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RESEARCH MEMORANDUM

INVESTIGATION OF BOATTAIL AND BASE PRESSURES OF TWIN-JET AFTERBODIES AT MACH NUMBER 1.91

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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SUMMARY

The boattail pressures and base pressures of two twin-jet afterbody configurations were investigated at Mach number 1.91. The twin-jet afterbodies were designed as a simple merging of two blunt-based conical afterbodies with spacings of 1.4 and 1.7 jet diameters between the jet center lines. Both convergent and convergent-divergent exit nozzles were investigated through a range of jet pressure ratios. In addition, the possibility of using a reflection plane and a single afterbody to obtain twin-jet model data was investigated.

The differences in the base pressures between the twin-jet afterbodies and a similar axially symmetric single-jet afterbody were generally small compared with the effects of other base variables, such as jet exit angle. With the jet off, the base pressures were lower for the twin-jet afterbodies than for the single-jet afterbody. Also, the base pressure of the model with 1.7 jet spacing generally was lower than that of the 1.4 model. With jet flow, the relative base pressures of the twin-jet afterbodies and the single-jet afterbody depended on the type of jet exit nozzle, the nozzle pressure ratio, and the jet spacing. The results obtained with the reflection plane and half-body were not quantitatively equivalent to those of the actual twin-jet models.

INTRODUCTION

The afterbody and base pressures of axially symmetric blunt-based bodies at supersonic speeds can be predicted to an engineering degree of accuracy by methods such as those of references 1 and 2. When a jet exits from the blunt base, however, the interference effects of the exiting jet on the base pressure make the predictions less reliable. Considerable data are being obtained, therefore, to determine the jet effects on the base pressures of various afterbody types.

For the case of multiple-jet afterbody configurations, the problem is further complicated by model asymmetry and mutual interference effects of the multiple jets. Reference 3 reports the results of tests of a five-jet afterbody at Mach 1.91. The present investigation is a preliminary evaluation of the relative pressures on the base and boattail of single and multijet afterbodies of comparable geometry. Two twin-jet models designed as a simple merging of two conical afterbodies were investigated at Mach 1.91. Both convergent and convergent-divergent exit nozzles were included. In addition, the method of utilizing a reflection plane and a single half-body to simulate twin-jet models was investigated.

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SYMBOLS

The following symbols are used in this report:

C_p pressure coefficient, $(p - p_0)/q_0$

D diameter

M Mach number

P total pressure

p static pressure

q dynamic pressure, $\gamma pM^2/2$

s distance between twin-jet center lines

x distance upstream measured from base

γ ratio of specific heats

θ angular coordinate used to locate static-pressure orifices measured from plane of twin-jet center lines as shown in fig. 3

Subscripts:

av average

b base

e nozzle exit

n nozzle

0 free stream

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APPARATUS AND PROCEDURE

The models investigated employed a common nose and midsection and two interchangeable twin-jet afterbodies with nozzle spacing ratios s/D_n of 1.4 and 1.7. These twin-jet afterbodies, shown in figures 1(b) and (c), were designed to simulate the annexing of two single, blunt-based, conical afterbodies (fig. 1(a)) and to maintain the jet to base diameter ratio of 0.714 and the boattail angle of 5.6°. However, the fairings of the twin-jet models upstream of the boattail-break were arbitrarily formed to adapt the twin-jet afterbodies to the common mid and nose sections. Convergent-divergent nozzle inserts (fig. 2), designed for a pressure ratio of 10, were used in addition to the convergent exit nozzles for some of the tests. The afterbody model instrumentation consisted of base-pressure orifices located as shown in figures 1(b), jet static orifices positioned inside but near a nozzle exit of each model (excluding the models employing the convergent-divergent nozzle inserts), and a distribution of static orifices along the boattail surface as shown in figure 3. In addition, the common midsection was instrumented with a rake of total-pressure tubes.

The tests were conducted in the Lewis 18- by 18-inch Mach number 1.91 wind tunnel. Throughout the experiment, the test-section total temperature was approximately 150° F, while the dewpoint was maintained at -5° or less. The tunnel test-section Reynolds number was 3.10×10^6 per foot.

Figure 4(a) shows a photograph of the 1.7 spacing ratio model mounted in the tunnel by means of a vertical support strut. Each twin-jet model was tested with the plane of nozzle center lines both parallel and perpendicular to the strut. High-pressure unheated air was ducted through the strut and into the models, permitting a variation of the jet total-pressure ratio P/p_0 from jet-off to approximately 15 for the models with convergent nozzles and 30 for the models with convergent-divergent nozzles. The tunnel static pressure p_0 used in determining these ratios was an average of the measurements from two wall orifices corrected by an increase of 4 percent to the pressure at the center of the tunnel from a previous calibration.

For the reflection-plane tests, splitter plates 6 inches wide and extending from the support strut to 3 inches beyond the base of the models were fitted to the afterbodies in the plane of symmetry perpendicular to the plane of the nozzle center lines. The tests with splitter-plate attachments were restricted to the case of the plane of the nozzle center lines perpendicular to the support strut. The 1.4 spacing ratio model and reflection plane are shown in the photograph in figure 4(b).

RESULTS AND DISCUSSION

Support-Strut Interference

In order to determine the order of magnitude of interference effects due to the support strut, the twin-jet models were tested with the plane of the nozzle center lines both parallel and perpendicular to the support strut. The effects of the model position on the average base pressure coefficient are shown in figure 5. In general, the base pressures were higher when the models were mounted with the jet-axis plane parallel to the support strut. The differences in the average base pressure coefficient due to model position varied with the type of jet exit nozzle used and with the jet pressure ratio. In some cases the differences in the average base pressure coefficient due to model position may be as great as or greater than those due to variations of the geometric parameters of the model. All the data are presented for both positions of the model relative to the support strut.

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Effect of Jet Spacing Ratio

Twin-jet configurations with jet spacing ratios s/D_n of 1.4 and 1.7 were investigated. The base pressures of the axially symmetric reference model $(s/D_n = 0)$ are an average of two base orifices located 90° apart, one of which was in line with the support strut. The data for the axially symmetric model were obtained from a previous unpublished investigation. The effects of jet spacing ratio on the average base pressure coefficient (fig. 6) varied both with the type of exit nozzles used and with the jet pressure ratio. Although the effects of jet spacing ratio in the low jet pressure ratio range are not clear, they appear to be small. At higher jet pressure ratios and with convergent exit nozzles, the rate of increase of base pressure with jet pressure ratio was slightly greater through the major part of the jet pressure ratio range for the twin-jet models than for the single-jet model. With convergent-divergent exit nozzles, the average base pressures at jet pressures beyond the minimum base pressure point were much lower for the 1.4 than for the 1.7 spacing ratio model; and, except at the highest jet pressure ratios tested, the base pressures of the axially symmetric single-jet model and the 1.7 spacing ratio model were about equal. For all cases, the jet-off base pressures were lower for the twin-jet models than for the single afterbody; and, in most cases, increasing the jet spacing from 1.4 to 1.7 decreased the jet-off base pressure.

Effect of Jet Exit Angle

The average base pressure coefficients are plotted as a function of the jet exit static-pressure ratio in figure 7. The figure shows a comparison of the twin-jet and single-jet data for both the convergent and convergent-divergent exit nozzles. If the effects of jet exit Mach number are neglected, it can be concluded that the effect on the average base pressure coefficient of increasing the jet exit angle from 0° to 10° is of the same order of magnitude for the twin-jet afterbodies as for the single-jet afterbody. The effect of jet spacing ratio was small compared with the effect of a 10° increase in the jet exit angle. Figure 7 also indicates that the average base pressure coefficients for the 1.7 jet spacing model were higher than those of the 1.4 model at jet static-pressure ratios greater than 1.0. This may result from the possible action of the jet flow in enlarging the region of separation already believed to exist in the valley between the twin jets just ahead of the base.

Longitudinal Boattail Pressure Distribution

The variations of the pressure coefficient with the nondimensional distance from the base x/D_b are presented in figure 8 for values of θ of 90° and 180° and along the plane of symmetry normal to the plane of jet center lines. For the $s/D_n = 1.7$ model (figs. 8(a) and (b)), some values at θ of 0° are also presented.

Figure 8 shows certain similar characteristics in the longitudinal pressure distributions for both twin-jet models. At the plane of symmetry, a large pressure drop preceding that at the base is evident for both models for the jet-off case and at low jet pressure ratios. This pressure drop is caused by the rapid turning of the body contour at the plane of symmetry near the point of intersection of the twin conical fairings. Hence, the pressure drop occurs much farther from the base for the $s/D_n = 1.7$ model than for the 1.4 model. For the 1.7 model, the flow separates at the point of intersection of the twin conical fairings. For an afterbody with a small base relative to the body size, such as that represented by the longitudinal cross section at the plane of symmetry, the flow downstream of the separation point on the base is turned back to the free-stream direction and is accompanied by the familiar trailing shock waves and an increased static pressure in the wake. It is believed that the increase in pressure at $\theta = 0^{\circ}$ on the 1.7 model results from this type of flow phenomenon. At high jet pressure ratios, the influence of high base pressures on the boattail was much greater at the plane of symmetry and at $\theta = 0^{\circ}$ than at other values of θ, as would be expected.

A large effect of model position on the boattail pressures is evident. When the plane of nozzle center lines was parallel to the support strut (figs. 8(b) and (d)), the general effect was to increase the pressures at the plane of symmetry, upstream of the pressure drop, to values higher than those at $\theta = 90^{\circ}$; whereas, with the plane of nozzle center lines normal to the support strut (figs. 8(a) and (c)), the pressures at the plane of symmetry were lower than at $\theta = 90^{\circ}$.

Circumferential Pressure Distributions

Unfortunately, the strut interference effects on the circumferential pressure distributions are large, and interpretation of these data is therefore difficult. However, some general trends can be observed (based on their occurrence) for most cases. For the $s/D_n = 1.4$ model (fig. 9(a)), the lowest boattail pressures near the base generally occurred at the plane of symmetry for the condition where the average base pressure was low. For high average base pressures (fig. 9(a), $P/p_0 = 14.5$), however, the pressures at the plane of symmetry near the base were higher than at other circumferential stations. For the 1.7 model (fig. 9(b)), the lowest boattail pressures near the base generally occurred near $\theta = 45^\circ$ rather than at $\theta = 0^\circ$. This may be due to the increase in pressure at $\theta = 0^\circ$ caused by separation at the intersection of the twin fairings, as previously discussed.

The mutual interference of the closely spaced twin jets might be expected to cause a deflection of the jets and also have an effect on the base pressure. Figure 10 shows a schlieren photograph of the $s/D_n = 1.4$ model with convergent nozzles at a pressure ratio P/p_0 of 14.9. No difference in the initial expansion angle of the exiting jets could be measured at $\theta = 0^\circ$ and 180° for this case. Although some distortion of the jets is evident farther downstream of the exit, this should have little or no effect on the base pressure.

The twin-jet models were not provided with sufficient instrumentation to determine total afterbody drag coefficients. Therefore, no comparisons of the relative drags of the twin-jet and single-jet afterbodies can be made.

Effect of Reflection Plane

The effects on the average base pressure coefficient of a reflection plane located at the plane of symmetry between the twin jets are shown in figure 11. With the reflection plane in place, the average base pressures were in general higher than those of the actual twin-jet model. The interference effects were greater than expected on the basis of the results of reference 1, in which a reflection plane and half-body were used to simulate an axially symmetric afterbody. In reference 1, however, no support strut was used ahead of the reflection plane, and, also, the reflection plane was somewhat smaller relative to the model size.

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SUMMARY OF RESULTS

The pertinent results of the experimental investigation of two twin-jet afterbody configurations at a Mach number of 1.91 can be summarized as follows:

1. The effects of jet spacing ratio varied both with the type of exit nozzle used and with the jet pressure ratio but were, in general, small compared with the effects of other base variables such as jet exit angle.

2. With the jet off, the average base pressures were lower for the twin-jet afterbodies than for a similar axially symmetric single-jet afterbody. With the jet on the relative base pressure depended on the type of exit nozzle used and the jet spacing ratio.

3. The base pressures measured with a reflection plane installed at the plane of symmetry to simulate twin jets with a single half-body were generally higher than those of the actual twin-jet models.

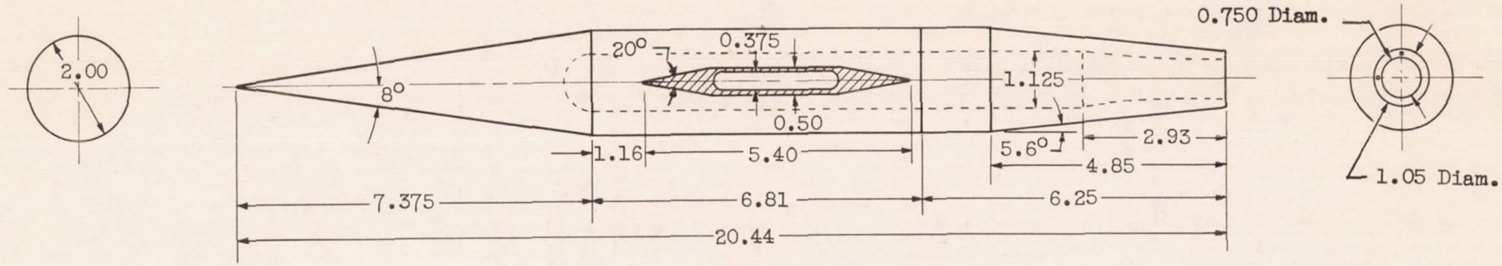
Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, March 3, 1955

REFERENCES

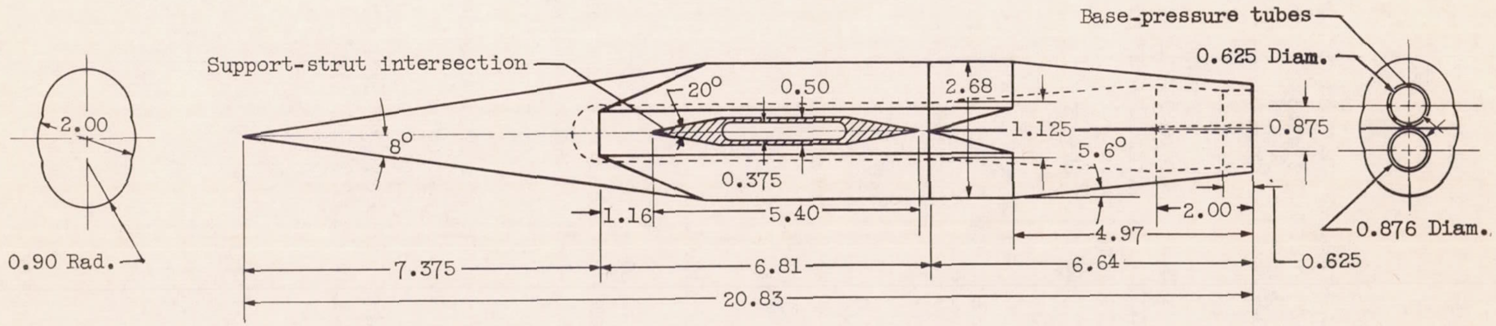
1. Cortright, Edgar M., Jr., and Schroeder, Albert H.: Investigation at Mach Number 1.91 of Side and Base Pressure Distributions over Conical Boattails without and with Jet Flow Issuing from the Base. NACA RM E51F26, 1951.

2. Jack, John R.: Theoretical Pressure Distributions and Wave Drags for Conical Boattails. NACA TN 2972, 1953.

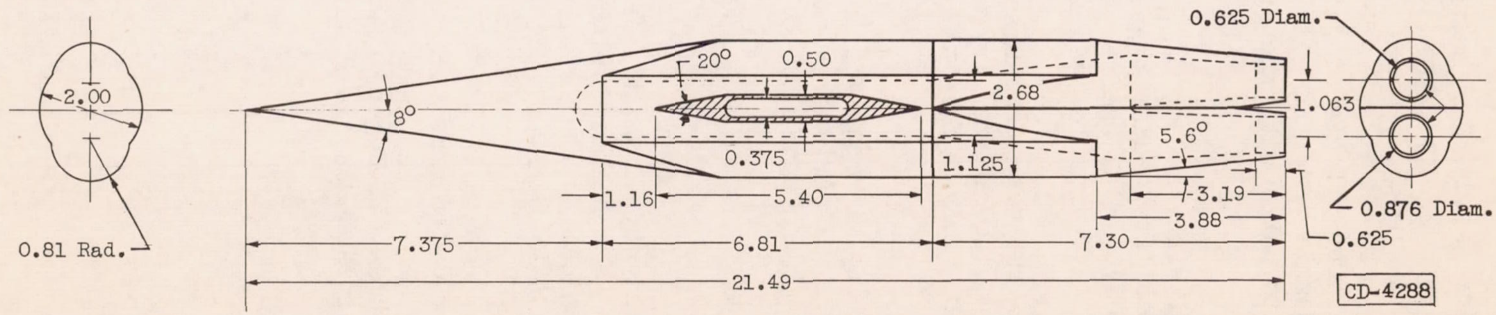
3. Baughman, L. Eugene: Wind-Tunnel Investigation at Mach 1.9 of Multijet-Missile Base Pressures. NACA RM E54L14, 1955.



(a) Single jet: $s/D_n = 0$.



(b) Twin jet: $s/D_n = 1.4$.



(c) Twin jet: $s/D_n = 1.7$.

Figure 1. - Model geometry (dimensions in inches).

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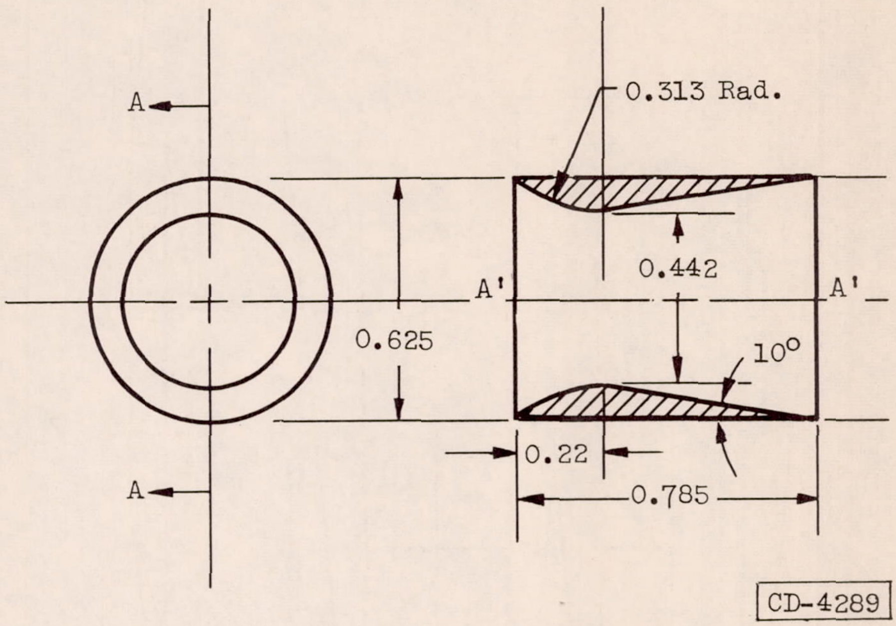

Figure 2. - Convergent-divergent nozzle insert (dimensions in inches).

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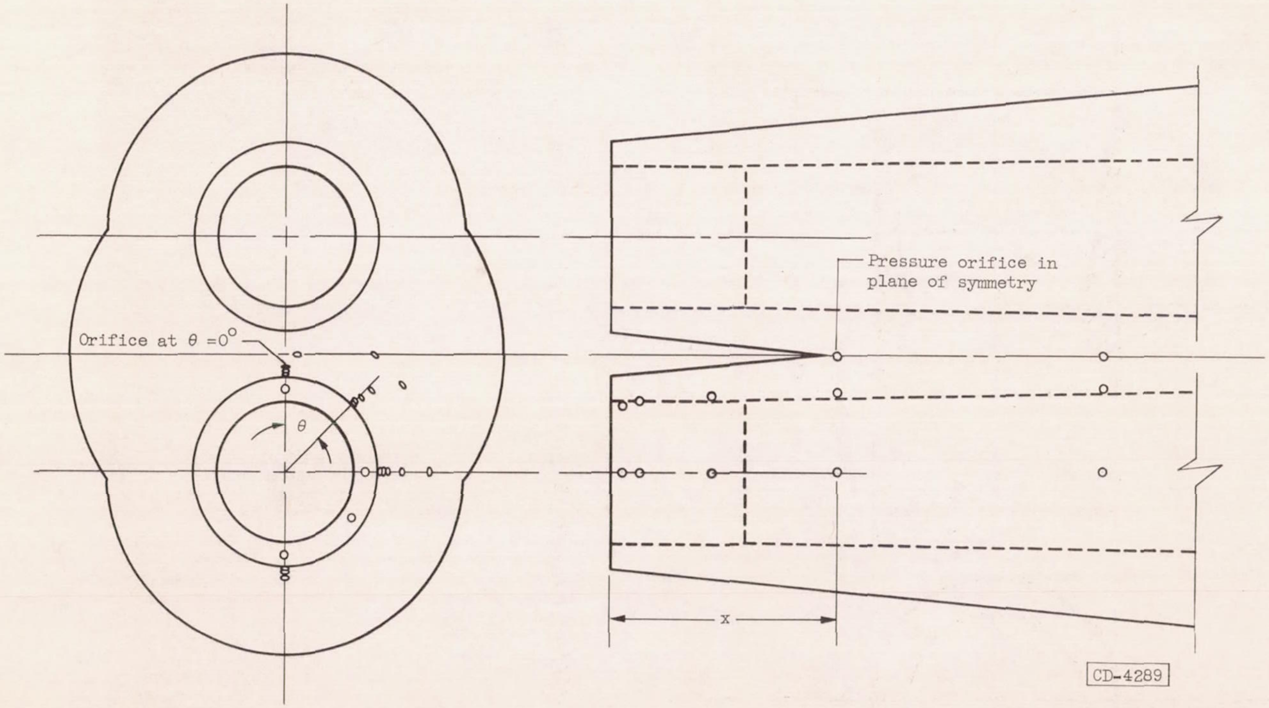

s/D_n = 1.4		s/D_n = 1.7	
x, in.	θ, deg	x, in.	θ, deg
Base	2.0	Base	5.3
Base	54.5	Base	93.4
Base	88.0	Base	129.3
Base	178.9	Base	173.0
0.141	14.5	0.172	0
.125	57.5	.141	51.0
.125	90.0	.156	90.0
.125	180.0	.156	174.9
.281	20.0	.281	0
.250	60.1	.266	51.0
.250	87.0	.281	90.0
.250	177.2	.281	176.0
.563	27.3	.531	0
.516	60.1	.531	53.0
.500	87.0	.531	90.0
.500	181.4	.531	180.0
1.031	35.7	1.047	9.9
1.000	64.5	1.016	57.5
1.000	88.0	1.000	90.0
2.000	46.3	2.031	33.2
2.016	68.1	2.016	61.8
2.016	87.0	2.016	90.0

Figure 3. - Location of static orifices.

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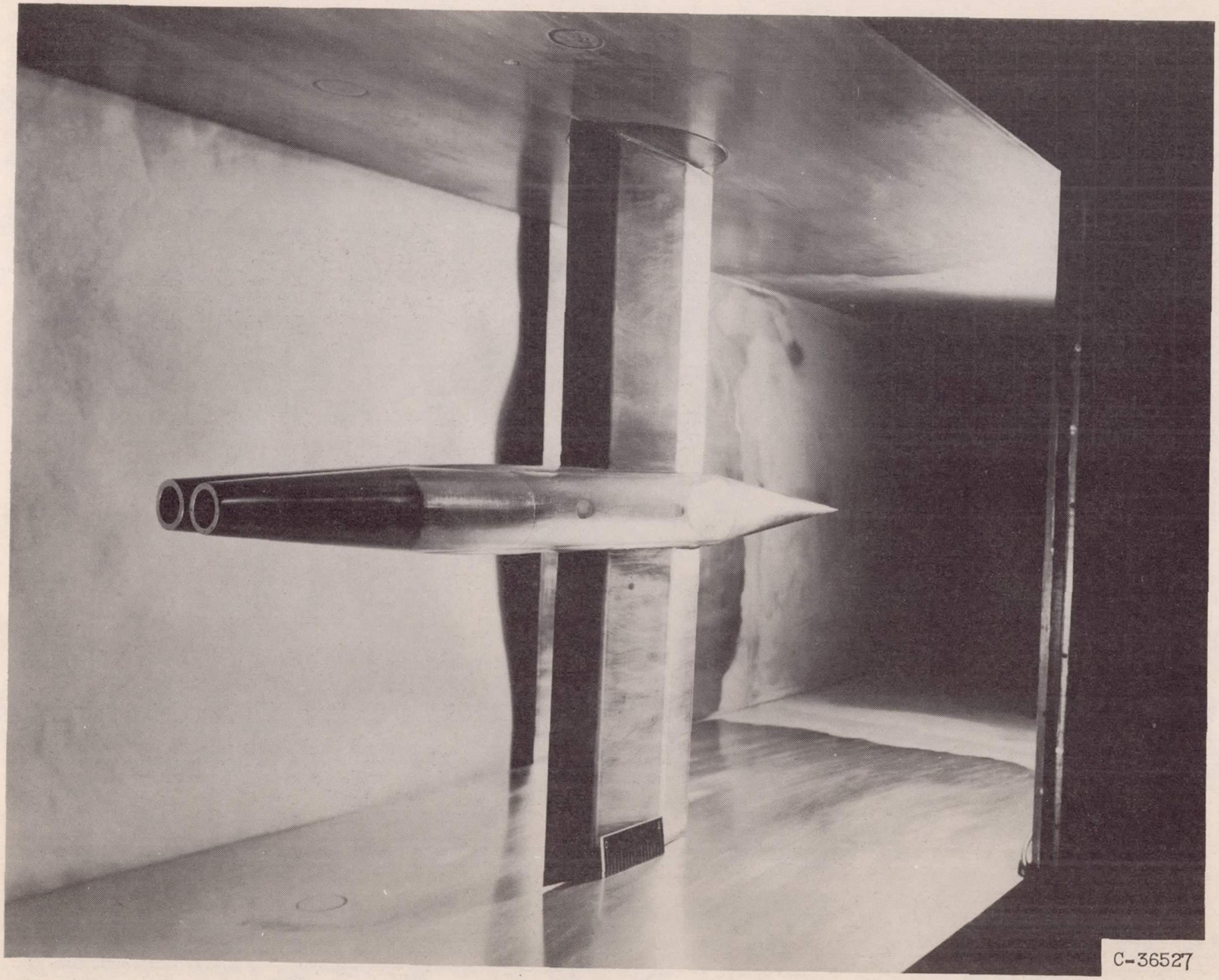

(a) Model with 1.7 spacing ratio.

Figure 4. - Photographs of twin-jet models in Lewis 18- by 18-inch Mach 1.91 wind tunnel.

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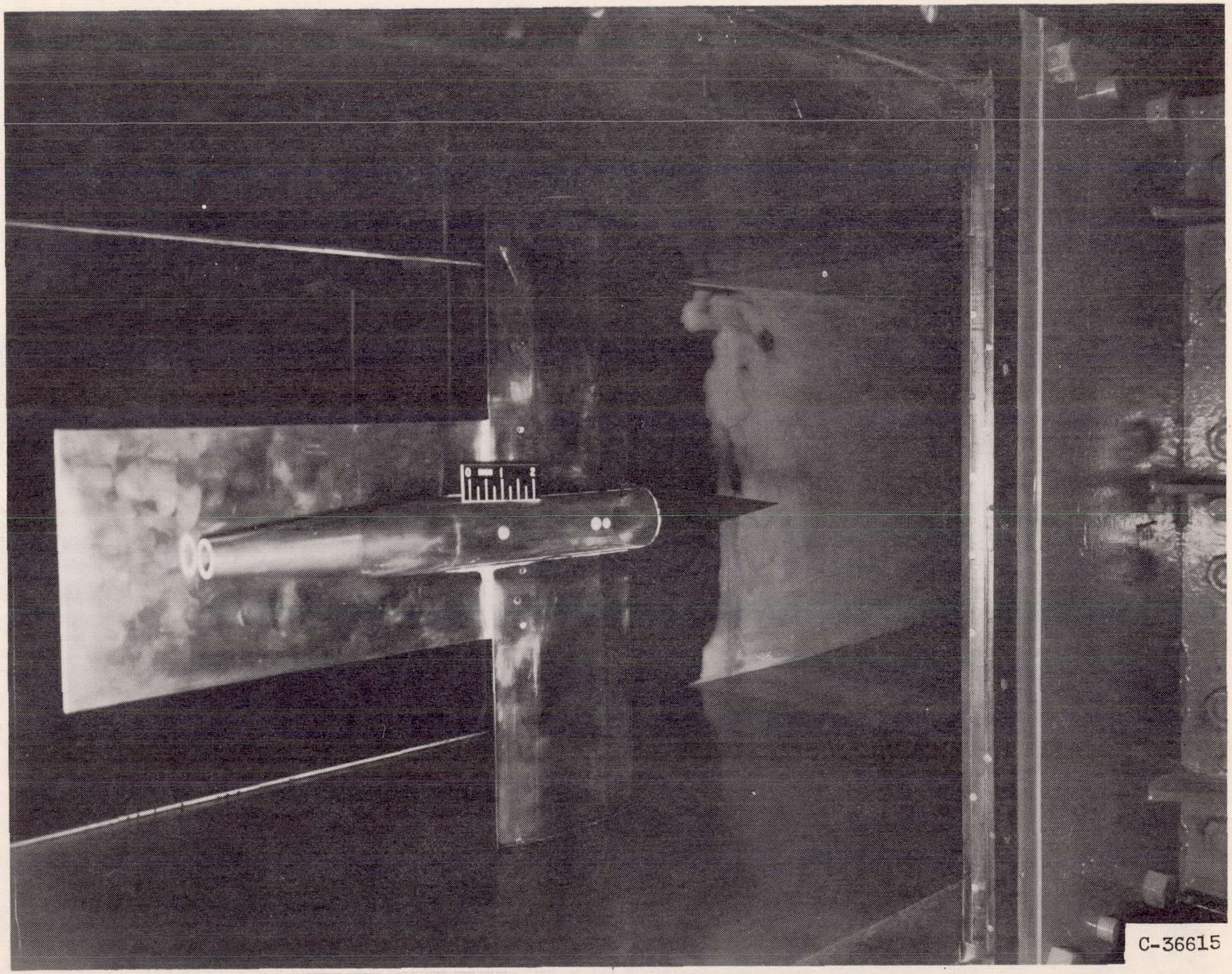

(b) Model with 1.4 spacing ratio and reflection plane.

Figure 4. - Concluded. Photographs of twin-jet models in Lewis 18- by 18-inch Mach 1.91 wind tunnel.

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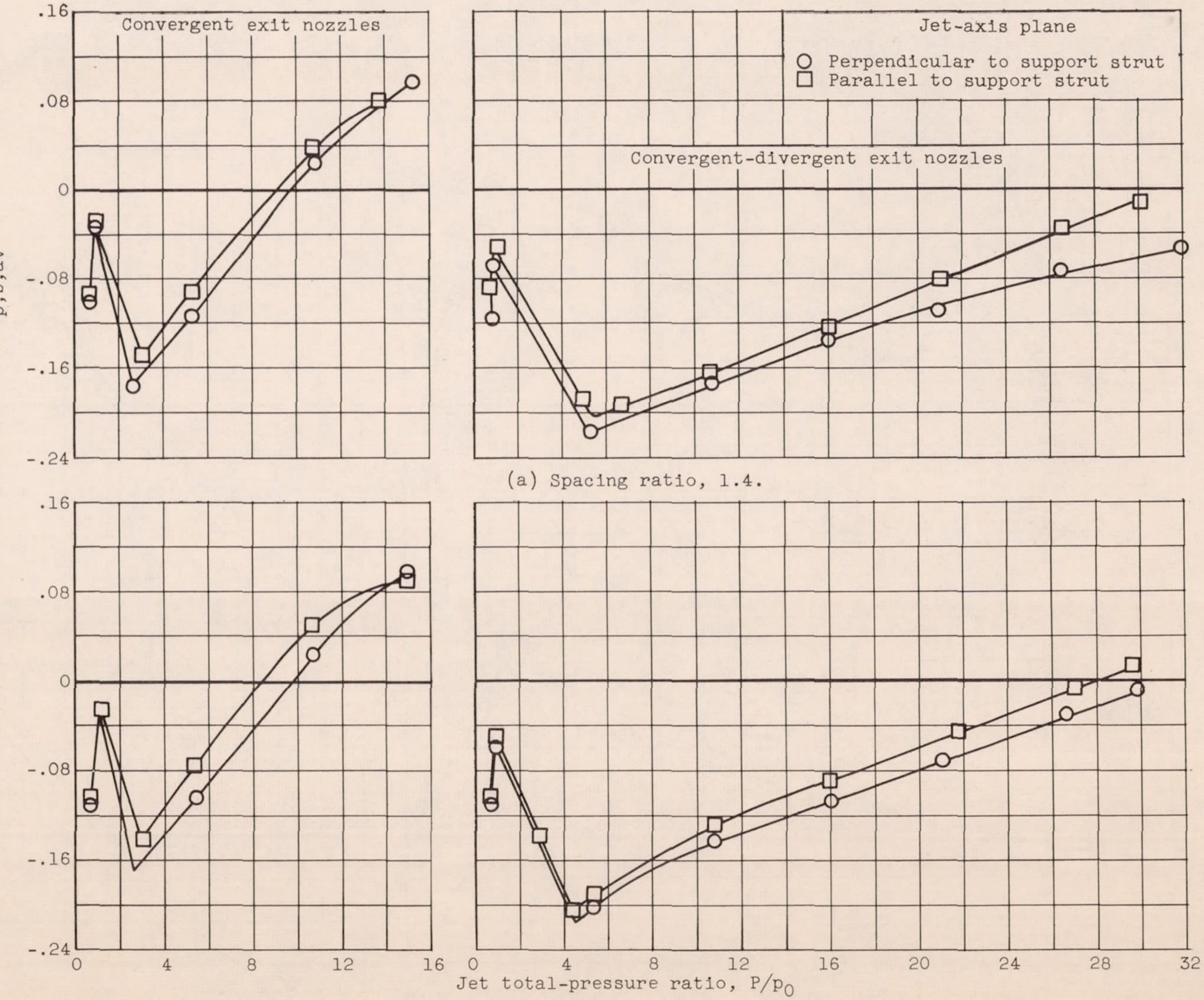

(a) Spacing ratio, 1.4.

(b) Spacing ratio, 1.7.

Figure 5. - Effect of relative position of model and support strut on average base pressure coefficient.

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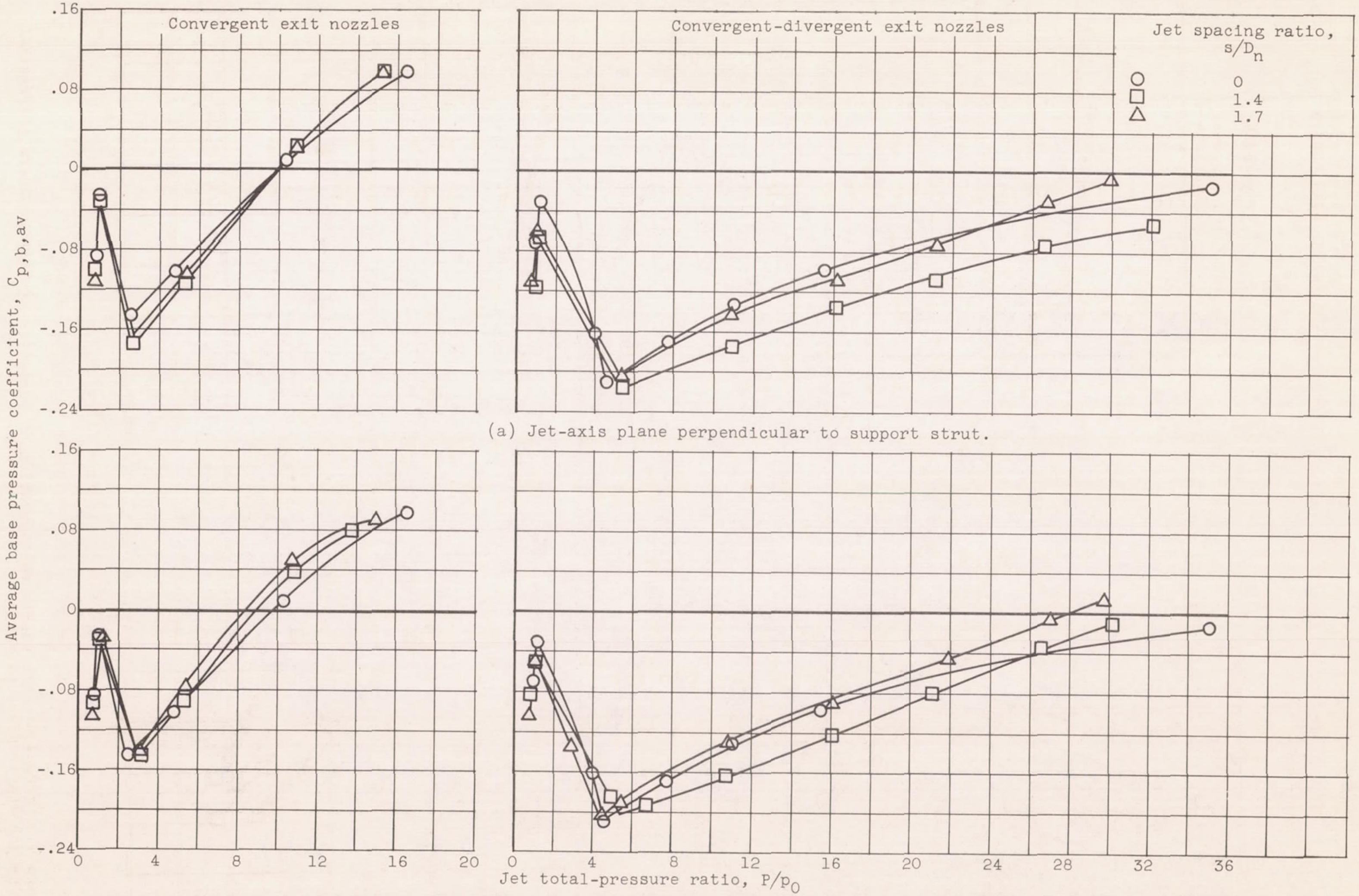

(a) Jet-axis plane perpendicular to support strut.

(b) Jet-axis plane parallel to support strut.

Figure 6. - Effect of jet spacing ratio on average base pressure coefficient.

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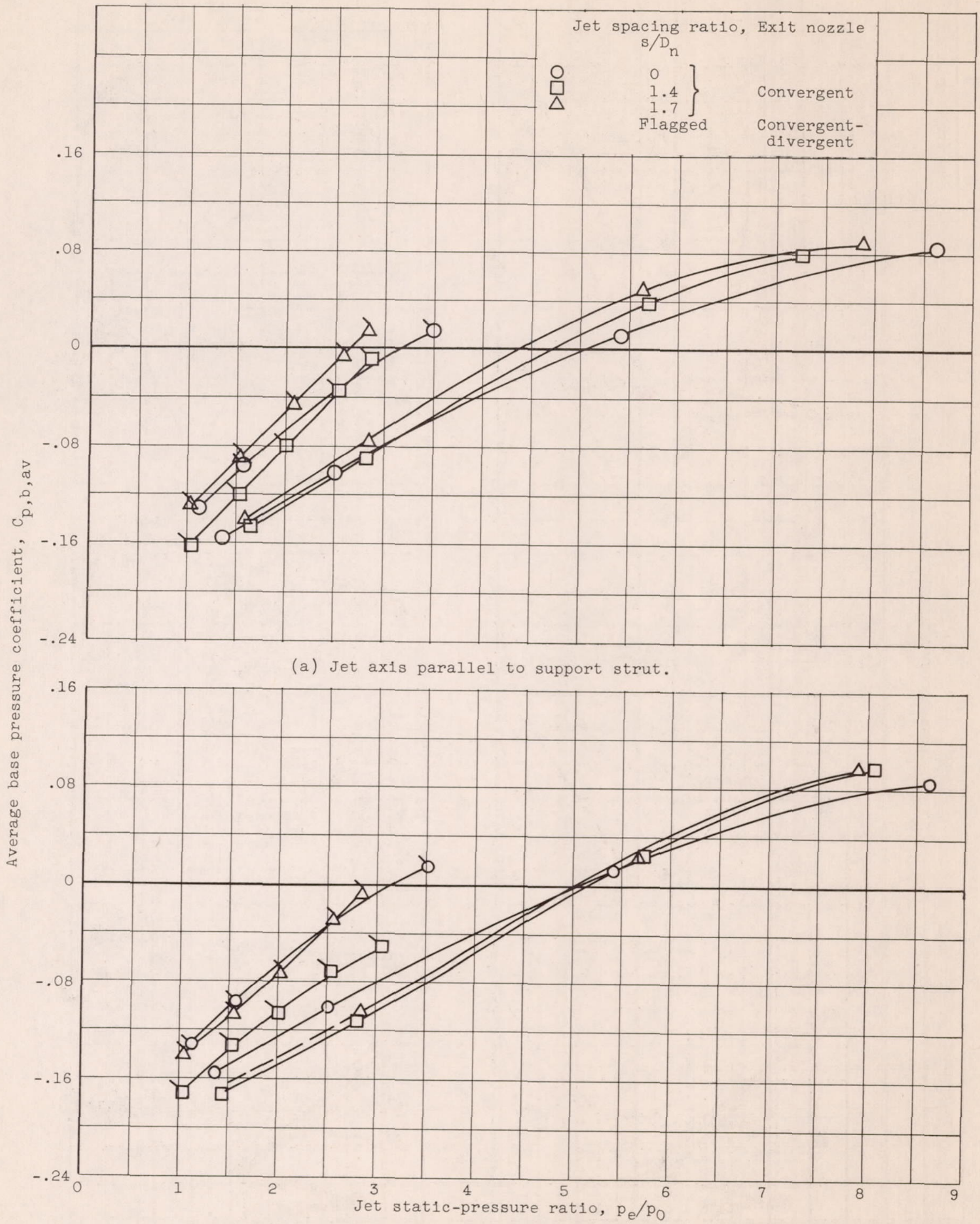

(a) Jet axis parallel to support strut.

(b) Jet axis perpendicular to support strut.

Figure 7. - Effect of exit nozzle configuration on variation of base pressure coefficient with jet static-pressure ratio.

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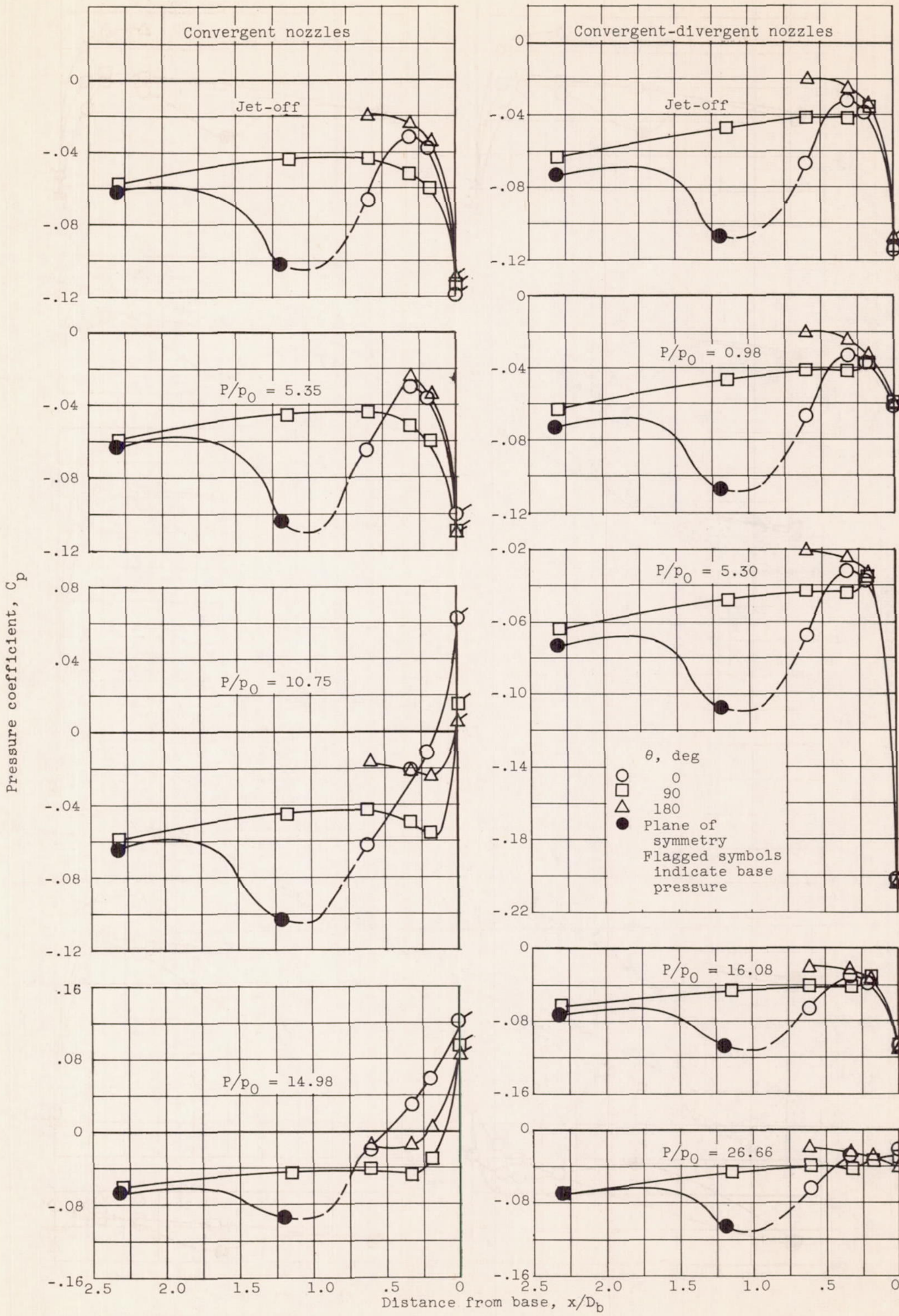
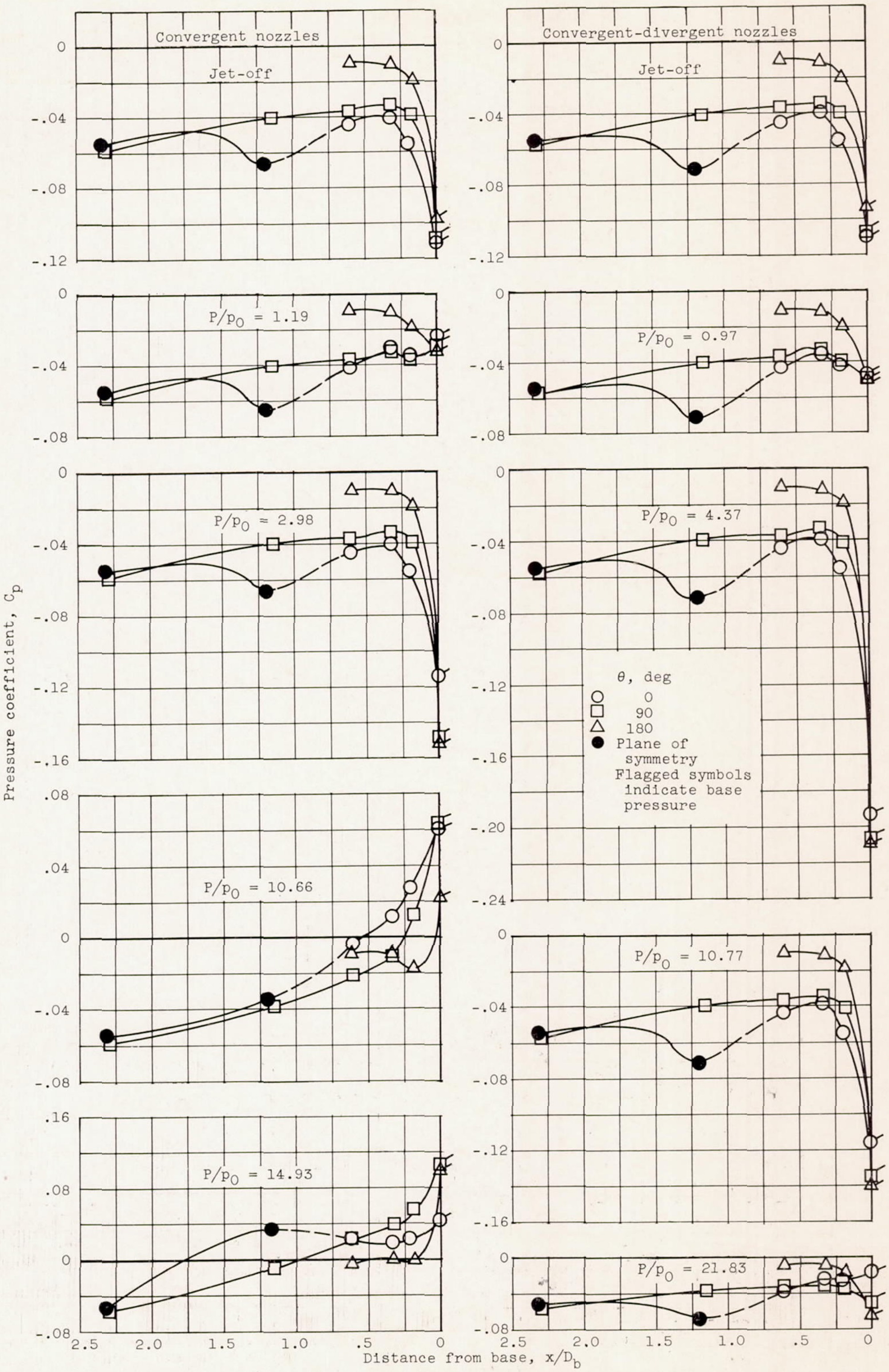


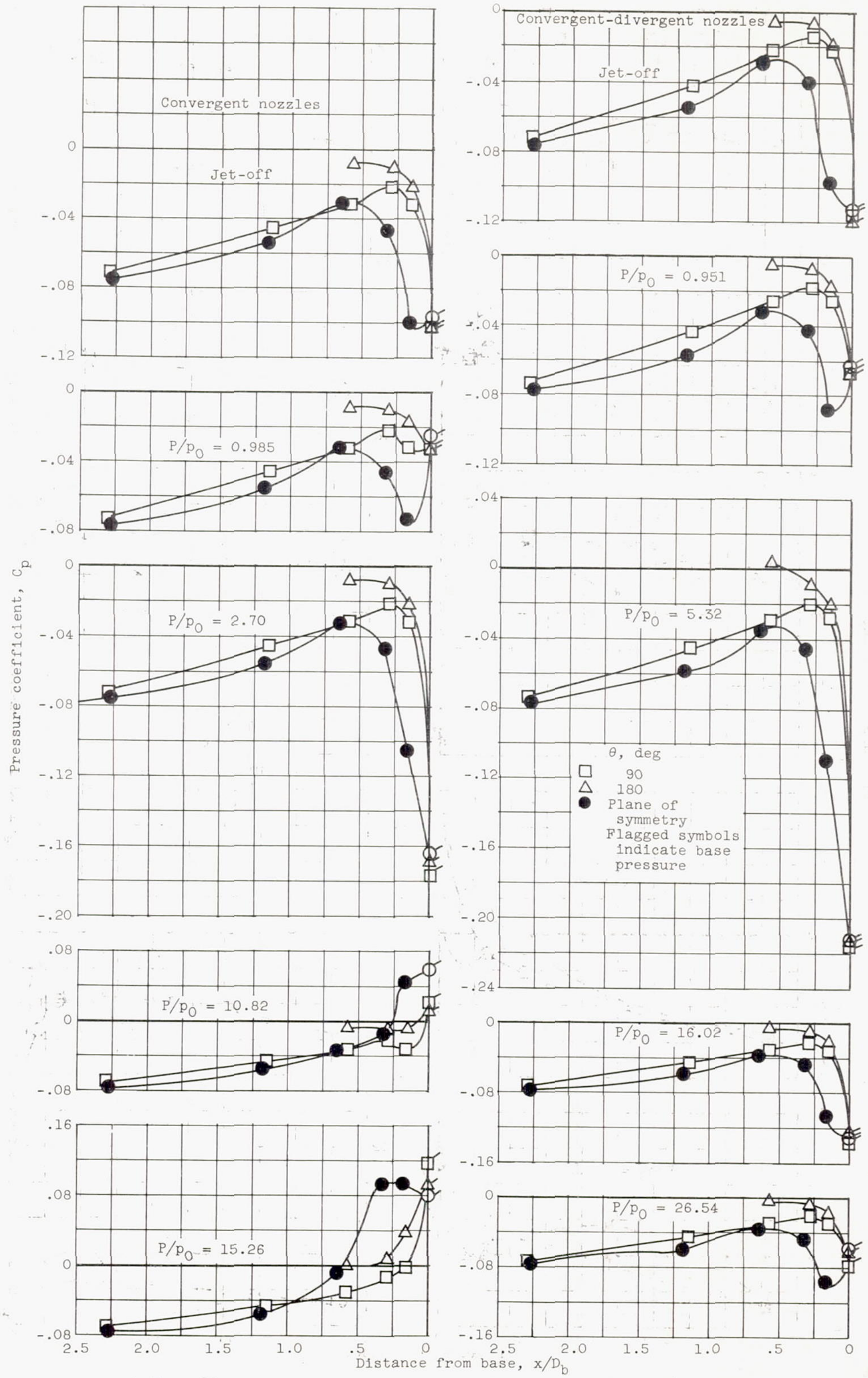
(a) Jet spacing ratio, 1.7; plane of nozzle center lines normal to support strut.

Figure 8. - Longitudinal boattail pressure distributions for twin-jet models.



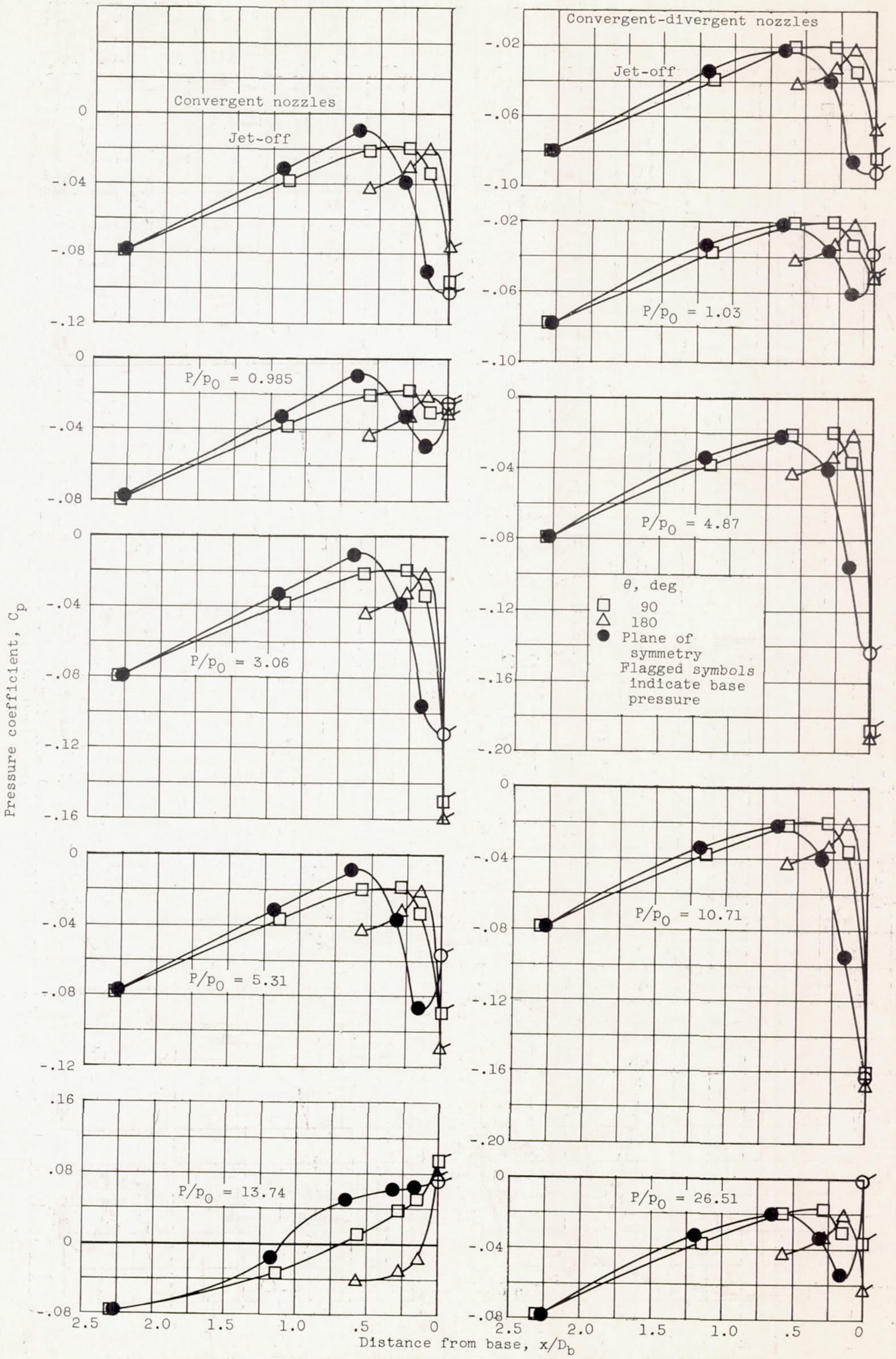
(b) Jet spacing ratio, 1.7; plane of nozzle center lines parallel to support strut.

Figure 8. - Continued. Longitudinal boattail pressure distributions for twin-jet models.



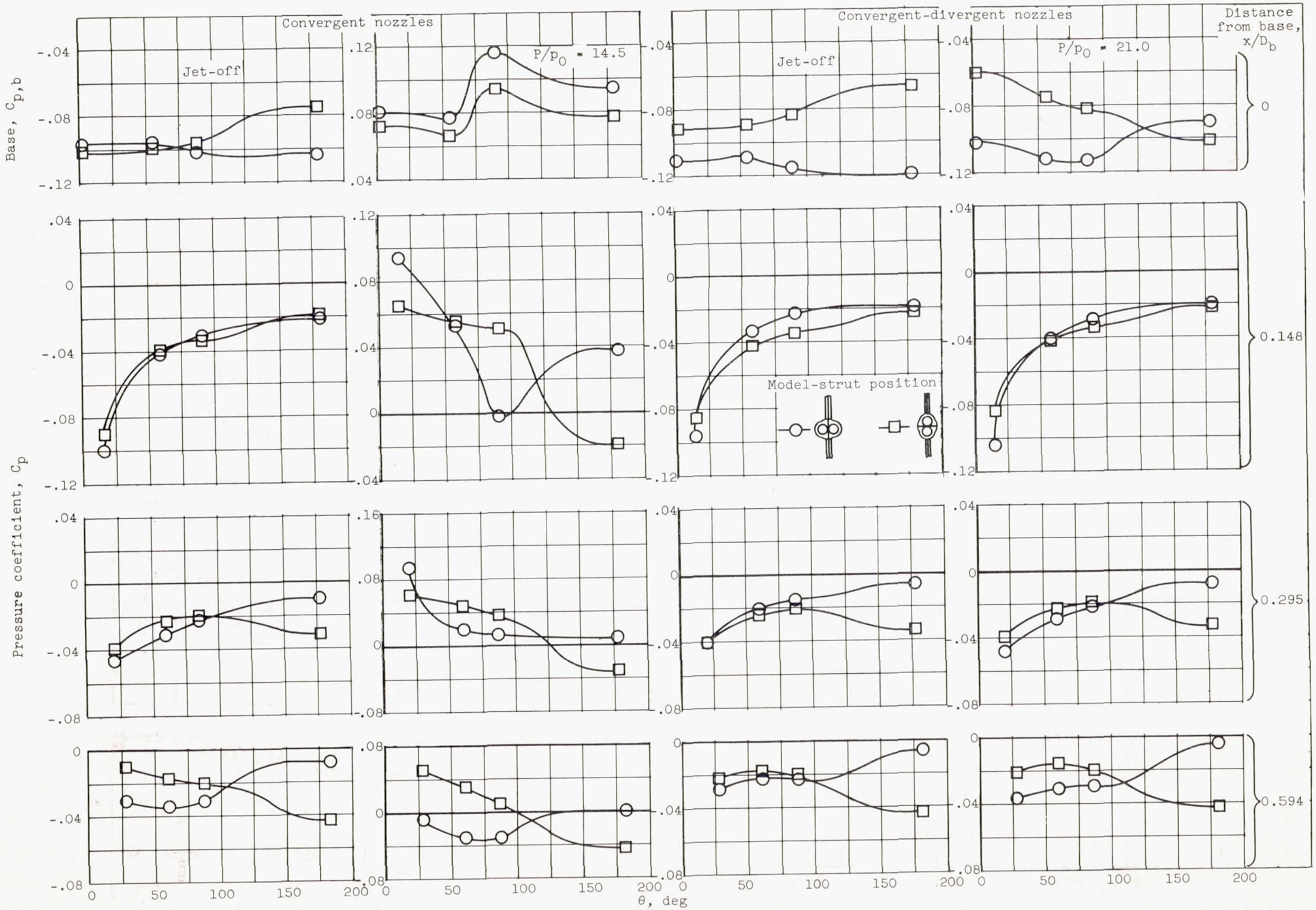
(c) Jet spacing ratio, 1.4; plane of nozzle center lines normal to support strut.

Figure 8. - Continued. Longitudinal boattail pressure distributions for twin-jet models.



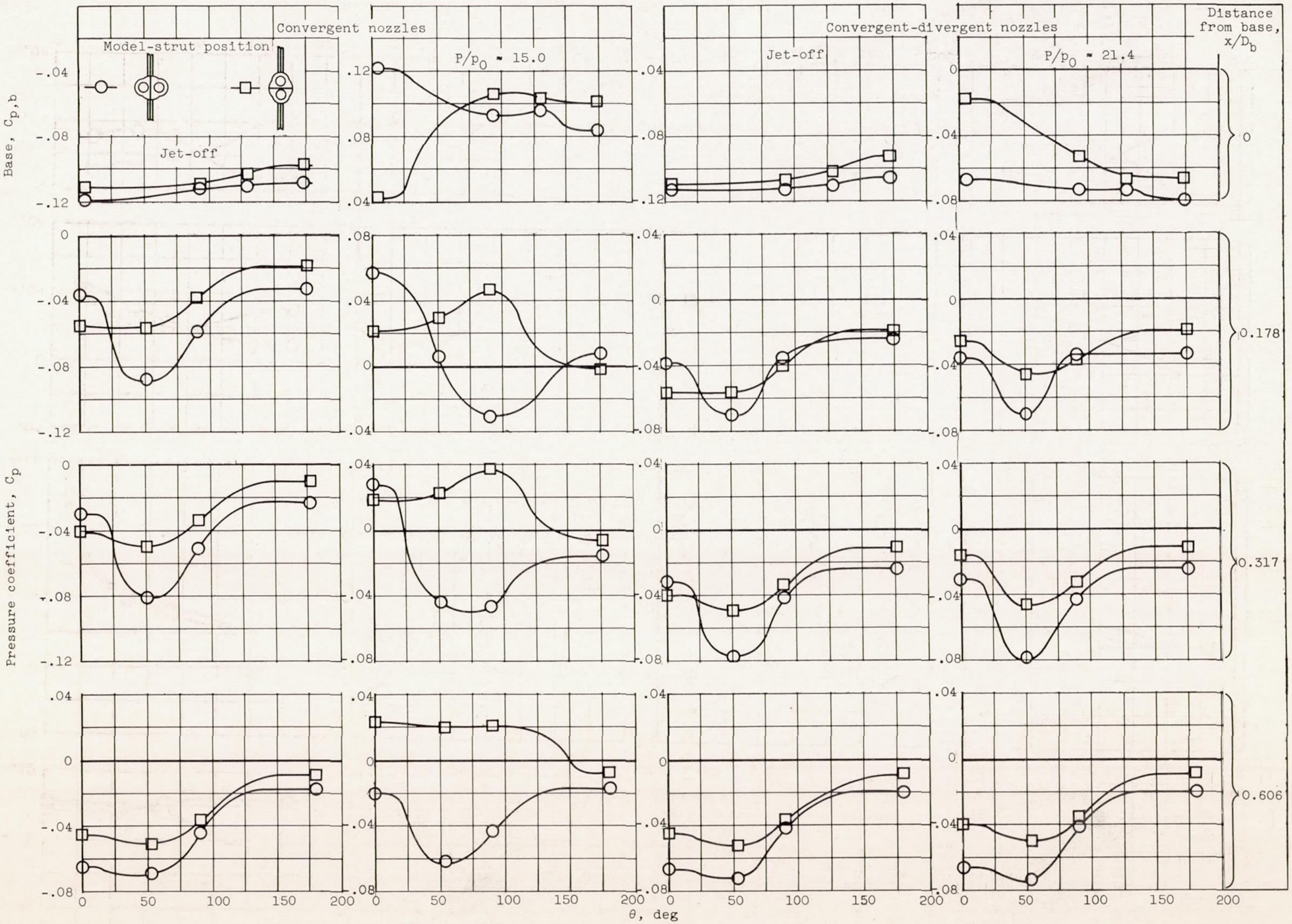
(d) Jet spacing ratio, 1.4; plane of nozzle center lines parallel to support strut.

Figure 8. - Concluded. Longitudinal boattail pressure distributions for twin-jet models.



(a) Model with 1.4 spacing ratio.

Figure 9. - Circumferential pressure distribution on twin-jet afterbodies at Mach number 1.91.



(b) Model with 1.7 spacing ratio.

Figure 9. - Concluded. Circumferential pressure distribution on twin-jet afterbodies at Mach number 1.91.

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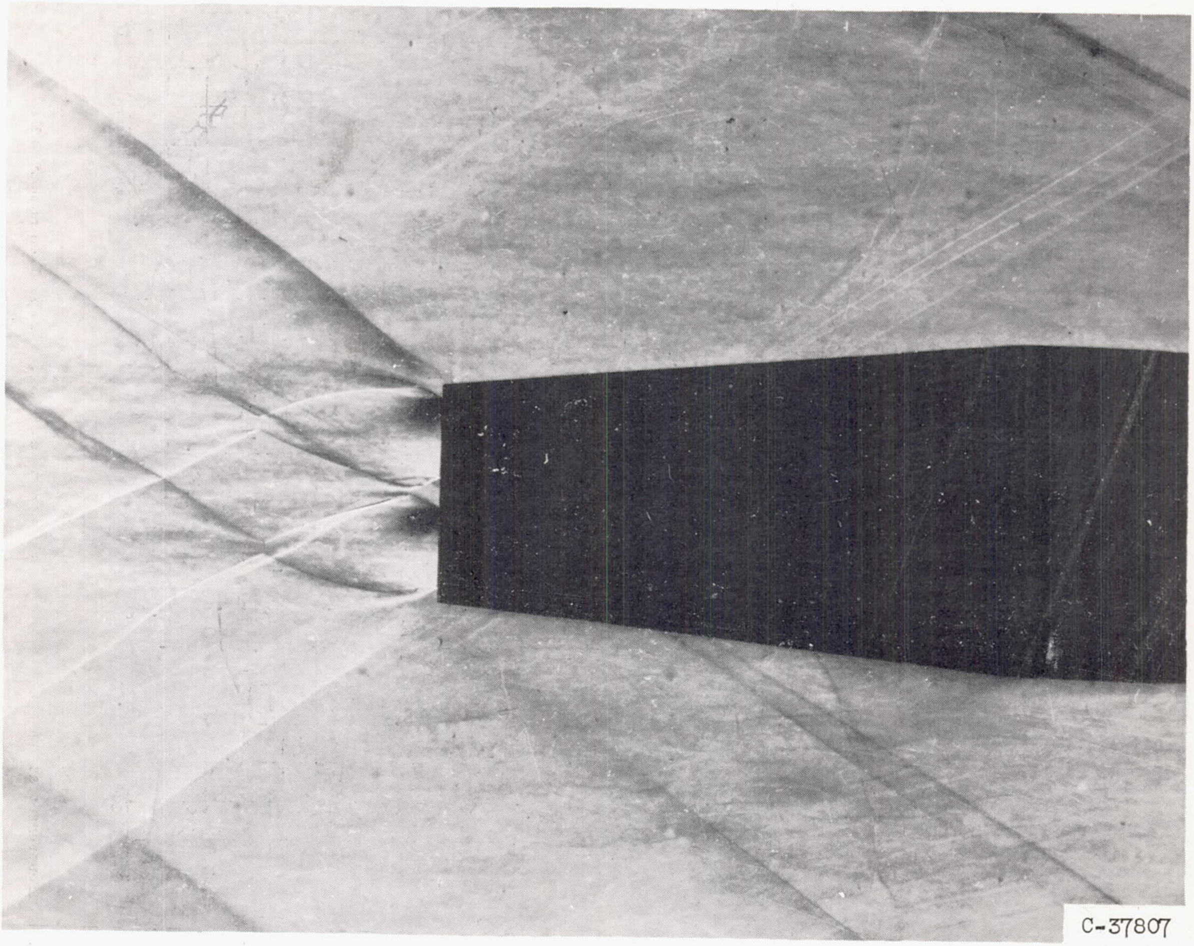

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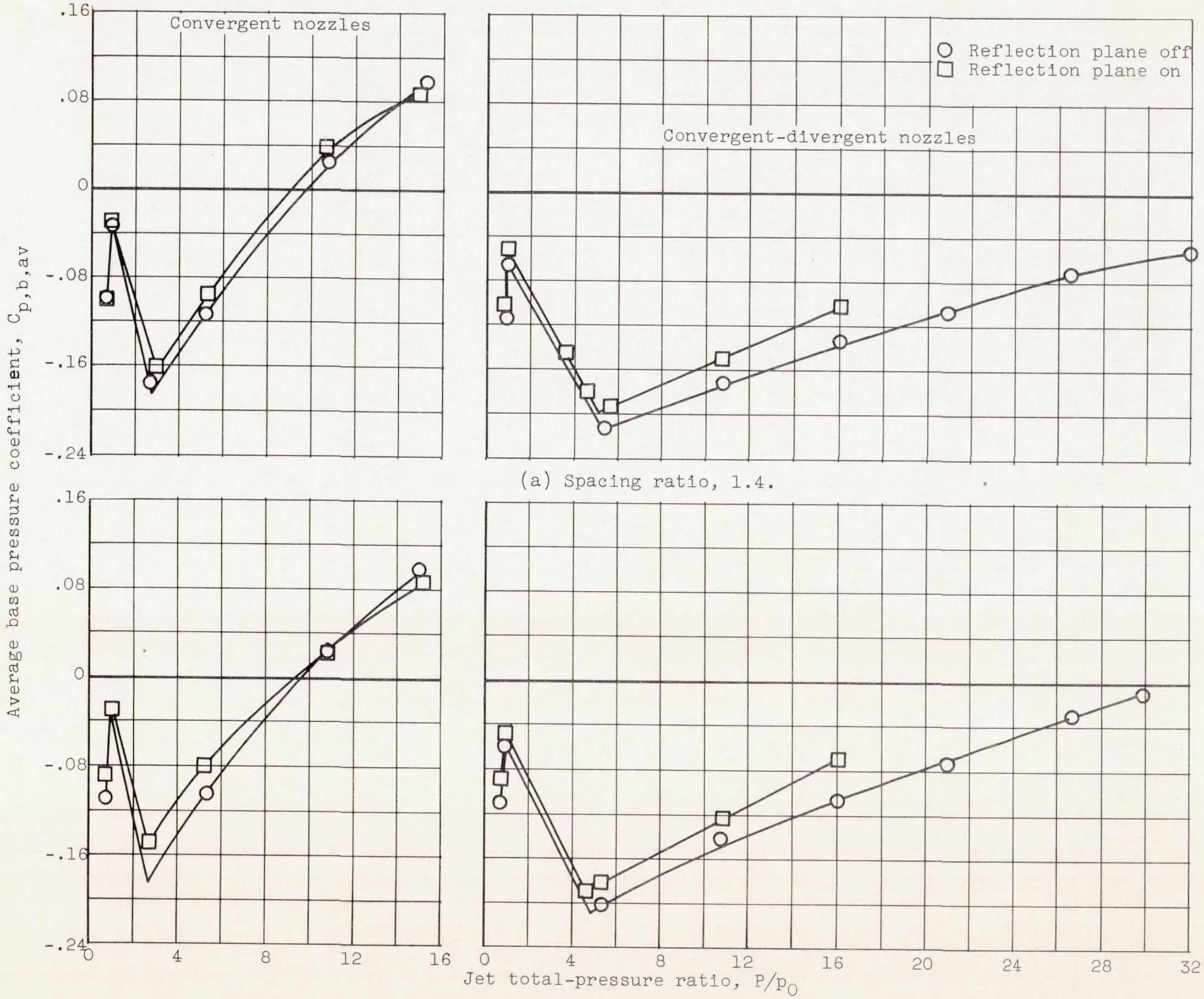
Figure 10. - Schlieren photograph of twin-jet model with spacing ratio of 1.4 and convergent exit nozzles. Total-pressure ratio, 14.9; Mach number, 1.91.



(a) Spacing ratio, 1.4.

(b) Spacing ratio, 1.7.

Figure 11. - Effect of reflection plane on average base pressure coefficient.