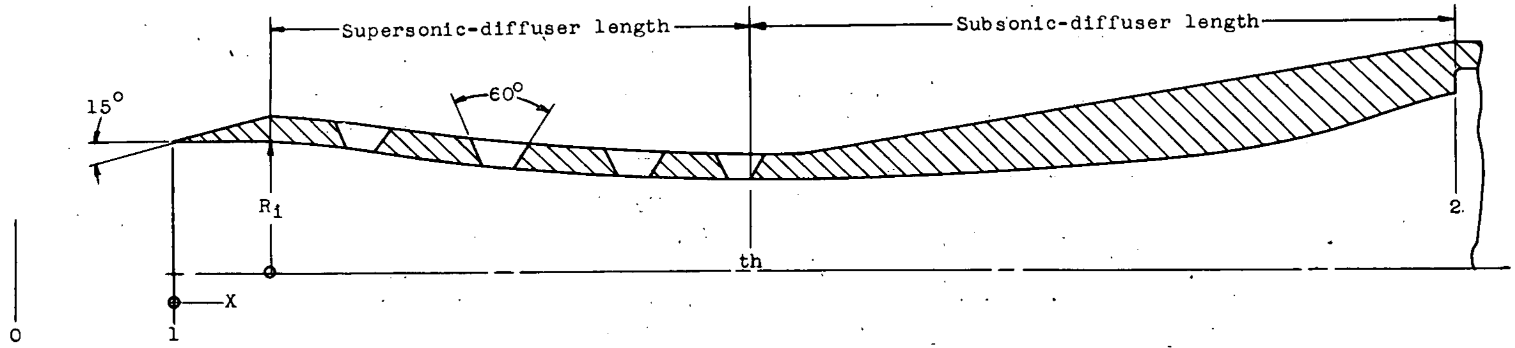

| X | $R_1$ |
|---|---|
| 0.19 | 0.219 |
| .50 | .204 |
| .75 | .189 |
| 1.00 | .181 |
| 1.09 | .180 |
| 1.25 | .181 |
| 1.50 | .184 |
| 1.75 | .207 |
| 2.00 | .245 |
| 2.25 | .315 |
| 2.51 | .350 |



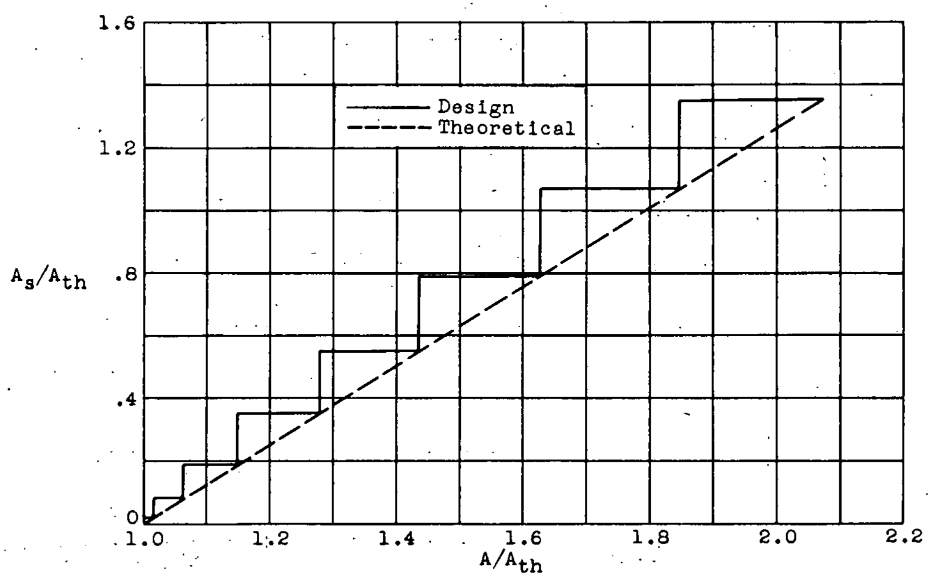

Distribution of perforated-to-throat area ratio

(a) Design Mach number $M_d$, 1.75.

Figure 5. - Cross sections of perforated diffusers.



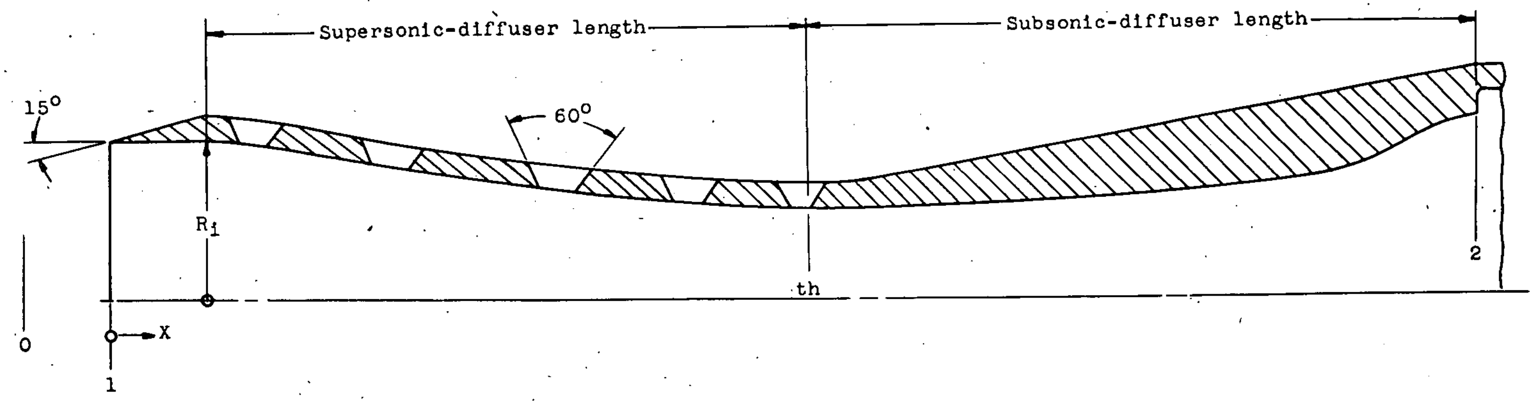

| X | $R_1$ |
|---|---|
| 0.19 | 0.263 |
| .50 | .230 |
| .75 | .203 |
| 1.00 | .184 |
| 1.14 | .182 |
| 1.25 | .192 |
| 1.50 | .192 |
| 1.75 | .209 |
| 2.00 | .228 |
| 2.25 | .256 |
| 2.55 | .350 |



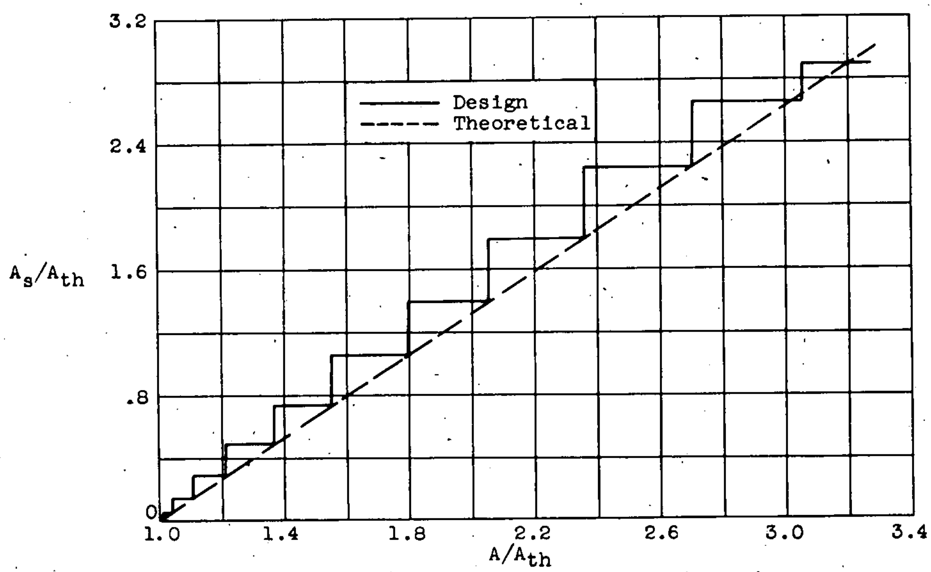

Distribution of perforated-to-throat area ratio

(b) Design Mach number $M_d$, 2.10.

Figure 5. - Cross sections of perforated diffusers.




| X | $R_1$ |
|---|---|
| 0.19 | 0.326 |
| .50 | .276 |
| .75 | .233 |
| 1.00 | .202 |
| 1.25 | .182 |
| 1.39 | .180 |
| 1.50 | .181 |
| 1.75 | .187 |
| 2.00 | .200 |
| 2.25 | .218 |
| 2.50 | .259 |
| 2.71 | .350 |




Distribution of perforated-to-throat area ratio

(c) Design Mach number $M_d$, 2.50.

Figure 5. - Cross sections of perforated diffusers.

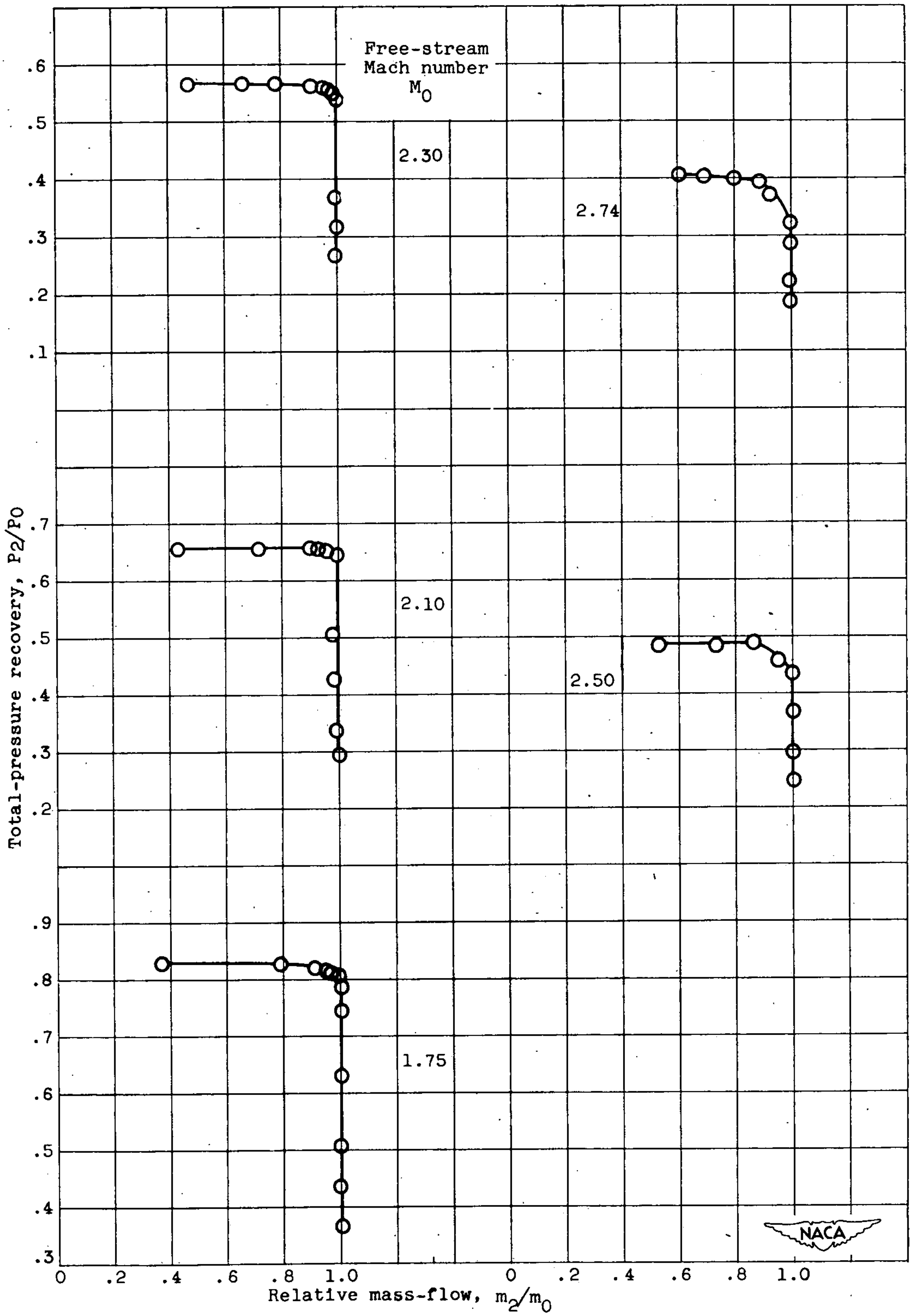
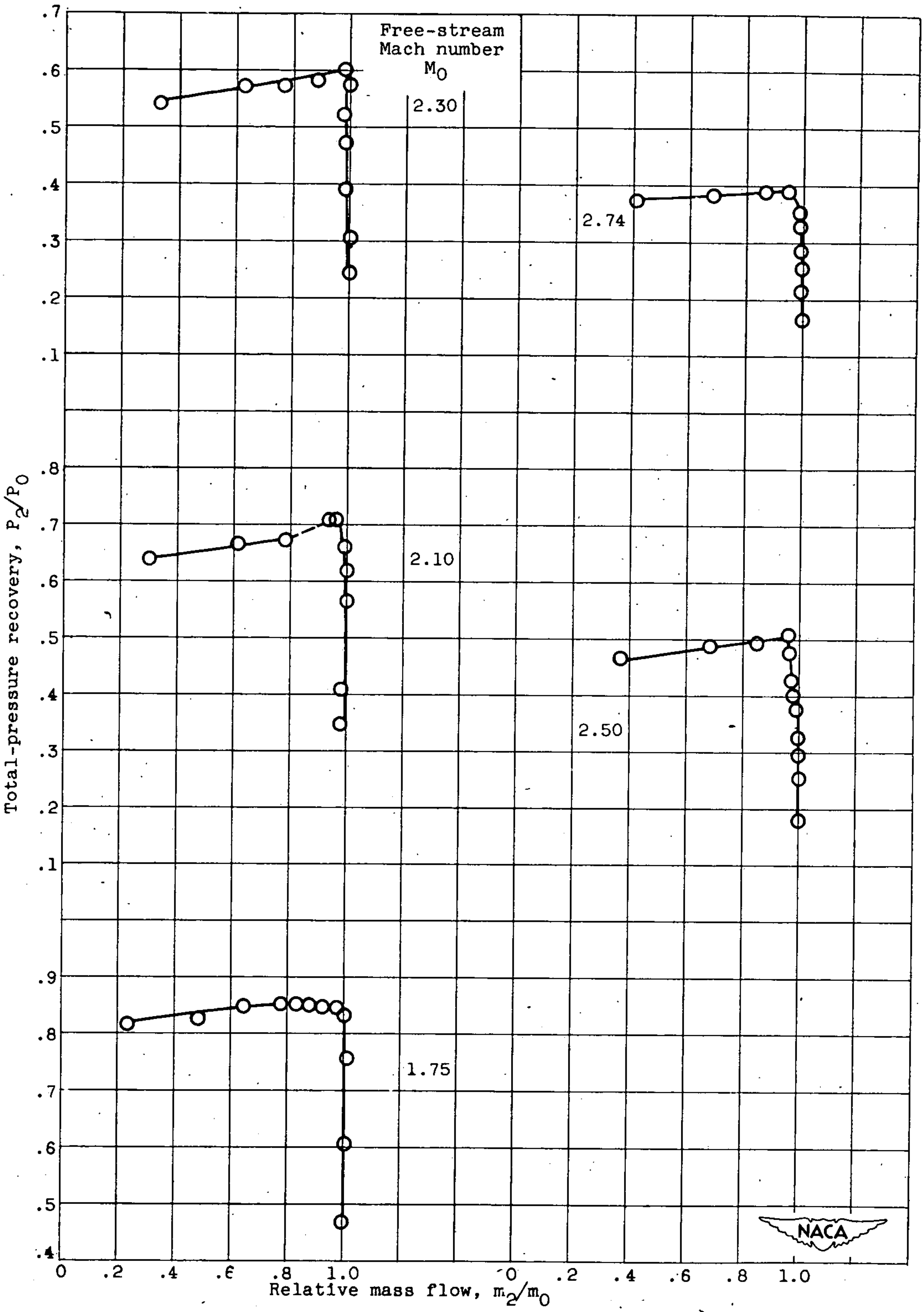
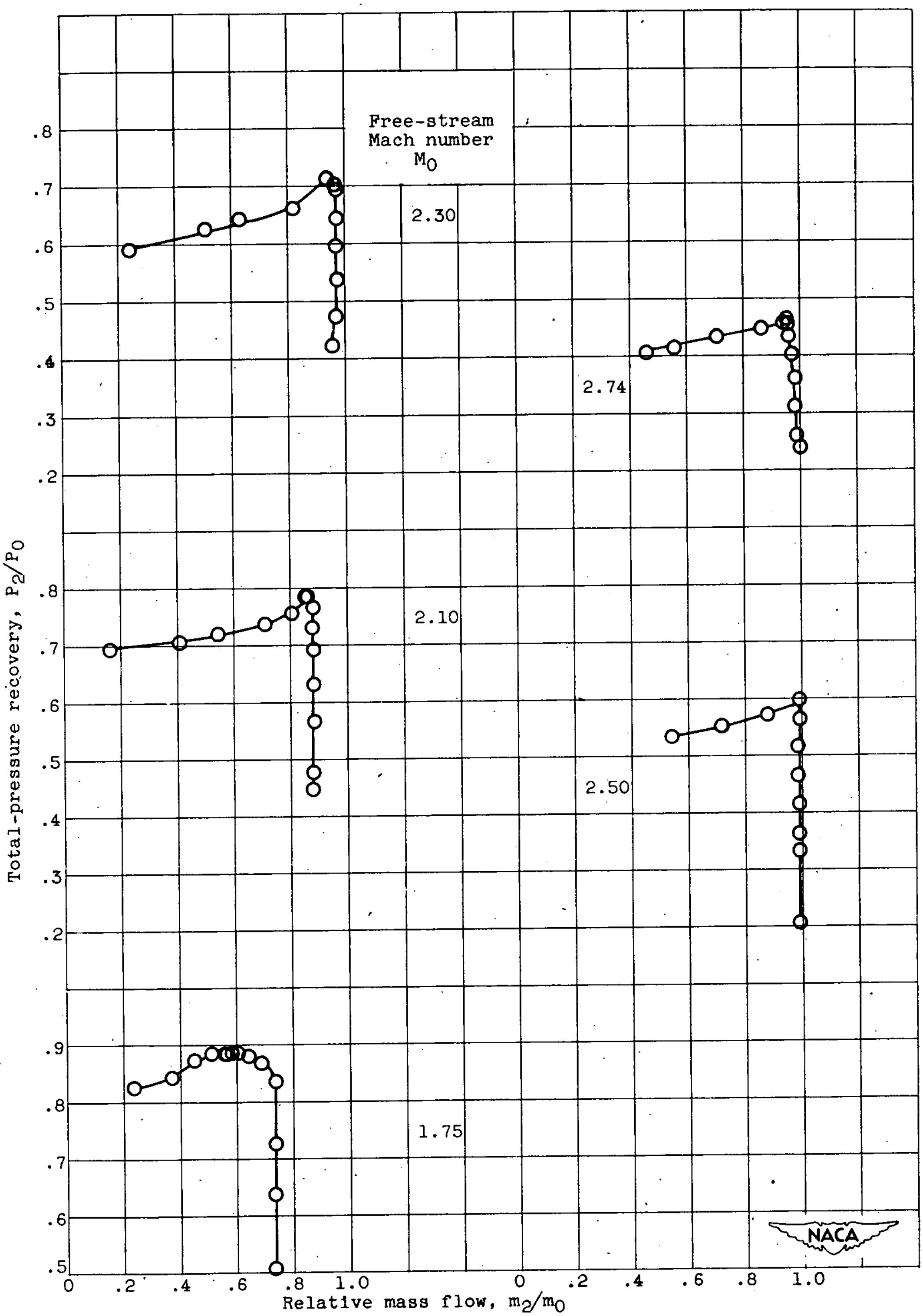



Figure 6. - Variation of pressure recovery with relative mass flow for normal-shock diffuser.



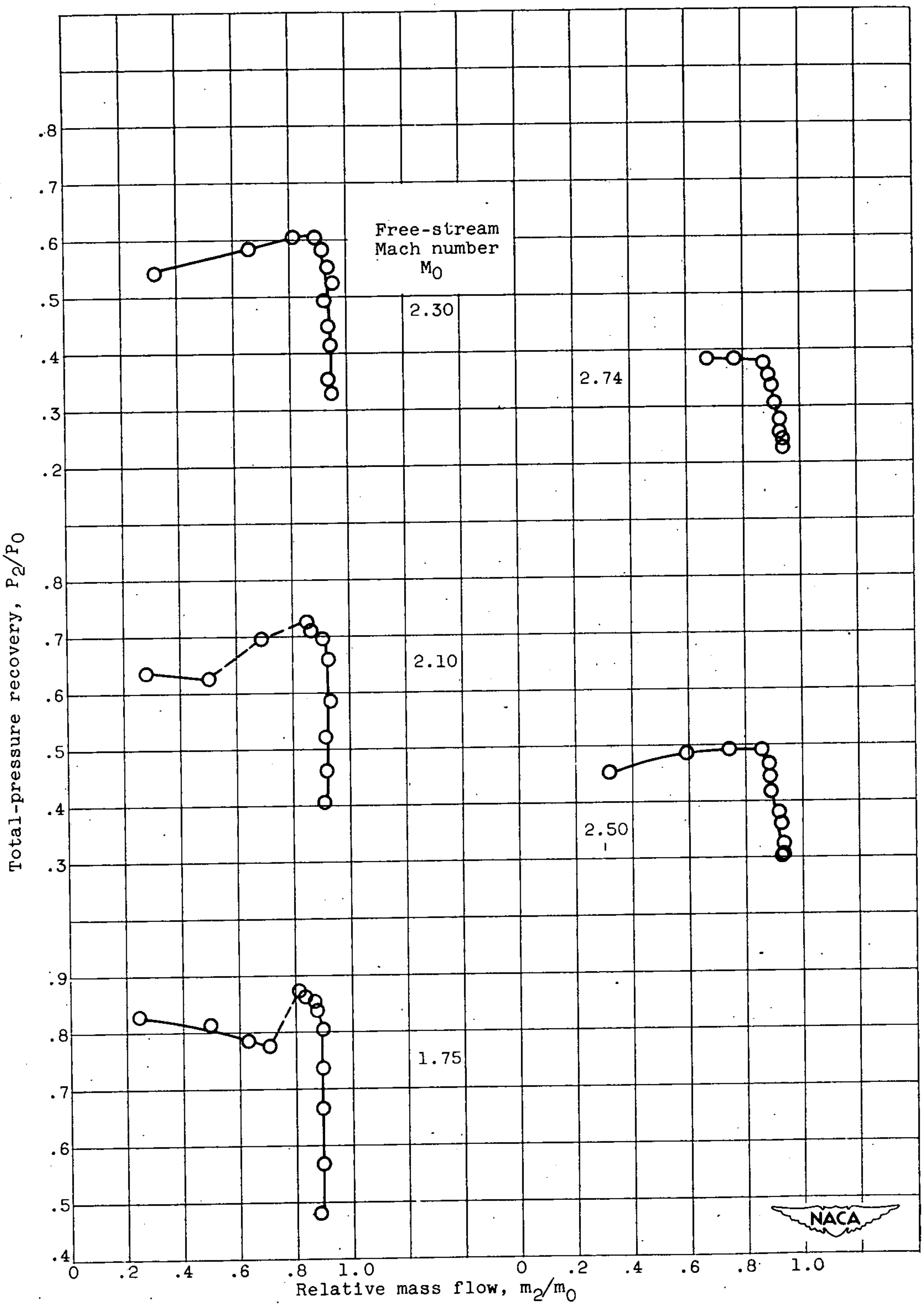

(a) Design Mach number $M_d$, 1.75.

Figure 7. - Variation of total-pressure recovery with relative mass flow for spike diffuser.



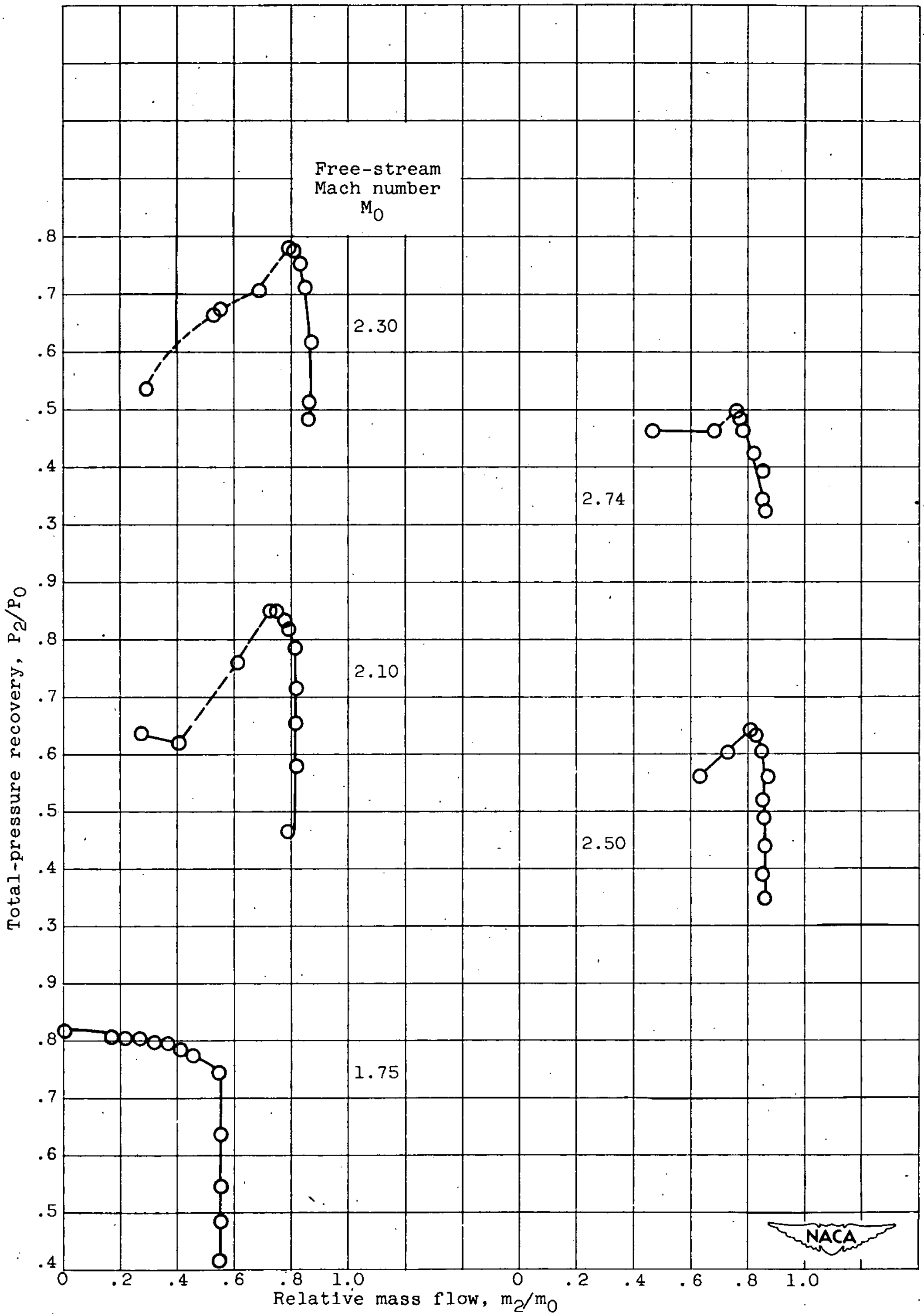

(b) Design Mach number $M_d$, 2.40.

Figure 7. - Concluded. Variation of pressure recovery with relative mass flow for spike diffuser.



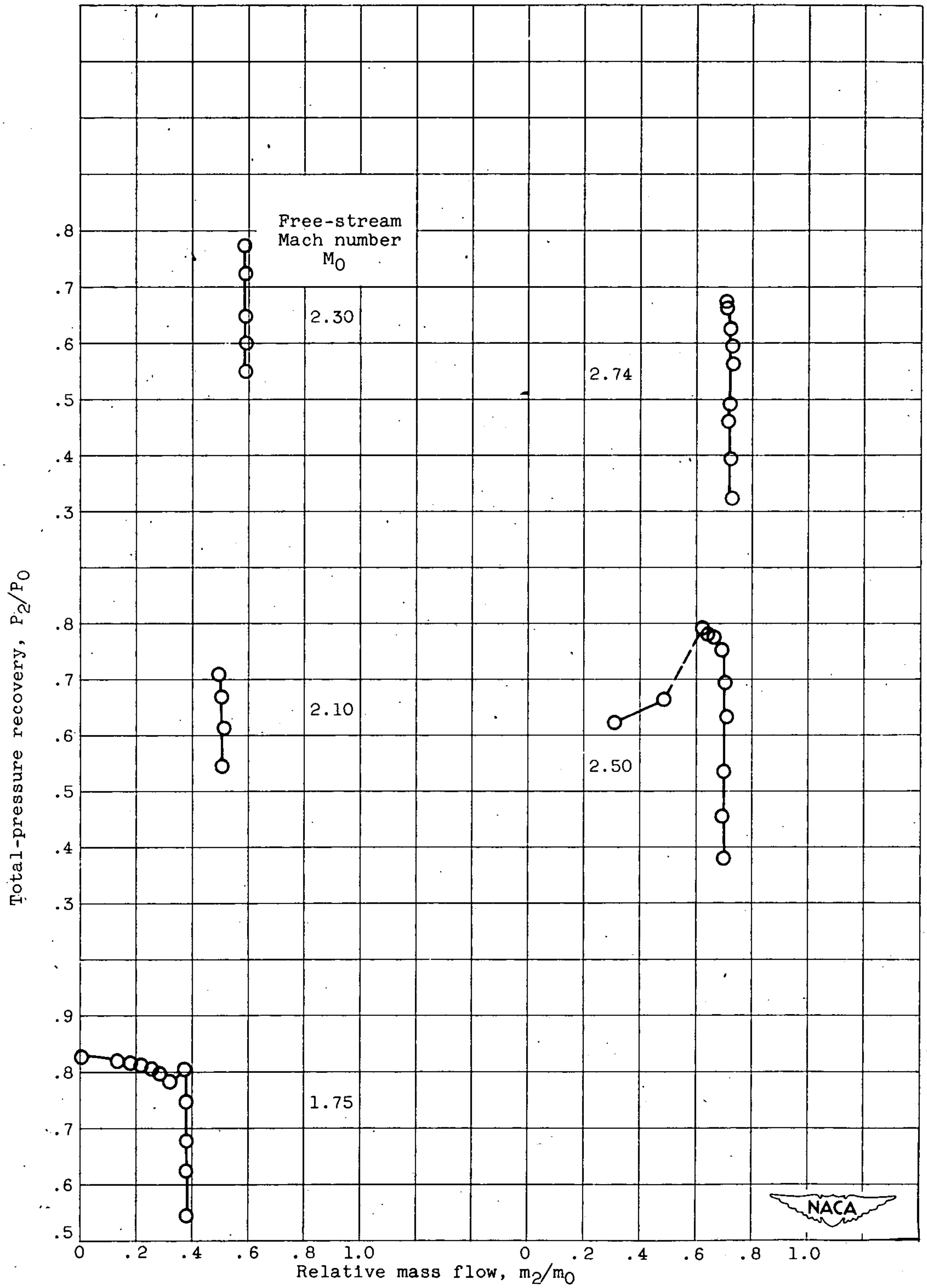

(a) Design Mach number $M_d$, 1.75.

Figure 8. - Variation of total-pressure recovery with relative mass flow for perforated diffuser.




(b) Design Mach number $M_d$, 2.10.

Figure 8. - Continued. Variation of total-pressure recovery with relative mass flow for perforated diffuser.




(c) Design Mach number $M_d$, 2.50.

Figure 8. - Concluded. Variation of total-pressure recovery with relative mass flow for perforated diffuser.

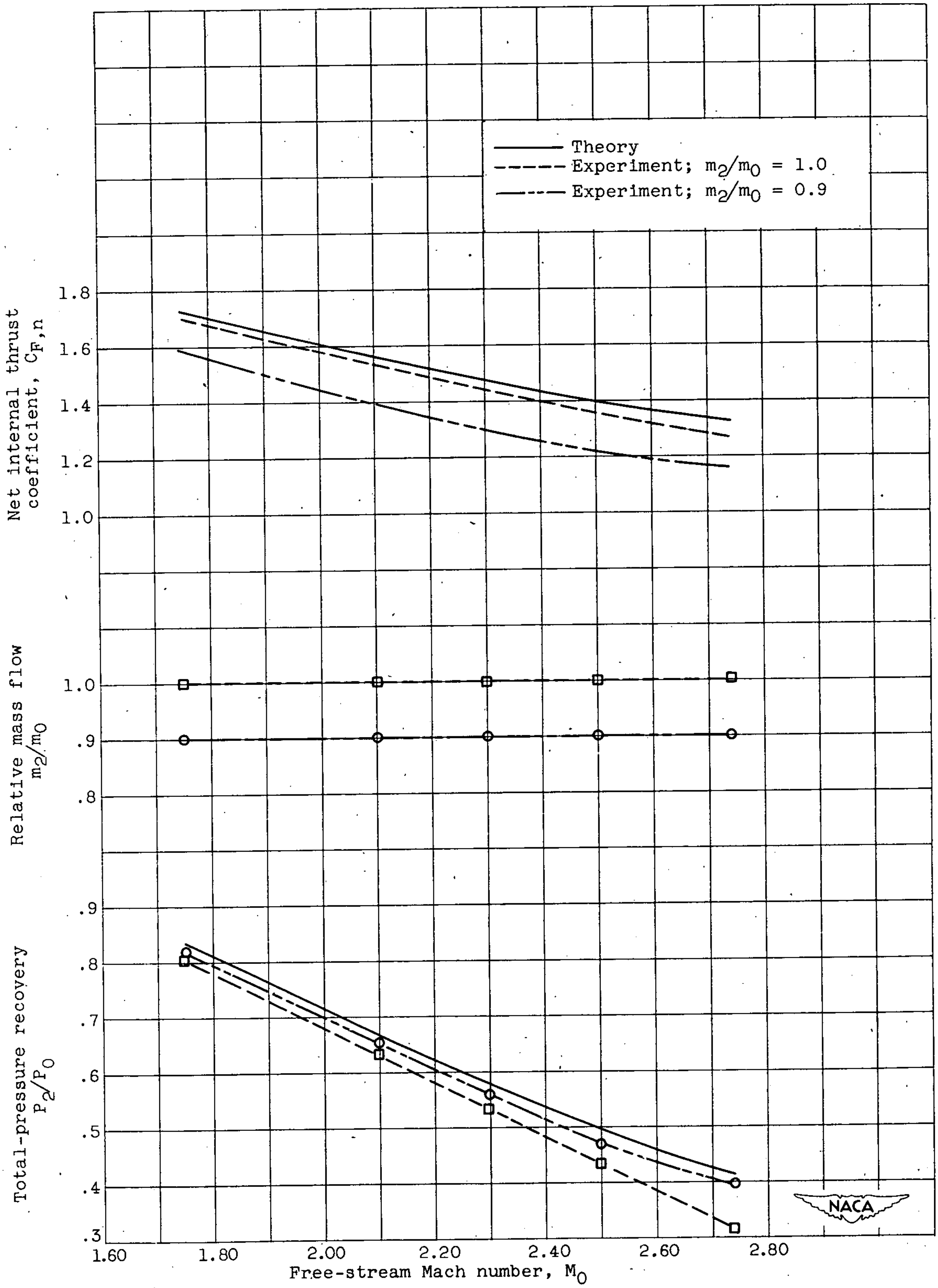
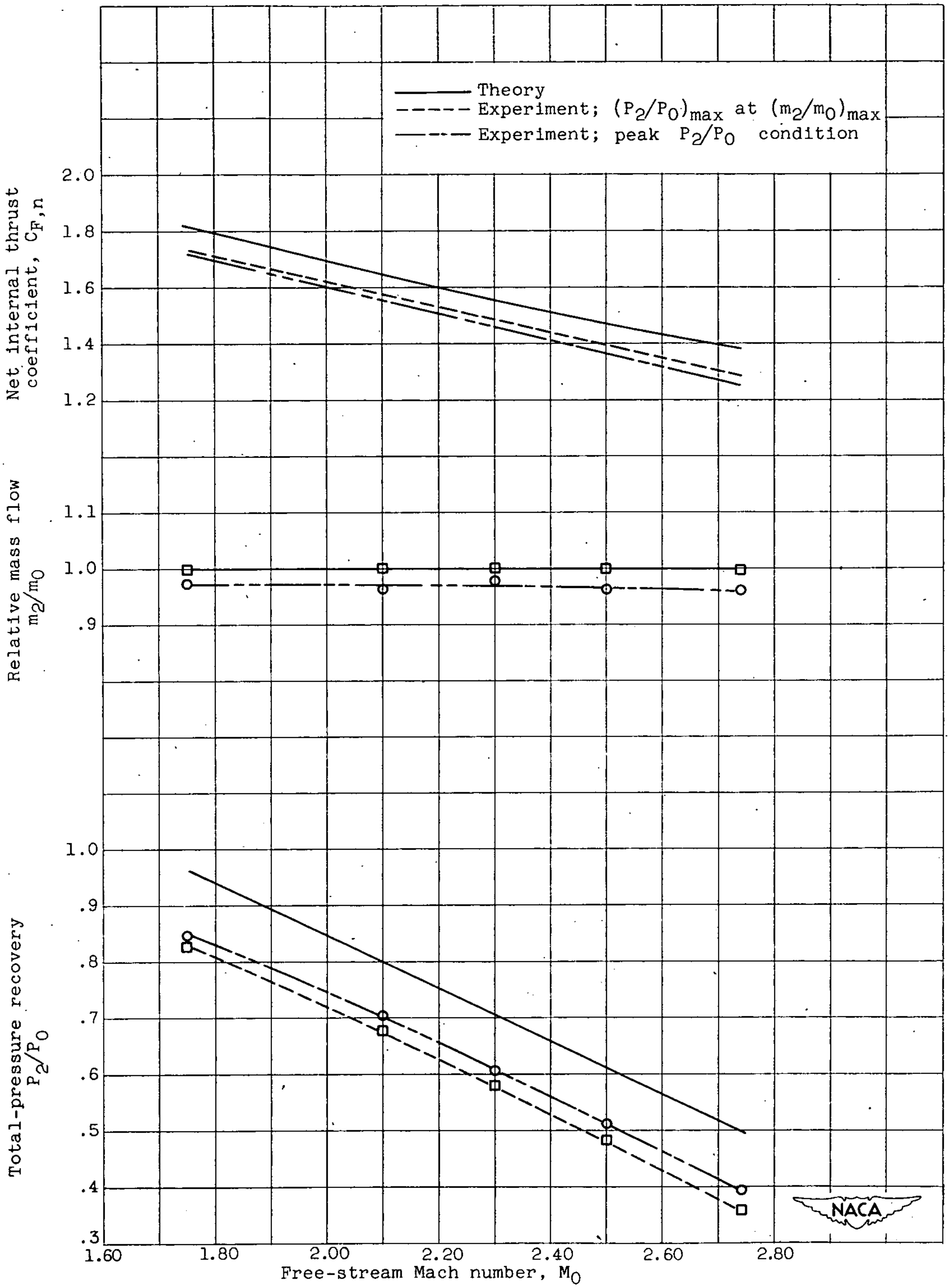
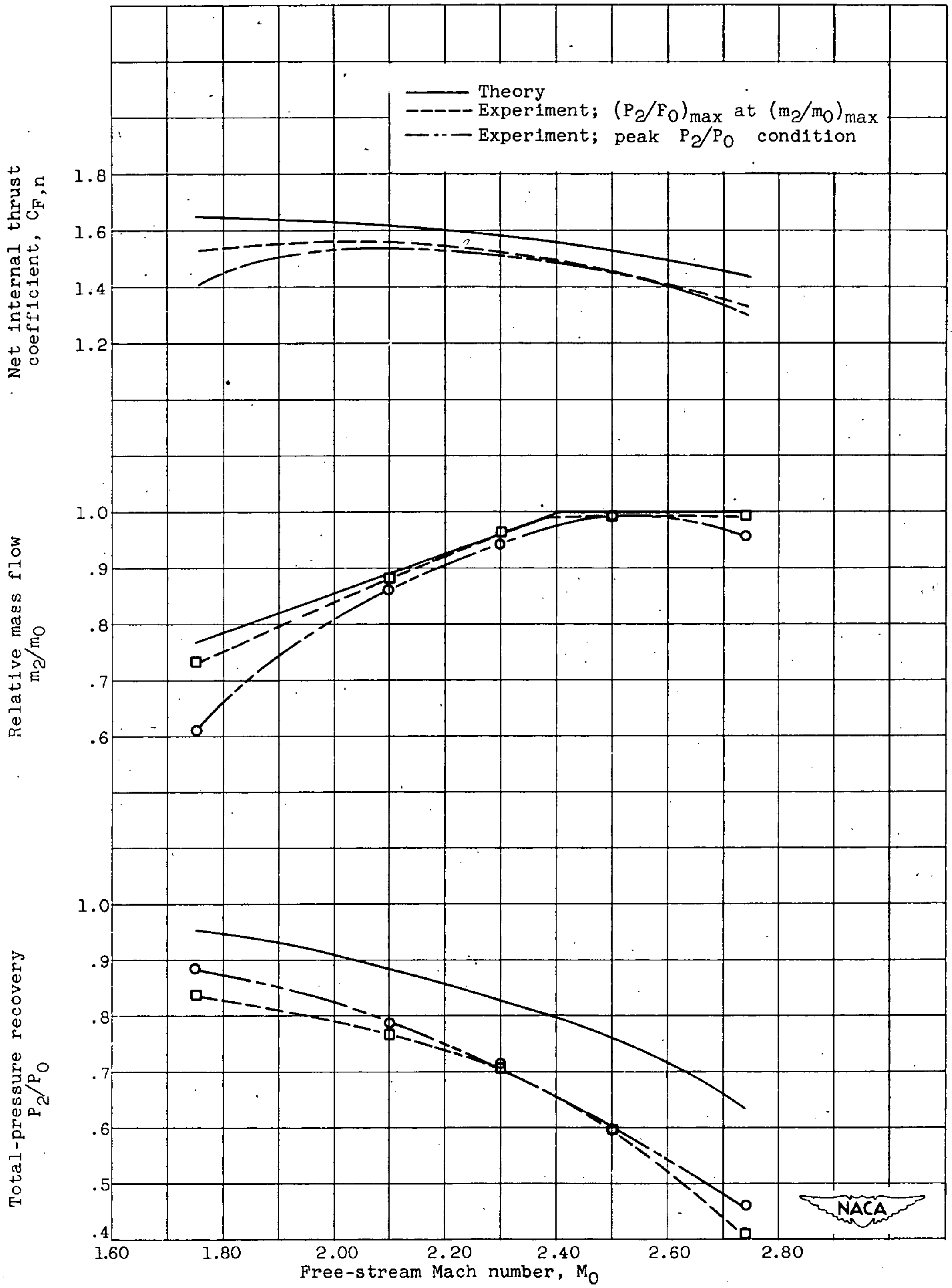



Figure 9. - Variation of diffuser performance with Mach number for normal shock diffuser.



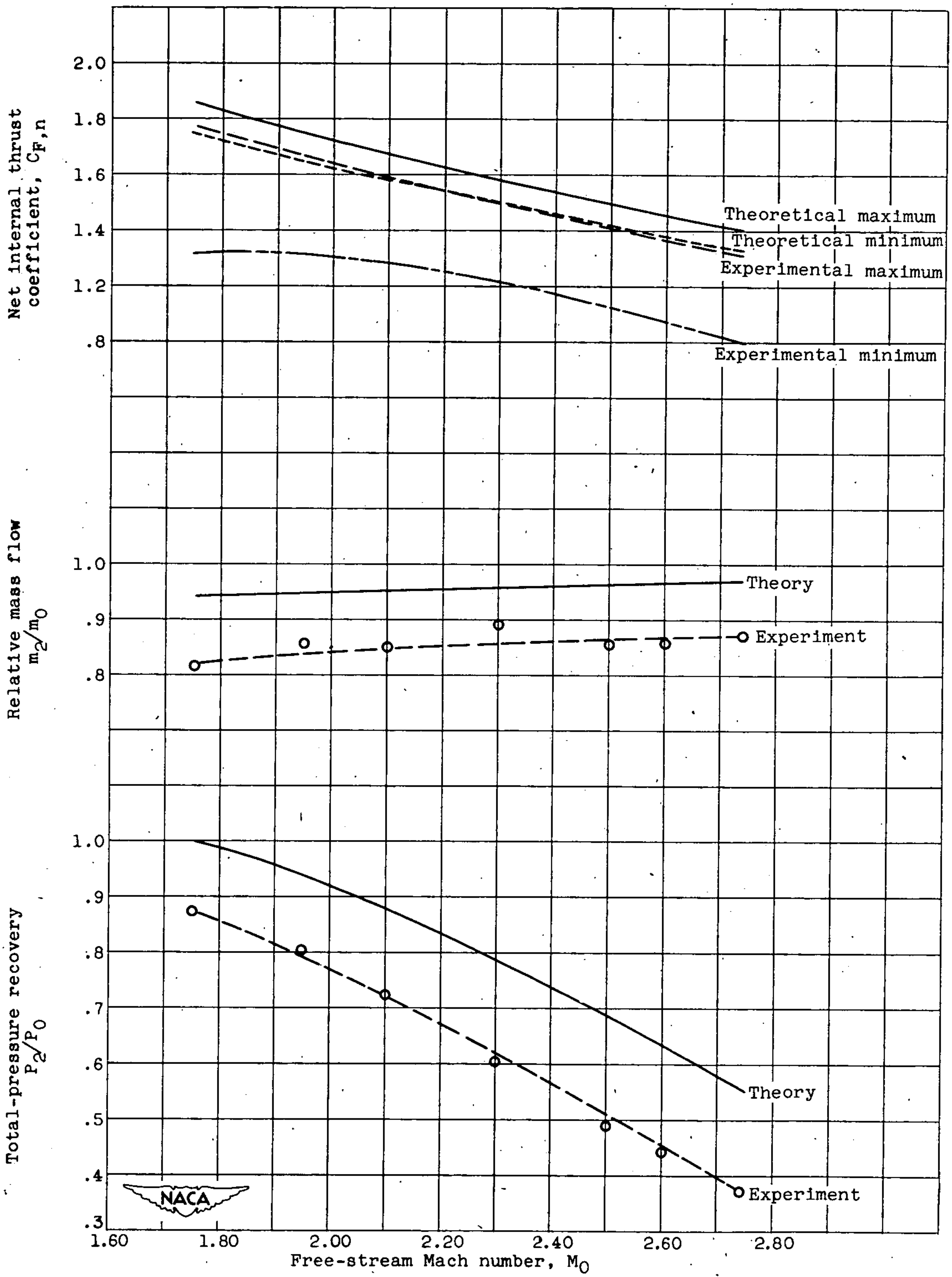

(a) Design Mach number $M_d$, 1.75.

Figure 10. - Variation of diffuser performance with Mach number for spike diffuser.



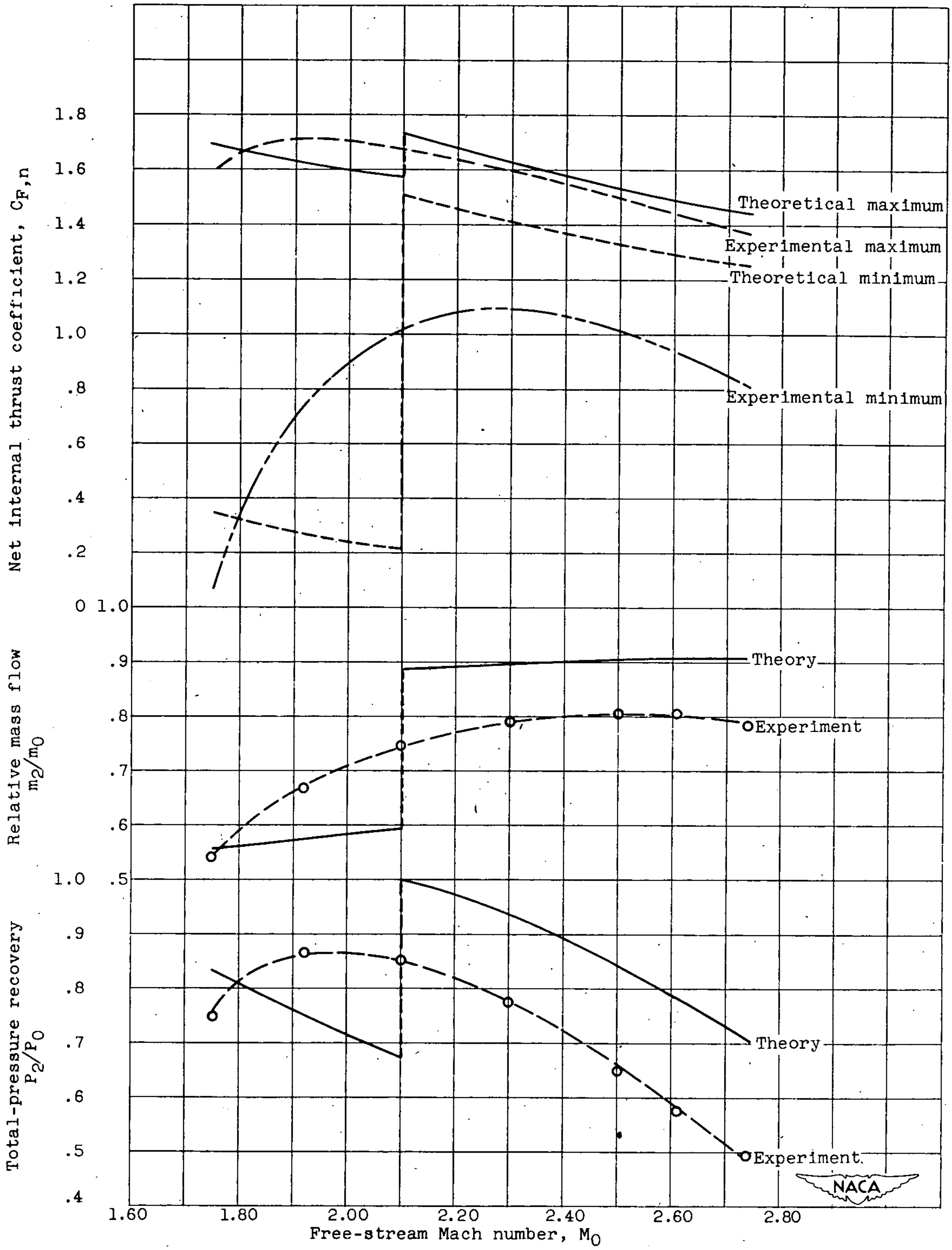

(b) Design Mach number $M_d$, 2.40.

Figure 10. - Concluded. - Variation of diffuser performance with Mach number for spike diffuser.



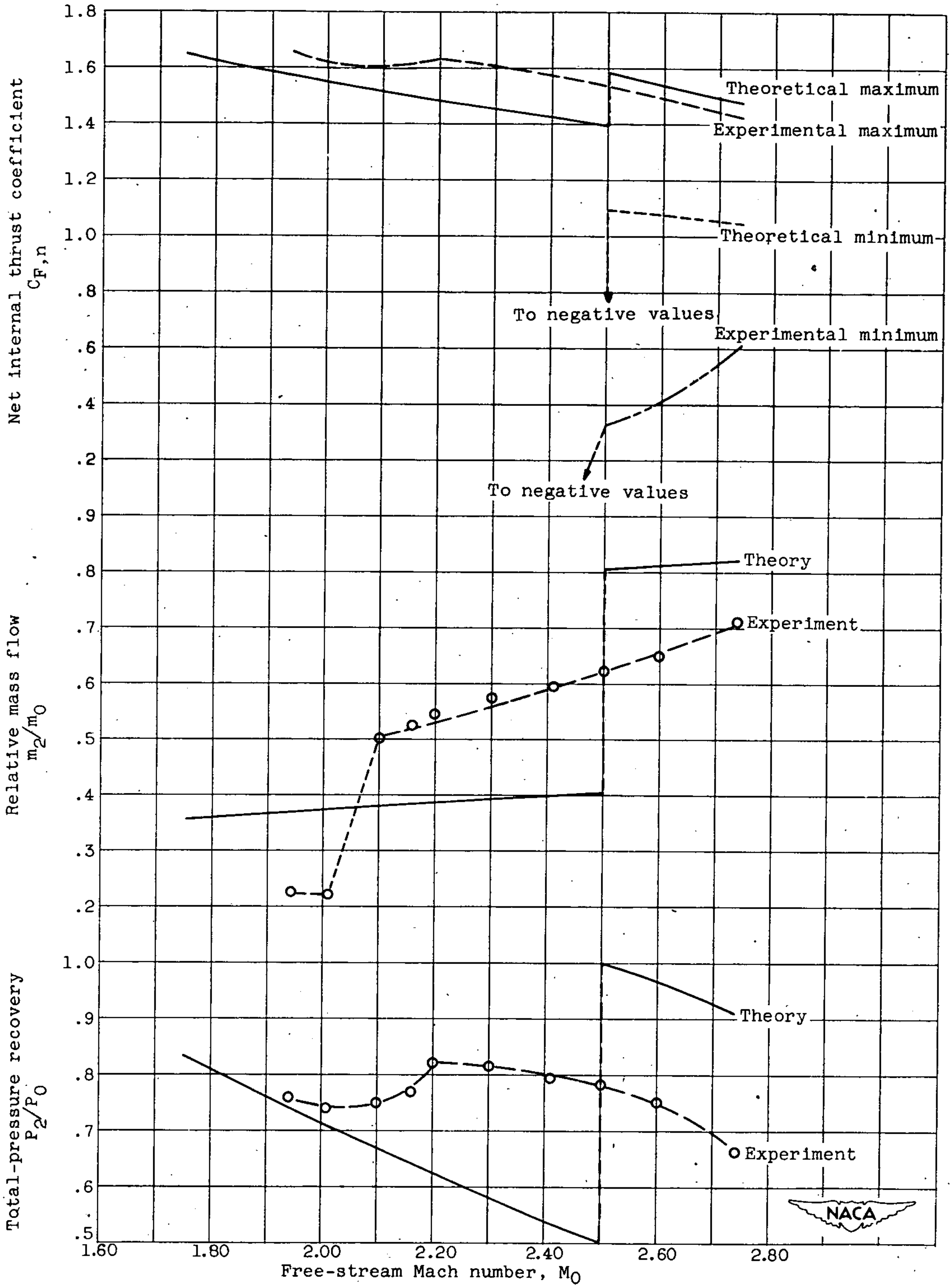

(a) Design Mach number $M_d$, 1.75.

Figure 11. - Variation of diffuser performance with Mach number for perforated diffuser.




(b) Design Mach number $M_d$, 2.10.

Figure 11. - Continued. - Variation of diffuser performance with Mach number for perforated diffuser.




(c) Design Mach number $M_d$, 2.50.

Figure 11. Concluded. Variation of diffuser performance with Mach number for perforated diffuser.

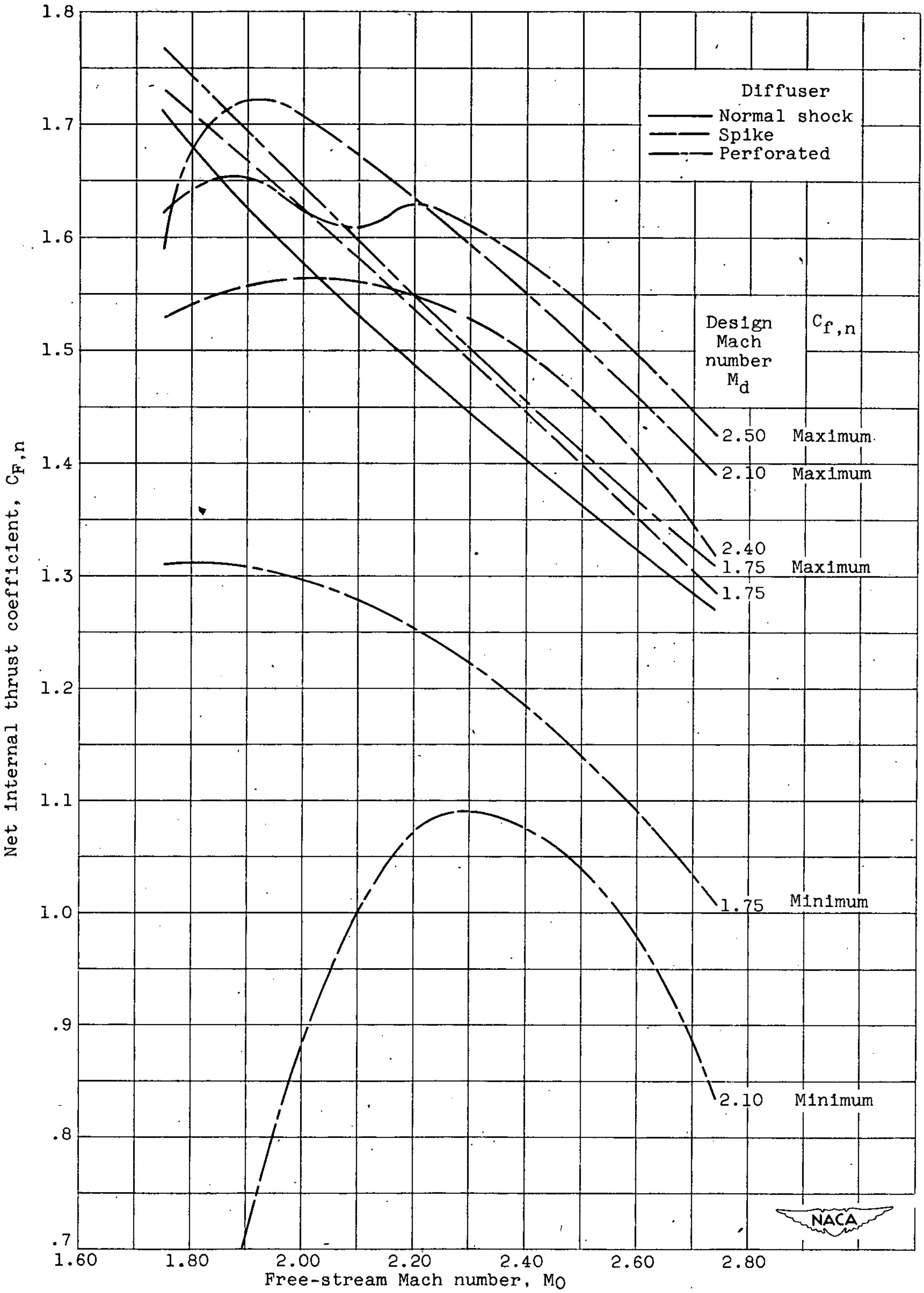



Figure 12. - Experimental variation of optimum net internal thrust coefficient with Mach number for six diffusers integrated with a simulated combustion chamber (constant $\tau$ of 4) and a choked variable outlet.

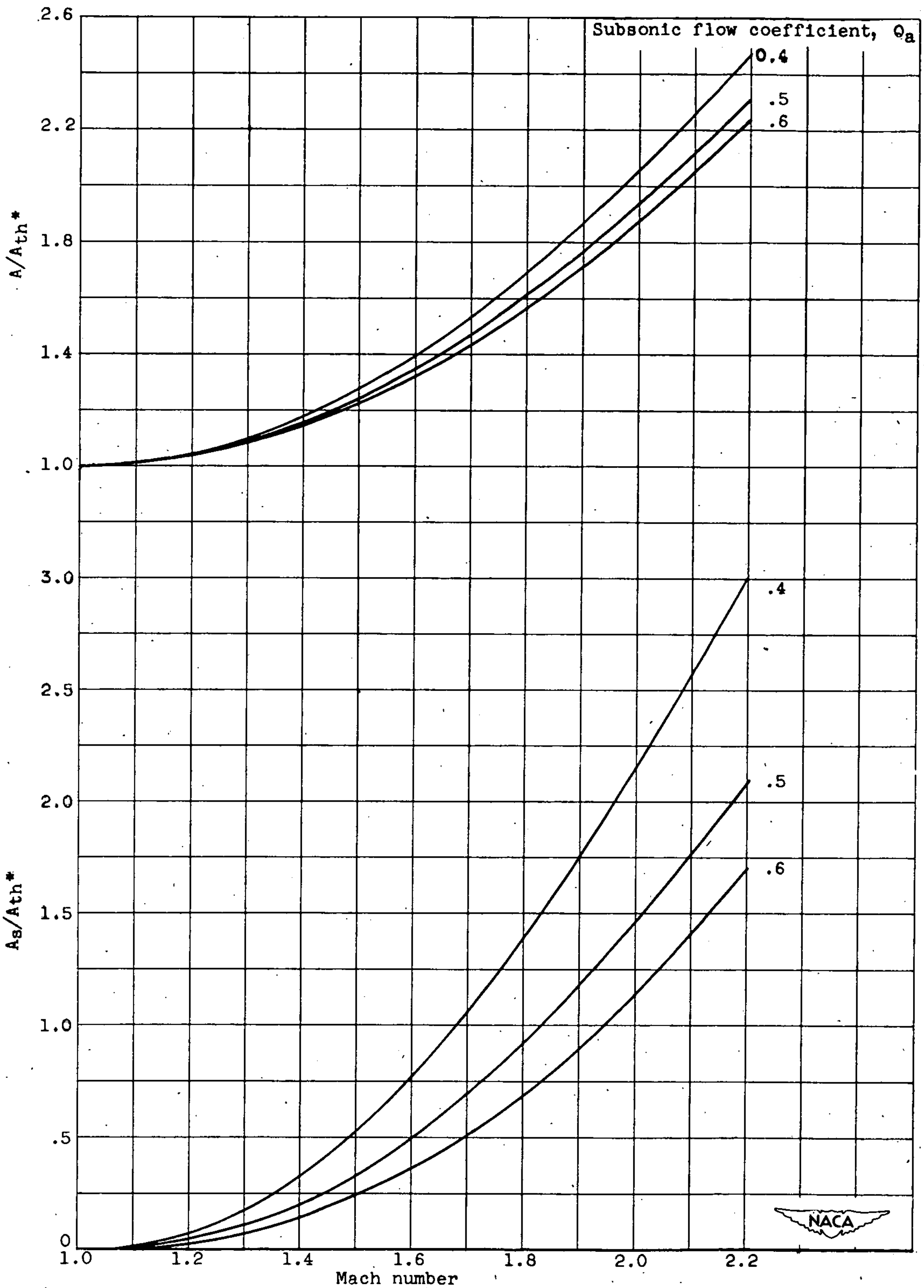



Figure 13. - Design curves for convergent-divergent perforated diffuser for three subsonic flow coefficients. Design Mach number $M_d$, 2.20.



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