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RESEARCH MEMORANDUM

PERFORMANCE CHARACTERISTICS OF CYLINDRICAL TARGET-TYPE THRUST REVERSERS

By Fred W. Steffen and Jack G. McArdle

Lewis Flight Propulsion Laboratory
Cleveland, Ohio

NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS
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SUMMARY

On the basis of preliminary investigations, it was concluded that cylindrical target-type thrust reversers would provide good thrust-reversal characteristics and, at the same time, be amenable to satisfactory stowage in the aircraft. An investigation was conducted, therefore, to determine the performance of cylindrical target-type thrust reversers over a wide range of geometric design variables. It was determined that the ratio of the frontal area of the reverser to the nozzle area was the most important design variable affecting reversal and that an optimum ratio of frontal area to nozzle area existed. A reverse-thrust ratio of 84 percent was obtained from a cylindrical reverser having a frontal area three to four times as large as the exhaust-nozzle area. Although not as important, an optimum width-to-height ratio was also found.

Modifications to the basic cylindrical reverser with full end plates offered various degrees of design and installation simplicity, but caused losses in performance. For the range of depths investigated, decreasing the depth of the reverser caused only minor losses. Decreasing the lip angle, end-plate angle, and end-plate depth caused large losses. Decreasing the frontal area, reverser depth, lip angle, and end-plate angle increased the minimum spacing required for unrestricted exhaust-nozzle flow.

It was determined that in quiescent air, and with a 7° cowl, a value of reverse thrust greater than 64 percent could not be achieved unless the reversed flow were attached to the cowl.

Because of flow instability, swept-type cylindrical thrust reversers were found to be generally undesirable. Some modifications improved the stability.

The thrust-modulation characteristics of a cylindrical target-type thrust reverser were also investigated and found to be satisfactory.

INTRODUCTION

Reverse thrust offers advantages for all types of jet aircraft. For bombers and transports, reverse thrust could be used to brake the landing roll and to control the glide path. In addition to these two features, reverse thrust could also be used to control the diving speed of fighter aircraft.

Although many thrust-reverser designs would require a major redesign of both engine and airplane, a target-type thrust-reversal device appears to be readily adaptable to an existing aircraft and engine combination. On the basis of performance and stowage considerations, preliminary investigations have shown two basic target-type thrust-reversal designs to be desirable. These are the hemispherical and cylindrical types. The performance of the hemispherical type is reported in reference 1.

The purpose of this investigation is to determine the performance of cylindrical-type thrust reversers and the effects of several modifications on their performance. These modifications include changes in frontal area, width-to-height ratio, depth, lip angle, end-plate depth, and end-plate shape. The performance of swept-type cylindrical thrust reversers, the relation of reverse-thrust ratio to reversed-flow attachment, and thrust-modulation characteristics are also presented.

All tests were run in quiescent air with cold flow, and the results are shown for an exhaust-nozzle pressure ratio of 2.0.

APPARATUS AND INSTRUMENTATION

Apparatus

The geometries of the cylindrical reversers used in this investigation are shown in figure 1. The basic cylindrical reverser shown in figure 1(a) has full end plates and end-plate and lip angles of 180°. This is the reverser used to evaluate the effects of frontal-area ratio and width-to-height ratio. For this and all other reversers, a is measured perpendicular to the axis of revolution, and b is measured parallel to the axis of revolution.

Figure 1(b) shows the cylindrical reverser with a depth-reducing plate installed.

The reverser used to determine the effect of a lip angle less than 180° is shown in figure 1(c). The lip angle was reduced by making the radius of the cylindrical surface r greater than half a.

The reverser used to study the effects of end-plate angle is shown in figure 1(d). The end plate was rotated about the front vertical edge of the reverser.

Figures 1(e) and (f) show the cylindrical reverser with concentric and nonconcentric end plates of reduced depth. The end-plate depth is considered to be the maximum depth of the end plate.

A typical swept-type cylindrical reverser is shown in figure 1(g). Cover plates were added to some of the swept-type configurations. A portion of the exhaust nozzle is included in the sketch to show the extent of the cover plates.

The model used to investigate thrust-modulation characteristics is shown in figures 1(h) and (i).

The mechanism used to measure forward and reverse thrust is shown in figure 2. 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 directly read from a balanced-pressure-diaphragm, null-type, thrust-measuring cell. In order to ensure 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 reversers 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 7° cowl 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. Total-pressure rakes were located along the cowl in order to determine reversed-flow boundaries. Forces on each half of the modulated cylindrical reverser were obtained from wall static-pressure taps located on the reverser.

PROCEDURE

Forward and reverse jet thrusts were obtained over a range of exhaust-nozzle total- to ambient-pressure ratios from 1.4 to 3.0. 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 reverse-thrust ratio. The reverse-thrust ratios given in this report are those that occur at the minimum spacing required for unrestricted nozzle flow. Spacing is defined as the axial distance between the nozzle lip and the reverser lip.

Jet thrusts and air flows were corrected for changes in inlet pressure. The data in this report are for an exhaust-nozzle pressure ratio of 2.0. For the entire investigation unheated air was used, and the pressure ratio was regulated by variation of inlet pressure. The effects of exhaust-nozzle pressure ratio on reverse-thrust ratio and the spacing ratio required for unrestricted nozzle flow are similar to those that occur with hemispherical reversers (ref. 1). The symbols used in this report are defined in the appendix.

RESULTS AND DISCUSSION

Frontal Area

The reverse-thrust ratio obtained from a cylindrical target-type thrust reverser with full end plates is primarily a function of the frontal-area ratio of the reverser. Frontal-area ratio is defined as the ratio of the frontal area of the reverser to the exhaust-nozzle area A_r/A_n. Figure 3 shows the variation in reverse-thrust ratio with frontal-area ratio for cylindrical reversers of several different width-to-height ratios. Width-to-height ratio is defined as the ratio of the projected width to the projected height b/a. The data in figures 3 to 7 are for full-depth reversers with 180° lip angles and full 180° end plates. A reverser frontal-area ratio of about 3 or 4 appears to be optimum and produces a reverse-thrust ratio of 84 percent. For smaller or larger frontal areas, the reverse-thrust ratio decreased.

The effect of frontal-area ratio on the minimum spacing ratio required for unrestricted nozzle air flow is shown in figure 4 for several width-to-height ratios. Spacing ratio is defined as the ratio of the spacing to the exhaust-nozzle diameter l/D_n. Although these data are somewhat scattered, it is evident that the minimum spacing ratio generally increases with a decrease in frontal-area ratio. Decreasing the width-to-height ratio below 1.6 does not affect the minimum spacing ratio. Increasing the width-to-height ratio above 1.6, however, increases the minimum spacing ratio.

The variation in size and shape of the reversed-flow boundary with reverser frontal-area ratio is shown in figure 5, which is a view looking forward along the tail pipe. The data in figure 5(a) are for a width-to-height ratio of 1.0, and the data in figure 5(b) are for a width-to-height ratio of 2.0. The flow boundaries were measured 4 nozzle diameters ahead of the exhaust-nozzle exit. Boundaries were located by points at which the dynamic pressure was reduced to 1/2 percent of the available dynamic pressure. Increasing the reverser frontal-area ratio from 1.985 to 2.85 at a width-to-height ratio of 1.0 caused the flow to attach to the cowl. The reversed flow remained attached to the cowl when the reverser frontal-area ratio was increased from 2.54 to 3.97 at a width-to-height ratio of 2.0.

Width-to-Height Ratio

The effect of the width-to-height ratio on reverse-thrust ratio is shown in figure 6 for a reverser frontal-area ratio of 3.77. The curve peaks at width-to-height ratios of 0.62 and 1.6. Of course, the frontal area of a reverser with a width-to-height ratio of 0.62 has the same shape as that of a reverser with a width-to-height ratio of 1.6. The difference is that the width (which is always measured parallel to the axis of revolution) of the former is the short dimension, while the width of the latter is the long dimension. However, cylindrical reversers with width-to-height ratios less than 1.0 caused flow instability. The gas discharged alternately from the top and bottom of the reverser in puffs, rather than in a continuous stream, and caused severe vibration.

For cylindrical reversers with 180° lip angles, changing the width-to-height ratio changes the shape of the reversed-flow boundaries but does not detach the flow, as shown in figure 7. For a cylindrical reverser with a lip angle of 146° (not shown), increasing the width-to-height ratio detaches the flow from the cowl.

Depth

The effect of decreasing the depth of cylindrical reversers by insertion of a flat plate is shown in figure 8. Decreasing the depth to 38 percent of its original value decreases reversal by only 10 percentage points. The minimum spacing ratio required for unrestricted nozzle flow is shown in figure 9 to increase 29 percentage points when the depth is reduced to 38 percent of the full depth.

The change in reverse-flow boundaries that occurs when the reverser depth is changed from 100 percent to 38 percent is shown in figure 10. As the depth is decreased, the flow boundary becomes more circumferentially uniform but does not detach from the cowl.

Lip Angle

Decreasing the lip angle of the reverser causes decreases in the reverse-thrust ratio, as shown in figure 11 for two reversers having different frontal-area and width-to-height ratios. Changing the lip angle from 180° to 146° decreases the reverse-thrust ratio by about 15 percentage points. The data points are joined by curved lines on the assumption that the reverse-thrust ratio would be some function of the cosine of the lip-angle supplement.

The minimum spacing required for the preceding two reversers is shown in figure 12 for two lip angles. Decreasing the lip angle from

180° to 146° increases the minimum spacing required for unrestricted nozzle flow by about 32 percentage points for both reversers. This trend is probably due, in part, to the fact that the depth was also decreased as the lip angle was decreased.

The reversed flow may or may not detach from the cowl as the lip angle is reduced. Reducing the lip angle of a reverser having a frontal-area ratio of 3.175 and a width-to-height ratio of 1.6 did not detach the flow (fig. 13(a)); reducing the lip angle of a reverser having a frontal-area ratio of 4.76 and a width-to-height ratio of 2.4 did detach the flow (fig. 13(b)).

End-Plate Angle

Decreasing the end-plate angle decreases the reverse-thrust ratio, as shown in figure 14. Decreasing the end-plate angle from 180° to 120° reduces the reverse-thrust ratio from 84 to 55 percent. The minimum spacing ratio required for unrestricted nozzle flow increases, as shown in figure 15, from 0.17 to 0.45. The reversed-flow boundaries change shape when the end-plate angle is reduced, as can be seen in figure 16, but the flow detaches over only a very small portion of the circumference of the cowl.

End-Plate Depth

Reducing the end-plate depth may facilitate retraction and stowage. The reverse-thrust ratio, however, decreases as the end-plate depth is reduced. This result is shown in figure 17 for reversers with lip angles of 180° and 146° and with concentric and nonconcentric end plates.

The effects of using either concentric or nonconcentric end plates are the same. The small effect of end-plate shape has also been found for reversers with frontal-area ratios different from those shown in figure 17 (unpublished data). As can be seen from figure 18, the minimum spacing required by either reverser for unrestricted nozzle flow is not affected by changes in end-plate depth.

Decreasing the end-plate depth, however, is effective in detaching the reversed flow from the cowl, as shown in figure 19.

Swept-Type Cylindrical Reversers

A reverser composed of two semicylinders with their axes at an angle to each other would have some mechanical advantages over an ordinary cylindrical reverser. The two semicylindrical sections would be rotated through an angle considerably less than 90°, and the cylindrical surfaces would, in effect, act as partial end plates.

Because of these advantages, several swept-type cylindrical reversers were tested. The results are summarized in figure 20. Because of the poor reversal caused by air escaping vertically out the top and bottom of the reverser (configuration (a)), it was necessary to add cover plates (configuration (b)). Configuration (b) produced fairly steady flow between pressure ratios of 2.4 and 2.9. At other pressure ratios the flow discharged discontinuously and caused severe vibration. Another phenomenon, air-flow hysteresis, was also introduced. The air flow through the system was less at any given pressure ratio when the pressure ratio was being increased than it was when the pressure ratio was being decreased.

Because it was felt that the instability and vibration present after the cover plates were installed were being caused by the flow attaching alternately to the top and bottom cover plates, baffles were added (configuration (c)). Flow instability and vibration were reduced, but the reverse-thrust ratio was only 44 percent.

Addition of end plates, as in configurations (d), (e), and (f), increased the reverse-thrust ratio. Although configuration (d) was unstable, configurations (e) and (f), with baffles, had improved stability and vibration characteristics. Configuration (f) was composed of conical sections which would more readily retract into a conical boattail. The height of the reverser varied from 1.25 nozzle diameters at the center to 1.43 nozzle diameters at the ends.

Increasing the sweep angle from 30° to 45° (configuration (g)) aggravated the instability. The addition of a splitter plate at the intersection of the two cylinders had no effect on the instability. In order to determine whether the cover plates were independently responsible for the instability and air-flow hysteresis, a straight cylindrical reverser with no sweepback was run with cover plates. This configuration (h) gave stable and normal air flow, indicating that cover plates by themselves are not a source of difficulty.

The reversed-flow fields obtained with some of the swept-type configurations are shown in figure 21. The flow was detached from the cowling for all the configurations for which the reversed-flow field was determined except configuration (f).

Relation of Reverse-Thrust Ratio to Reversed-Flow Attachment

In order to obtain high reverse thrust, it is necessary to turn the exhaust gases through a large angle. At some angle, however, the turned gases will attach to the cowling. The reverse-thrust ratio when the turn angle is large enough to cause the flow to attach to the 7° cowl is roughly defined in figure 22 for cylindrical reversers. Values of reverse-thrust ratio for both straight and swept-type cylindrical reversers with various modifications are categorized according to whether the reversed flow is attached or detached. For any value of reverse-thrust ratio above 64 percent, it appears that the flow will attach to the 7° cowl. The tests from which these data were obtained were run in quiescent air. A free-stream velocity would probably allow a higher value of reverse-thrust ratio before attachment occurred. Depending on the particular installation, it may or may not be permissible to allow the reversed flow to attach to the cowl.

Thrust-Modulation Characteristics

Because of the high rotational inertia of the compressor and turbine in a turbojet engine, it would be desirable to control engine thrust by some means other than engine rotational speed. A thrust reverser which could modulate the thrust of the engine from full forward to full reverse by changing the direction of the exhaust jet appears ideal. With such a reverser, aircraft could make landing approaches with engines running at full speed and with the required amount of forward or reverse thrust. Upon touchdown, only reverser actuation time would elapse before full reverse or forward thrust could be obtained, because the engine would already be at full speed.

In order to determine the thrust-modulation characteristics of a cylindrical target-type thrust reverser, the model shown in figures 1(h) and (i) was built and tested. In the reverse-thrust position, the reverser had a projected frontal area 3.17 times as large as the exhaust-nozzle area and a width-to-height ratio of 1.6. In the forward-thrust position, the reverser formed a large-diameter, long ejector. The ejector had no measurable effect on forward jet thrust. The ejector pumping characteristics were not determined.

The thrust-modulation characteristics are shown in figure 23. Reverse-thrust ratio is plotted against angular position of the reverser. Negative values of reverse-thrust ratio are equivalent to percentages of forward thrust. Sketches of reverse-flow boundaries are also shown. The shading within the reverse-flow boundaries indicates the relative magnitude of the reversed-flow velocity. For the first 15° of actuation the jet is not intercepted by the reverser. From about 30° to 75°, a 1° change in actuation angle causes approximately a 3-percentage-point change in thrust. At 75°, maximum reverse thrust is obtained, but the flow is attached to the cowl. By actuating the reverser to the 90° position, the maximum reverse-thrust ratio is maintained, and the flow is detached from the cowl.

The forces and moments which act on the halves of the semicylinder as the reverser is actuated are shown schematically in figure 24(a) and graphically in figure 24(b). These are, of course, the forces which occur with a 4-inch-diameter nozzle operating at a pressure ratio of 2.0.

The forward jet thrust of the nozzle at this pressure ratio would have been 270 pounds. The measured weight flow was about 8 pounds per second. The moments about the pivot point tend to open the reverser for forward thrust in all the positions for which data points are shown. Between the 15° and 30° actuation angles, the force changes direction and moves to the other side of the pivot point; therefore, there must be at least one actuation angle at which the moment about the pivot point is zero. Thus, if the actuating mechanism failed during reverse-thrust operation, the reverser would return to the zero-moment position from aerodynamic forces alone. It is estimated that about 97 percent of the forward thrust would be obtainable at the zero-moment position. Although it would seem undesirable for most applications, the pivot point could be relocated so that the halves of the semicylinder would move to a reverse-thrust position if the actuation force were lost.

SUMMARY OF RESULTS

A reverse-thrust ratio as high as 84 percent was obtained from a cylindrical target-type thrust reverser. This value occurred when the reverser had a frontal area three to four times the exhaust-nozzle area. For smaller or larger frontal areas, the reverse-thrust ratio was less.

A width-to-height ratio of 1.6 appeared to be optimum for a cylindrical reverser. Reversers with width-to-height ratios less than 1.0 produced unstable flow conditions. Modifications to the basic cylindrical reverser with full end plates offered various degrees of design and installation simplicity, but caused losses in performance. Decreases in lip angle, end-plate angle, and end-plate depth caused the most severe losses. For the range of depths investigated, decreasing the reverser depth caused relatively minor losses. The spacing required for unrestricted nozzle air flow increased with a decrease in frontal area, reverser depth, lip angle, and end-plate angle.

Because of the high turning angles associated with high reverse-thrust ratios, the reversed flow attached to the 7° cowl when reverse-thrust ratios greater than 64 percent were attained in quiescent air.

Swept-type cylindrical reversers caused unstable-flow conditions. Some modifications improved the stability.

The thrust-modulation characteristics of a cylindrical target-type thrust reverser were found to be satisfactory.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, September 29, 1955

APPENDIX - SYMBOLS

The following symbols are used in this report:

A	area, sq in.
a	reverser height, measured perpendicular to axis of revolution, in.
b	reverser span, measured parallel to axis of revolution, in.
D	diameter, in.
l	axial distance between nozzle exit and lip of cylinder, in.
r	radius, in.
x	axial distance, in.
α	actuation angle, deg
ε	end-plate angle, deg
η_R	reverse-thrust ratio
λ	lip angle, deg
σ	sweep angle, deg

Subscripts:

n	nozzle
r	reverser

REFERENCE

1. Steffen, Fred W., McArdle, Jack G., and Coats, James W.: Performance Characteristics of Hemispherical Target-Type Thrust Reversers. NACA RM E55E18, 1955.

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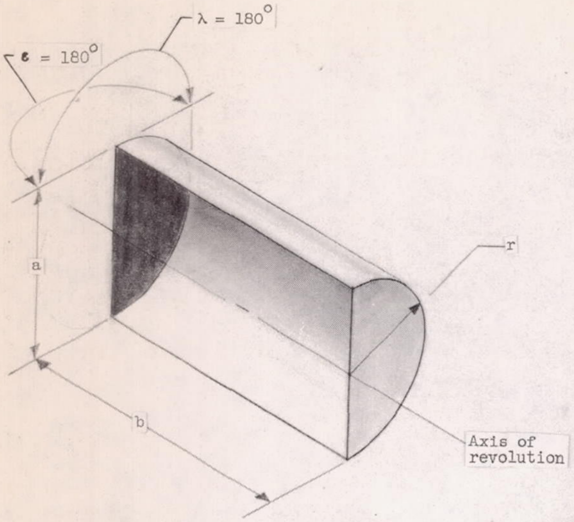
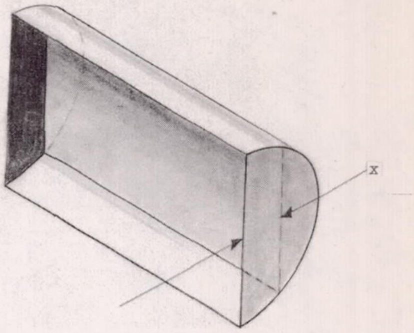
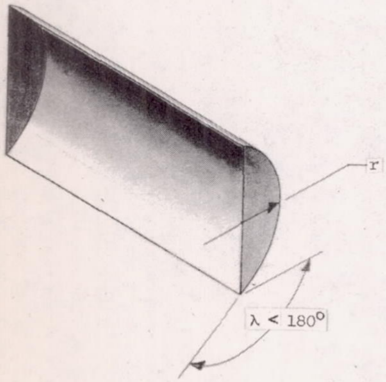


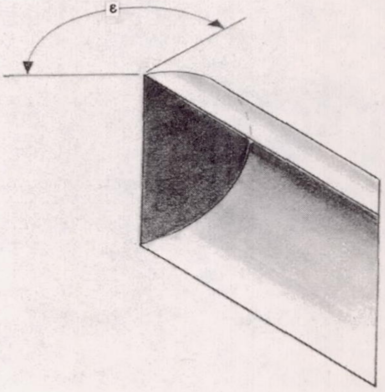
(a) Basic cylindrical reverser with full end plates.



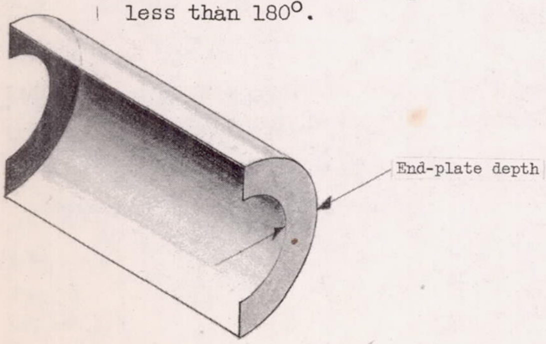
(b) Basic cylindrical reverser with depth-reducing plate.



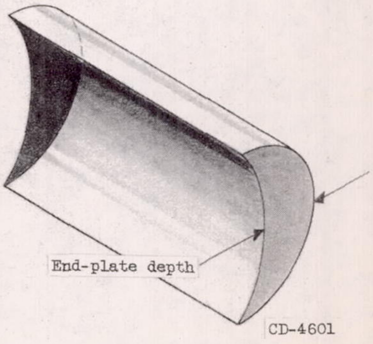
(c) Reverser with lip angle λ less than 180°.



(d) Reverser with variable end-plate angle ε.

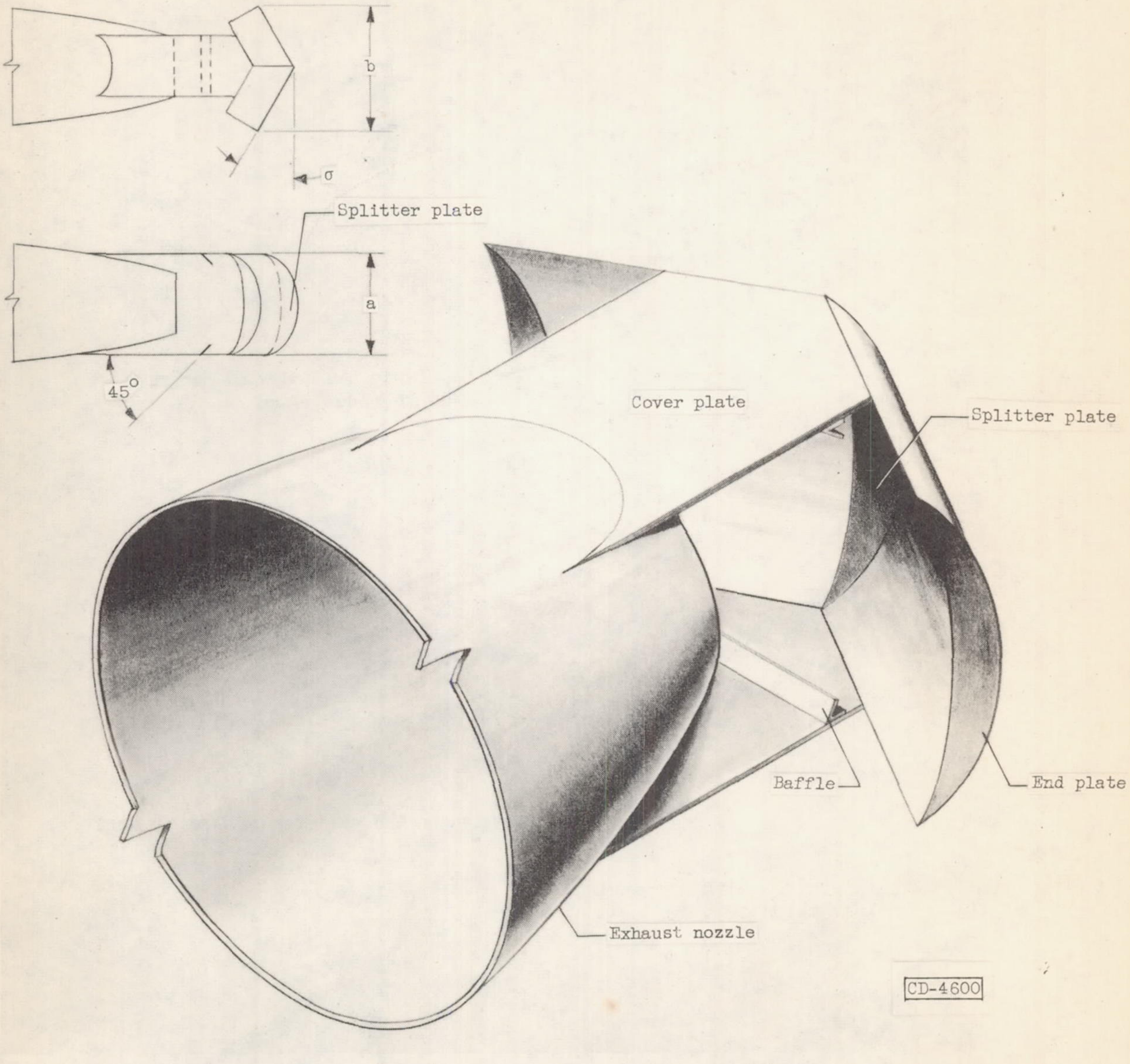


(e) Reverser with concentric end plates.



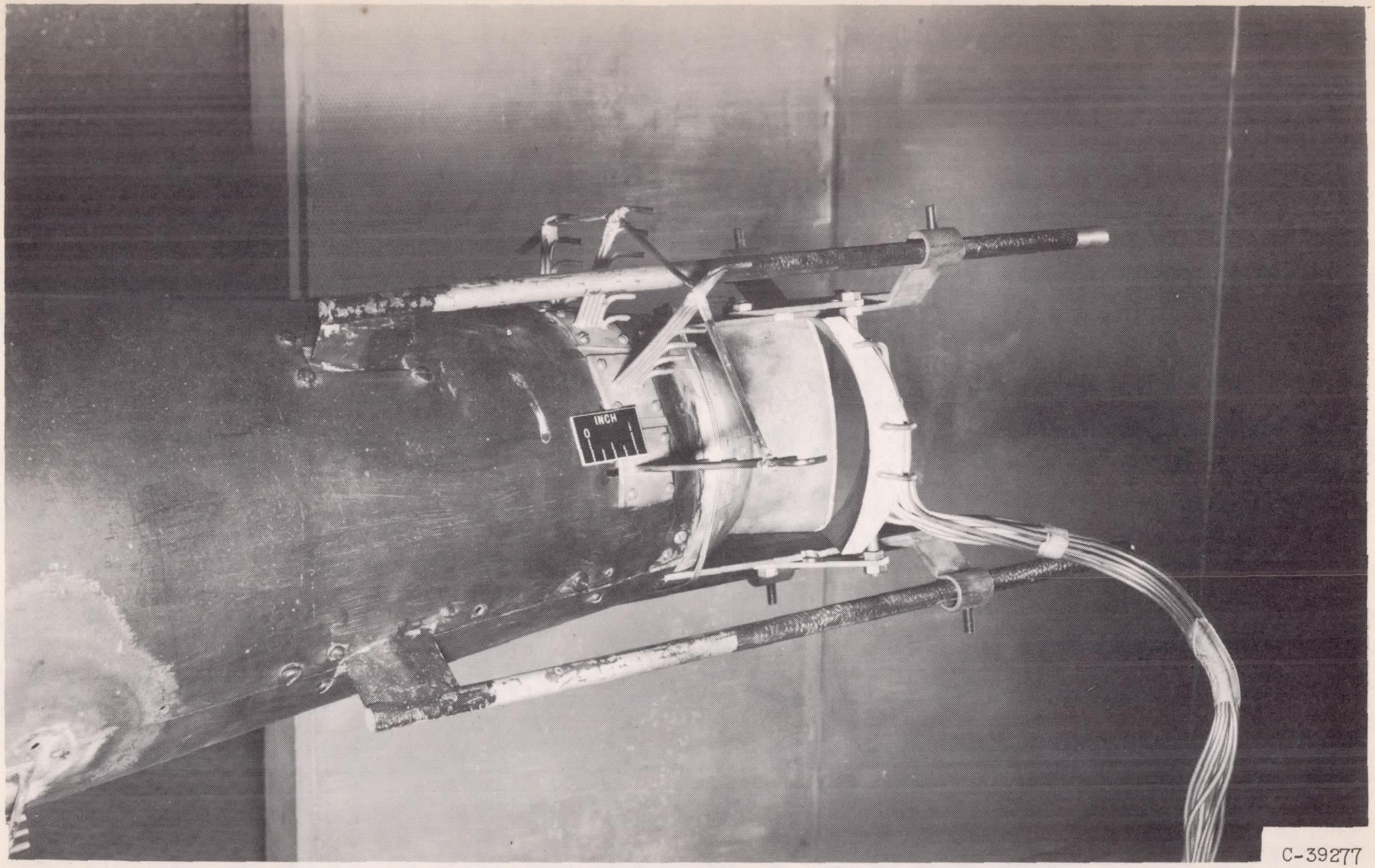
(f) Reverser with nonconcentric end plates.

Figure 1. - Cylindrical thrust reversers.



(g) Swept-type cylindrical thrust reverser with end plates, cover plates, baffles, and splitter plate.

Figure 1. - Continued. Cylindrical thrust reversers.



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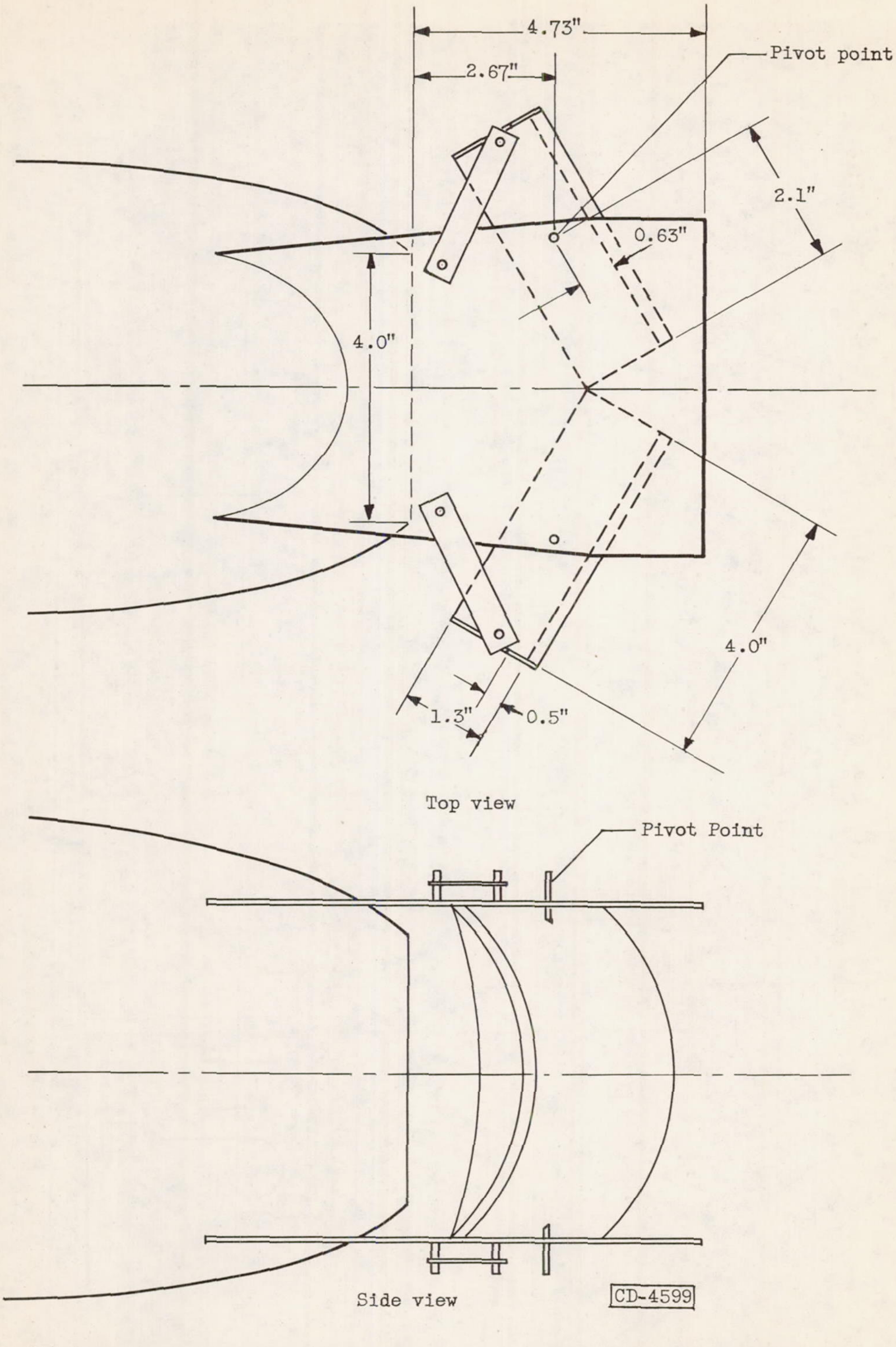
(h) Photograph of cylindrical reverser used to determine thrust-modulation characteristics. Reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 146°; end-plate angle, 180°; nonconcentric end plates.

Figure 1. - Continued. Cylindrical thrust reversers.



(i) Schematic diagram of cylindrical thrust reverser used to determine thrust-modulation characteristics.

Figure 1. - Concluded. Cylindrical thrust reversers.

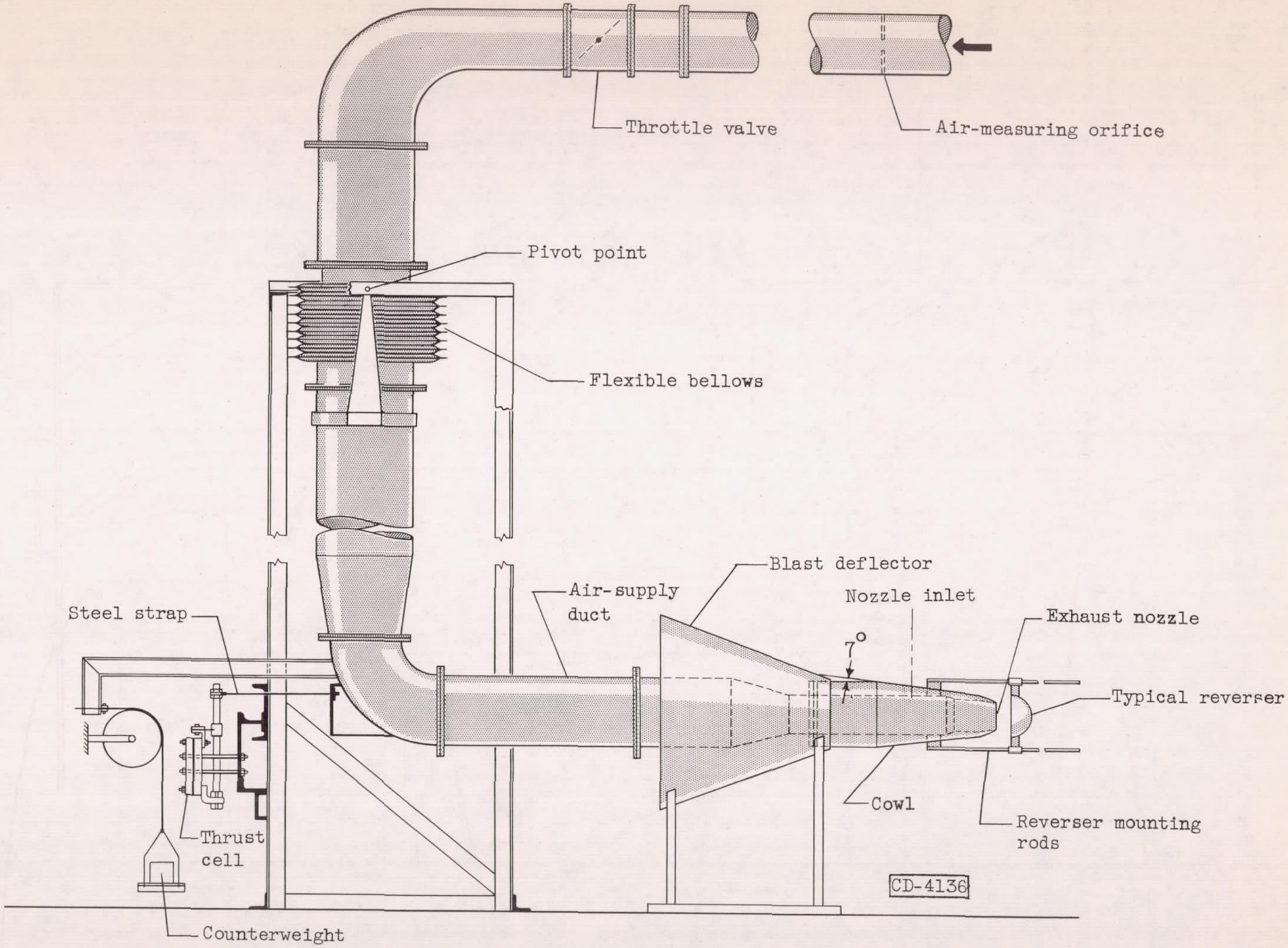


Figure 2. - Schematic diagram of setup for thrust-reversal investigation.

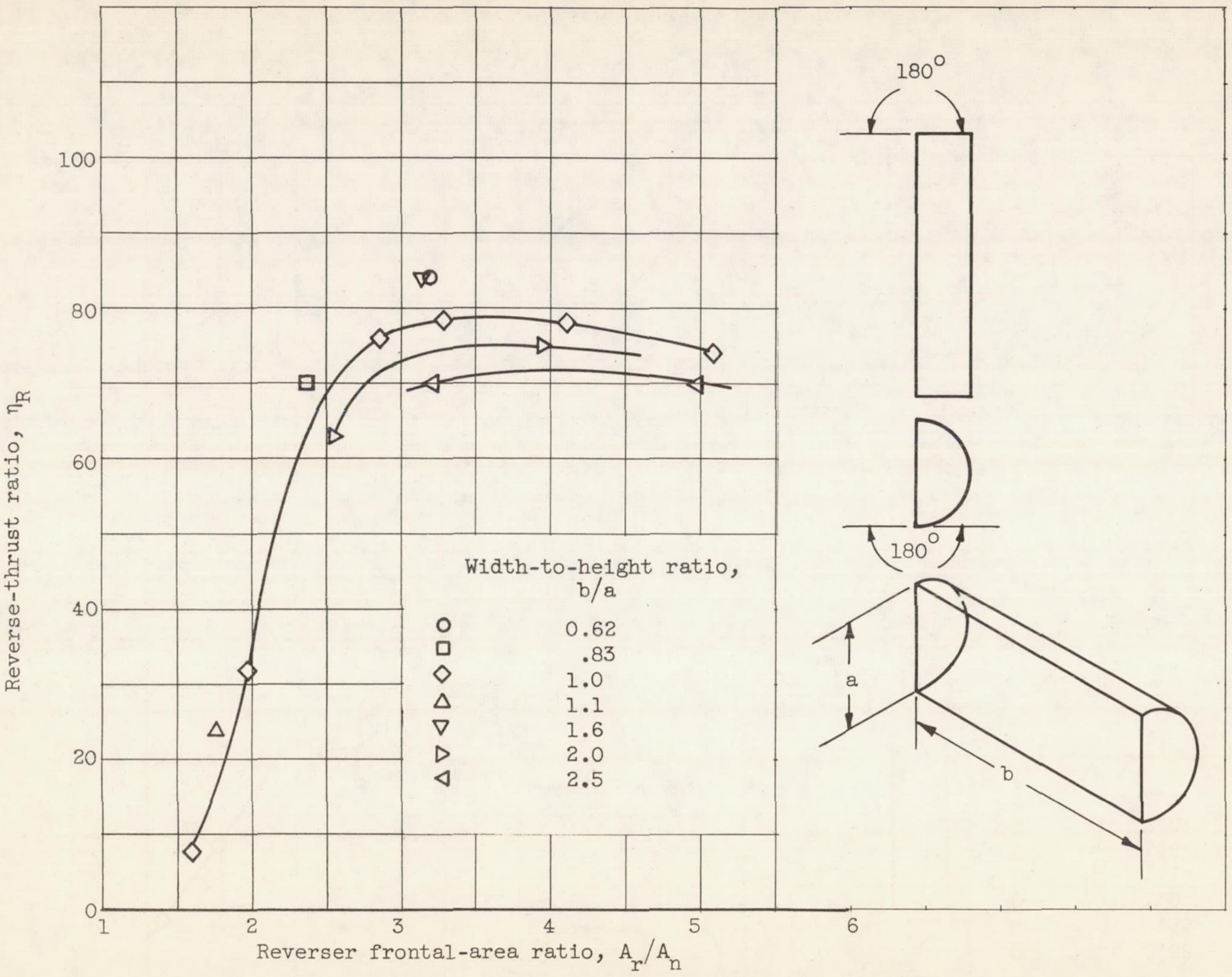


Figure 3. - Effect of reverser frontal-area ratio on reverse-thrust ratio. Exhaust-nozzle pressure ratio, 2.0; lip angle, 180°; end-plate angle, 180°; full end plates.

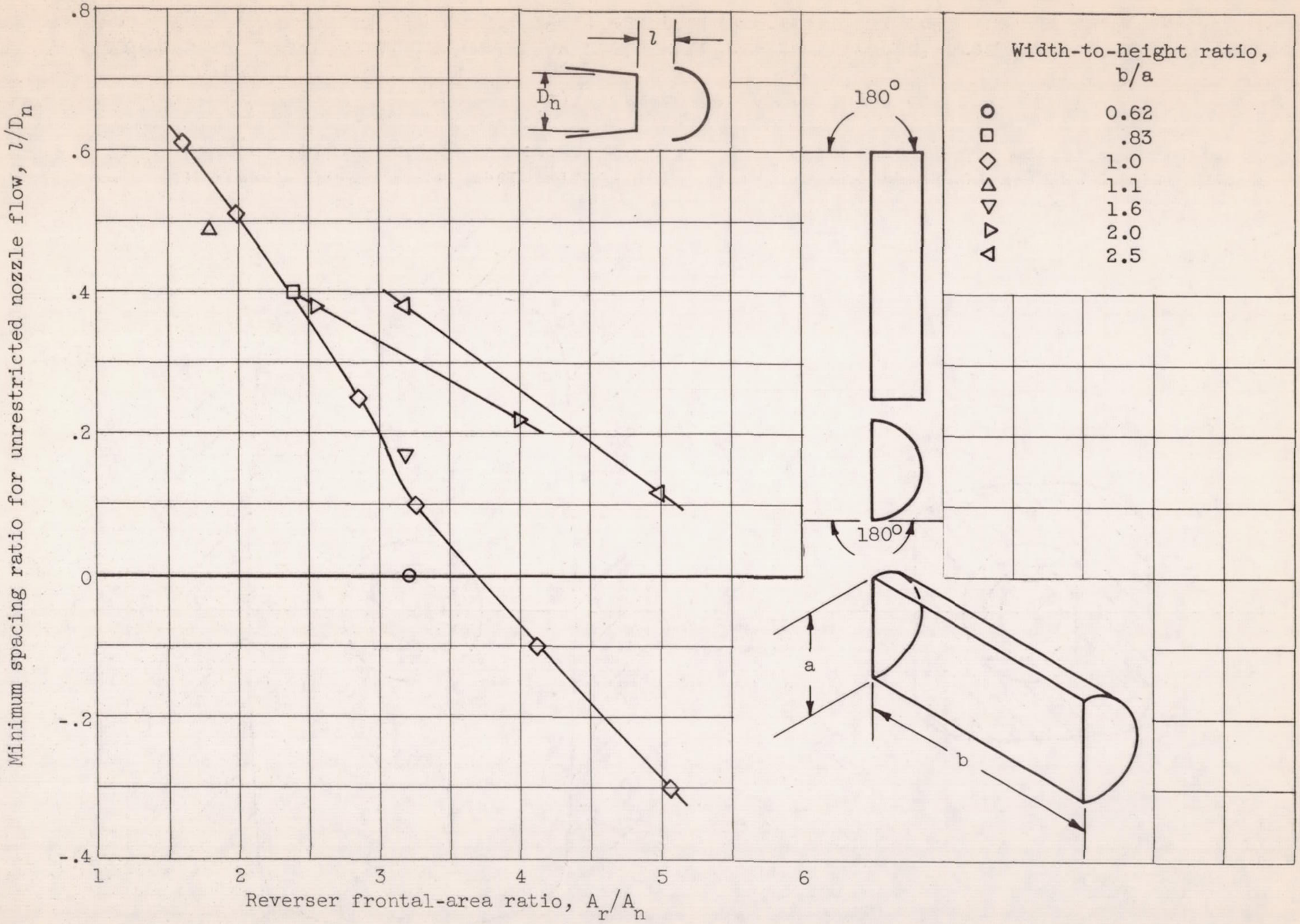
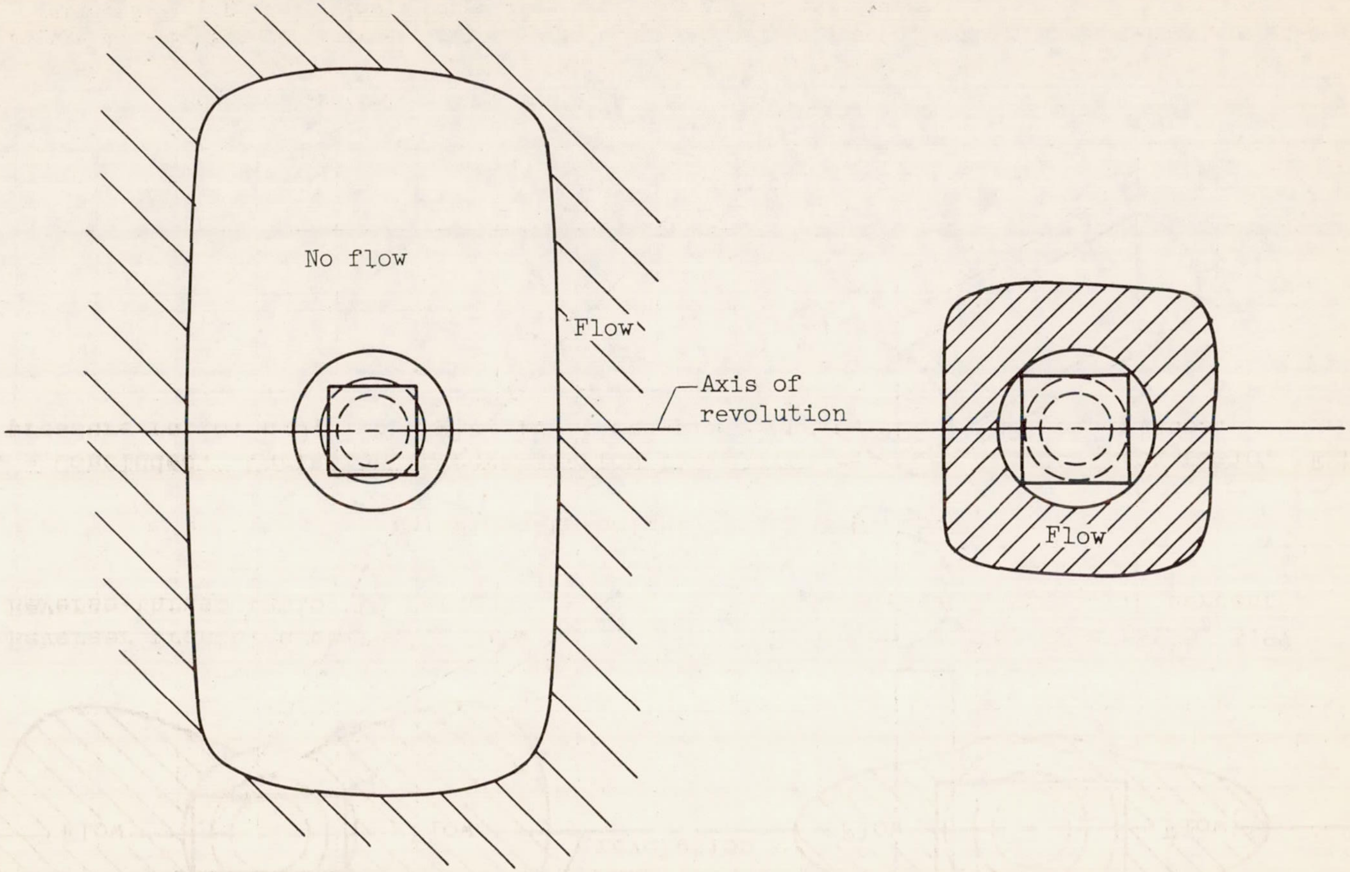


Figure 4. - Effect of reverser frontal-area ratio on minimum spacing ratio. Exhaust-nozzle pressure ratio, 2.0; lip angle, 180°; end-plate angle, 180°; full end plates.

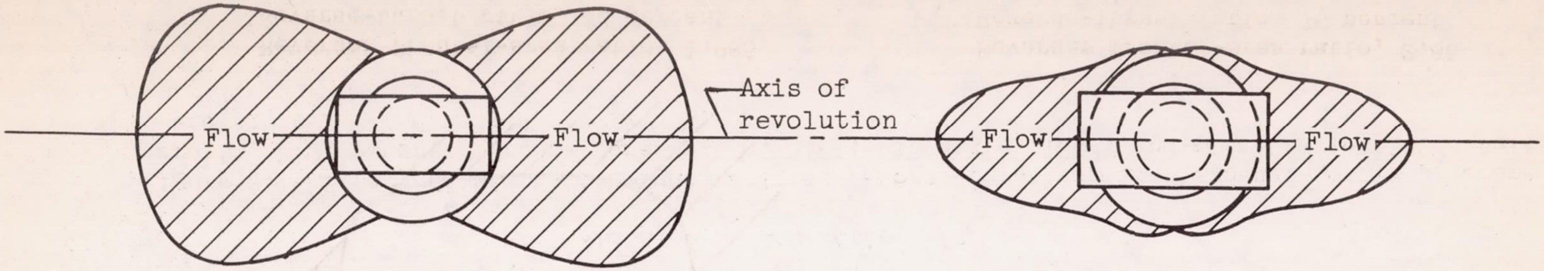


Reverser frontal-area ratio, 1.985
Reverse-thrust ratio, 32 percent

Reverser frontal-area ratio, 2.85
Reverse-thrust ratio, 76 percent

(a) Width-to-height ratio, 1.0.

Figure 5. - Variation in reverse-flow field with reverser frontal-area ratio. Exhaust-nozzle pressure ratio, 2.0; lip angle, 180°; end-plate angle, 180°; full end plates.



Reverser frontal-area ratio, 2.54
Reverse-thrust ratio, 63 percent

Reverser frontal-area ratio, 3.97
Reverse-thrust ratio, 75 percent

(b) Width-to-height ratio, 2.0.

Figure 5. - Concluded. Variation in reverse-flow field with reverser frontal-area ratio. Exhaust-nozzle pressure ratio, 2.0; lip angle, 180°; end-plate angle, 180°; full end plates.

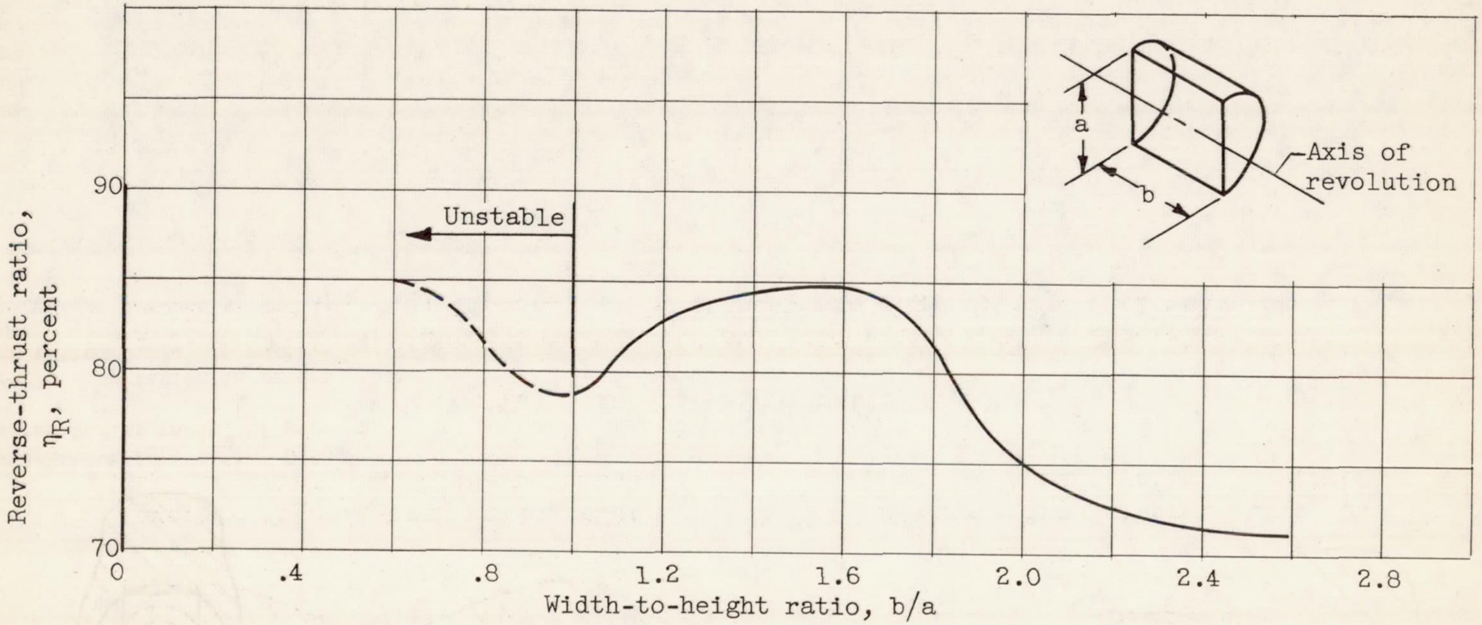
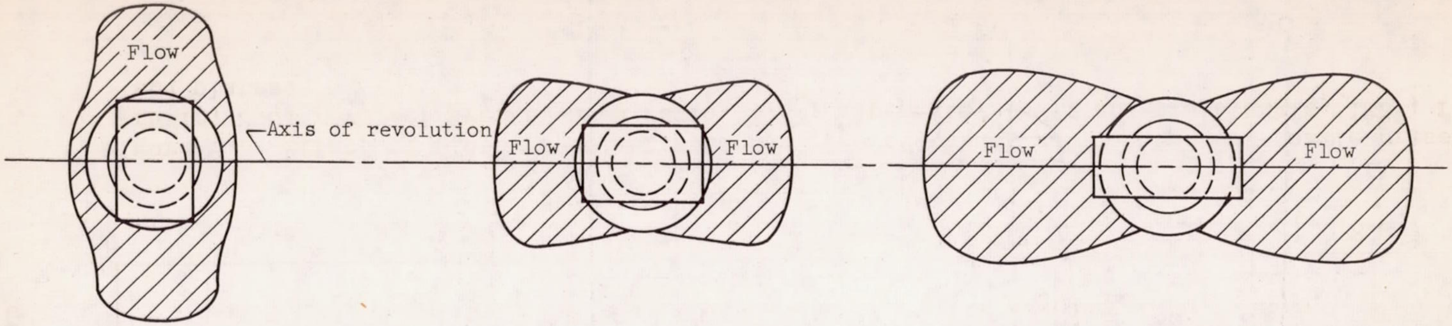


Figure 6. - Effect of width-to-height ratio on reverse-thrust ratio. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.77; lip angle, 180°; end-plate angle, 180°; full end plates.



(a) Width-to-height ratio, 0.62; reverse-thrust ratio, 84 percent.

(b) Width-to-height ratio, 1.6; reverse-thrust ratio, 84 percent.

(c) Width-to-height ratio, 2.5; reverse-thrust ratio, 70 percent.

Figure 7. - Variation in reverse-flow field with width-to-height ratio. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; lip angle, 180°; end-plate angle, 180°; full end plates.

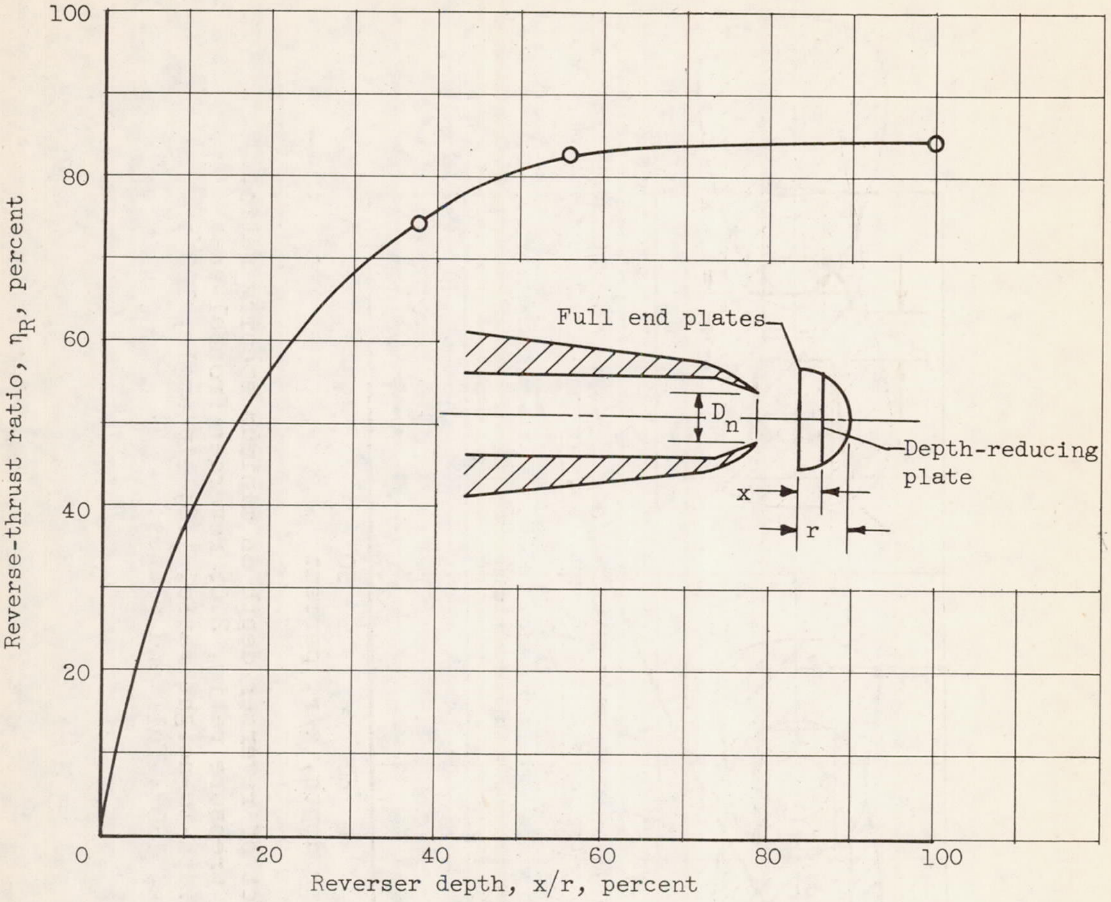


Figure 8. - Effect of reverser depth on reverse-thrust ratio. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 180°; end-plate angle, 180°; full end plates.

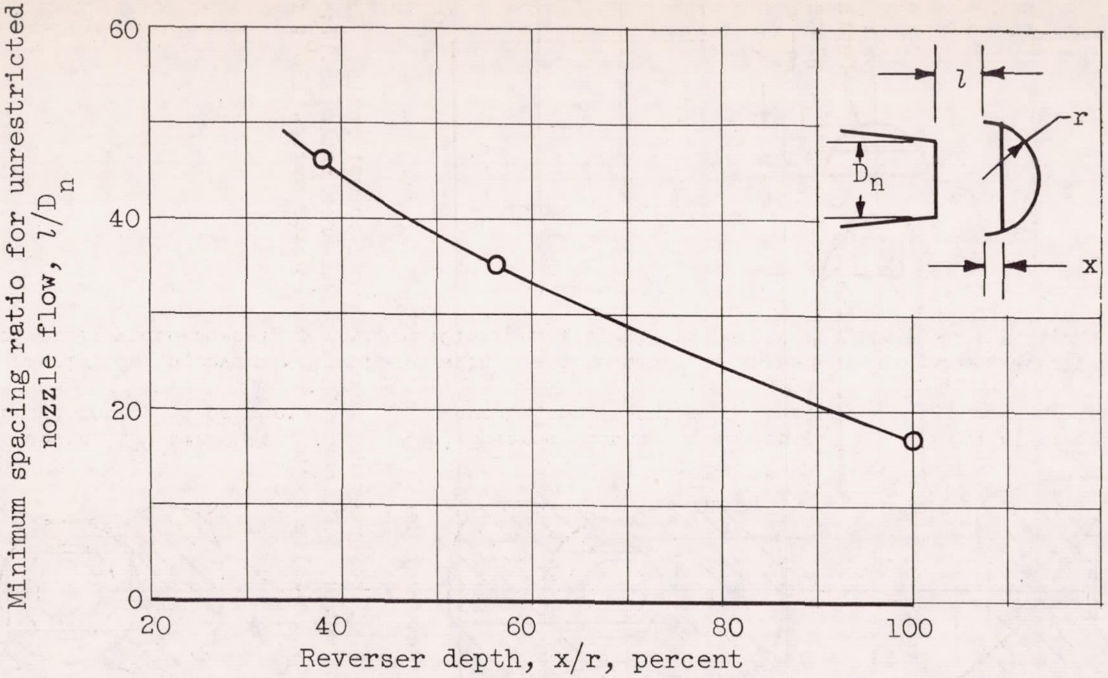
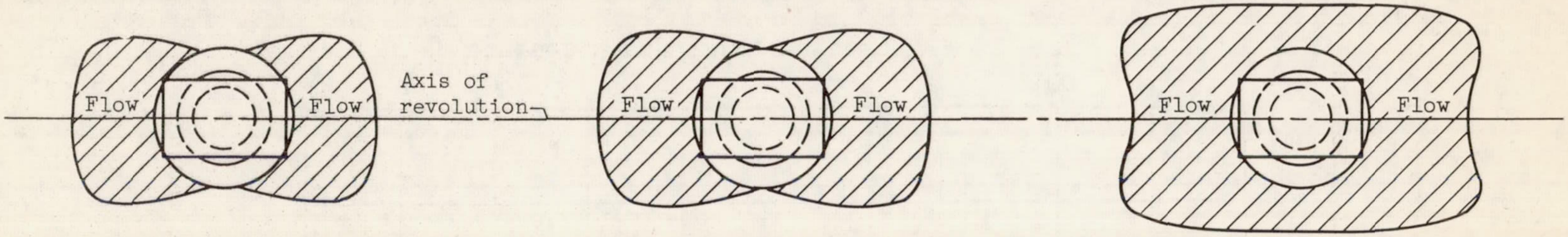


Figure 9. - Effect of reverser depth on minimum spacing ratio. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 180°; end-plate angle, 180°; full end plates.



(a) Reverser depth, 100 percent; reverse-thrust ratio, 84 percent.

(b) Reverser depth, 56 percent; reverse-thrust ratio, 83 percent.

(c) Reverser depth, 38 percent; reverse-thrust ratio, 74 percent.

Figure 10. - Variation in reverse-flow field with reverser depth. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 180°; end-plate angle, 180°; full end plates.

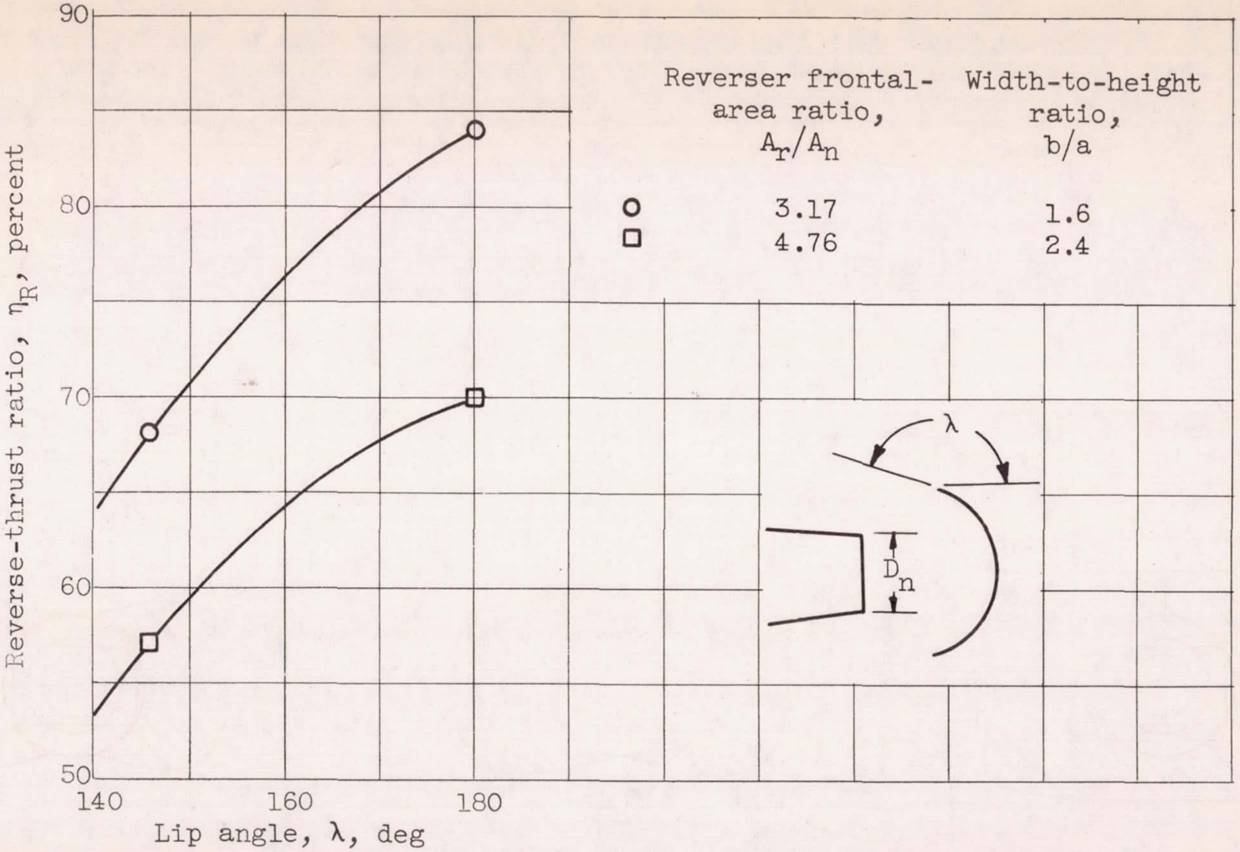


Figure 11. - Effect of lip angle on reverse-thrust ratio. Exhaust-nozzle pressure ratio, 2.0; end-plate angle, 180°; full end plates.

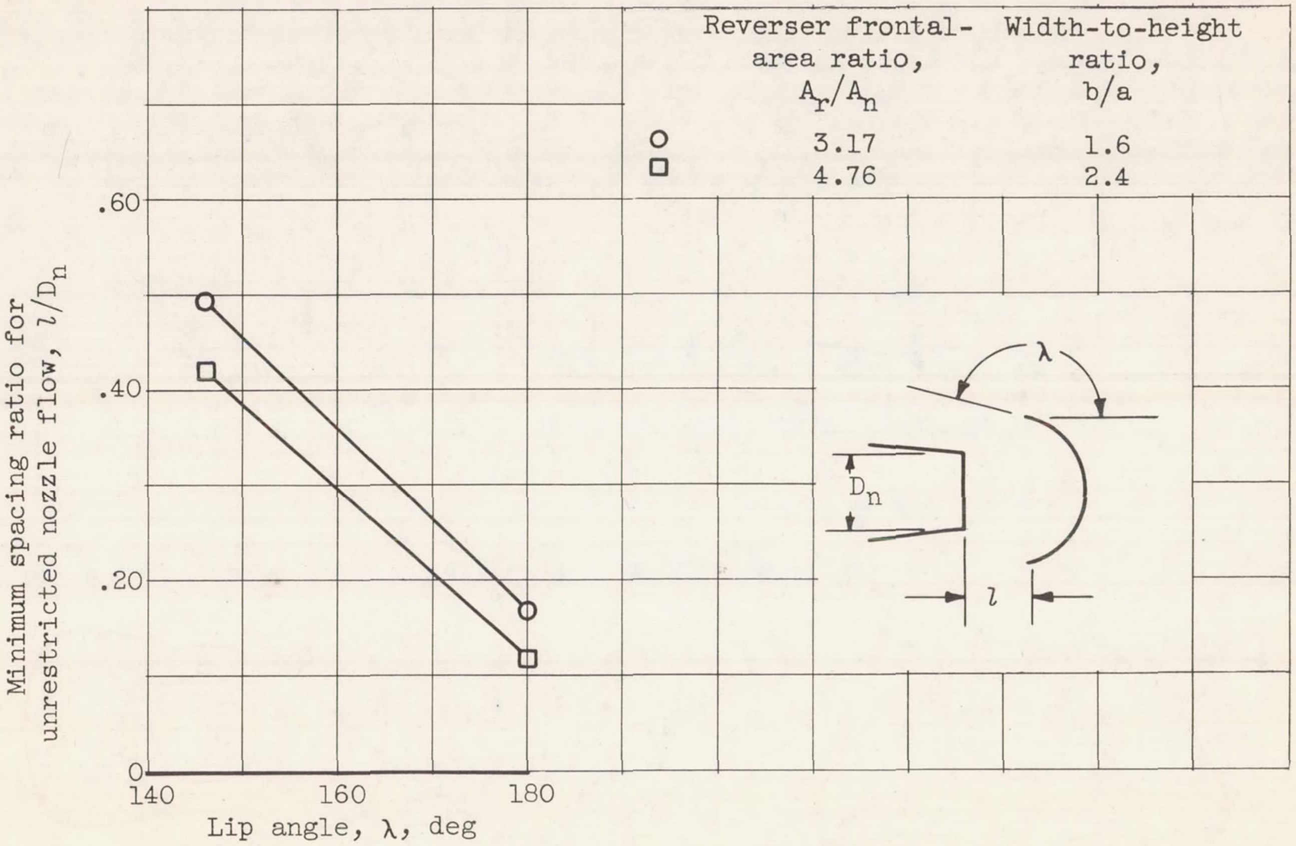
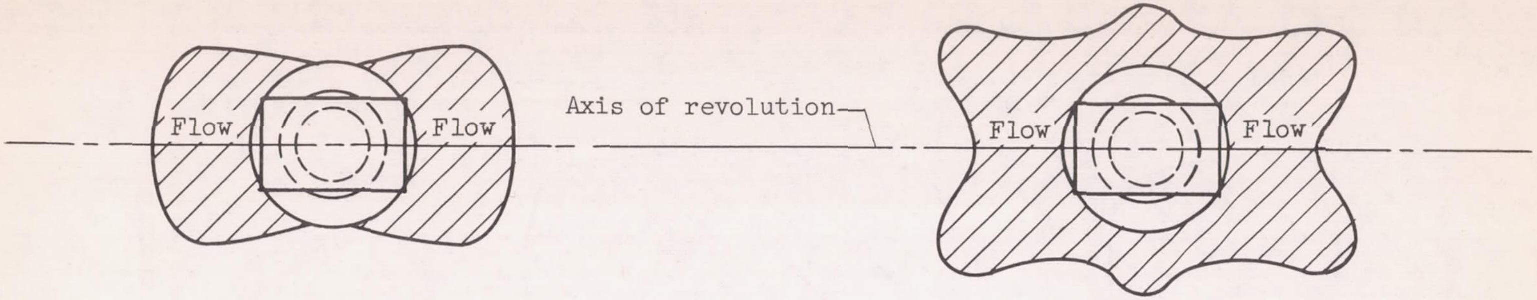


Figure 12. - Effect of lip angle on minimum spacing ratio. Exhaust-nozzle pressure ratio, 2.0; end-plate angle, 180°; full end plates.

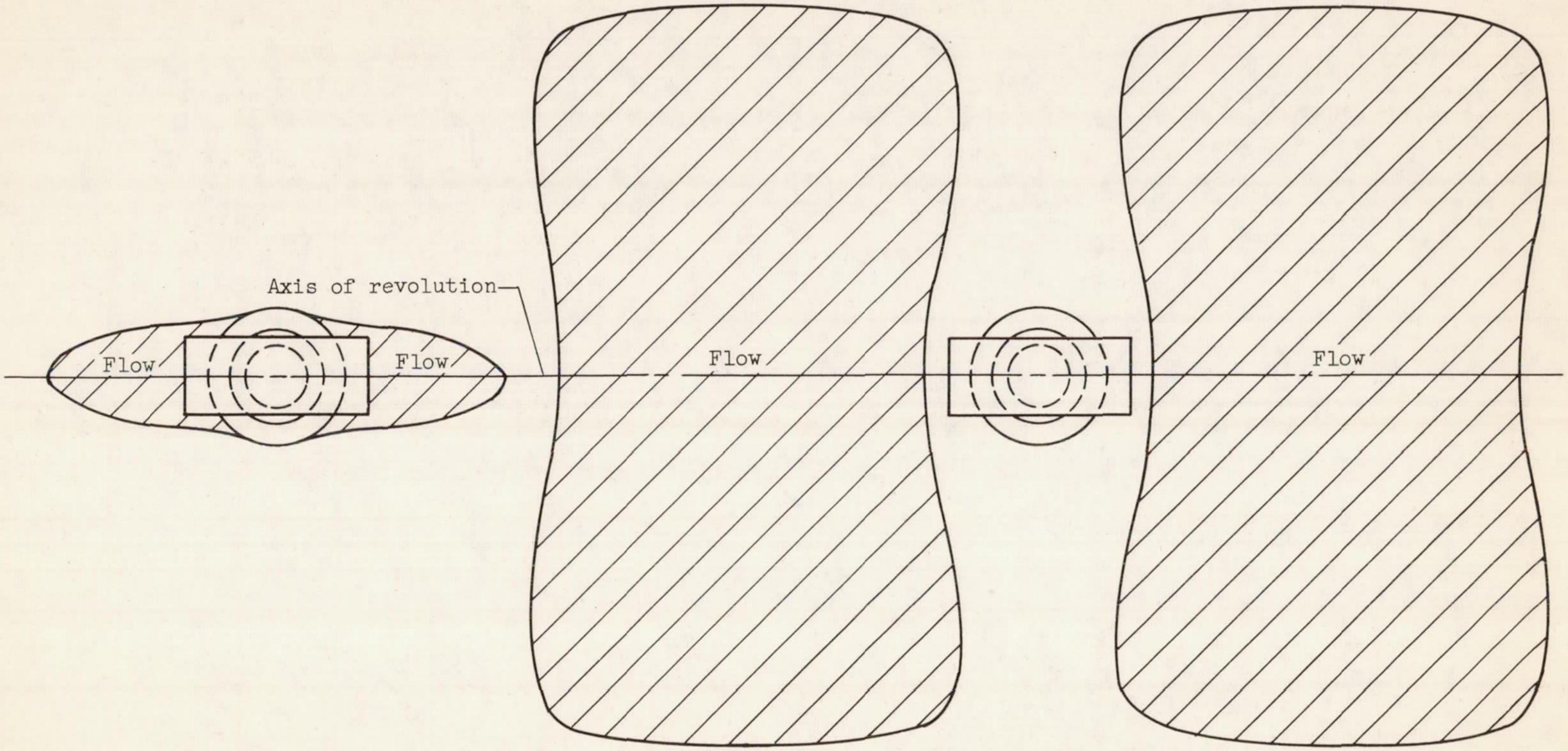


Lip angle, 180°
Reverse-thrust ratio, 84 percent

Lip angle, 146°
Reverse-thrust ratio, 68 percent

(a) Reverser frontal-area ratio, 3.175; width-to-height ratio, 1.6.

Figure 13. - Variation in reverse-flow field with reverser lip angle. Exhaust-nozzle pressure ratio, 2.0; end-plate angle, 180°; full end plates.



Lip angle, 180°
Reverse-thrust ratio, 70 percent

Lip angle, 146°
Reverse-thrust ratio, 57 percent

(b) Reverser frontal-area ratio, 4.76; width-to-height ratio, 2.4.

Figure 13. - Concluded. Variation in reverse-flow field with reverser lip angle. Exhaust-nozzle pressure ratio, 2.0; end-plate angle, 180°; full end plates.

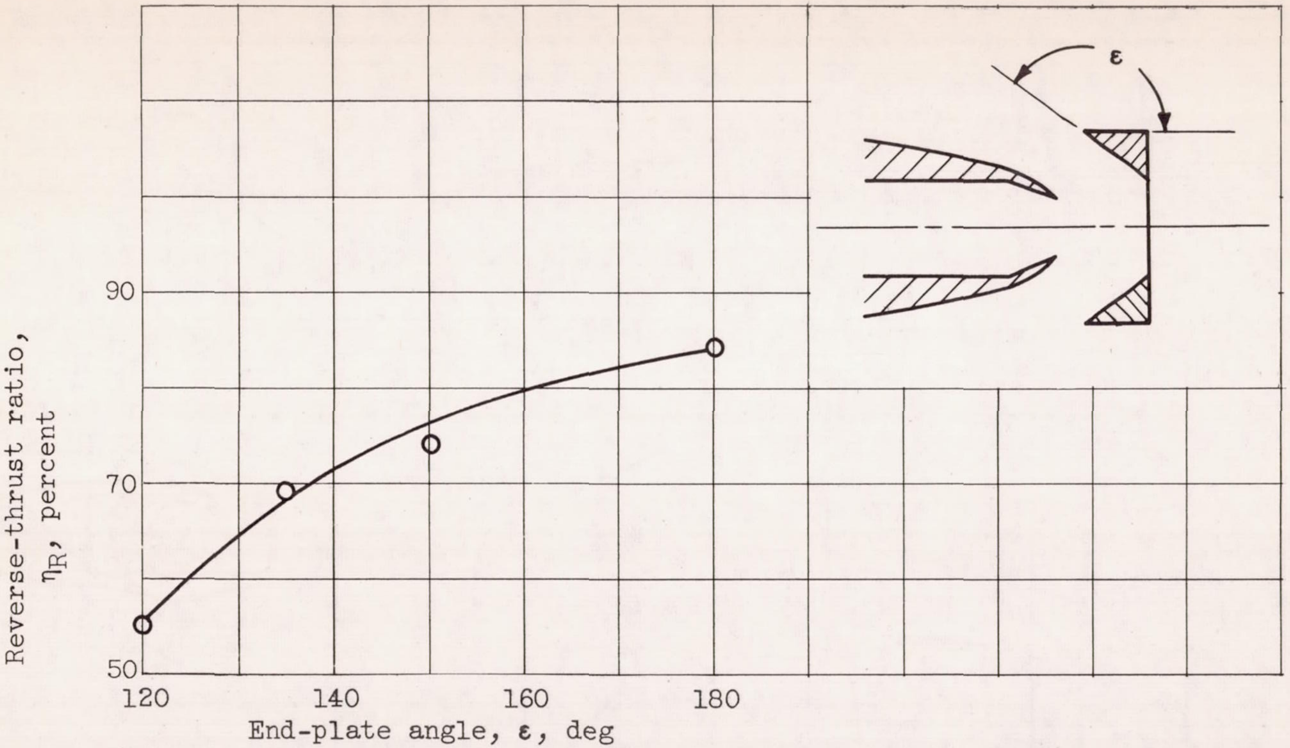


Figure 14. - Effect of end-plate angle on reverse-thrust ratio. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 180°; full end plates.

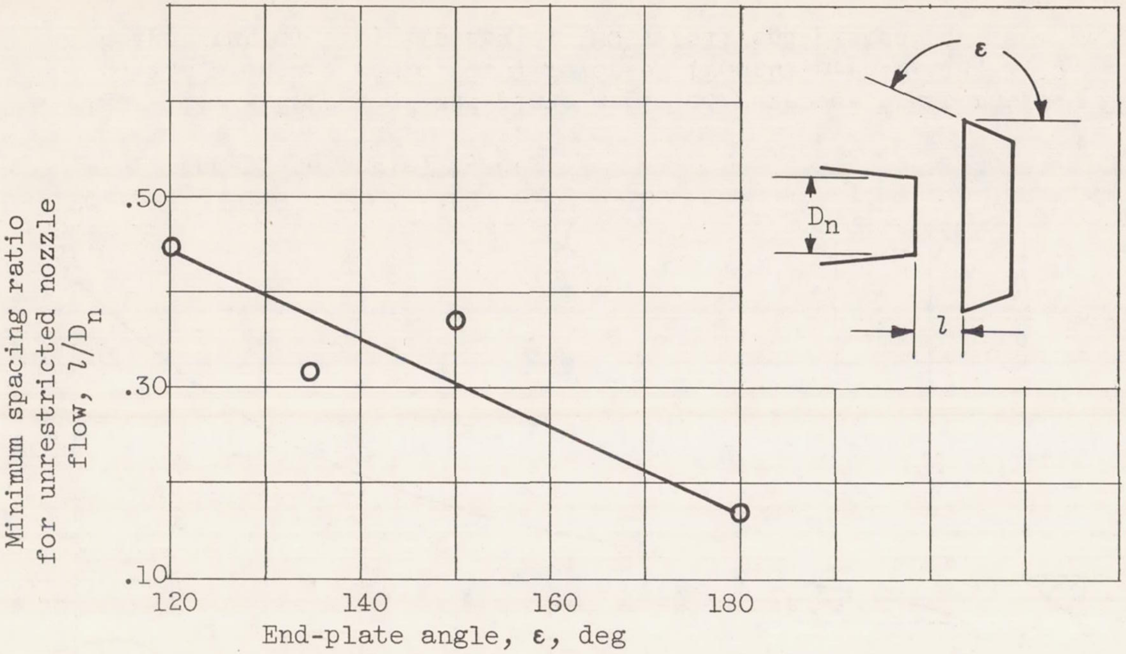
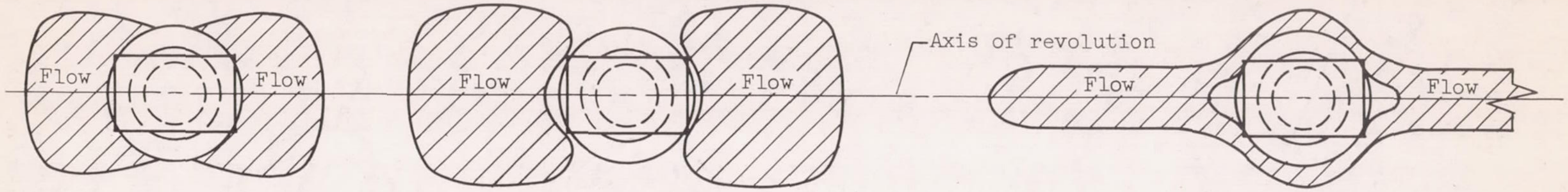


Figure 15. - Effect of end-plate angle on minimum spacing. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 180°; full end plates.



(a) End-plate angle, 180°; reverse-thrust ratio, 84 percent.

(b) End-plate angle, 150°; reverse-thrust ratio, 74 percent.

(c) End-plate angle, 135°; reverse-thrust ratio, 69 percent.

Figure 16. - Variation in reverse-flow field with end-plate angle. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 180°; full end plates.

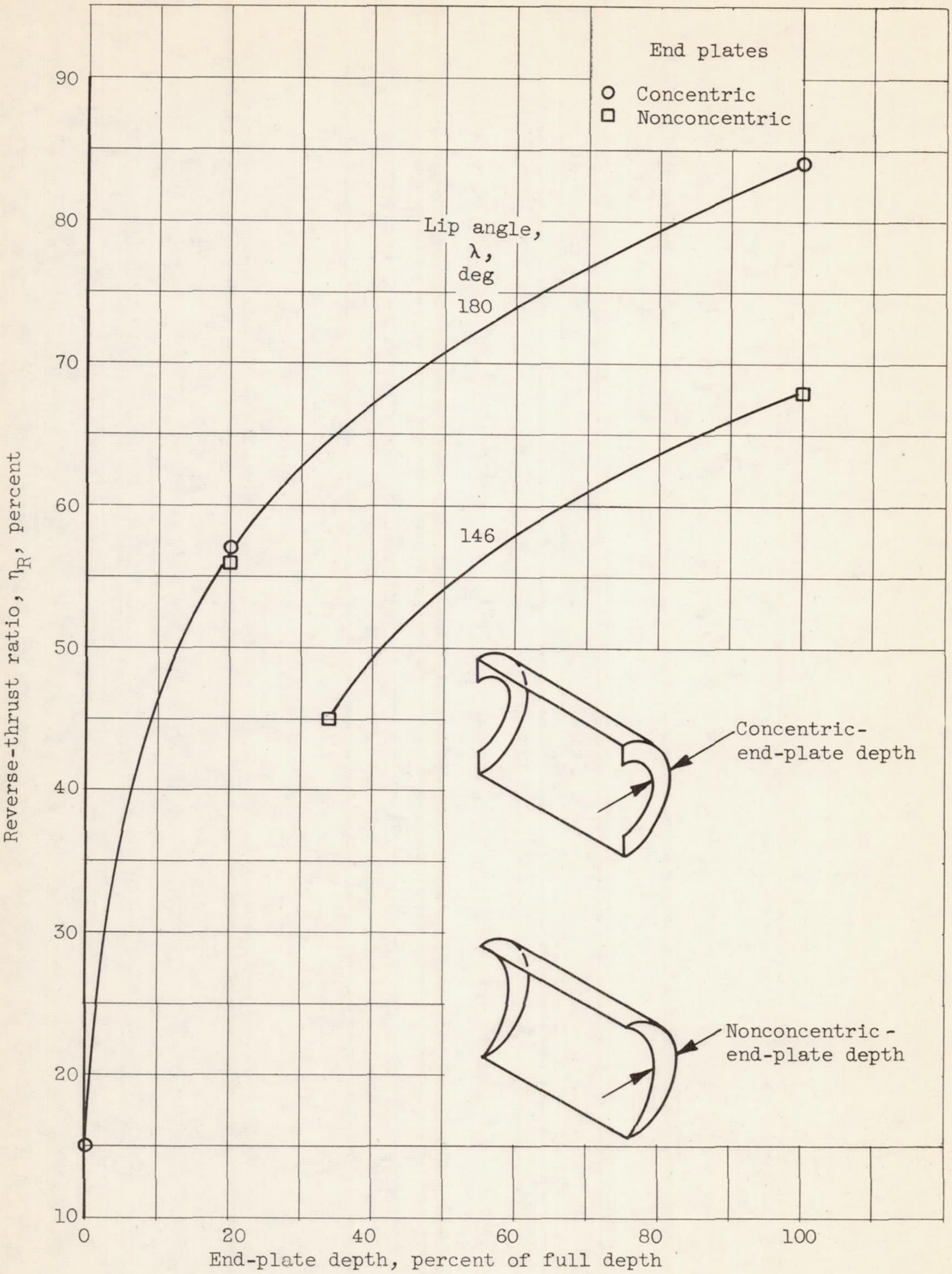


Figure 17. - Effect of end-plate depth on reverse-thrust ratio. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; end-plate angle, 180°.

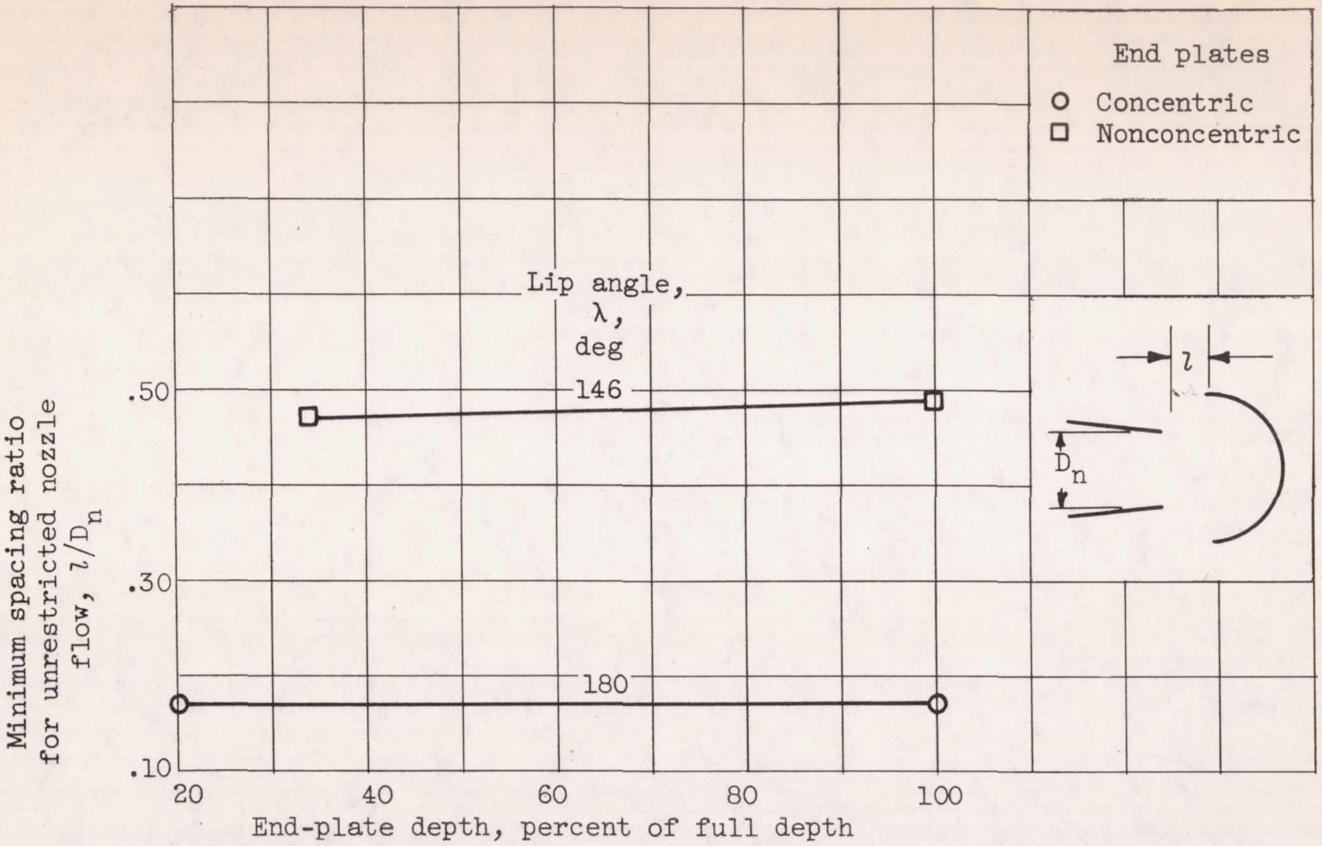
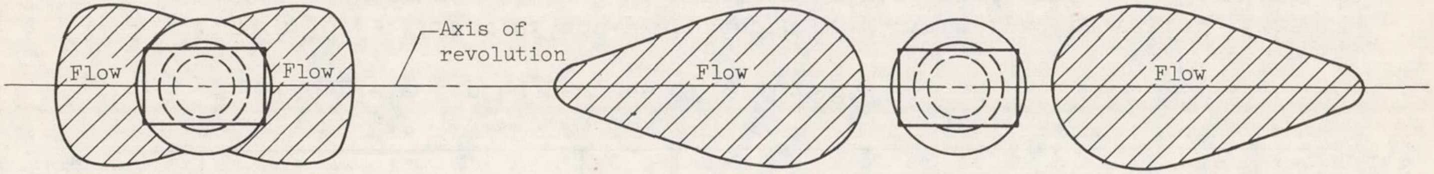
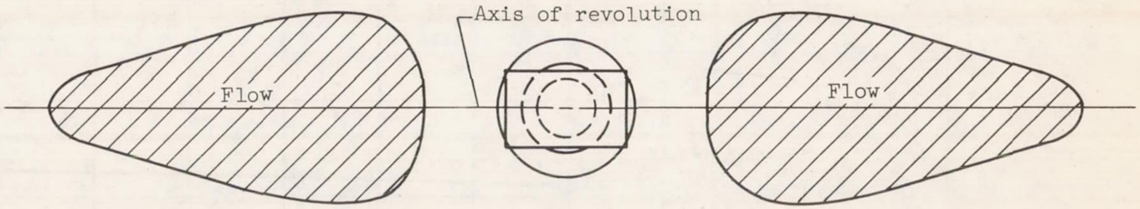


Figure 18. - Effect of end-plate depth on minimum spacing ratio. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; end-plate angle, 180°.



(a) End-plate depth, 100 percent of full depth; reverse-thrust ratio, 84 percent.

(b) Concentric-end-plate depth, 20 percent of full depth; reverse-thrust ratio, 58 percent.



(c) Nonconcentric-end-plate depth, 20 percent of full depth; reverse-thrust ratio, 56 percent.

Figure 19. - Variation in reverse-flow field with end-plate depth. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 180°; end-plate angle, 180°.

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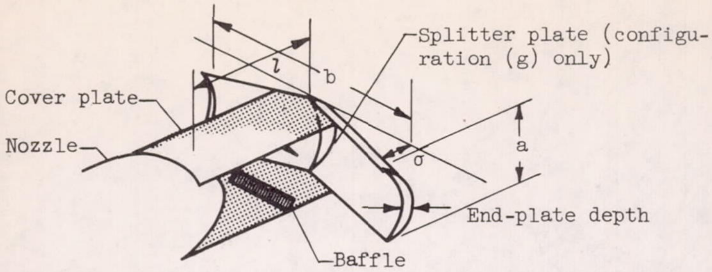
CJ-5 back



Configuration	Sweep angle, σ, deg	End-plate depth, percent	Cover plates	Baffles	Minimum spacing ratio for unrestricted nozzle flow, l/D_n	Remarks
a	30	0	No	No	0.63	Gases escape vertically
b	30	0	Yes	No	1.01	Unstable flow at exhaust-nozzle pressure ratio below 2.4 and above 2.9
c	30	0	Yes	Yes	0.95	Acceptably stable
d	30	38	Yes	No	1.01	Unstable
e	30	34	Yes	Yes	1.01	Acceptably stable
f	30	38	Yes	Yes	1.00	Acceptably stable (conical sections)
g	45	38	Yes	No	1.04	Violently unstable, even with splitter plate
h	0	34	Yes	No	0.47	Stable

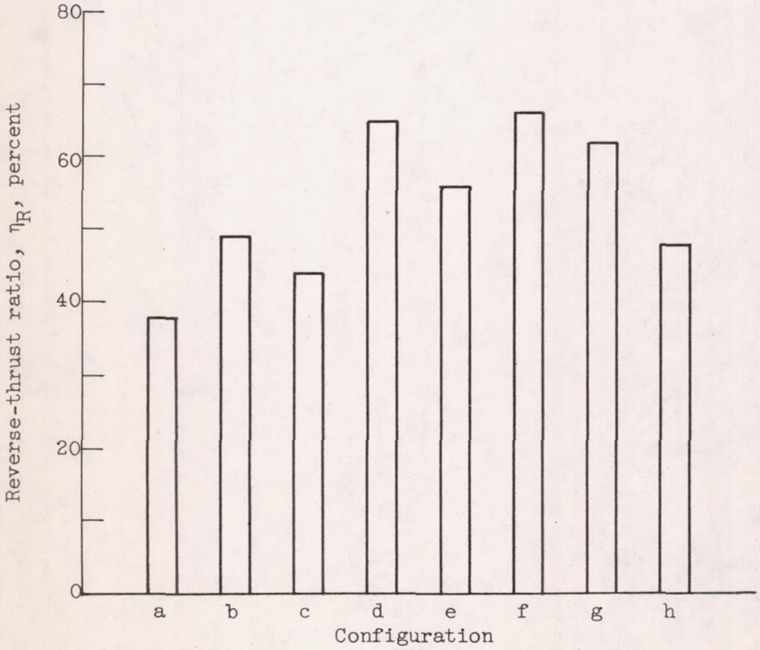
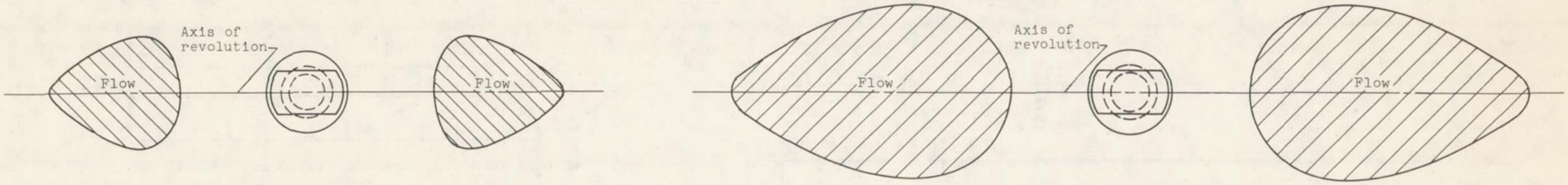


Figure 20. - Performance of swept-type reversers. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6.

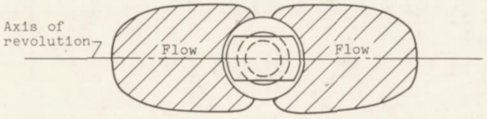


(a) Configuration (a).

(b) Configuration (c).

(c) Configuration (d).

(d) Configuration (e).



(e) Configuration (f).

Figure 21. - Reverse-flow fields from swept-type reverser. Exhaust-nozzle pressure ratio, 2.0.

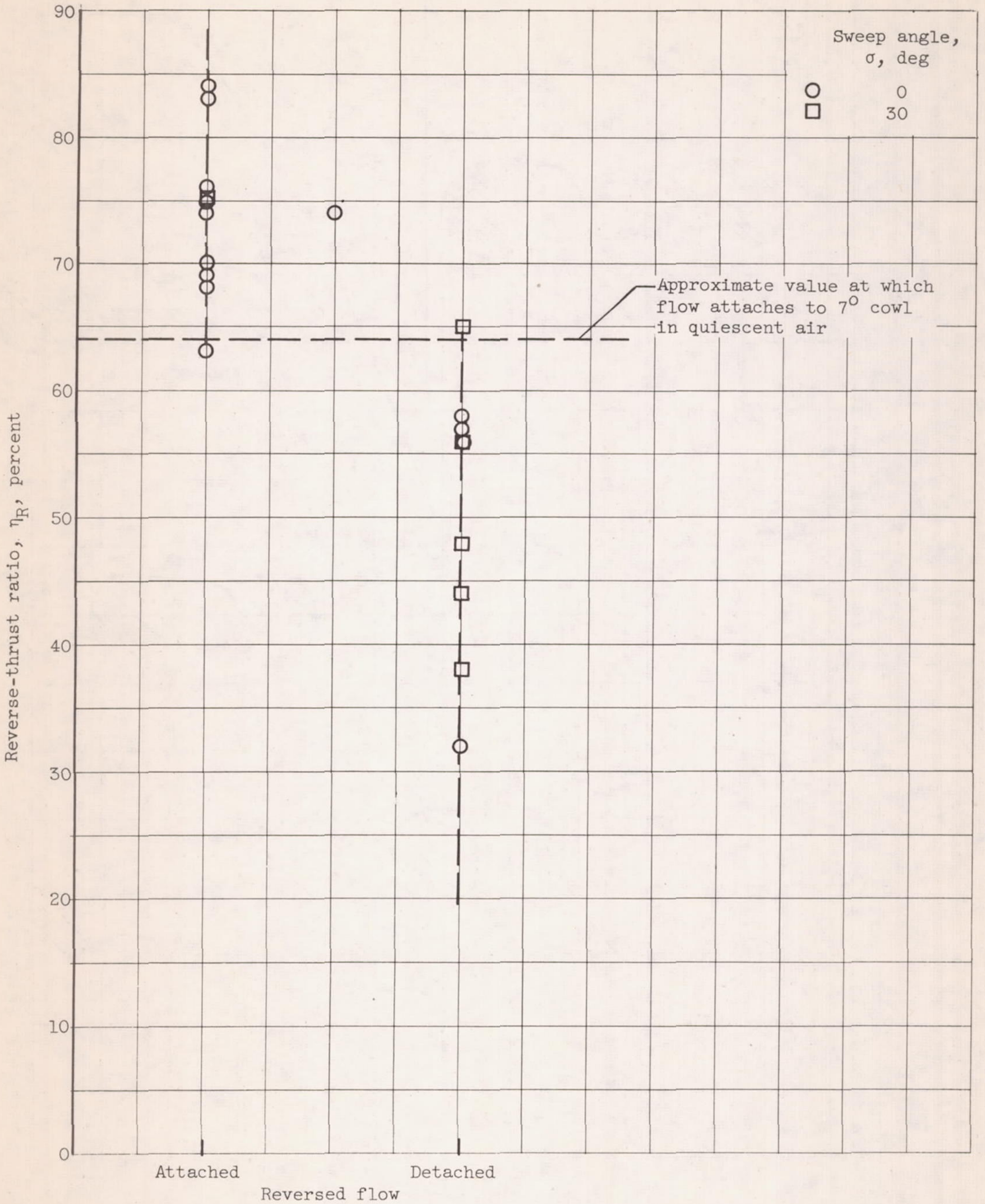


Figure 22. - Relation of reverse-thrust ratio and reversed-flow attachment. Exhaust-nozzle pressure ratio, 2.0; cowl angle, 7°.

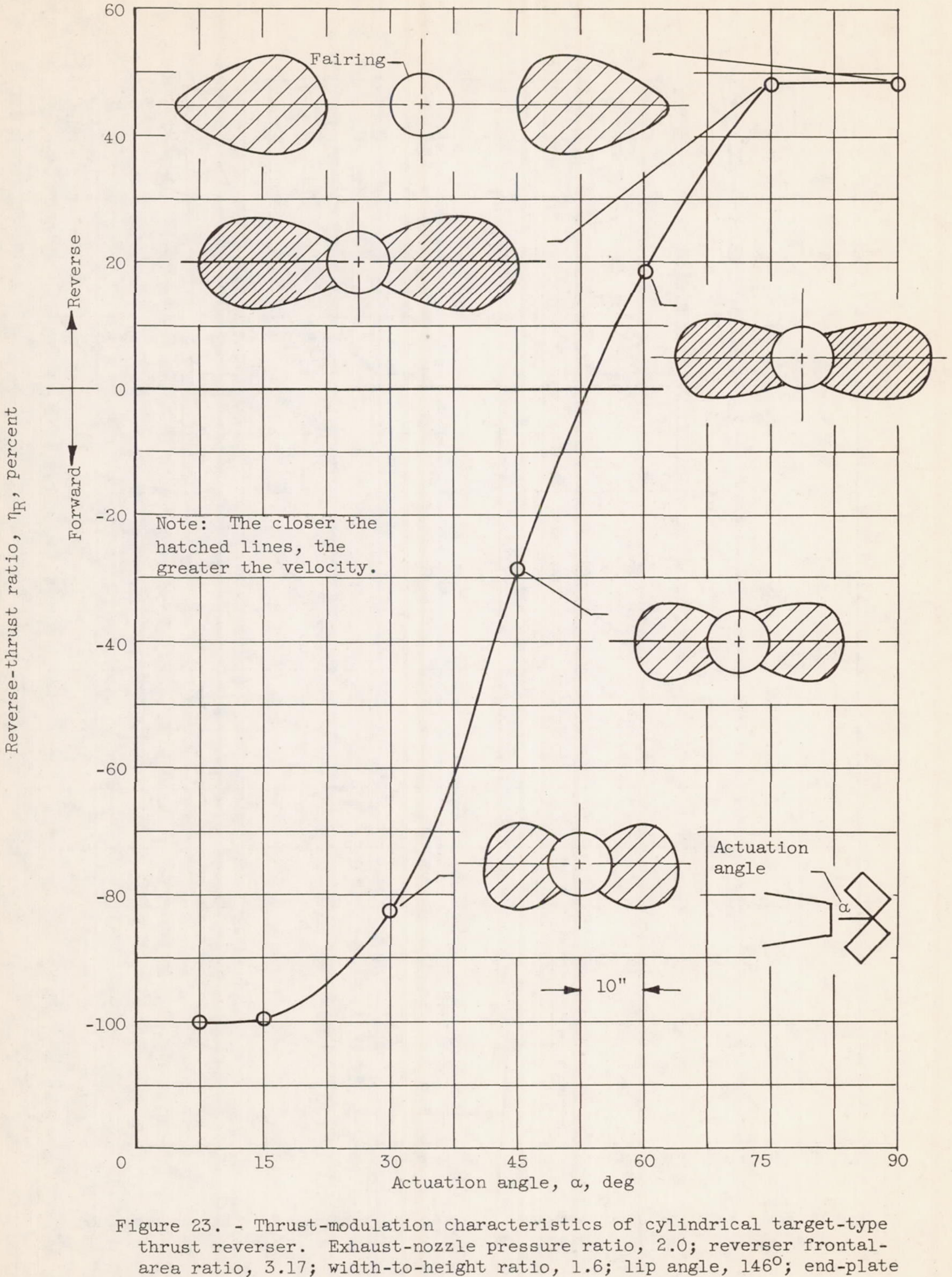
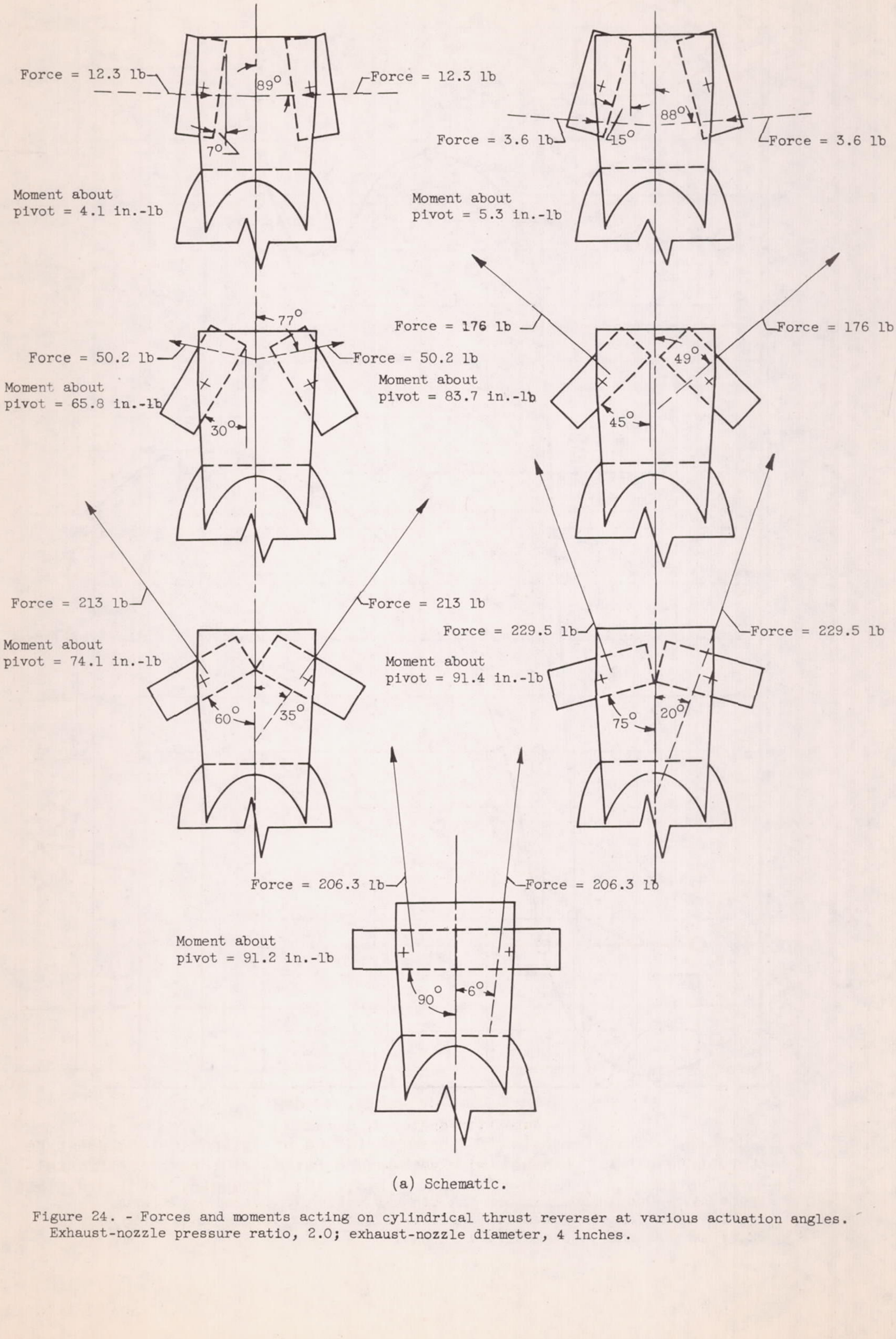
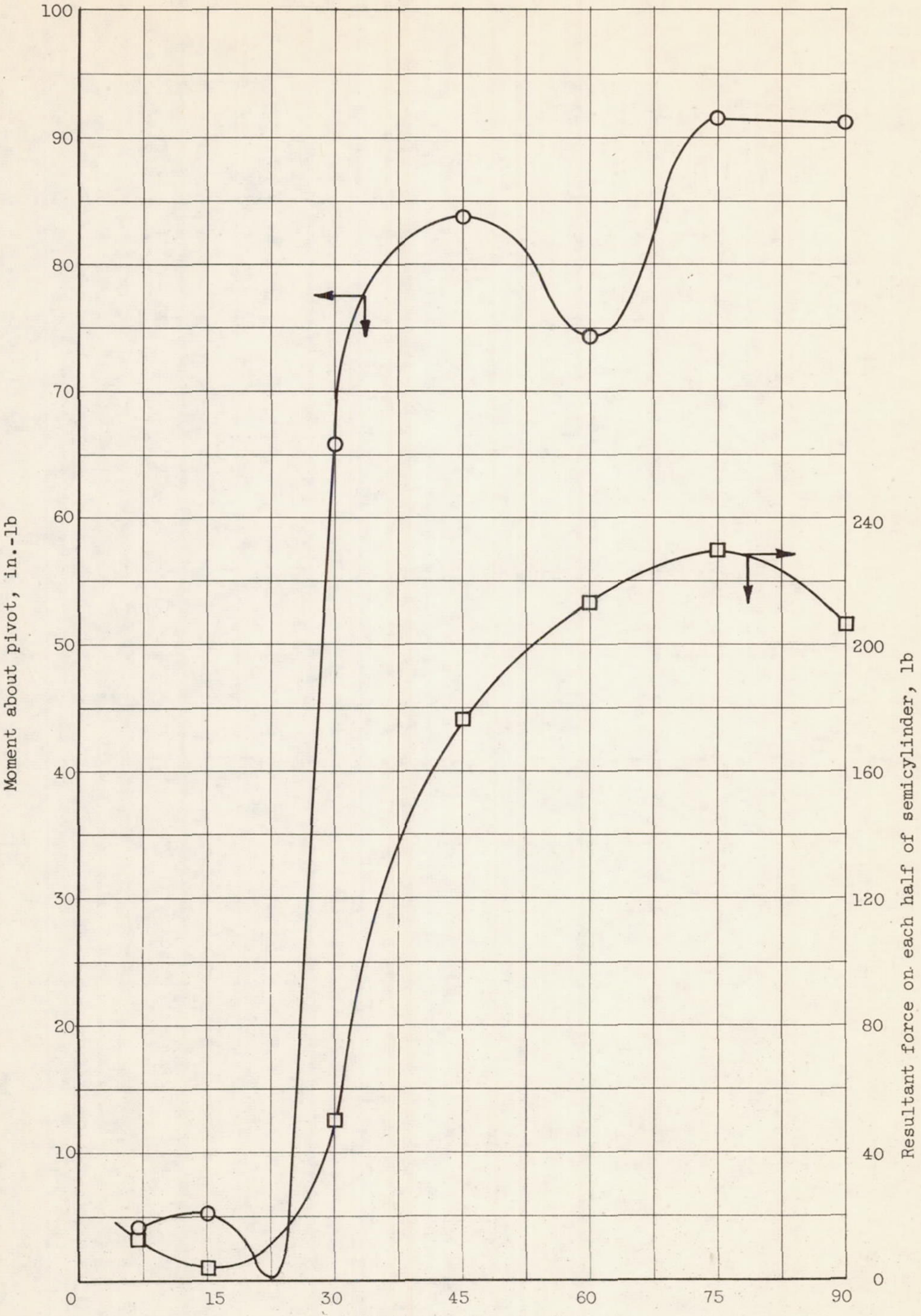


Figure 23. - Thrust-modulation characteristics of cylindrical target-type thrust reverser. Exhaust-nozzle pressure ratio, 2.0; reverser frontal-area ratio, 3.17; width-to-height ratio, 1.6; lip angle, 146°; end-plate angle, 180°; nonconcentric end plates.



(a) Schematic.

Figure 24. - Forces and moments acting on cylindrical thrust reverser at various actuation angles. Exhaust-nozzle pressure ratio, 2.0; exhaust-nozzle diameter, 4 inches.



(b) Graphic.

Figure 24. - Concluded. Forces and moments acting on cylindrical thrust reverser at various actuation angles. Exhaust-nozzle pressure ratio, 2.0; exhaust-nozzle diameter, 4 inches.