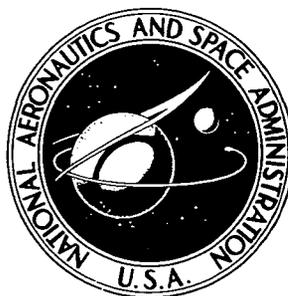


**NASA TECHNICAL  
MEMORANDUM**



**NASA TM X-3087**

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**LATERAL-DIRECTIONAL STABILITY  
CHARACTERISTICS OF  
A WING-FUSELAGE CONFIGURATION  
AT ANGLES OF ATTACK UP TO 44°**

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OF A WING-FUSELAGE CONFIGURATION AT ANGLES  
OF ATTACK UP TO  $44^{\circ}$

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SUMMARY

An investigation has been conducted to determine the effects of configuration variables on the lateral-directional stability characteristics of a wing-fuselage configuration. The variables under study included variations in the location of a single center-line vertical tail and twin vertical tails, wing height, fuselage strakes, and horizontal tails. The study was conducted in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.30, at angles of attack up to  $44^{\circ}$  and at sideslip angles of  $0^{\circ}$  and  $\pm 5^{\circ}$ .

The results of this study indicate that the wing-body configuration (strakes off) with the mid wing position exhibits a favorable break in both directional and lateral stability at the higher angles of attack (near and above maximum lift), whereas the directional stability for the high wing configuration remains relatively constant. For the wing-body configuration with the strake on, raising the wing-strake combination results in a large destabilizing increment in directional stability at the lower angles of attack and a large destabilizing increment in the lateral stability above maximum lift. For the mid wing configuration (strake off), all the vertical-tail positions studied provide a stabilizing increment in directional stability up to the highest test angle of attack. For the mid wing configuration (strakes on), adding the single vertical tail results in a stabilizing increment in the directional stability up to an angle of attack of  $30^{\circ}$ , above which the single tail contributes a destabilizing effect. The spanwise location of the vertical tails has a significant effect on the directional-stability characteristics at high angles of attack; the twin vertical tails in the most forward and outboard location studied exhibited a stable increment in directional stability throughout the test angle-of-attack range. For the model with the high wing, none of the vertical-tail positions studied provided a stable increment throughout the entire angle-of-attack range. Extending the wing fuselage strakes completely to the nose of the model results in a favorable change in the directional stability throughout the test angle-of-attack range.

## INTRODUCTION

Significant emphasis is being placed on high maneuverability in the design of modern-day fighter aircraft. During combat maneuvering, relatively high angles of attack can be achieved, and past experience has indicated that some fighters experience serious stability and control problems at these higher angles. Therefore it appears desirable to devote considerable effort to the study of those aerodynamic characteristics which may have a significant effect on high angle-of-attack operation.

This paper presents the results of a study aimed at determining the effect of configuration variables on the directional-stability characteristics of a general research model designed to be representative of a typical fighter configuration. The variables under study included wing height, wing-fuselage strakes, variations in the location of twin and single vertical tails, and horizontal tails. The investigation was conducted in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.30, which corresponds to a Reynolds number based on the mean geometric chord of  $2.06 \times 10^6$ . The angle-of-attack range of the study varied from  $0^\circ$  to  $44^\circ$  at sideslip angles of  $0^\circ$  and  $\pm 5^\circ$ .

## SYMBOLS

The results as presented are referred to the body-axis system with the exception of the lift and drag coefficients, which are referred to the wind-axis system. The moment reference center was located at a point 65.91 cm rearward of the fuselage nose along the model reference line. (See fig. 1.) All measurements were made in the U.S. Customary Units and converted to the International System of Units.

b	wing span, 50.80 centimeters
$C_D$	drag coefficient, $\frac{\text{Drag}}{qS}$
$C_L$	lift coefficient, $\frac{\text{Lift}}{qS}$
$C_l$	rolling-moment coefficient, $\frac{\text{Rolling moment}}{qSb}$
$C_{l\beta}$	effective-dihedral parameter, $\frac{\Delta C_l}{\Delta \beta}$ , per degree
$C_m$	pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS\bar{c}}$
$C_n$	yawing-moment coefficient, $\frac{\text{Yawing moment}}{qSb}$

$C_{n\beta}$	directional stability parameter, $\frac{\Delta C_n}{\Delta \beta}$ , per degree
$C_Y$	side-force coefficient, $\frac{\text{Side force}}{qS}$
$C_{Y\beta}$	side-force parameter, $\frac{\Delta C_Y}{\Delta \beta}$ , per degree
$\bar{c}$	wing mean geometric chord, 23.30 centimeters
$q$	free-stream dynamic pressure, newtons/meter <sup>2</sup>
$S$	wing reference area, 0.10322 meter <sup>2</sup>
$\alpha$	angle of attack, degrees
$\beta$	angle of sideslip, degrees
$\Delta$	increment in forces or moments

#### MODEL DESCRIPTION

Drawings of the model studied are presented in figure 1, and a photograph of the model mounted on a sting in the Langley high-speed 7- by 10-foot tunnel is presented in figure 2. As illustrated in figure 1(a), the basic model consisted of a simple wing-fuselage combination; the cambered and twisted wing had an aspect ratio of 2.5, a taper ratio of 0.20, a wing leading-edge sweep angle of 44°, and an NACA 64A series airfoil section (measured streamwise) with a thickness ratio of 6 percent at the fuselage juncture and 4 percent at the wing tip. The airfoil ordinates for the twisted and cambered wing (design lift coefficient of 0.35) are tabulated in reference 1. The wing height was varied as shown in figure 1(a) so that the configuration represented either a mid or high wing configuration. The wing-fuselage strake was a thin (0.159-cm-thick) flat plate having a sharp leading edge and was moved to the various positions along with the wing. The basic strake was extended (see fig. 1(a)) to the nose of the model by adding a thin flat plate (1.27 cm wide) to the model.

Both single and twin vertical tails were investigated. The planform area of the single center-line vertical tail was equal to the sum of the areas of the twin vertical tails. The location of the vertical tails was varied (longitudinally for the single tail and both longitudinally and spanwise for the twin tails) as shown in figure 1(a). Both the single and twin vertical tails, as well as the horizontal tail (see figs. 1(b) and 1(c)), had a 64A series airfoil section used streamwise with a thickness ratio of 4 percent.

## TEST AND CORRECTIONS

The investigation was conducted in the Langley high-speed 7- by 10-foot tunnel at a Mach number of 0.30, at angles of attack up to  $44^\circ$  and at angles of sideslip of  $0^\circ$  and  $\pm 5^\circ$ . The test Reynolds number, based on the wing mean geometric chord, was  $2.06 \times 10^6$ . Transition strips 0.32 cm wide of No. 100 carborundum grains were placed 1.14 cm streamwise from the leading edge of the wings and 2.54 cm behind the nose on the fuselage.

Because of the aerodynamic load, corrections to the model angle of attack and sideslip were made for deflections of the balance and sting support system. Pressure measurements obtained from orifices located within the fuselage base cavity were used to adjust the drag coefficient to a condition of free-stream static pressure at the model base. Jet boundary and blockage corrections were found to be negligible and therefore were not applied to the data.

## PRESENTATION OF RESULTS

The longitudinal aerodynamic characteristics are presented in figure 3 and the lateral-directional characteristics in figures 4 to 16. The following list of figures is presented as an aid in locating the data:

	Figure
Effect of wing location and wing-fuselage strake on the longitudinal characteristics. Vertical and horizontal tails off . . . . .	3
Effect of wing height on the lateral-directional characteristics of the model with strake and vertical and horizontal tails off . . . . .	4
Effect of wing height on the lateral-directional characteristics of the model with strake on and vertical and horizontal tails off . . . . .	5
Effect of afterbody on the lateral-directional characteristics of the model with mid wing location and vertical and horizontal tails off . . . . .	6
Effect of center vertical tail on the lateral-directional characteristics of the model with mid wing location and with strake and horizontal tails off. Vertical tail located in row A . . . . .	7
Effect of location of the twin vertical tails on the lateral-directional characteristics of the model with mid wing location and with strake and horizontal tails off . . . . .	8
Effect of center vertical tail on the lateral-directional characteristics of the model with mid wing location and with strake on and horizontal tails off. Vertical tail located in row A . . . . .	9

	Figure
Effect of spanwise location of the twin vertical tails on the lateral-directional characteristics of the model with mid wing location and with strake on and horizontal tails off . . . . .	10
Effect of center vertical-tail location on the lateral-directional characteristics of the model with high wing location and with strake and horizontal tails off . . . . .	11
Effect of spanwise location of the twin vertical tails on the lateral-directional characteristics of the model with high wing location and with strake and horizontal tails off . . . . .	12
Effect of center vertical-tail location on the lateral-directional characteristics of the model with high wing location and with strake on and horizontal tails off . . . . .	13
Effect of spanwise location of the twin vertical tails on the lateral-directional characteristics of the model with high wing location and with strake on and horizontal tails off . . . . .	14
Effect of horizontal tail on the lateral-directional characteristics of the model with high wing location and with strake on. Center vertical tail located in row C . . . . .	15
Effect of wing-fuselage strake on the lateral-directional characteristics of the model with mid wing location and with horizontal tails off . . . . .	16

## DISCUSSION

### Longitudinal Characteristics

The longitudinal aerodynamic characteristics of the wing-fuselage model (without the horizontal tails) with the various strake combinations are presented in figure 3. Adding the strake to the wing body (discussed in detail in ref. 1) results in a large increase in lift at the higher angles of attack. The basic wing-fuselage configuration exhibits linear pitching-moment characteristics up to maximum lift, above which a slight increase in stability is evident. The addition of the strakes results in a large unstable change in the low lift stability level, as would be expected from the addition of lifting area ahead of the center of gravity, and an abrupt pitch-up at maximum lift. These data are presented for the model without a horizontal tail. With the addition and proper placement of a horizontal-tail surface, this pitch-up could probably be eliminated; however, the use of the horizontal tail to trim a statically stable configuration would result in a significant trim penalty in maximum lift.

## Lateral-Directional Characteristics

The effects of wing height on the lateral-directional characteristics of the wing-fuselage model with the strake and vertical tails off are presented in figure 4. The model with the mid wing location exhibits a favorable break in the directional stability parameter at an angle of attack of  $22^\circ$ , whereas the model with the wing in the high location possesses a constant level of  $C_{n\beta}$  with increasing angle of attack. Moving the wing height location from the high position to the mid position (fig. 4) also results in a significant stabilizing increment in the effective-dihedral parameter  $C_{l\beta}$ . The major contributor to these characteristics appears to be wing-induced sidewash effects on the fuselage afterbody, as evidenced by the data presented in figure 6(a) and in reference 2. The data of figure 6(a) illustrate that the favorable break in  $C_{n\beta}$  for the mid wing configuration disappears when the fuselage afterbody is removed.

The effect of wing height on the lateral-directional characteristics for the model with the strake on is shown in figure 5. At the lower angles of attack, moving the wing to a high position on the fuselage results in a large destabilizing increment in the directional stability  $C_{n\beta}$ . The effects noted are probably the results of changes in the flow around the model forebody. (Note the effect of wing height on the side-force parameter in fig. 5 and the absence of any effect at low angles of attack when the aft fuselage section is removed (fig. 6(b).) At the higher angles of attack, above  $26^\circ$ , there appears to be an unfavorable sidewash effect (see fig. 6(b)) on the fuselage afterbody as a result of the wing-fuselage-strake combination. It should be noted that the effect on  $C_{n\beta}$  noted in figure 6(b) is opposite of that presented in figure 6(a). Raising the wing to the high position increases the angle of attack at which  $C_{l\beta}$  exhibits instability. This effect is probably the result of a delay in vortex breakdown which is exhibited by the lift curves of figure 3(a).

The fuselage utilized for the model was designed to allow a high degree of versatility and is used in a number of general research programs. Therefore this fuselage does not closely represent the fuselage of an actual high performance airplane. As a result, the level of directional stability is not representative of such airplanes; therefore, only the incremental effects of adding the vertical tails are discussed herein.

In regard to the mid wing configuration (strake off), the single vertical tail provides a stabilizing increment in directional stability up to the highest test angle of attack. (See fig. 7.) The magnitude of the increment is, of course, significantly affected by an adverse flow field (probably wing wake effects) so that at the higher angles of attack the vertical-tail contribution to stability is small. Above an angle of attack of  $25^\circ$ , adding the vertical tail results in a destabilizing effect on  $C_{l\beta}$ .

The results were not significantly altered by replacing the single tail (fig. 8) with the twin tails at the various spanwise locations (located so that the tail volume, product of the tail area and moment arm, is the same). However, the twin tails did not give the destabilizing effect on  $C_{l\beta}$  as did the single vertical tails. (Compare figs. 7 and 8.)

The addition of the strake to the model with the mid wing location, as illustrated by the data of figures 9 and 10, caused the single vertical tail to be in an unfavorable side-wash field so that the vertical tail contributes a destabilizing increment to the directional stability at angles of attack above  $30^\circ$ . (See fig. 9.) The results for the twin vertical tails show similar trends (fig. 10) to those illustrated for the single tail. In addition, the twin vertical tails exhibit significant effects of spanwise location on the directional stability at high angles of attack. This effect on the directional-stability characteristics did not appear in the data for the configuration with the strake off (fig. 8), and therefore, must be associated with the flow field created by the vortex system coming off the strake. Positive increments in directional stability result from moving the twin vertical tails forward and outboard. (See fig. 10.) With the vertical tails in the most forward and outboard location, a stabilizing increment in directional stability is evident (fig. 10(b)) throughout the test angle-of-attack range.

The addition of the vertical tails to the model with the wing in the high position and the strake off results in essentially the same trends as those exhibited by the configuration with the mid wing location. (See figs. 11 and 12.) Adding the strake to the model, as shown by the data presented in figures 13 and 14, results in an overall reduction in the stability level at the lower angles of attack. (Compare figs. 11 and 13.) This effect is the result of a combination of a change in the wing-body stability level brought about by the flow around the forebody and a reduction in the vertical-tail contribution to stability caused by an adverse sidewash effect. Even though these data for the high wing location exhibited trends similar to those for the mid wing location, none of the tail locations produced a stable increment in directional stability throughout the test angle-of-attack range.

At angles of attack above  $28^\circ$ , the addition of the horizontal tails to the model results in a favorable increment in  $C_{n\beta}$  and  $C_{l\beta}$ . (See fig. 15.) There is the possibility that this increment could be the result of a favorable pressure gradient on the horizontal tail; this gradient affects the strake vortex system and causes improved flow conditions at the tail of the model.

The effect of wing-fuselage strakes on the aerodynamic characteristics for the various model configurations studied at the mid wing location is presented in figure 16. Adding the basic strake to the model results in an unfavorable change in directional and lateral stability at angles of attack above  $24^\circ$ . By consideration of the side-force data of figure 16(a) as well as the afterbody-off data of figure 16(b), it would appear that for

this configuration, the unfavorable shift is due primarily to sidewash effects on the afterbody. Extending the strake completely to the nose of the model (see fig. 1(a)) alters the flow characteristics at the nose of the model and results in a favorable change in the directional stability throughout the test angle-of-attack range. This effect occurred for both configurations with and without the afterbody; this result indicated that the effect is primarily on the forebody. This effect is not evident in  $C_{l\beta}$ , a further indication of the forebody's role in the improved  $C_{n\beta}$ . Experiments have shown that configurations which derive a high level of  $C_{n\beta}$  at high angles of attack from the nose tend to exhibit unstable damping in yaw at high angles of attack.

### SUMMARY OF RESULTS

A study to determine the effects of configuration variables on the lateral-directional stability characteristics of a wing-body configuration yields the following results:

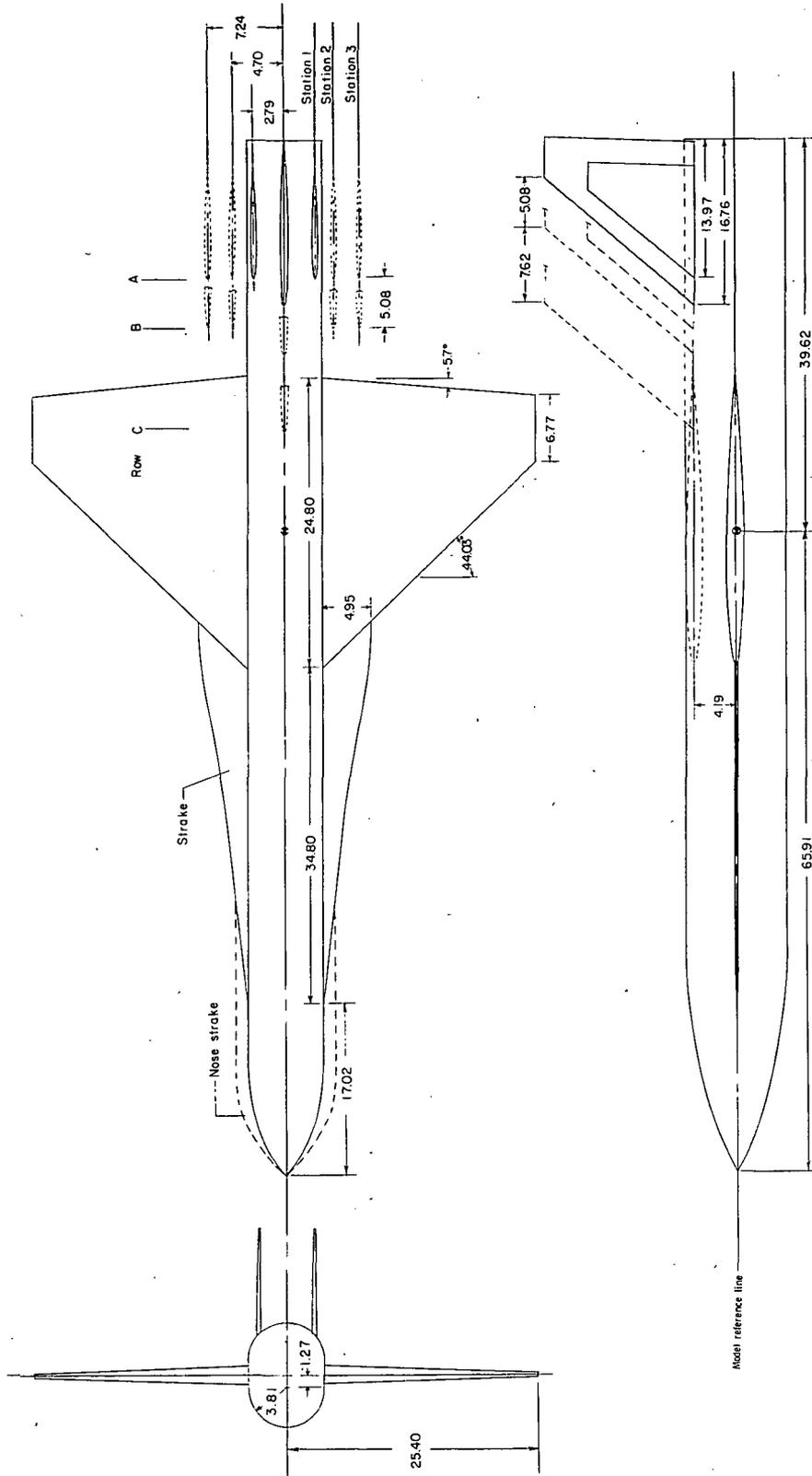
1. The wing-body configuration (strake off) with the mid wing position exhibits a favorable break in both directional and lateral stability at the higher angles of attack (near and above maximum lift), whereas the directional stability for the high wing configuration remains relatively constant.
2. For the wing-body configuration with the strake on, raising of the wing-strake combination results in a large destabilizing increment in directional stability at the lower angles of attack and a large destabilizing increment in the effective-dihedral parameter  $C_{l\beta}$  above maximum lift.
3. For the mid wing configuration (strake off), all the vertical-tail positions studied provide a stabilizing increment in directional stability up to the highest test angle of attack.
4. For the mid wing configuration (strake on), adding the single vertical tail results in a stabilizing increment in the directional stability up to an angle of attack of  $30^\circ$ , above which the single tail contributes a destabilizing effect. There is a significant effect of vertical-tail spanwise location on the directional-stability characteristics at high angles of attack; the twin vertical tails in the most forward and outboard location studied exhibit a stable increment in directional stability throughout the test angle-of-attack range.
5. For the model with the high wing configuration, none of the vertical-tail positions studied provides a stable increment throughout the entire angle-of-attack range.

6. Extending the wing-fuselage strake completely to the nose of the model results in a favorable change in the directional stability throughout the test angle-of-attack range.

Langley Research Center,  
National Aeronautics and Space Administration,  
Hampton, Va., June 18, 1974.

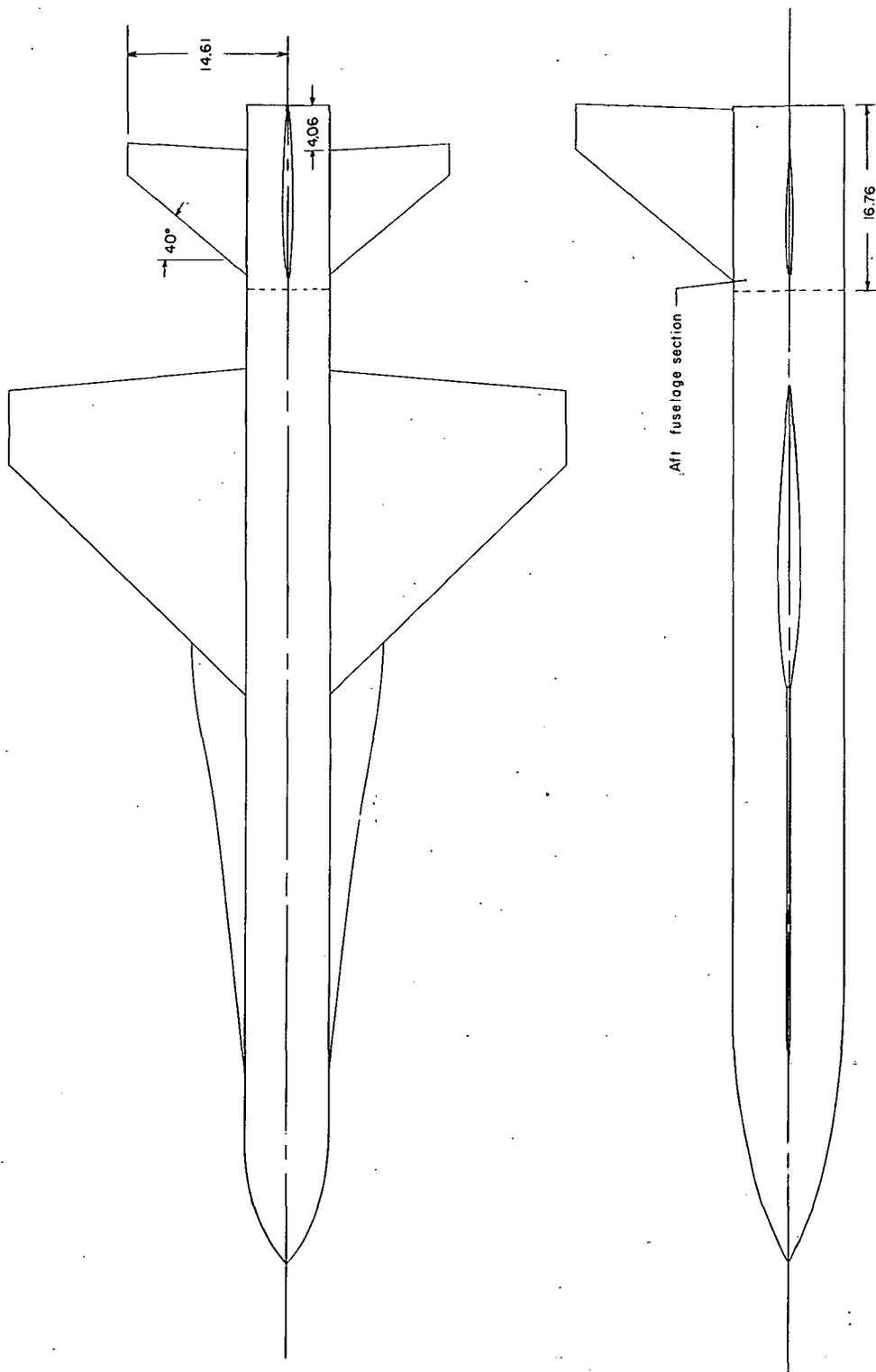
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1. Henderson, William P.; and Huffman, Jarrett K.: Effect of Wing Design on the Longitudinal Aerodynamic Characteristics of a Wing-Body Model at Subsonic Speeds. NASA TN D-7099, 1972.
2. Polhamus, Edward C.; and Spreemann, Kenneth P.: Subsonic Wind-Tunnel Investigation of the Effect of Fuselage Afterbody on Directional Stability of Wing-Fuselage Combinations at High Angles of Attack. NACA TN 3896, 1956.



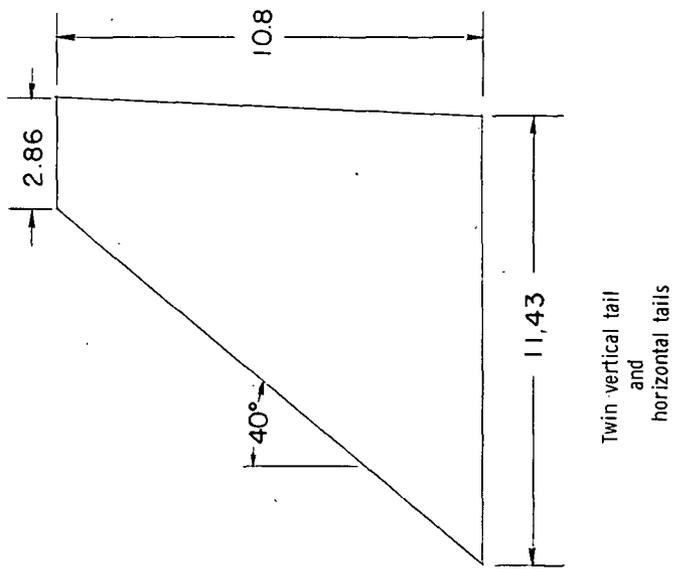
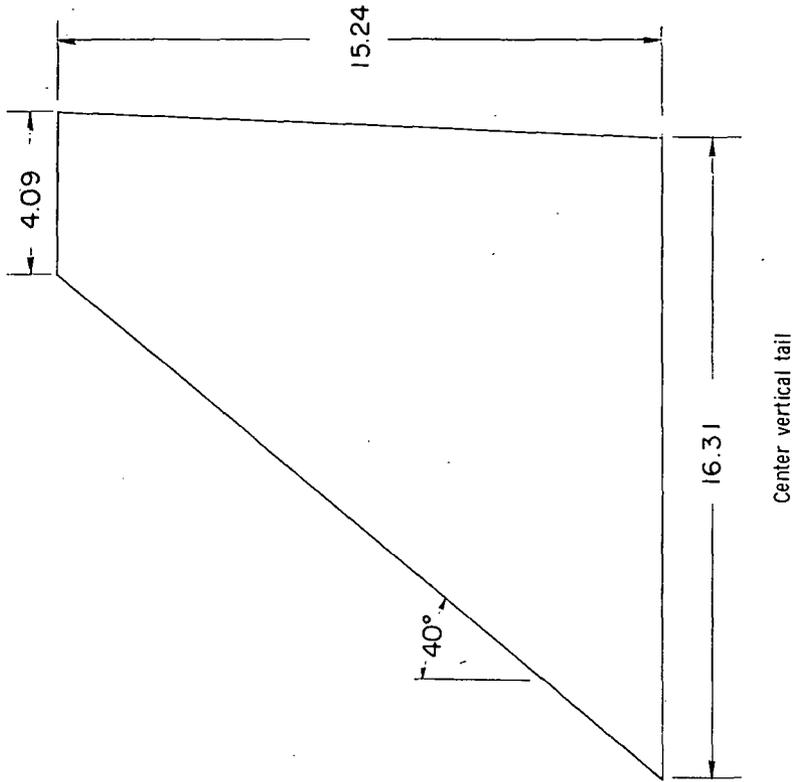
(a) Three-view drawing.

Figure 1.- Drawings of model. All dimensions are in centimeters unless otherwise noted.



(b) Drawing showing horizontal tail.

Figure 1.- Continued.



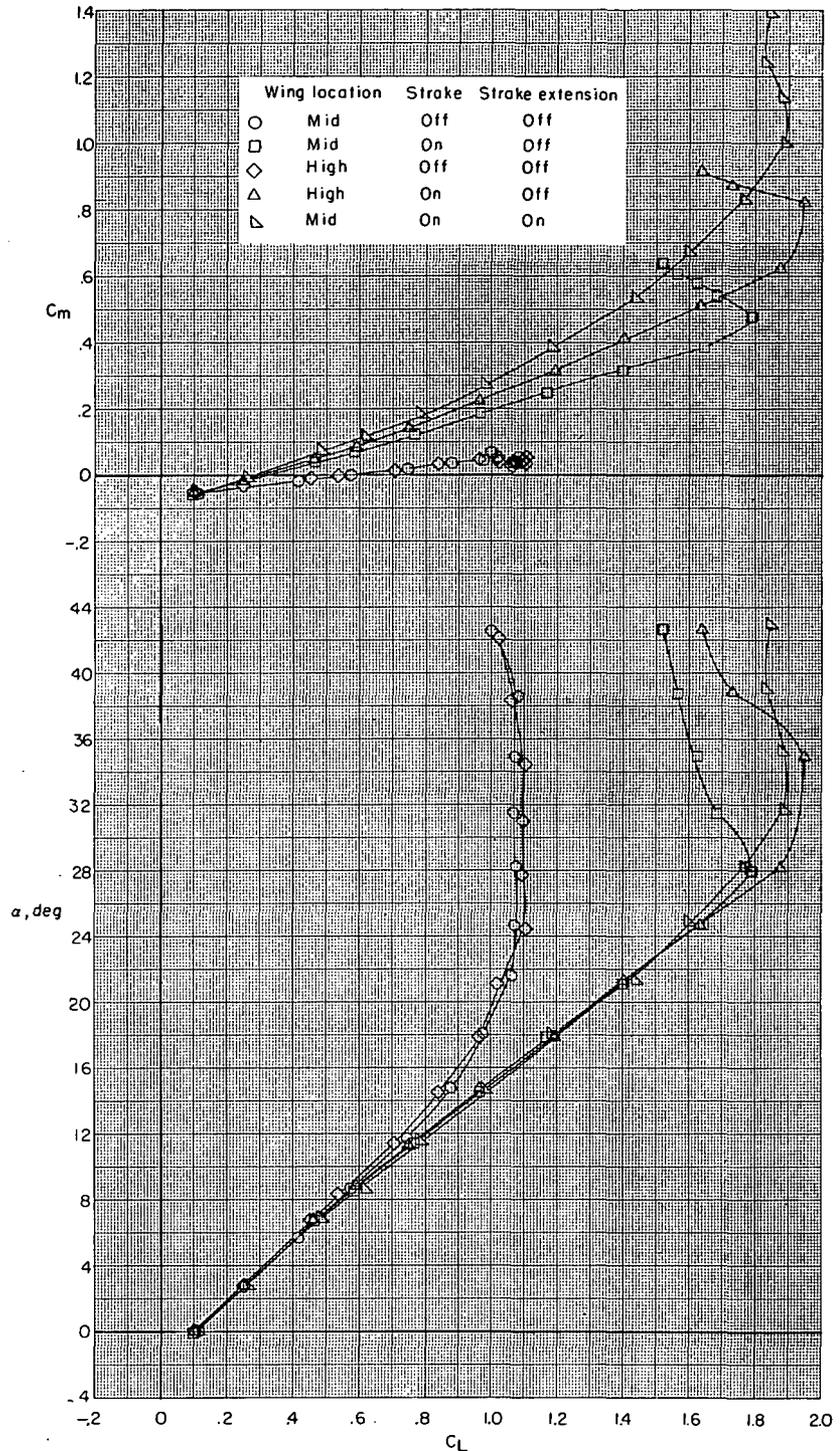
(c) Drawing of the horizontal and vertical tails.

Figure 1.- Concluded.



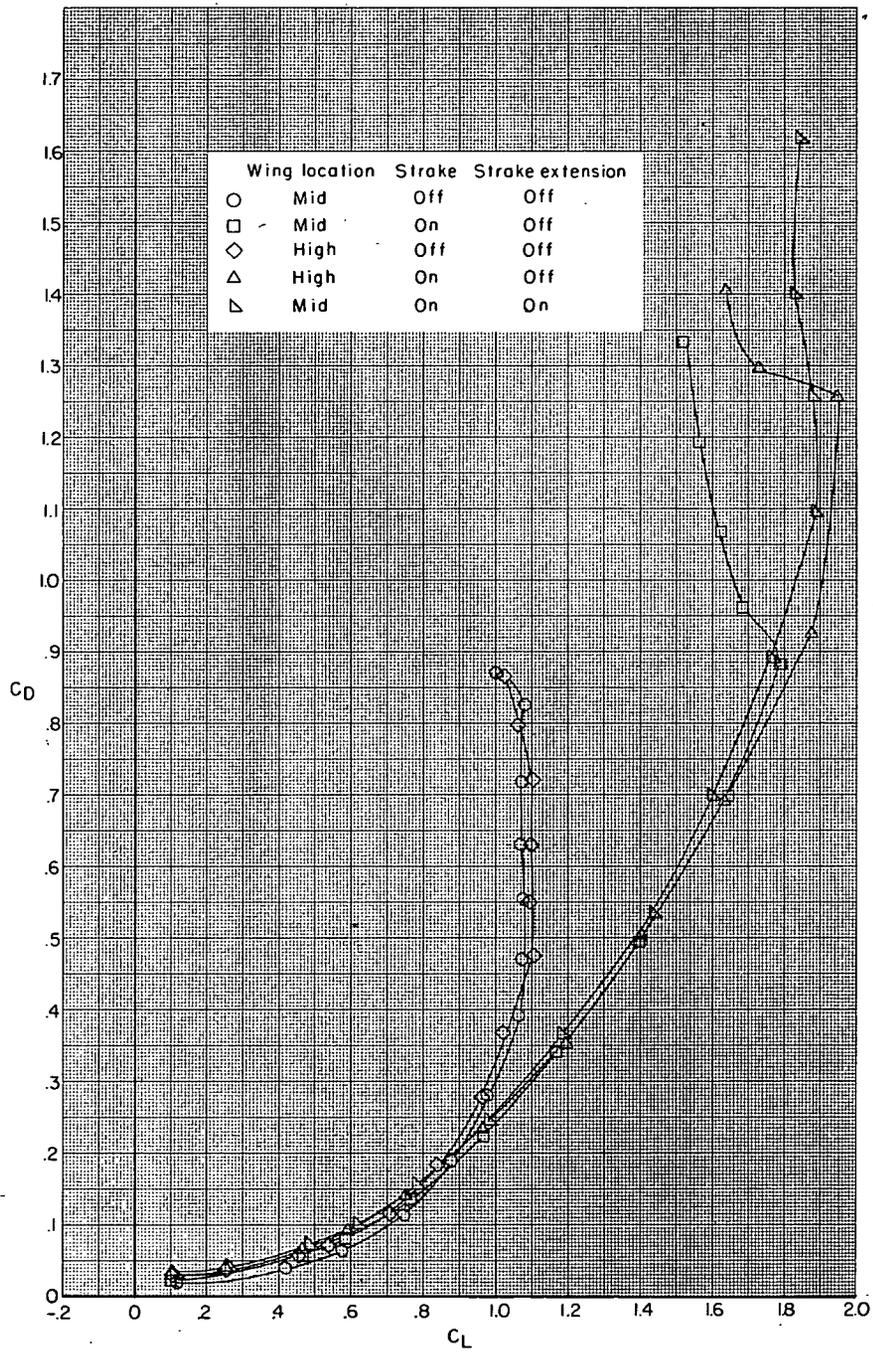
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Figure 2.- Photograph of model in Langley high-speed 7- by 10-foot tunnel.



(a) Variation of  $C_m$  and  $\alpha$  with  $C_L$ .

Figure 3.- Effect of wing location and wing-fuselage stroke on the longitudinal characteristics. Vertical and horizontal tails off.



(b) Variation of  $C_D$  with  $C_L$ .

Figure 3.- Concluded.

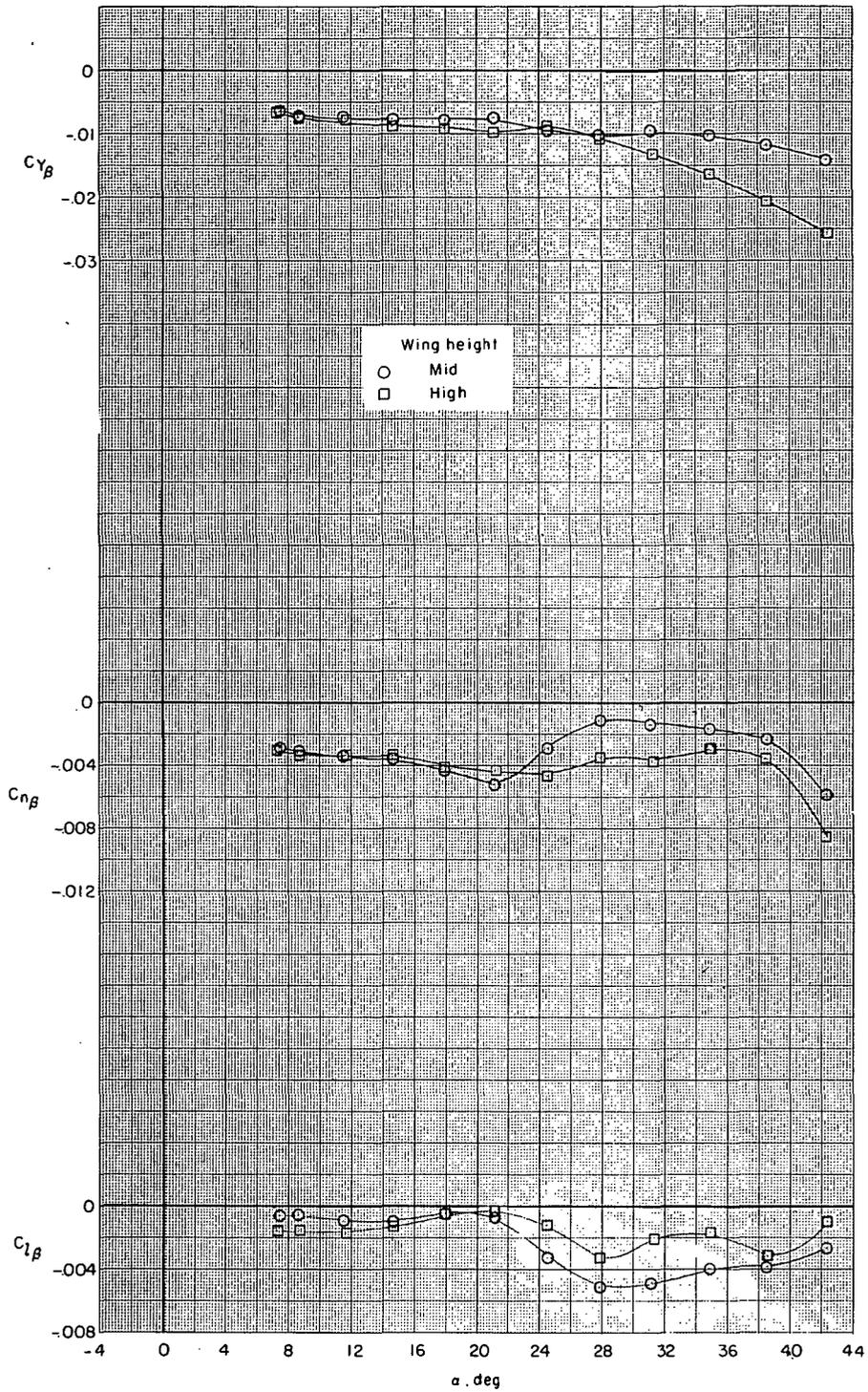


Figure 4.- Effect of wing height on the lateral-directional characteristics of the model with strake and vertical and horizontal tails off.

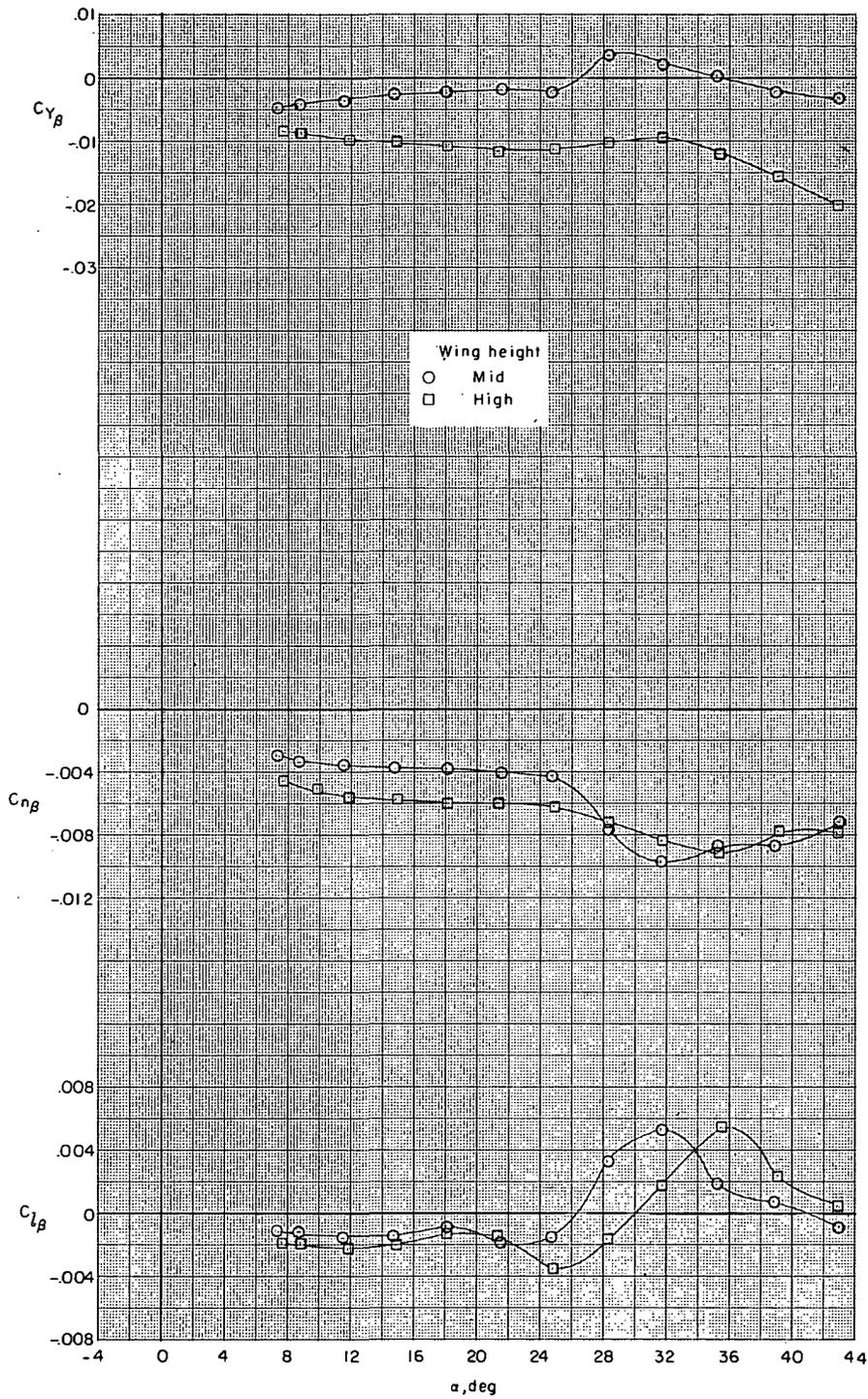
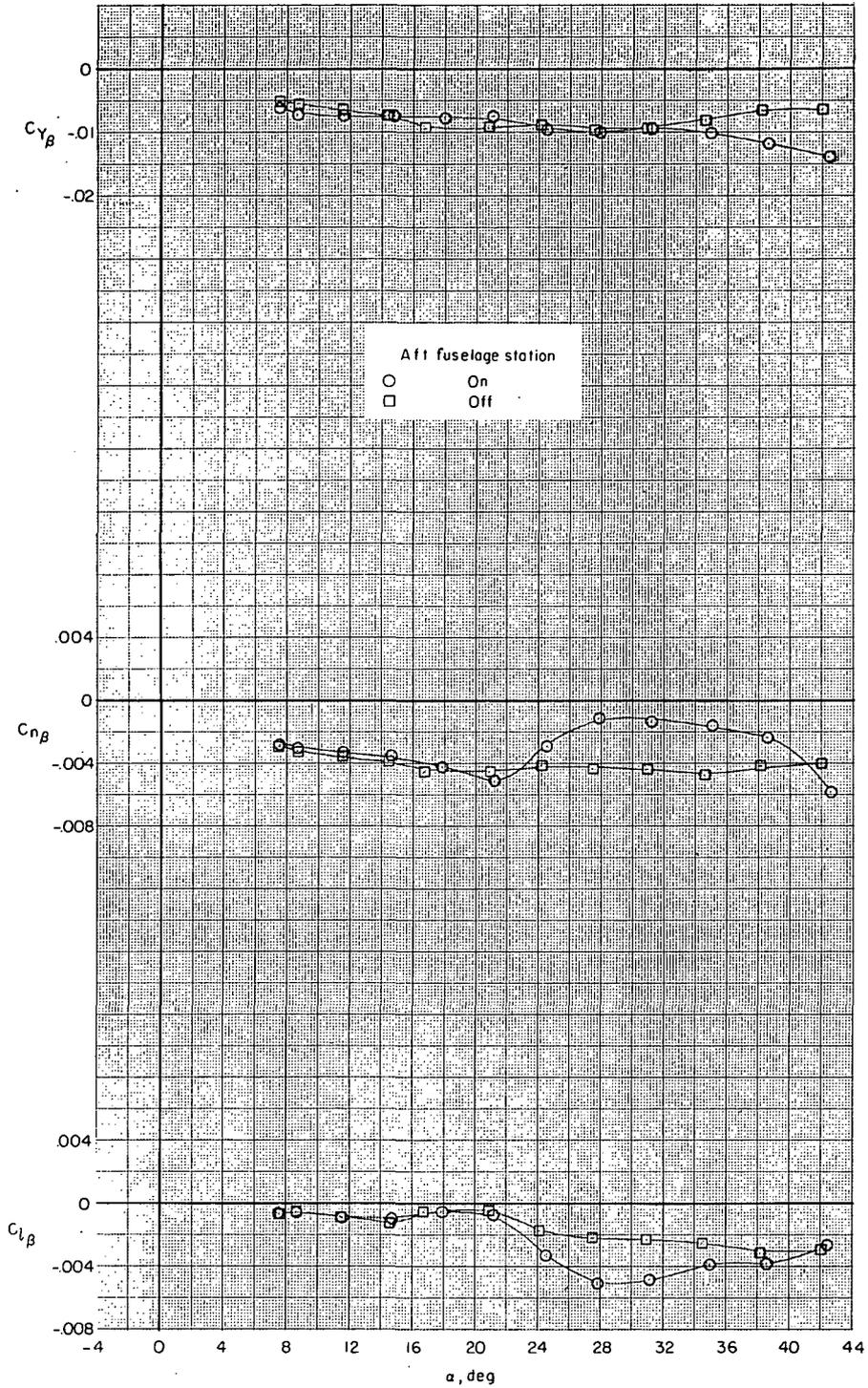
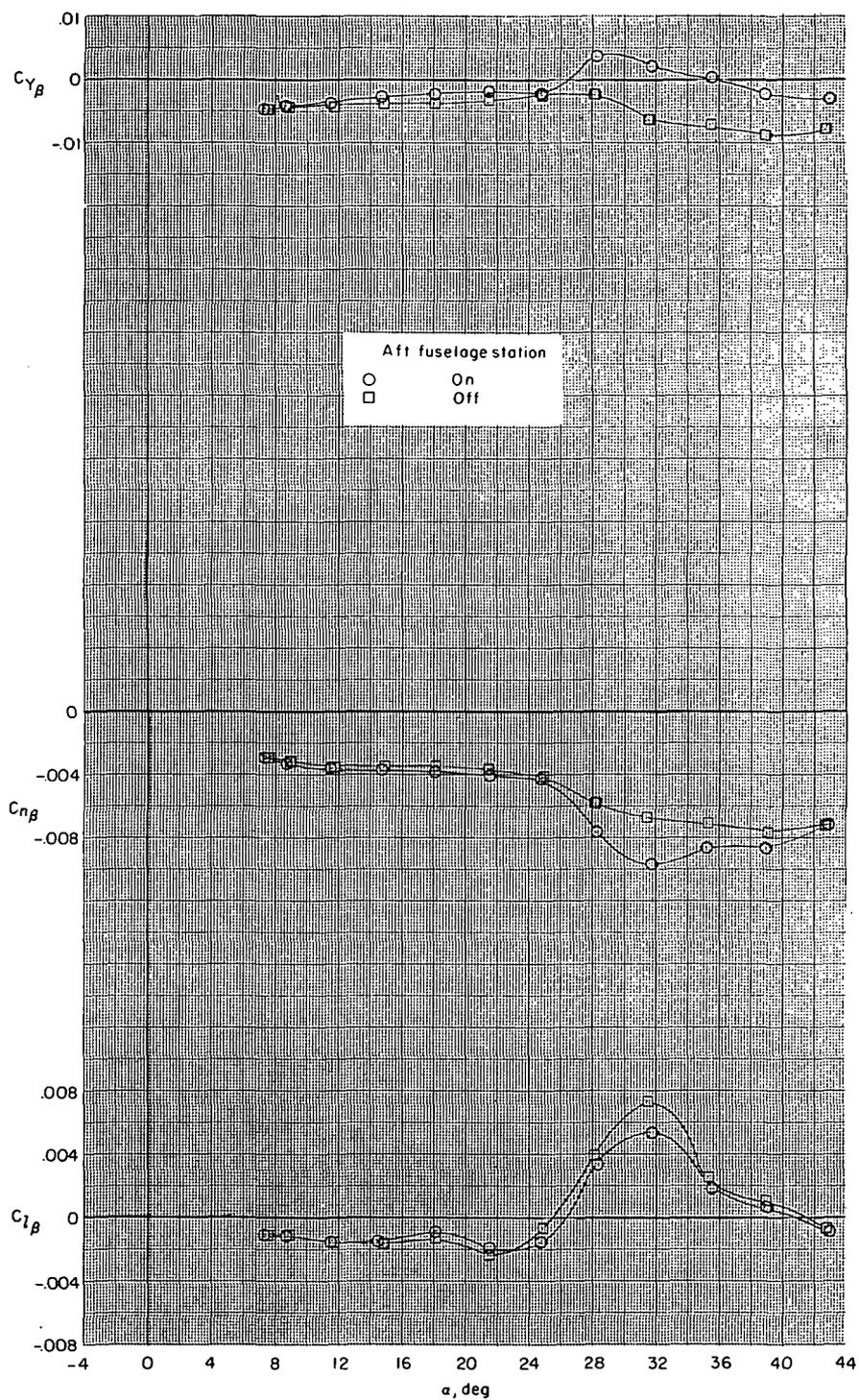


Figure 5.- Effect of wing height on the lateral-directional characteristics of the model with strake on and vertical and horizontal tails off.



(a) Strake off.

Figure 6.- Effect of afterbody on the lateral-directional characteristics of the model with mid wing location and vertical and horizontal tails off.



(b) Strake on.

Figure 6.- Concluded.

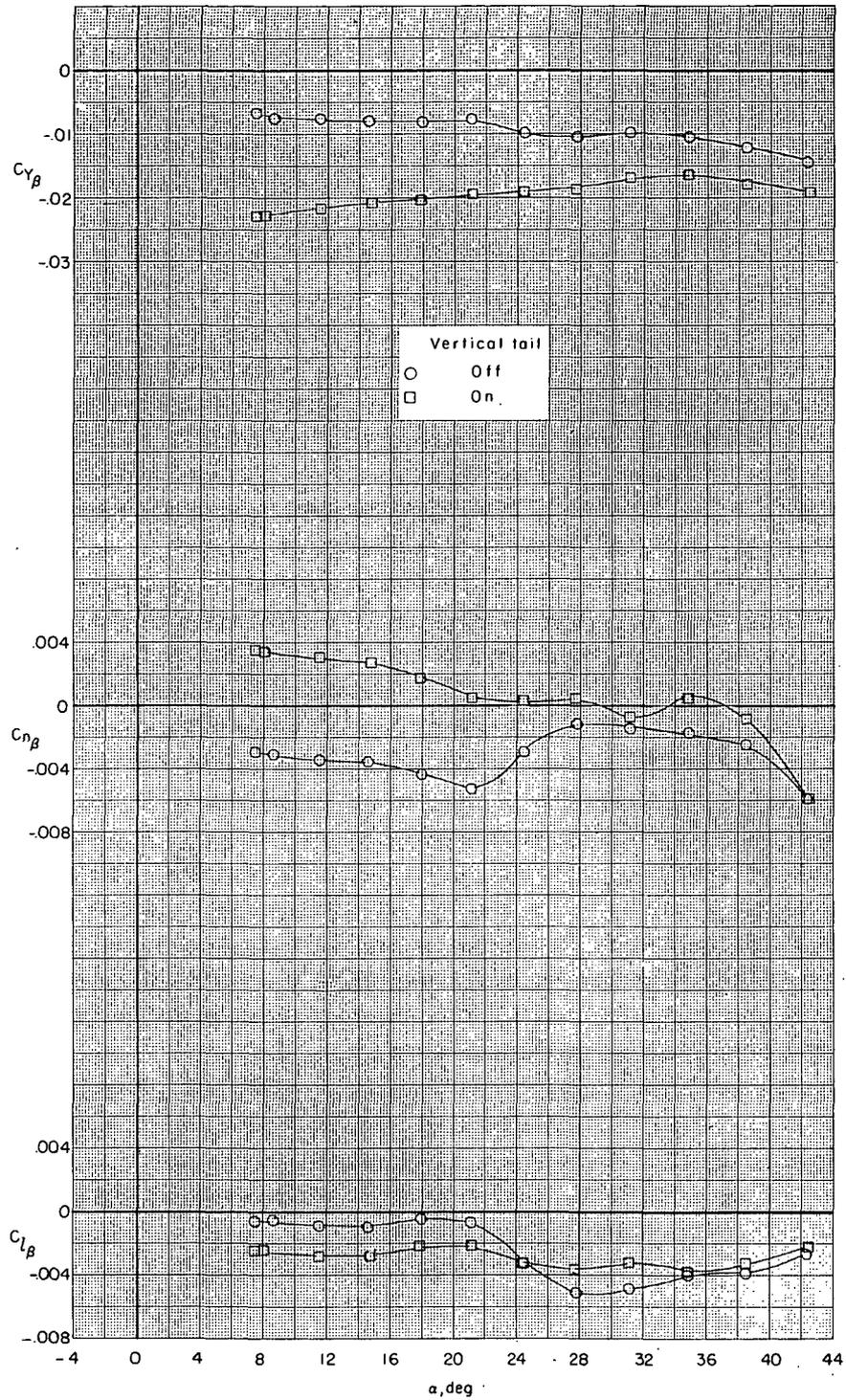


Figure 7.- Effect of center vertical tail on the lateral-directional characteristics of the model with mid wing location and with strake and horizontal tails off. Vertical tail located in row A.

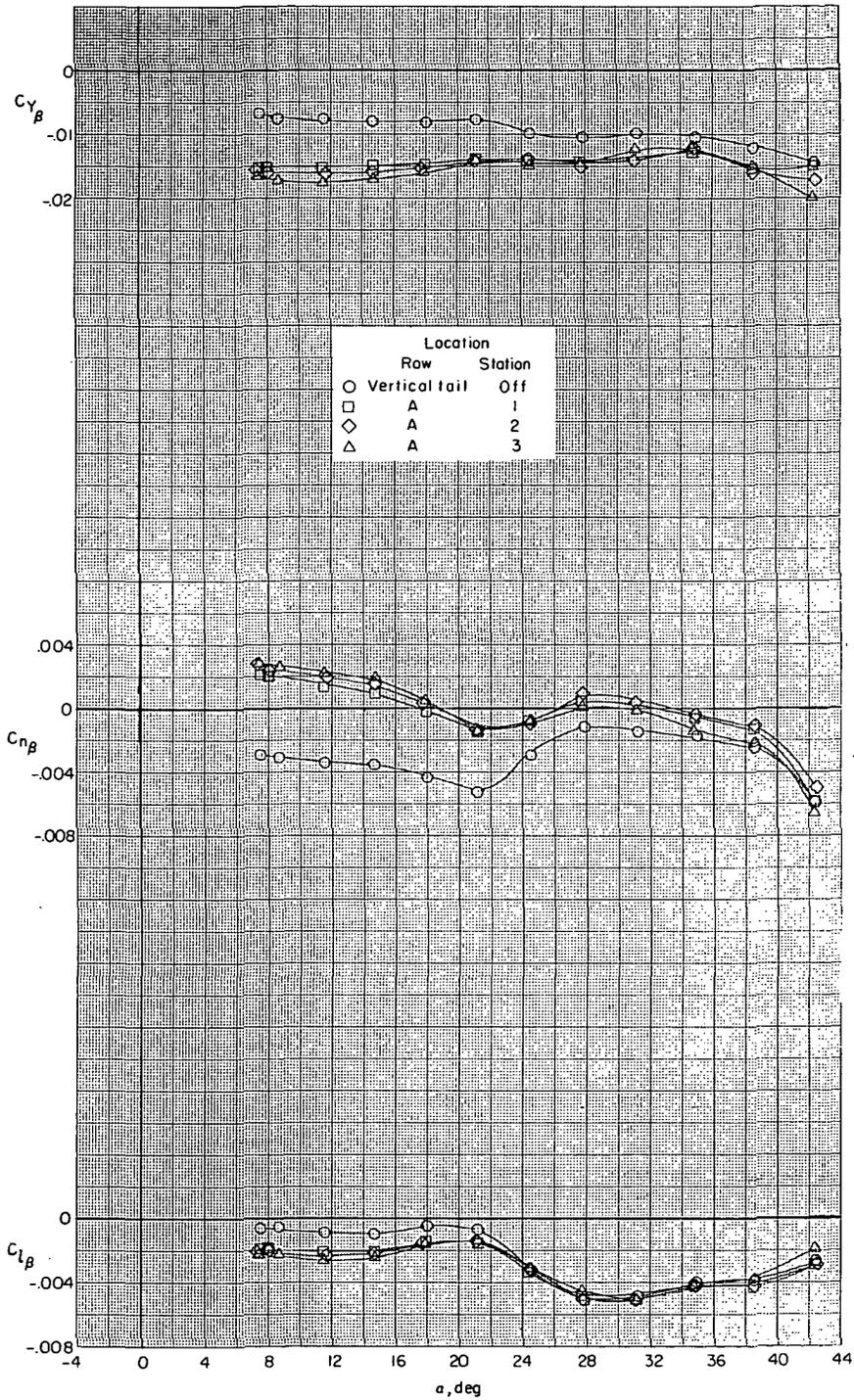


Figure 8.- Effect of location of the twin vertical tails on the lateral-directional characteristics of the model with mid wing location and with strake and horizontal tails off.

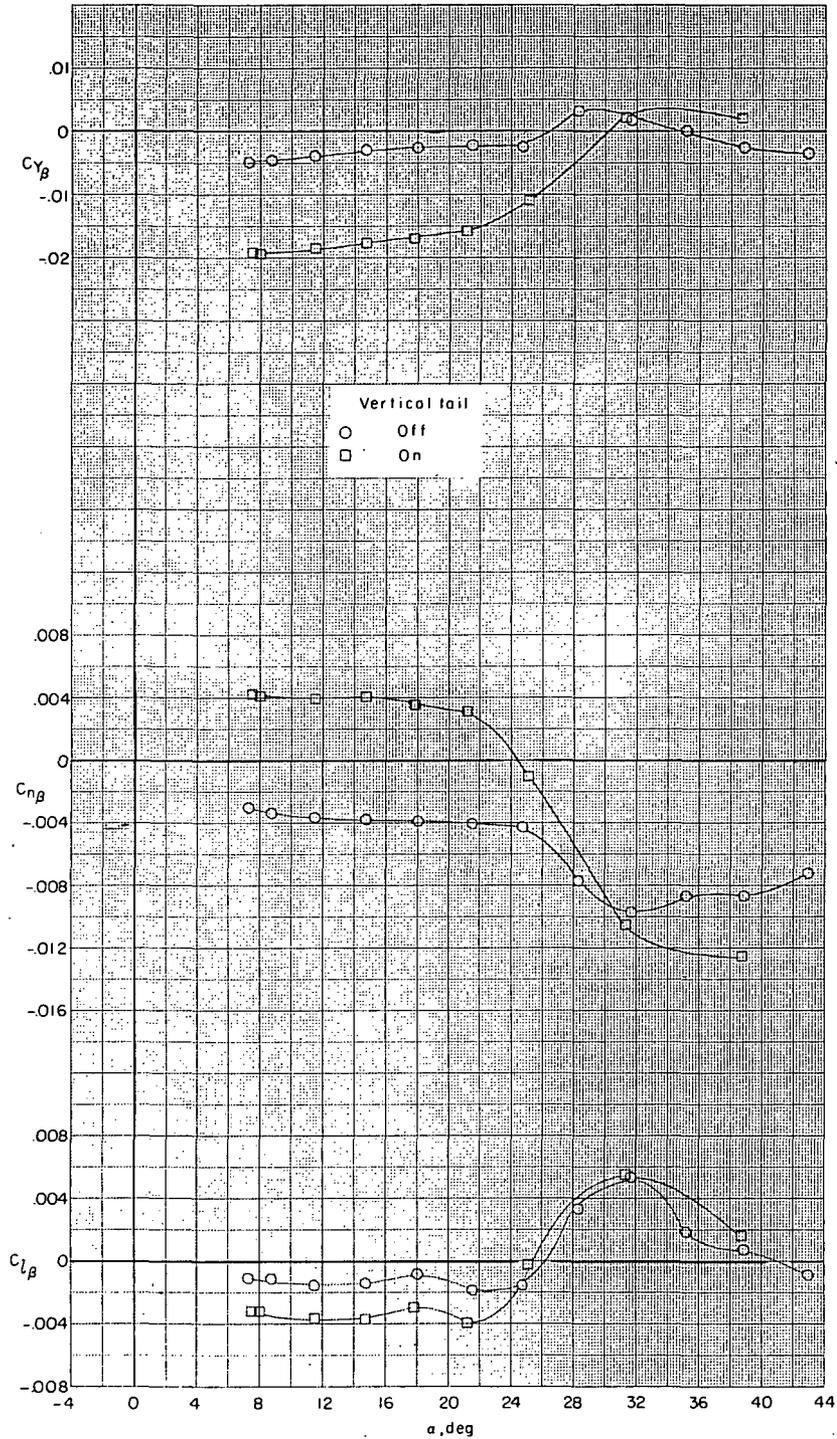
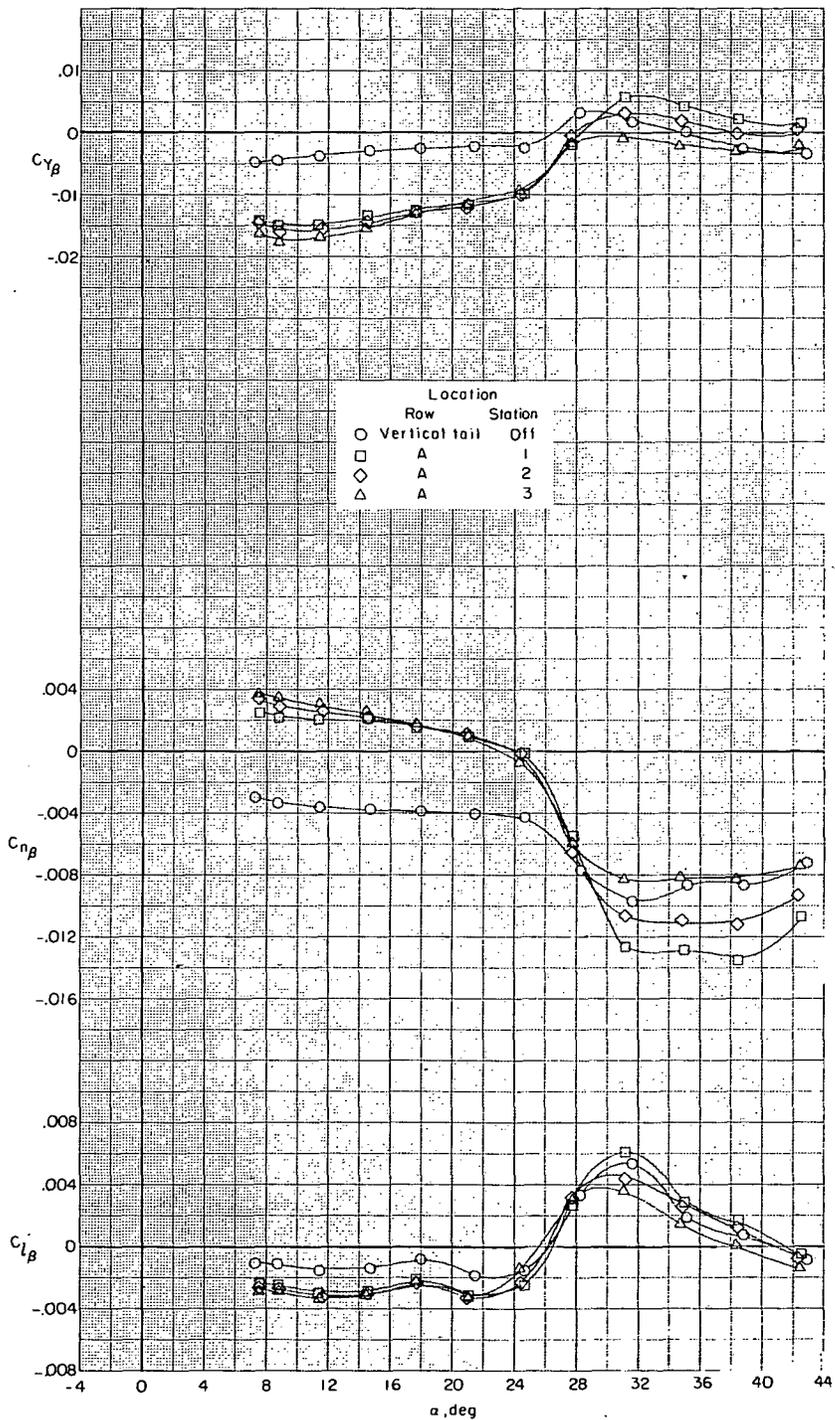
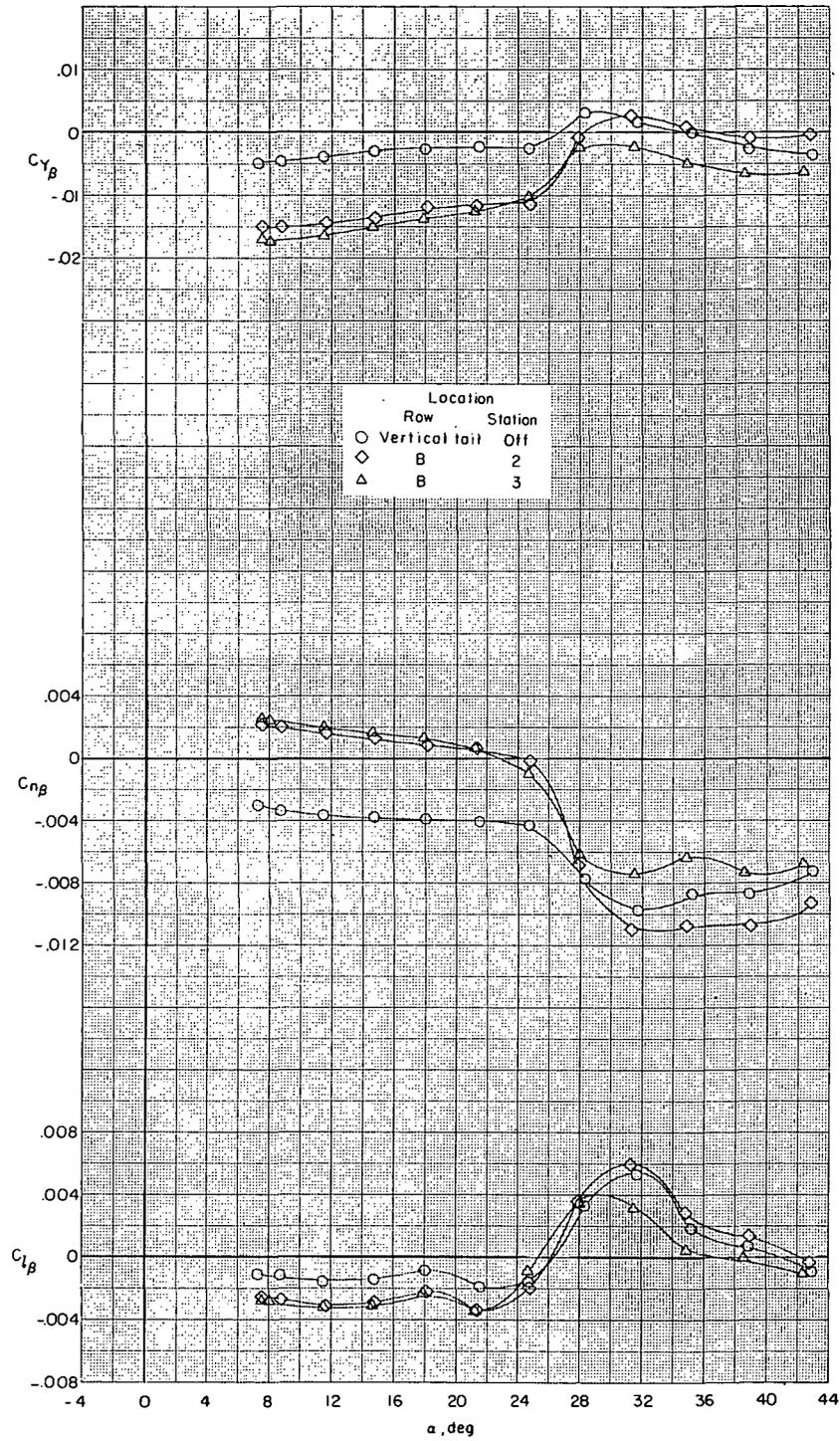


Figure 9.- Effect of center vertical tail on the lateral-directional characteristics of the model with mid wing location and with strake on and horizontal tails off. Vertical tail located in row A.



(a) Twin vertical tails located in row A.

Figure 10.- Effect of spanwise location of the twin vertical tails on the lateral-directional characteristics of the model with mid wing location and with strake on and horizontal tails off.



(b) Twin vertical tails located in row B.

Figure 10.- Concluded.

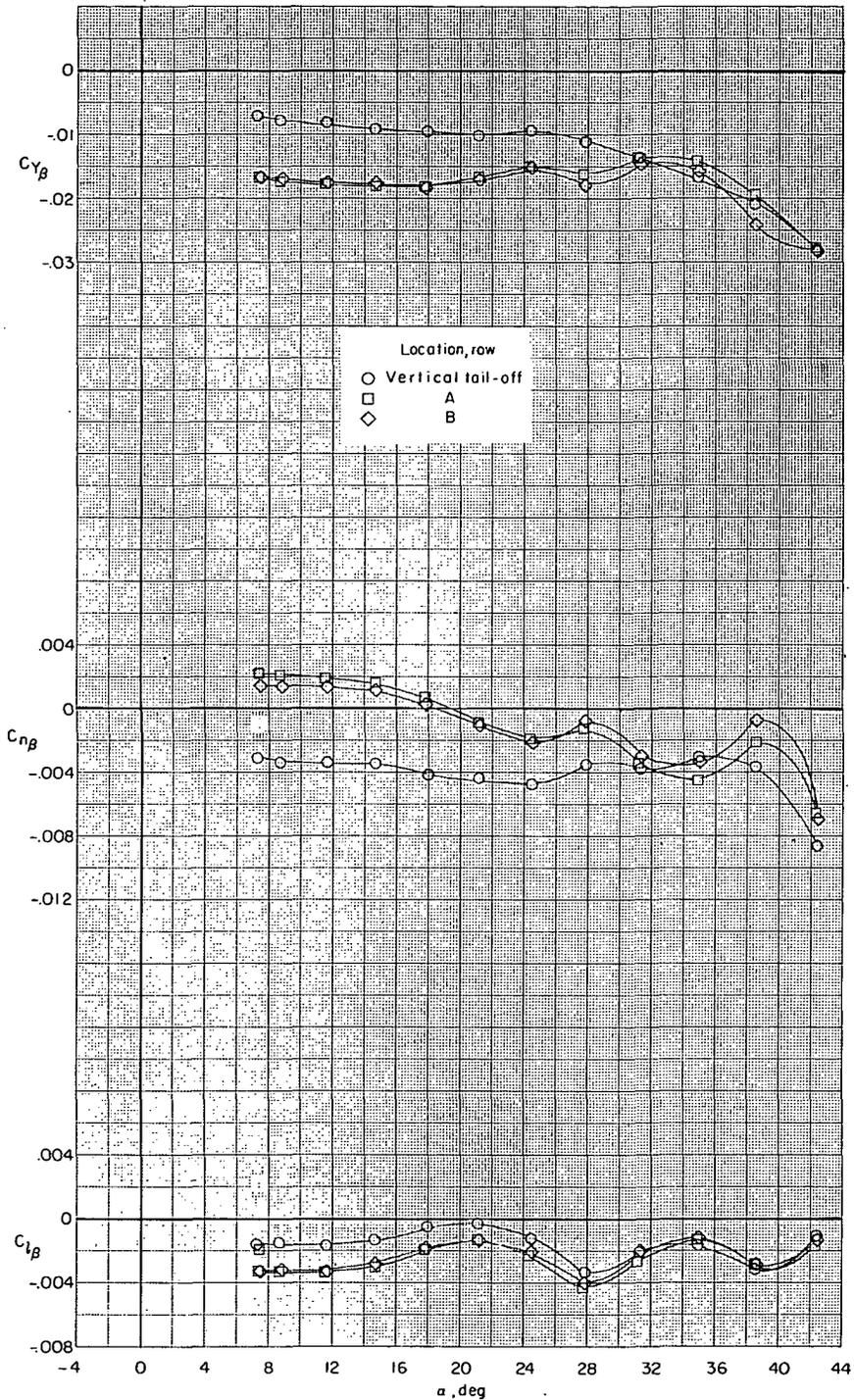
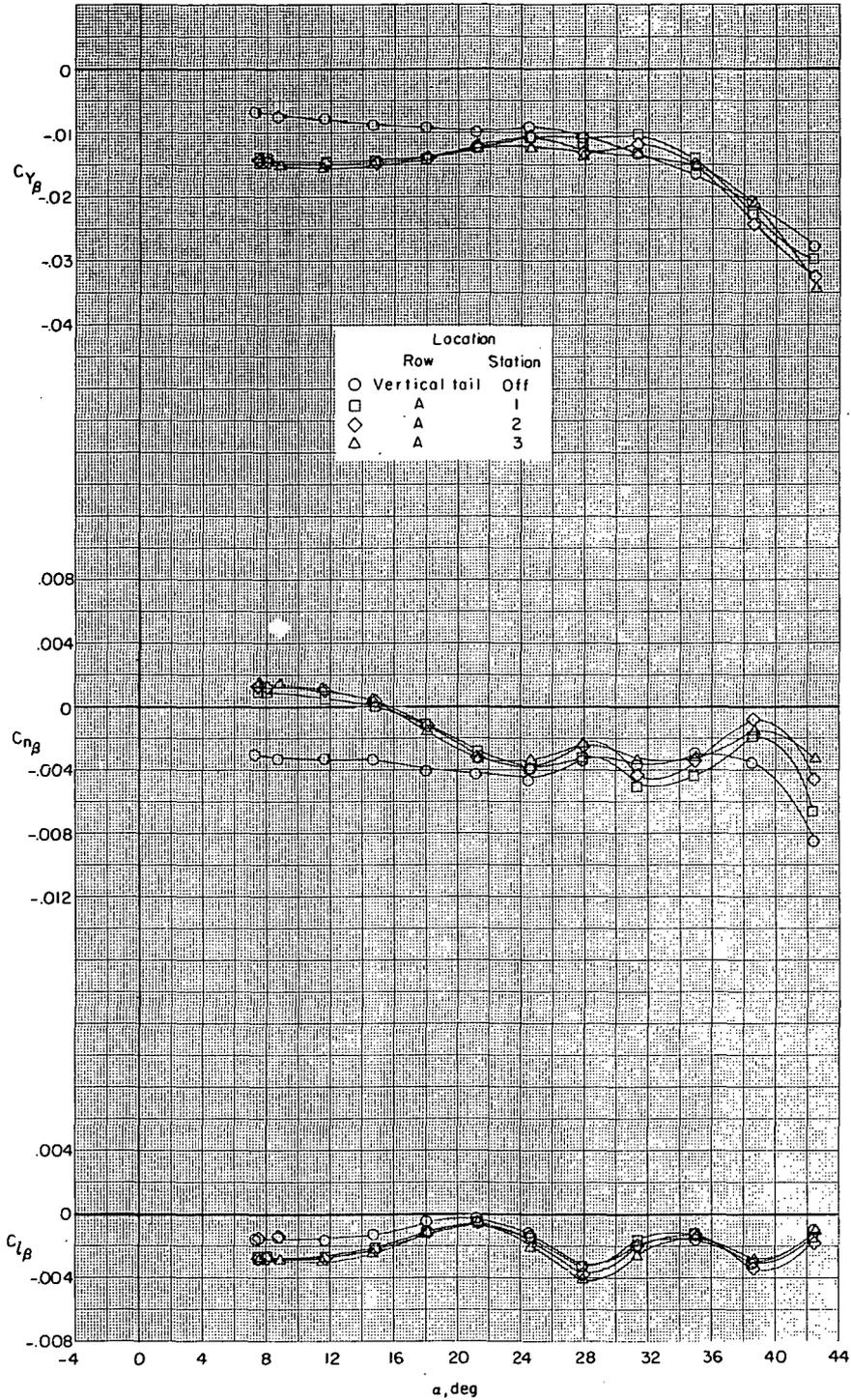
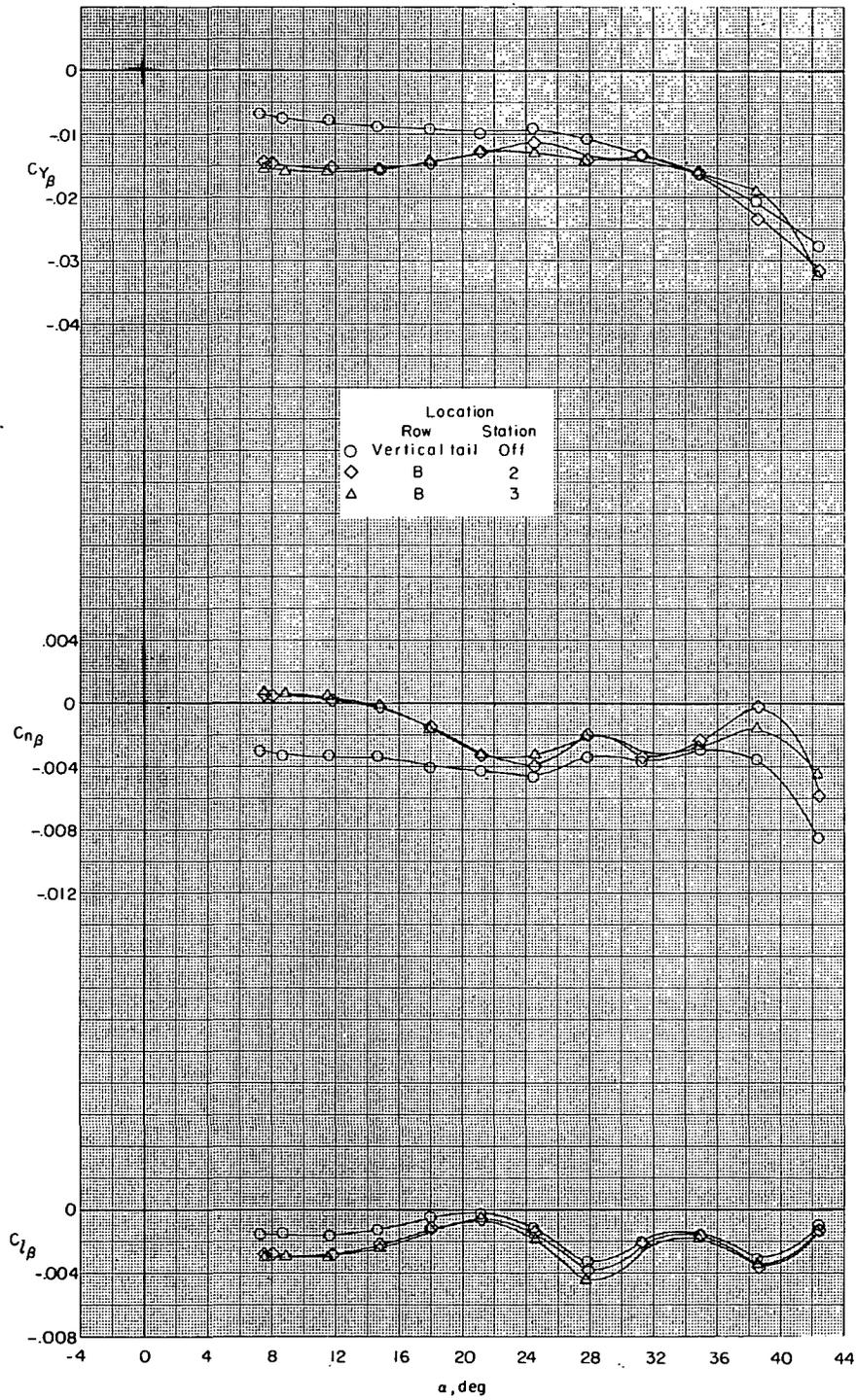


Figure 11.- Effect of center vertical-tail location on the lateral-directional characteristics of the model with high wing location and with strake and horizontal tails off.



(a) Twin vertical tails located in row A.

Figure 12.- Effect of spanwise location of the twin vertical tails on the lateral-directional characteristics of the model with high wing location and with strake and horizontal tails off.



(b) Twin vertical tails located in row B.

Figure 12.- Concluded.

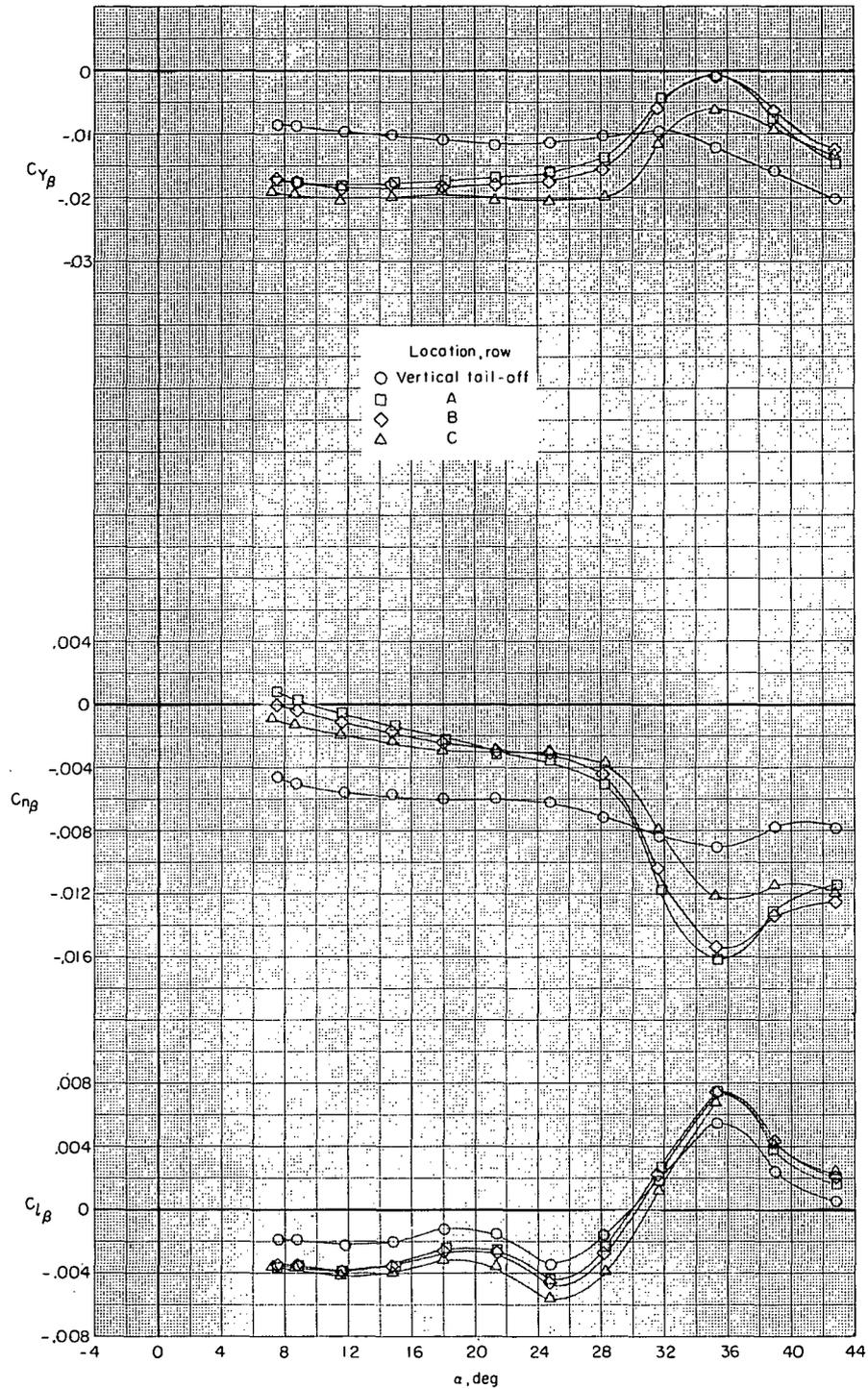
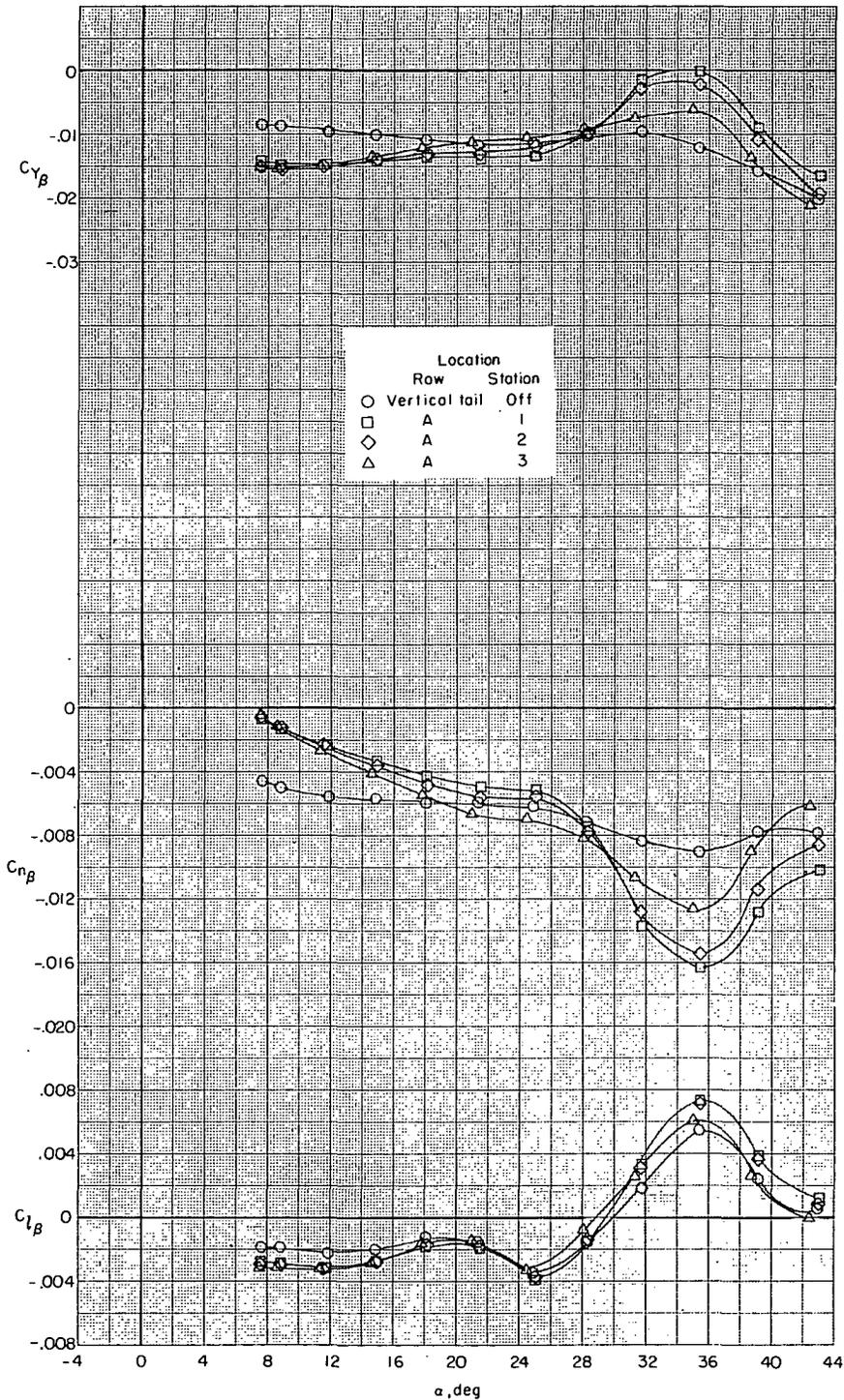
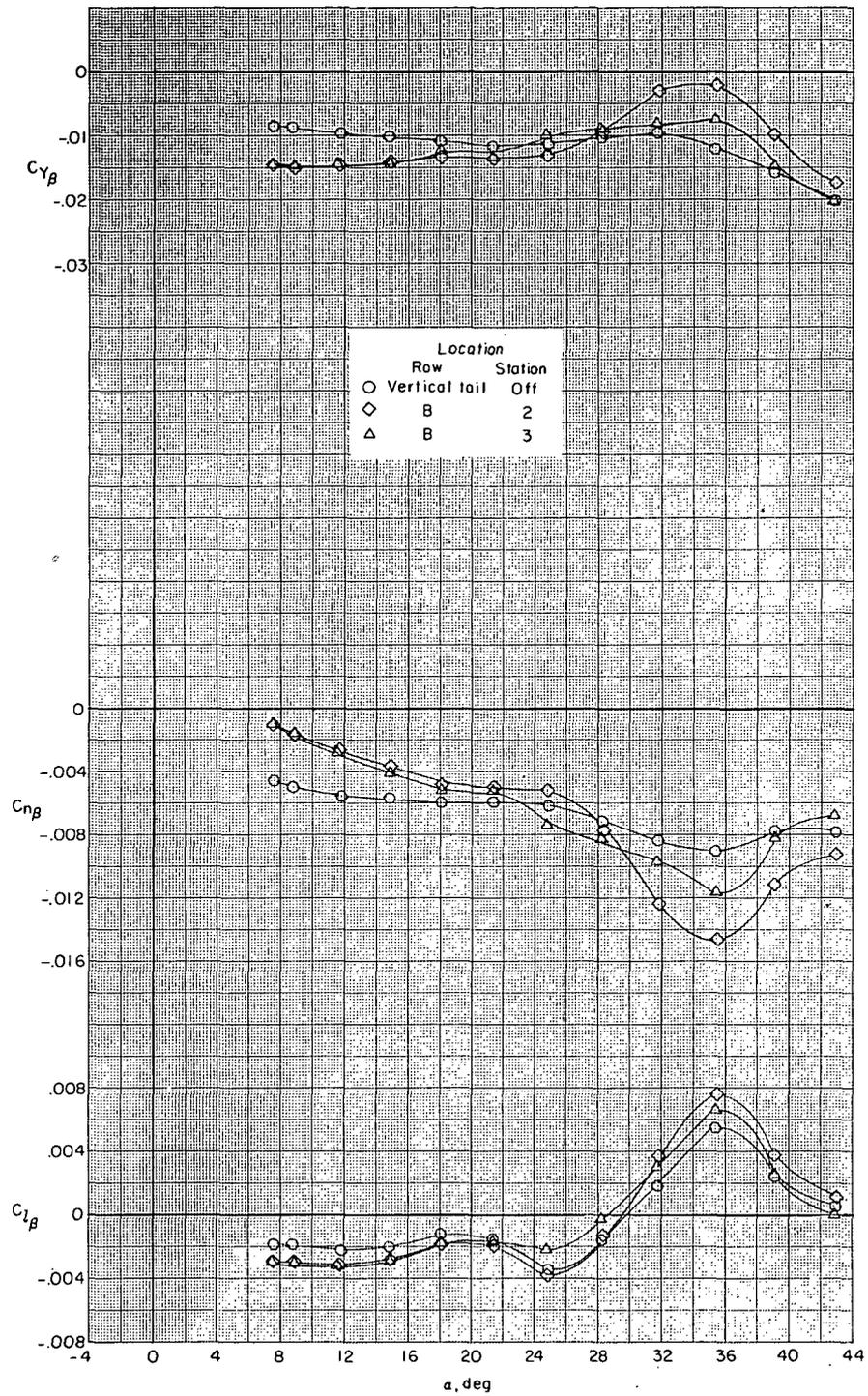


Figure 13.- Effect of center vertical-tail location on the lateral-directional characteristics of the model with high wing location and with strake on and horizontal tails off.



(a) Twin vertical tails located in row A.

Figure 14.- Effect of spanwise location of the twin vertical tails on the lateral-directional characteristics of the model with high wing location and with strake on and horizontal tails off.



(b) Twin vertical tails located in row B.

Figure 14.- Concluded.

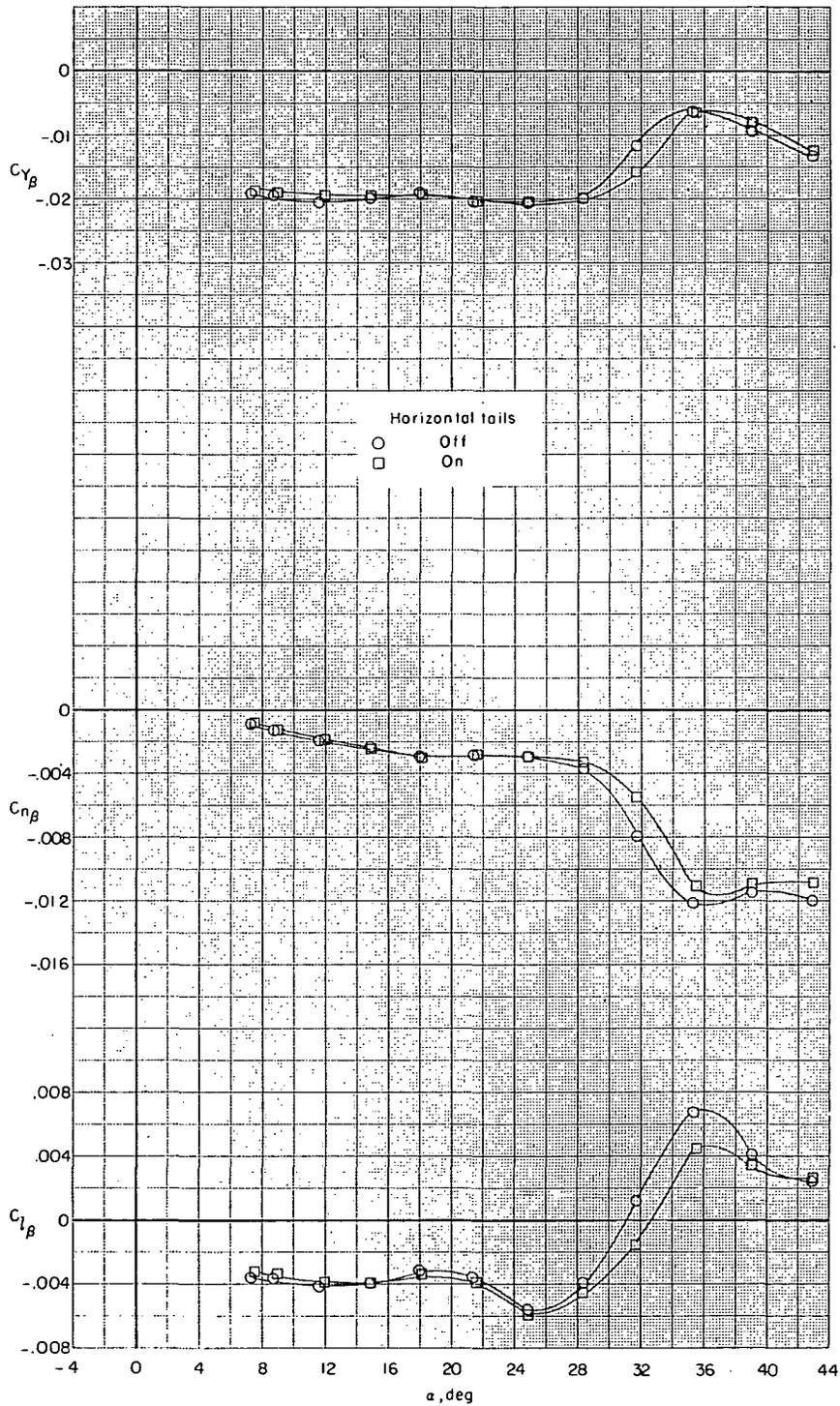
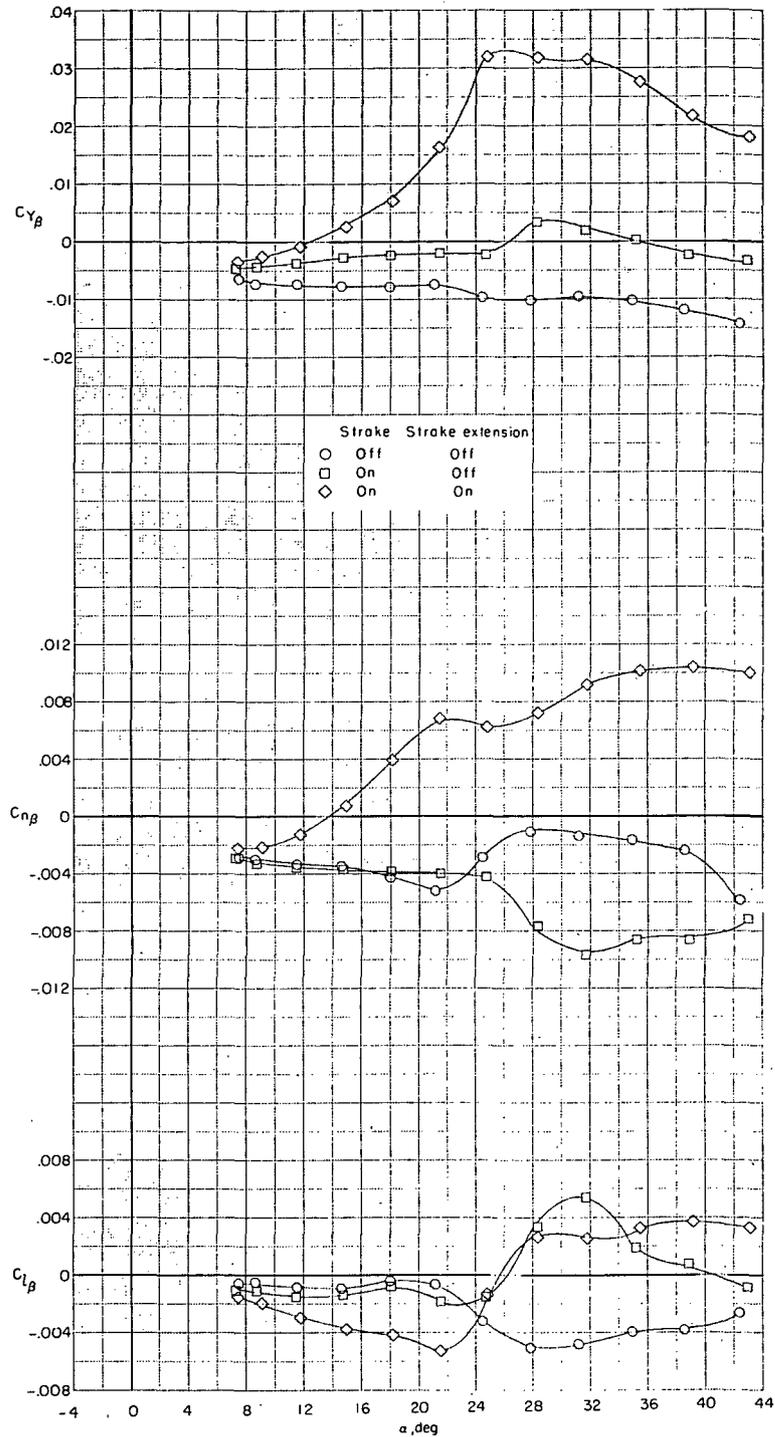
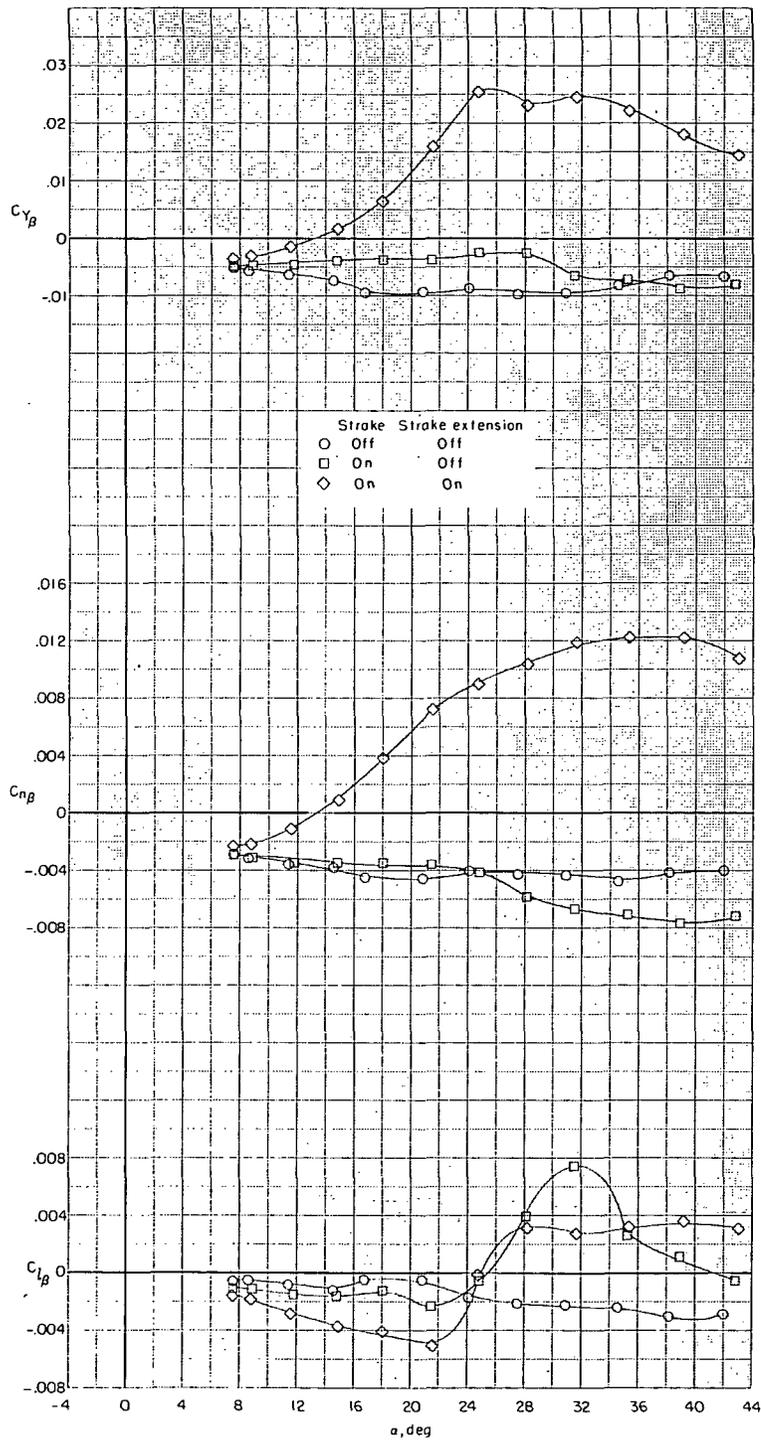


Figure 15.- Effect of horizontal tail on the lateral-directional characteristics of the model with high wing location and with strake on. Center vertical tail located in row C.



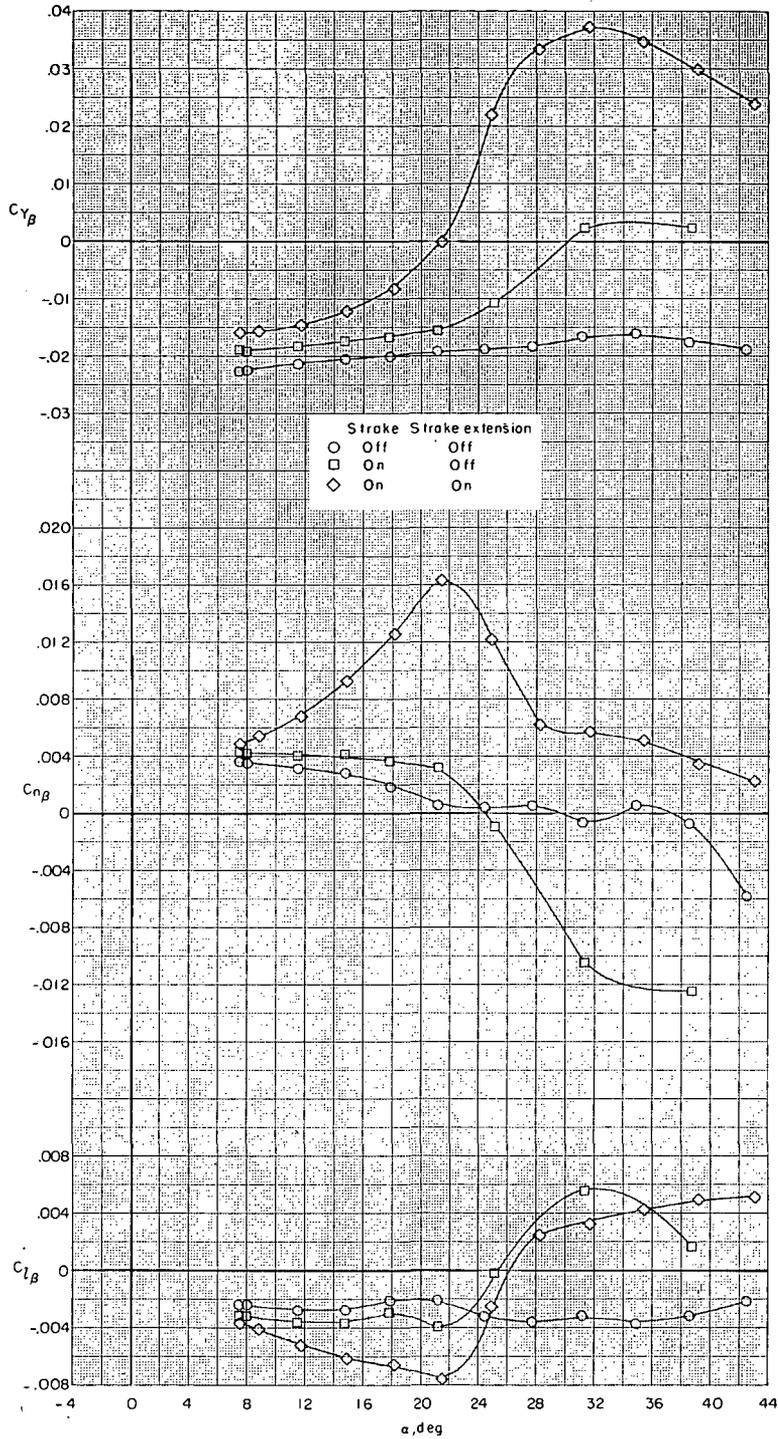
(a) Vertical tail off and afterbody on.

Figure 16.- Effect of wing-fuselage strake on the lateral-directional characteristics of the model with mid wing location and with horizontal tails off.



(b) Vertical tail off and afterbody off.

Figure 16.- Continued.



(c) Center vertical tail located in row C and afterbody on.

Figure 16.- Concluded.



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