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RESEARCH MEMORANDUM

AN INVESTIGATION OF STING-SUPPORT INTERFERENCE ON BASE PRESSURE AND FOREBODY CHORD FORCE AT MACH NUMBERS FROM 0.60 TO 1.30

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
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AN INVESTIGATION OF STING-SUPPORT INTERFERENCE ON BASE PRESSURE AND FOREBODY CHORD FORCE AT MACH NUMBERS FROM 0.60 TO 1.30

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SUMMARY

Tests were conducted to determine the interference effects of various sting-support configurations on the base pressure and foredrag characteristics of a wing-fuselage combination with a turbulent boundary layer over the after portion of the fuselage.

The primary variable investigated was the length of the constant-diameter portion of a sting support. The sting-support diameter was 0.932 model-base diameters and terminated in a conical afterbody with a half-angle of 8°. The test Mach number range was from 0.60 to 1.30 and the Reynolds number based on model length was 5.4×10^{6}.

It was found that if the constant-diameter portion of the sting was sufficiently long to eliminate "length" interference effects to base pressure and foredrag at high subsonic speeds, $M \approx 0.9$, then for all higher Mach numbers within the range of these tests, the length interference effects were zero. It was further shown that changes in angle of attack had little effect upon the length interference effects to both base pressure and foredrag.

Foredrag data free of length interference effects were achieved with a constant-diameter sting length of four model-base diameters for Mach numbers of 1.025 and greater. For Mach numbers less than 1.025, although the length interference effects were small, a sting length longer than four model-base diameters would be required to completely eliminate length interference.

A special test using a rear sting support consisting of a sting to model-base-diameter ratio of 0.932 and a 1° half-angle conical afterbody beginning at the base of the model showed no interference effects on foredrag at and above a Mach number of 1.075 and only slight effect at Mach numbers less than 1.075.

INTRODUCTION

Interference to the flow about models tested in wind tunnels can result from the presence of wind-tunnel walls and from the mechanism required to support the model. This interference to the flow can present serious difficulties in the interpretation of the experimental data. The support of models from the rear by means of sting supports is widely used in high-speed wind tunnels. At supersonic Mach numbers of 1.5 and above, sufficient experimental data are available to permit the design of sting supports having negligible interference on base pressure and foredrag (ref. 1). However, in the transonic range adequate design information is lacking.

A common type of sting support consists of a constant-diameter sting followed by a conical afterbody terminating in a cylindrical support. It has been shown in reference 2 that the interference resulting from this type of sting support may be separated into two classes. These are, first, the interference to the flow resulting from the presence of the constant-diameter sting, referred to as "diameter" effect and, second, the interference to the flow resulting from the proximity to the model base of the conical afterbody, referred to as "length" effect. The present analysis is concerned primarily with the length effect on base pressure and foredrag when the sting diameter, the cone angle, the cylindrical-support diameter, and the Reynolds number are held constant. Consideration was also given to the effect on base pressure and foredrag of a 1° tapered sting and a 9-percent reduction in sting diameter. All of the data were obtained in the transonic speed range ($M = 0.60$ to 1.30) at a Reynolds number of 5.4×10^6, based on model length, with a turbulent boundary layer ahead of the base of the model.

SYMBOLS

a maximum radius of fuselage

b length of fuselage including portion removed to accommodate sting

C_C total chord-force coefficient, $\frac{\text{chord force}}{q_o S_w}$

C_{D_B} base-drag coefficient, $\frac{\text{base drag}}{q_o S_w}$

C_{C_f} forebody chord-force coefficient, $C_C - C_{D_B}$

D_B diameter of model base

d	diameter of sting
L	length of conical afterbody
l	length of constant-diameter sting between the model base and the conical afterbody
M_o	free-stream Mach number
P	pressure coefficient, $\frac{p - p_o}{q_o}$
P_B	base-pressure coefficient, $\frac{p_B - p_o}{q_o}$
p	static pressure
p_B	base pressure
p_o	free-stream static pressure
q_o	free-stream dynamic pressure, $\frac{1}{2} \rho_o V_o{}^2$
r	radius of sting, $\frac{d}{2}$
S	local cross-sectional area of conical afterbody
$S'(\xi)$	$\frac{dS}{d\xi}$
S_W	total wing area including that blanketed by fuselage
V_o	free-stream velocity
(x,y)	coordinates
α	angle of attack
β	$\sqrt{1 - M_o{}^2}$
θ	cone half-angle
ξ	variable of integration along x axis when (x,y) is the point for which the pressure is being computed
ρ_o	free-stream mass density

APPARATUS AND TEST METHODS

These tests were conducted in the Ames 2- by 2-foot transonic wind tunnel. This facility is a variable-density tunnel equipped with a flexible-plate nozzle and perforated test-section walls which permit operation through the Mach number range of 0.60 to 1.30.

The model used in this investigation was a boattailed body of revolution with a trapezoidal-plan-form wing of symmetric circular-arc section (fig. 1). The sting supports used were obtained by modifying the basic sting support shown in figure 2(a). The primary test configuration consisted of a constant-diameter sting of length, l, with a conical afterbody of half-angle equal to 8° as shown in figure 2(b). In order to obtain length effects the location of the model in the wind-tunnel was fixed and the conical afterbody was moved fore and aft to vary the length of the constant-diameter sting. Two additional support configurations were used. These were the 1° tapered sting (fig. 2(c)) and the basic sting support (fig. 2(a)).

Chord-force and base-pressure measurements were made for angles of attack of 0° and 8.7°. At 16.4° angle of attack, only base-pressure measurements were made. The boundary layer was determined to be turbulent over the after portion of the fuselage by visual observation of the rate of drying of a luminescent lacquer. This method is described in reference 3. The Mach number range of these tests was 0.60 to 1.30 and the Reynolds number based on model length was held constant at 5.4×10^6.

Accuracy of the base-pressure coefficient measurements is estimated to be ±0.005 at an average tunnel stagnation pressure of 13-1/2 pounds per square inch. Chord-force-coefficient measurements are estimated to have an accuracy of ±0.0005. The free-stream Mach number was preset to within ±0.0025 of the desired values. The deflection of the sting and, therefore, the model angle of attack, changed with Mach number due to the varying aerodynamic load. These changes, which did not exceed $\pm 1/4^\circ$ at 8.7° and $\pm 1/2^\circ$ at 16.4°, have no effect on the conclusions made in this report so that for simplicity all data will be referred to by their nominal angle of attack.

RESULTS AND DISCUSSION

The parameters used in this report to demonstrate the sting-support interference effects are d/D_B and l/D_B, that is, diameter effect and length effect, respectively.

Base-Pressure Interference

Effect of l/D_B ($\theta = 8^\circ$, $d/D_B = 0.932$).- The data of figure 3 show that at subsonic speeds for all angles of attack tested the base pressure continued to decrease with increasing length of the constant-diameter sting for the full range of sting lengths tested. Thus, even for the longest sting, some interference attributable to the presence of the 8° conical afterbody existed. This result is to be expected since at subsonic speeds the presence of the cone makes itself felt far upstream. In the vicinity of $M = 1.0$ the variation of base pressure as a function of l/D_B was similar to that at subsonic speeds.

An adaptation of the theory of reference 4, presented in the appendix, has been used to estimate the interference effect of the 8° conical afterbody upon the base pressure at zero angle of attack. The variation of pressure coefficient at the position of the model base with changes in length of the constant-diameter sting was calculated for subsonic Mach numbers. This calculated variation is compared in figure 3 with the experimentally determined variation of base-pressure coefficient with varying l/D_B ratios. Of course, numerical agreement would not be expected since the theory neglected the presence of the model. However, if it is assumed that the influence of the model is a constant, then a suitable theory should predict a curve parallel to the experimental values. Because of the good agreement shown in figure 3, it is felt that the theory can be used to estimate the length effect for conical afterbodies in the high subsonic speed range.

In supersonic flow, interference to base pressure from the conical portion of the sting support results from the fact that the pressure rise associated with the shock wave ahead of the conical afterbody is transmitted upstream through the model wake. The critical l/D_B ratio is defined as the minimum l/D_B at which any further increase in sting length no longer affects the base pressure. As shown by the data of figure 3, the critical value of l/D_B in general decreases with increasing Mach number.

Increasing the angle of attack had little effect on the critical l/D_B ratio at Mach numbers of 1.10 and above as shown by the data of figure 3. This is in agreement with the conclusion made in reference 1 wherein, based upon results of tests made at $M = 1.93$, it was concluded that sting supports designed to have small effect upon base pressure at $\alpha = 0^\circ$ may be expected to have equally small effects up to $\alpha = 60^\circ$.

Effect of d/D_B ($\theta = 3.5^\circ$, $d/D_B = 0.855$, $l/D_B = 4.61$).- A comparison of the base pressure for d/D_B ratios of 0.932 and 0.855 (fig.3) indicates that a diameter interference effect is present in all of the data of figure 3 at both 0° and 8.7° angles of attack and over the complete Mach number range of these tests. Furthermore, the magnitude cf this diameter effect appears to be relatively unaffected by Mach number. This demonstrates the need for tests covering the complete range of d/D_B ratios to determine the diameter effects on base pressure in the transonic speed range.

Tapered sting tests ($\theta = 1^\circ$, $d/D_B = 0.932$, $l/D_B \approx 0$).- The base pressure was measured with the model supported on a 1° tapered sting (fig. 2(c)) at angles of attack of 0° and 8.7°. The data are presented in figure 3 for comparison.

The 1° tapered sting can be considered as producing a diameter effect, since the sting diameter increases in the region of separated flow behind the model. References 2 and 5 show a trend of increasing base pressure with increasing sting diameter above a d/D_B ratio of 0.85 at a Mach number of 1.5. The base-pressure data obtained from tests with the 1° tapered sting (effective $d/D_B > 0.932$) and the two constant-diameter stings ($d/D_B = 0.932$, 0.855) at an $l/D_B = 4.61$ indicate a similar trend. Furthermore, this trend was present at both 0° and 8.7° angles of attack throughout the range of Mach numbers tested.

Foredrag Interference

For many cases such as aircraft development work the aerodynamicist is interested in foredrag rather than total drag and therefore base-drag interference of a sting support becomes unimportant. In the low supersonic speed range as the l/D_B ratio is decreased, first base pressure and then forebody chord force is affected by the proximity of the conical afterbody as shown by comparison of the data in figures 3 and 4. Therefore, a sting support designed to eliminate the support length effects on foredrag only could be shorter than that designed to eliminate these effects on base pressure, thereby providing greater load capacity. This is an important consideration if a model is to be tested at high angles of attack or high Reynolds numbers.

Effect of l/D_B ($\theta = 8^\circ$, $d/D_B = 0.932$).- The following forebody chord-force results are similar to those obtained from analysis of the base-pressure data. This is to be expected because the mechanism by which the conical afterbody influences both base pressure and forebody chord force is essentially the same. In the subsonic speed range the data in figure 4 show that length interference effects on forebody chord force apparently existed at all l/D_B ratios tested. The variation of forebody chord force as a function of l/D_B showed no unusual trends in the vicinity of $M = 1.0$. At supersonic speeds the critical value of l/D_B is reached at successively lower values with increasing Mach number. A change of angle of attack from 0° to 8.7° had little effect on the length interference effects over the Mach number range tested. On the basis of these results an l/D_B ratio of 4 appears adequate for making the forebody chord-force interference small within the Mach number range of 0.60 to 1.30 for the model tested. A practical size sting support will probably always give some interference in the high subsonic speed range.

Effect of d/D_B ($\theta = 3.5^{\circ}$, $d/D_B = 0.855$, $l/D_B = 4.61$).- The data of figure 4 show that throughout the test Mach number range there was little or no change in forebody chord force resulting from reducing the d/D_B ratio from 0.932 to 0.855 at an l/D_B of 4.61. Furthermore, as has been mentioned, the data obtained with the 1° tapered sting can be considered as representing an effective diameter greater than 0.932, and these data are in agreement with the preceding results at and above a Mach number of 1.075. These comparisons are indicative of forebody chord-force results which are free of diameter effects, and therefore are free of all interference effects from the sting support when l/D_B is above the critical value. This observation is in accord with results presented in reference 5. Specifically, in this reference it was found from tests of a similar body of revolution that for a Reynolds number of 5×10^6 or for tests at a lower Reynolds number with a turbulent boundary layer induced by a roughness strip on the nose of the model, that no effect on foredrag of reducing the d/D_B ratio from 0.96 to 0.44 was evident at a Mach number of 1.50. If it is assumed that the difference in Mach number (1.30) of the present report and that of the reference report (1.50) negligibly affects the interference effects, then it is believed that the turbulent boundary layer of the present tests would preclude any diameter effects on the foredrag. However, further tests are needed in the transonic speed range to prove this conclusively.

Tapered sting tests ($\theta = 1^{\circ}$, $l/D_B \approx 0$, $d/D_B = 0.932$).- The data of figure 4 allow comparisons of the interference effects on forebody chord force of a 1° tapered sting to that of an 8° conical afterbody. Although there is considerable scatter in the values for the 1° sting, the data are in agreement above the critical l/D_B ratio at Mach numbers of 1.075 and higher. Since it has been shown for the 8° conical afterbody that the forebody chord force is free of interference from the sting support above the critical l/D_B, then the data from the 1° tapered sting also appears to be interference free. Below a Mach number of 1.075 interference from the 1° tapered sting is evident to a small degree.

An obvious advantage can be gained in structural strength by employing tapered stings. However, it is yet to be determined what l/D_B would be required in order to reduce the subsonic interference effect due to the 1° tapered sting to a level comparable with that of a sting support with an l/D_B of 4 and $\theta = 8^{\circ}$.

CONCLUSIONS

Tests were made of a wing-body model to determine the interference effect of various sting-support configurations (consisting of a constant-diameter sting followed by a conical afterbody) on the base pressure and forebody chord force. The boundary layer was turbulent over the after portion of the fuselage. The tests were conducted over a range of Mach numbers from 0.60 to 1.30 at a constant Reynolds number of 5.4×10^6 based on fuselage length.

1. The interference to base pressure and foredrag due to the conical afterbody at high subsonic speeds was found to exceed that encountered at all higher speeds tested.

2. There was little effect of angle of attack on base pressure and foredrag interference due to the conical afterbody.

3. The length of constant-diameter sting, preceding an 8° half-angle conical support, that will yield foredrag results free of length interference effects is four model base diameters for Mach numbers of 1.025 and greater. For Mach numbers less than 1.025, although the length interference effects are small, a sting length longer than four model base diameters would be required to eliminate length interference effects.

4. Foredrag results that are free of sting-support interference were obtained at and above a Mach number of 1.075 from a sting support consisting of a sting to model-base diameter ratio of 0.932 and a 1° half-angle conical afterbody beginning at the base of the model.

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National Advisory Committee for Aeronautics
Moffett Field, Calif., Nov. 16, 1954

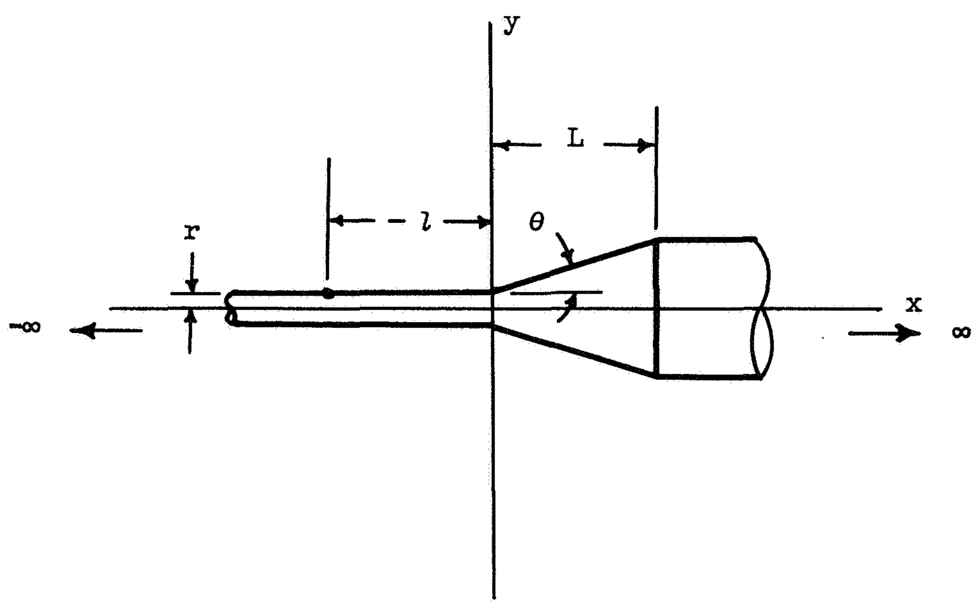
APPENDIX

The purpose of this analysis is to estimate, for subsonic speeds, the interference to the model base pressure resulting from the presence of a conical afterbody on the sting. In order to simplify the problem, the presence of the model is neglected. Therefore, the calculated pressure coefficient would not be expected to agree in magnitude with the measured base-pressure coefficient but would be expected to indicate the variation with the distance of the conical afterbody from the location of the base of the model.

The subsonic flow about any body of revolution is given to the first order by equation 12 of reference 4.

$$P(x,y) = -\frac{1}{2\pi}\int_{-\infty}^{\infty}\frac{S'(\xi)(x-\xi)d\xi}{[(x-\xi)^2+(\beta y)^2]^{3/2}} \tag{1}$$

The sting support can be approximated by a semi-infinite length sting followed by a conical afterbody of length L terminating in a semi-infinite length support, as shown in the following sketch:



In this sketch $-l$ and r represent a point on the sting in the (x,y) plane at which the pressure coefficient will be computed. To evaluate the integral it is first necessary to determine $S'(\xi)$ from $-\infty$ to ∞.

$$-\infty < x < 0 \qquad S'(\xi) = 0$$

$$0 < x < L \qquad S'(\xi) = 2\pi \tan\theta(r + \xi \tan\theta)$$

$$L < x < \infty \qquad S'(\xi) = 0$$

With the substitution of $S'(\xi)$ into equation (1) and denoting a point on the sting by (l,r), the integral becomes

$$P(l,r) = -\tan\theta \int_0^L \frac{(r + \xi\tan\theta)(l - \xi)d\xi}{[(l - \xi)^2 + (\beta r)^2]^{3/2}} \tag{2}$$

As a result of factoring $(\beta r)^2$ from the denominator and making the substitution of $-Z = l-\xi/\beta r$, equation (2) can be written

$$P(l,r) = \frac{\tan\theta}{\beta}\left(1 + \frac{l}{r}\tan\theta\right)\int_{\frac{-l}{\beta r}}^{\frac{L-l}{\beta r}} \frac{ZdZ}{(Z^2 + 1)^{3/2}} +$$

$$\tan^2\theta \int_{\frac{-l}{\beta r}}^{\frac{L-l}{\beta r}} \frac{Z^2 dZ}{(Z^2 + 1)^{3/2}} \tag{3}$$

Equation (3) can be integrated to give the pressure coefficient in terms of Mach number M, cone angle θ, length of conical afterbody L, radius of sting r, and length of constant-diameter sting l.

$$P(l,r) = \tan\theta\left[\frac{1}{\sqrt{\left(\frac{l}{r}\right)^2 + \beta^2}} - \frac{\frac{L}{r}\tan\theta + 1}{\sqrt{\left(\frac{L}{r} - \frac{l}{r}\right)^2 + \beta^2}}\right] +$$

$$\tan^2\theta\left[\sinh^{-1}\frac{\left(\frac{L}{r} - \frac{l}{r}\right)}{\beta} - \sinh^{-1}\frac{\left(\frac{-l}{r}\right)}{\beta}\right] \tag{4}$$

The validity of equation (4) depends on the $\sinh^{-1}$ function being positive. Therefore, the equation is only applicable for negative values of l. Furthermore, for values of l approaching zero the small perturbation assumption of the theory is violated. In figure 3, $P(l,r)$ is plotted as a function of l/D_B, where $D_B = \frac{2r}{(d/D_B)}$.

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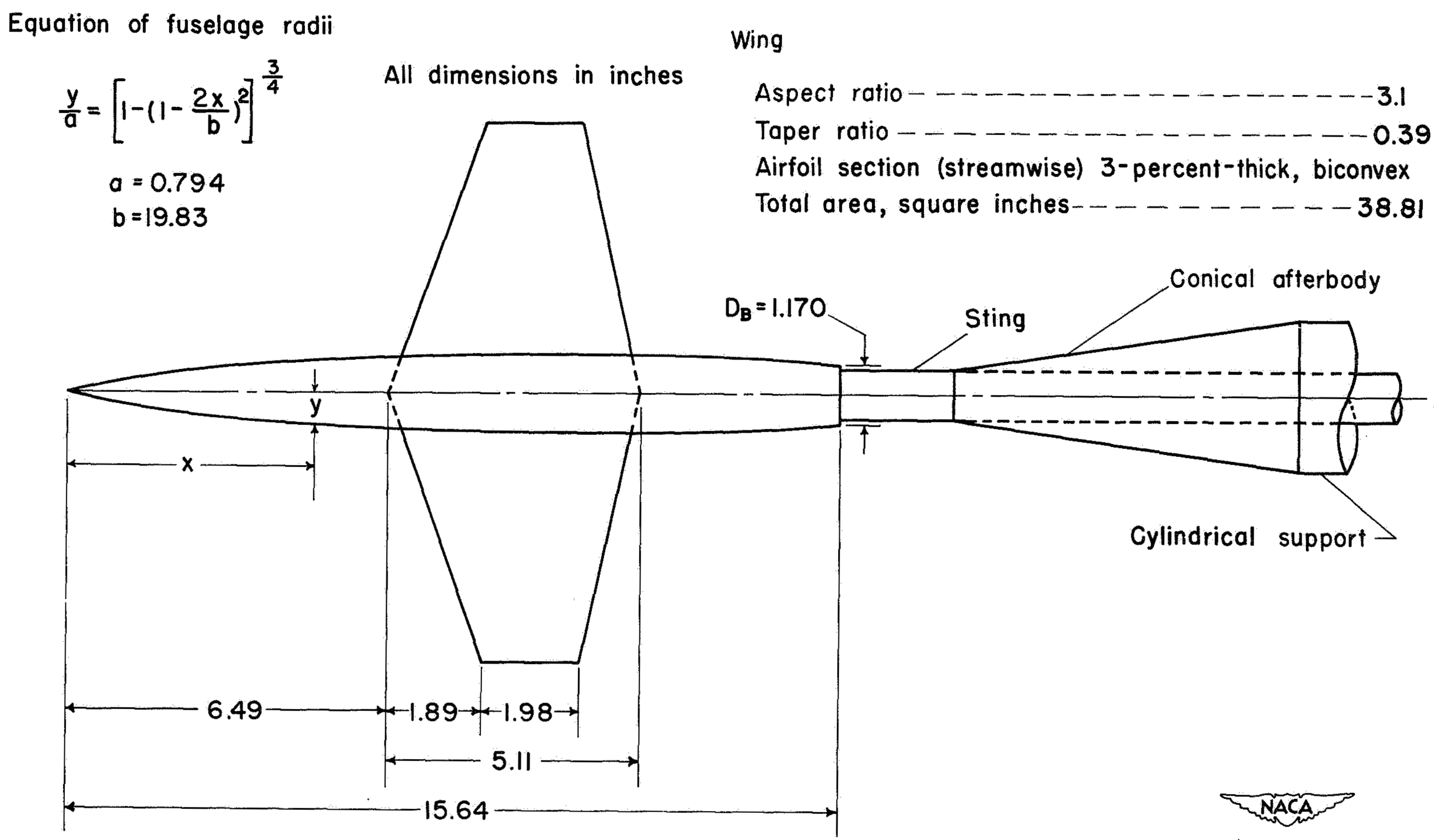
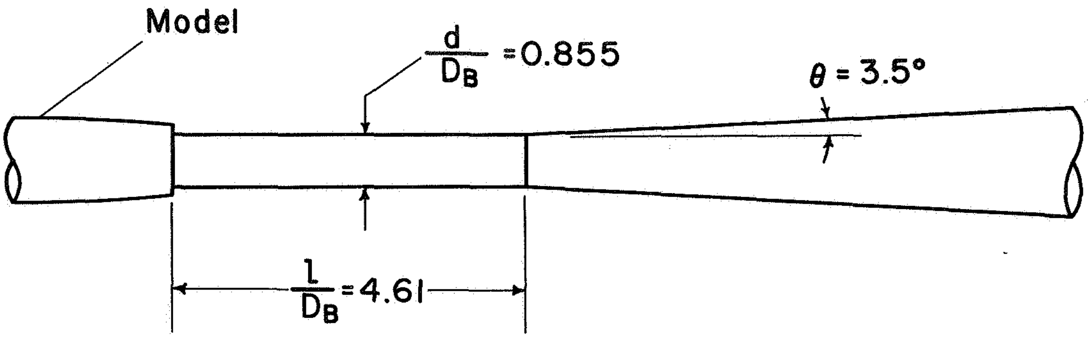
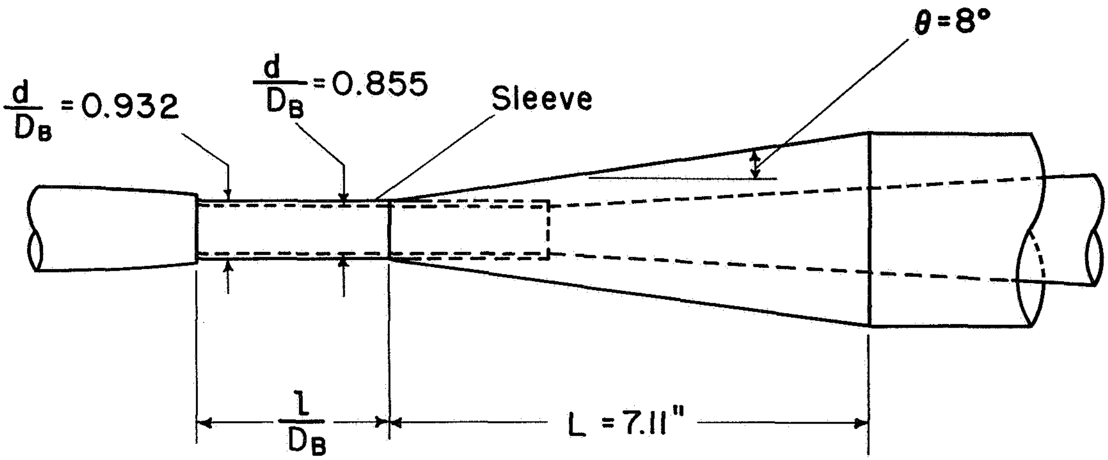


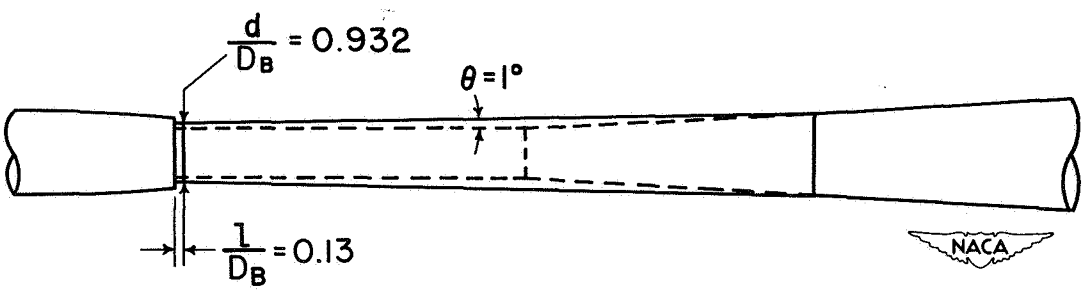
Figure 1.- Plan view of the model mounted on a rear sting support.



(a) Basic sting support.



(b) Basic support with sleeve and 8° conical afterbody.



(c) Basic support with 1° tapered sting.

Figure 2.- Sting supports.

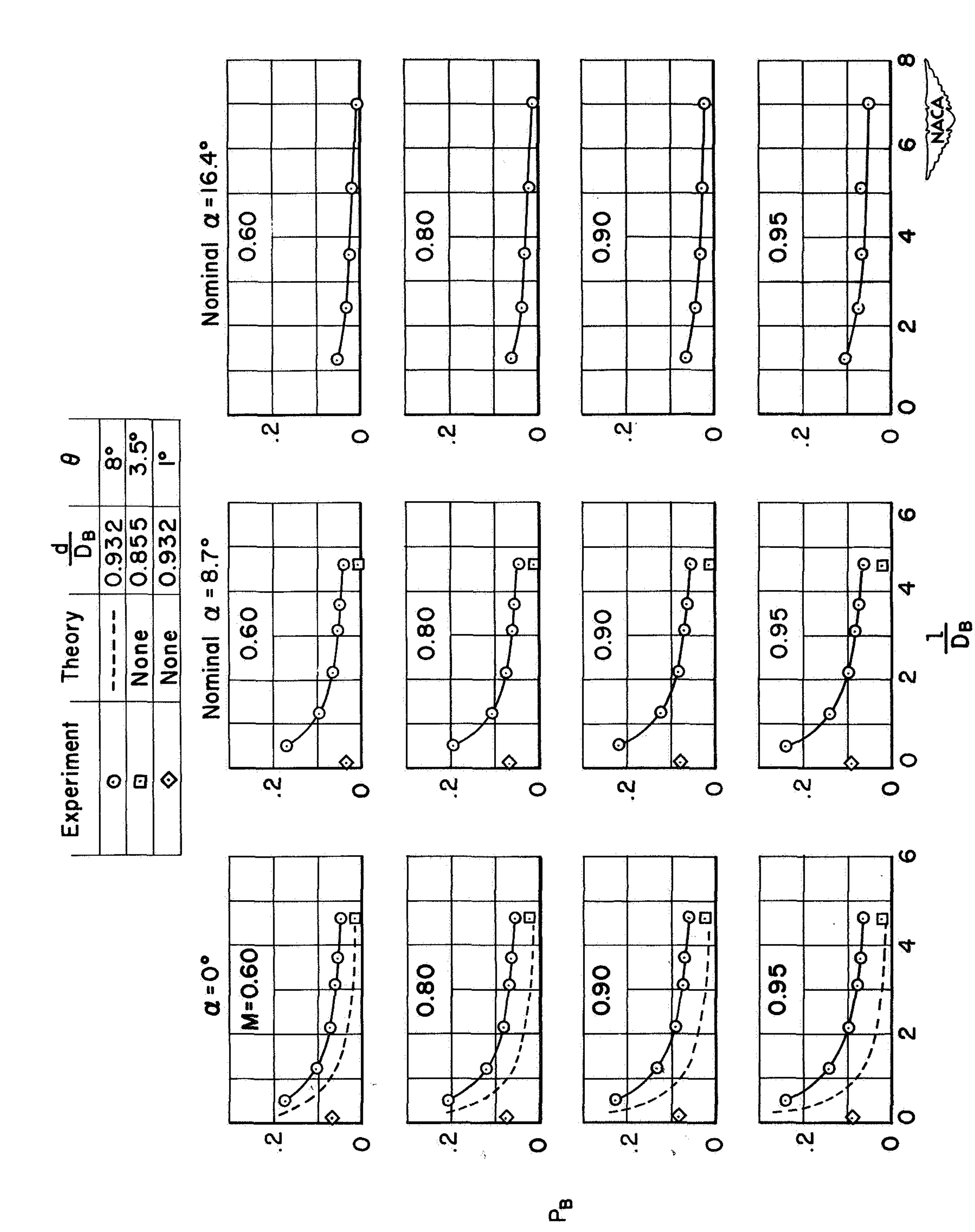


Figure 3.- Effects upon base-pressure coefficient of the ratio of sting length to model-base diameter.

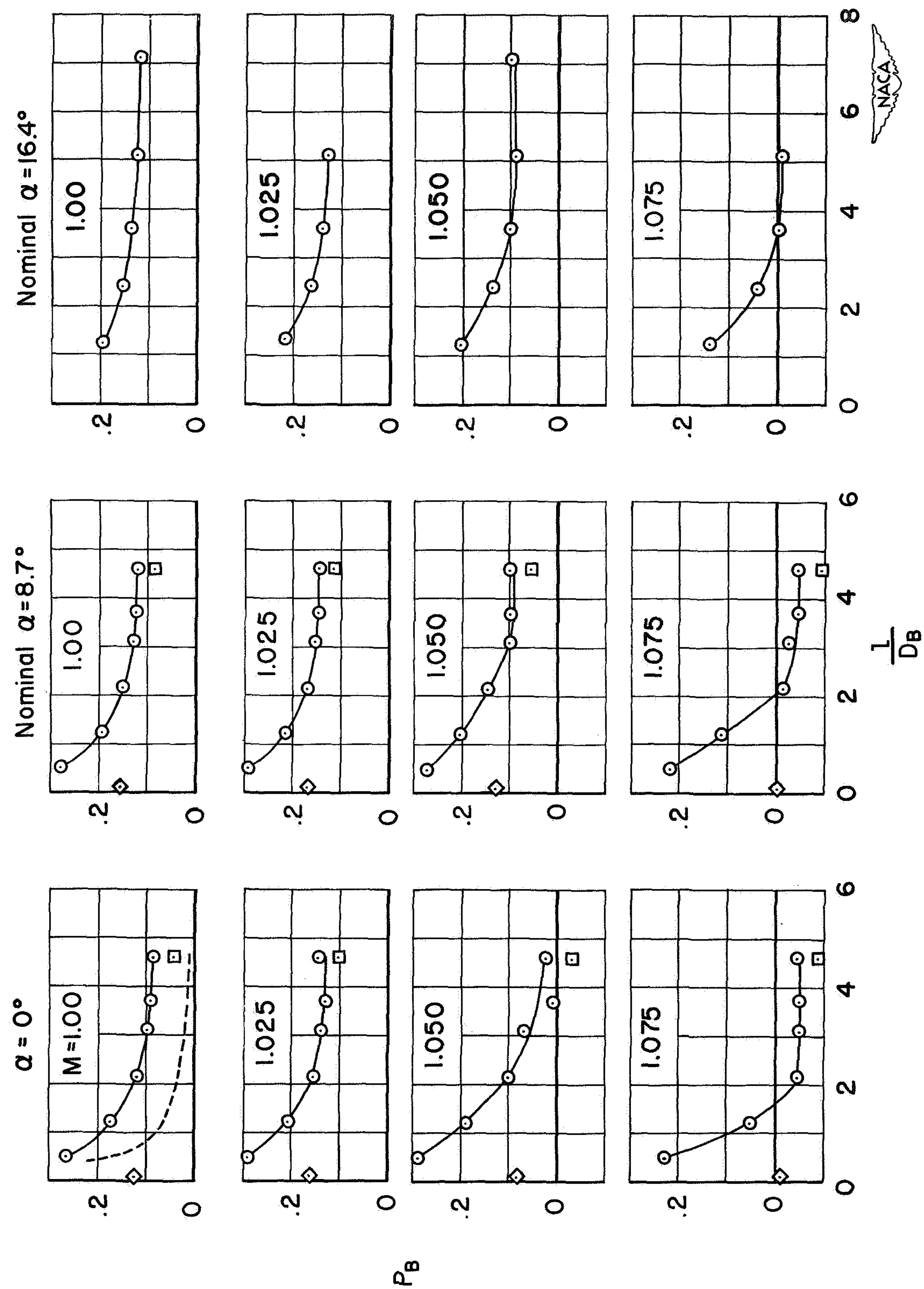


Figure 3.- Continued.

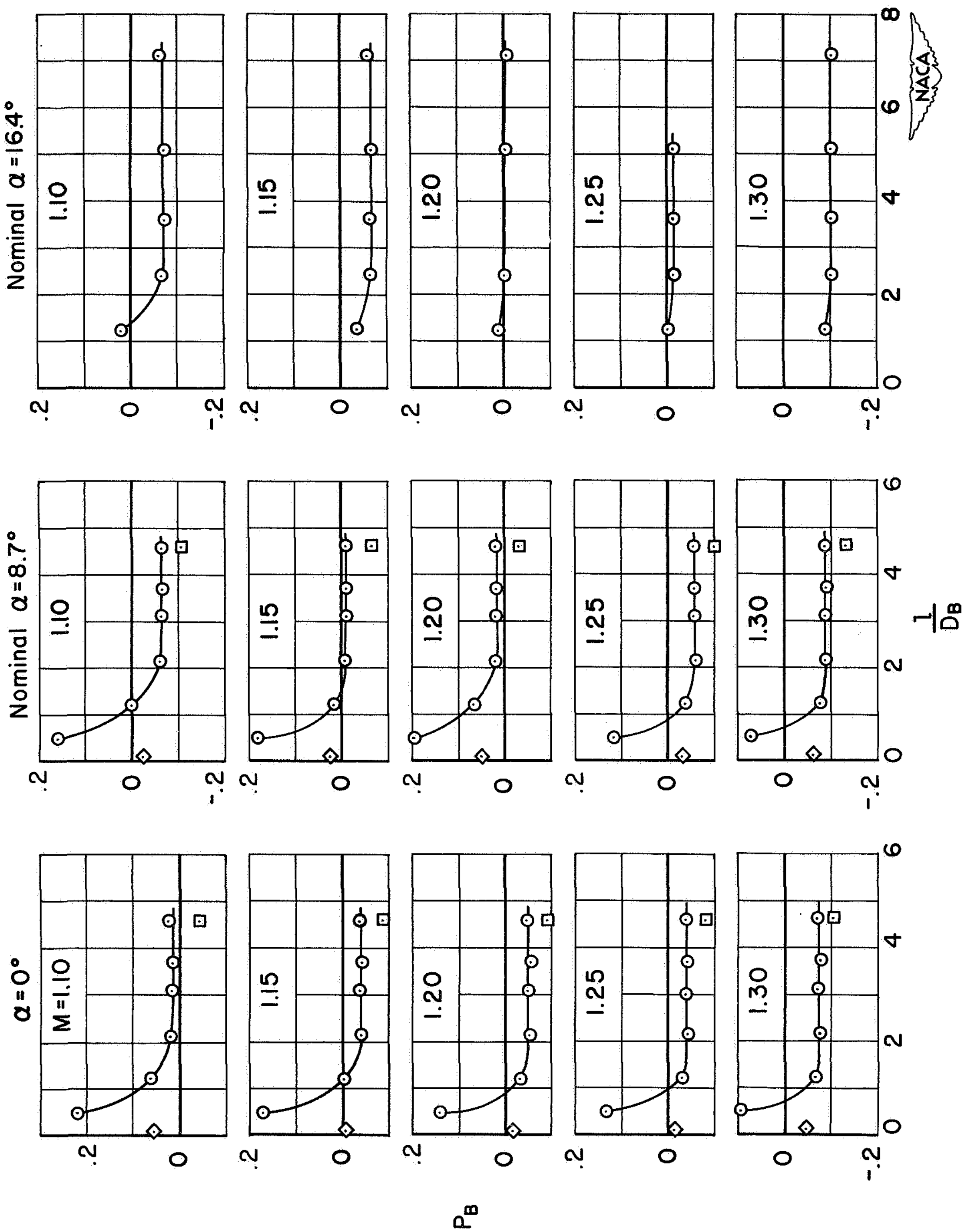


Figure 3.- Concluded.

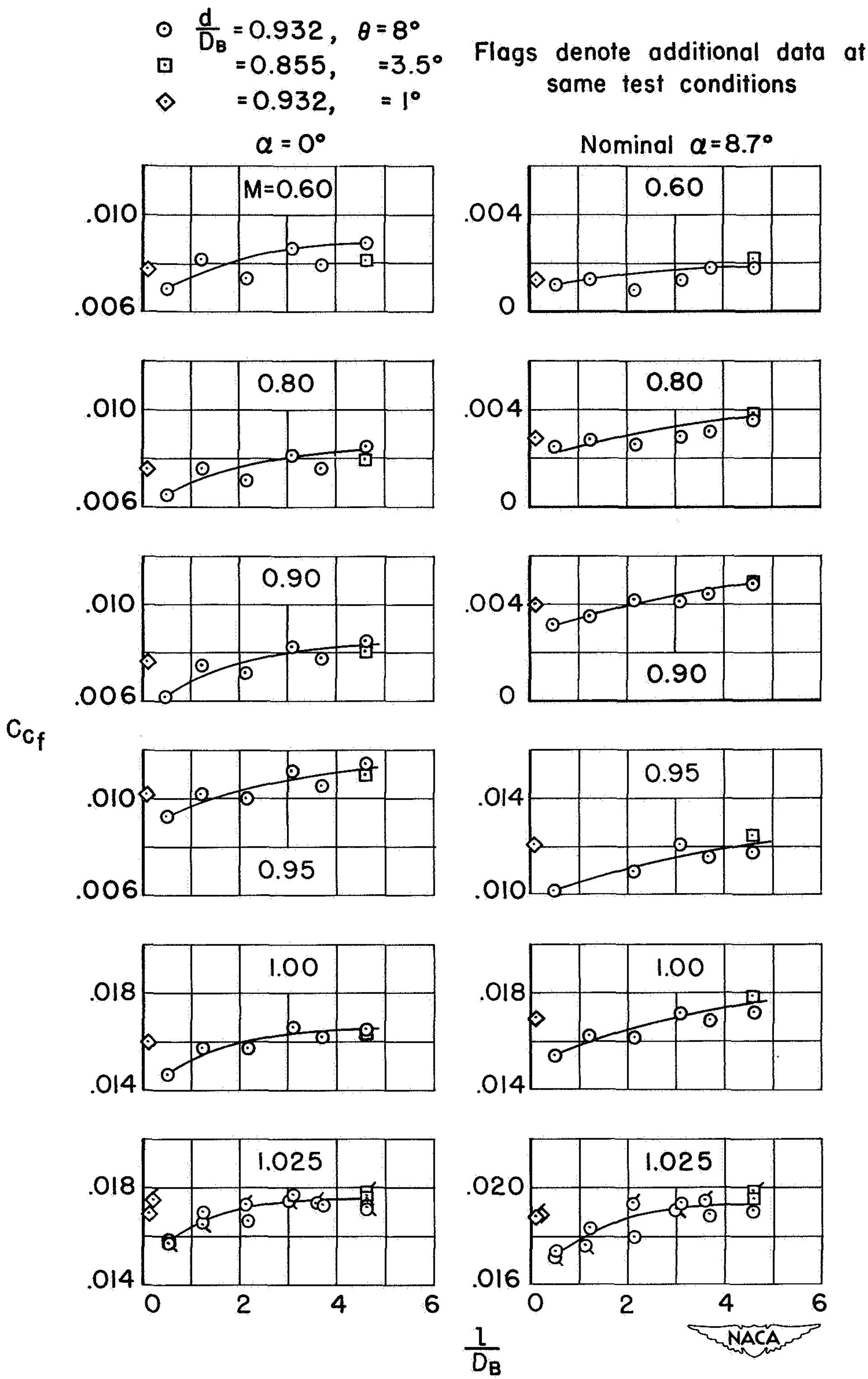


Figure 4.- Effects upon forebody chord-force coefficient of the ratio of sting length to model-base diameter.

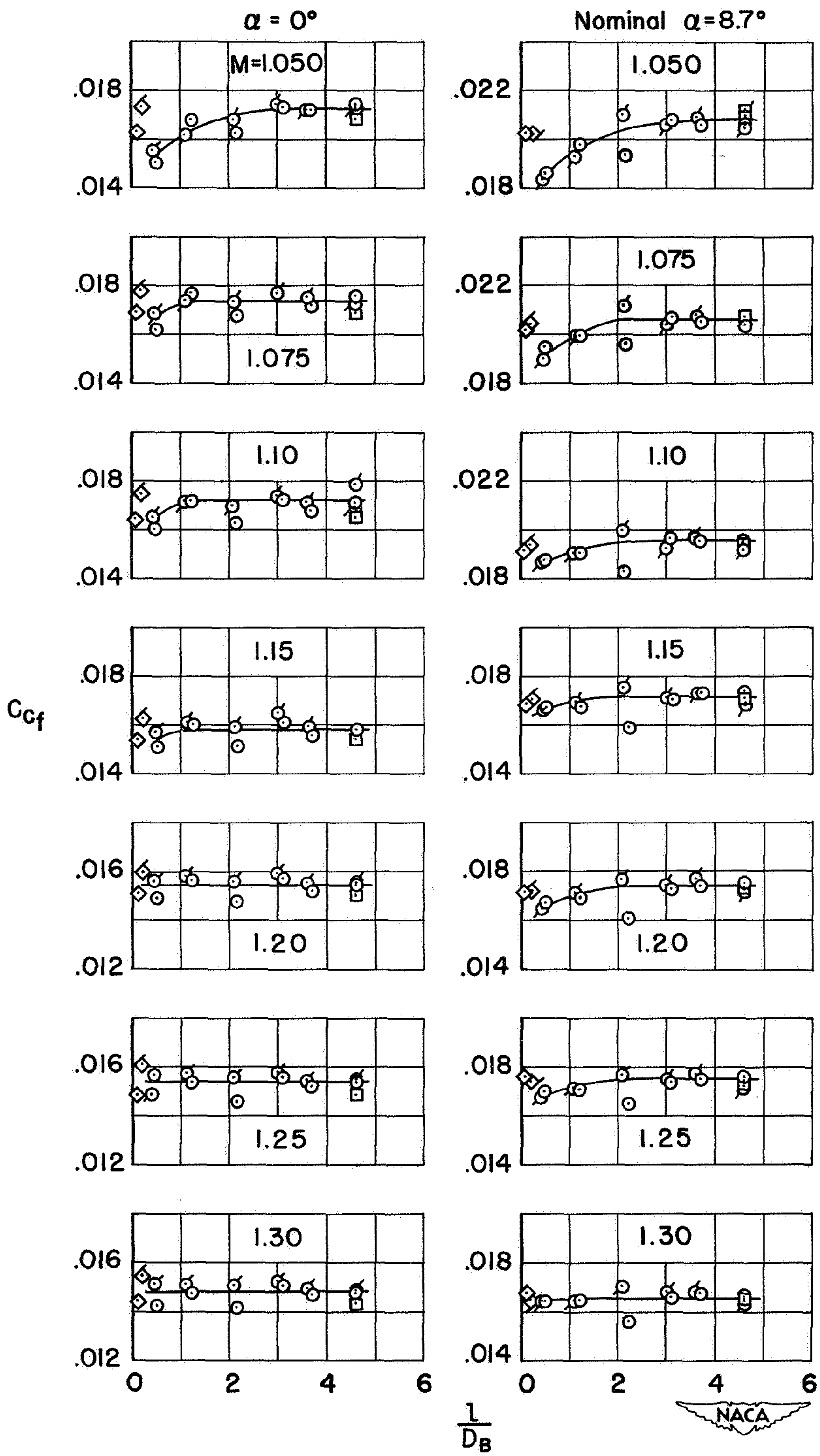


Figure 4.- Concluded.