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EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF SUPPORT INTERFERENCE ON THE PRESSURE DISTRIBUTION OF A BODY OF REVOLUTION AT A MACH NUMBER OF 3.12 AND REYNOLDS NUMBERS FROM 2×10^6 TO 14×10^6

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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EXPERIMENTAL INVESTIGATION OF THE EFFECTS OF SUPPORT INTERFERENCE ON THE PRESSURE DISTRIBUTION OF A BODY OF REVOLUTION AT A MACH NUMBER OF 3.12 AND REYNOLDS NUMBERS FROM 2×10^6 TO 14×10^6

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SUMMARY

An experimental investigation was performed to determine the effect on base and forebody pressures of using a sting modified with varying length splitter plates and fins instead of a conventional sting to support a cone-cylinder body of revolution. The investigation was conducted at a Mach number of 3.12 for a Reynolds number range of 2×10^6 to 14×10^6 and for an angle of attack range of 0° to 9°.

The influence of the varying length splitter plates and fin modifications was confined to local disturbances on the forebody and base. With the splitter plate there was a negligible effect on body pressures and with the fin, a small effect on body pressures.

For Reynolds numbers of 8×10^6 and 14×10^6 there was a negligible effect of the splitter plate modification on the base pressure, and at a Reynolds number of 2×10^6 there was a small effect. Positioning the leading edge of the splitter plate at or ahead of the base made no appreciable change in the influence of the modifications on base pressure at a Reynolds number of 14×10^6. With the fin-type modification there was a small increase in base pressure.

Varying the angle of attack did not appreciably change the magnitude of the interference of the support modification.

INTRODUCTION

In wind tunnel testing it is essential that interference effects be minimized or accounted for in the presentation and use of data. In the investigation of sting-mounted bodies of revolution in a supersonic stream the effects on base pressure can be large, as is shown in reference 1. By keeping the sting diameter small relative to the base diameter the effect of the sting can be minimized, but with bodies of revolution that are severely boattailed the sting diameter may become too small to provide adequate support for the model.

The purpose of this investigation at the NACA Lewis laboratory is to determine the effect on base and forebody pressures (with emphasis on the former) of using a modified sting instead of a conventional sting support. The pressure distributions were experimentally determined for a body of revolution with both a conventional and a modified sting at a Mach number of 3.12 and over a Reynolds number range of 2×10^6 to 14×10^6. Angle of attack range was from 0° to 9°.

SYMBOLS

The following symbols are used in this report:

C_p	pressure coefficient, $p - p_0/q_0$
l	body length
M_0	free-stream Mach number
p	static pressure
q_0	free-stream dynamic pressure, $\gamma/2p_0M_0^2$
Re	Reynolds number, $\rho U_0 l/\mu$
U_0	free-stream velocity
x,r,θ	cylindrical coordinates
α	angle of attack
γ	ratio of specific heats, 1.40
μ	viscosity
ρ	density

ϕ perturbation velocity potential

Subscripts:

0 free-stream conditions

b base

APPARATUS AND PROCEDURE

The tests were conducted in the NACA Lewis 1- by 1-foot variable Reynolds number tunnel, a nonreturn tunnel with test section Mach number of 3.12 ± 0.03. The inlet pressure varied from 7 to 50 pounds per square inch absolute and a stagnation temperature of $55^{\circ} \pm 5^{\circ}$ F was maintained throughout the investigation. In order to reduce condensation effects to a negligible amount, the tunnel air was dried to a dewpoint of approximately -55° F.

The model (fig. 1) was a body of revolution with a conical forebody and cylindrical afterbody machined from hardened 4340 steel and polished to a 16 microinch finish. A sting-type support was utilized. Angle of attack was varied by rotating each model in the plane of the splitter plate and fin about a point 4 inches upstream of the base. Interference of the basic sting on the base pressures at zero angle of attack was minimized by designing the sting on the basis of data from reference 1.

The instrumentation consisted of five rows of 0.035 inch inside diameter static-pressure orifices located at stations given in table I and six 0.048 inch inside diameter base static-pressure orifices located in one quadrant in pairs 30° apart (fig. 2). For complete pressure distributions with respect to the meridional angle, the model was tested at both positive and negative angles of attack. The model was one of a series used for a body of revolution investigation and was not instrumented specifically for this study. As a result the region of the body immediately ahead of the base was not sufficiently well instrumented to determine in great detail the local regions of disturbance from the modified support. All pressures were read on a differential dibutyl phthalate multiple manometer board.

The sting support was modified by fastening individually three splitter plates and three fins to the sting as shown in figure 2. These fins were investigated at $\theta = 0^{\circ}$ and at $\theta = 180^{\circ}$ since the base instrumentation was located in one quadrant only. Both the splitter plates and the fins had the same angle of sweepback but could be varied in length by changing the positions of the leading edge relative to the base.

REDUCTION OF DATA AND METHOD OF CALCULATION

In the reduction of pressure data the free-stream static pressure was assumed to be the static pressure measured on the tunnel wall opposite the model tip. The base pressure coefficients are all averaged values, since the variation in the six base pressures did not exceed ± 3 percent from the mean.

The theoretical curves of pressure distribution over the body at zero angle of attack were calculated by both a linearized and a second-order theory. The linearized solution assumed the following form of the pressure coefficient:

$$C_p = -\frac{2}{U_0}\left(\frac{\partial \phi}{\partial x}\right) - \left(\frac{dr}{dx}\right)^2$$

where $\left(\frac{\partial \phi}{\partial x}\right)$ is the axial perturbation velocity associated with zero angle of attack. These perturbation velocities were computed using the numerical method of reference 2. For the second-order theory the exact pressure coefficient at each point was determined by an iteration procedure using the technique described in reference 3.

DISCUSSION OF RESULTS

The experimental variations of the pressure coefficient with axial station and of the base pressure coefficient with angle of attack for a Reynolds number of 14×10^6 are presented in figures 3 and 4, respectively, for the sting-mounted body of revolution to establish a reference for comparison. The body pressure coefficients are compared in figure 3 with theoretical curves computed from linearized theory and from the more exact second-order theory to indicate the generally satisfactory flow conditions under which the tests were conducted. The data for the sting modified with the three varying length splitter plates of figure 2 are also plotted on figure 3. A comparison of the data for the modified and unmodified sting-supported model shows no effect on the body pressures. The fins gave the same agreement. (It should be noted that none of the pressure orifices represented in this plot was located in the predictable disturbance fields from the splitter plate or fins.)

Figure 4 presents the variation of base pressure coefficient with angle of attack for the body of revolution supported by the unmodified and modified stings. The effect of the splitter plate is small (fig. 4(a)). The base pressure in the instrumented quadrant is

increased because of the influence of the fins at $\theta = 180^{\circ}$ (fig. 4(b)); while at $\theta = 0^{\circ}$ (fig. 4(c)) the effect is small. This result indicates that either a slight pressure gradient exists across the base with the fin installed or a nonuniformity existed in the tunnel flow.

Since there was no appreciable effect on base pressure of varying the length of the fins or splitter plate ahead of the base (figs. 4(a), (b), and (c)), a single length was chosen for investigation over the range of Reynolds number, and the remainder of the discussion is devoted to this length. The longest fins and splitter plate were used, since this length combined with a given sting diameter would make the best support with respect to the maximum strength in bending.

Determination of the forebody pressure coefficient at zero angle of attack and all Reynolds numbers investigated showed no effect due to the sting modification. Figure 3 is thus a representative variation of pressure coefficient with axial station for all Reynolds numbers tested. The absence of any appreciable effect of the sting modification was also observed at angles of attack of 3° to 9° over the Reynolds number range investigated. The data of figure 5 were obtained at a Reynolds number of 14×10^{6} but are representative of the 8×10^{6} and 2×10^{6} data at angle of attack.

The disturbances emanating from the splitter plates and fins would be expected to influence the body pressures in a localized region near the base. In the case of the splitter plate this region would lie approximately within the area enclosed by the intersection with the body of a Mach cone emanating from the intersection of the leading edge of the splitter plate and the body. This disturbance would be expected to be very weak. Because of the symmetrical nature of the fin leading edge and the finite shock wave from it, this disturbance would be stronger than for the splitter plate; consequently the disturbed region would be larger. No effort was made to predict the interference field theoretically.

Some static-pressure orifices in the circumferential row at $x/l = 0.976$ were subject to the effects described, and the experimental pressure coefficients are presented in figures 6 and 7 for the splitter plate and fin, respectively. At all angles of attack the effect of the splitter plate was small for all Reynolds numbers. In the case of the fin located at $\theta = 0^{\circ}$ and the model at 0° and 3° angle of attack (fig. 7), the increments in pressure coefficients for the $\theta = 0^{\circ}$ to 45° region are approximately 0.01 to 0.02 as a result of the compression wave from the leading edge of the fin for the 8×10^{6} and 14×10^{6} Reynolds number data. There was little or no influence of the fin on the remainder of the pressure coefficients from $\theta = 45^{\circ}$ to 180° nor for the 9° angle of attack for θ from 0° to 180°. At a Reynolds number of 2×10^{6} (fig. 7(c)), the region of influence is a little larger than at the

higher Reynolds numbers. With the fin on the bottom at $\theta = 180^{\circ}$ the circumferential pressures, not shown, yield similar curves showing little or no effect except in the compression region as previously mentioned. Where the modification partially or completely severed a static tap the corresponding data point was omitted, which accounts for a break in several of the curves at $\theta = 0^{\circ}$ or 180°.

The variation of the base pressure coefficient with angle of attack for the Reynolds number range investigated is presented in figure 8. For Reynolds numbers of 14×10^6 and 8×10^6 the data for the sting modified with splitter plate (fig. 8(a)) showed a small increase in pressure coefficient above that for the unmodified sting. Considering the probable scatter of the data, the change in pressure coefficient due to the splitter plate is not significant. The same conclusions are generally true at a Reynolds number of 2×10^6, although the effect of the splitter plate at $\alpha = 0$ appears too large to be due entirely to scatter. With the fin mounted on the sting at $\theta = 0^{\circ}$ and 180° (figs. 8(b) and 8(c), respectively), there was a small change in the base pressure for the angle-of-attack and Reynolds number ranges investigated. The change in pressure coefficient due to the addition of the fin was larger than for the splitter plate, indicating a maximum of 0.008. This represents a small change in magnitude of the measured drag, since the total drag coefficient for the body alone is 0.18. The influence of the support modification was not appreciably changed by going to angle of attack.

The results of this investigation indicate that either the fin or splitter plate technique may be utilized to stiffen slender sting supports without introducing appreciable errors in the measured base pressures of slender bodies of revolution with a turbulent boundary layer at the base. In addition to having the smallest effect on base pressure, a properly designed splitter plate may extend forward of the base for additional strength and yet have only a negligible effect on the pressures over the after portions of the body. It should be recognized that the splitter-plate-type support would generally not have the half-cylinder protuberance resulting from modification of the original sting and that it may incorporate additional structure on one side of the plate provided no disturbances are created that extend ahead of the splitter plate.

SUMMARY OF RESULTS

The following results were obtained from an investigation of the pressures acting over a cone-cylinder body at a Mach number of 3.12 over a Reynolds number range from 2×10^6 to 14×10^6 with a sting support modified for increased structural rigidity:

1. The influence of the splitter plates and fins attached to the sting and extending forward of the base was confined to the local disturbance regions on the body and to the base. In the case of the splitter plate, the pressure disturbance on the body pressures was small.

2. The effect of the splitter plate modification on the base pressure was negligible at Reynolds numbers of 8×10^6 and 14×10^6 and had a maximum value of 0.008 at a Reynolds number of 2×10^6. Extending the leading edge of the splitter plate ahead of the base did not appreciably increase the interference effect on base pressure at a Reynolds number of 14×10^6.

3. There was a small increase in base pressure over part of the base in the case of the fin-type modification, indicating the presence of base pressure gradients.

4. At Reynolds numbers of 8×10^6 and 14×10^6, the small effect on base pressure of the splitter plate and fin modifications appeared to be essentially invariant with angle of attack.

Lewis Flight Propulsion Laboratory
National Advisory Committee for Aeronautics
Cleveland, Ohio, May 25, 1953

REFERENCES

1. Chapman, Dean R.: An Analysis of Base Pressure at Supersonic Velocities and Comparison with Experiment. NACA Rep. 1051, 1951. (Supersedes NACA TN 2137.)

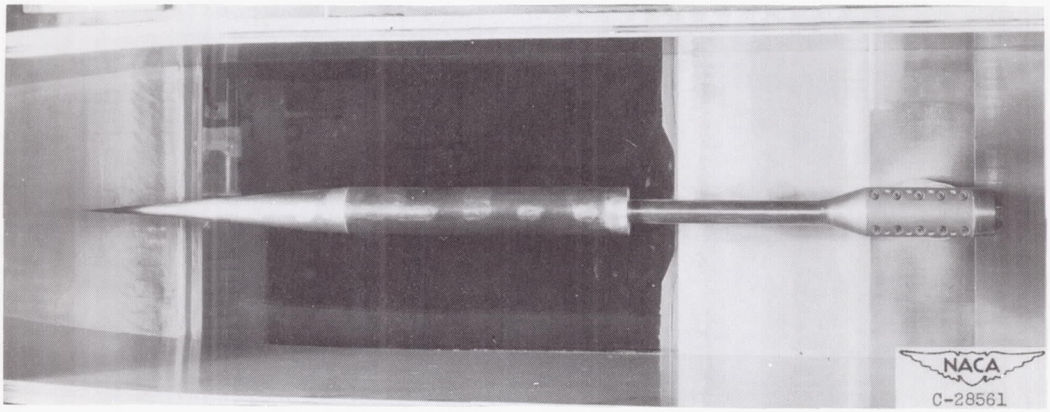
2. von Kármán, Theodor, and Moore, Norton B.: Resistance of Slender Bodies Moving with Supersonic Velocities, with Special Reference to Projectiles. Trans. A.S.M.E., vol. 54, no. 23, Dec. 15, 1932, pp. 303-310.

3. Van Dyke, Milton D.: Practical Calculation of Second-Order Supersonic Flow Past Nonlifting Bodies of Revolution. NACA TN 2744, 1952.

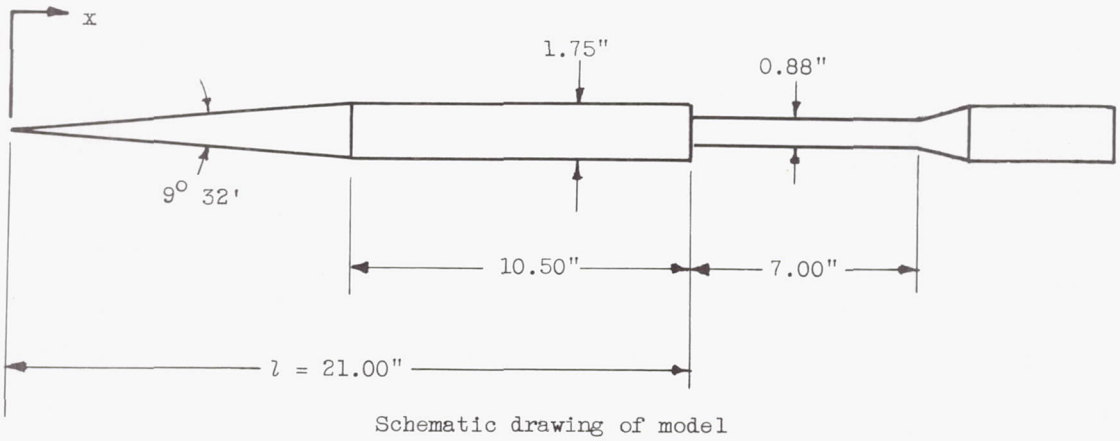
TABLE I. - LOCATION OF STATIC-PRESSURE ORIFICES

FOR MODEL 

x/l	Meridional angle, θ, deg				
	0	22.5	45	67.5	90
0.143	x				x
.238	x	x	x	x	x
.333	x				x
.428	x				x
.494	x	x	x	x	x
.505	x	x	x	x	x
.534	x				x
.563	x				x
.591	x	x	x	x	x
.620	x				x
.643	x				x
.738	x	x	x	x	x
.833	x				x
.928	x				x
.976	x	x	x	x	x



Model installed in Lewis 1 by 1-foot supersonic wind tunnel



Schematic drawing of model

Figure 1. - Model used in this investigation.

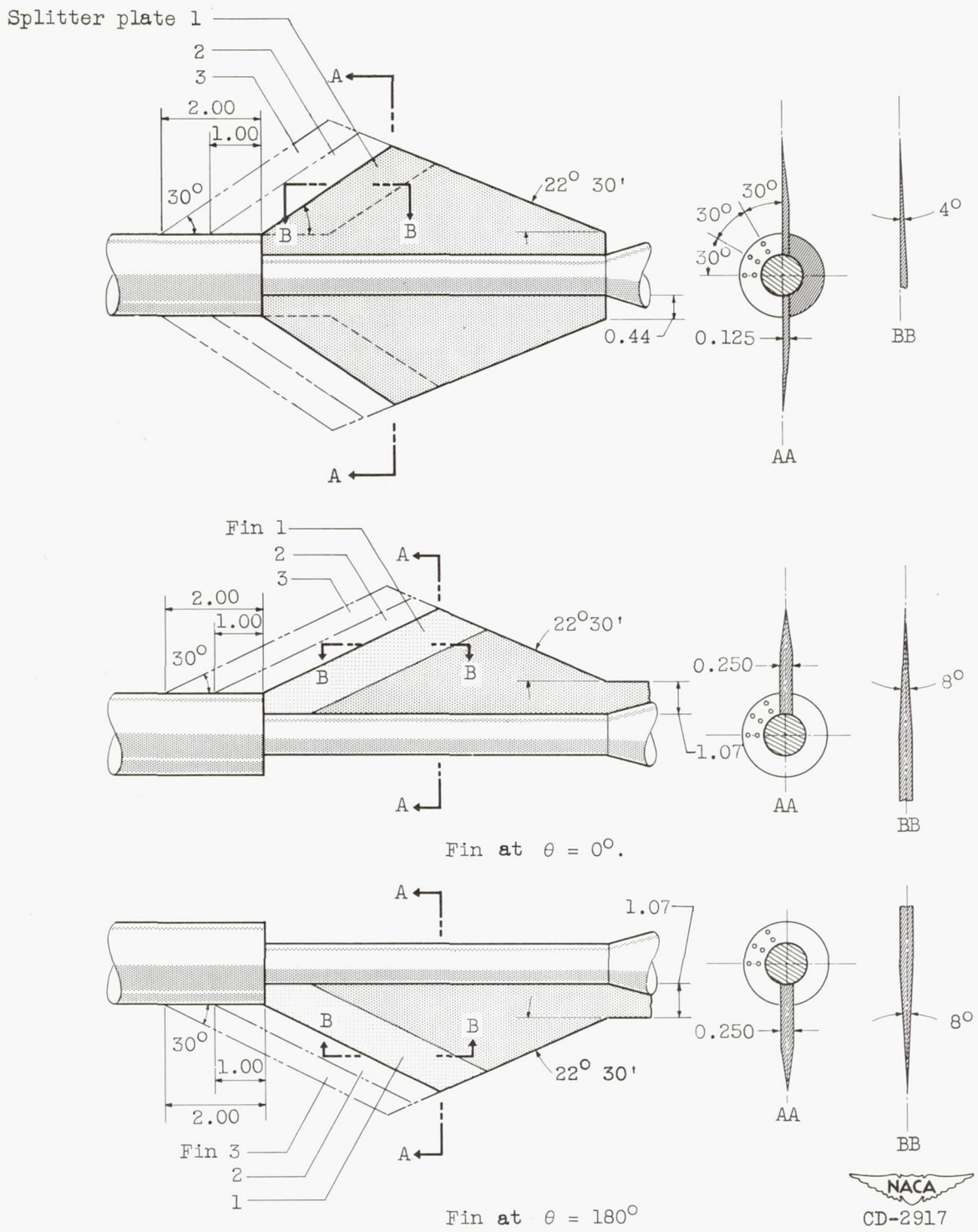


Figure 2. - Schematic diagram of splitter plate and fin sting modifications. (All dimensions are in inches.)

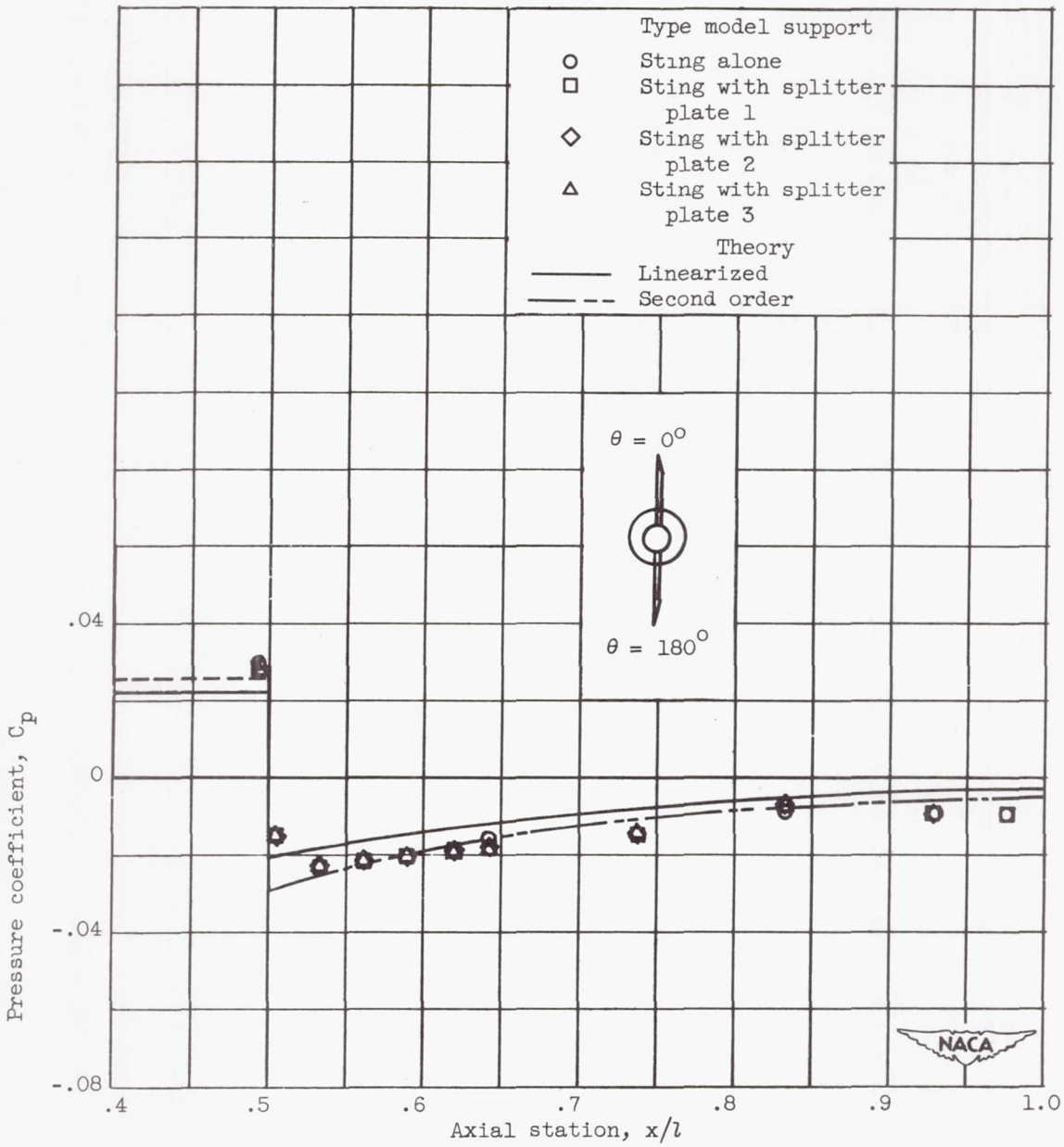
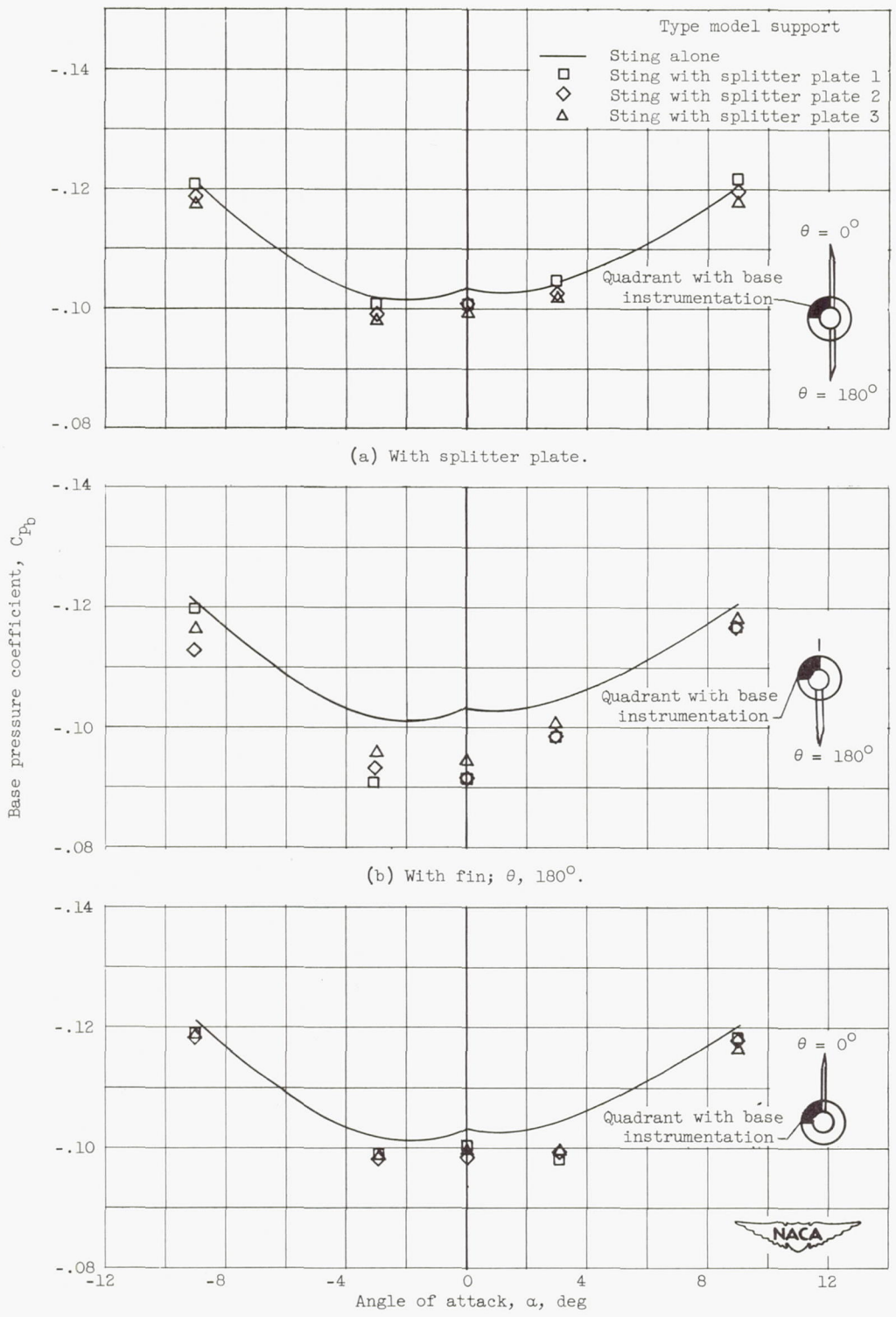


Figure 3. - Experimental and theoretical axial variation of pressure coefficient for model at zero angle of attack and zero meridional angle and Reynolds number of 14×10^6.



(a) With splitter plate.

(b) With fin; θ, 180°.

(c) With fin; θ, 0°.

Figure 4. - Variation of base pressure coefficient with angle of attack for Reynolds number of 14×10^6.

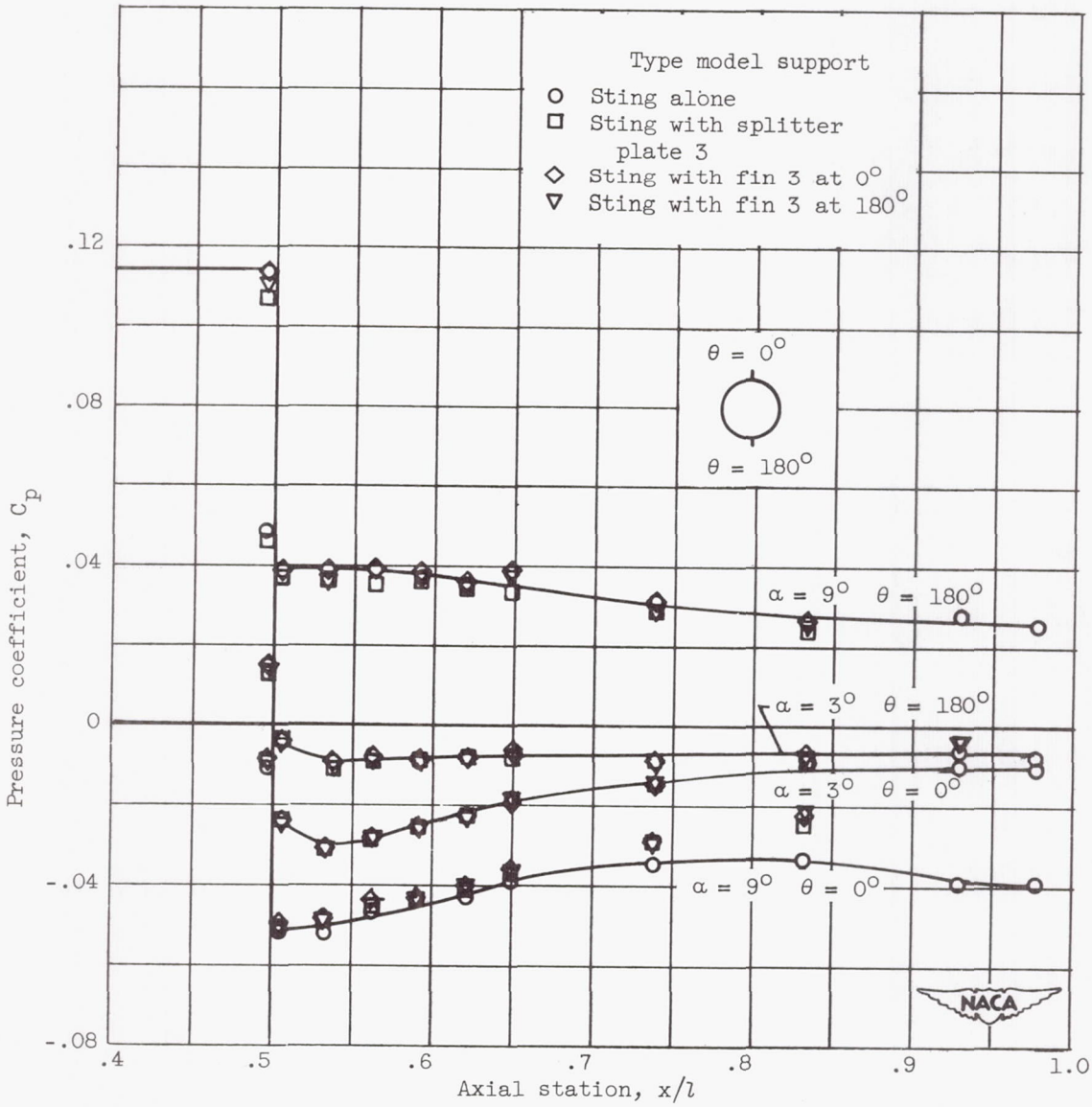
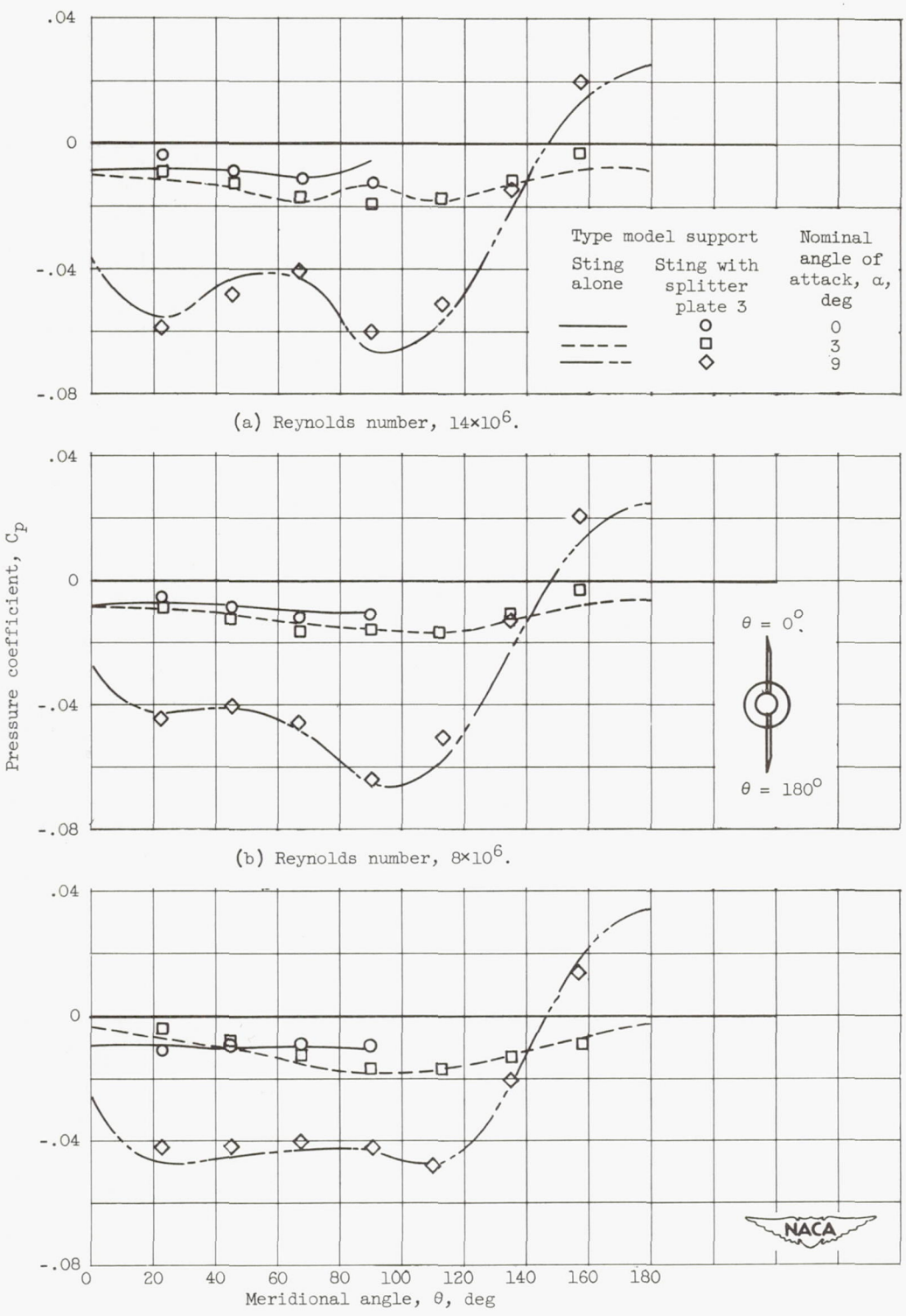


Figure 5. - Experimental axial variation of pressure coefficient for two angles of attack and Reynolds number of 14×10^6.

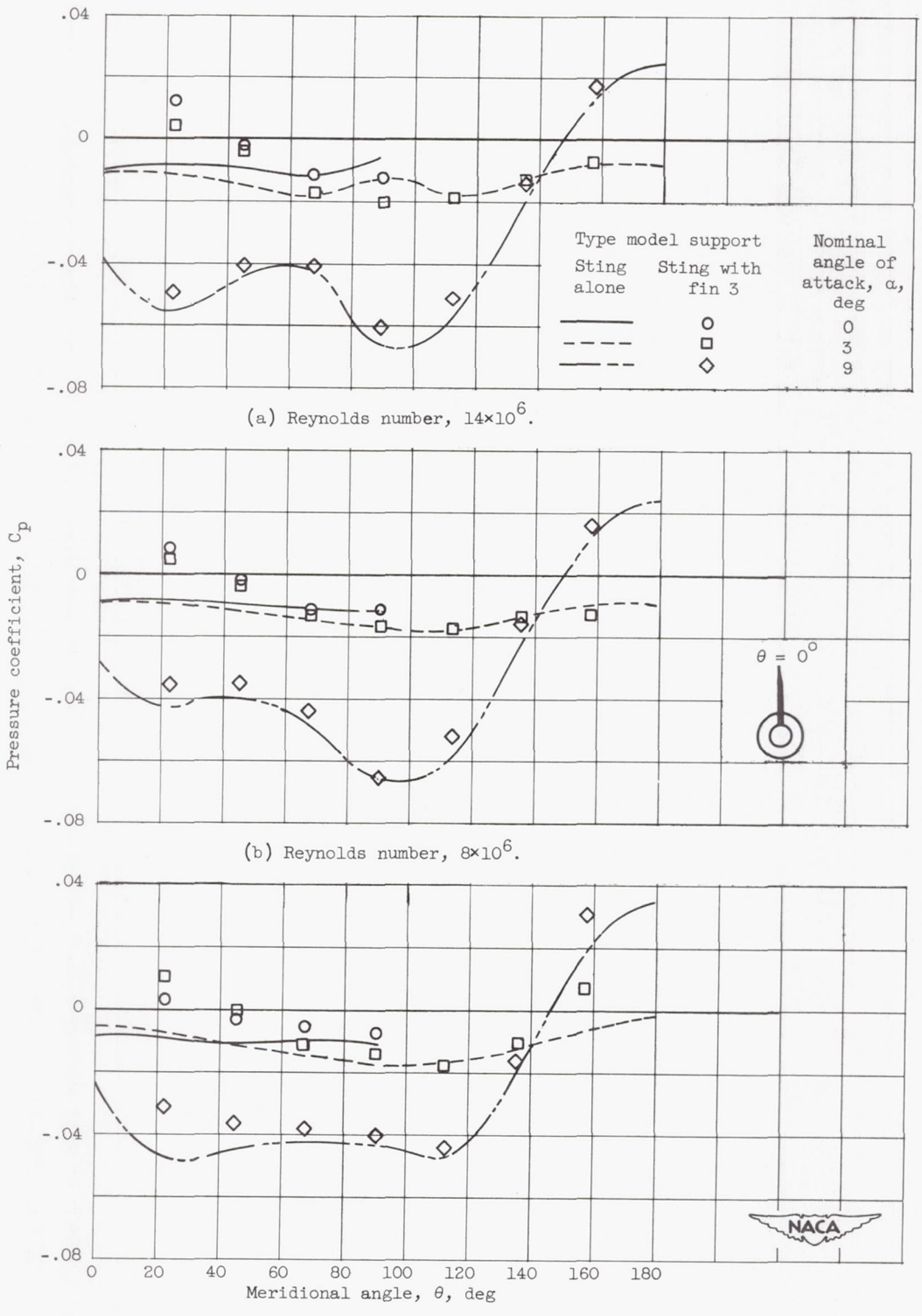


(a) Reynolds number, 14×10^6.

(b) Reynolds number, 8×10^6.

(c) Reynolds number, 2×10^6.

Figure 6. - Experimental variation of pressure coefficient with meridional angle for axial station of 0.976 presenting effect of splitter plate modification.

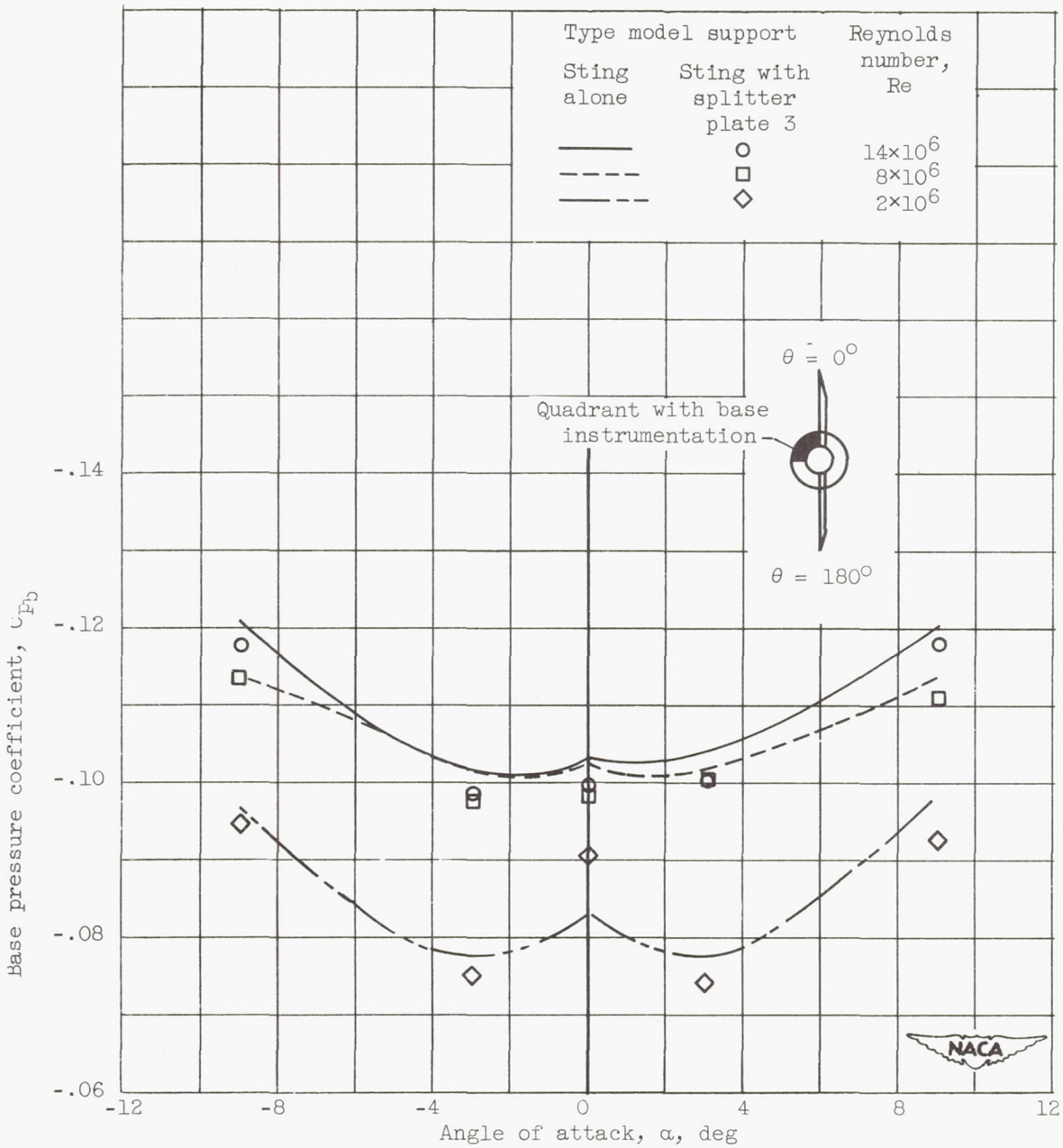


(a) Reynolds number, 14×10^6.

(b) Reynolds number, 8×10^6.

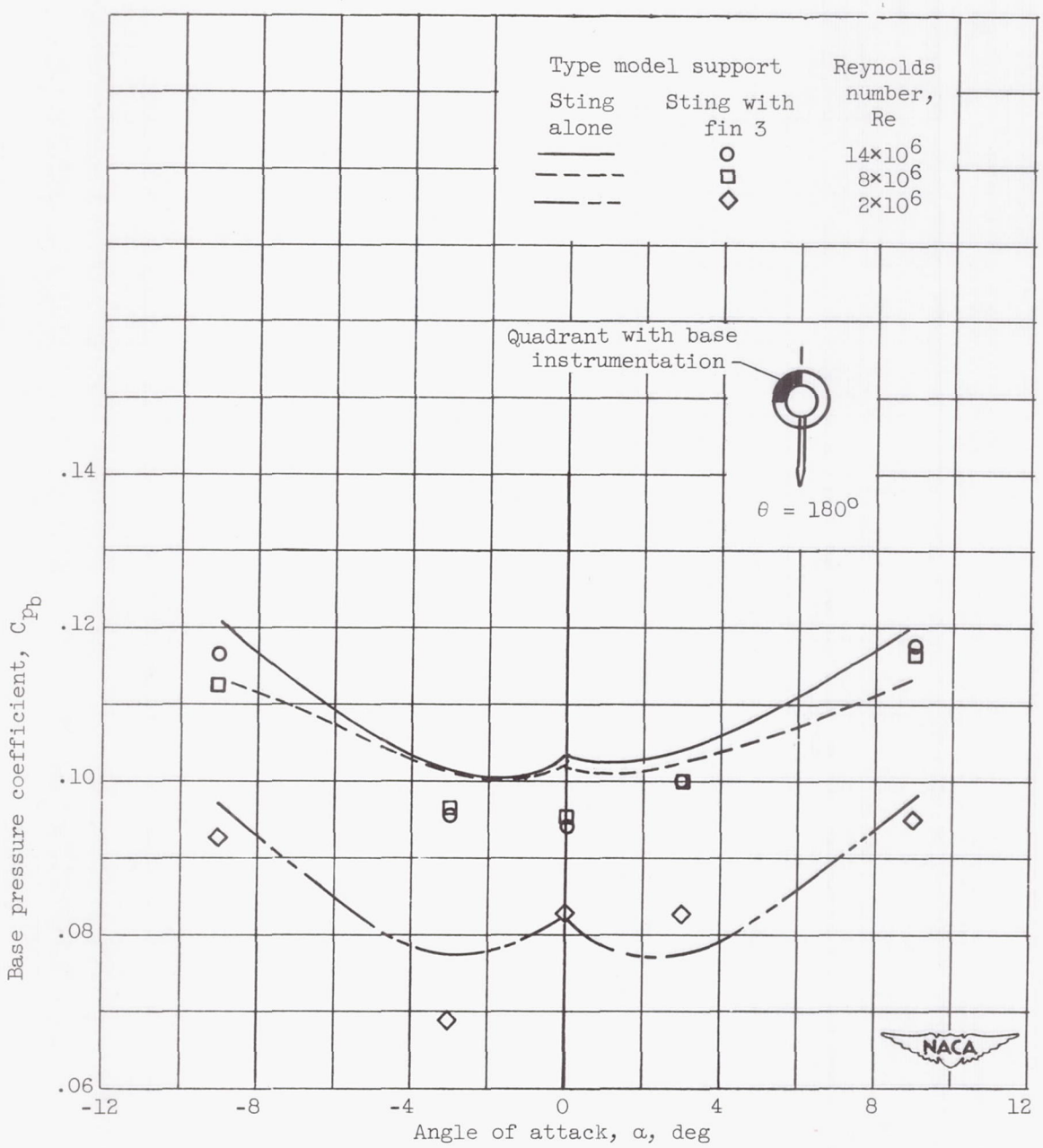
(c) Reynolds number, 2×10^6.

Figure 7. - Experimental variation of pressure coefficient with meridional angle for axial station of 0.976 presenting effect of fin modification.



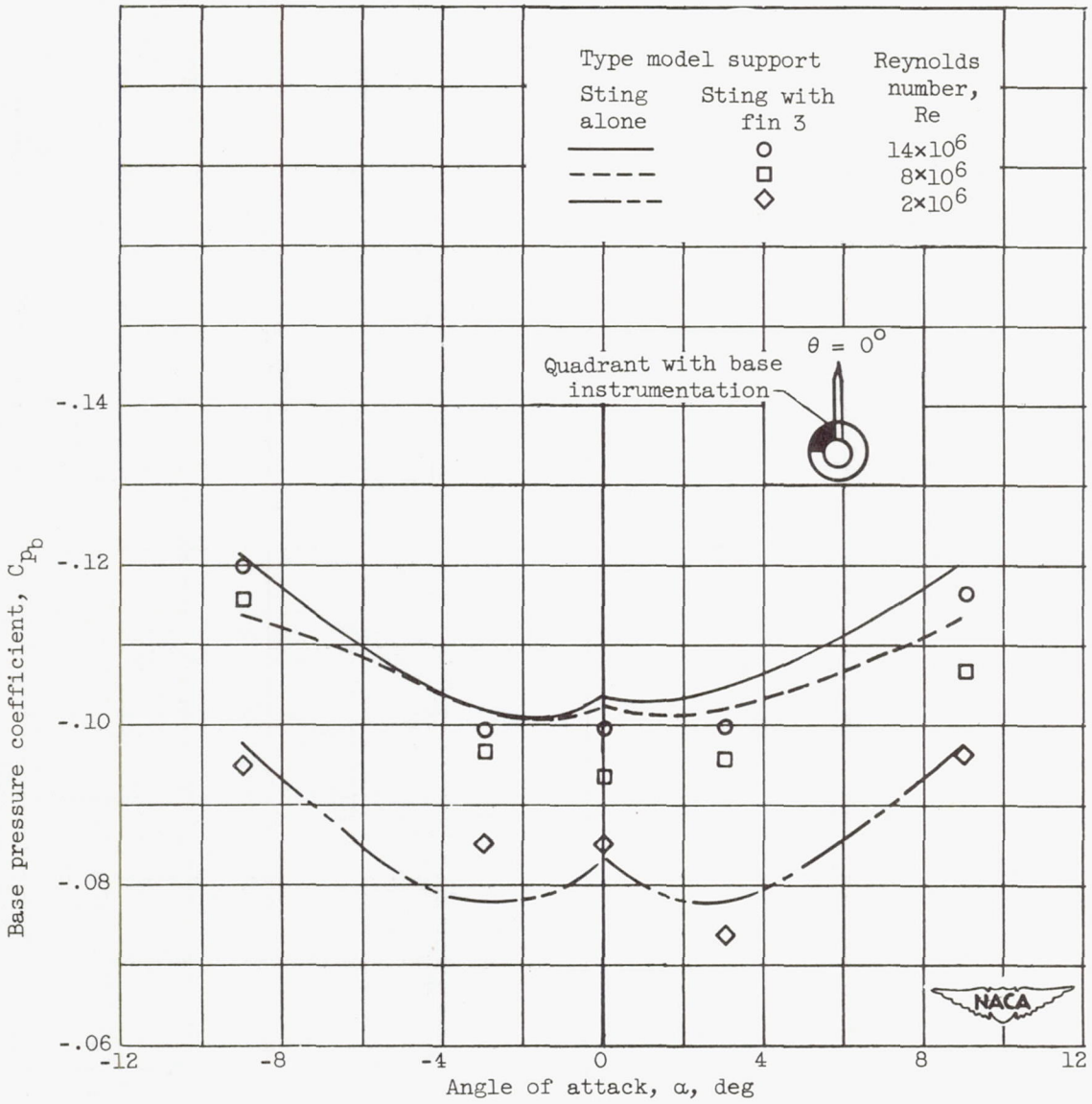
(a) With splitter plate.

Figure 8. - Variation of base pressure coefficient with angle of attack for Reynolds numbers of 14×10^6, 8×10^6, and 2×10^6.



(b) With fin; θ, 180°.

Figure 8. - Continued. Variation of base pressure coefficient with angle of attack for Reynolds numbers of 14×10^6, 8×10^6, and 2×10^6.



(c) With fin; θ, 0°.

Figure 8. - Concluded. Variation of base pressure coefficient with angle of attack for Reynolds numbers of 14×10^6, 8×10^6, and 2×10^6.