RM E55E18

NACA

RESEARCH MEMORANDUM

PERFORMANCE CHARACTERISTICS OF HEMISPHERICAL TARGET-TYPE THRUST REVERSERS

By Fred W. Steffen, Jack G. McArdle, and James W. Coats

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

WASHINGTON

September 27, 1955

40

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

PERFORMANCE CHARACTERISTICS OF HEMISPHERICAL TARGET-TYPE THRUST REVERSERS

By Fred W. Steffen, Jack G. McArdle, and James W. Coats

SUMMARY

An investigation was conducted to determine the reverse-thrust performance of hemispherical target-type thrust reversers over a wide range of geometric variables. The data were obtained from small-scale models with unheated air.

Several factors were found which increased the flow turn angle and thus the reverse-thrust ratio. The most important of these was hemisphere diameter. A maximum reverse-thrust ratio of 82 percent was obtained with a 1.8-closed-nozzle-diameter hemisphere. A further increase in hemisphere diameter did not improve reverse-thrust ratio. Slight improvements in performance were obtained with some reversers by operating with the reverser close to the nozzle and with the exhaust nozzle open slightly from the size required for normal forward thrust.

In order to obtain high values of reverse-thrust ratio, it was necessary to turn the flow very close to the boattail. In cases where the flow attached to the boattail, the pressure reductions on the boattail were large enough to account for as much as 20 percent of the reverse-thrust ratio. However, for most hemisphere diameters, variations in boattail shapes had little effect on reverse-thrust ratio.

A reverser fabricated from a spherical or cylindrical surface and a flat plate was found to have satisfactory performance. This type reverser might be more adaptable to stowage and jet directional control than a hemispherical type.

INTRODUCTION

Many uses for thrust reversers on jet aircraft have been proposed. They include braking the landing roll, reversing or spoiling thrust during the landing approach so that 100-percent engine speed may be maintained, and braking during diving maneuvers to limit flight speed.

To be used effectively, the reverser must give the desired amount of reverse thrust without affecting engine operation. Also, the design must lend itself to stowage with a minimum amount of boattail or base drag. Other required characteristics for safe operation are discussed in reference 1.

As part of an over-all investigation of thrust reversers and their associated problems at the NACA Lewis laboratory, tests have been conducted with cold flow on models of target-type thrust reversers. Reference 2 shows that the reverse-thrust performance of a hemispherical target is satisfactory and that a hemispherical target can be retracted to give a reasonably smooth boattail. 3729

Reference 2 presents the performance over a limited range of variables. The purpose of this report is to show the performance of a hemispherical thrust reverser over a wide range of geometric variables and to show some of the factors which affect reverse-thrust performance. The effects of several simplifications to the hemispherical design are also shown. The effects of most of the design variables of the reverser are shown at an exhaust-nozzle total- to ambient-pressure ratio of 2.0. The basic data over a wide range of conditions are also included, however, so that other comparisons may be made if desired.

APPARATUS AND INSTRUMENTATION

Apparatus

Typical geometry of the hemispherical reverser is shown in figure 1. The geometries of reversers created by installing flat plates in the back of a hemisphere and in a cylinder are shown in parts (a) and (b), respectively, of figure 2. The diameters and flat-plate locations for all the reversers tested are listed in table I.

The various boattail configurations tested are shown in figure 3. The 4-inch-diameter exhaust nozzle, which was the same for all boattails, is also shown in figure 3.

The mechanism used to measure thrust in both positive and negative directions is shown in figure 4. The air-supply duct was connected to the laboratory air system by flexible bellows and pivoted to a steel frame so that axial thrust forces along the pipe, both forward and reverse, could be freely transmitted to and read from a balanced-pressure-diaphragm, null-type, thrust-measuring cell. In order to assure that the steel strap used to transmit the force from the duct to the thrust cell was always in tension, it was sometimes necessary to preload the system with counterweights. The deflectors were mounted on four rods extending from tabs located 8 inches ahead of the exhaust-nozzle exit. A blast deflector, which was attached to the floor of the test cell, was placed around the boattail to prevent the reversed flow from impinging on the air-supply-duct flanges.

Instrumentation

Air flow through the system was measured by means of a standard A.S.M.E. sharp-edged orifice. Two total-pressure tubes, about 8 inches ahead of the exhaust-nozzle exit, were used to measure exhaust-nozzle total pressure, while a barometer was used to measure ambient exhaust pressure. Wall static taps and total- and static-pressure rakes were located along the boattail during some runs in order to determine reversed-flow characteristics. A tuft plate was also installed between the nozzle and the reverser during some runs to determine the flow turn angle.

PROCEDURE

Forward jet thrust of the nozzle was obtained over a range of exhaust-nozzle total- to ambient-pressure ratios from 1.4 to 3.0. Reverse jet thrusts were then obtained over the same range of pressure ratios with reversers attached to nozzle-boattail combinations at various spacings. (Spacing ratio is defined as the ratio of the axial distance between the nozzle lip and the reverser lip to the nozzle diameter.) The ratio of the reverse jet thrust of a given configuration at a given pressure ratio to the forward jet thrust of the nozzle alone at the same pressure ratio was thus obtained and defined as the basic reverse-thrust ratio. The ratio of the flow passed during reverse-thrust operation to the air flow passed during forward-thrust operation was similarly obtained and defined as the air-flow ratio. Jet thrusts and air flows were corrected for changes in inlet pressure.

Except for the tests run specifically to evaluate the effect of boattail shape on performance, all tests were run with the convex boattail shown in figure 3(a). For the entire investigation, unheated air was used, and the pressure ratio was regulated by variation of the inlet pressure.

The symbols used in this report are defined in appendix A. Definitions of basic reverse-thrust ratio and air-flow ratio are presented mathematically in appendix B.

RESULTS AND DISCUSSION

Operating Characteristics

There is a range of spacings for which the reverse-thrust ratio of target-type reversers will generally remain about constant or increase slightly as spacing is reduced. However, a spacing will eventually be reached at which the mass flow through the engine will be reduced and, in the case of a turbojet-engine installation, the turbine temperature will be increased. The spacing can be decreased further without encountering turbine overtemperature if the engine exhaust nozzle is opened.

The minimum spacing that can be used on an engine with a fixed-area exhaust nozzle as dictated by limiting turbine temperature is shown in figure 5(a) as a function of hemisphere diameter. Spacing is presented as a ratio of the spacing to the diameter of the exhaust nozzle. As might be expected, the minimum spacing decreases as the hemisphere diameter increases. 3729 The accompanying variation in reverse-thrust ratio with hemisphere diameter is shown in figure 5(b). Reverse-thrust ratio increases rapidly with an increase in hemisphere diameter and reaches a maximum of about 82 percent with a hemisphere- to nozzle-diameter ratio of 1.8.

As stated previously, closer spacings than the minimum ones shown in figure 5 can be used if the exhaust nozzle is opened. The reverse-thrust ratios obtained and the nozzle openings required for this type operation are shown in figure 6 for several size hemispheres. Reverse-thrust ratio and nozzle-opening ratio are plotted against spacing ratio. The gains in reverse-thrust ratio which result from closer spacings than can be used with a fixed-area nozzle are small (a maximum of 3 percentage points) and are probably insufficient to justify the installation of a variable-area nozzle. It can also be seen from this figure that the reverse-thrust ratio is primarily a function of hemisphere diameter. The method by which figure 6 was obtained from the experimental data is described in appendix C.

All the data shown in figures 5 to 11 and 13 to 16 were run with the convex boattail (shown in fig. 3(a)) installed. The effects of other boattail shapes will be discussed in the section Effect of Boattail Shape on Reverse-Thrust Ratio.

Relation of Flow Turn Angle and Reverse-Thrust Ratio

Because the reverse-thrust ratio would be expected to be a function of the flow turn angle, several factors which affect the turn angle, such as spacing and hemisphere diameter, were investigated.

For example, in figure 7 a typical hemisphere is shown operating at two different spacings. As the spacing ratio decreased, the mean turn angle and the reverse-thrust ratio decreased. The mean turn angle was approximated from the mean angle of the tufts and is shown by the large arrow. These data show that very low spacings will decrease the flow turn angle and thus cause the sharp decreases in reverse-thrust ratio which are shown in figure 6.

The large reverse-thrust ratios given by the big hemispheres result from high turning angles. Figure 8 shows that a big hemisphere turns the flow through a high angle and gives a large reverse-thrust ratio. The high turning angle is caused by a large force produced by pressure acting over the big-reverser frontal area. This principle applies to the turning surfaces of any reverser.

In addition to spacing and hemisphere diameter, the lip angle of the spherical surface also affects the flow turn angle and thus the reverse-thrust ratio. A 20° decrease in lip angle caused a 23-percentage-point decrease in the reverse-thrust ratio obtained from a 1.50-closed-nozzle-diameter hemisphere.

Theoretically, the reverse-thrust ratio would be expected to vary as the cosine of the supplement of the turn angle from 0 to 100 percent, as shown by the dashed curve in figure 9. A curve of measured reverse-thrust ratio and measured turn angle is also shown in figure 9. The turn angles were measured from tufts and are therefore only approximate. Although the measured curve is 25 to 35 percentage points lower, it follows closely the trend of the theoretical curve. Thus, for high reverse-thrust ratios, it is necessary to turn the flow through a large angle and, with this type of reverser, direct it very close to the nacelle or fuselage skin.

The difference between theoretical and measured reverse-thrust ratio depends on pressure losses and, to some extent, on the boattail shape, as will be discussed in the section Effect of Boattail Shape on Reverse-Thrust Ratio.

Reverse-Flow Velocities and Pressures Along Boattail

The reverse-flow velocities along the convex boattail for two different size hemispheres at two different spacings are shown in figure 10. For both hemispheres, the reverse-thrust ratio and the flow turn angles are high and thus the flow eventually attaches to the boattail. However, the gas velocity decreases from 1100 feet per second at the reverser exit to only 400 feet per second a short distance forward. This fact suggests that, if a free-stream velocity existed, the flow might detach from the boattail.

The static-pressure distribution along the convex boattail during reverse-thrust operation is shown in figure 11. Pressure data are shown for a hemisphere at two different spacing and reverse-thrust ratios. In both cases the flow is attached to the boattail and the pressure is decreased below atmospheric over the last 3 or 4 inches of the tail pipe. This reduction in pressure accounts for about 20 percent of the reverse thrust. Because the greatest decrease in pressure occurs close to the nozzle lip, the reversed thrust due to the reduced pressure will probably be about the same for any practical nozzle contraction ratio.

The pressure drop on the boattail is accompanied by a further turn of the gas flowing from the hemisphere, and therefore the boattail may be considered as part of the thrust-reversal mechanism.

Effect of Boattail Shape on Reverse-Thrust Ratio

The reverse-thrust ratios obtained from two different hemispheres mounted behind several boattails are shown in figure 12. The maximum change in reversal due to change in boattail shape amounted to 7 percentage points for the small size reverser but only 3 percentage points for the large size reverser. The 7-percentage-point change occurred as the boattail was changed from a convex to a blunt or concave configuration with a 1.5-nozzle-diameter hemisphere at a spacing ratio of 0.50. Use of the large-lip boattail caused an unstable flow field that resulted in destructive vibration. The tendency for the reversed flow to attach to the boattail for high reverse-thrust ratios was no less with the blunt or concave boattail than with the convex boattail. Air flow for a given spacing and hemisphere diameter was also unaffected.

Modifications to a Hemispherical Thrust Reverser

From pressure surveys in the rear of a hemisphere, it was found that a stagnant region existed in the rear portion and that the lip did the major portion of the turning. Flat plates were thus placed at various depths in the hemispheres and in a cylinder. Reverse-thrust ratio at a nozzle pressure ratio of 2.0 as a function of flat-plate location is shown for two hemispheres and a cylinder in figure 13. Reverse-thrust ratio decreases as the flat plate is moved towards the front of the hemisphere. The decrease is negligible for the 1.67-nozzle-diameter hemisphere but large for the 1.50-nozzle-diameter hemisphere. For a given reverser diameter and depth, the cylindrical surface appears superior to the spherical surface by about 8 percentage points. Air flow for a given spacing and reverser size was relatively unaffected by the flat-plate location. Shallow, flat-backed configurations such as these, in which the flat plate could be separated from the lip, might be more adaptable to stowage than a complete hemisphere. The flat plate might also be folded in such a way as to be used as a jet directional control vane.

CONCLUSIONS

For a hemispherical-type reverser with a given boattail, the flow turning angle and thus the reverse-thrust ratio can be increased primarily by increasing the size of the hemisphere. The maximum reverse-thrust ratio obtained during this investigation was 82 percent and was obtained with a 1.8-nozzle-diameter hemisphere. A further increase in hemisphere size did not improve reverse-thrust ratio.

Operation with the hemisphere close to the nozzle and with the nozzle area increased to avoid turbine overtemperature improved performance slightly for some size hemispheres and permitted a savings in overall length.

Because the reverse-thrust ratio is a function of the flow turn angle, it is necessary to direct the flow very close to the nacelle or fuselage skin for high reverse-thrust ratios. Reversed flow which, for high reverse-thrust ratios, attached to the boattail decreased from sonic velocity to about 400 feet per second within $3\frac{1}{2}$ nozzle diameters. This flow might detach if a free-stream velocity were present.

Pressure reductions on a convex boattail with the flow attached were large enough to account for as much as 20 percent of the reverse thrust. Nevertheless, the effect of changing the boattail shape was generally small, about 5 percentage points.

A reverser with satisfactory performance can be fabricated from a spherical or cylindrical surface and a flat plate. This type reverser might be more adaptable to stowage and directional control than a completely hemispherical reverser.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, June 3, 1955

APPENDIX A

SYMBOLS

The following symbols are used in this report:

D diameter, in.

F thrust, lb

l axial distance between nozzle exit and lip of hemisphere, in.

P total pressure, lb/sq ft abs

p static pressure, lb/sq ft abs

r radius, in.

w air flow, lb/sec

x axial distance, in.

δ ratio of total pressure at nozzle inlet to absolute pressure at NACA standard sea-level conditions

η_R reverse-thrust ratio

θ ratio of total temperature at nozzle inlet to absolute temperature at NACA standard sea-level conditions

τ turn angle, deg

Subscripts:

b basic

C cylinder

F forward

H hemisphere

j jet

n nozzle

nc	nozzle closed
no	nozzle open
R	reverse
0	ambient

3729

CA-2

APPENDIX B

DEFINITIONS

Basic reverse-thrust ratio $\eta_{R,b}$ is defined as $\left(\frac{F_j}{\delta}\right)_R \Big/ \left(\frac{F_j}{\delta}\right)_F$.

Air-flow ratio is defined as $\left(\frac{w\sqrt{\theta}}{\delta}\right)_R \Big/ \left(\frac{w\sqrt{\theta}}{\delta}\right)_F$.

APPENDIX C

METHOD OF OBTAINING DIMENSIONS AND DATA OF FIGURE 6 FROM BASIC DIMENSIONS AND BASIC DATA

Much of the basic data (figs. 14 to 16) was obtained at spacings where the air-flow ratio was less than 100 percent. On the basis of some test results, it was assumed that, if all the dimensions of the configurations which passed less than 100 percent air flow could be scaled up in proportion to the air-flow ratio, then the configuration would pass 100 percent air flow and yet turn the flow with the same degree of efficiency. But because the scaled-up nozzle would be too large for normal forward-thrust operation, it was necessary to calculate a corresponding closed-nozzle diameter. The size of the reverser may then be compared with the closed-nozzle diameter.

Thus, the data shown in figure 6 for variable-area-nozzle operation were obtained from the basic data in figure 14 as follows: A cross plot was made of air-flow ratio and basic reverse-thrust ratio against basic spacing ratio at a nozzle pressure ratio of 2.0 for all the basic hemisphere diameters investigated. Basic spacing ratio is defined as $(l/D_n)_b$ and basic hemisphere diameter is defined as $(D_H/D_n)_b$. For each basic hemisphere size, then, curves of D_H/D_{nc}, η_R, l/D_{nc}, and D_{no}/D_{nc} can be plotted against $(l/D_n)_b$ by using

$$\frac{D_H}{D_{nc}} = \left(\frac{D_H}{D_n}\right)_b \frac{1}{\sqrt{\left(\frac{w\sqrt{\theta}}{\delta}\right)_R \Big/ \left(\frac{w\sqrt{\theta}}{\delta}\right)_F}}$$

$$\eta_R = \frac{\eta_{R,b}}{\left(\frac{w\sqrt{\theta}}{\delta}\right)_R \Big/ \left(\frac{w\sqrt{\theta}}{\delta}\right)_F}$$

$$\frac{l}{D_{nc}} = \left(\frac{l_b}{D_n}\right)_b \frac{1}{\sqrt{\left(\frac{w\sqrt{\theta}}{\delta}\right)_R \Big/ \left(\frac{w\sqrt{\theta}}{\delta}\right)_F}}$$

and

$$\frac{D_{no}}{D_{nc}} = \frac{1}{\sqrt{\left(\frac{w\sqrt{\theta}}{\delta}\right)_R \Big/ \left(\frac{w\sqrt{\theta}}{\delta}\right)_F}}$$

By entering the latter set of curves at some value of D_H/D_{nc} and crossplotting at a constant $(l/D_n)_b$, corresponding values of η_R, l/D_{nc}, 3729
and D_{no}/D_{nc} can be obtained. Curves of η_R and D_{no}/D_{nc} against l/D_{nc} for various values of D_H/D_{nc} can then be drawn (fig. 6).

REFERENCE

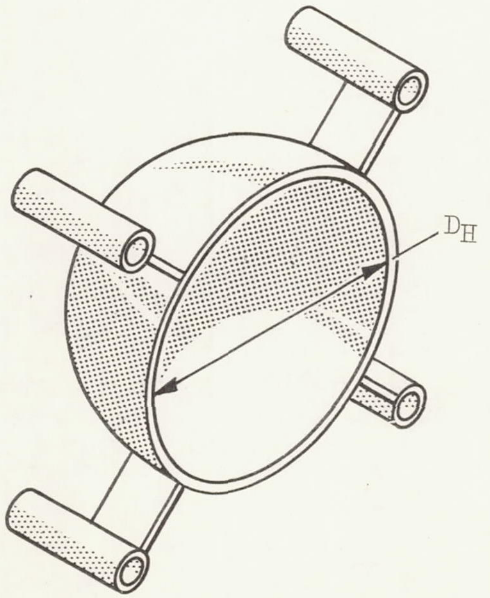
1. Sutter, Joseph: Reverse Thrust for Jet Transports. Paper presented at meeting SAE, New York (N.Y.), Apr. 12-15, 1954.

2. Steffen, Fred W., Krull, H. George, and Ciepluch, Carl C.: Preliminary Investigation of Several Target-Type Thrust-Reversal Devices. NACA RM E53L15b, 1954.

3729

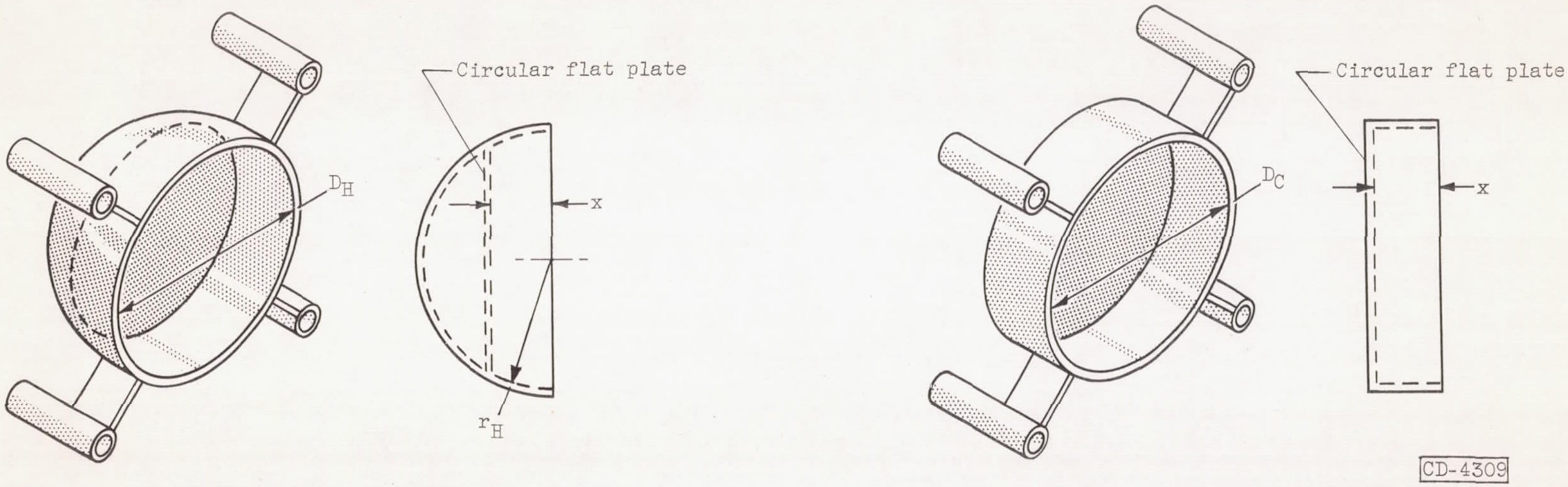
TABLE I. - GEOMETRIES AND DIMENSIONS OF REVERSERS INVESTIGATED

Type	Diameter, D, in.	Flat-plate-location parameter, x/r
Hemisphere	5.5	----
	6.0	----
	6.7	----
	7.1	----
	7.6	----
	8.2	----
Hemisphere with flat plate	6.0	0.50
	6.0	.34
	6.0	.17
	6.7	.50
Cylinder with flat plate	6.0	0.56



CD-4309

Figure 1. - Typical model of hemispherical thrust reverser.



(a) Flat plate in hemisphere.

(b) Flat plate in cylinder.

Figure 2. - Typical models used to investigate effects of inserting a flat plate in hemisphere and cylinder.

3729

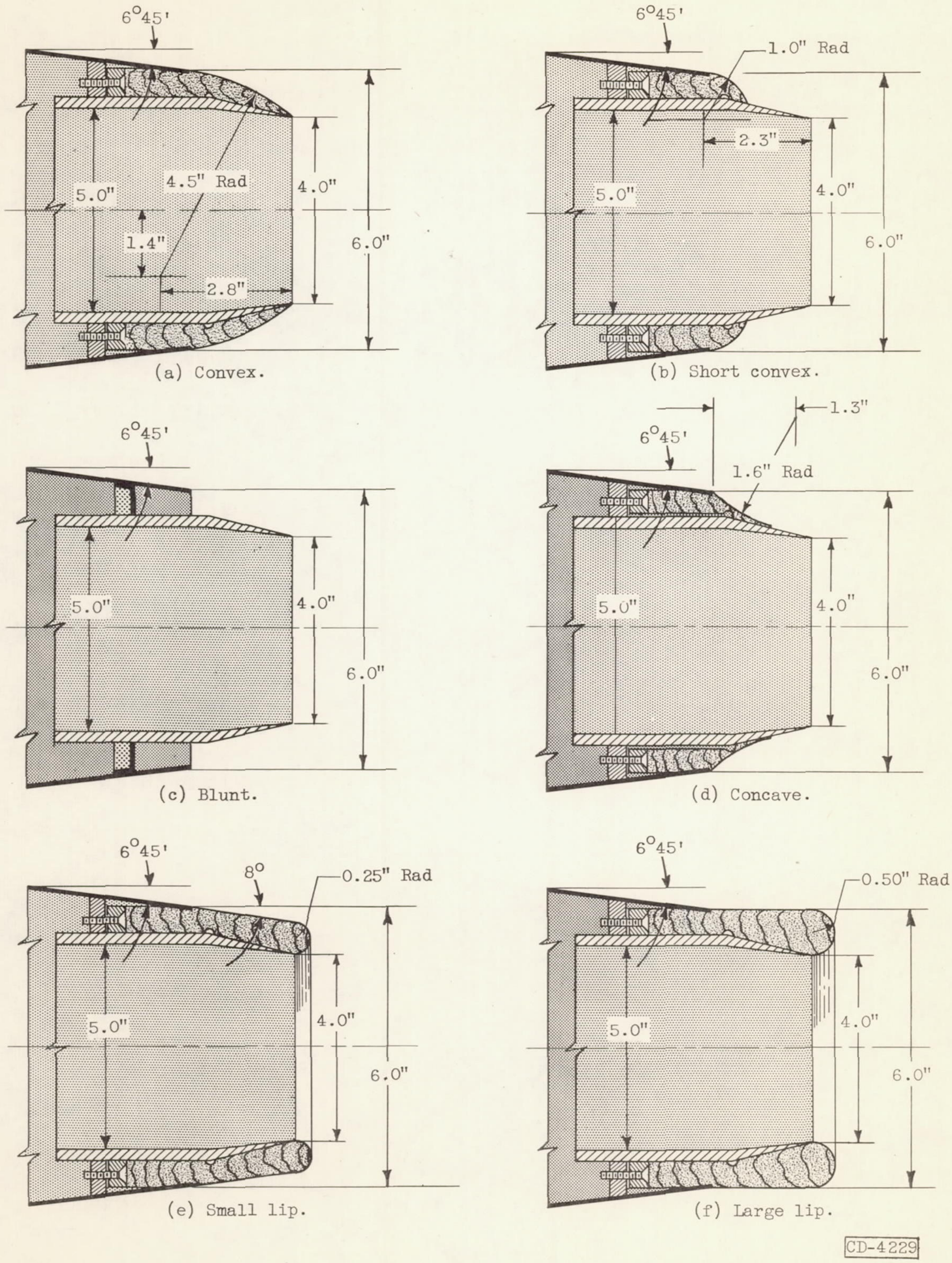


Figure 3. - Configurations used to study effects of boattail shape on reverse-thrust ratio.

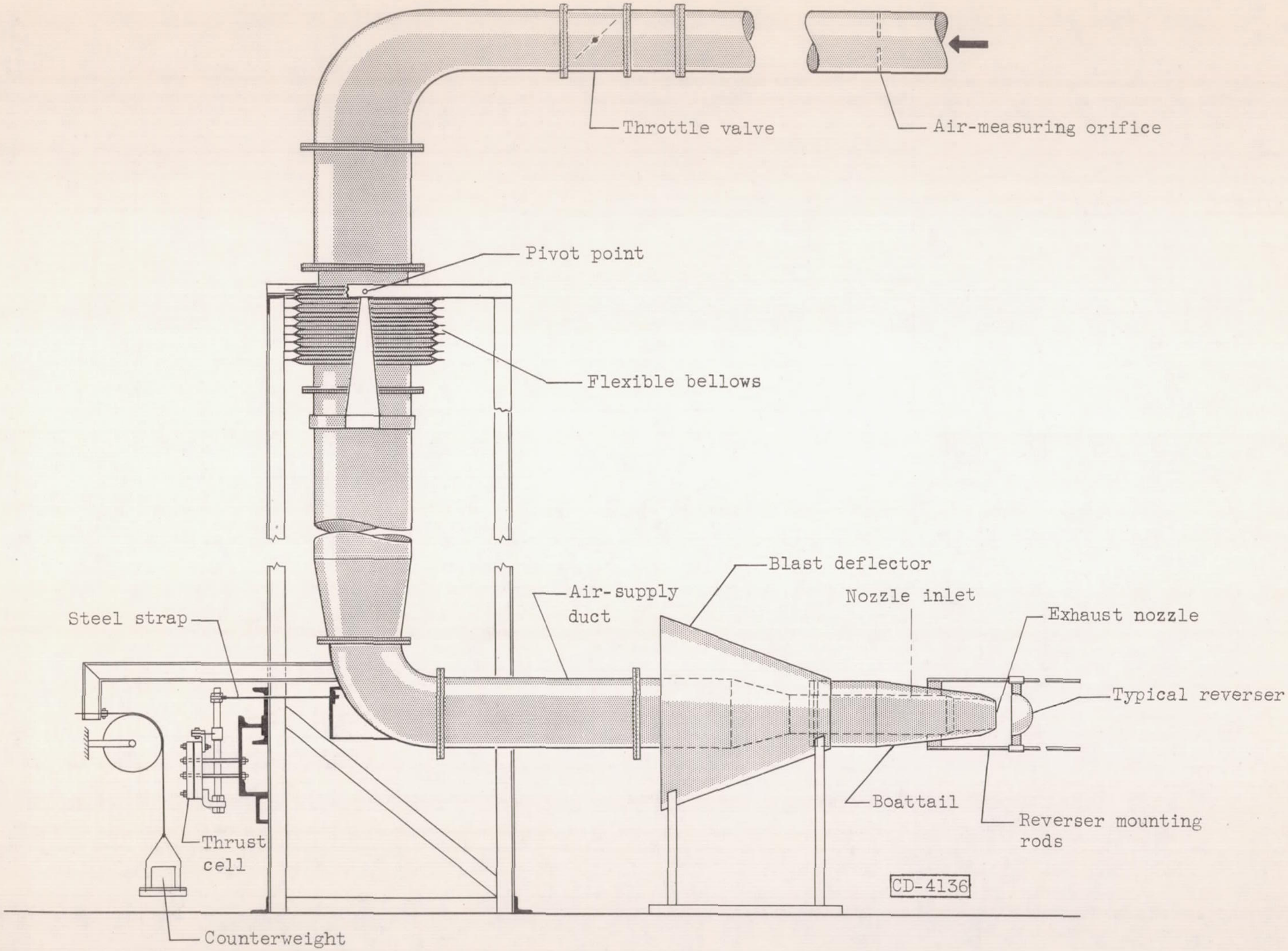


Figure 4. - Schematic diagram of setup for thrust-reversal investigation.

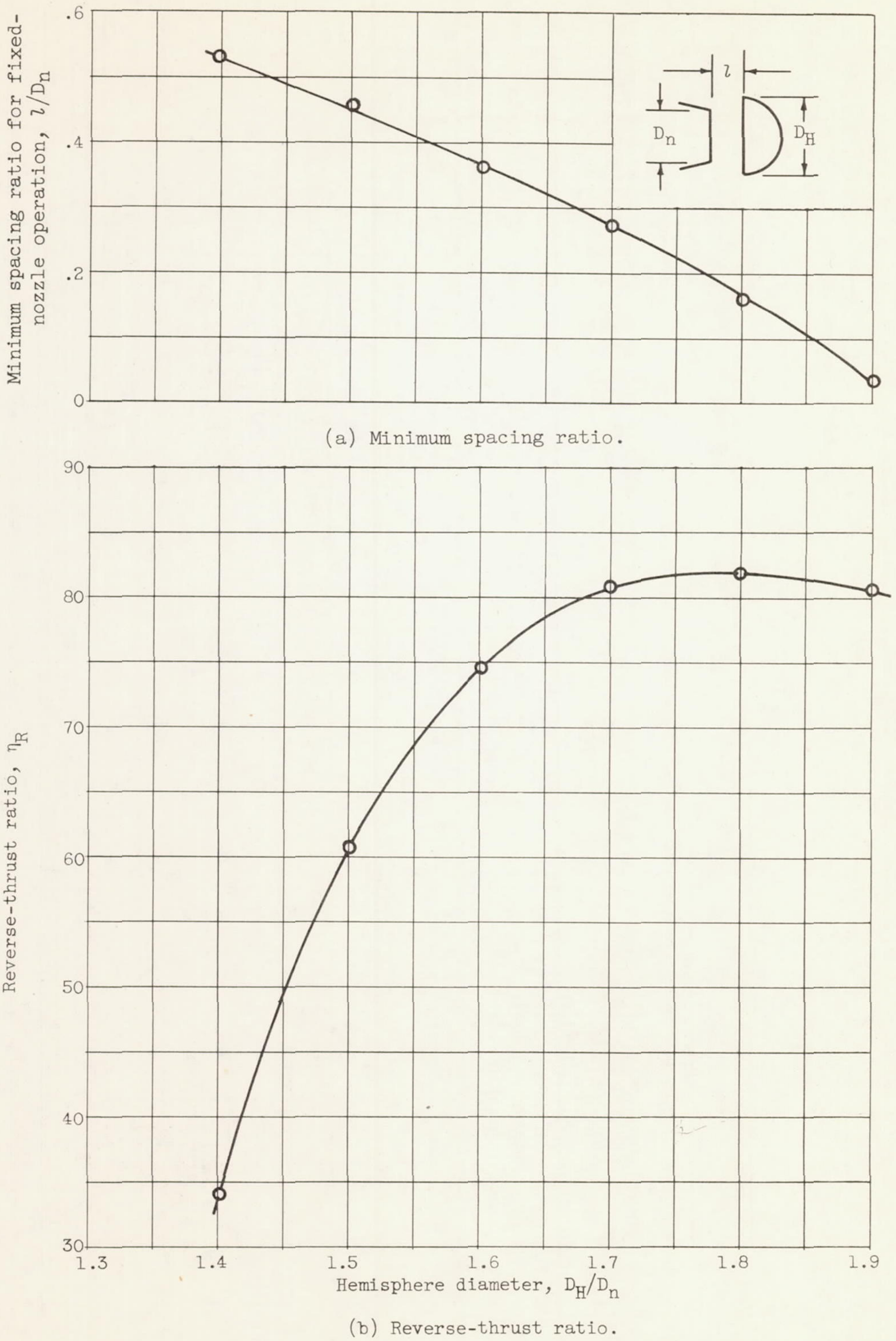
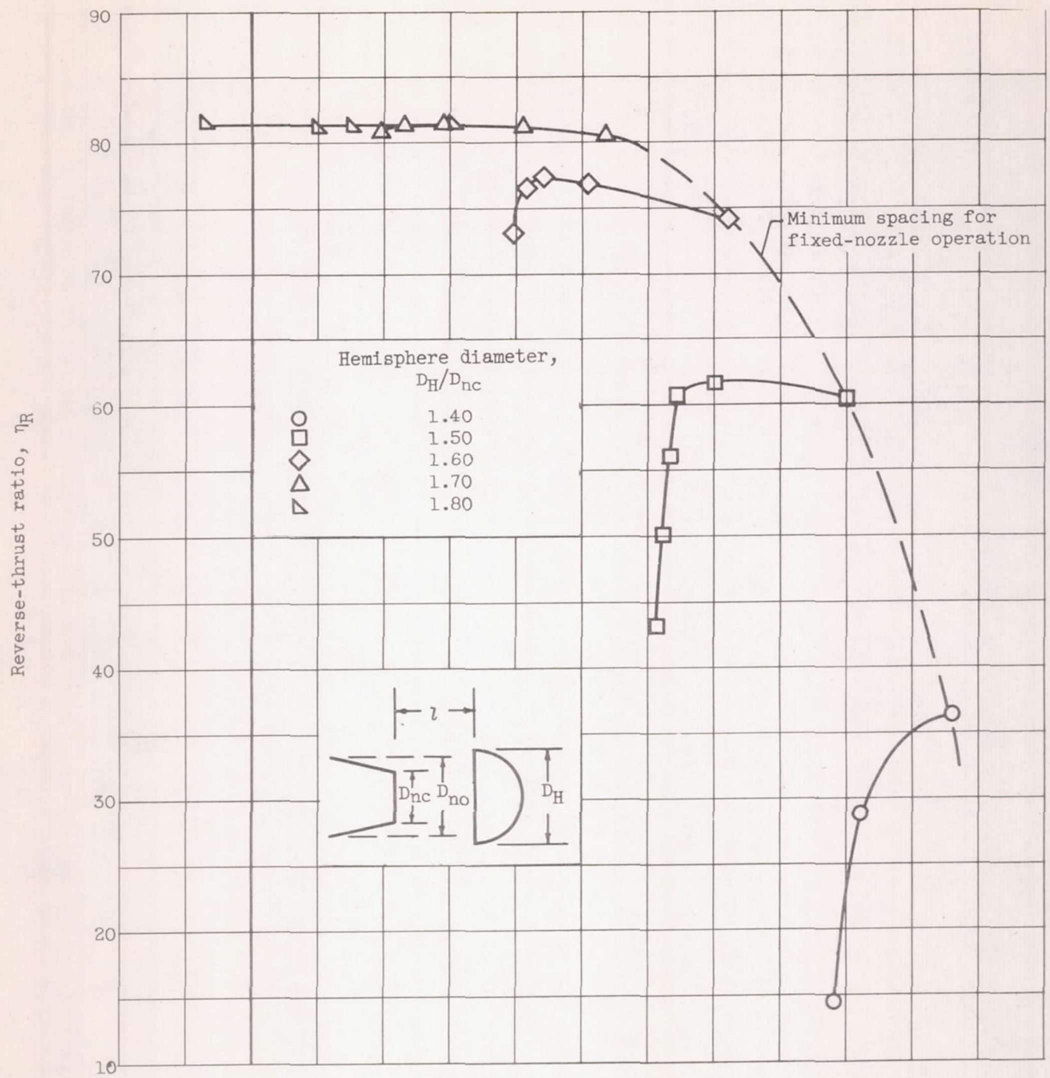
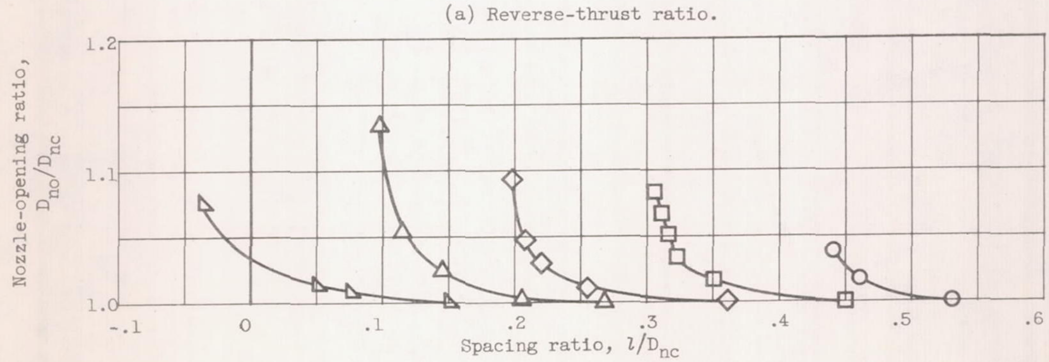


Figure 5. - Minimum spacing required for fixed-nozzle operation and reverse-thrust ratios obtained for various-size hemispherical reversers. Exhaust-nozzle pressure ratio, 2.0.

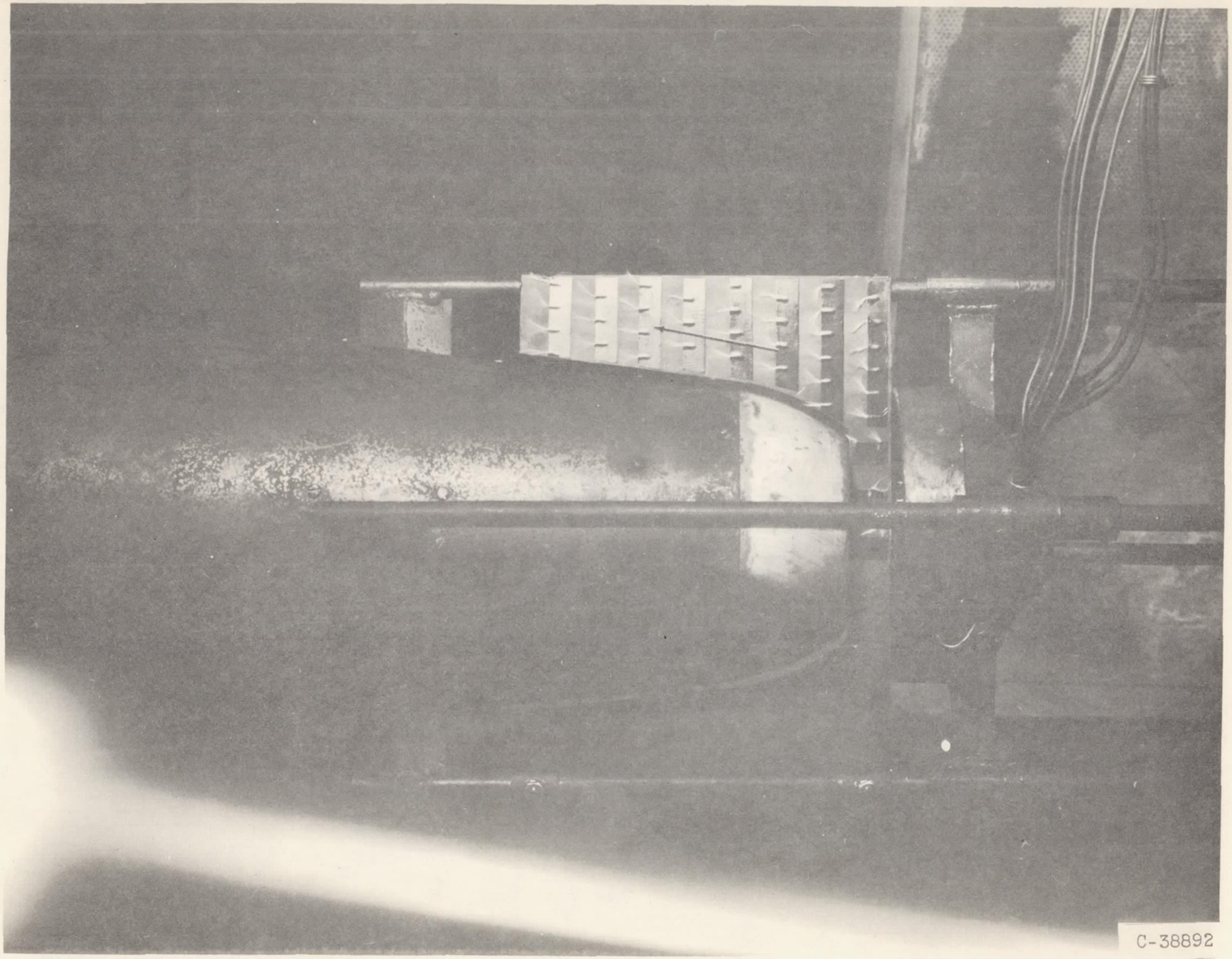


(a) Reverse-thrust ratio.



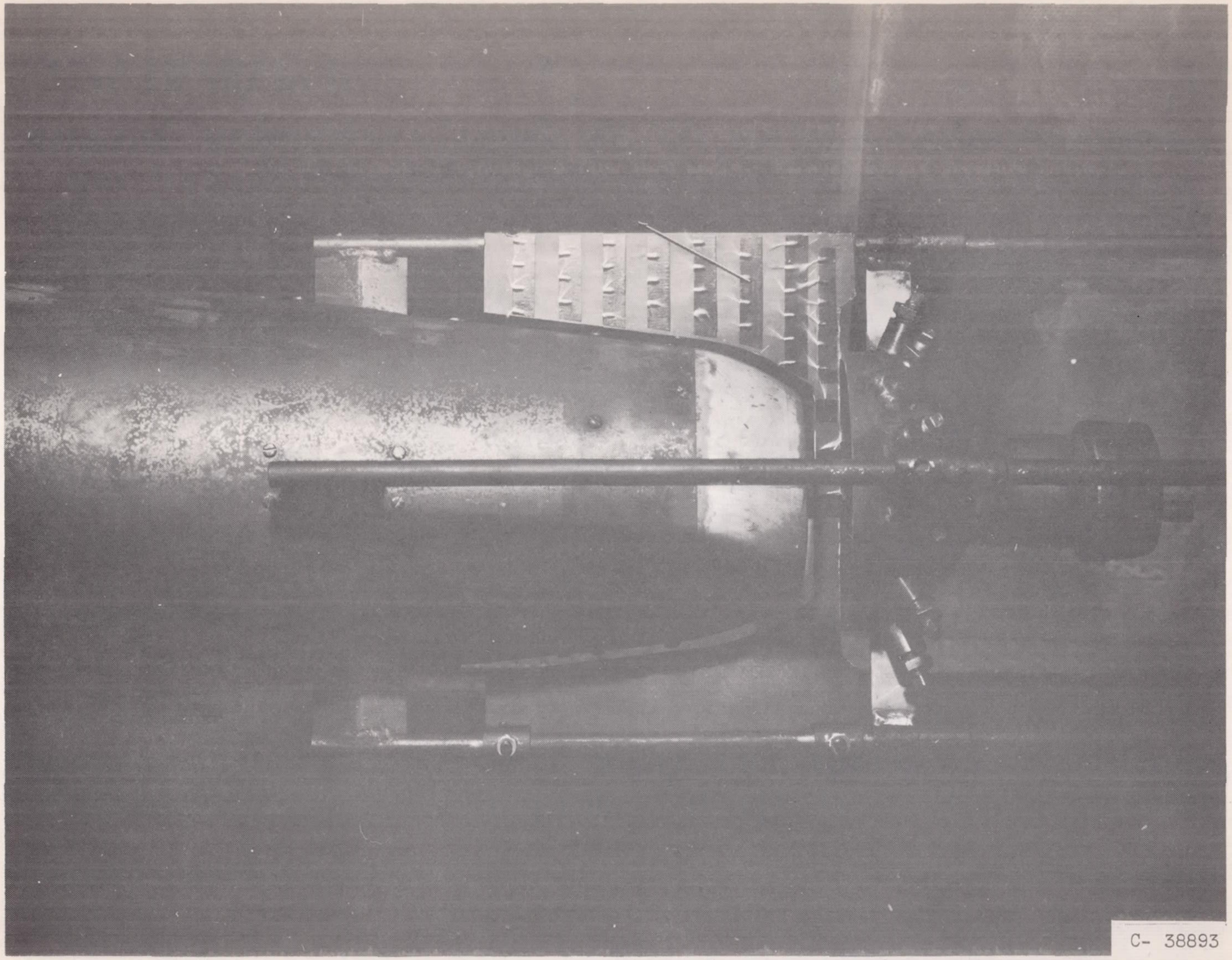
(b) Nozzle-opening ratio.

Figure 6. - Reverse-thrust ratios obtained with variable-area nozzle, and nozzle openings and spacings required to maintain constant turbine temperature. Exhaust-nozzle pressure ratio, 2.0.



(a) Large spacing ratio.

Figure 7. - Effect of spacing on flow turn angle. Exhaust-nozzle pressure ratio, 1.4.



(b) Small spacing ratio.

Figure 7. - Concluded. Effect of spacing on flow turn angle. Exhaust-nozzle pressure ratio, 1.4.

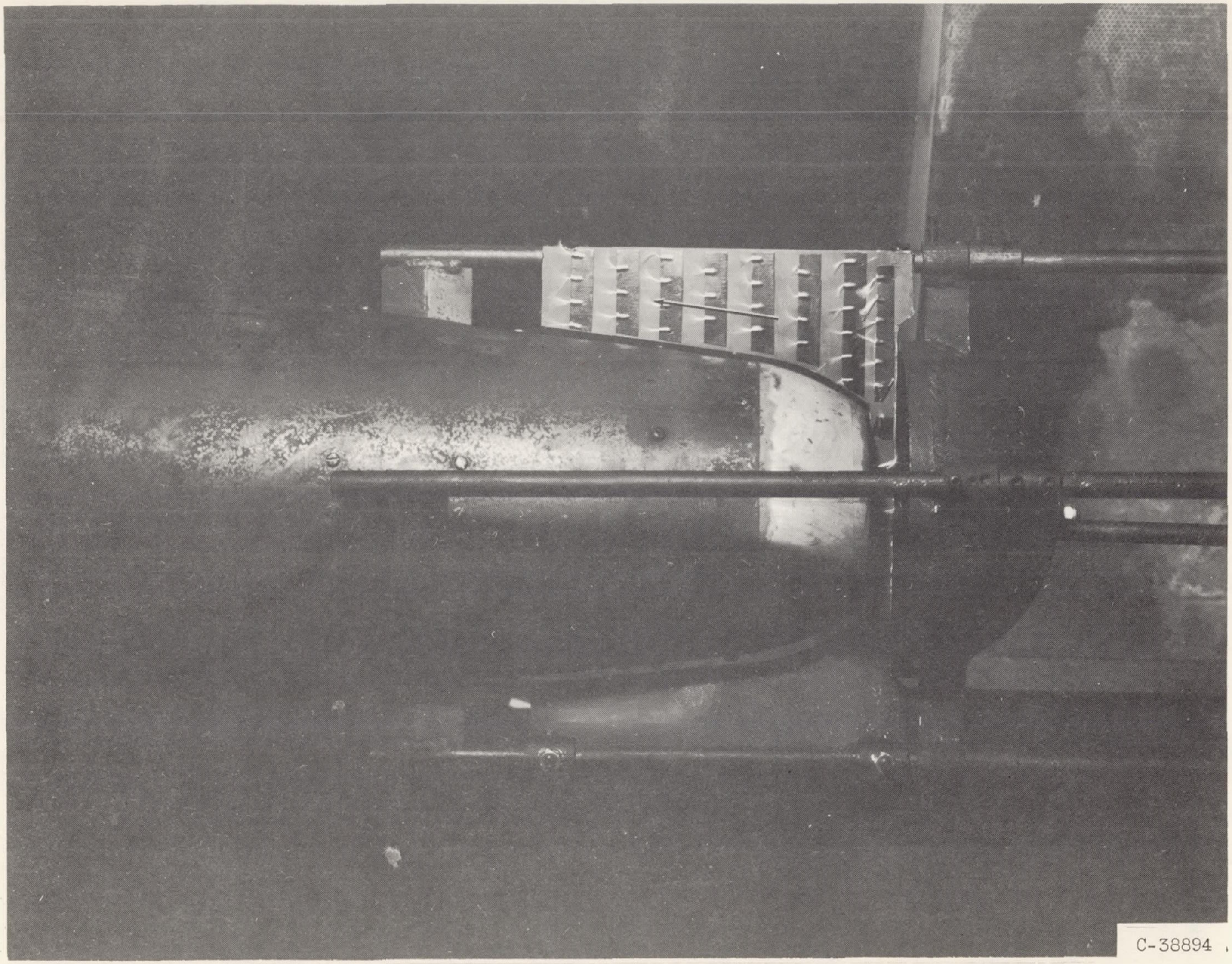


Figure 8. - Effect of large hemisphere on flow turn angle. Exhaust-nozzle pressure ratio, 1.4.

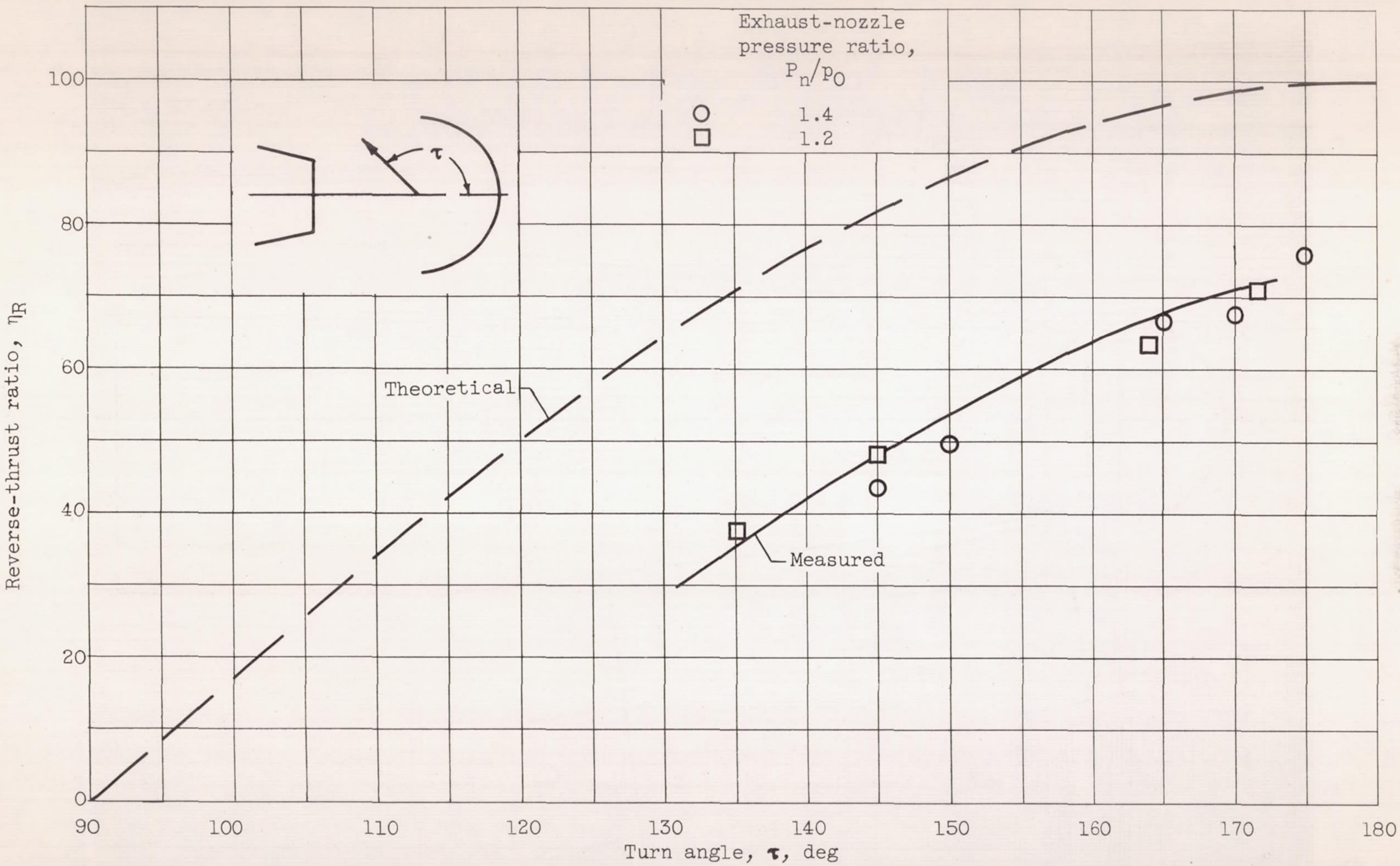
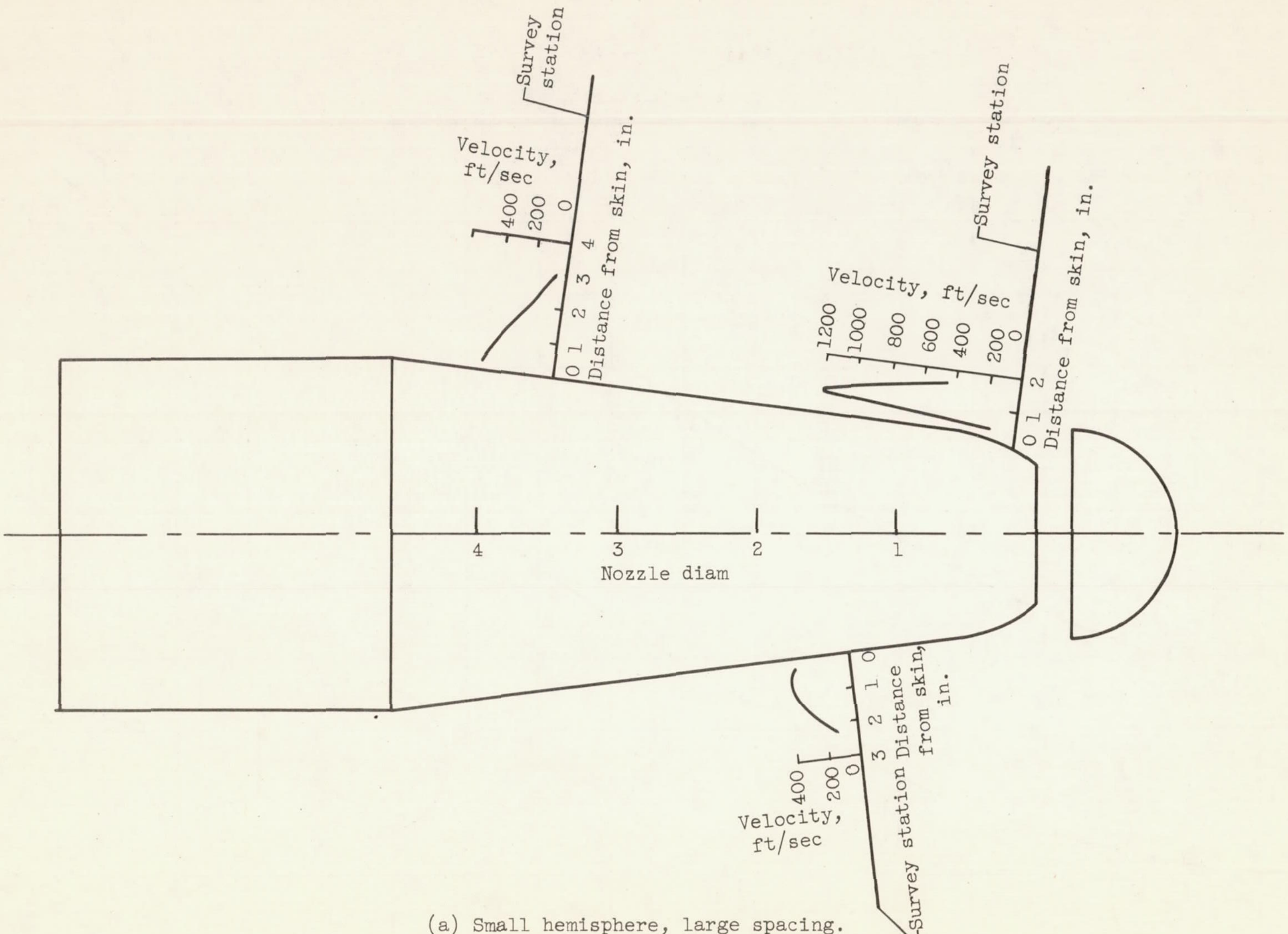
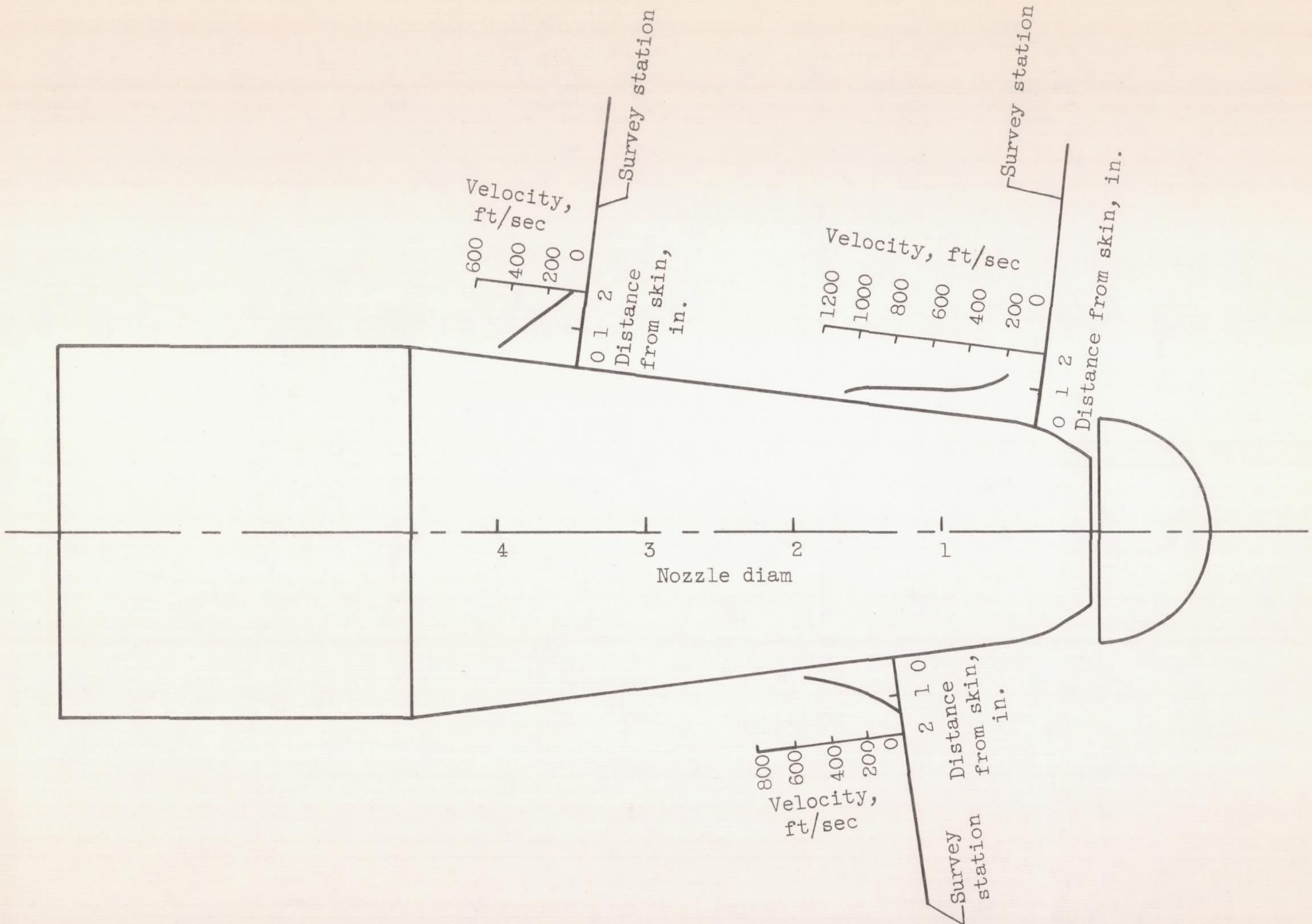


Figure 9. - Relation of reverse-thrust ratio to turn angle.



(a) Small hemisphere, large spacing.

Figure 10. - Reverse-flow velocities along convex boattail during reverse-thrust operation. Exhaust-nozzle pressure ratio, 2.0.



(b) Large hemisphere, small spacing.

Figure 10. - Concluded. Reverse-flow velocities along convex boattail during reverse-thrust operation. Exhaust-nozzle pressure ratio, 2.0.

3729

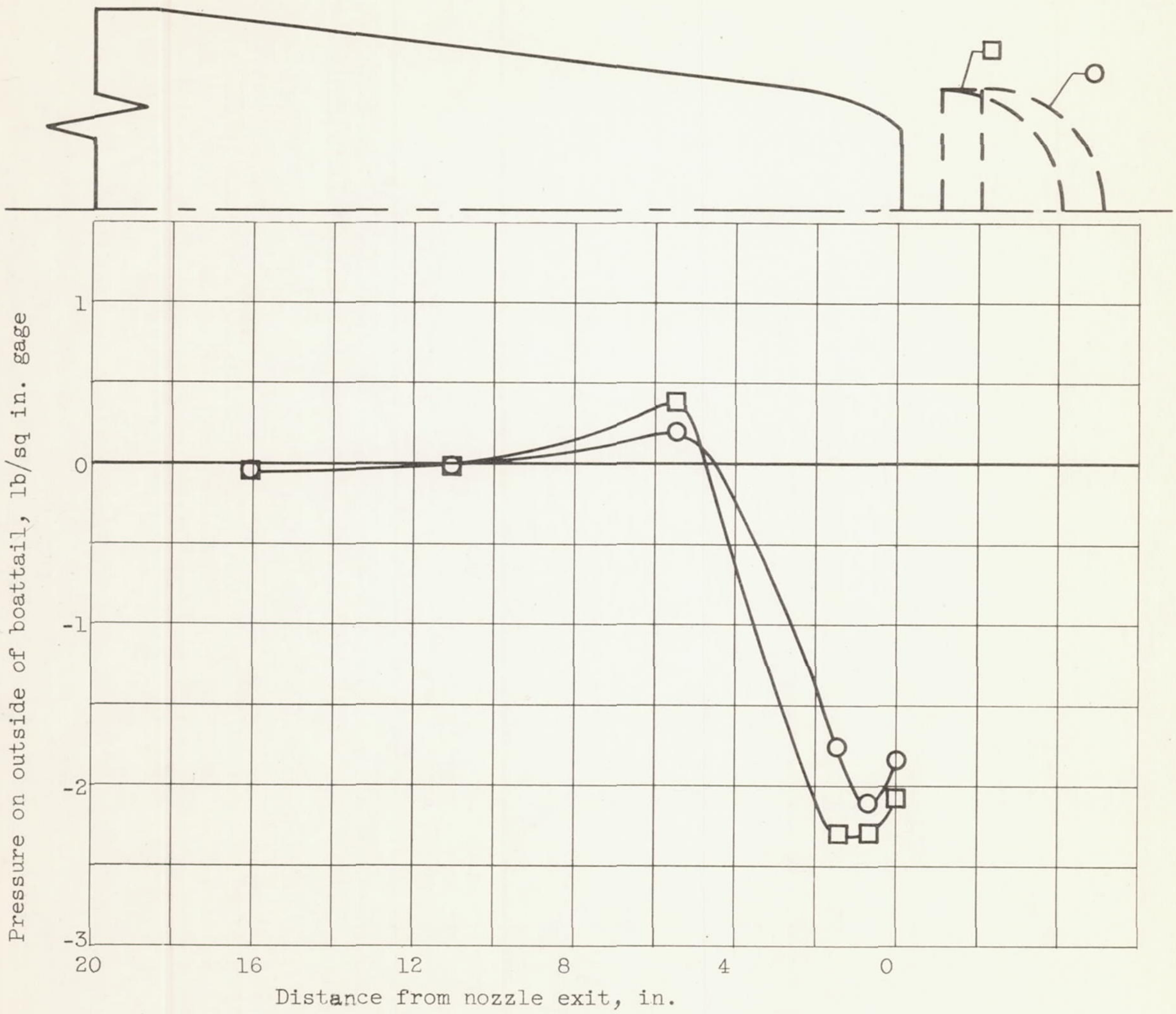


Figure 11. - Static-pressure distribution along convex boattail during reverse-thrust operation. Exhaust-nozzle pressure ratio, 2.0.

3729

CA-4 back

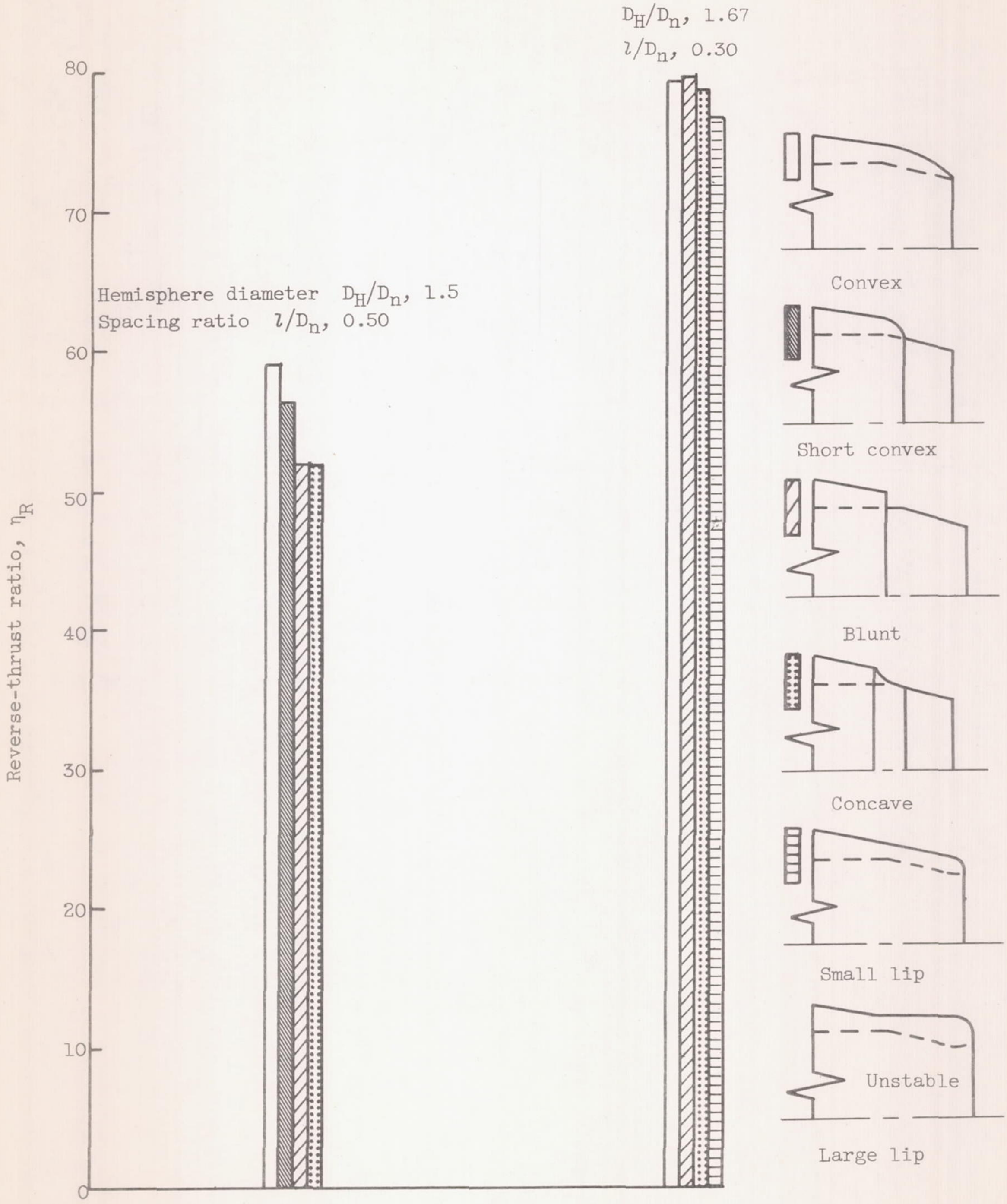


Figure 12. - Effect of boattail shape on reverse-thrust ratio. Exhaust-nozzle pressure ratio, 2.0.

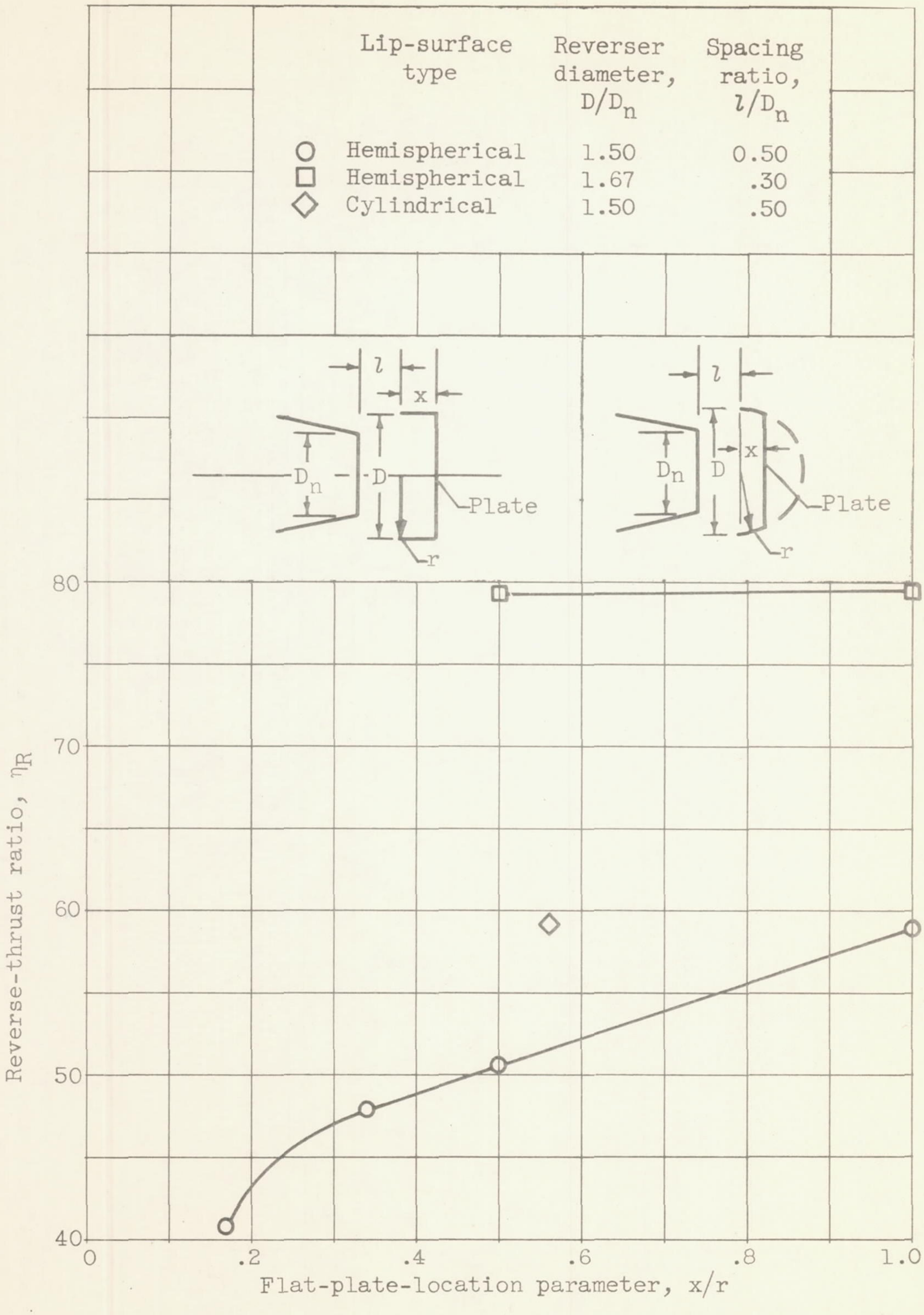
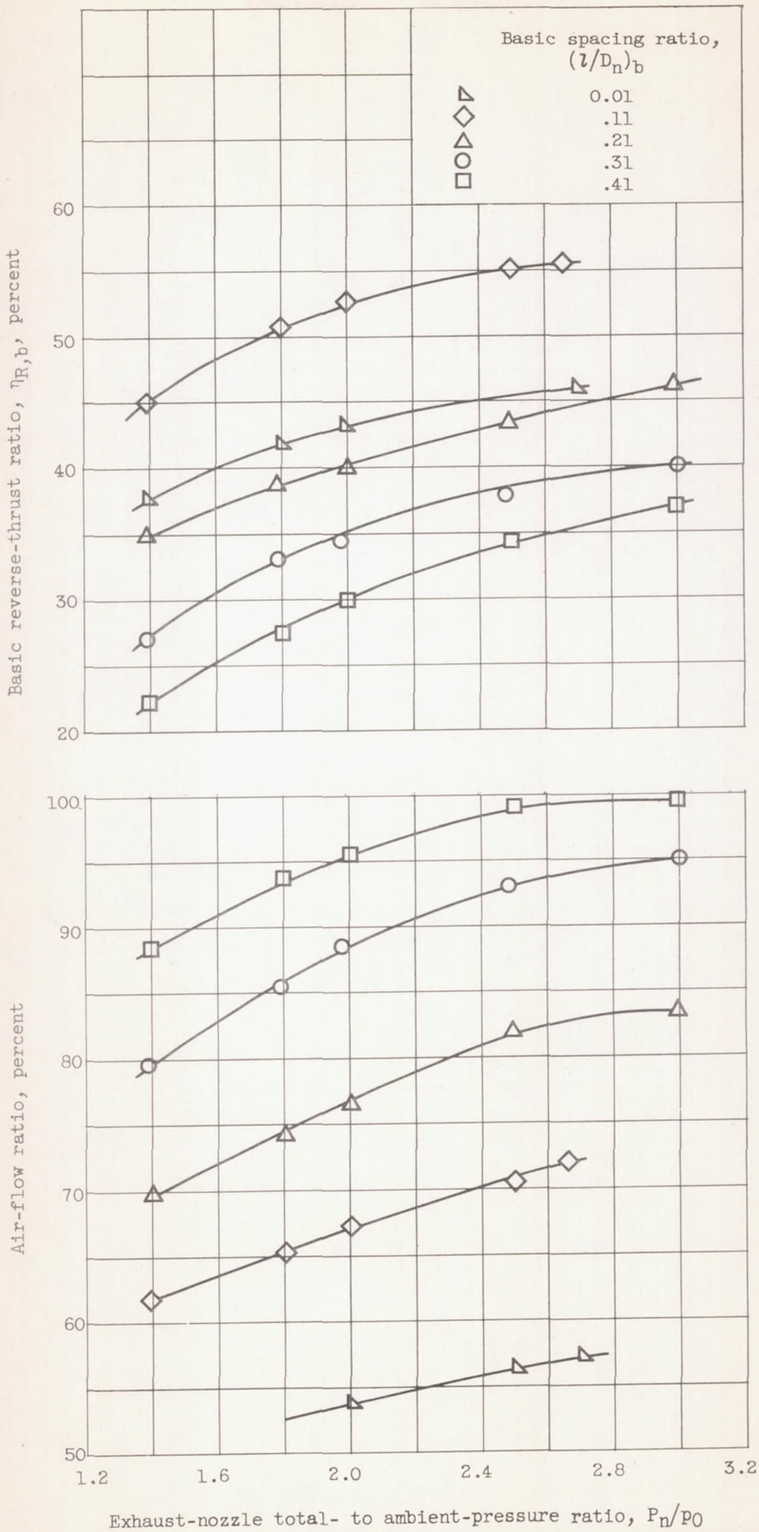
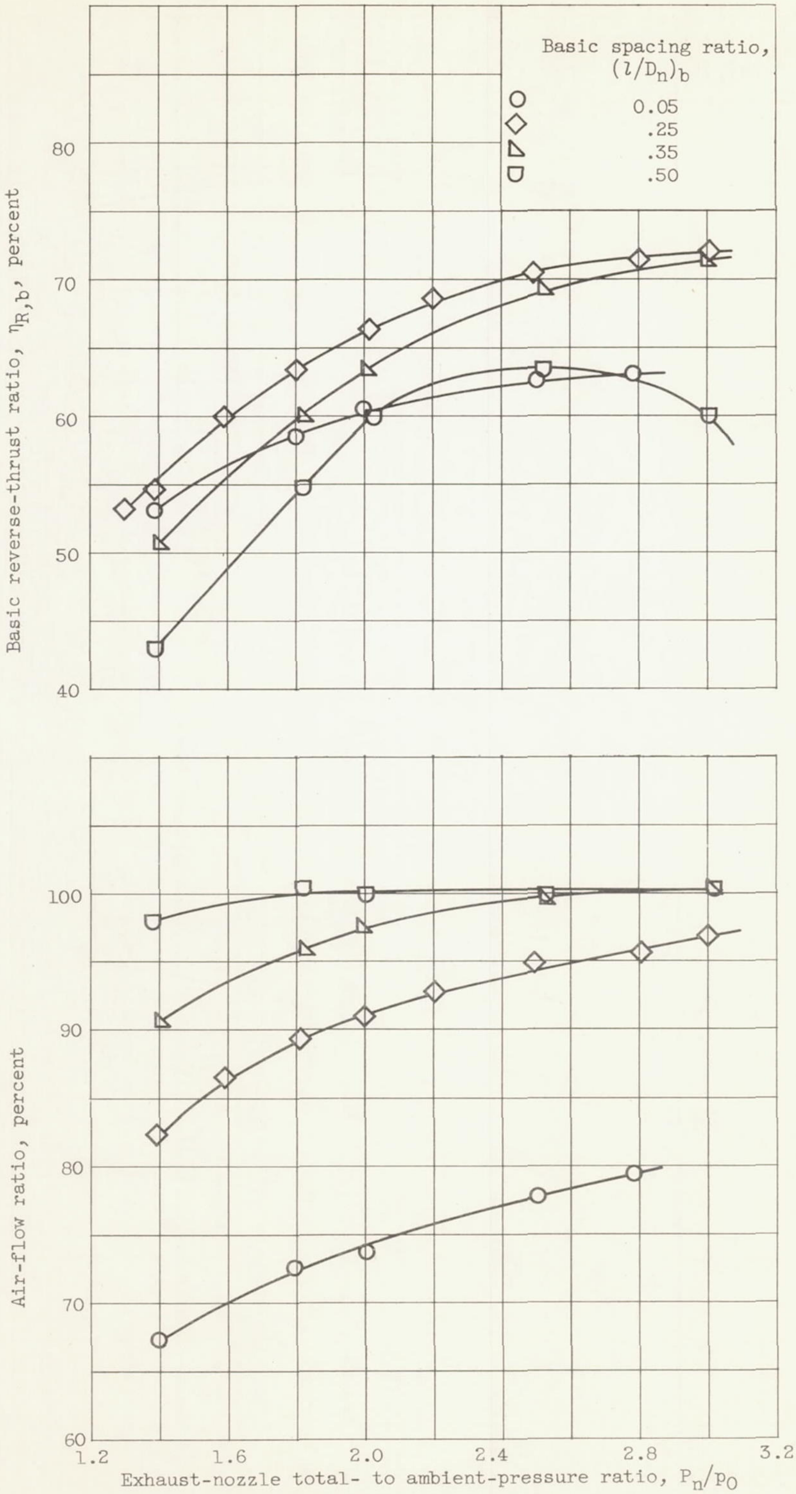


Figure 13. - Effect of installing flat plates at various positions in thrust reverser. Exhaust-nozzle pressure ratio, 2.0.



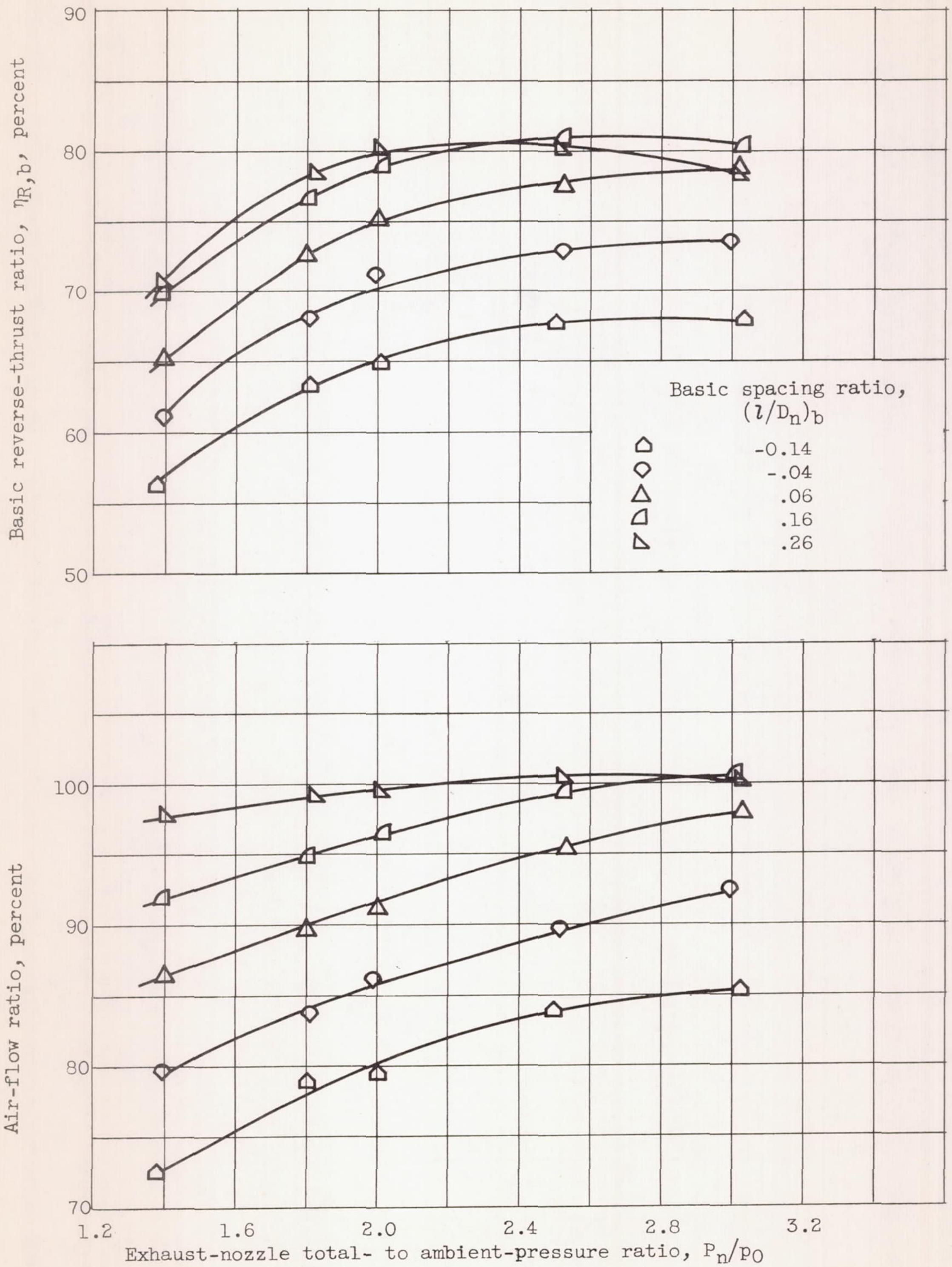
(a) Basic hemisphere diameter, 1.38 basic nozzle diameter.

Figure 14. - Performance of hemispherical thrust reverser.



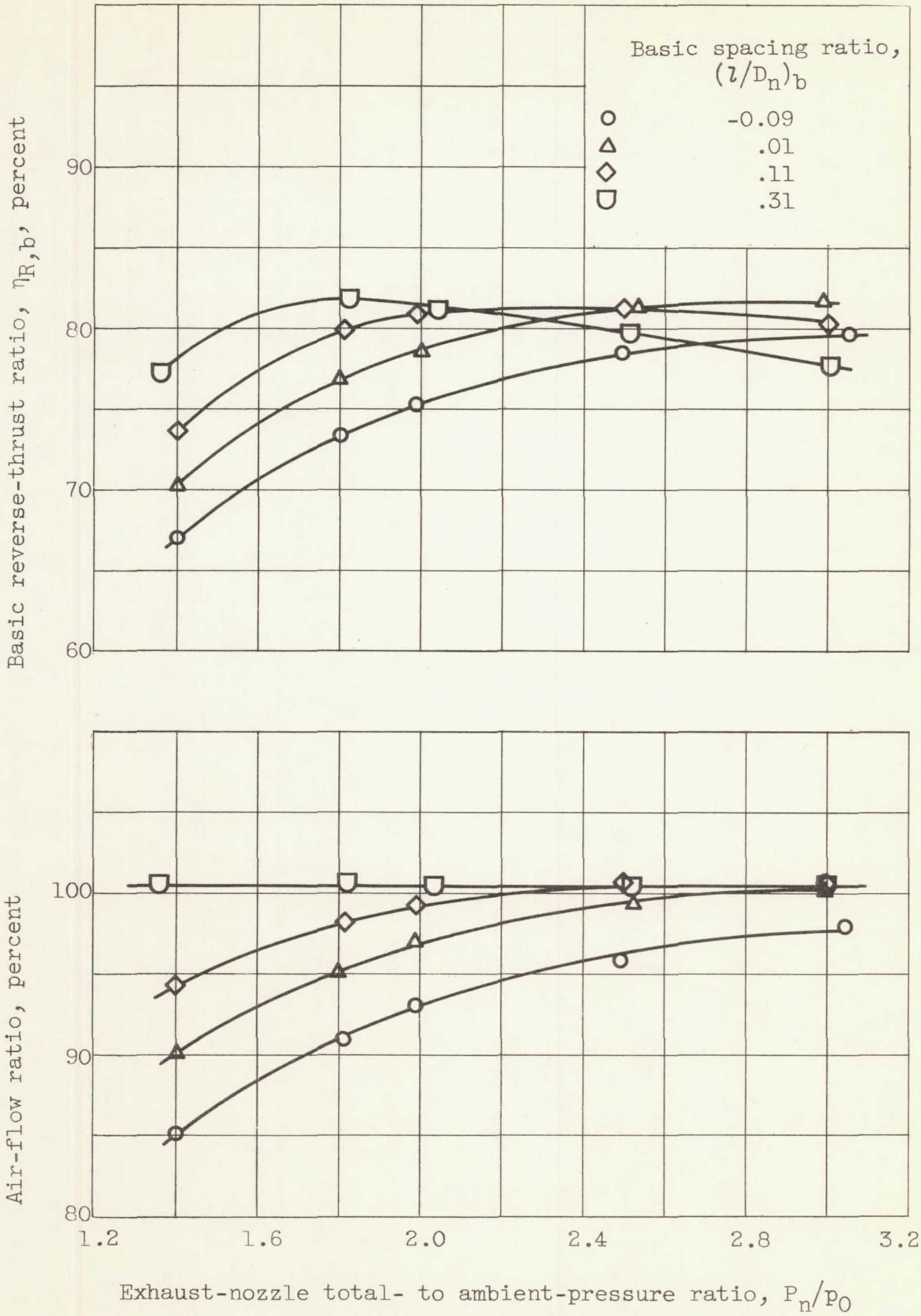
(b) Basic hemisphere diameter, 1.50 basic nozzle diameter.

Figure 14. - Continued. Performance of hemispherical thrust reverser.



(c) Basic hemisphere diameter, 1.67 basic nozzle diameter.

Figure 14. - Continued. Performance of hemispherical thrust reverser.

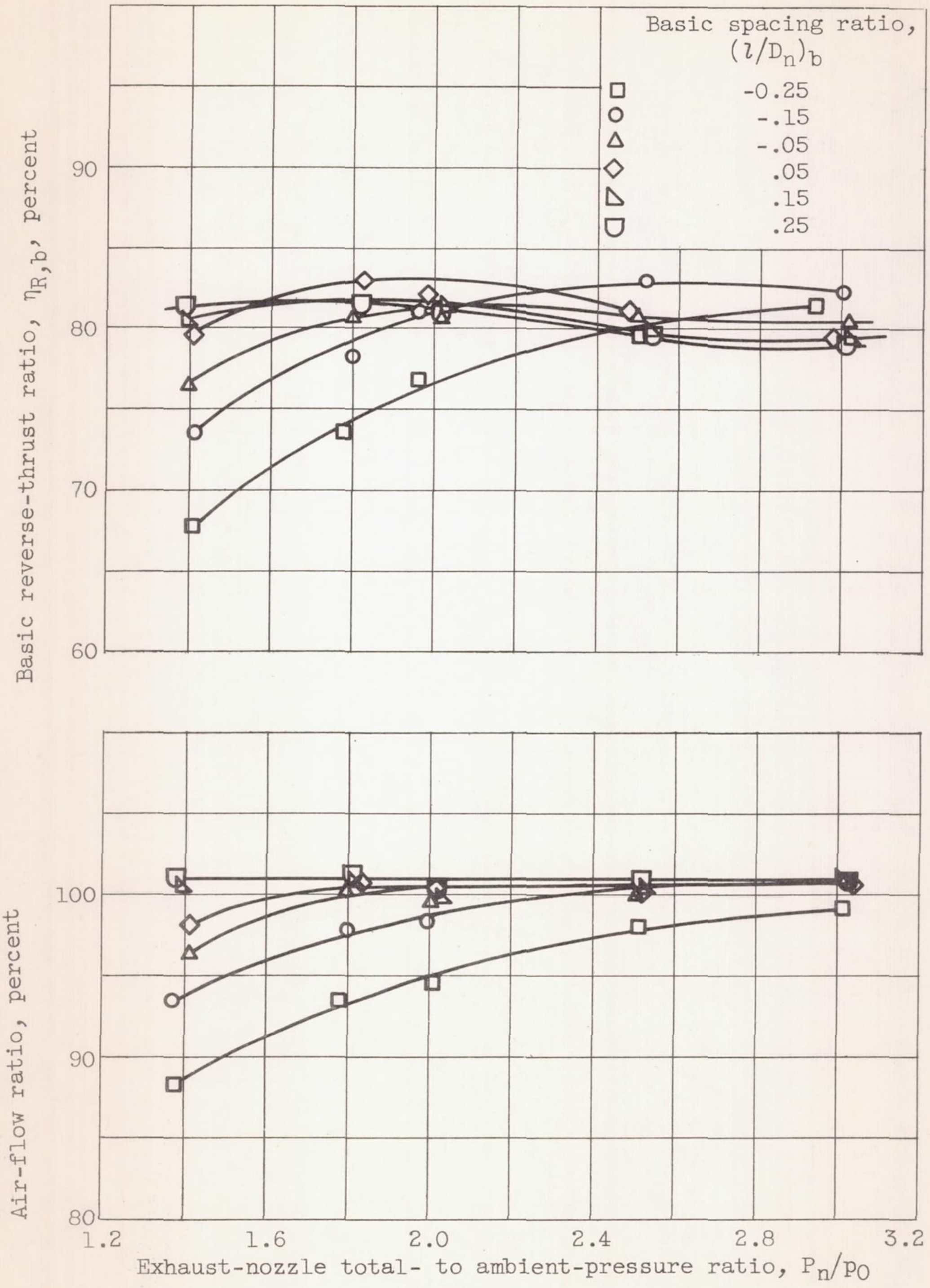


(d) Basic hemisphere diameter, 1.78 basic nozzle diameter.

Figure 14. - Continued. Performance of hemispherical thrust reverser.

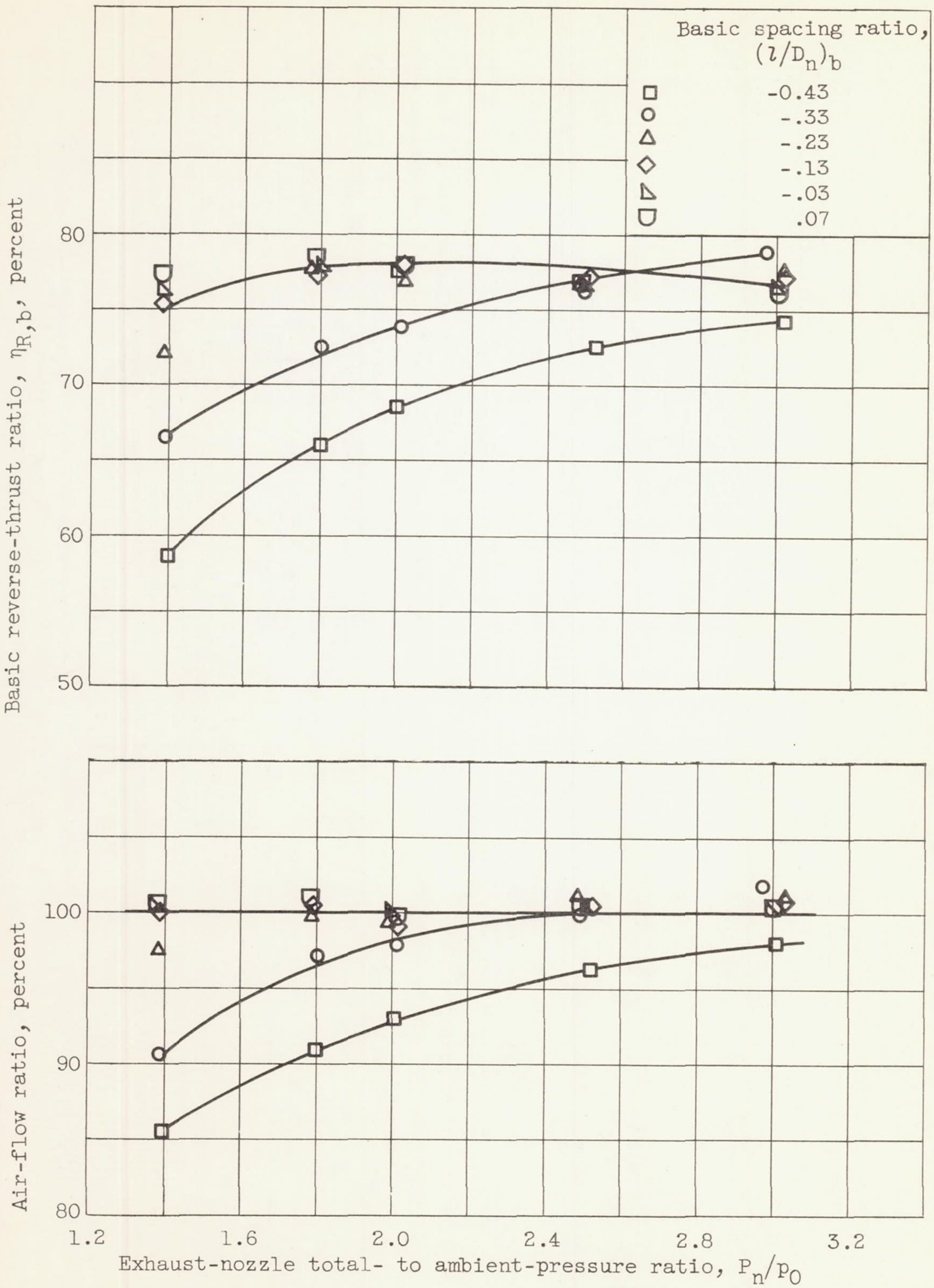
3729

CA-5



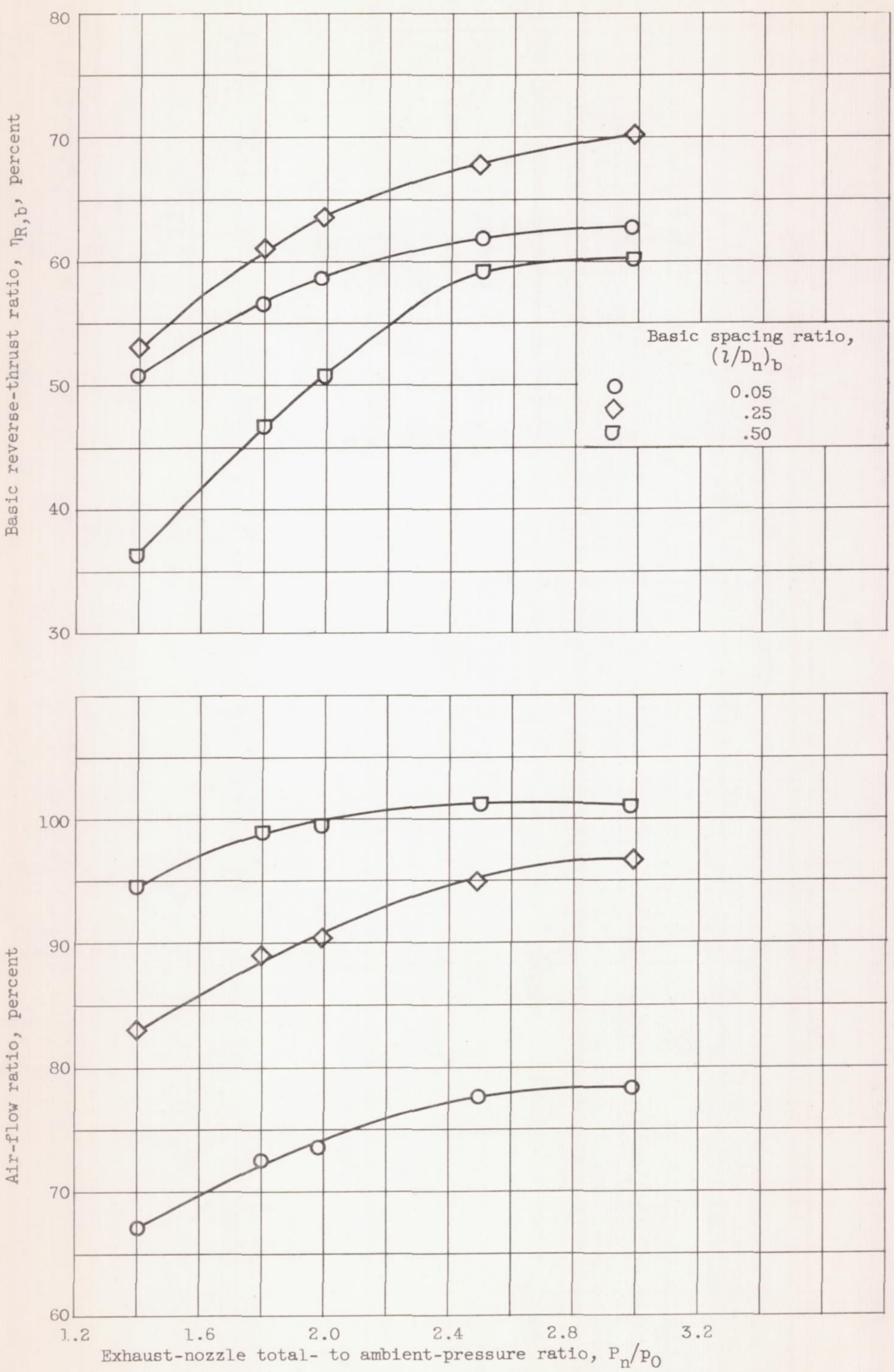
(e) Basic hemisphere diameter, 1.90 basic nozzle diameter.

Figure 14. - Continued. Performance of hemispherical thrust reverser.



(f) Basic hemisphere diameter, 2.00 basic nozzle diameter.

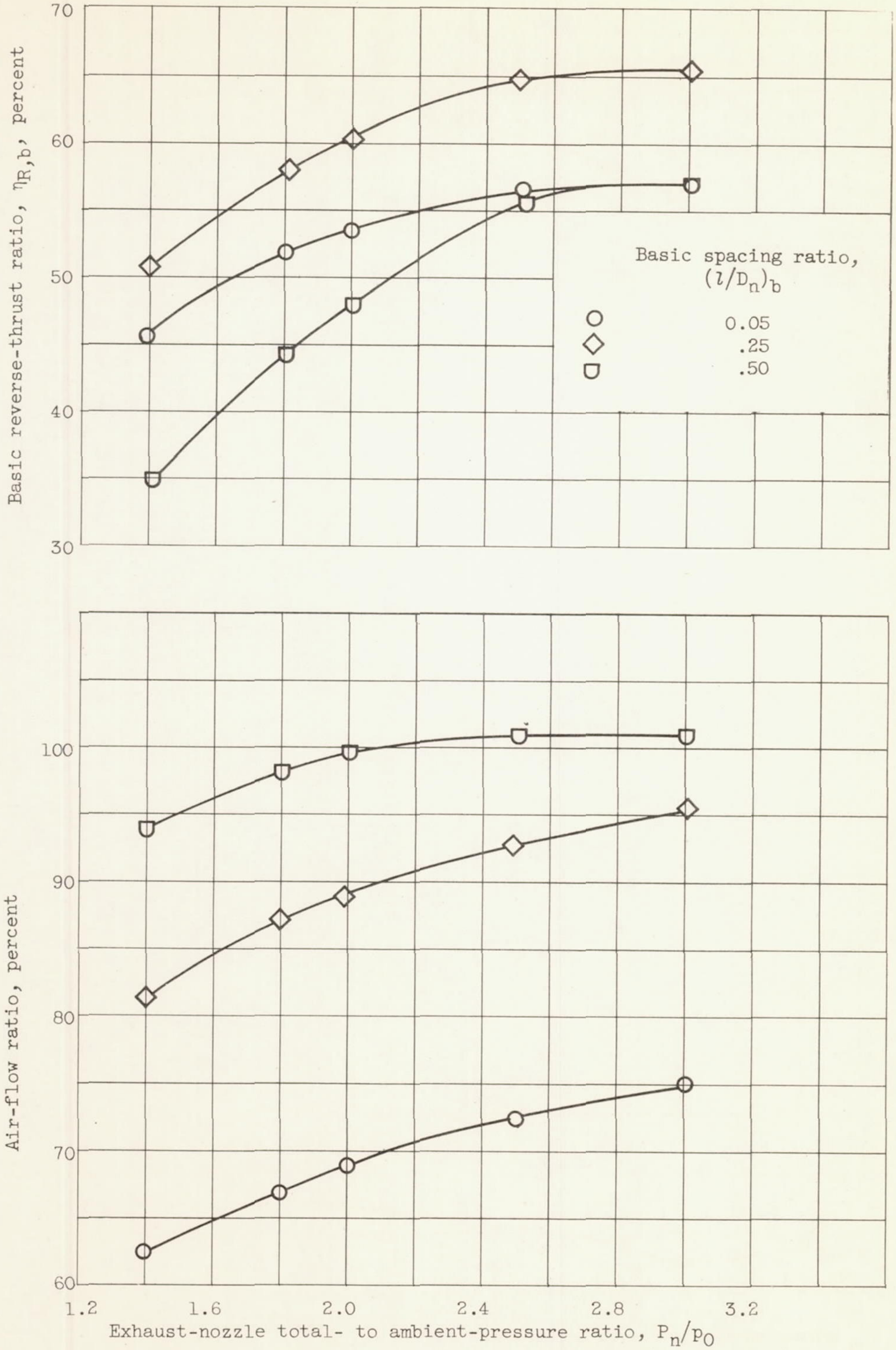
Figure 14. - Concluded. Performance of hemispherical thrust reverser.



(a) Basic hemisphere diameter, 1.50 basic nozzle diameter; flat-plate-location parameter, 0.50.

Figure 15. - Performance of hemispherical thrust reverser with flat plate installed.

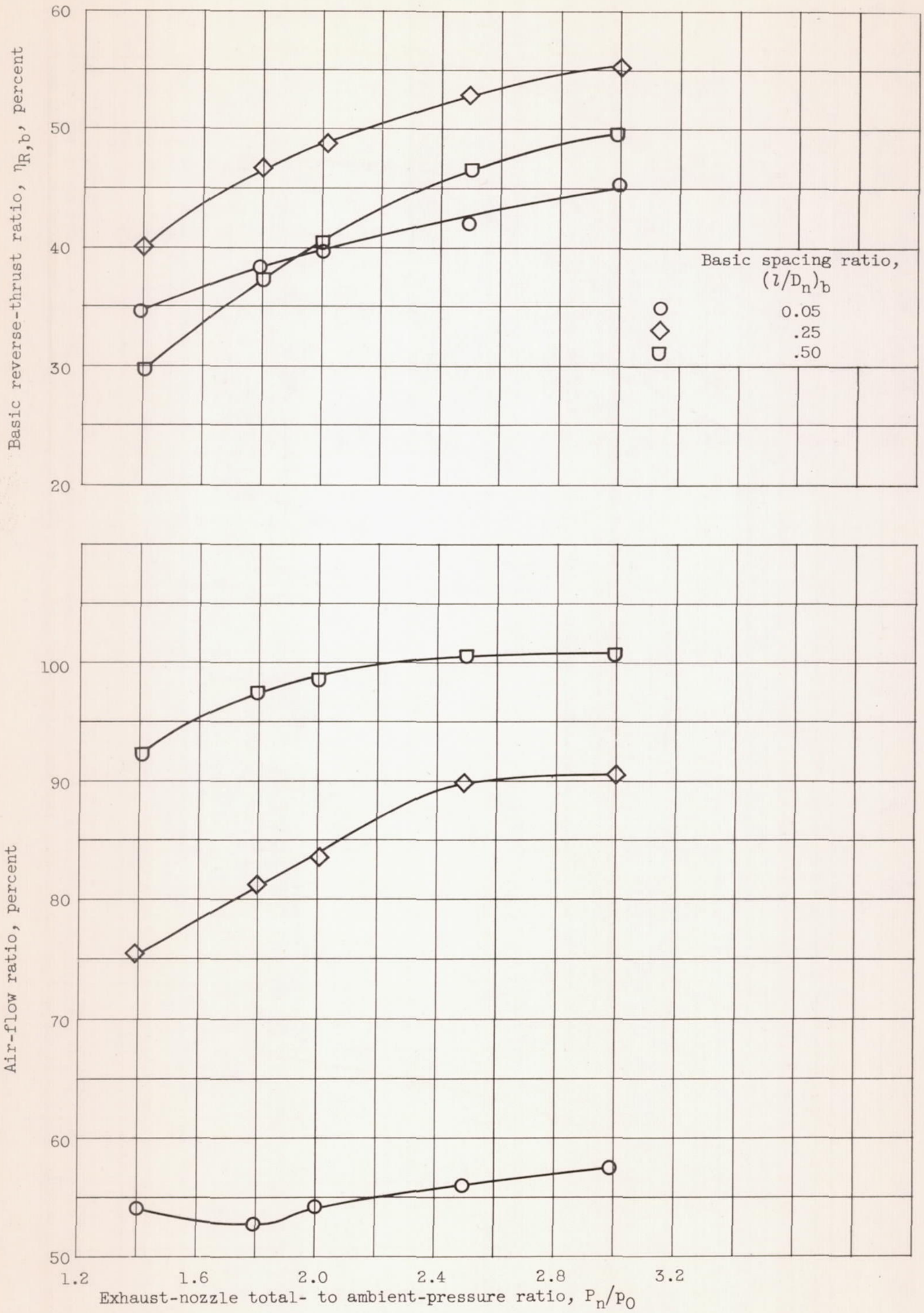
3729



(b) Basic hemisphere diameter, 1.50 basic nozzle diameter; flat-plate-location parameter, 0.34.

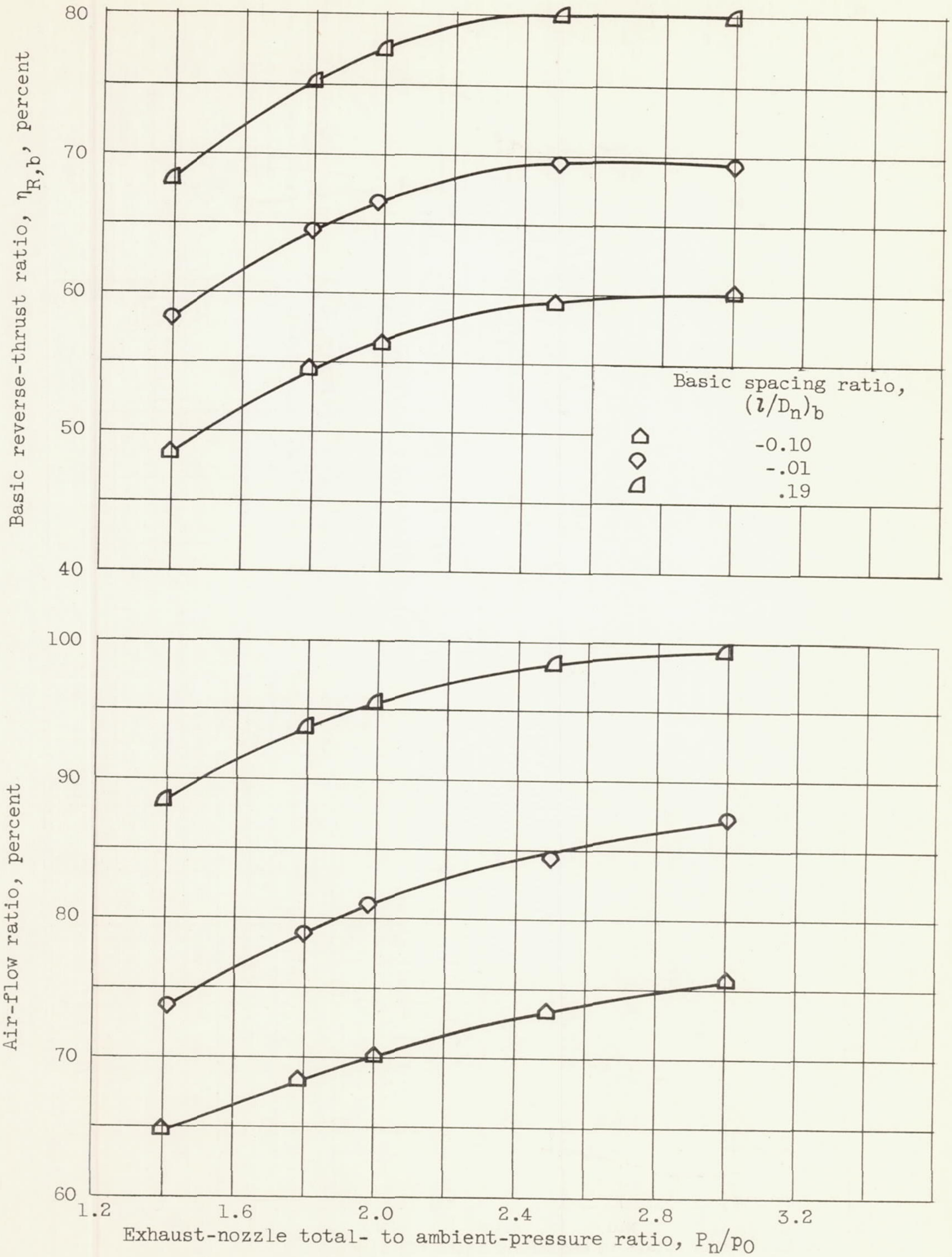
Figure 15. - Continued. Performance of hemispherical thrust reverser with flat plate installed.

3729



(c) Basic hemisphere diameter, 1.50 basic nozzle diameter; flat-plate-location parameter, 0.17.

Figure 15. - Continued. Performance of hemispherical thrust reverser with flat plate installed.



(d) Basic hemisphere diameter, 1.67 basic nozzle diameter; flat-plate-location parameter, 0.50.

Figure 15. - Concluded. Performance of hemispherical thrust reverser with flat plate installed.

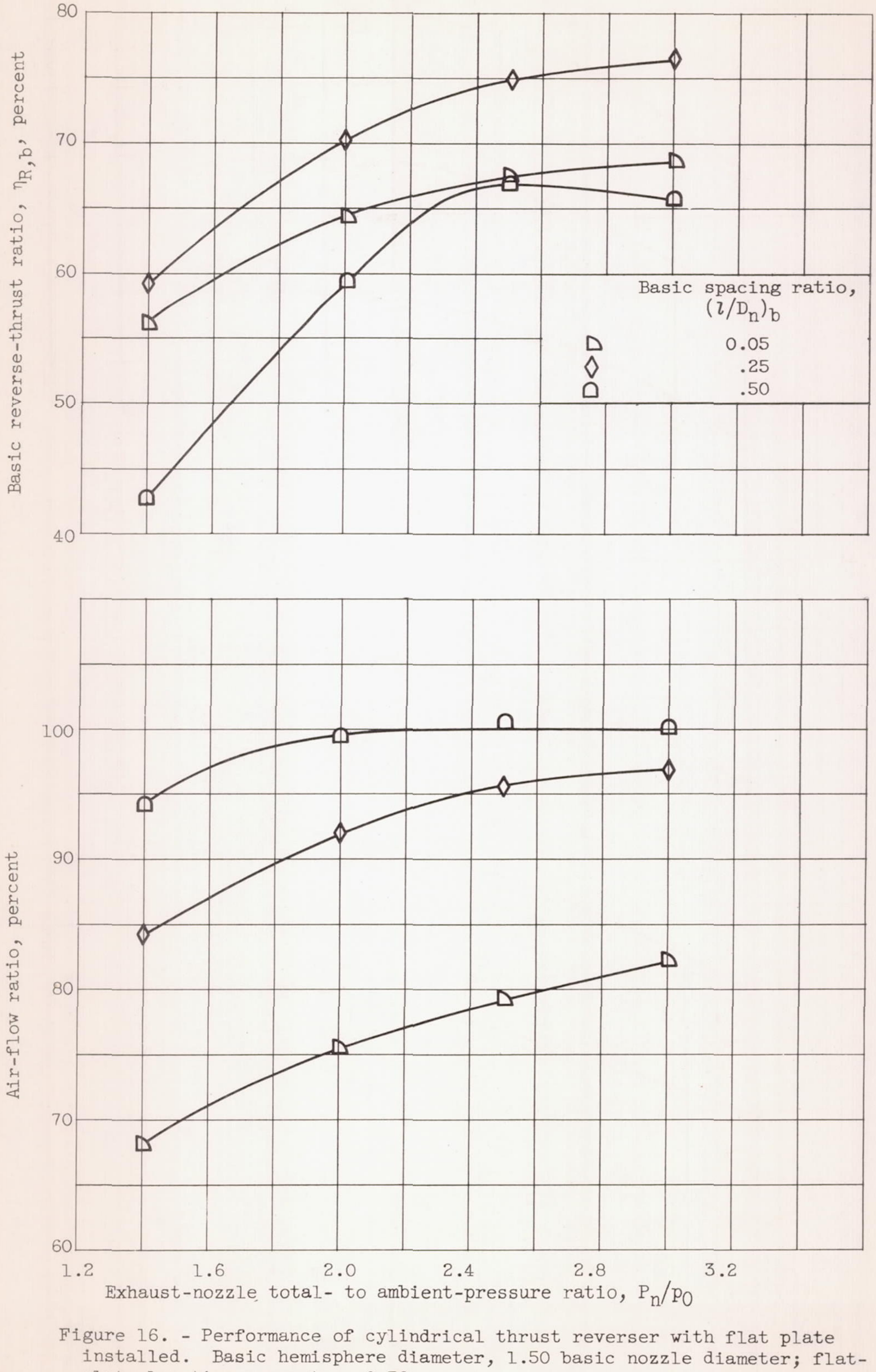


Figure 16. - Performance of cylindrical thrust reverser with flat plate installed. Basic hemisphere diameter, 1.50 basic nozzle diameter; flat-plate-location parameter, 0.56.