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RESEARCH MEMORANDUM

THE ORIGIN AND DISTRIBUTION OF SUPERSONIC STORE INTERFERENCE FROM MEASUREMENT OF INDIVIDUAL FORCES ON SEVERAL WING-FUSELAGE-STORE CONFIGURATIONS

I.- SWEPT-WING HEAVY-BOMBER CONFIGURATION WITH LARGE STORE (NACELLE). LIFT AND DRAG; MACH NUMBER, 1.61

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NATIONAL ADVISORY COMMITTEE
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SUMMARY

A supersonic wind-tunnel investigation of the origin and distribution of store interference has been performed in the Langley 4- by 4-foot supersonic pressure tunnel at $M = 1.6$ in which separate forces on a store, a fuselage, a swept wing, and a swept-wing—fuselage combination were measured. The store was separately sting-mounted on its own six-component internal balance and was traversed through a wide systematic range of spanwise, chordwise, and vertical positions. The configuration investigated simulated a heavy bomber-type airplane with a large store which also represented a nacelle having frontal area equivalent to a twin-engine nacelle.

Large changes in store and wing-fuselage drag may occur with small changes in store position - either spanwise, chordwise, or vertically. The interference drag of the store in the presence of the wing or fuselage is explained in a qualitative (and to some extent quantitative) way from consideration of the pressure field of the wing or fuselage and the resultant buoyant forces on the store. The store interference drag measured in the presence of the wing-fuselage combination compares favorably with the sum of the store interference drags measured in the presence of fuselage alone and in the presence of the wing alone. The interference drags of the wing and fuselage arising from the flow field of the store are similarly explained from considerations of the position of the wing and fuselage in the pressure field of the store. The fact that in most store positions investigated the simple buoyancy considerations were useful indicates that reflected disturbances and the possible presence of local choking between components did not materially contribute to the interference.

Store positions for which high drag is encountered by the store are the same positions, in general, for which high drag is also encountered by the wing-fuselage combination. The same is true, in general, for store positions for low drag.

No consistent correlation was obtained between the drags of the complete configuration and a visual inspection of the area diagrams for these configurations determined according to the supersonic area-rule concept.

INTRODUCTION

Research on external stores and nacelles to date has shown that, although favorable interference has been found for some configurations, the performance penalties incurred with other configurations can be very large. Also, the interference involved is complicated and difficult to generalize. Reference 1, in which a large amount of recent transonic and supersonic stores work is referenced and analyzed shows that total interference drags due to the presence of the store of up to 4 to 5 times the free-air store drags have been incurred in many investigations. This reference further shows that, with the exception of a limited area-rule correlation presented therein, little qualitative or quantitative design criteria are available. The conclusion was also reached in reference 1 that the details of the configurations and of the flow and the local interference between the components were important and that attention must therefore be given to detail design of the components, junctures, and so forth, as well as to area-rule considerations.

The development of useful design criteria is hampered by the fact that the many configurations investigated to date are largely unrelated and by the fact that the ranges of store positions tested are often very limited. Furthermore, little or no force breakdown data have been obtained from which the source and distribution of interference might be understood.

In recognition of the need for stores data more general in nature and more useful to designers in both a qualitative and quantitative way, a detailed investigation of stores interference at supersonic speeds has been undertaken in the Langley 4- by 4-foot supersonic pressure tunnel. Reference 2 (see also the references listed therein) covers one phase of this work, involving calculation and measurement of interference forces on a parabolic body in the relatively simple flow field of a reflection plate. An experimental approach aimed at obtaining experimental information on several generalized aircraft configurations has also been initiated. In this program (the results of which will be published in several papers), the individual forces and moments (six components) have been measured on various sting-mounted stores in the vicinity of several wing, fuselage, and wing-fuselage configurations, for which individual forces and moments (three components) are also simultaneously measured. Force breakdown data were thus obtained from which the origin of interference could be determined. A wide range of store positions was covered, whether of "practical" interest or not, in order to show trends and magnitudes of interference for a large part of the airplane flow field. Some effects of fuselage shape, wing plan form, store shape, size, and fins were investigated. Most of the tests were performed at a Mach number of 1.6, with some additional tests at a Mach number of 2.

The present report presents the first part of the results of this experimental investigation - the lift and drag at a Mach number of 1.6 on a store, a fuselage, a wing, and a wing-fuselage combination. The wing-fuselage configuration simulates a swept-wing heavy bomber, whereas the store represents a twin-engine (equivalent frontal area) nacelle (with no provision for internal flow) or a very large external store. The data are presented with a somewhat limited "illustrative" analysis in order to expedite publication.

SYMBOLS

C_L lift coefficient of fuselage, wing, or wing-fuselage combination as noted, Lift/qS

C_D drag coefficient of fuselage, wing, or wing-fuselage combination as noted, Drag/qS

C_{L_s} lift coefficient of store, Lift/qF

C_{D_s} drag coefficient of store, Drag/qF

$C_{D_{su}}$ drag coefficient of store, uncorrected for store base drag

$C_{D_{B_s}}$ base drag coefficient of store, $P_{B_s} \frac{A}{F}$

C_{L_t} total lift coefficient of complete configuration (wing fuselage plus store) based on wing area, $C_L + C_{L_s} \frac{F}{S}$

C_{D_t} total drag coefficient of complete configuration (wing fuselage plus store) based on wing area, $C_D + C_{D_s} \frac{F}{S}$

P pressure coefficient, $\frac{p - p_o}{q}$

P_{B_s}	pressure coefficient on store base, $\frac{p - p_o}{q}$
S	total area of wing semispan, 0.5 sq ft
F	maximum frontal area of store, 0.0123 sq ft
S/F	ratio of wing area to store maximum frontal area, 40.6
A	area of store base, 0.005 sq ft
q	dynamic pressure, lb/sq ft
p	local static pressure, lb/sq ft
p_o	stream static pressure, lb/sq ft
x	chordwise position of store midpoint, measured from nose of fuselage (see fig. 1(a)), in.
y	spanwise position of store center line, measured from fuselage center line, in.
z	vertical position of store center line, measured from wing chord plane, positive downward, in.
β	cotangent of Mach angle, $\sqrt{M^2 - 1}$
θ	roll angle of cutting plane (see sketch, fig. 33(a))

APPARATUS AND TESTS

Models and Equipment

The models and the general arrangement of the test setup are shown in figure 1. Complete dimensions are given in this figure and in table I. The wing-fuselage combination was designed to simulate a swept-wing heavy bomber-type airplane. The store was sized to a frontal area equivalent to a twin-engine nacelle and simulates at the same time, of course, a large external store.

The wing and fuselage were constructed of metal and were half-models mounted on a boundary-layer bypass plate (fig. 1) $10\frac{3}{4}$ inches from the tunnel wall. A four-component strain-gage balance was housed within the plate and measured normal force, chord force, pitching moment, and rolling moment. The wing passed through a cover plate and was fastened directly to the balance. The fuselage half-model was fastened to the wing, with a clearance of approximately 0.040 inch between the fuselage plane of symmetry and the surface of the bypass plate. A special fixture was provided for mounting the fuselage for tests without the wing. The angle of attack was variable through 0° to 4° for these tests. Pressure orifices were provided on the fuselage base for measurement of base pressure.

The store was constructed of metal and was mounted on the standard support sting, which provides pitching and translational motion in the horizontal plane (the plane of the model wing in this case). The store-support equipment included a remotely operated crank by means of which the store could be rotated and thereby moved to the various vertical (z) positions with respect to the wing. (See front view, fig. 1(a).) The store and balance rotated as they moved from one height (z) to another; hence, resolution of measured forces and moments was necessary to obtain values in the vertical and horizontal planes. A six-component strain-gage internal balance was utilized in the store.

The store axial or chordwise location was varied by changing the length of the support sting during shutdown between tunnel runs (fig. 1(a)). Store base pressure was obtained by measurement of the pressure in the store-balance cavity.

The tests were performed in the Langley 4- by 4-foot supersonic pressure tunnel at Mach numbers of 1.6 and 2.0 and at Reynolds numbers per foot of 4.20×10^{6} and 3.62×10^{6}, respectively. This report presents only lift and drag at $M = 1.6$ on the store, the wing, the fuselage, and the wing-fuselage combination described above.

Tests and Methods

The range of positions through which the store was varied are shown in figure 1(a). For each run, the store was located at one chordwise (x) position, its spanwise and vertical location changed to discrete spanwise and vertical positions (y and z) shown by the grid in figure 1(a). The forces and base pressures on the models at each position were recorded. The angle of attack of the wing-fuselage model was 0° except at one vertical position ($z = 2.09$) at which measurements were also made with wing-fuselage angles of attack of 2° and 4°. The angle of attack of the store remained at zero for all measurements except the store-alone pitch tests.

The store was pitched in the horizontal plane from $\alpha = 0^{\circ}$ to $\alpha = 10^{\circ}$ in an interference-free position to obtain the force characteristics of the store alone. The wing, fuselage, and wing-fuselage combination were also pitched under interference-free conditions to obtain the basic data on these components.

The store was run in conjunction with fuselage, wing, and wing-fuselage in all the spanwise positions shown in figure 1(a) and at the chordwise and vertical positions shown in the following table:

Configuration	Chordwise position, x, in.	Vertical position, z, in.
Store with fuselage	6, 12, 18, 27, and 33	1.15, 1.67, and 2.09
Store with wing	18, 21, 24, 27, 30, and 33	1.15, 1.67, and 2.09
Store with wing and fuselage	6, 12, 18, 21, 24, 27, 30, and 33	1.15, 1.67, 2.09, and -1.31

A 1/4 inch wide strip of number 60 carborundum grains and shellac was located for all tests on both surfaces of the wing at the 10-percent chord point, on the fuselage nose 1/2 inch from the tip, and on the store nose 1/4 inch from the tip in order to insure boundary-layer transition from laminar to turbulent.

Support Interference

Measurements of static pressures were made on the surface of the boundary-layer bypass plate with wing and fuselage removed. The measurements indicated that there were no disturbances at the surface of the plate and that the Mach number was uniform and equal to the tunnel Mach number. The ability of this technique to reproduce the data obtained on full-span models is demonstrated in reference 3.

It will be noted from examination of figure 1 that the sting shown supporting the store in the most forward location is in a position to produce a flow field that interferes with the fuselage afterbody and wing tip. This sting was used for store positions $x = 6$, 12, and 18, whereas shorter stings (as shown for the rearward store position in fig. 1(a)) were used for all other values of x. The magnitude of the interference of the store sting on the fuselage drag will be shown later in the discussion section entitled, "Drag of Fuselage in Presence of Store." The fuselage and wing-fuselage data points forward of $x = 18$ have been connected with dashed lines in the basic-data figures to indicate that interference is present in an amount indicated to be small (relative to the drag of the wing-fuselage combination) but is not accurately known. The store data are unaffected by this interference.

Some interference is also present in the wing and fuselage data as a result of the proximity of the cylindrical portion of the sting (supporting the store) to the wing and fuselage. Inasmuch as this sting is cylindrical and relatively small in diameter, it is believed that these effects are negligible. Examination of the data provides evidence supporting this conclusion.

The effect of the store-support sting on store drag (exclusive of base drag) is shown in reference 4 and others to be negligible at the supersonic Mach numbers of the present tests. The store base pressure is shown in reference 5 to be somewhat more negative as a result of interference of a sting of the size used in this case.

The foregoing considerations of interference and support effects and examination of the data obtained indicates that the forces measured are essentially free (except as noted) of extraneous interferences due to the support systems used.

Precision of Test Data

Inasmuch as this report is concerned mainly with changes in interference forces as the store is moved from position to position, the accuracies quoted are relative rather than absolute. The numbers listed below thus represent the ability to obtain repeat data for the same nominal test condition.

The repeatability or relative accuracies are estimated from an inspection of repeat test points and static-deflection calibrations to be as follows:

x, in. . . . . ±0.025
y, in. . . . . ±0.05
z, in. . . . . ±0.05

Store:
C_{D_S} . . . . ±0.005
C_{L_S} . . . . ±0.010
α_S, deg . . . . ±0.2

Wing-fuselage:
C_D . . . . ±0.0005
C_L . . . . ±0.005
α, deg . . . . ±0.1

RESULTS AND DISCUSSION

Basic Data

Isolated store and wing-fuselage data.- The isolated configuration components were tested so that the interference effects could be evaluated in terms of the isolated forces and in terms of equivalent angle of attack.

Figure 2(a) shows lift and drag coefficients referred to the wind axis for the store alone at angles of attack up to above 10°. As was stated in a previous section, the store was rolled as the values of vertical height z were changed. The store was consequently tested in pitch in both the plane of the pitch beam and in the plane of the side-force beam. The lift and drag data thus obtained are shown to agree within the stated accuracy of the tests.

Figure 2(b) presents the interference-free data for the wing, fuselage, and wing-fuselage combination. Lift coefficient and drag coefficient on the wind axis are shown for angles of attack from 0° to 4°. Limitations of the test apparatus prevented a greater angle-of-attack range.

Included in this figure are data showing the effect on isolated store drag of moving the store toward the boundary-layer bypass plate. In figure 2(c) store drag coefficient is plotted as a function of spanwise position. Reference 2 showed that interference of this type can be predicted by consideration of the buoyant effect of the pressure field. The store is shown in the sketch in two positions: one in which the Mach line from the nose reflects from the plate and just touches the base of the store, the other in which the conical shock angle from the store nose is substituted for the Mach line. It can be seen that the store position for which interference first occurs lies somewhere between these two extremes. This interference represents the effect of the pressure field of an image store on the store under consideration in the absence of wing and fuselage. Interference of this sort is present for the farthest inboard store positions for all data presented, but, because of its small magnitude, it has not been separately considered in the analysis which follows.

Chordwise plots of lift and drag.- The basic data are presented in figures 3 to 22 in the form of plots of lift and drag coefficients against the chordwise position of the midpoint of the store. Offset vertical and horizontal scales are used so that data for the 11 spanwise positions can be shown in a single figure. On the right and left margins the zero for each curve is identified with the line symbol corresponding to that spanwise position. On each figure is shown a sketch of the configuration involved. The spanwise and chordwise store positions at which measurements were obtained are indicated by the appropriate symbol on the grid drawn to scale below the sketch.

The nature of the flow field about a slender body suggests that a Mach line offset be used for the forces on the store in the presence of the fuselage and for the forces on the fuselage in the presence of the store. Thus, the horizontal scale is given in terms of the parameter $x - \beta y$ for the store forces and $x + \beta y$ for the fuselage forces where β is the tangent of the Mach angle. Each value of $x - \beta y$ represents a Mach line originating from the fuselage center line at x and swept back at an angle whose cotangent is β. With this type of plot there is a correspondence between force coefficients at constant $x \pm \beta y$ and, in general, peaks and valleys in the curves are alined vertically. This technique allows the curves of chordwise variation of coefficients to be faired as a "family"; thereby, a more accurate fairing between test points than would otherwise be possible is obtained.

When the wing is a part of the configuration, the flow field of the wing becomes predominant. The wing sweep angle, the taper ratio, and other three-dimensional effects become important. The Mach line sweep is near enough to the wing sweep in this case to allow both store forces in the presence of the wing or wing-fuselage and wing or wing-fuselage forces in the presence of the store to be plotted against $x - \beta y$. Because of the complex nature of the wing flow field, these plots do not exhibit the near vertical correspondence of peaks and valleys, but the technique again serves to simplify the fairing of the curves between the experimental points.

Store base drag.- The store base diameter was 64 percent of the maximum diameter. This configuration corresponds roughly to a nacelle with an open base for a jet exit. Consequently, the store-drag information has been presented with the measured drags corrected to correspond to a base pressure equal to free-stream static pressure (figs. 3, 7, and 11). The store-drag data with no correction for base-pressure applied are presented in figures 4, 8, and 12. Although the estimation of the interference drag for a closed afterbody is made difficult by the presence of large pressure gradients, it is believed that estimates can be made using flow-field considerations and methods outlined in later sections.

A comparison of corrected and uncorrected store drags is presented in figure 23 for four spanwise stations. This figure shows that the basic character of the variations is similar for both data. The uncorrected data tend, in general, to exhibit higher maximum drags and lower minimum drags. This is understandable, as will be evident from later discussion, from considerations of the presence of the store afterbody in positive or negative pressure fields.

All drag values presented in the analysis figures which follow are corrected to a base pressure equal to free-stream static pressure unless specifically labeled "uncorrected."

Contour Plots

Contour plots of drag and lift for selected configurations are presented as figures 24 to 32. These plots have been prepared from the basic data figures (figs. 3 to 22) and are constructed to show the force on the particular configuration component involved for various positions of the store midpoint. The store midpoint is the reference point (the point at which the force coefficient is plotted) for all the contour plots.

Store drag.- Figures 24 to 26 show the drag of the store (coefficient based on store frontal area) in the presence of the fuselage, wing, and wing-fuselage combination. The influence of the fuselage is shown (fig. 24) to increase or decrease the drag of the store by about 25 percent, depending upon the chordwise or spanwise position of the store. The drag contours make angles with respect to the fuselage center line which are approximately equal to the Mach angle for this Mach number. The effect of vertical displacement of the store (z) is relatively unimportant (fig. 24(b)).

The influence of the wing on the drag of the store is shown (fig. 25) to be considerably greater and increases or decreases the drag of the store by about 60 percent for the store in closest proximity to the wing ($z = 1.15$). The store midpoint locations for highest drag are those from the center of the wing to just forward of the leading edge. Forward or rearward of these positions the drag decreases rapidly. The contour lines make angles with the wing center line which are slightly greater than either the Mach angle or the angle of the wing leading edge. The spanwise attenuation of the effects of the wing is apparent. Also, from parts (a) and (b) of figure 25, the large effect of vertical displacement (between store and wing) is apparent in that both the favorable and unfavorable interferences are substantially decreased.

The influence of the wing-fuselage combination on the drag of the store is shown (fig. 26) to be somewhat less than that of the wing alone. The moderation of the influence of the wing by the fuselage in the region for maximum drag is a consequence of the fact that the fuselage interference is favorable in this region (fig. 24).

The effect of angle of attack of the wing-fuselage combination (compare figs. 26(b) and (c)) is to increase the store drag generally and to shift the location of the peak drags rearward.

Figure 27 shows, for comparison with figure 26, the drag of the store (in the presence of the wing-fuselage combination) with no base-pressure correction applied. The maximum drag is shown to be increased by omission of the correction, and the high-drag contours ($C_D = 0.38$, for example) extended to nearly the full span of the wing. This high-drag region corresponds to store position from which the store base is beneath the afterportion of the wing chord, at which point very large suction pressures are produced by the wing. This point will be discussed more fully in a later section entitled "Analysis."

Wing and fuselage drag.- The drags of the fuselage, wing, and wing-fuselage combination (coefficients based on wing area) in the presence of the store are shown in figures 28 to 30. Contours for store positions forward of $x = 18$ have been omitted because of the presence of interference of the store sting, as discussed earlier. The drag coefficient of the fuselage (fig. 28) is seen to vary approximately ± 0.001 or about 20 percent from the isolated value (about 0.0050). This variation in drag is equivalent to about two-thirds of that produced by the fuselage on the store. (The ratio of wing area to store frontal area is 40.6.)

The effects of the store on the drag of the wing (fig. 29) are shown to be about 50 percent larger than that of the store on the fuselage. The region for unfavorable interference is the region covered by the inboard half of the wing.

The effects of the store on the drag coefficient of the wing-fuselage combination are shown (fig. 30) to be somewhat greater than the effects of the store on either the wing or fuselage alone. The store-midpoint positions for high drag are similar to those for the wing alone.

A comparison of figures 30 and 26 shows that the effects of the store on wing-fuselage drag are approximately equal to the effects of the wing-fuselage on store drag (taking into account the fact that the store and wing-fuselage drag coefficients are based on different areas). Also, store positions at which drag of the store is high (or low) are also those at which drag of the wing-fuselage combination is high (or low). Thus, the additive nature of the interference can be expected to produce drag values for the complete configuration which are considerably higher and lower than the free-air values.

Figure 31 shows the total drags for the complete configuration (wing fuselage plus store). The total drag of the complete configuration varies from 0.035 to 0.023, depending upon the position of the store. Inasmuch as the sum of the drag coefficients of the isolated wing-fuselage combination and isolated store total 0.0276, these numbers correspond to an increase of 27 percent and a decrease of 17 percent from the interference-free value as a result of mutual interference.

The positions of highest drag are, as before, in the region of the inboard portion of the wing. Forward and back of this region, the drag drops rapidly to below the interference-free value. In the region of the wing tip, in contrast to the more inboard regions, the mutual interferences of store and wing-fuselage effectively cancel to give essentially interference-free values of drag.

Increasing the vertical displacement between store and wing ($z = 2.09$) materially reduces the value of total drag of the configuration with the store in the region of the wing root. Changing the angle of attack to 4° (fig. 31(c)) raises the level of total drag by about 0.010, by virture of the drag due to lift, with the interference increments and regions remaining approximately the same.

Lift.- Figure 32 shows that the total lift of the complete configuration is positive over most of the range of store positions and is at a maximum equivalent to the lift produced by an angle of attack of about $1\frac{1}{2}^{\circ}$. (See fig. 2.) At the store position for which the maximum favorable total lift interference was produced (fig. 22(a)), the store contributed lift equal to that produced by a store angle of attack of 4.6° (fig. 14(a)), which, however is only 6 percent of the total interference lift produced. The lift is little affected by store vertical displacement (z), (fig. 32(b)). At $\alpha = 4^{\circ}$ (fig. 32(c)), the general level of the lift values shown is raised because of wing lift, but the interference picture remains essentially the same.

ANALYSIS

Area-Rule Analysis

The supersonic area rule as advanced by Whitcomb and Jones offers a method of dealing with a complicated interference problem, in its basic premise that the drag of a whole configuration is equal to or related to the average of the drags of a series of bodies derived by a specified geometric procedure. The results of investigations of large systematic families of configurations have rarely been available for correlation with the area rule, especially in the case of external stores. Inasmuch as the present tests involve a large systematic family of configurations (store positions), it is of interest to analyze the experimental results in the light of the area rule.

R. T. Jones proposes for supersonic speeds (ref. 6) a method of analyzing the wave drag of aircraft based on the series of cross-sectional area distributions obtained by the longitudinal variations of areas intercepted by planes tangent to Mach cones for a series of roll angles (θ). The method, although simple in concept, is extremely tedious in its application. Whitcomb, in independently applying this same concept in reference 7, uses three planes covering roll angles from 0° to 90°.

The total drags of the complete configuration (wing-fuselage plus store) are shown in figure 33. In this figure, for each of the experimental drag points shown, the area distributions of the corresponding configurations are given as obtained by sectioning the configurations by Mach planes tangent to the Mach cone at roll angles of 15°, 45°, and 75°. (The cutting plane is perpendicular to the wing plane at $\theta = 90^\circ$.) The three distributions shown are taken as representative of the infinite series of Mach planes from $\theta = 0^\circ$ to $\theta = 90^\circ$. Also shown is a sketch of the wing-fuselage-store configuration corresponding to each data point.

According to the hypothesis of the area-rule, the wave drag of the configuration is the average of the drags of bodies of revolution having longitudinal area distributions equivalent to those obtained for each of the series of (roll angle) Mach planes used. Because of the time required for the calculation of drag from area distributions, the area diagrams themselves are presented for examination and comparison with the measured drag values. The general shape of the area diagram, that is, the overall fineness ratio, the local slopes, and the degree of smoothness, should be indicative of the relative drags if correlation is obtained.

Figure 33 shows little correlation between the drag curves and the series of area plots. For instance, on the basis of the area distribution, there appears to be little choice between chordwise positions 18 and 24 (part (a) of fig. 33), yet for one position the peak drag was measured and for the other position a drag near the lowest was obtained. In part (b) of figure 33, which concerns a midspan store position, there appears to be a closer relationship between the measured drag values and the area diagrams. Part (c) of figure 33 shows, for store spanwise positions corresponding to the wing tip, that little correlation is found between the somewhat smaller variations in drag and the area diagrams. In general, it is apparent that the correlation indicated is not sufficiently pronounced or consistent to be useful.

An attempt was made to correlate the data reported herein by using the coincidence or displacement of the area peaks due to the wing and to the stores. This method was used in reference 1 with limited success for the data used in that case. The correlation of the present data (not presented) vaguely showed a trend, but the scatter of data points was somewhat larger than the trend shown. The correlation is therefore of little value.

The foregoing analysis thus shows that visual inspection of supersonic area-rule diagrams does not provide correlation with the data obtained on the fuselage—swept-wing—store configuration at $M = 1.6$. It therefore appears that examination of the details of the flow, with particular attention to the effect of the pressure field of one component on another component, may be useful in explaining interference effects. The analysis which follows takes this approach and attempts to provide a more basic understanding of the interference effects encountered.

Pressure-Field Analysis

The work of reference 2 shows that the interference produced by a store in the vicinity of a reflection plane can be calculated with reasonable accuracy. Continuation and extension of this type of work should in time result in the development of theoretical methods for calculating accurately the interference of actual airplane configurations. However, such calculations will probably be complicated and time consuming and, although useful for final design evaluations, may not be sufficiently simple or flexible for preliminary design study work.

For this type of work, it appears that a simple understanding of the sources and distribution of the interference effects, perhaps through a qualitative mapping of the pressure fields involved, would be very useful. Consequently, the results of this investigation have been analyzed with this object in mind. The method used considers the effect of the pressure field of one component on another component but does not consider such effects as local choking or reflection of disturbances. Much of the analysis presented tends to be illustrative and qualitative in nature, although it is shown that quantitative estimates can be cautiously made from the results presented in many cases.

Drag of store in presence of fuselage.- The effects of the fuselage upon the drag of the store are rather readily explained, as is shown in figure 34. In this figure are shown the chordwise variations of store drag for four spanwise stations (from fig. 3), with the store spotted at various positions with respect to the fuselage. A pressure field has been drawn for the fuselage based upon the fuselage surface-pressure distribution (also shown in fig. 34) which was calculated by means of linearized theory by using the method of reference 8. The divisions between the regions of positive and negative pressures have been constructed, as permitted by linearized theory, by drawing Mach lines from the point on the body where the calculated pressures pass through the stream-static value. Thus, the flow field is mapped into a region of positive and negative pressures.

Examination of the location of the store nose and afterbody in the flow field shows that the value of drag shown at the corresponding point on the drag curve is explained in a qualitative way by simple "buoyancy" considerations. The values of drag above the value for the isolated store are a consequence of the presence of the store nose in a region of positive pressure or the presence of the afterbody in a region of negative pressure, and the peak value is in every case a result of a combination of these effects. The values of drag below those for the isolated store can similarly be explained by negative pressures on the store nose or positive pressures on the store afterbody.

Thus, it appears that, in the simple case of the interference of a fuselage on a store, the store drags can be qualitatively estimated from simple considerations of the pressure field of the fuselage. Furthermore, it has been demonstrated in reference 9 that quantitative values of interference drags for a fuselage-store combination can be obtained by use of the buoyancy technique.

Drag of store in presence of wing.- For the case of the effects of the wing upon store drag, the wing pressure field cannot easily be predicted theoretically or even easily estimated. The measured store base pressures were therefore examined to determine whether these pressures could be used as a "survey" to supply information as to the nature of the wing flow field.

Figure 35 presents the chordwise variations of store base pressure (for four spanwise positions at $z = 1.15$) measured in the presence of the fuselage and in the presence of the wing-fuselage combination. The difference between these two curves gives the effect of the wing, or in the use considered here, a rough survey of the effective static-pressure field produced by the wing. This survey, because of the presence of a mixing region and a wake behind the store, in addition to the effects of flow angularities, local choking, and reflection of disturbances, cannot be expected to give a true static pressure distribution. However, it is believed that an effective pressure distribution has been obtained from which a qualitative map of the wing pressure field can be drawn and from which evaluation of the interference drag might be attempted.

It will be noted that the variations and gradients of store base pressure in the presence of the fuselage are rather small relative to those in the presence of the wing. Consequently, this approach is unusable in connection with fuselage-store interference. The variations of base pressure produced by the wing are very large, however, and it is apparent that even a rough survey should serve to show the qualitative nature of the flow field.

By locating the point on the store axis at which the pressure (store base pressure due to the presence of the wing) passes from positive to negative and by assuming that appropriate Mach lines may be drawn symmetrically with respect to the wing section, a rough map of the pressure field of the wing at that particular spanwise position is constructed. This field is seen to consist of a positive region extending ahead of the wing leading edge and terminating rather suddenly in a bow shock, a negative-pressure region extending essentially to the wing trailing edge inboard and to considerably behind the wing trailing edge for outboard stations, and a following positive-pressure region.

Figure 36 shows the chordwise variation of the drag of the store in the presence of the wing, along with sketches showing the store in a number of positions in the wing pressure field as constructed in figure 35. As in the case of the fuselage, the effects of the wing are explained by the location of the store nose and afterbody in the positive- and negative-pressure regions produced by the wing.

In an attempt to determine the validity of a quantitative use of the pressure-field information of figure 35, the drag of the store has been calculated by the buoyancy method with this pressure-field information for all positions shown (a to h) in figure 36. The values of drag are shown as the large square symbols. Despite the crudeness of the pressure-field survey used, the agreement shown is acceptable.

These results thus show that a relatively simple knowledge or a survey (preferably obtained by more exact research methods than the method herein used) of a wing pressure field may be sufficient to explain both the direction and the level of interference of the wing upon a store.

Drag of store in presence of wing-fuselage combination.- Inasmuch as the effects of the wing and fuselage on the store drag have been shown to be readily understood, and to some extent predictable, it is of interest to compare the measured effects of the wing-fuselage combination with the measured effects of the separate components. In figure 37 the chordwise variations of drag for the store in the presence of fuselage, wing, and wing-fuselage combination are shown for four spanwise positions. The wing is shown to produce the highest and the lowest drag values. At the position where the highest drag due to the wing alone occurs, the drag due to fuselage alone is well below the free-stream value. Consequently, the drag value measured for the store in the presence of the wing-fuselage combination in this region appears to represent the sum of these positive and negative interferences and is generally below the wing-alone value. The same effect is noted for the low drag region ahead of this drag peak where the thrust exerted on the store by the wing alone is reduced by the drag introduced by the fuselage alone to produce a compromise drag for the combination. It will be noted that the curve for the drag of the store in the presence of the wing-fuselage combination corresponds very closely to that for the store in the presence of the fuselage ahead of the point where the effect of the wing is felt.

In the extreme rearward positions, addition of the interference effects does not appear to take place. Although the drag of the store is below the free-stream value in the presence of both wing alone and fuselage alone, the drag in the presence of the combination lies between the individual values. Since this phenomenon is shown to be more prominent for the more inboard positions, it is probably a consequence of wing-fuselage interference or local choking due to the proximity of the three components, or both.

The extent to which the interference drags of the store produced by the wing and fuselage can be added to give the interference of the wing-fuselage combination is more clearly illustrated in figure 38. Here the measured values of store drag in the presence of the wing-fuselage combination are compared with the sum of the isolated store drag and the drag increments above or below the free-air value produced by the fuselage alone and by the wing alone. The generally good agreement between the curves indicates that the interference effects of wing and fuselage can be estimated or considered separately and added together to give the total effect with reasonable accuracy.

Drag of fuselage in presence of store.- The drag of the fuselage in the presence of the store is considered in terms of the pressure field of the store in figure 39. On this figure is shown the drag of the fuselage plotted against store chordwise position for four spanwise stations. The relative positions of store and fuselage are shown for a number of points on the drag curves. The pressure field of the store is also shown and was constructed in the same fashion as the fuselage pressure field (fig. 34) from the surface pressure distribution for the store calculated by means of linear theory.

The fuselage drag is explained by the effects of the store pressure field upon the fuselage for the more rearward store positions. The fuselage drag is above the isolated value when the fuselage afterbody is in the negative-pressure region of the store (positions d and h) and below the isolated value when the fuselage afterbody is in the positive-pressure region of the store (position f).

The forward dips in the curves are not explained by the effect of store pressures since only the cylindrical center section of the fuselage is affected (positions a and e). These lower drags are a consequence of interference of the conical portion of the store sting on the fuselage afterbody (see fig. 1(a)) which is present in all fuselage and wing-fuselage data for store positions corresponding to values of x of 6, 12, and 18. The magnitude of these effects on the fuselage along with the decrease which occurs as the store is moved (spanwise) away from the fuselage is apparent from figure 39. As mentioned previously, the basic data figures (figs. 15 to 22) have been faired with dashed lines between $x = 6$ and $x = 18$ in order to call attention to the presence of these spurious effects.

Drag of wing in presence of store.- The variations of wing drag with chordwise position of the store for four spanwise stations are shown in figure 40. The position of the local wing section with respect to the store and its flow field for a number of points on the curve is shown in the sketches. As in the previous cases presented, the drag of the wing (above or below the isolated-wing value) is explained by the position of the local wing section in the positive- or negative-pressure field of the store. High drags are a consequence of positive pressures over the forward portion of the wing section or negative pressures over the rearward portion of the wing section, or both, whereas low drags are a consequence of pressures of opposite sign. These results thus indicate that the interference effects on the portion of the wing in the immediate vicinity of the store are of principal importance, although the actual interference is complex and is spread over a large portion of the wing.

Drag of wing-fuselage in presence of store.- The variations of drag of the fuselage, wing, and wing-fuselage combination in the presence of the store are shown in figure 41. The shape of the curve for the wing-fuselage combination is very close to that for the wing alone. The increment between these curves is different from the drag of the fuselage alone (lowest curve) by a large amount, largely because of wing-fuselage interference. This interference tends to obscure the relative effects of the store in the three curves.

The extent to which the interferences of the store on the wing and fuselage alone are additive is shown in figure 42. The sum of the increments above or below the free-air drag for the wing alone and fuselage alone have been added to the drag coefficient for the isolated combination (0.0213) to obtain the curve drawn with long dashes in figure 42. The values of drag thus calculated agree well with those measured for the wing-fuselage combination in the presence of the store.

Total drag of complete configuration.- Figure 43 presents plots of the drag of the store in the presence of the wing-fuselage combination, the drag of the wing-fuselage combination in the presence of the store, and the sum of these two curves - the total drag of the complete configuration. The data are plotted against the chordwise position of the store for four spanwise stations. All coefficients in this figure are based on wing area S.

Figure 43 shows that at all spanwise stations the peak drags for store and wing-fuselage combination occur at the same store position. Thus, the store positions for which the wing-fuselage combination produces unfavorable interference on the store are also those for which the store produces unfavorable effects upon the wing-fuselage combination. The same result appears to be generally true for positions for favorable interference. The curve of total drag coefficient consequently exhibits a large variation in drag of the complete configuration with store chordwise position. About half this variation is due to variation in store drag and half to variation in wing-fuselage drag.

Lift interference.- Examination of the wing-lift data (fig. 18) in the same fashion shown previously in the drag analysis shows that the effects of the store on wing lift are consistent with the effects of the store on wing drag previously shown. When the store nose section is beneath the wing, positive interference lift is produced on the wing; conversely, when the store afterbody is beneath the wing, negative interference lift is produced on the wing.

The effect of the wing on the store lift (fig. 10) is similarly consistent with the drag analysis presented earlier. It is significant to note that the effective negative-pressure field beneath the wing chord is the predominating influence and produces positive interference lift on the store over a wide range of store positions.

The effects of the store on fuselage lift and of the fuselage on store lift are relatively small (figs. 16 and 6).

The interference lift on the wing due to the store and on the store due to the wing are both positive for a wide range of store positions (figs. 18 and 10). As a result, the contour plot for the complete configuration (fig. 32) shows a large range of store positions wherein the total lift is increased. These positions are largely, but not entirely, those wherein the interference drag is unfavorable.

Effect of Store Vertical Displacement and Wing-Fuselage Angle of Attack

The effects of vertical displacement between store and wing on store drag and lift in the presence of the wing-fuselage combination are illustrated in figures 44 and 45. The effects are shown to be small for the forward chordwise positions where the drag and lift are influenced primarily by the fuselage. For the more rearward positions, however, where the store is in the influence of the wing, the drag peaks are greatly reduced in height and width by moving the store (vertically) away from the wing. As might be expected, this decrease in unfavorable interference is accompanied by a decrease in favorable interference for store positions ahead of or behind this drag peak. The effects of store vertical position on store lift are considerably smaller but are of the same nature as the effects upon store drag.

The effects of vertical position of store on the variations of wing-fuselage drag and lift are shown in figures 46 and 47 to be somewhat similar to the effects upon the variations of store lift and drag.

Figures 48 and 49 show the effects of vertical position of the store on the total drag and lift (wing fuselage plus store). Again, the large effect which vertical position has upon the drag when the store is located in the region of the wing is apparent. For the farthest inboard position ($y = 3$ inches), moving the store (vertically) away from the wing will, in almost all chordwise positions, materially reduce the drag. In the farthest tipward position shown ($y = 10.2$ inches) moving the store away from the wing lowers the drag a small amount for only a narrow range of store chordwise positions. For some store chordwise positions at all spanwise positions shown, there appears to be a small advantage in close proximity between store and wing.

The effects of wing-fuselage angle of attack on store drag and lift are illustrated in figures 50 and 51. Since the wing-fuselage combination was pitched about the center line of the balance (fig. 1(a)) whereas the store angle of attack remained at 0°, the actual distance between the store and local wing chord line varies from the nominal value specified. Angle-of-attack data were obtained only for a store-wing displacement of $z = 2.09$ inches, at which position, as was shown previously, the interference effects are considerably less than for smaller values of z. It has been shown previously (fig. 36) that the most rearward peak in the drag curve is due to the combination of positive pressures on the store nose and negative pressures on the store afterbody. The valley or minimum point forward of this peak is a consequence of positive pressures impinging on the store afterbody. The effect of wing-fuselage angle of attack (fig. 50) is to increase the height of the peak and increase the depth of the valley. This result is due to the increased strength of the positive-pressure region ahead of and beneath the wing which is to be expected as the angle of attack is increased. The higher positive pressures are shown in figure 51 to decrease store lift through the same range of store positions.

The effects of wing-fuselage angle of attack on wing-fuselage and total-configuration (wing fuselage plus store) drag and lift are illustrated in figures 52 to 55. The effects of angle of attack on the interference are somewhat masked by the lift and the drag produced by the angle of attack. It can be seen, however, that the curves for all angle-of-attack conditions are similar in character and that the variations of drag with store chordwise position are in general amplified as the angle of attack is increased.

Remarks on the Store-Support Problem

The preceding experimental results do not contain the forces on, or the effects of, struts or pylons for the store. It seems reasonable to assume that the support pylon will not materially alter the store positions for high or low drag, especially if the pylon is very thin, or highly swept, or both. However, because a pylon is a wing-like structure with appreciable frontal area as well as considerable lateral area, it is apparent that local interference of the same type shown in detail in this report will exist between store and pylon and between pylon and wing. It appears likely, therefore, that the pylon cannot be considered as having a constant increment depending only upon its geometry, size, or shape but must be considered as another configuration component producing a pressure field of its own and being acted upon by the pressure fields of the other components.

The pressure-field analysis contained in this report should be useful in a qualitative way in estimating pylon effects. Further research is needed, however, to obtain a better understanding of pylon effects and to obtain quantitative information for design use.

CONCLUSIONS

The results of a supersonic wind-tunnel investigation at a Mach number of 1.6 in which separate forces were measured on a store, a fuselage, a swept wing, and a swept-wing—fuselage combination for a very wide range of store positions provides the following conclusions:

1. Large changes in store and wing-fuselage drag may occur with small changes in store position - either spanwise, chordwise, or vertically.

2. The interference drag of the store in the presence of the wing or fuselage is explained in a qualitative (and to some extent quantitative) way from consideration of the pressure field of the wing or fuselage and the resultant buoyant forces on the store.

3. The store interference drag measured in the presence of the wing-fuselage combination compares favorably with the sum of the store interference drags measured in the presence of fuselage alone and in the presence of the wing alone.

4. The interference drags of the wing and fuselage arising from the flow field of the store are similarly explained from considerations of the position of the wing and fuselage in the pressure field of the store.

5. The fact that in most store positions investigated the simple buoyancy considerations were useful indicates that reflected disturbances and the possible presence of local choking between components did not materially contribute to the interference.

6. Store positions for which high drag is encountered by the store are the same positions, in general, for which high drag is also encountered by the wing-fuselage combination. The same is true, in general, for store positions for low drag.

7. Drag data presented in the form of contour plots show that store positions for high drag for the complete configuration (wing fuselage plus store) were in the vicinity of the wing inboard on the span. For store positions toward the wing tip, forward, or back of the wing, the drag decreases rapidly to the interference-free value and to a value considerably lower in some positions. Increasing the vertical displacement between store and wing substantially decreases the mutual interference (both favorable and unfavorable).

8. No consistent correlation was obtained between the drags of the complete configuration and a visual inspection of the area diagrams for these configurations determined according to the supersonic area-rule concept.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., January 3, 1955.

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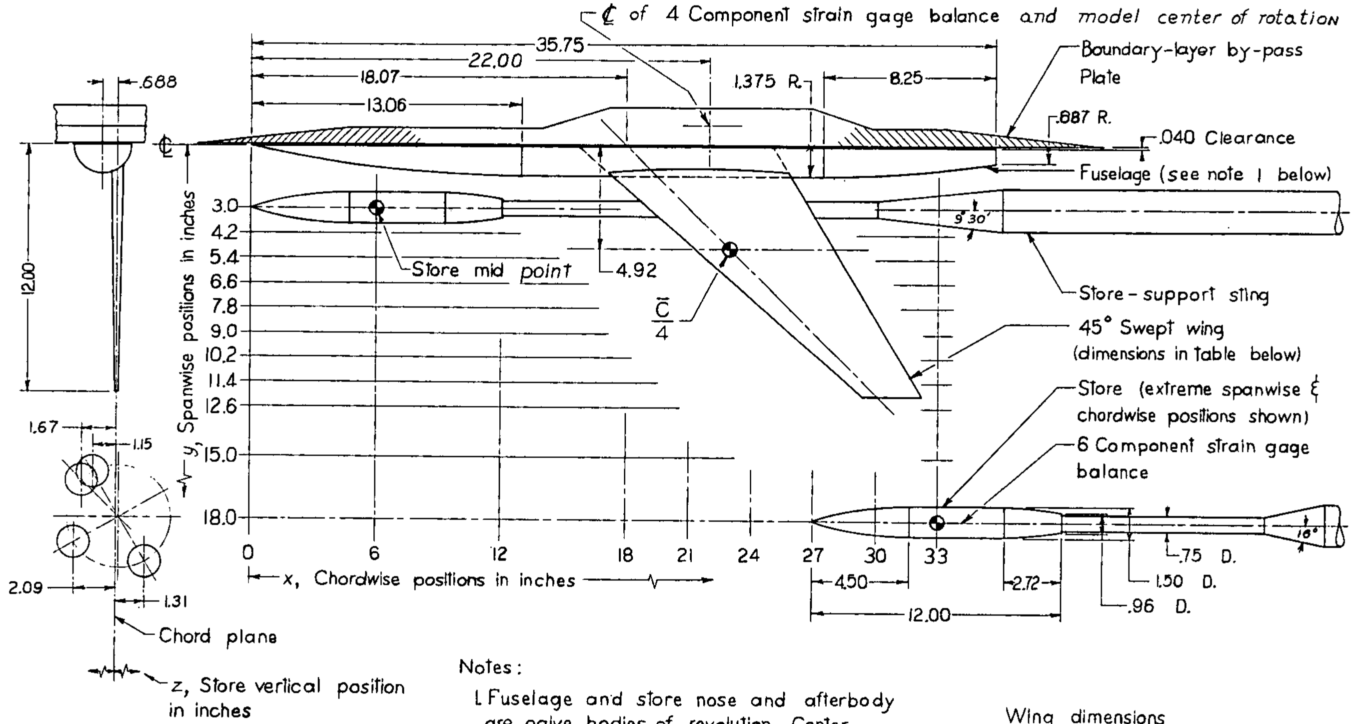
TABLE I.- PERTINENT MODEL DIMENSIONS

Store:	
Maximum diameter, in.	1.5
Maximum frontal area, sq ft	0.0123
Base diameter, in.	0.96
Base area, sq ft	0.005
Overall length, in.	12
Nose fineness ratio	3
Afterbody fineness ratio	1.82
Overall fineness ratio	8
Ratio of wing area to store maximum frontal area	40.6
Fuselage:	
Maximum diameter, in.	3.942
Maximum frontal area (semicircle), sq ft	0.0206
Base diameter, in.	1.372
Base area (semicircle), sq ft	0.0051
Overall length, in.	37.450
Nose fineness ratio	4.75
Afterbody fineness ratio	3
Overall fineness ratio	13
Swept wing:	
Semispan, in.	12
Mean aerodynamic chord, in.	6.580
Area (semispan), sq ft	0.500
Sweep (c/4), deg	45
Aspect ratio	4
Taper ratio	0.3
Center line chord, in.	9.23
Section	NACA 65A006



Notes:

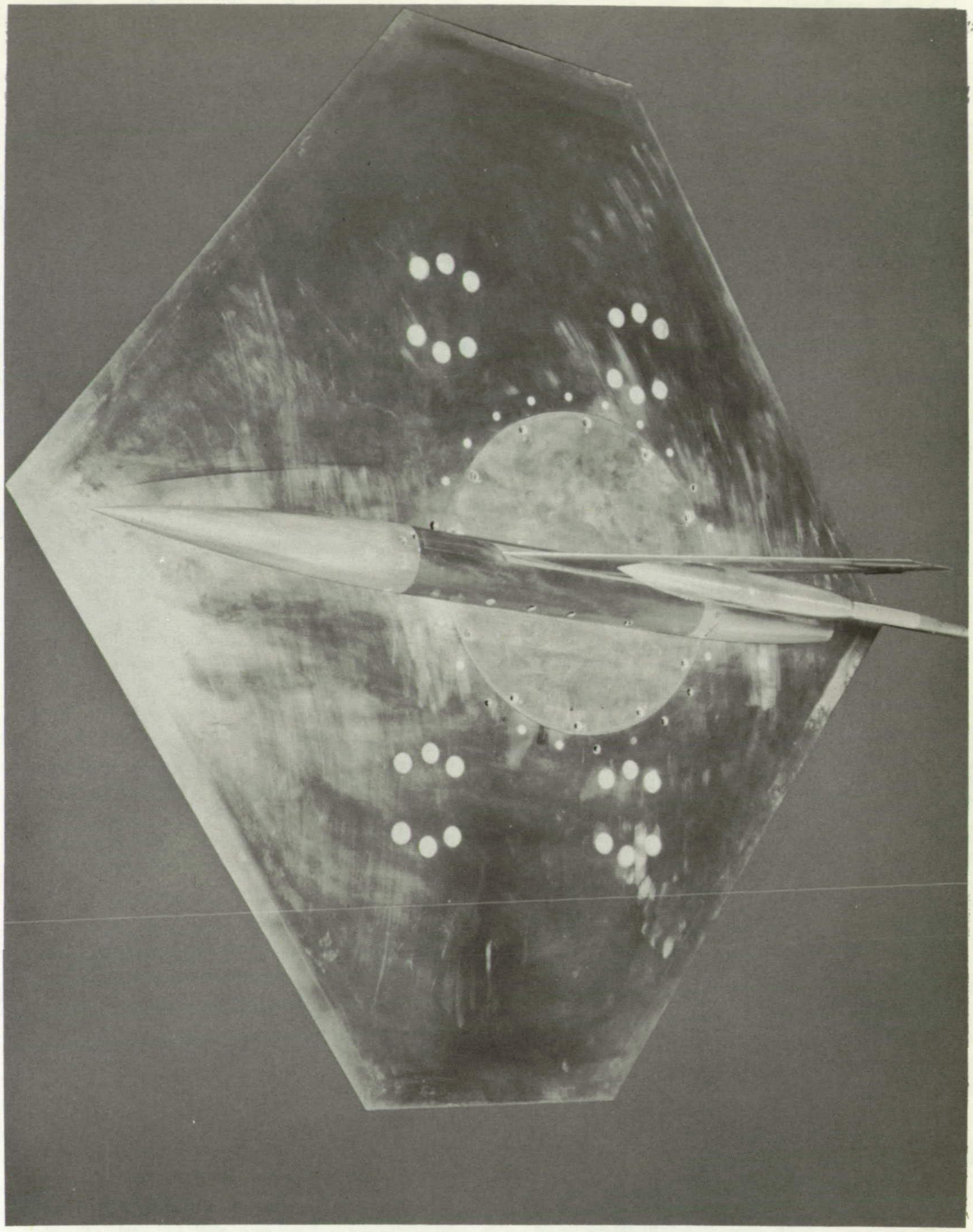
1. Fuselage and store nose and afterbody are ogive bodies of revolution. Center sections are cylindrical
2. All dimensions in inches.

Wing dimensions

Semi-span	12
Sweep $\frac{c}{4}$	45°
Aspect ratio	4
Taper ratio	0.3
℄ Chord	9.23
Section	65A-006

(a) Layout of models showing dimensions of components and ranges of store positions investigated.

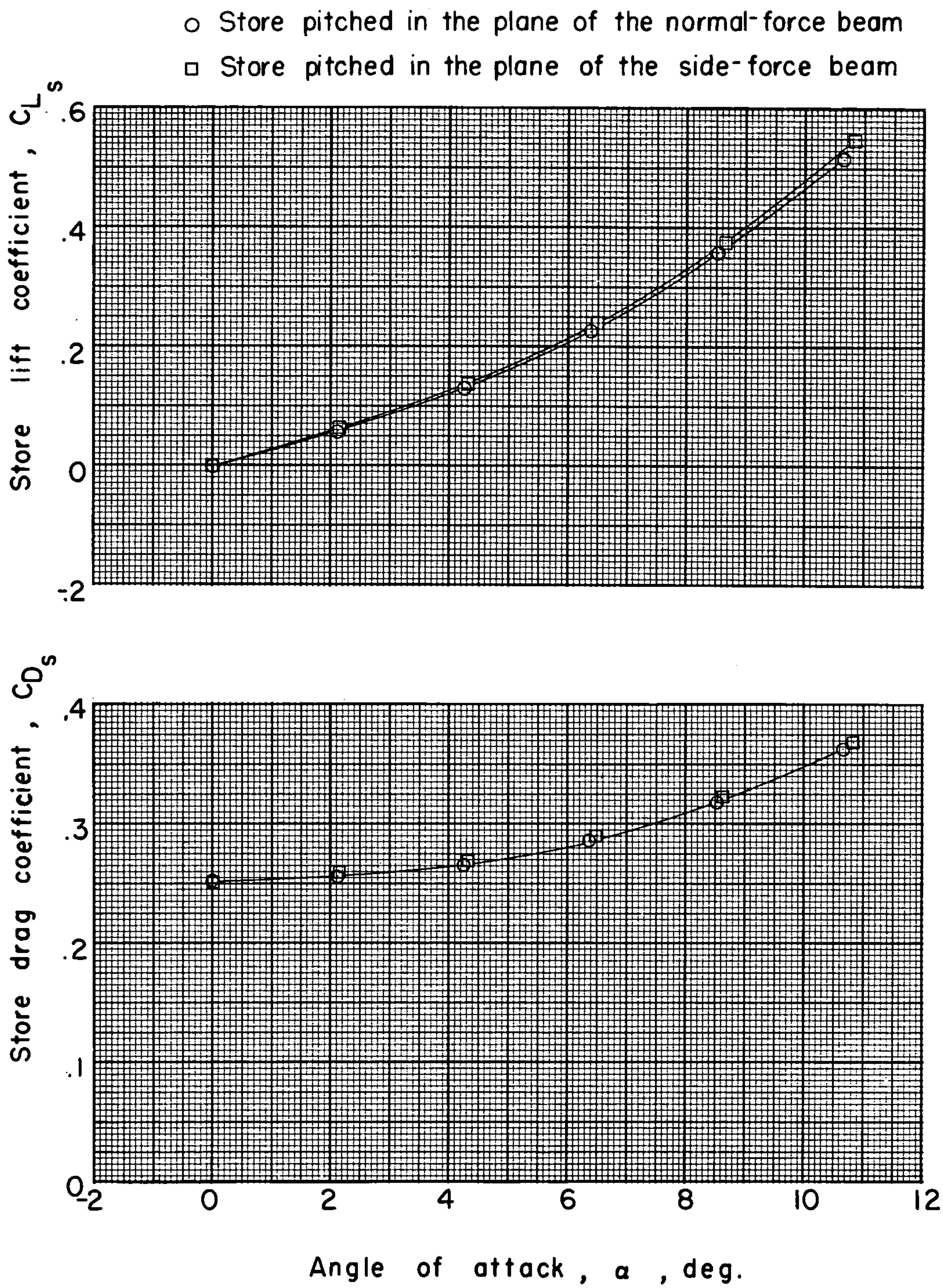
Figure 1.- Details of models and supports.



L-87526

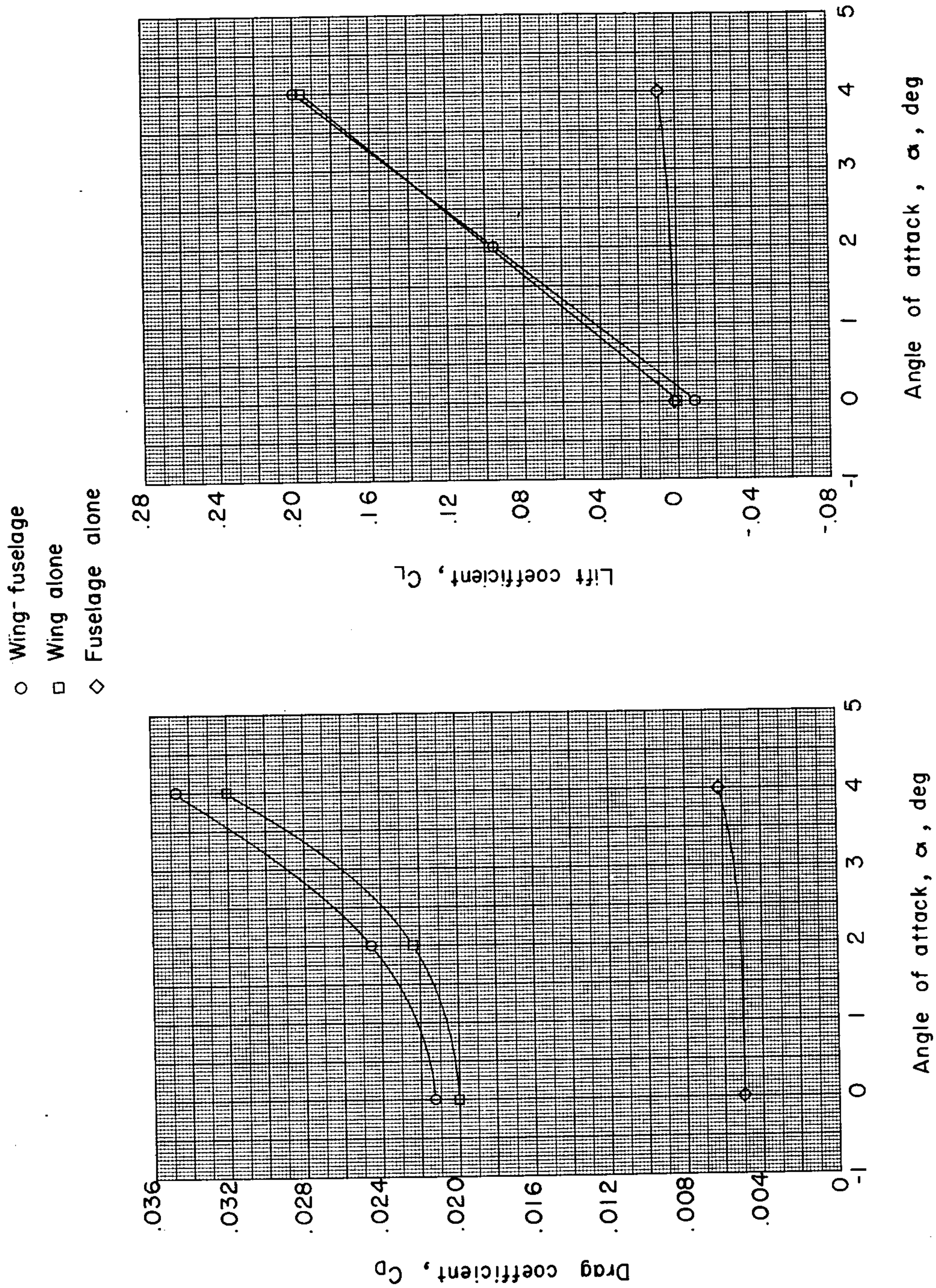
(b) Photograph of model. Transition strips not shown.

Figure 1.- Concluded.



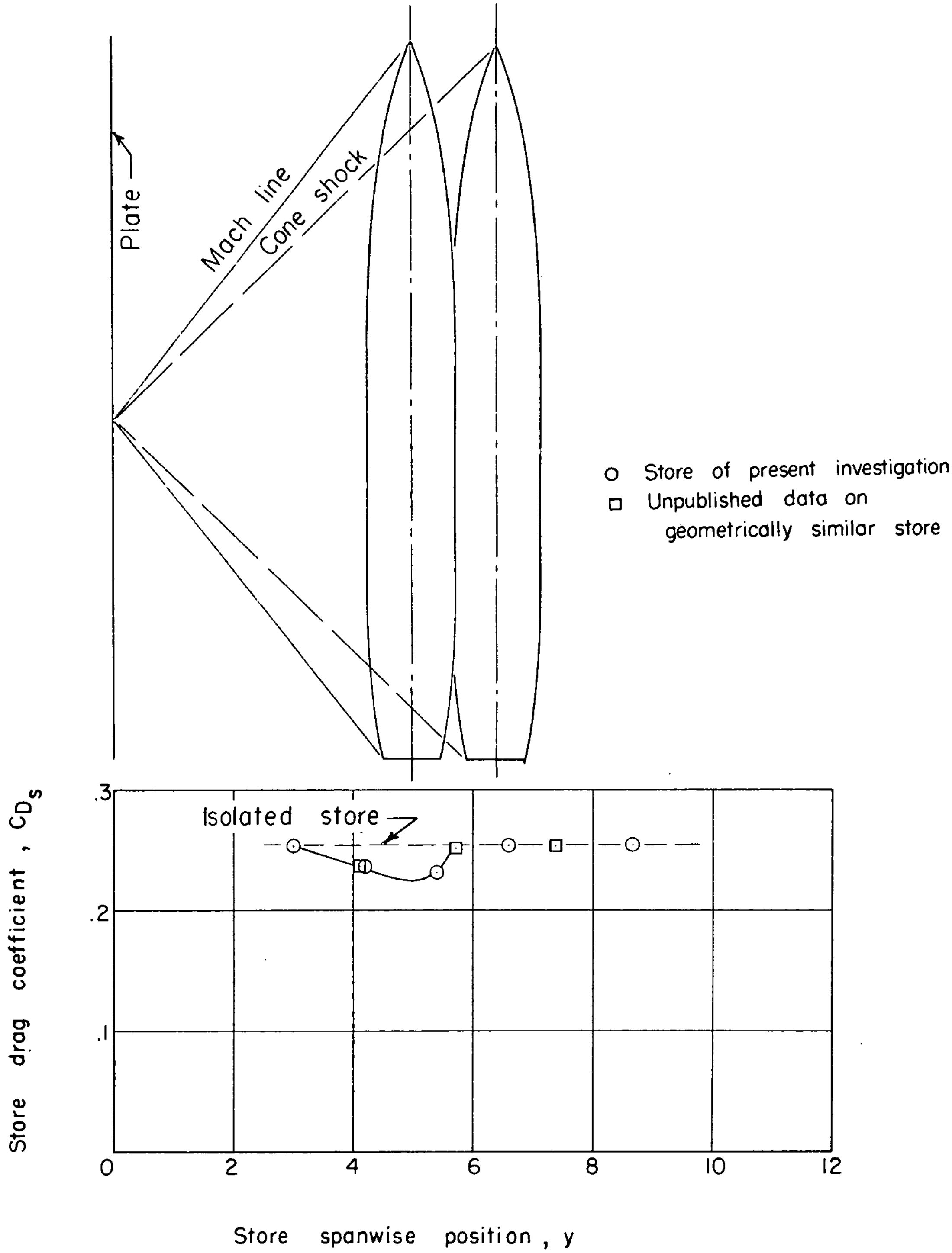
(a) Store lift and drag.

Figure 2.- Aerodynamic characteristics of the isolated configuration components.



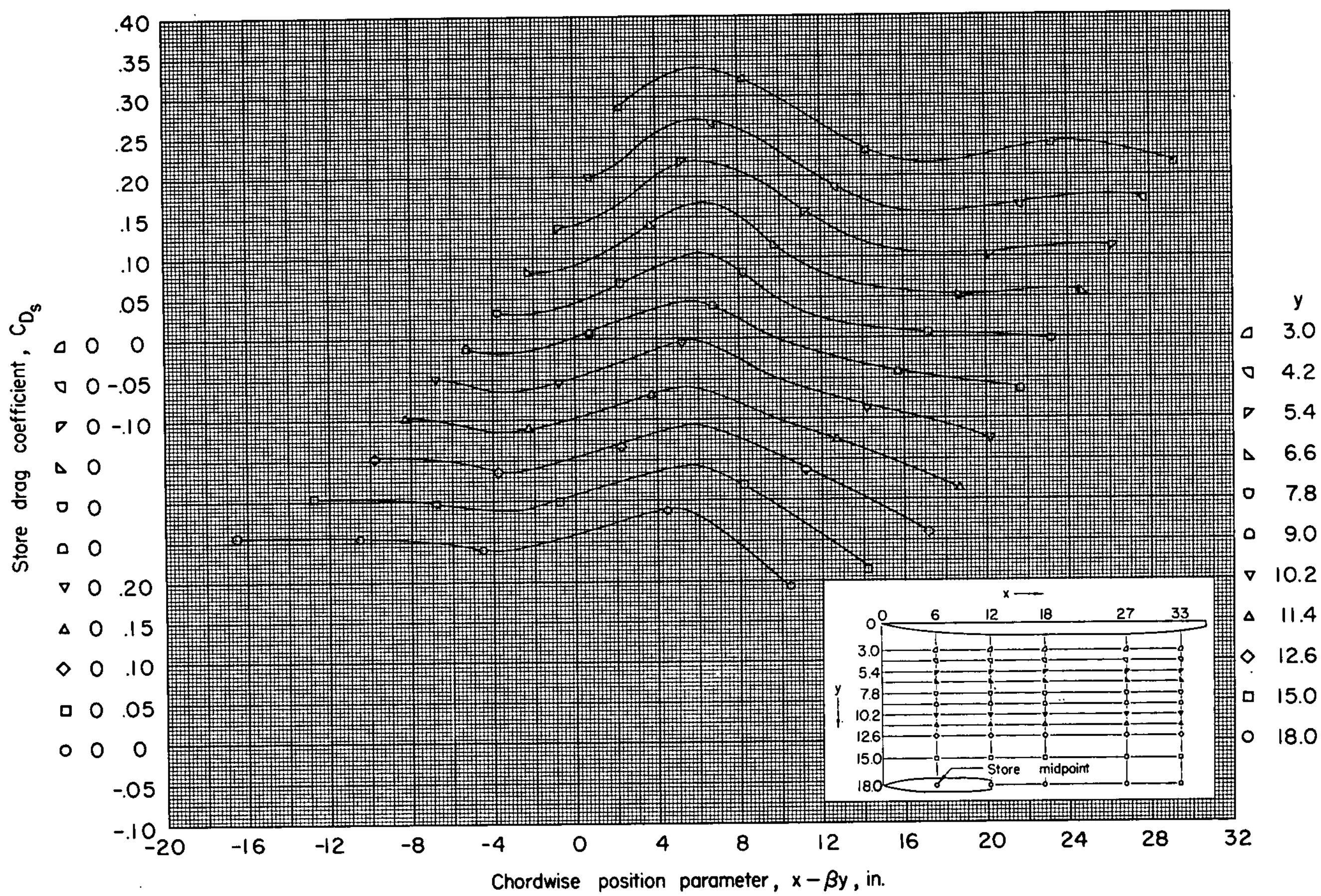
(b) Wing, fuselage, and wing-fuselage lift and drag.

Figure 2.- Continued.



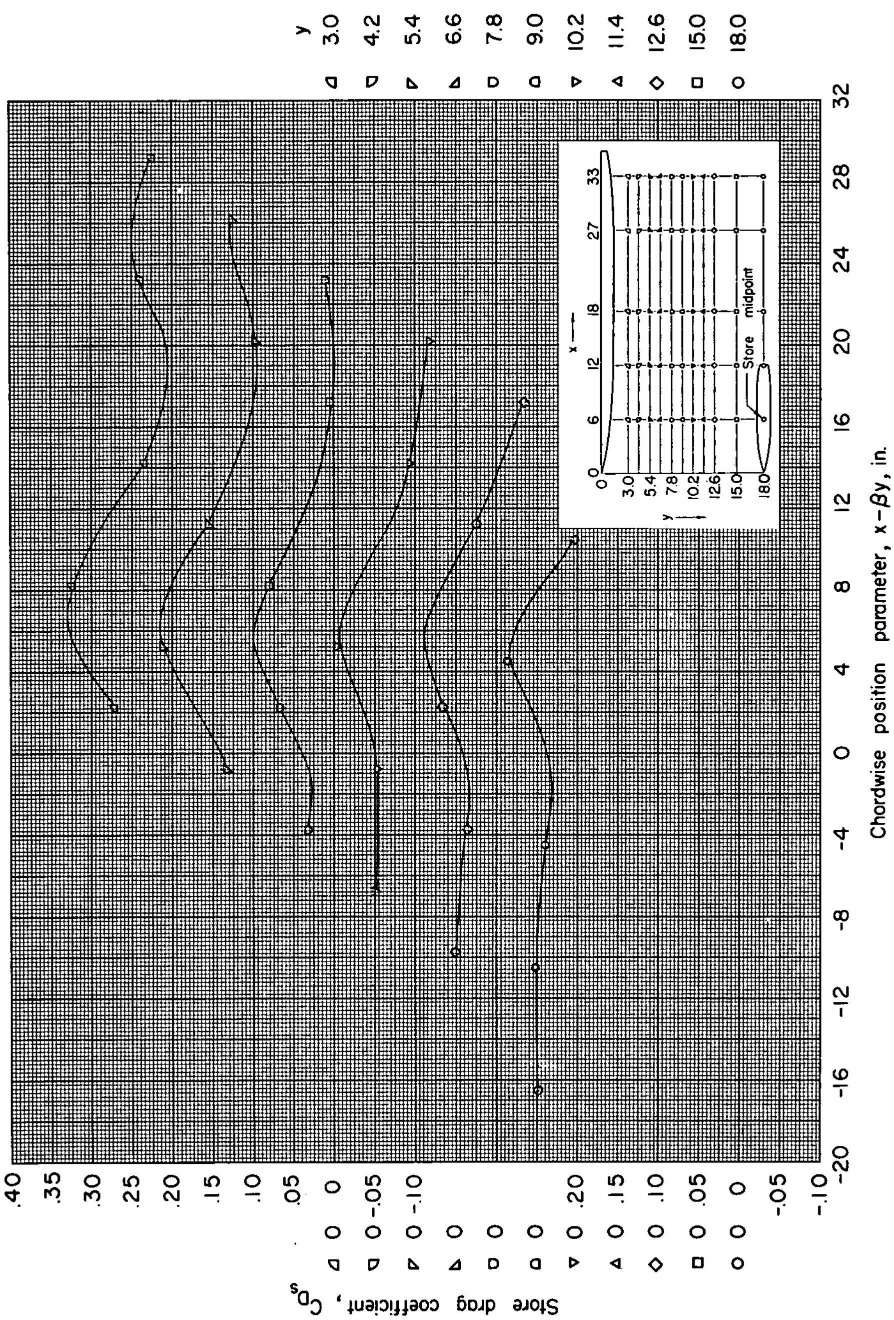
(c) Store drag in the vicinity of the boundary-layer by-pass plate.

Figure 2.- Concluded.



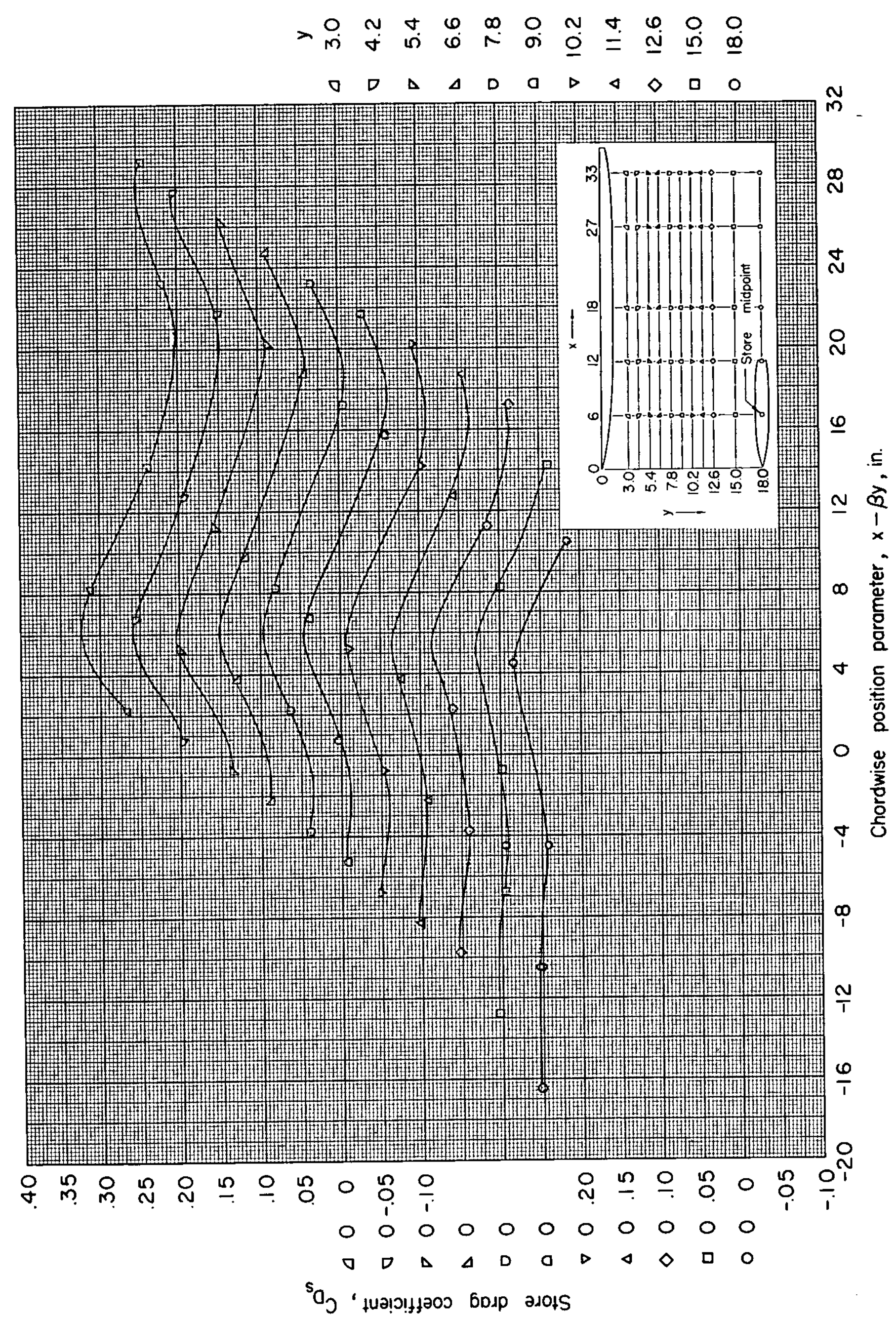
(a) $z = 1.15$ inches; $\alpha = 0^{\circ}$.

Figure 3.- Drag of store in presence of fuselage.



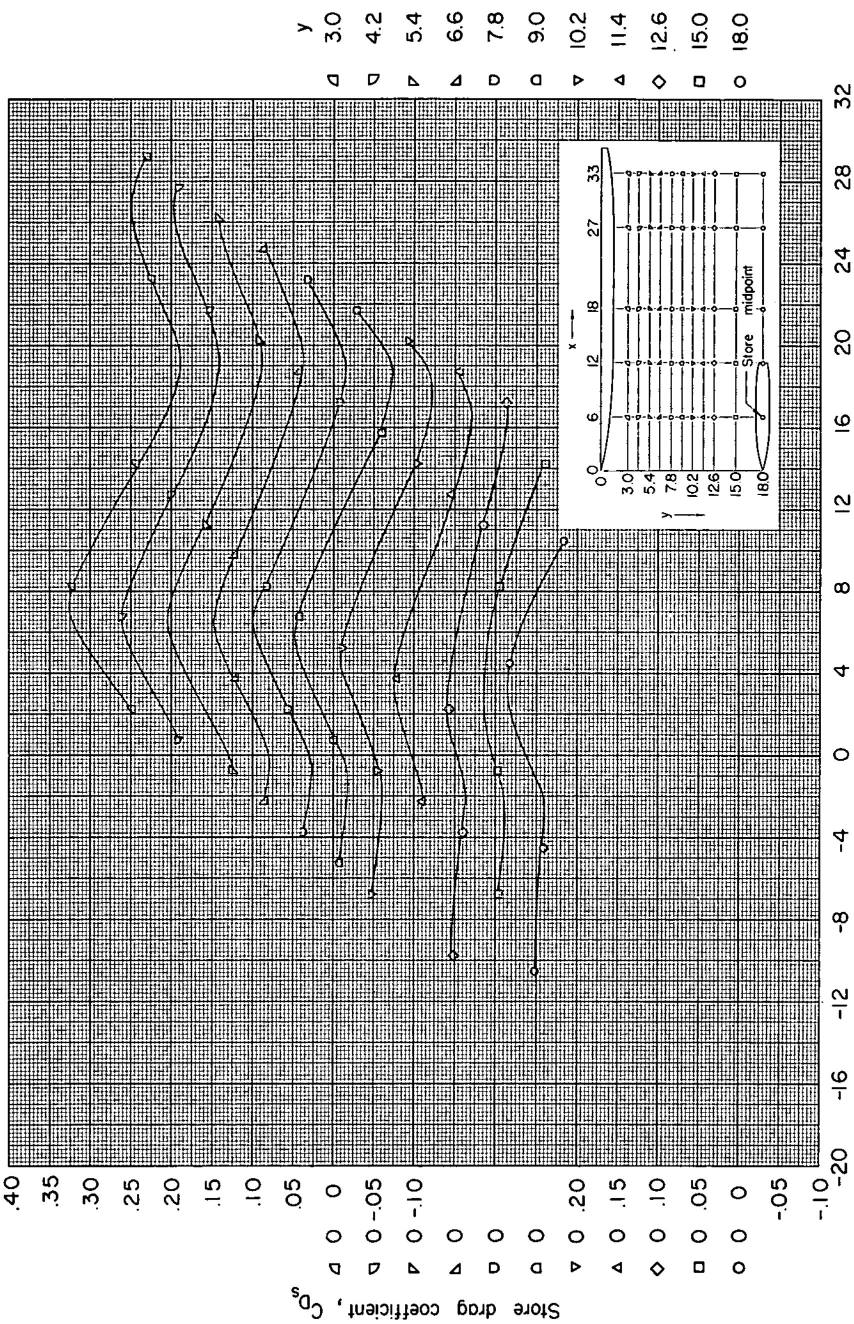
(b) z = 1.67 inches; α = 0°.

Figure 3.- Continued.



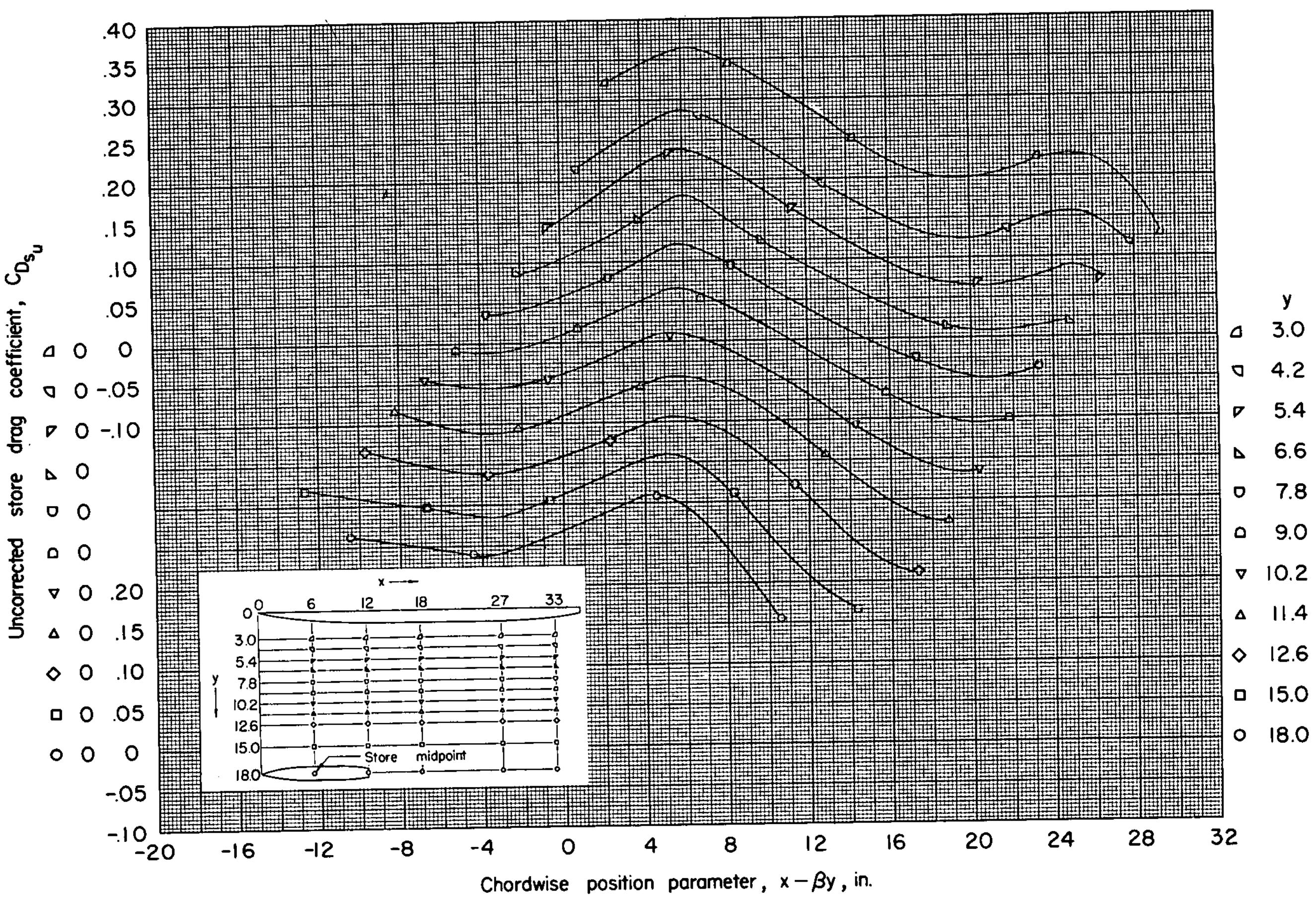
(c) z = 2.09 inches; α = 0°.

Figure 3.- Continued.



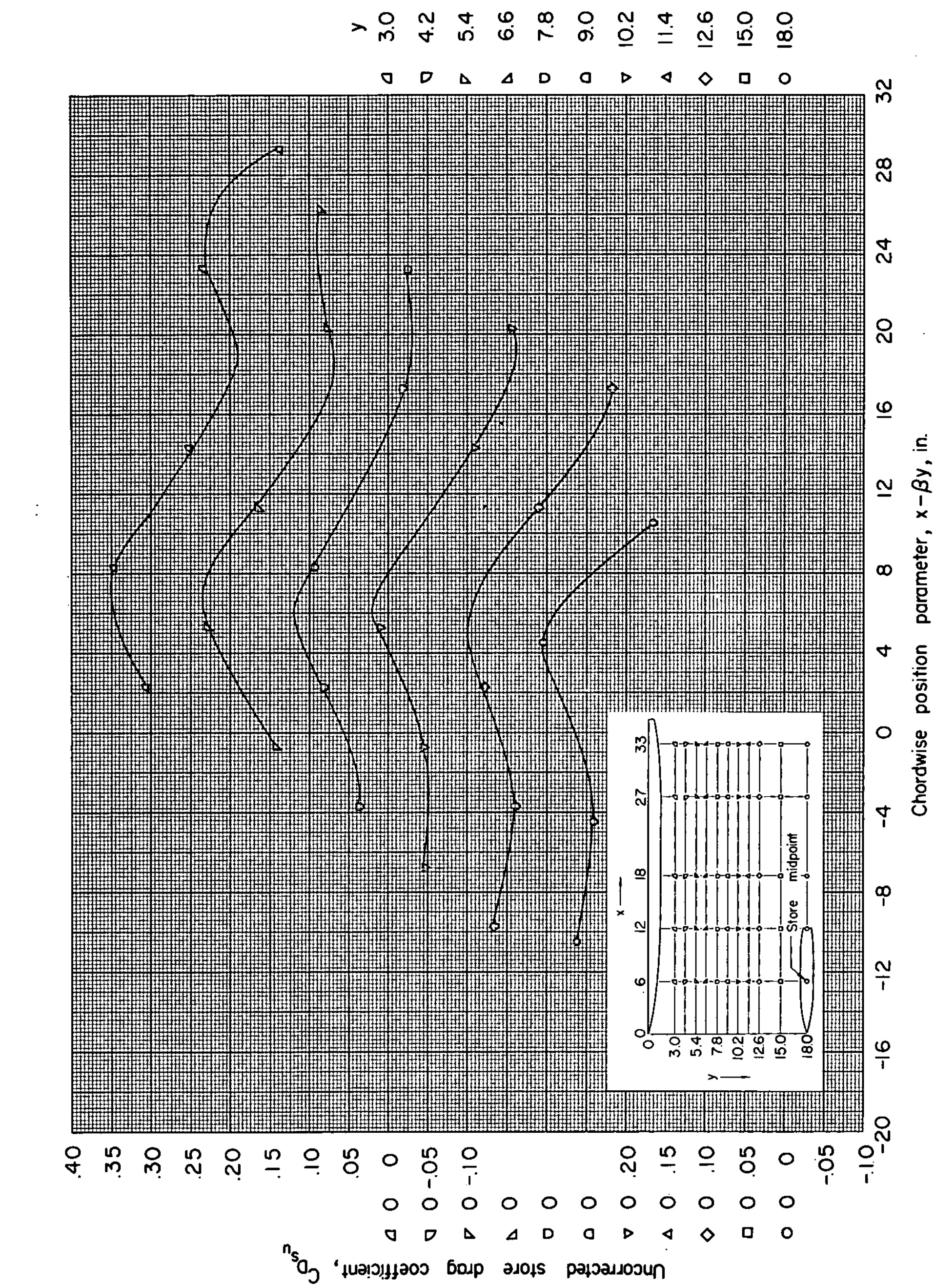
(d) z = 2.09 inches; α = 4°.

Figure 3.- Concluded.



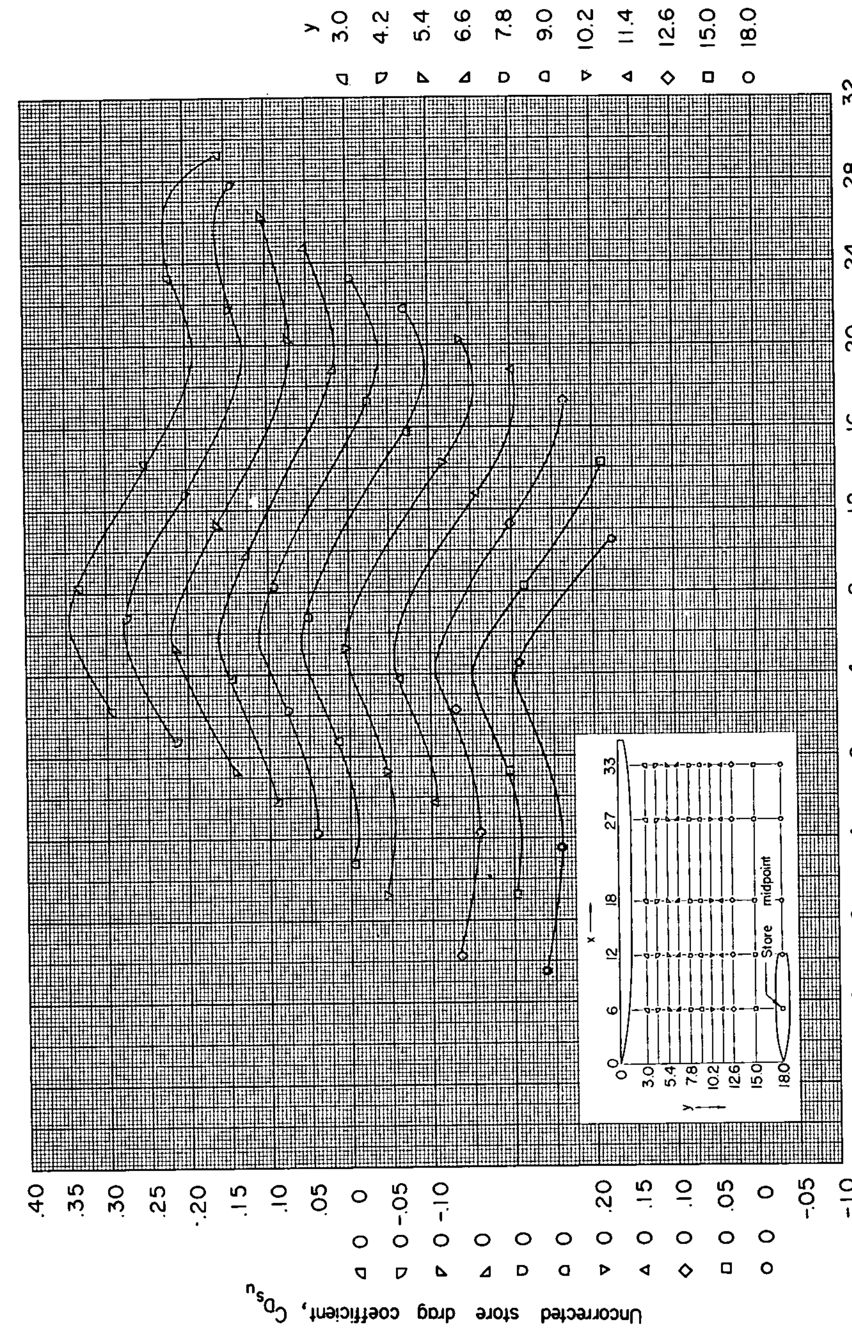
(a) z = 1.15 inches; $\alpha = 0^{\circ}$.

Figure 4.- Drag of store in presence of fuselage. (Drag uncorrected for base pressure.)



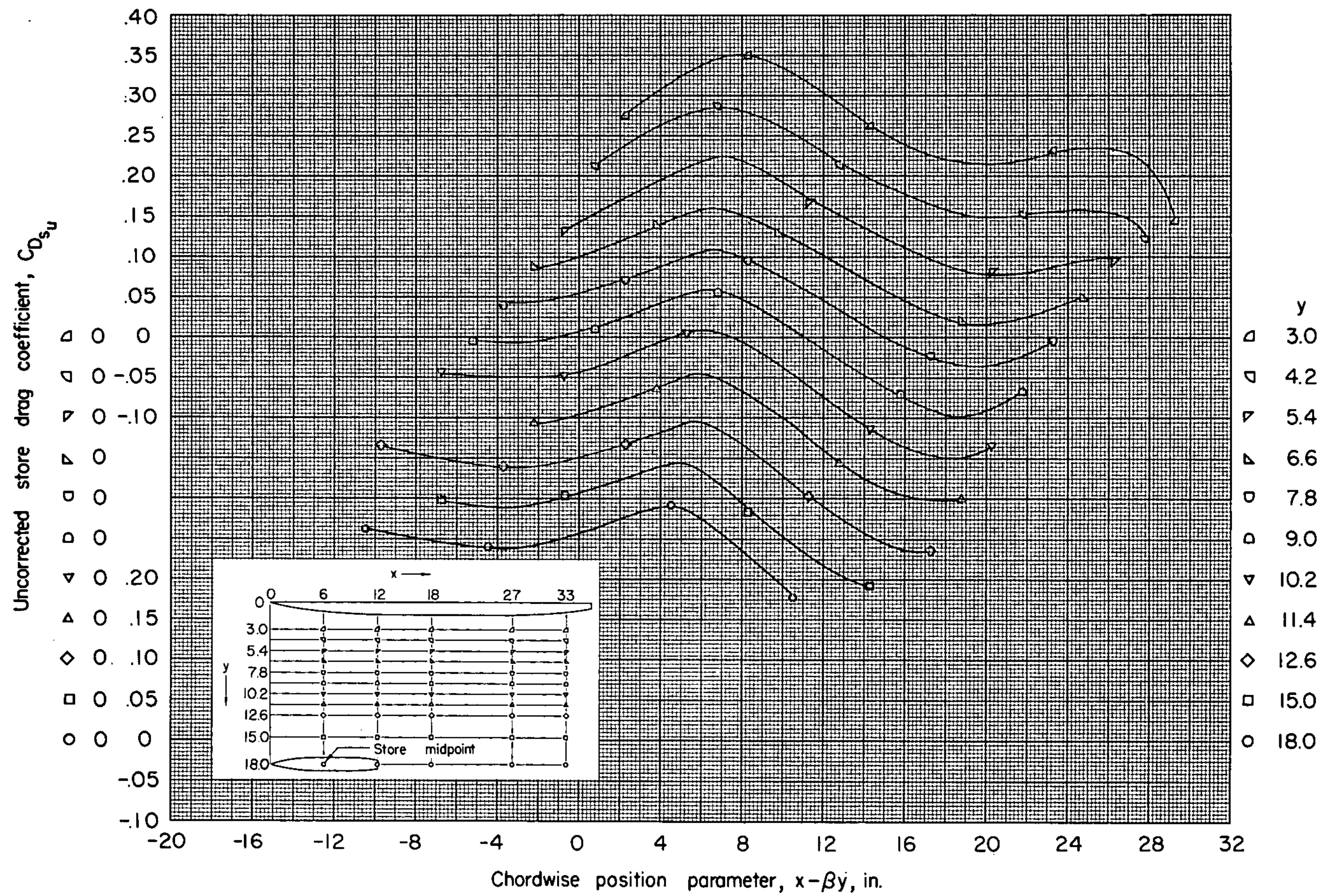
(b) $z = 1.67$ inches; $\alpha = 0^{\circ}$.

Figure 4.- Continued.



(c) $z = 2.09$ inches; $\alpha = 0^{\circ}$.

Figure 4.- Continued.



(d) z = 2.09 inches; α = 4°.

Figure 4.- Concluded.

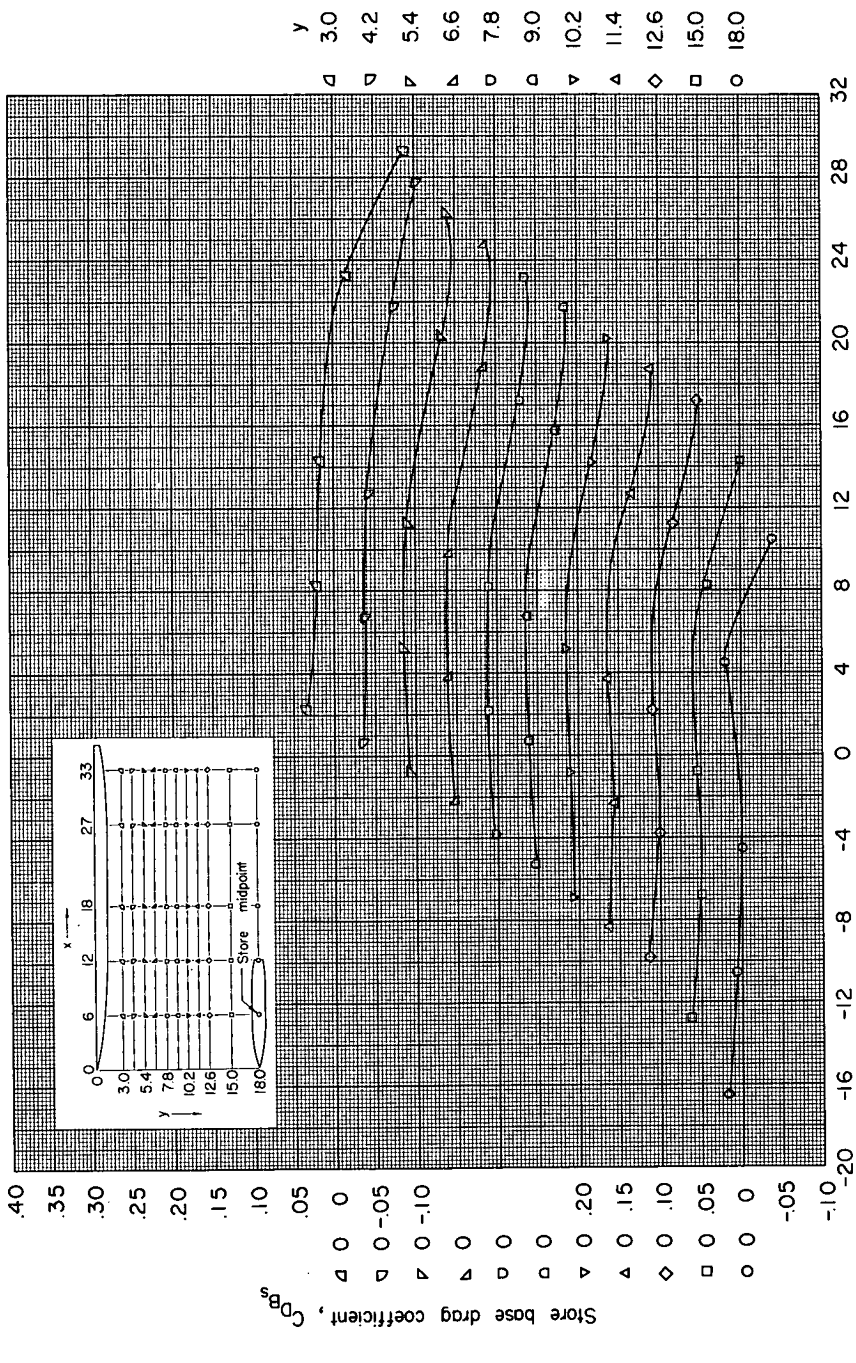


Figure 5.- Base drag of store in presence of fuselage. $z = 1.15$ inches; $\alpha = 0^{\circ}$.

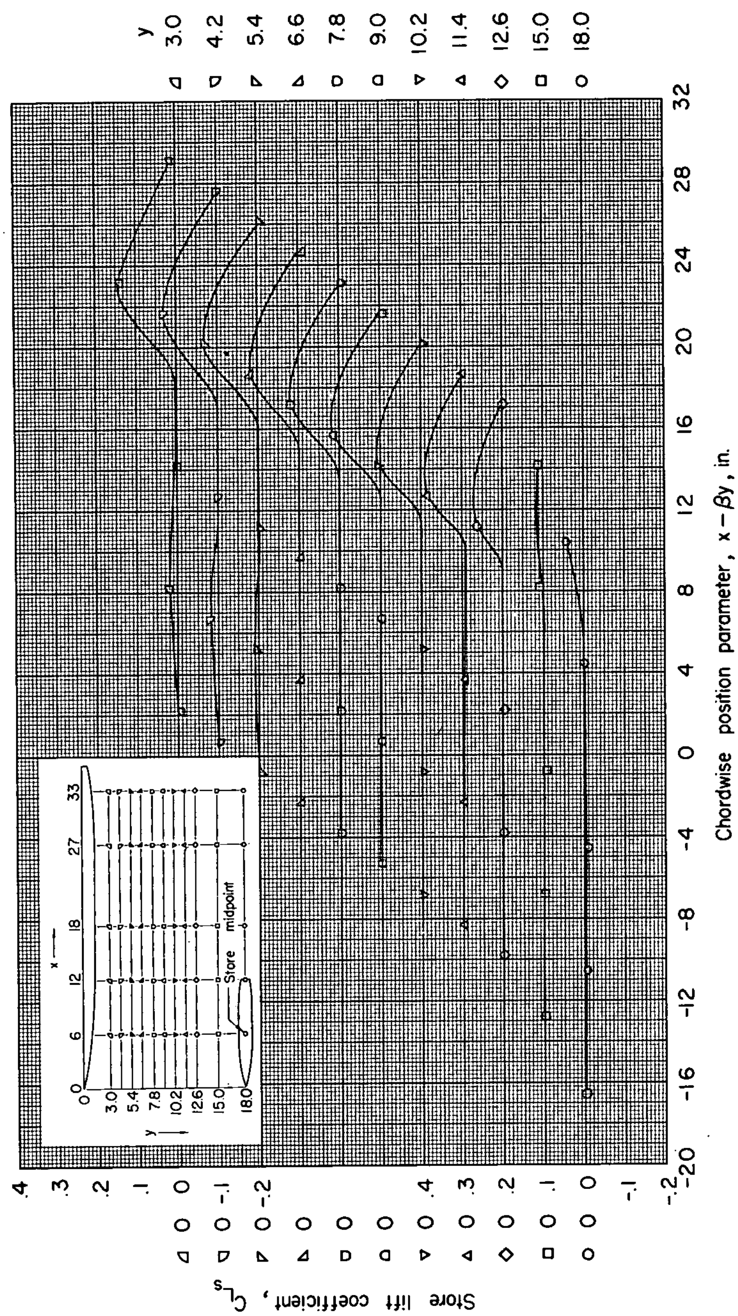
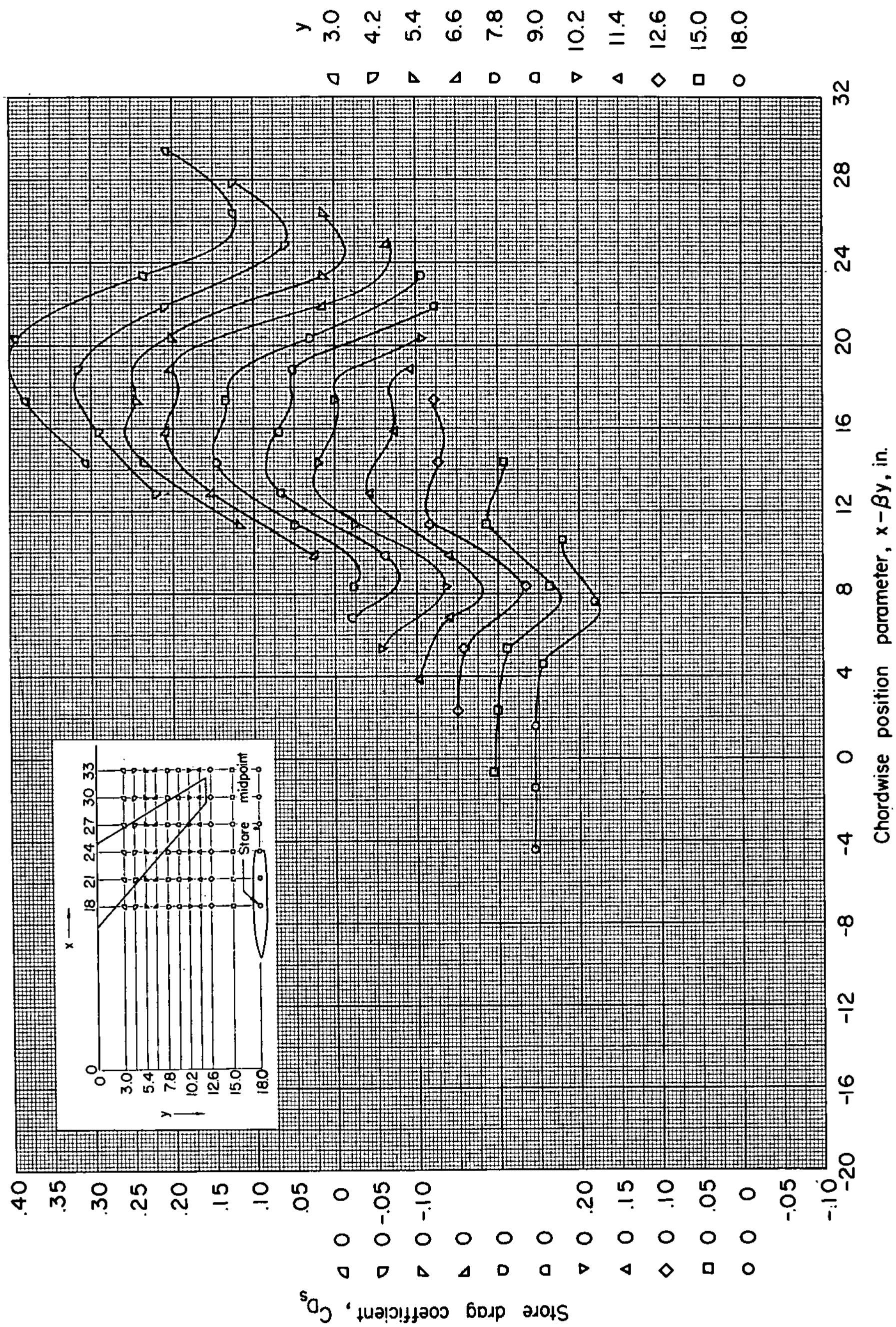
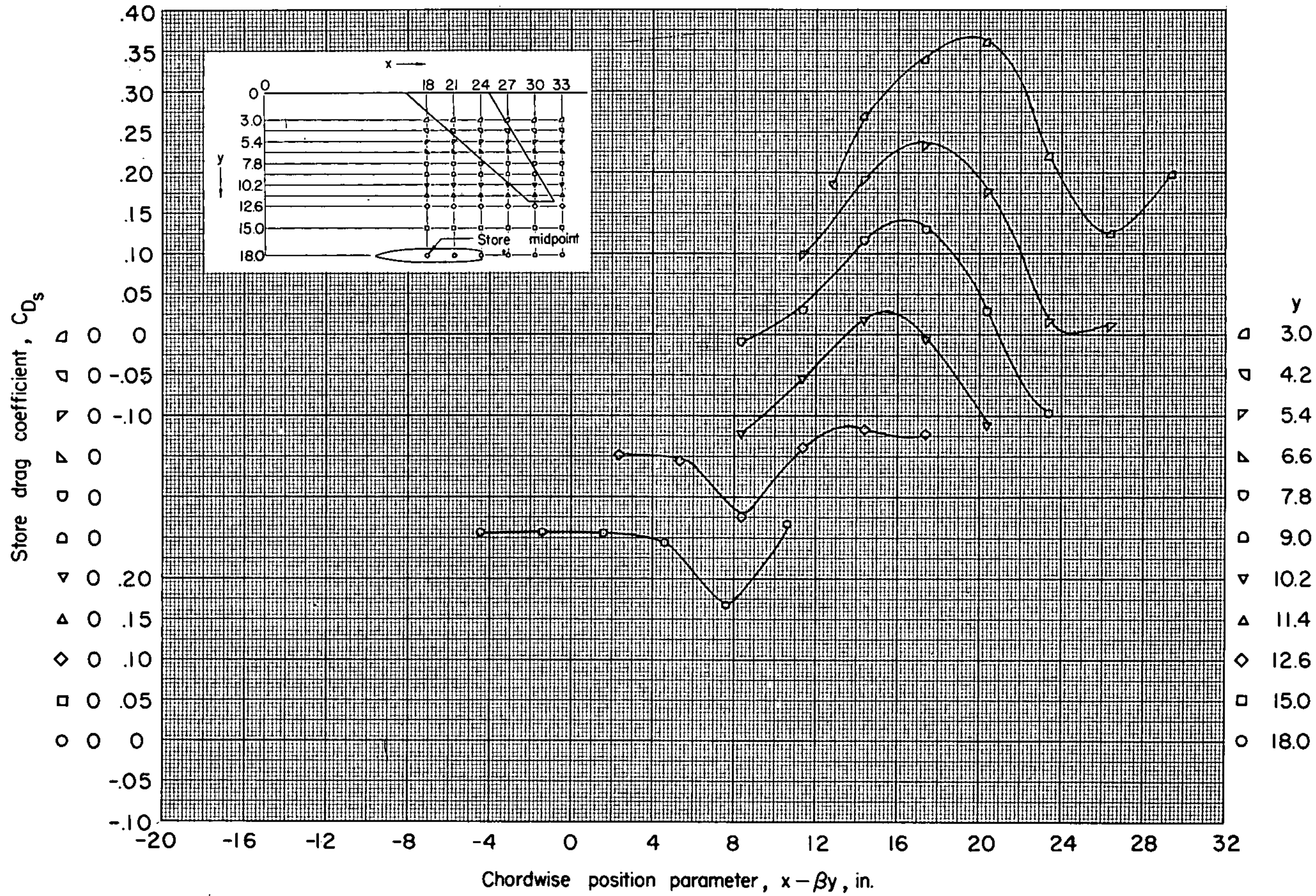


Figure 6.- Lift of store in presence of fuselage. $z = 1.15$ inches; $\alpha = 0^\circ$.



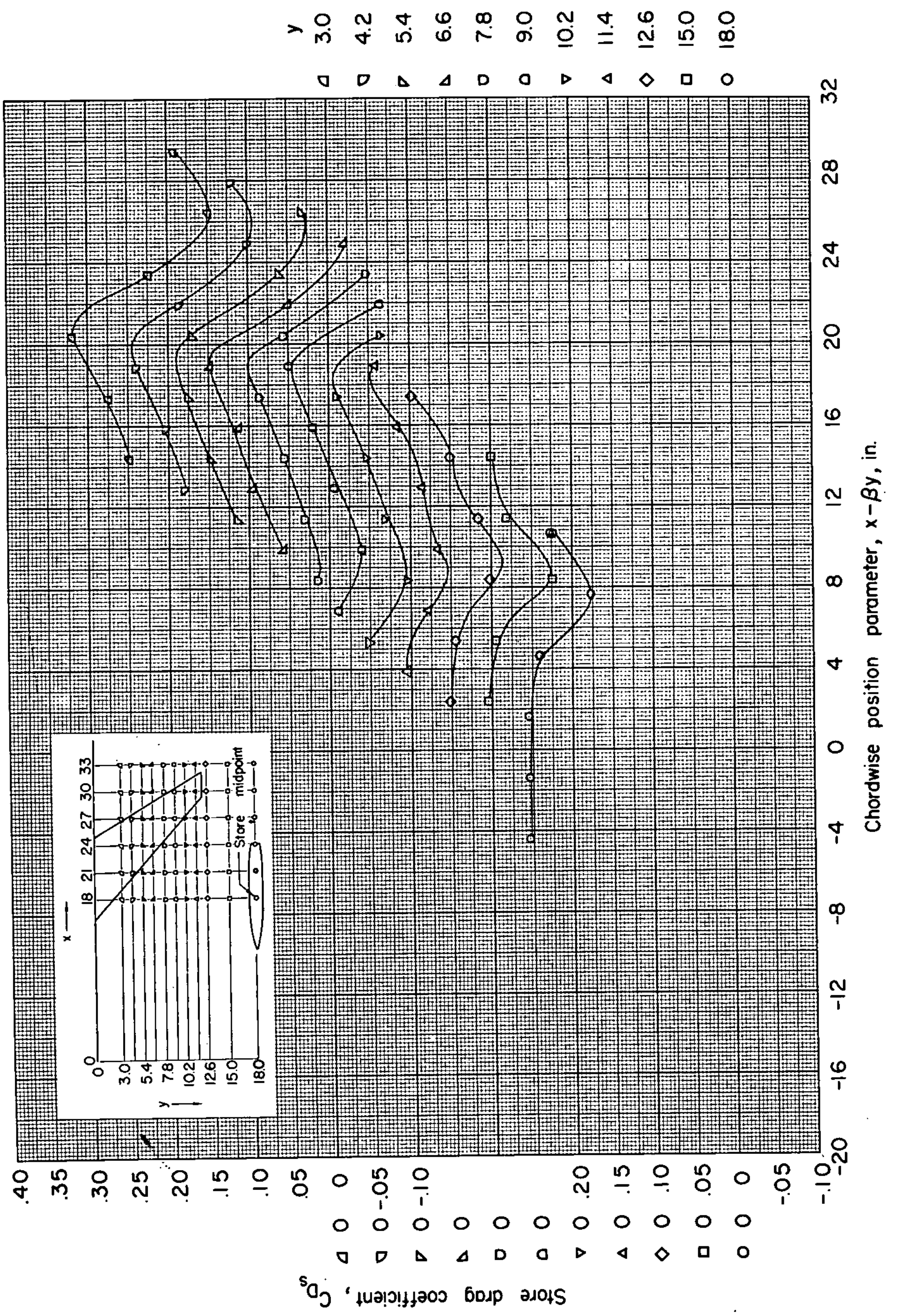
(a) z = 1.15 inches; α = 0°.

Figure 7.- Drag of store in presence of wing.



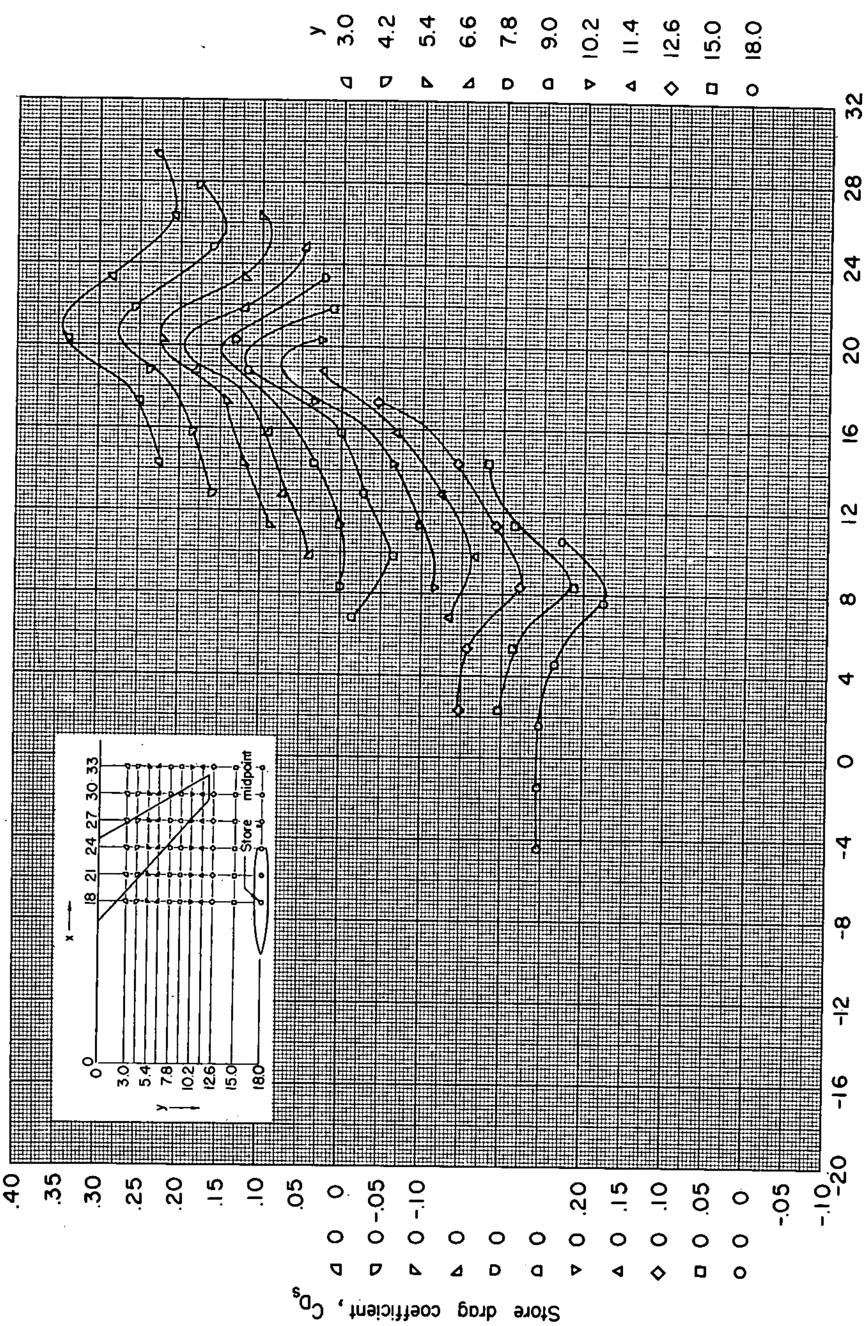
(b) $z = 1.67$ inches; $\alpha = 0^{\circ}$.

Figure 7.- Continued.



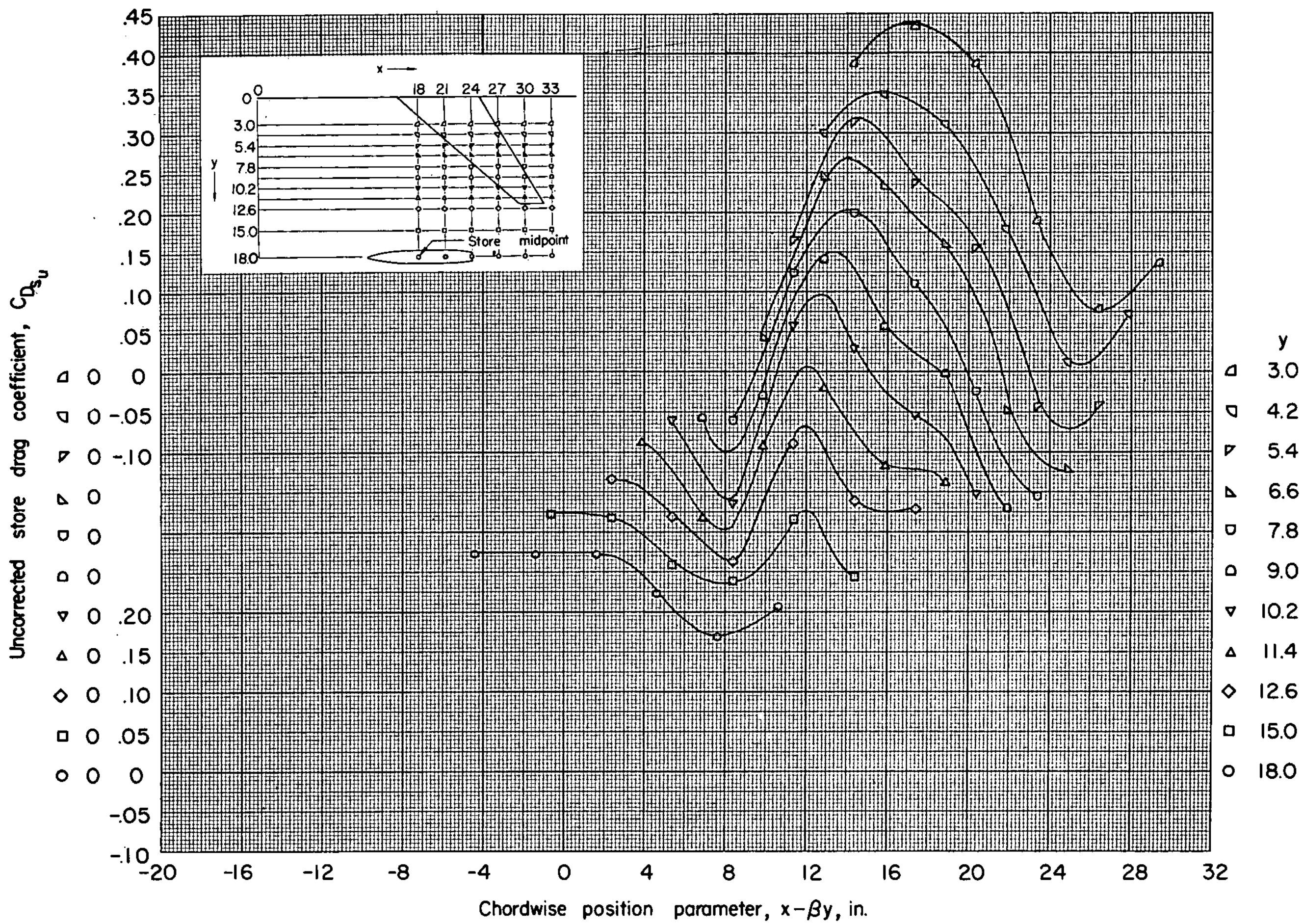
(c) $z = 2.09$ inches; $\alpha = 0^{\circ}$.

Figure 7.- Continued.



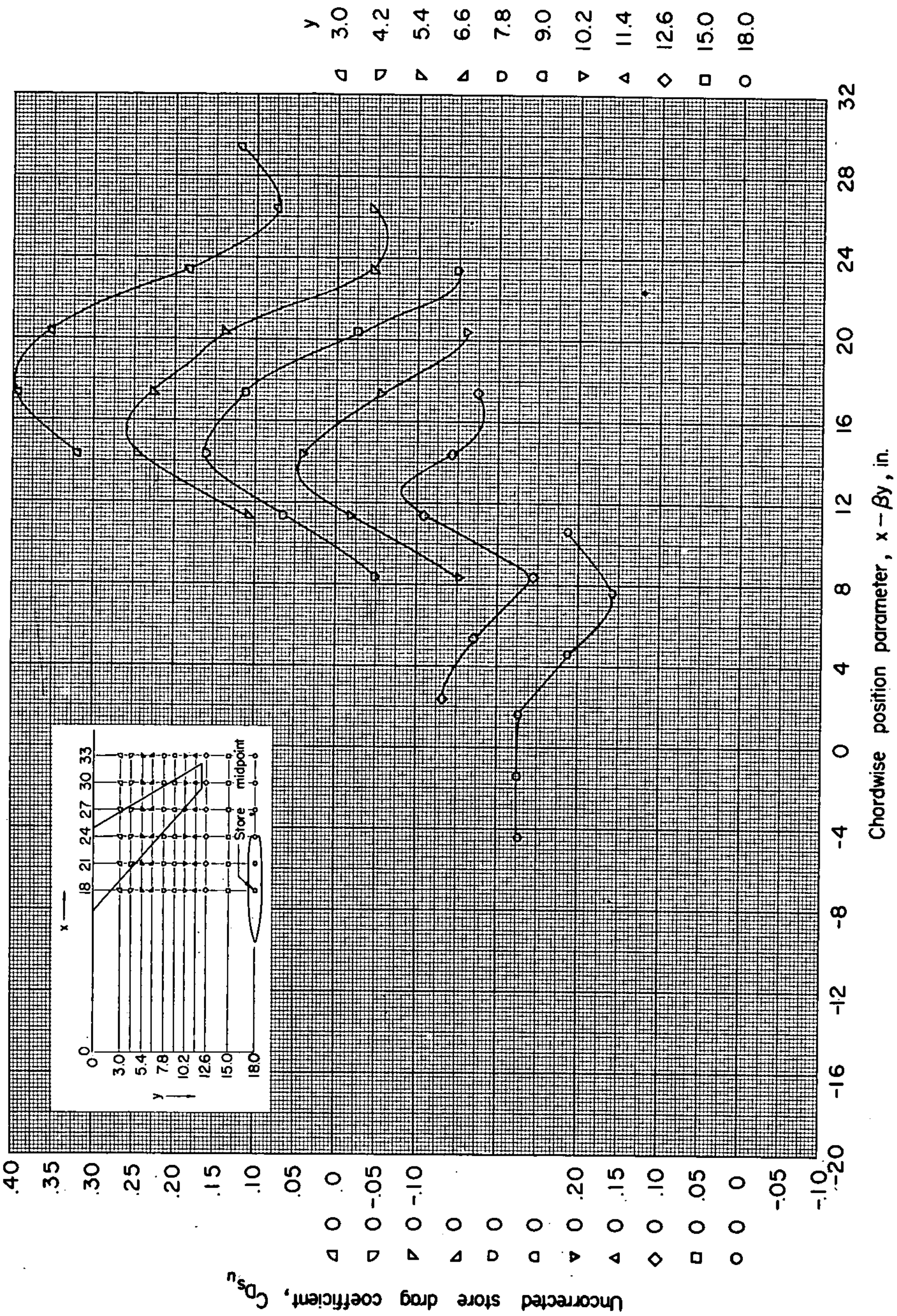
(d) z = 2.09 inches; α = 4°.

Figure 7.- Concluded.



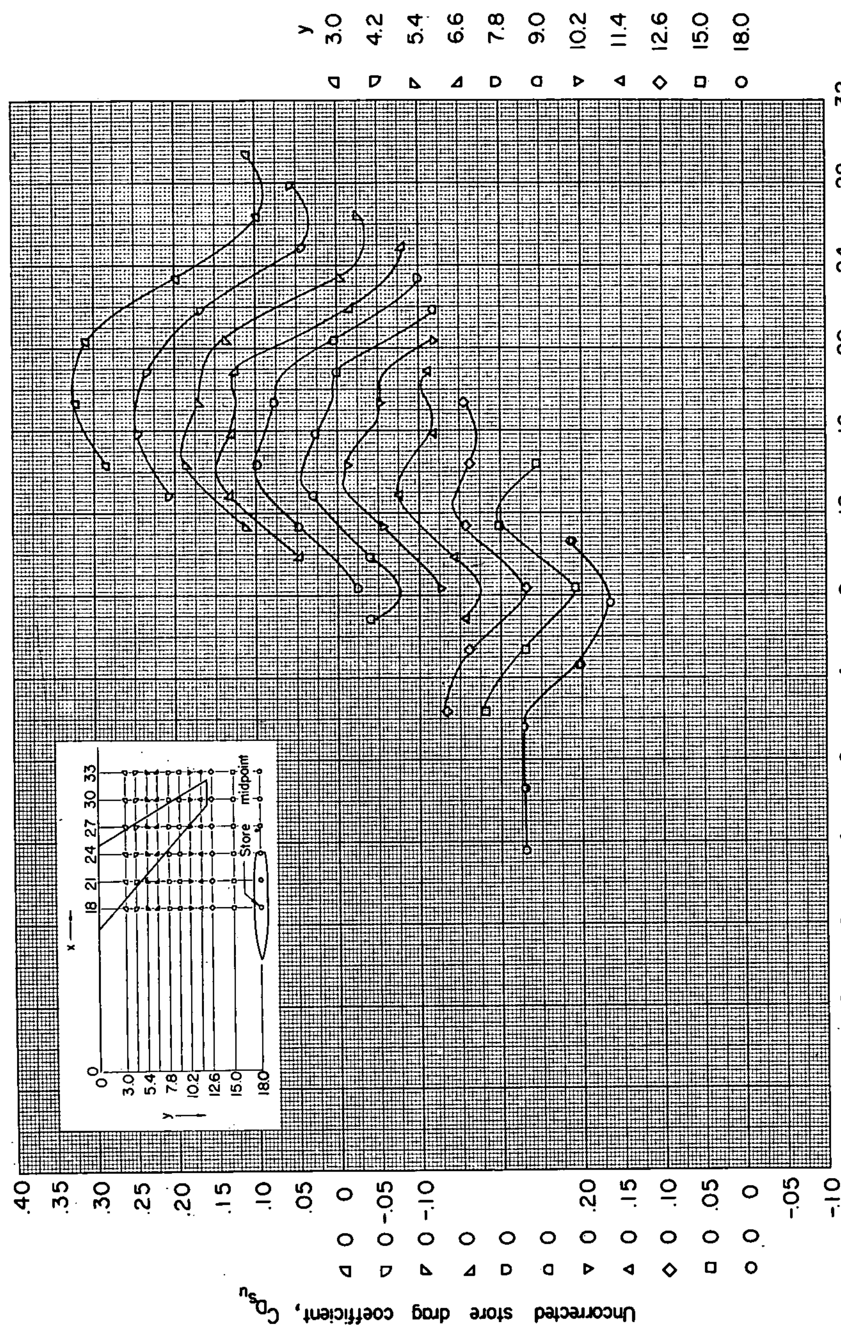
(a) $z = 1.15$ inches; $\alpha = 0^{\circ}$.

Figure 8.- Drag of store in presence of wing. (Drag uncorrected for base pressure.)



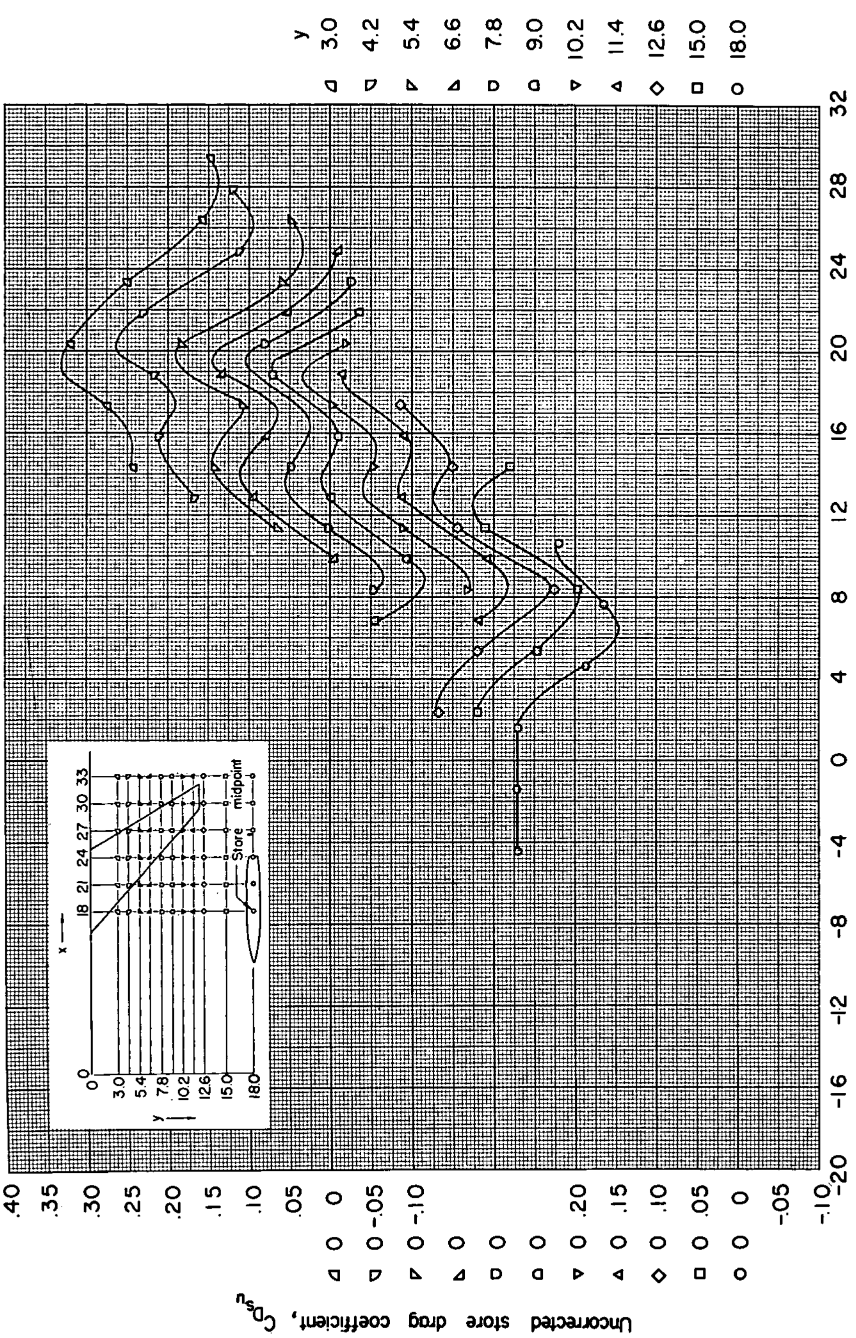
(b) z = 1.67 inches; α = 0°.

Figure 8.- Continued.



(c) z = 2.09 inches; α = 0°.

Figure 8.- Continued.



(d) z = 2.09 inches; α = 4°.

Figure 8.- Concluded.

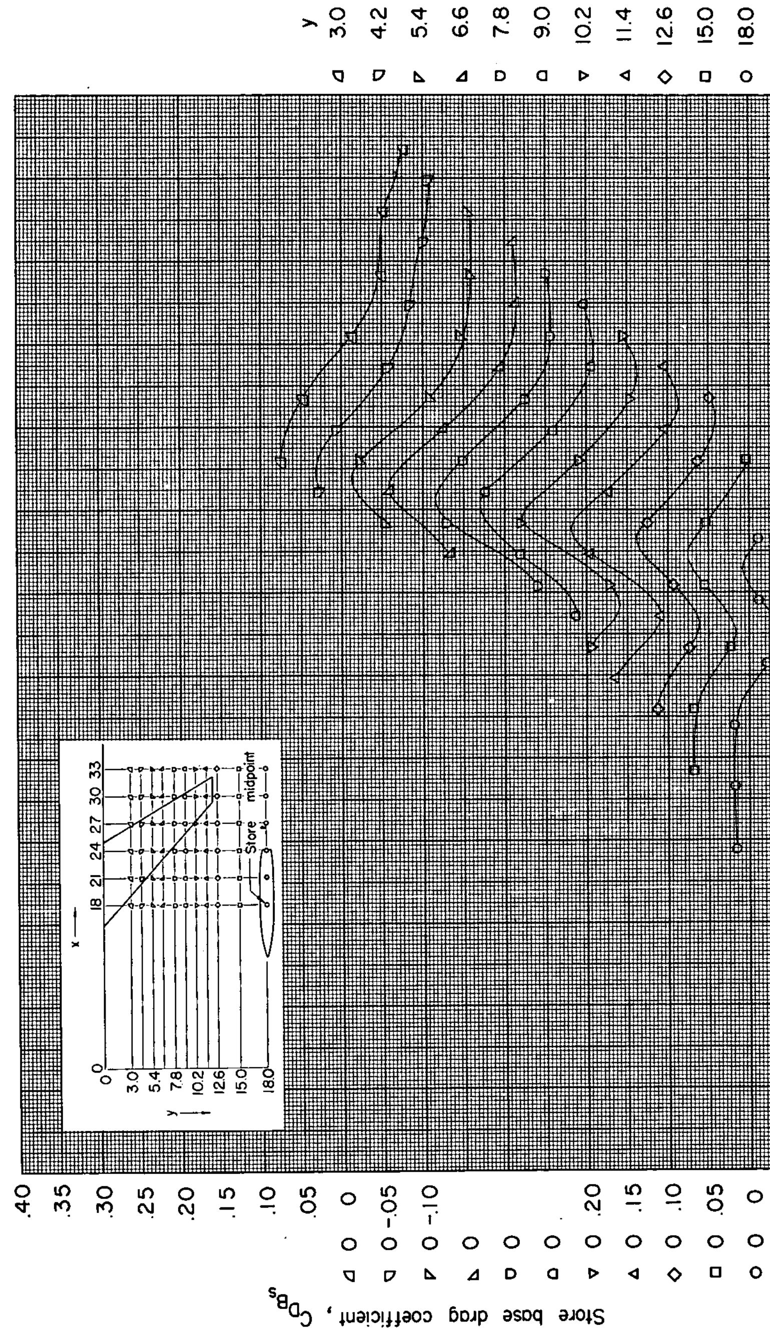
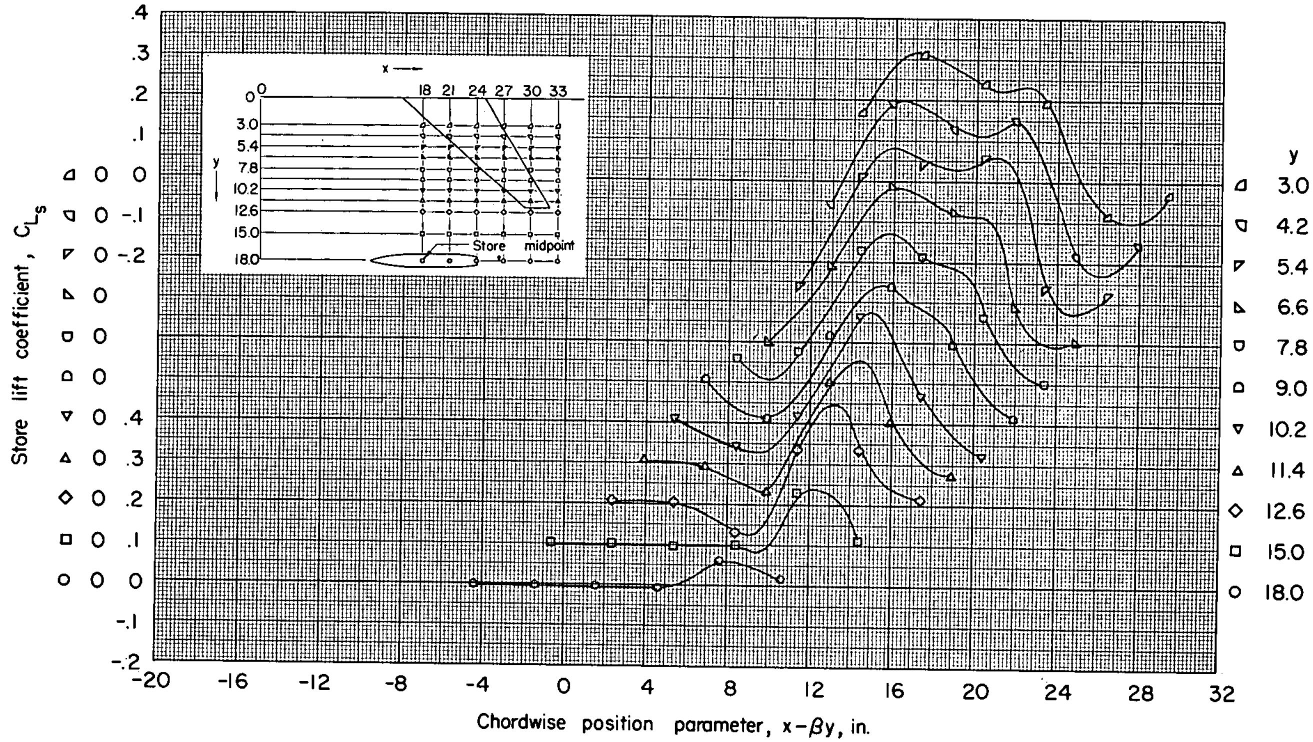
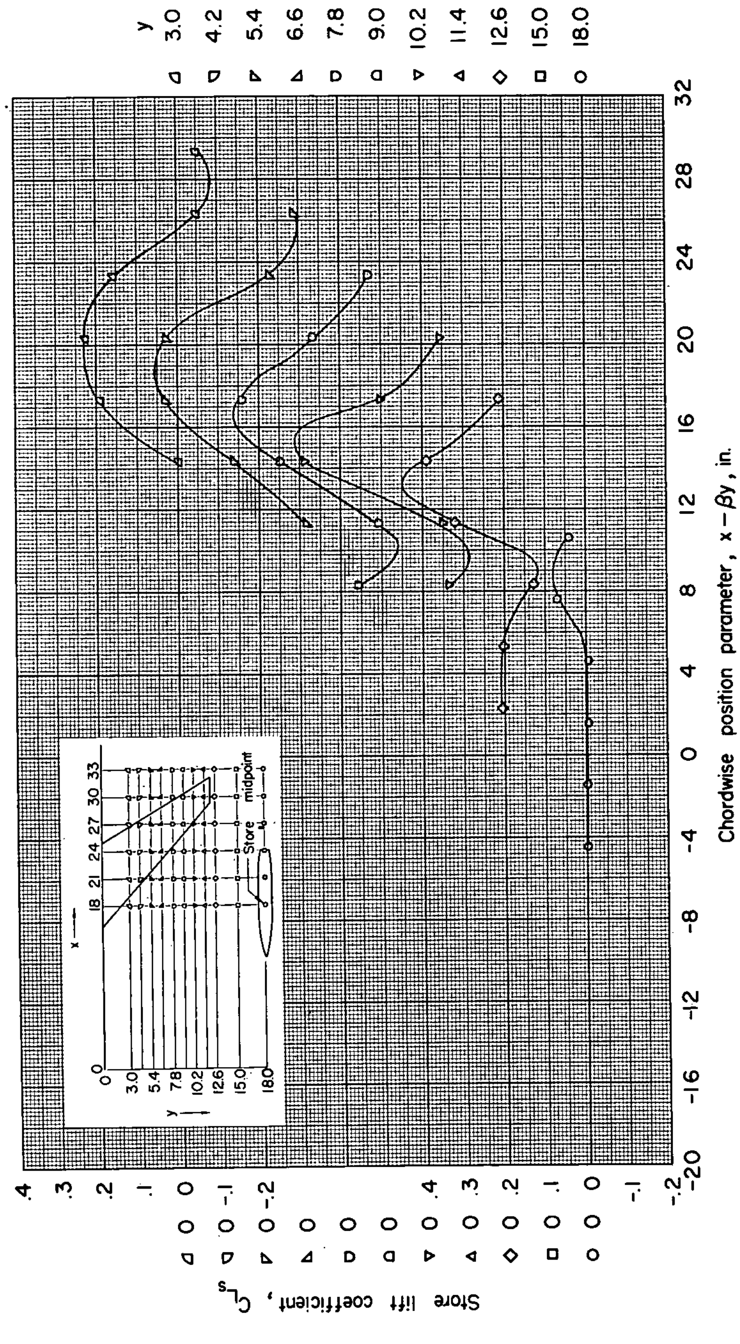


Figure 9.- Base drag of store in presence of wing. z = 1.15 inches; α = 0°.



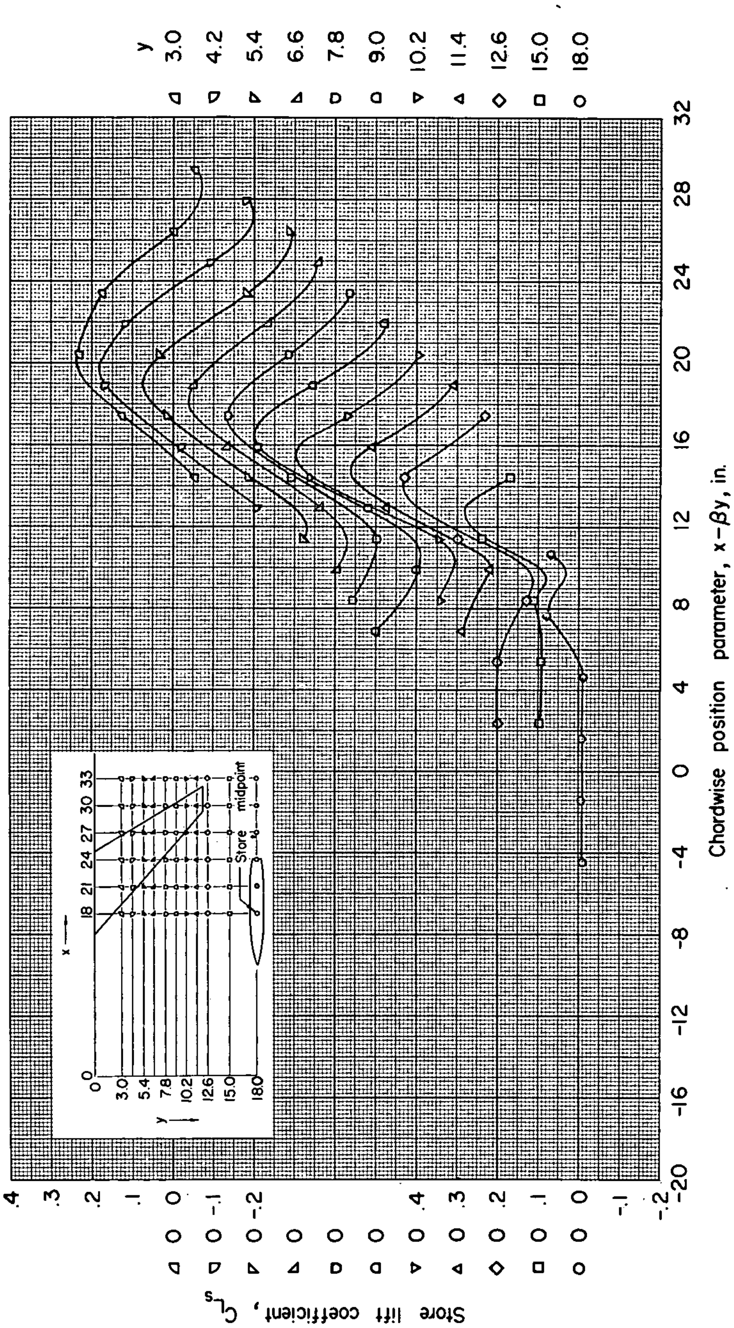
(a) $z = 1.15$ inches; $\alpha = 0^{\circ}$.

Figure 10.- Lift of store in presence of wing.



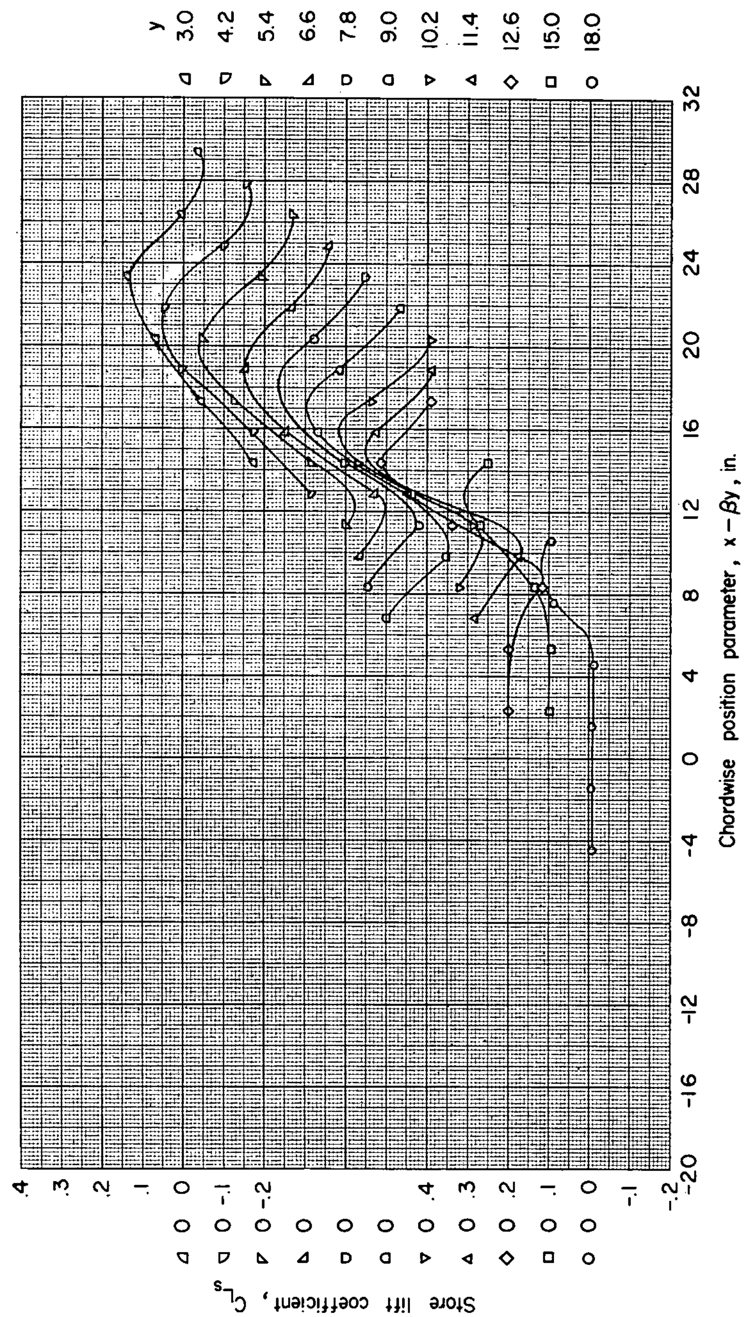
(b) z = 1.67 inches; α = 0°.

Figure 10.- Continued.



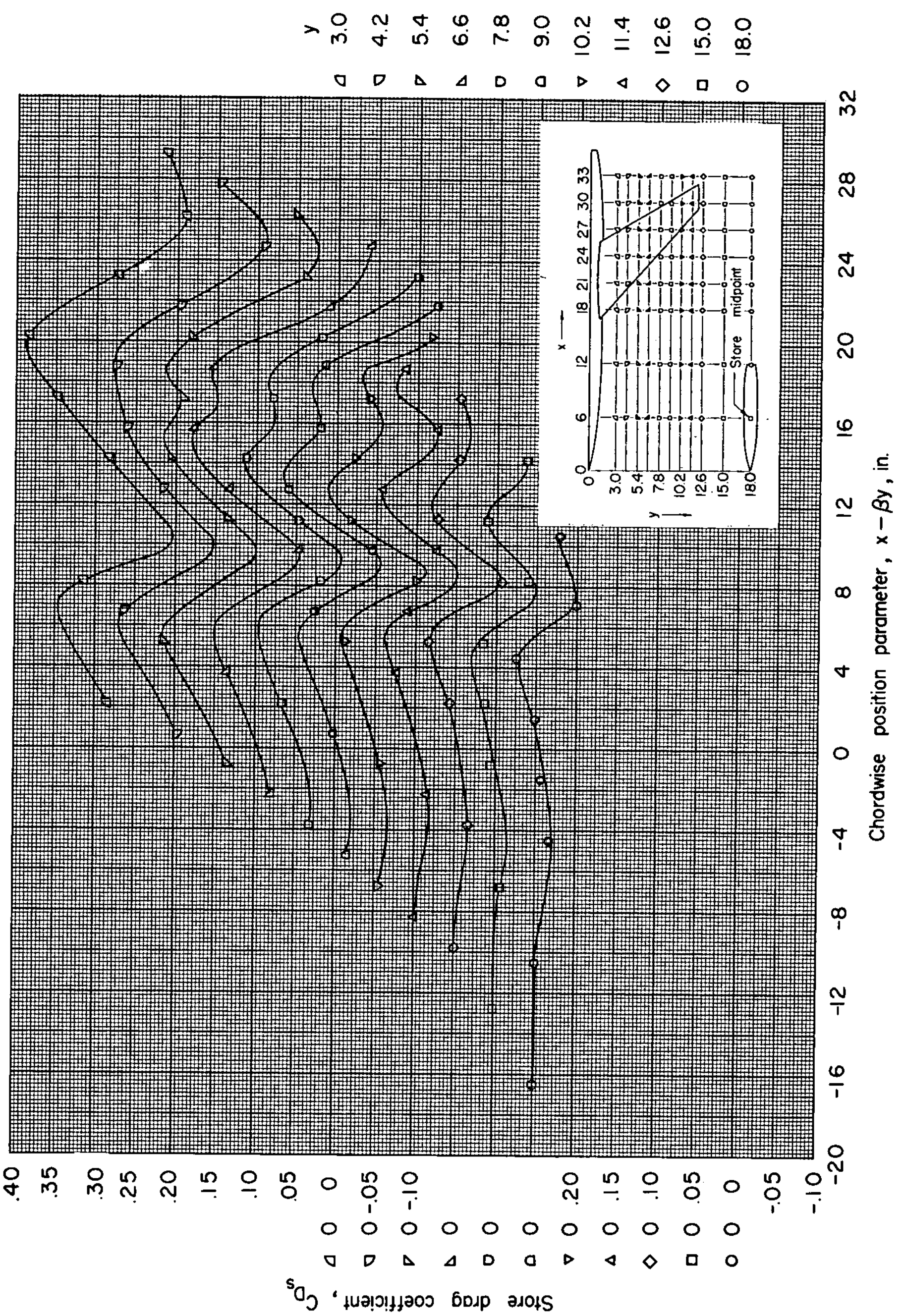
(c) z = 2.09 inches; α = 0°.

Figure 10.- Continued.



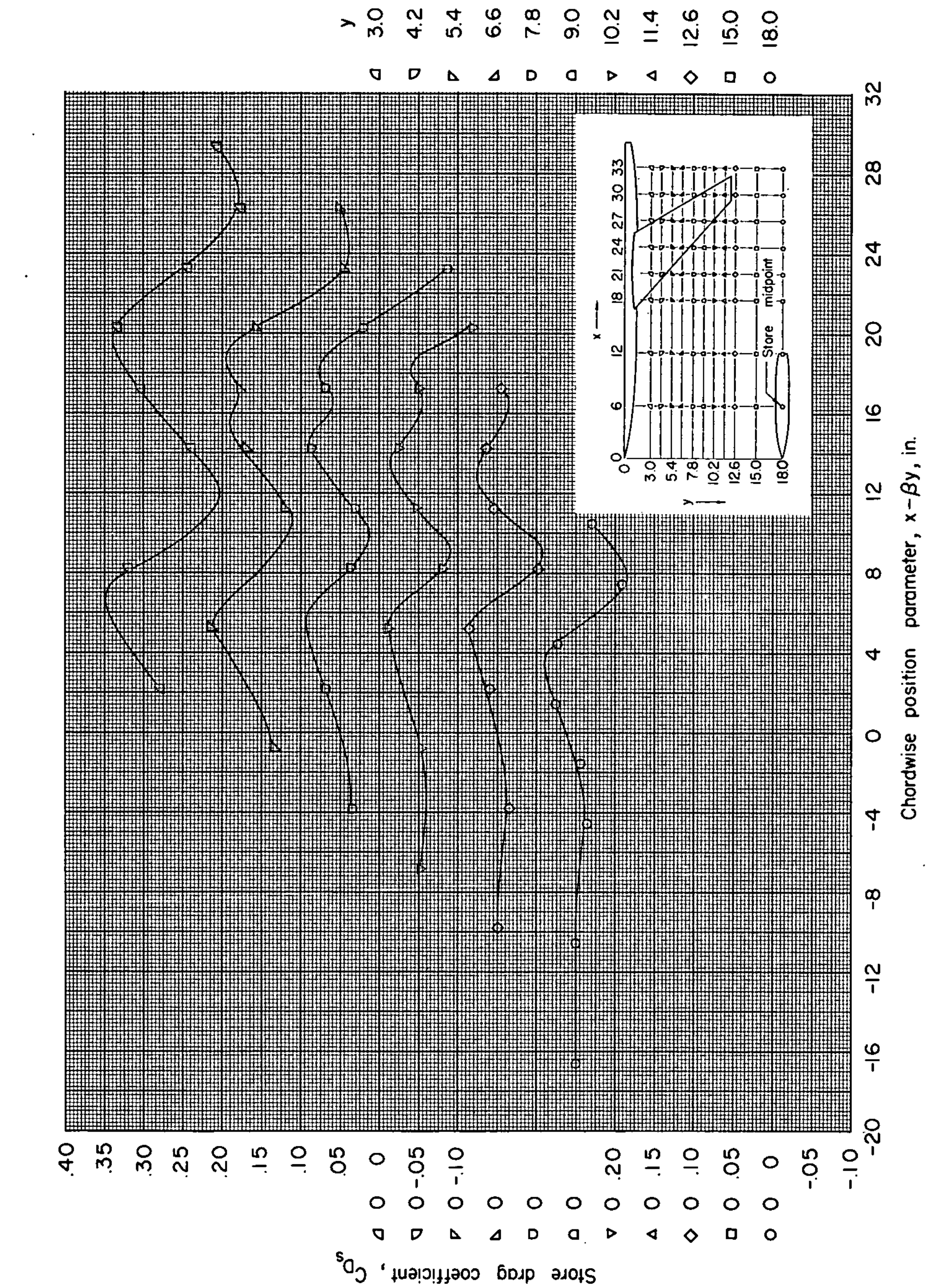
(d) z = 2.09 inches; α = 4°.

Figure 10.- Concluded.



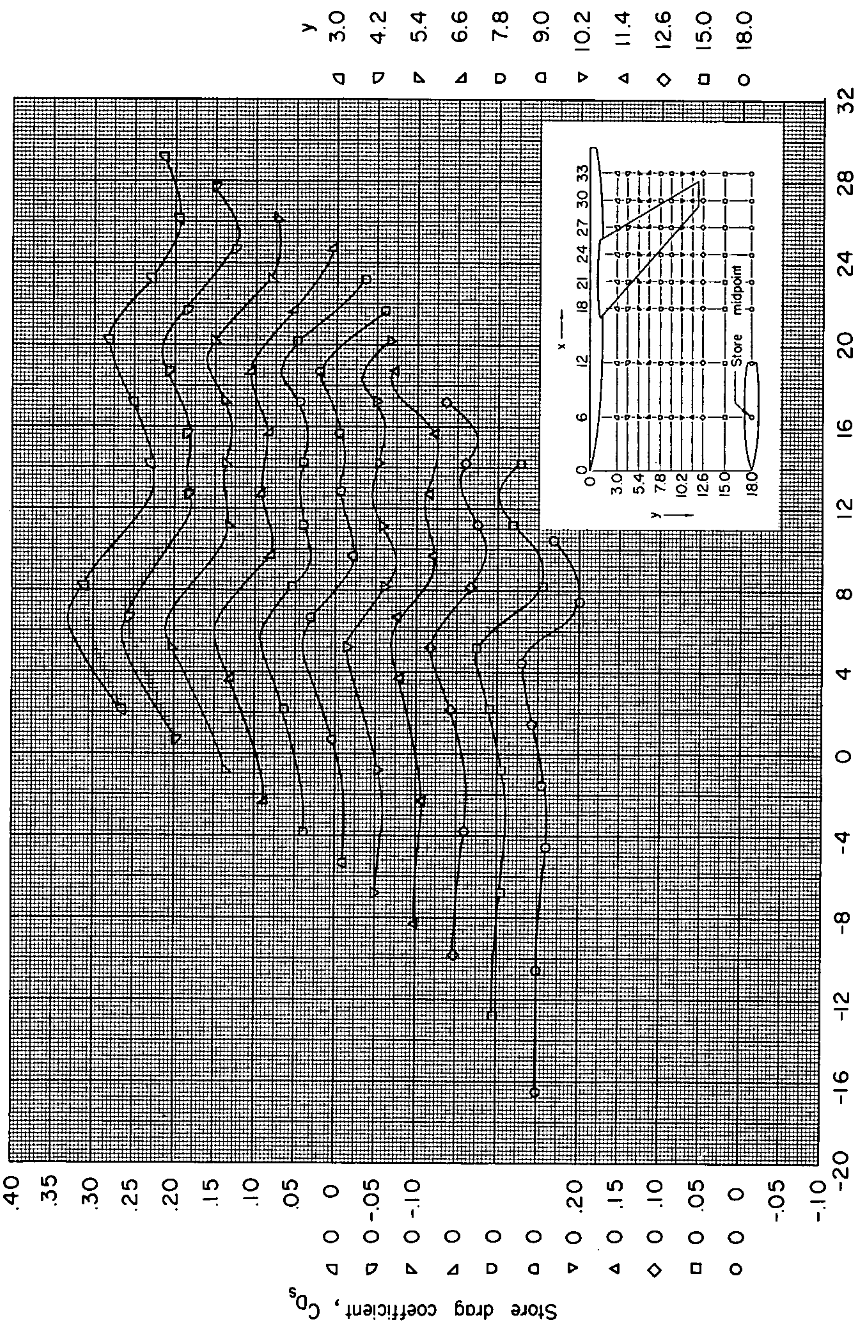
(a) z = 1.15 inches; α = 0°.

Figure 11.- Drag of store in presence of wing-fuselage combination.



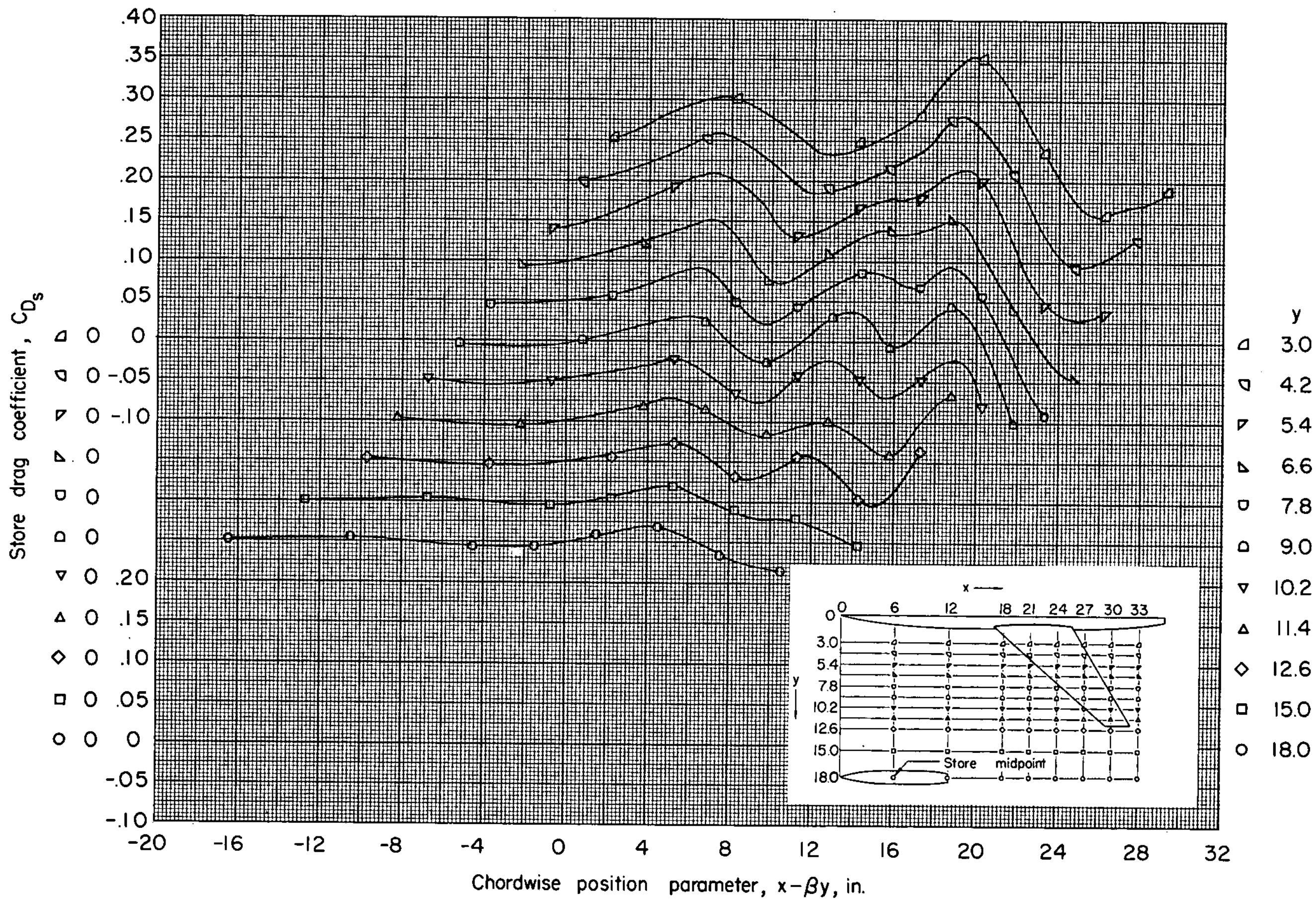
(b) $z = 1.67$ inches; $\alpha = 0^{\circ}$.

Figure 11.- Continued.



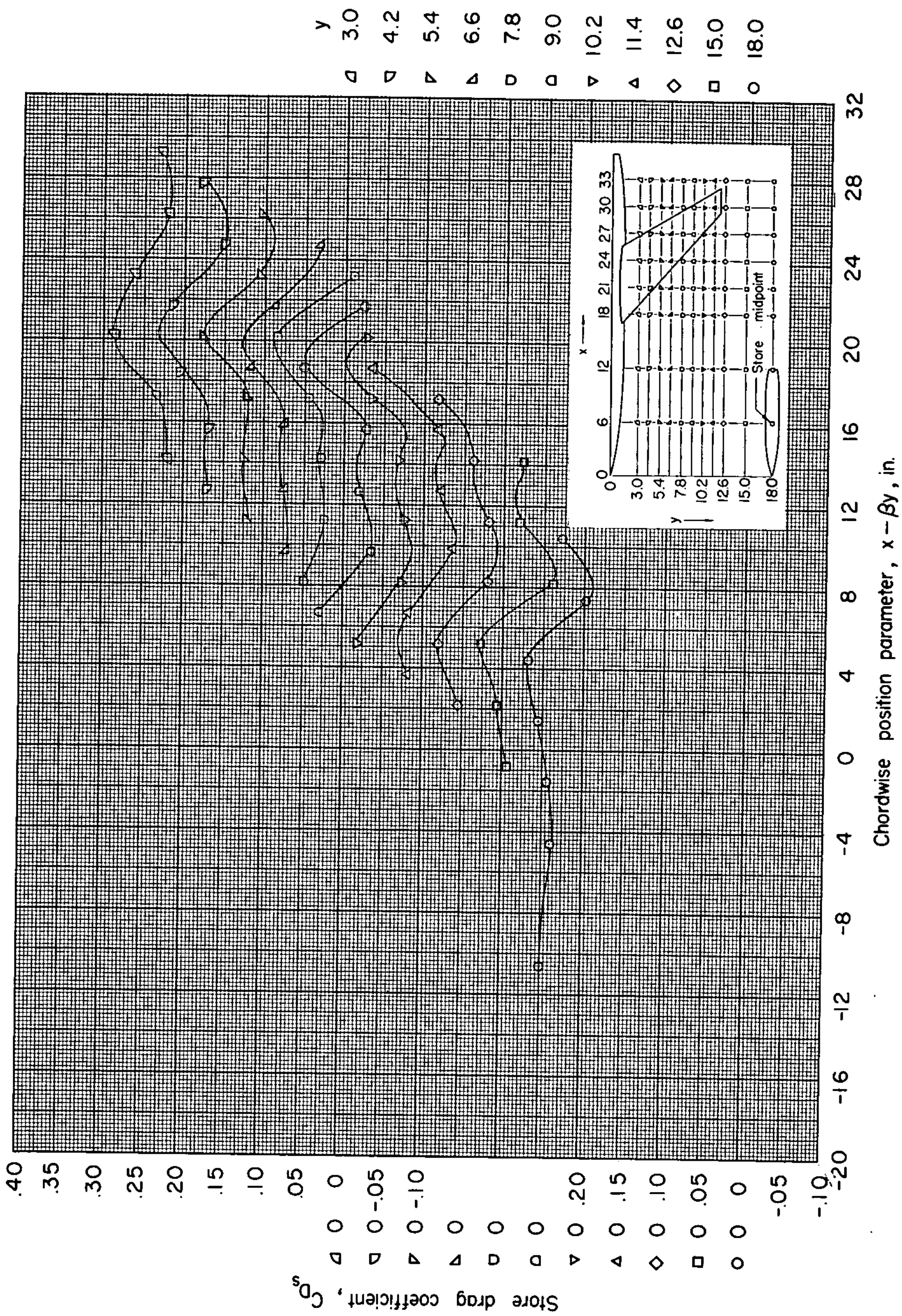
(c) z = 2.09 inches; α = 0°.

Figure 11.- Continued.



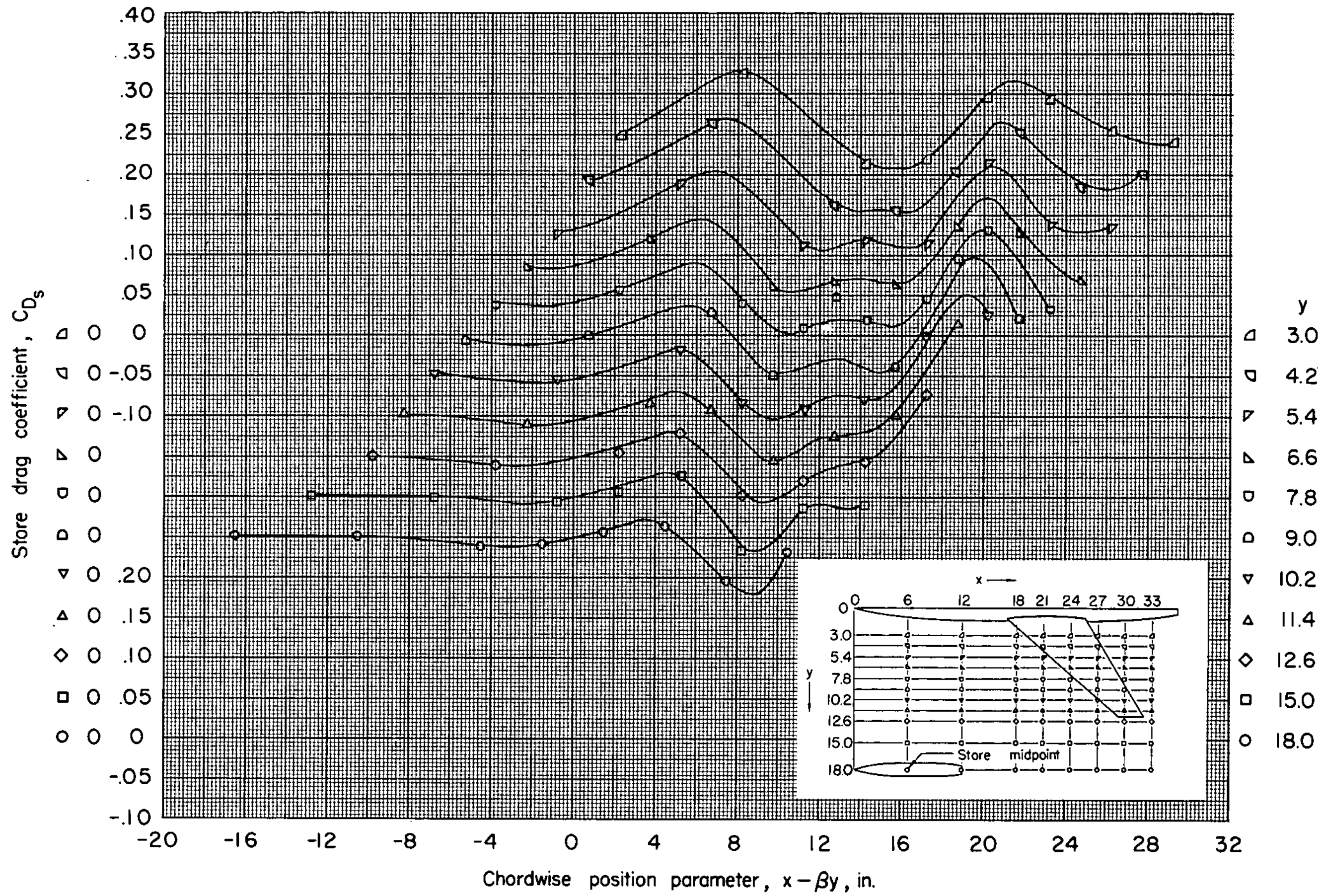
(d) z = -1.31 inches; α = 0°.

Figure 11.- Continued.



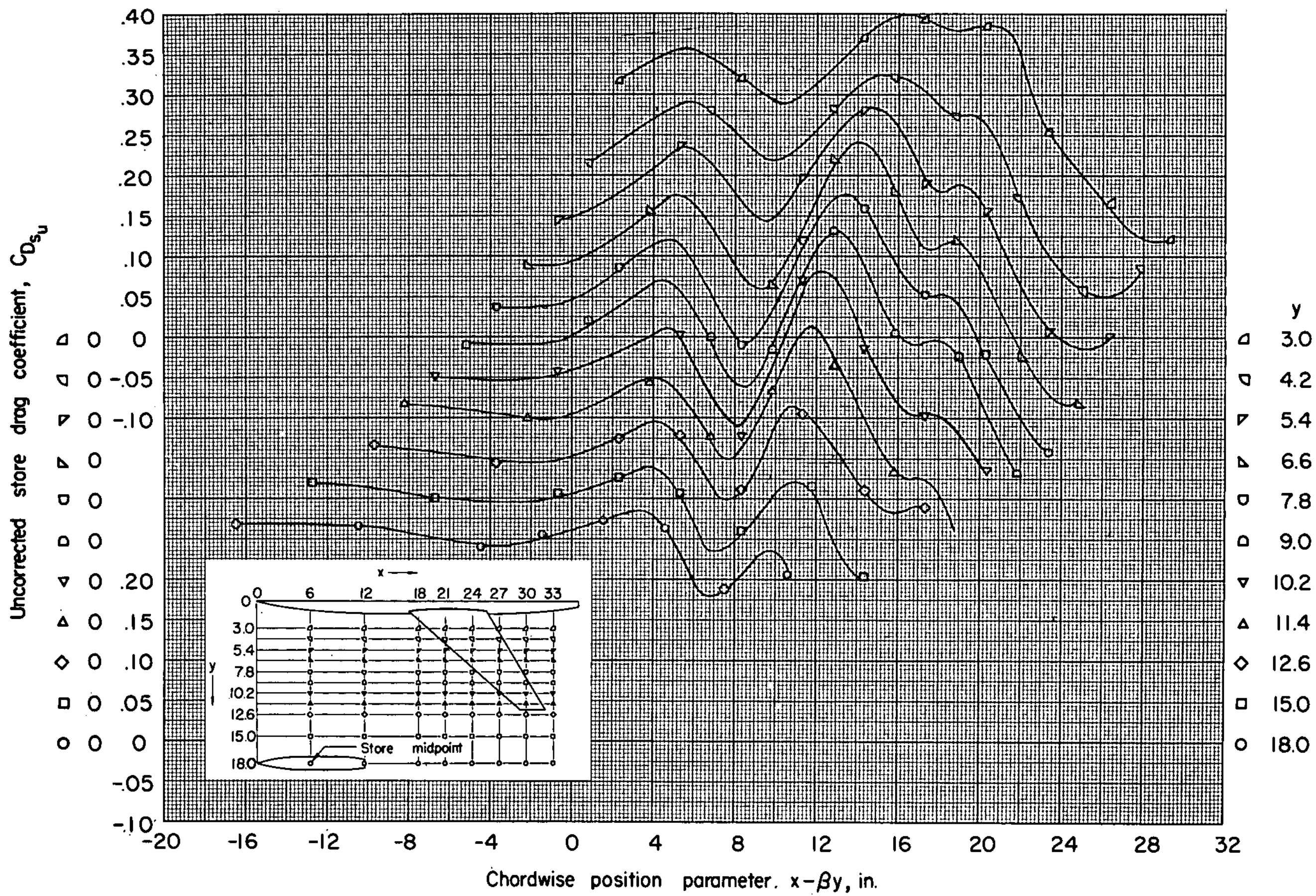
(e) z = 2.09 inches; α = 2°.

Figure 11.- Continued.



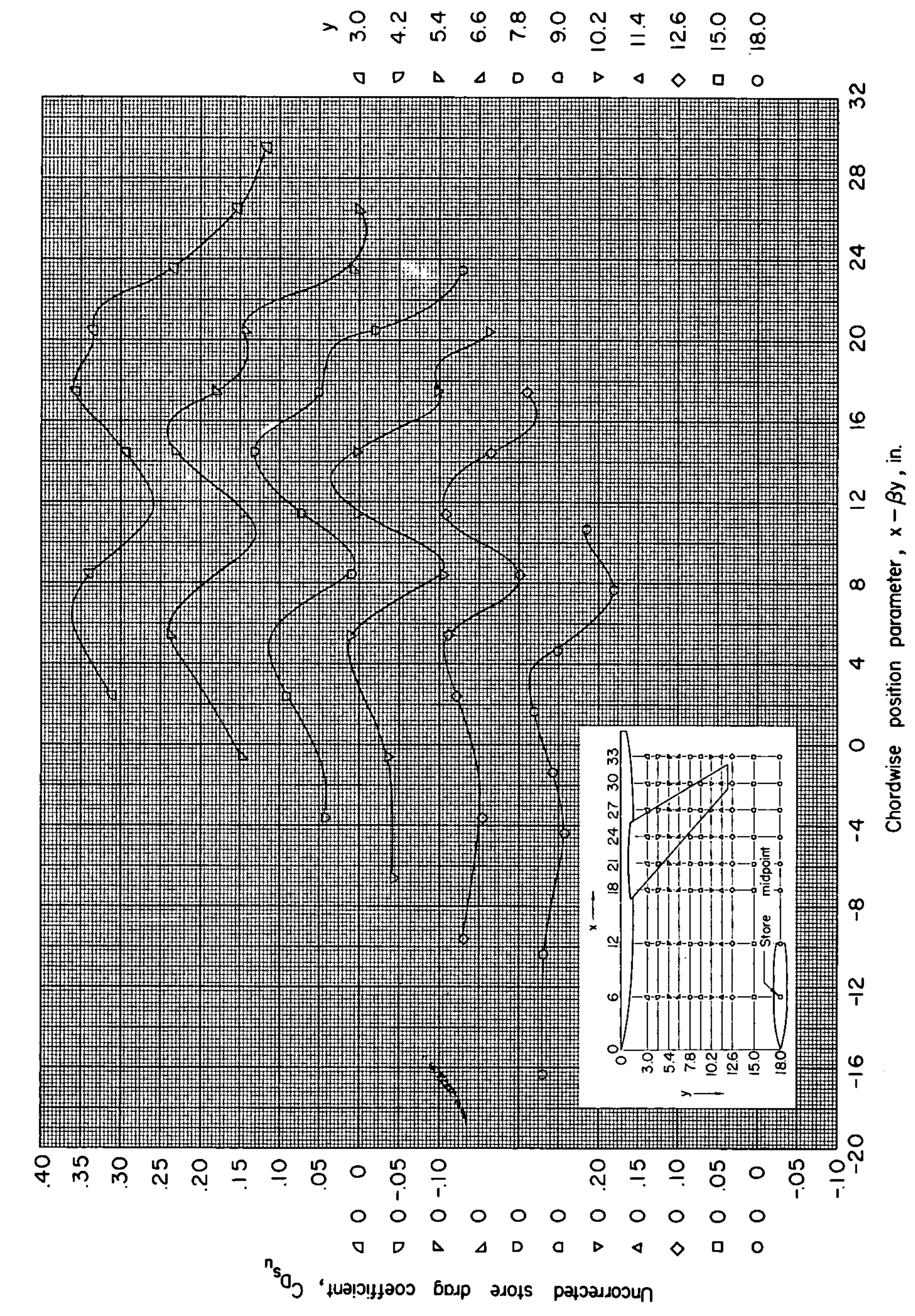
(f) $z = 2.09$ inches; $\alpha = 4^{\circ}$.

Figure 11.- Concluded.



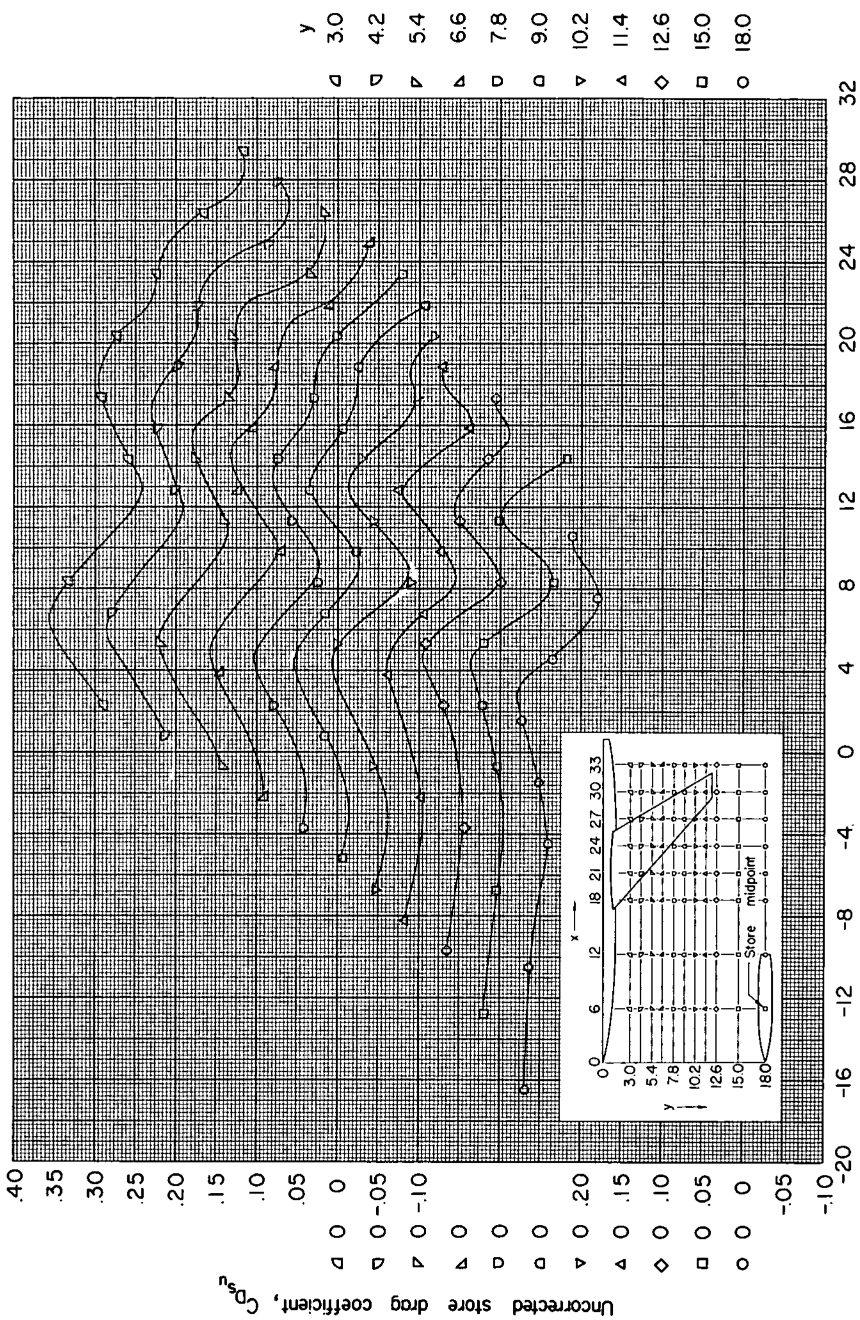
(a) $z = 1.15$ inches; $\alpha = 0^{\circ}$.

Figure 12.- Drag of store in presence of wing-fuselage combination. (Drag uncorrected for base pressure.)



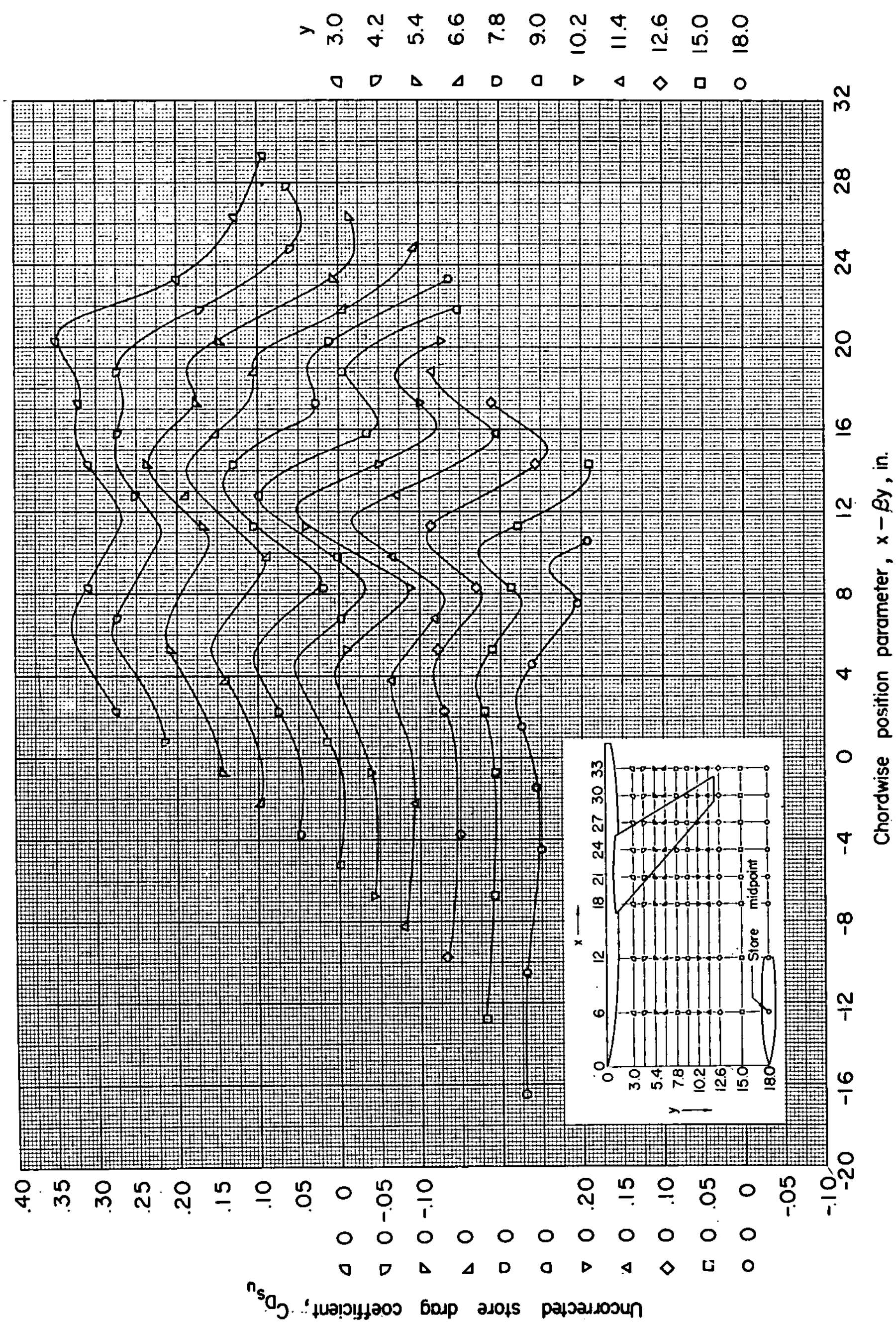
(b) z = 1.67 inches; α = 0°.

Figure 12.- Continued.



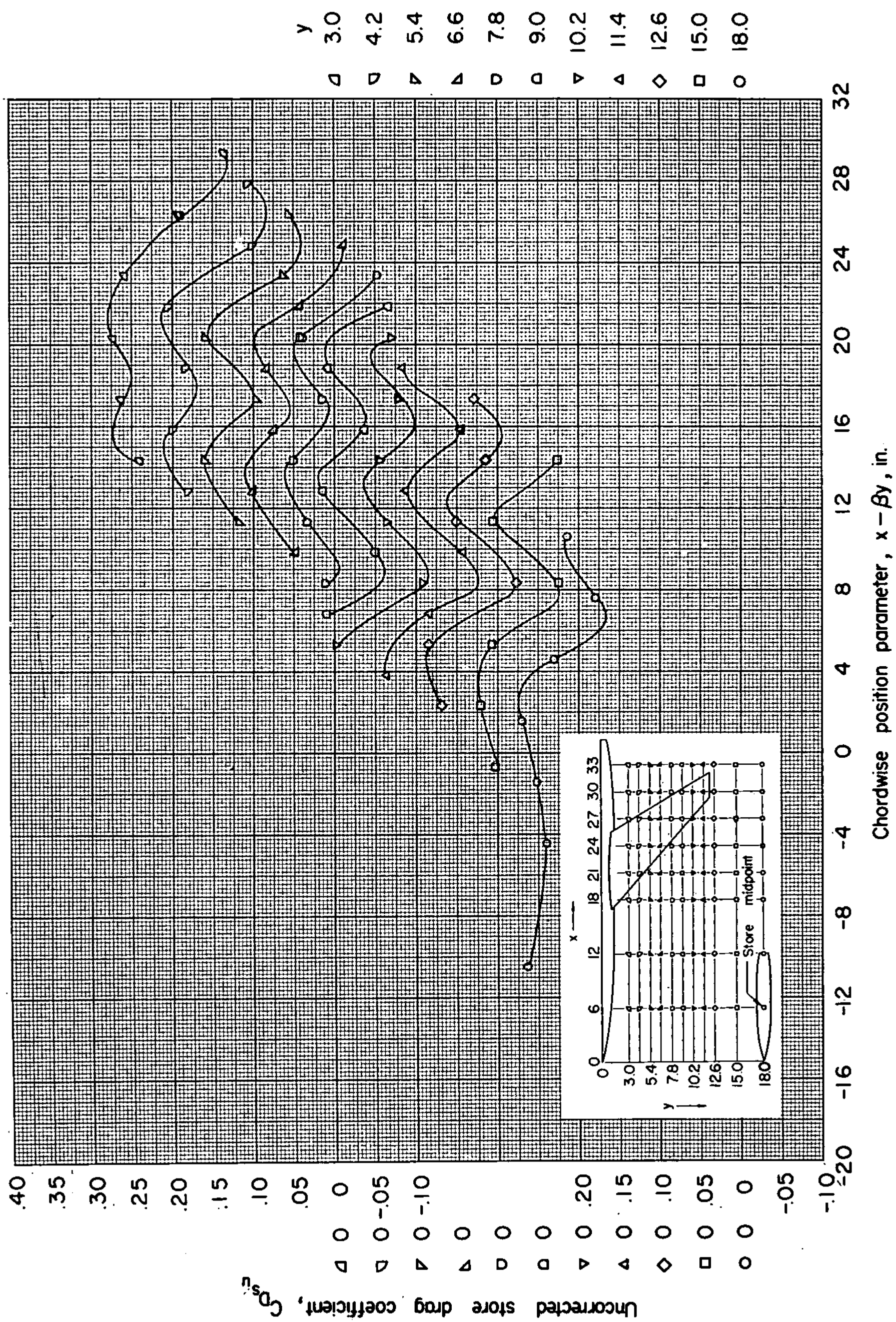
(c) z = 2.09 inches; α = 0°.

Figure 12.- Continued.



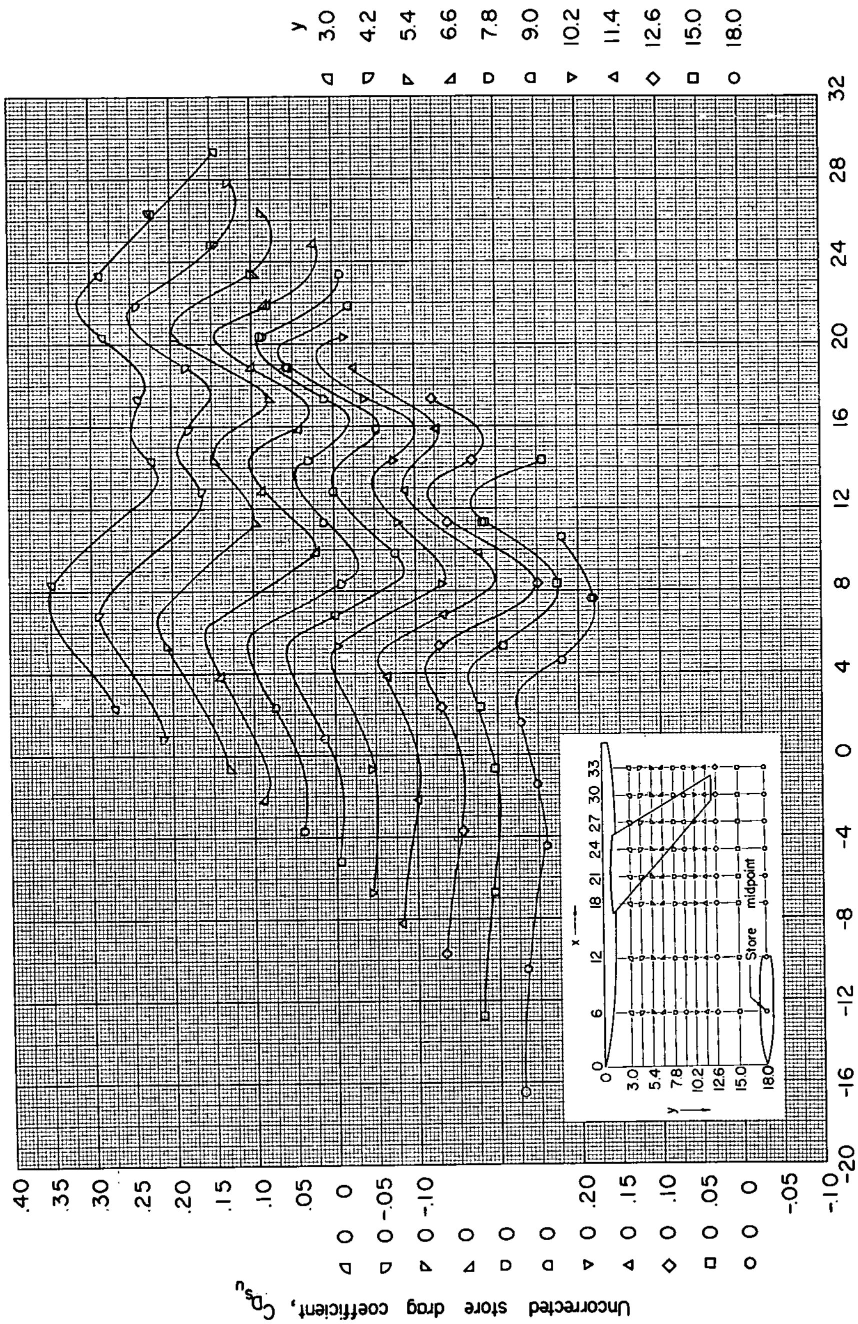
(d) $z = -1.31$ inches; $\alpha = 0^{\circ}$.

Figure 12.- Continued.



(e) $z = 2.09$ inches; $\alpha = 2^{\circ}$.

Figure 12.- Continued.



(f) z = 2.09 inches; α = 4°.

Figure 12.- Concluded.

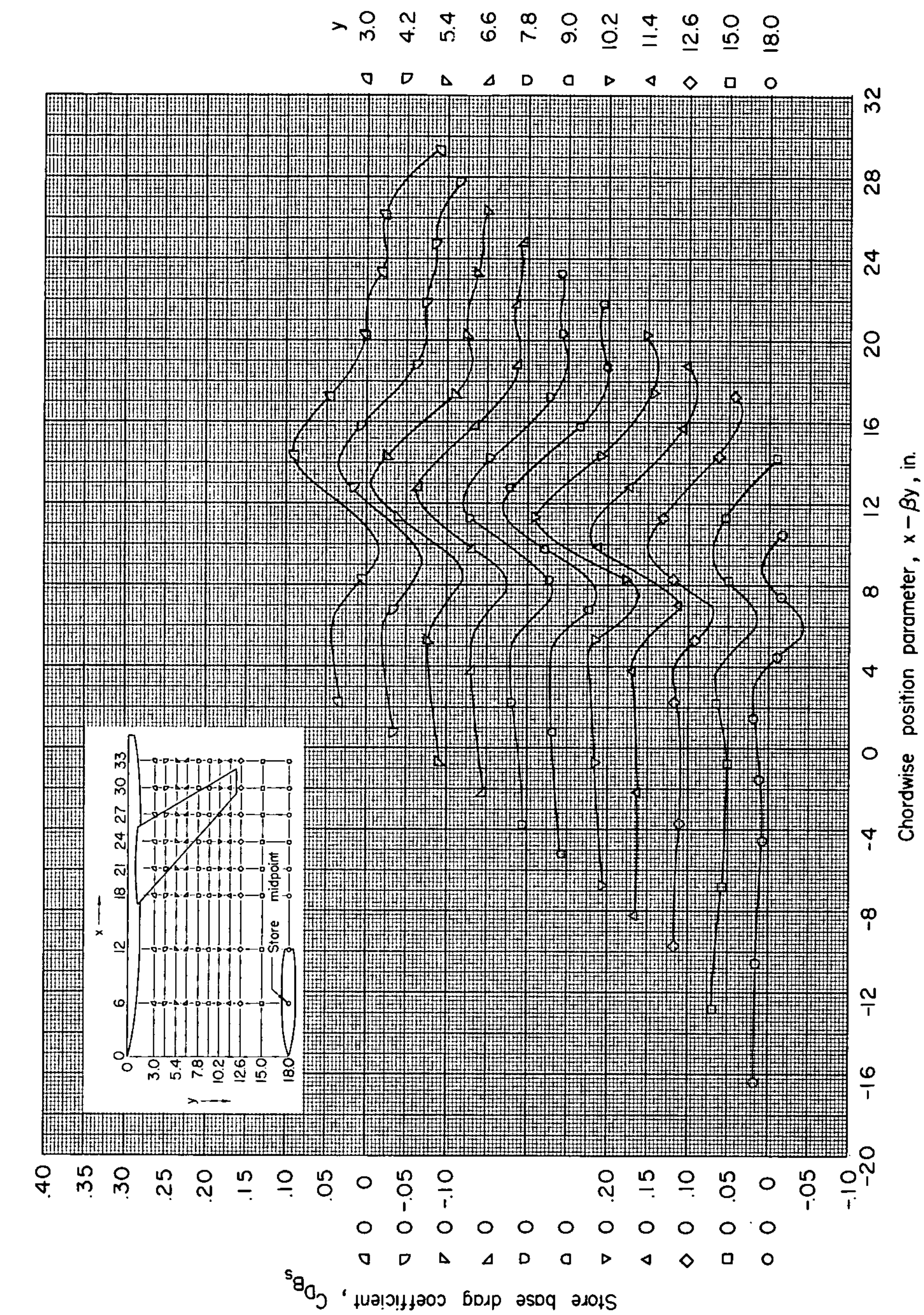
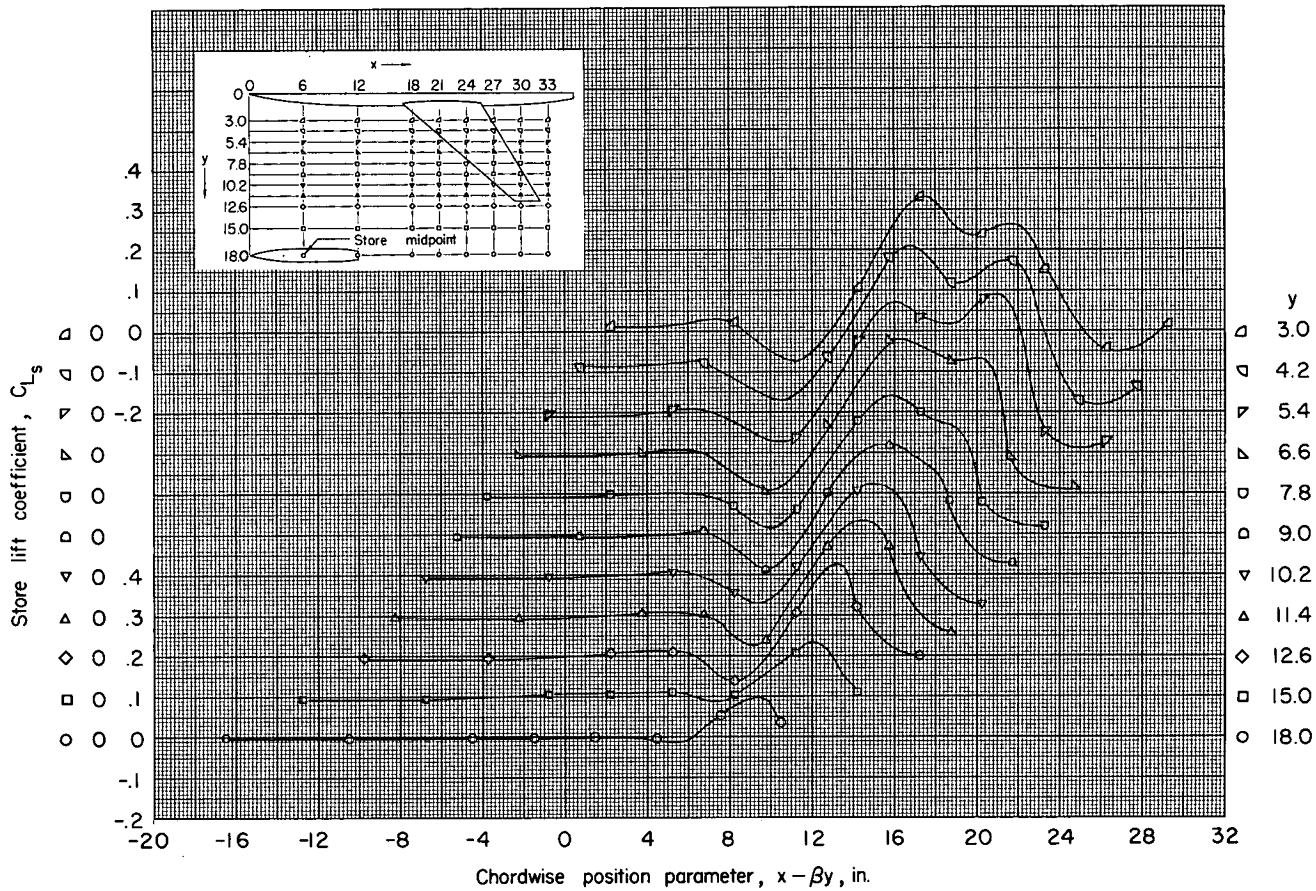
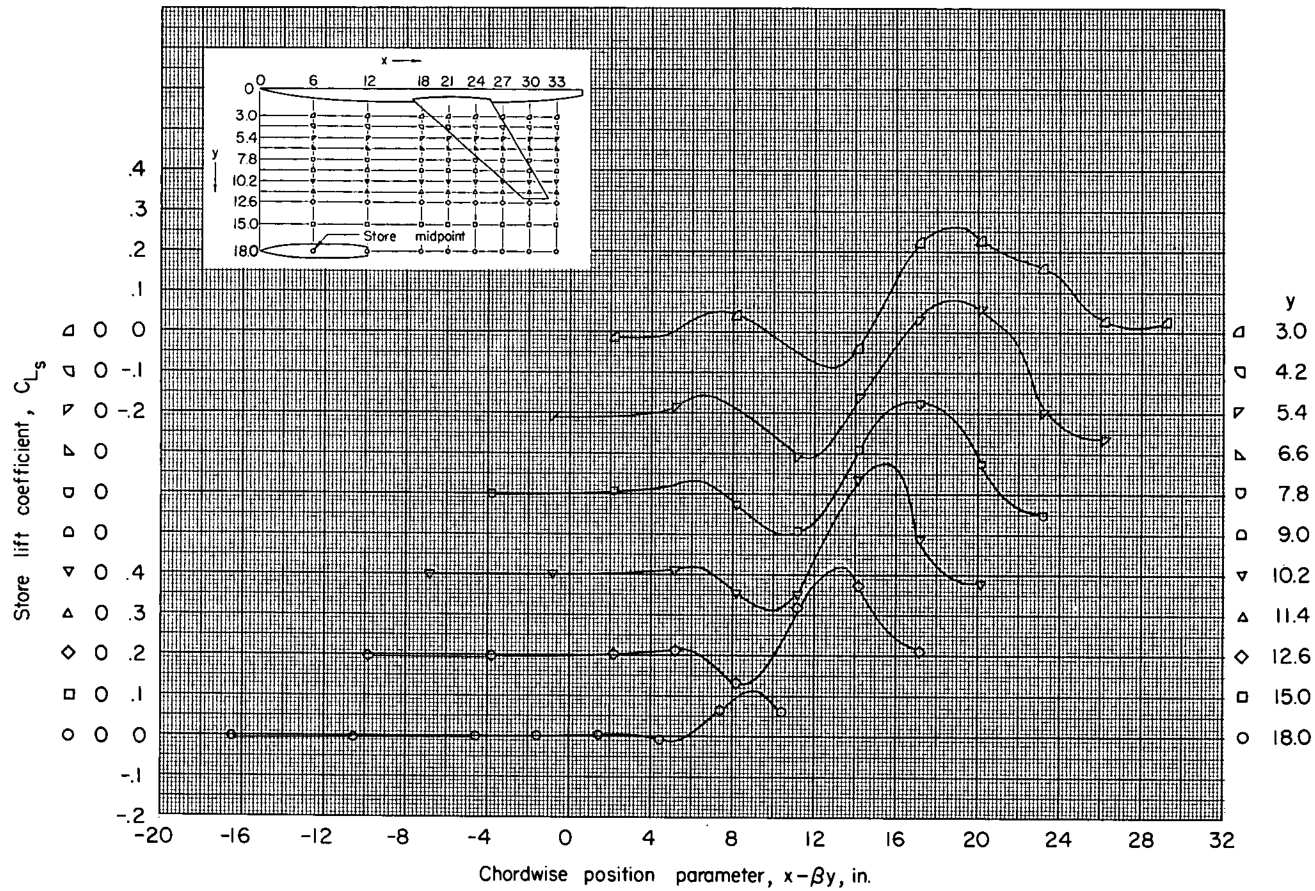


Figure 13.- Base drag of store in presence of wing-fuselage combination. $z = 1.15$ inches; $\alpha = 0^{\circ}$.



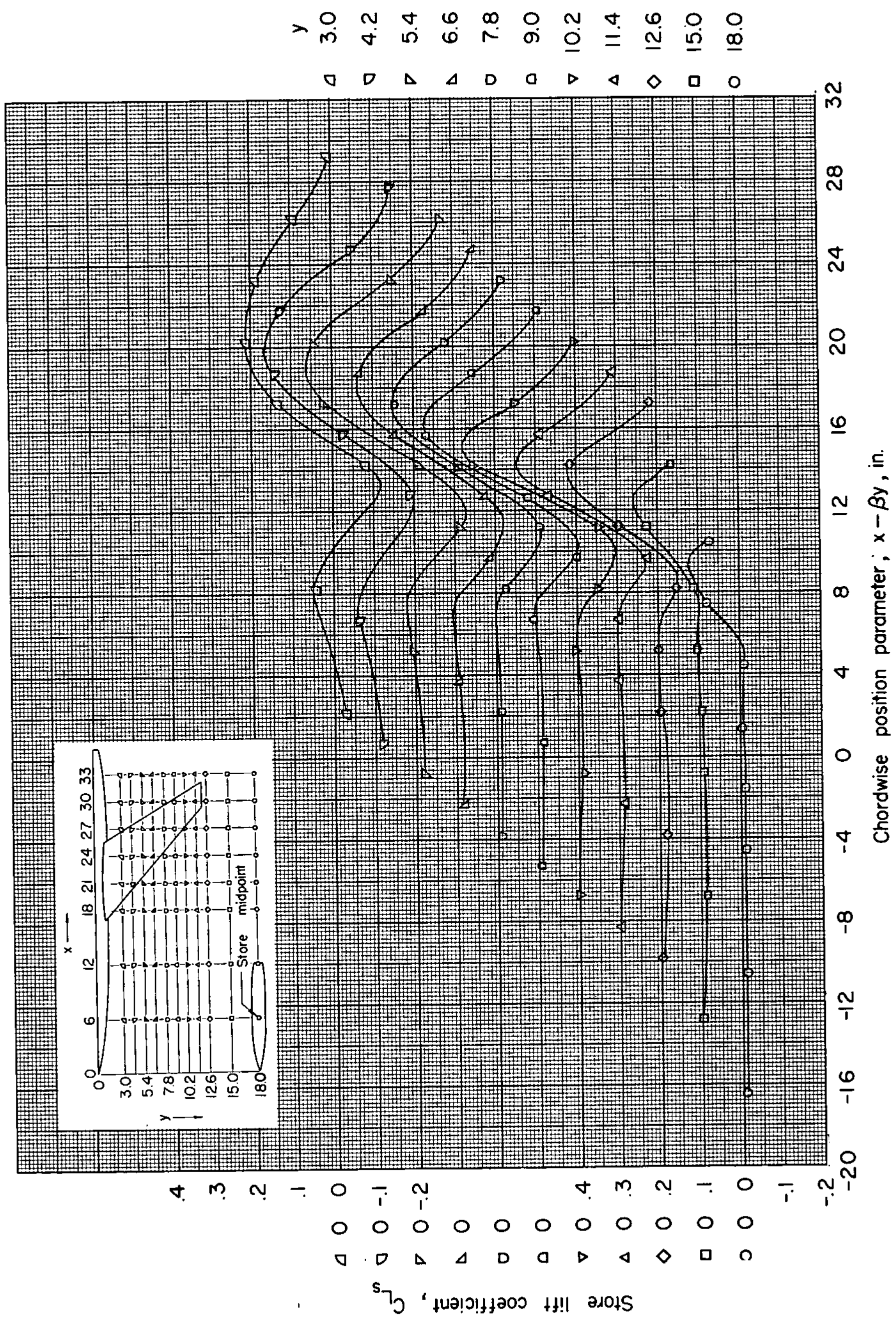
(a) $z = 1.15$ inches; $\alpha = 0^{\circ}$.

Figure 14.- Lift of store in presence of wing-fuselage combination.



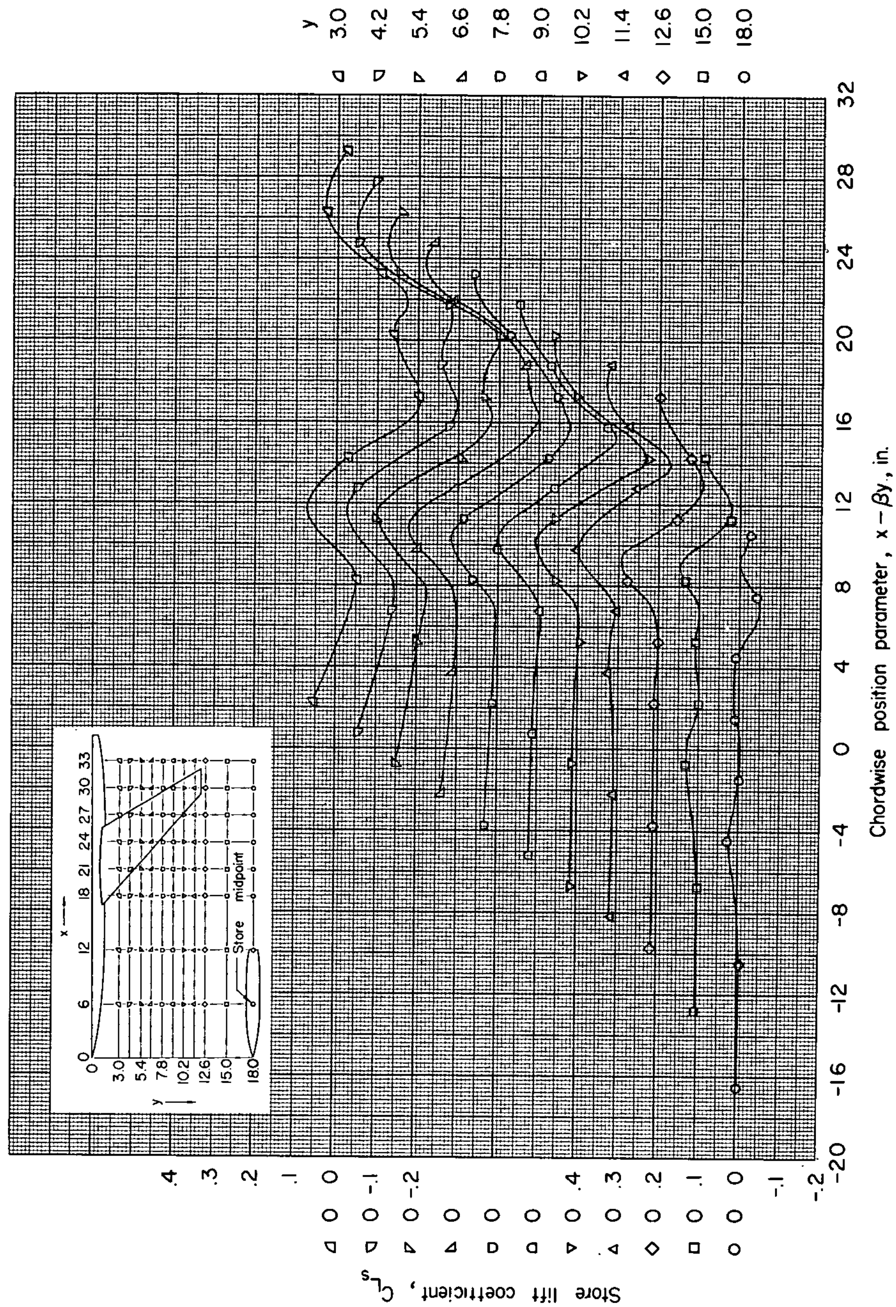
(b) z = 1.67 inches; $\alpha = 0^{\circ}$.

Figure 14.- Continued.



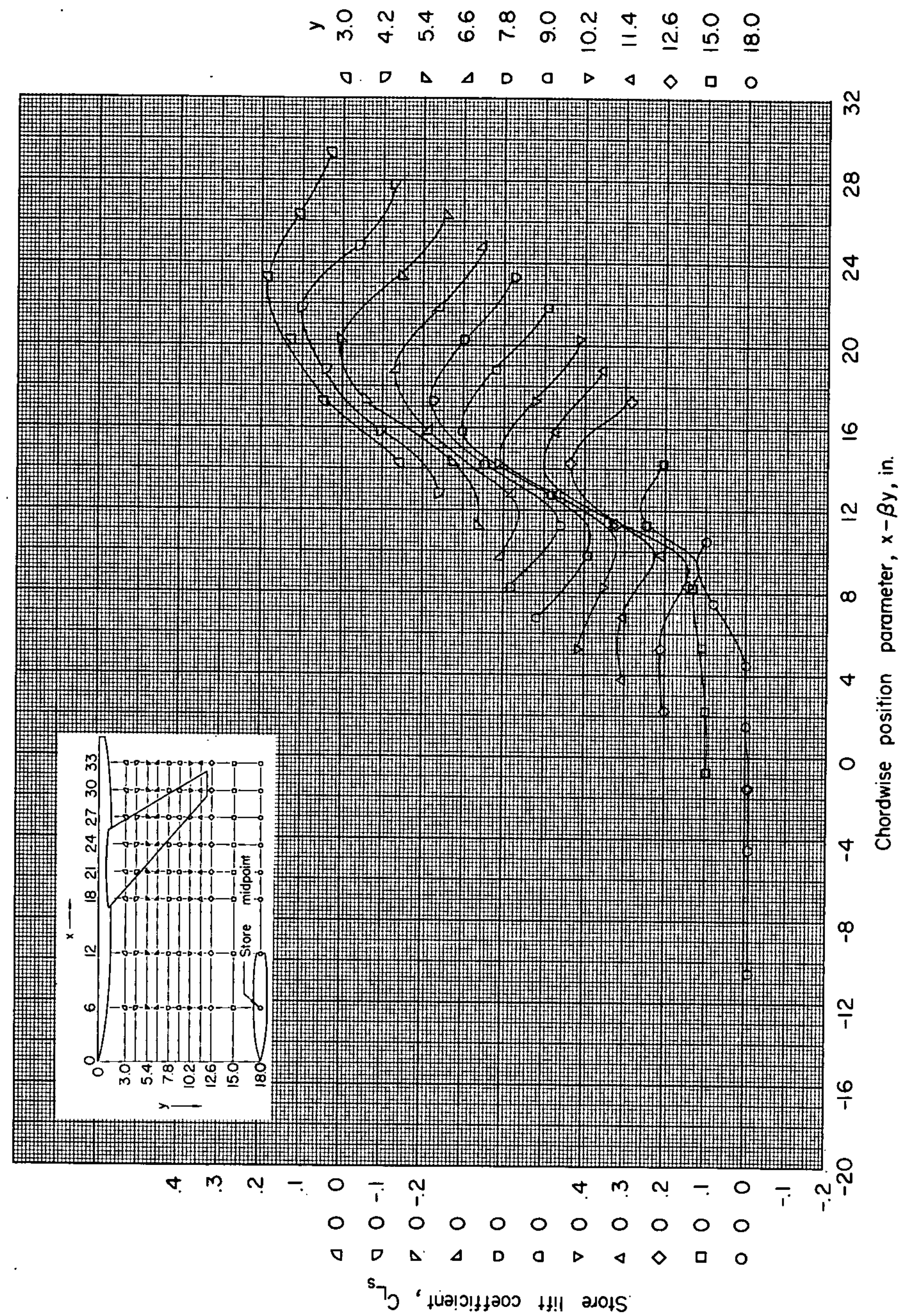
(c) $z = 2.09$ inches; $\alpha = 0^{\circ}$.

Figure 14.- Continued.



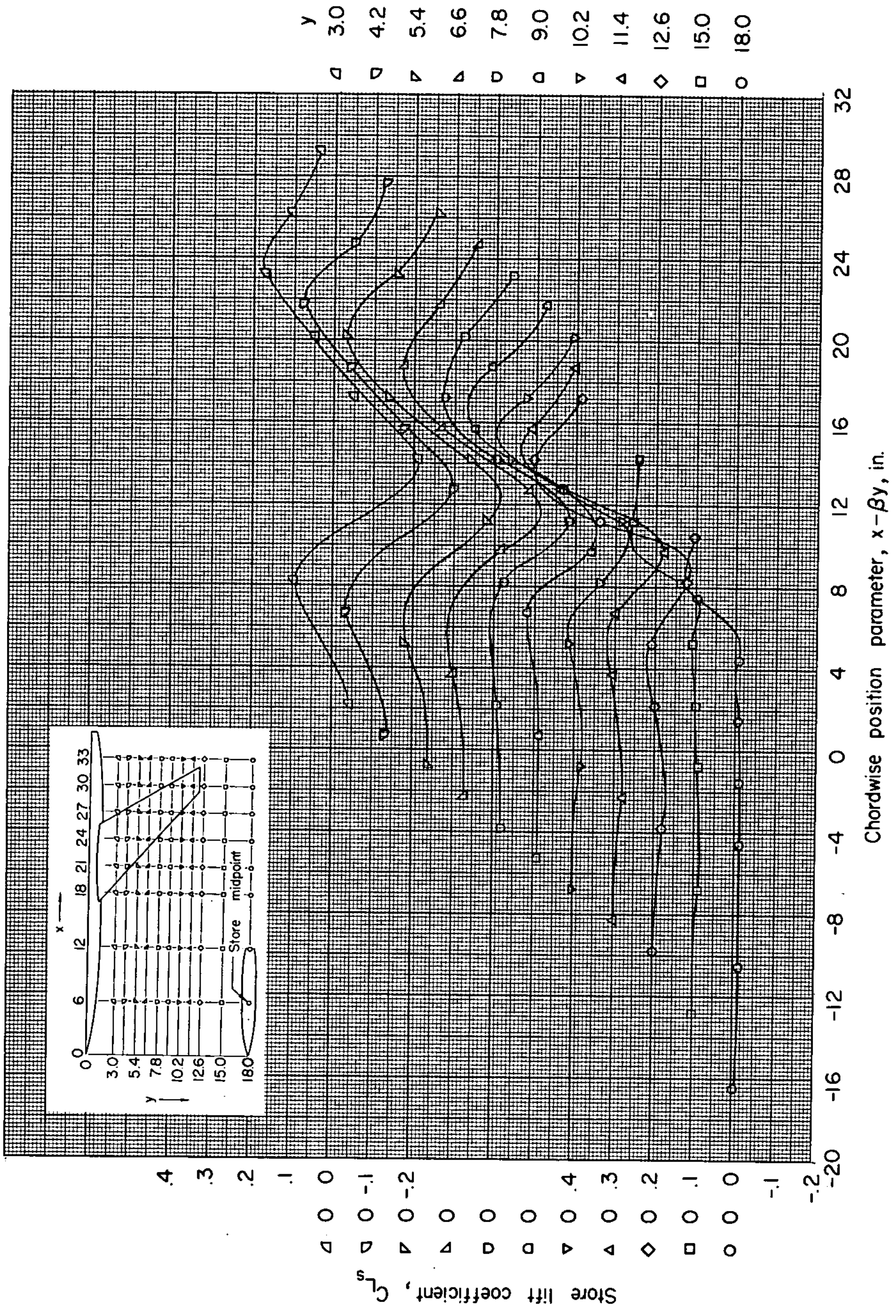
(d) z = -1.31 inches; α = 0°.

Figure 14.- Continued.



(e) $z = 2.09$ inches; $\alpha = 2^{\circ}$.

Figure 14.- Continued.



(f) z = 2.09 inches; α = 4°.

Figure 14.- Concluded.

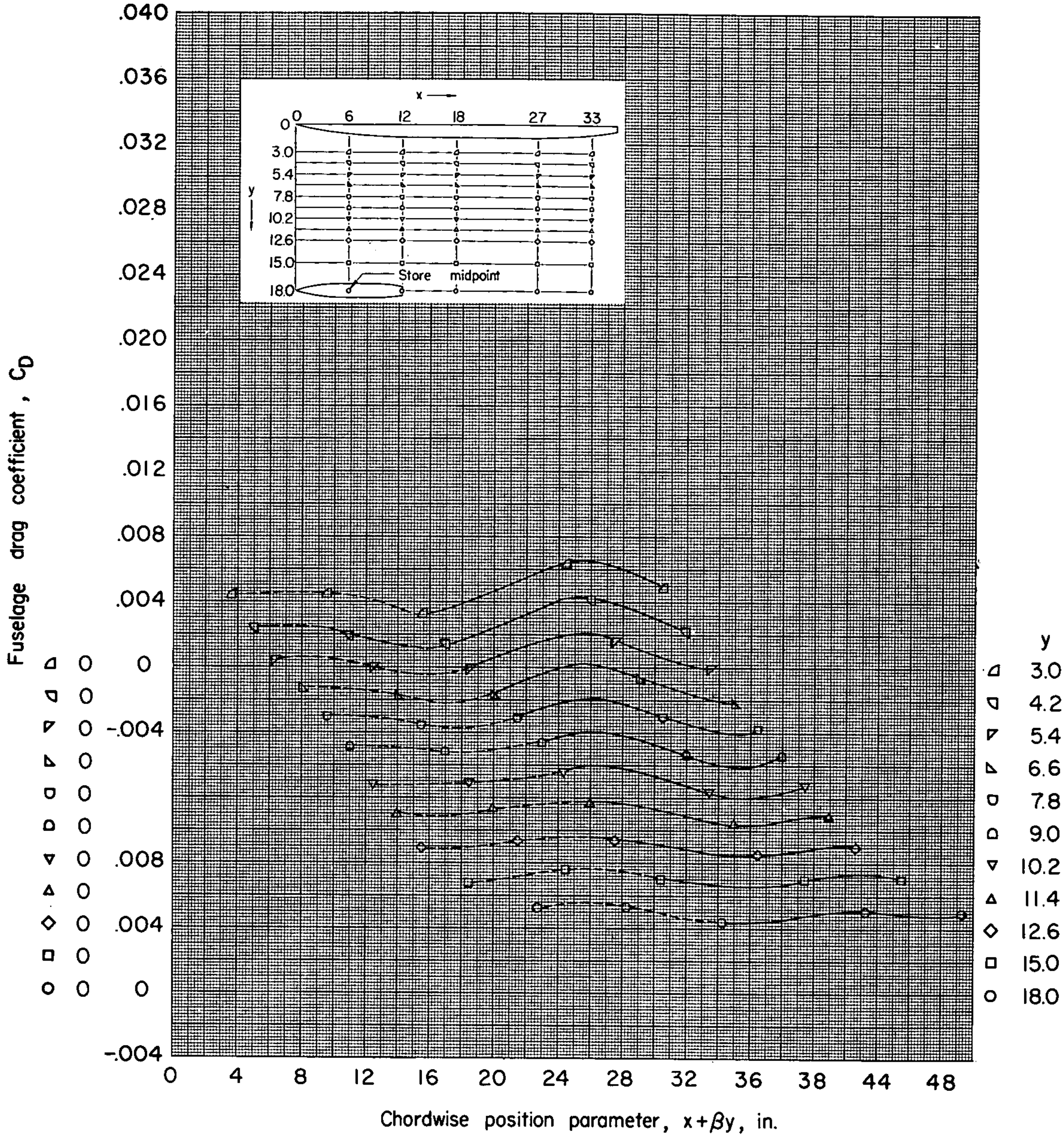


Figure 15.- Drag of fuselage in presence of store. $z = 1.15$ inches; $\alpha = 0^{\circ}$. Dashed lines indicate presence of interference of store sting.

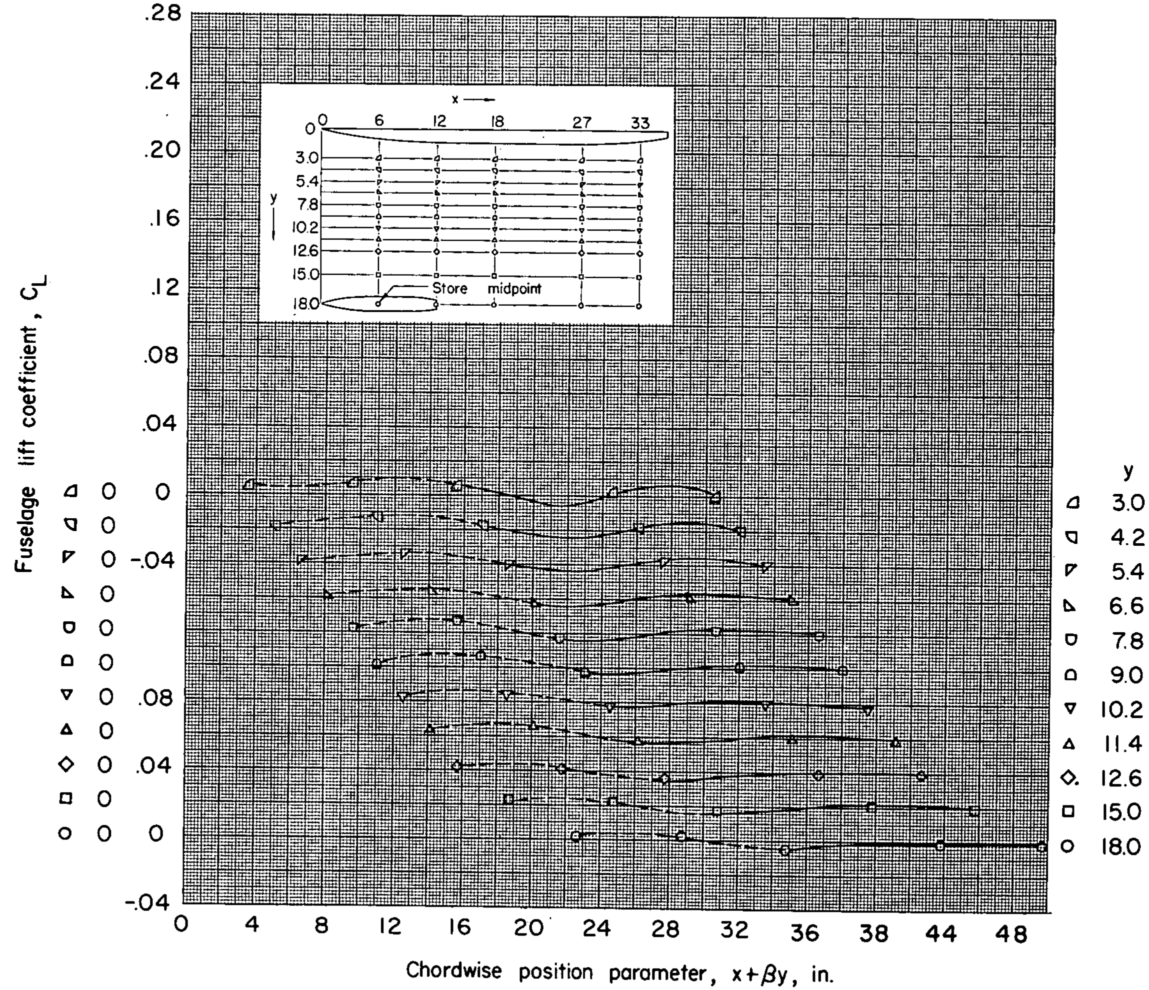
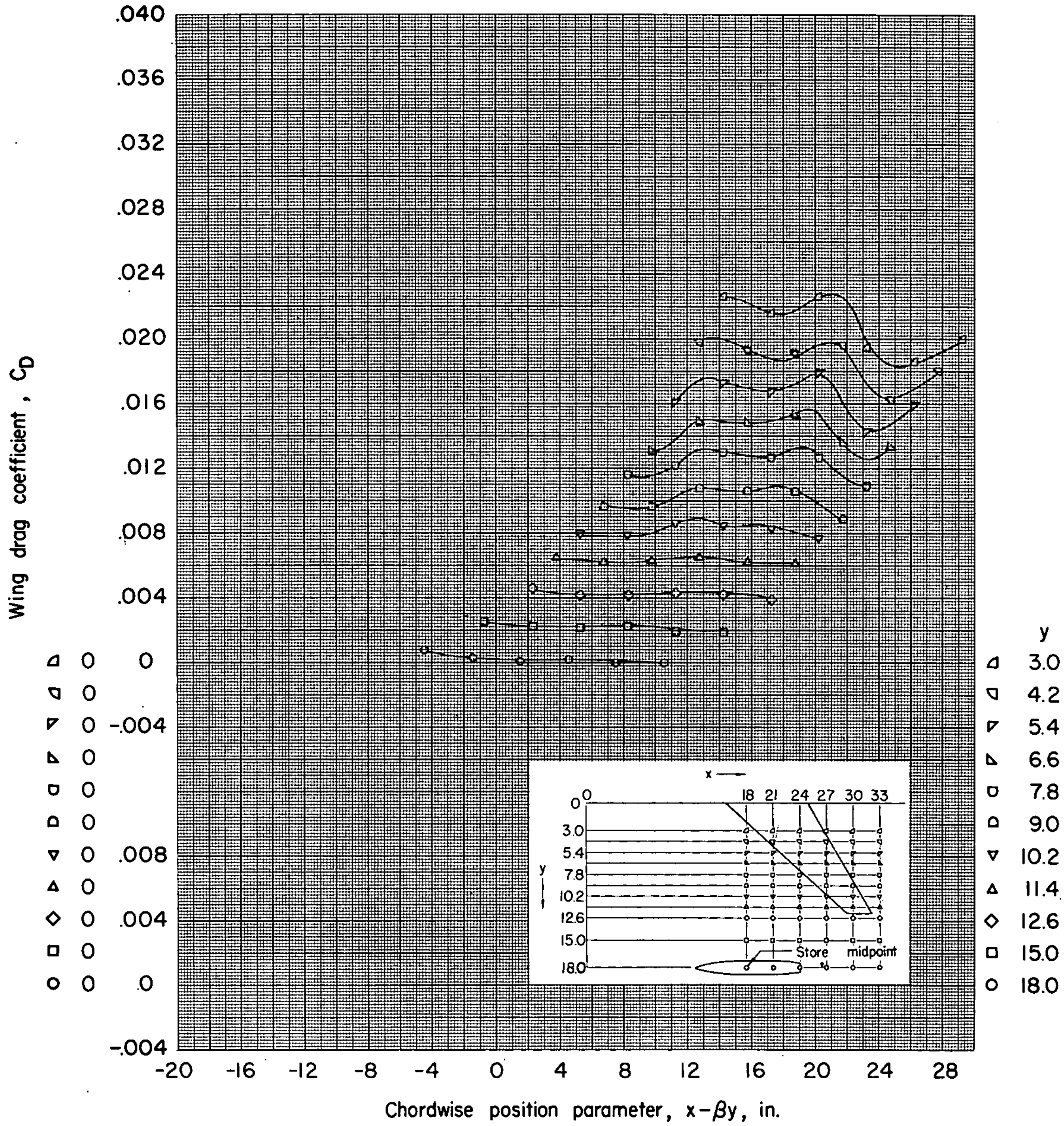
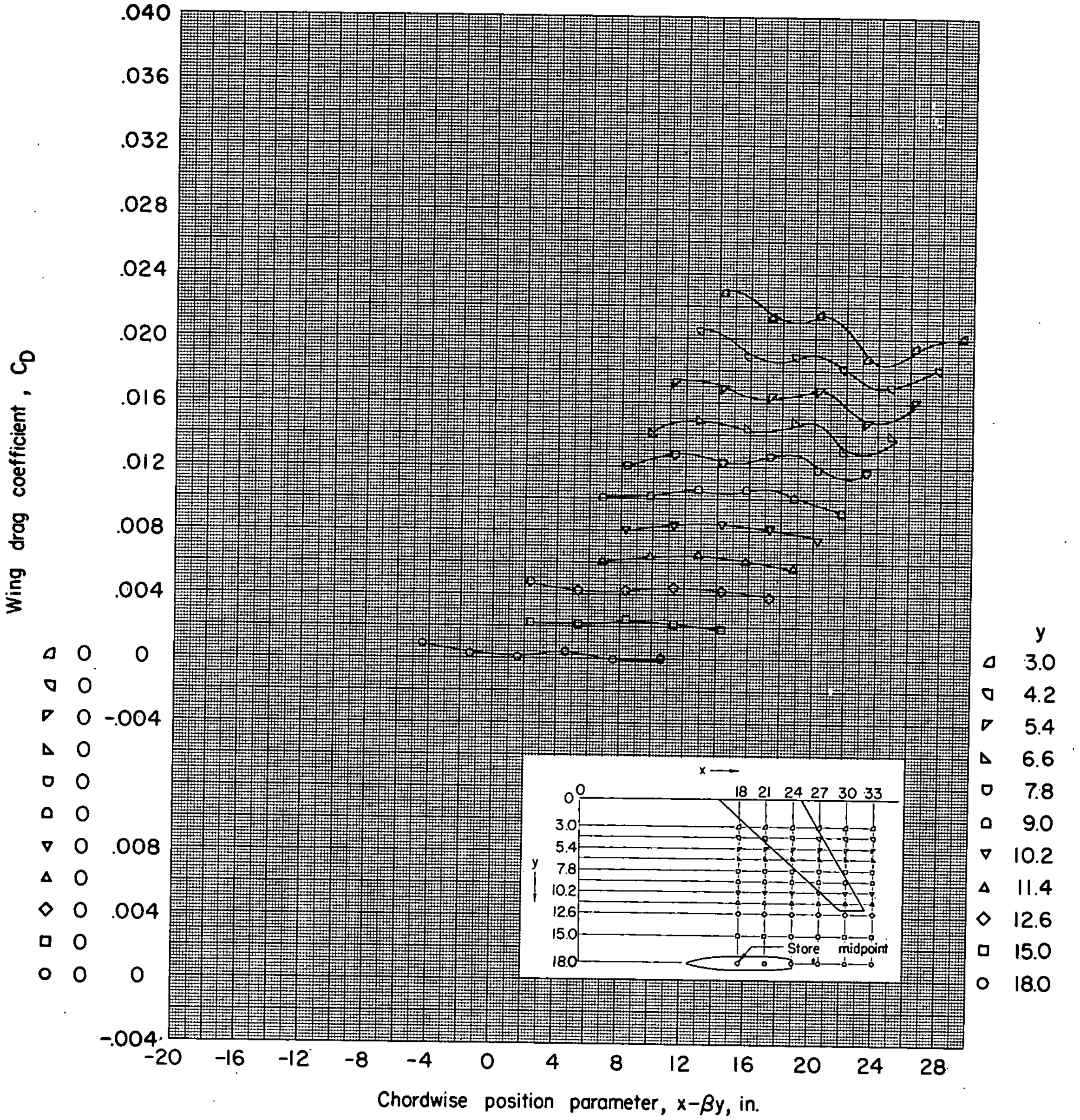


Figure 16.- Lift of fuselage in presence of store. $z = 1.15$ inches; $\alpha = 0^{\circ}$. Dashed lines indicate presence of interference of store sting.



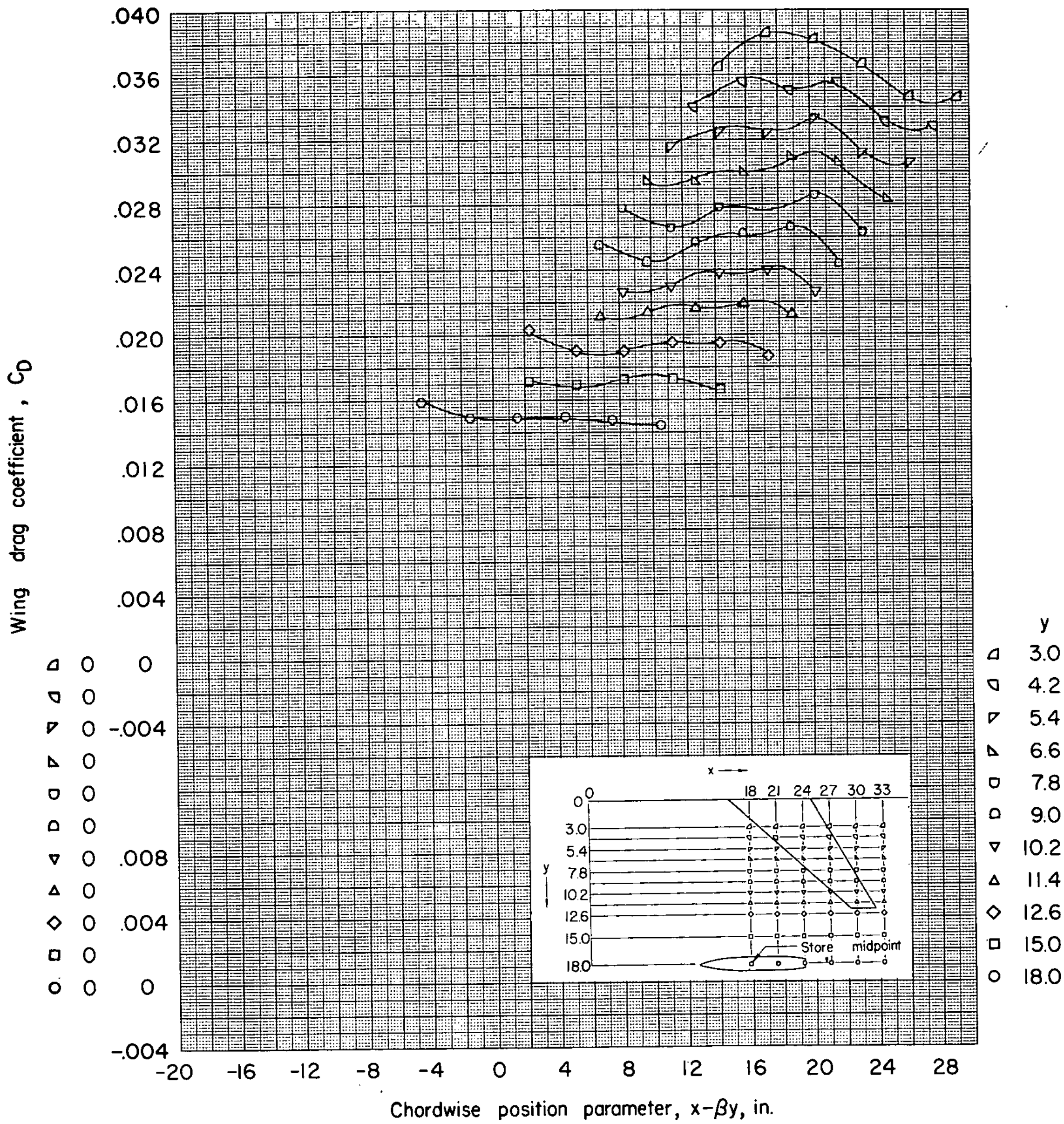
(a) z = 1.15 inches; α = 0°.

Figure 17.- Drag of wing in presence of store.



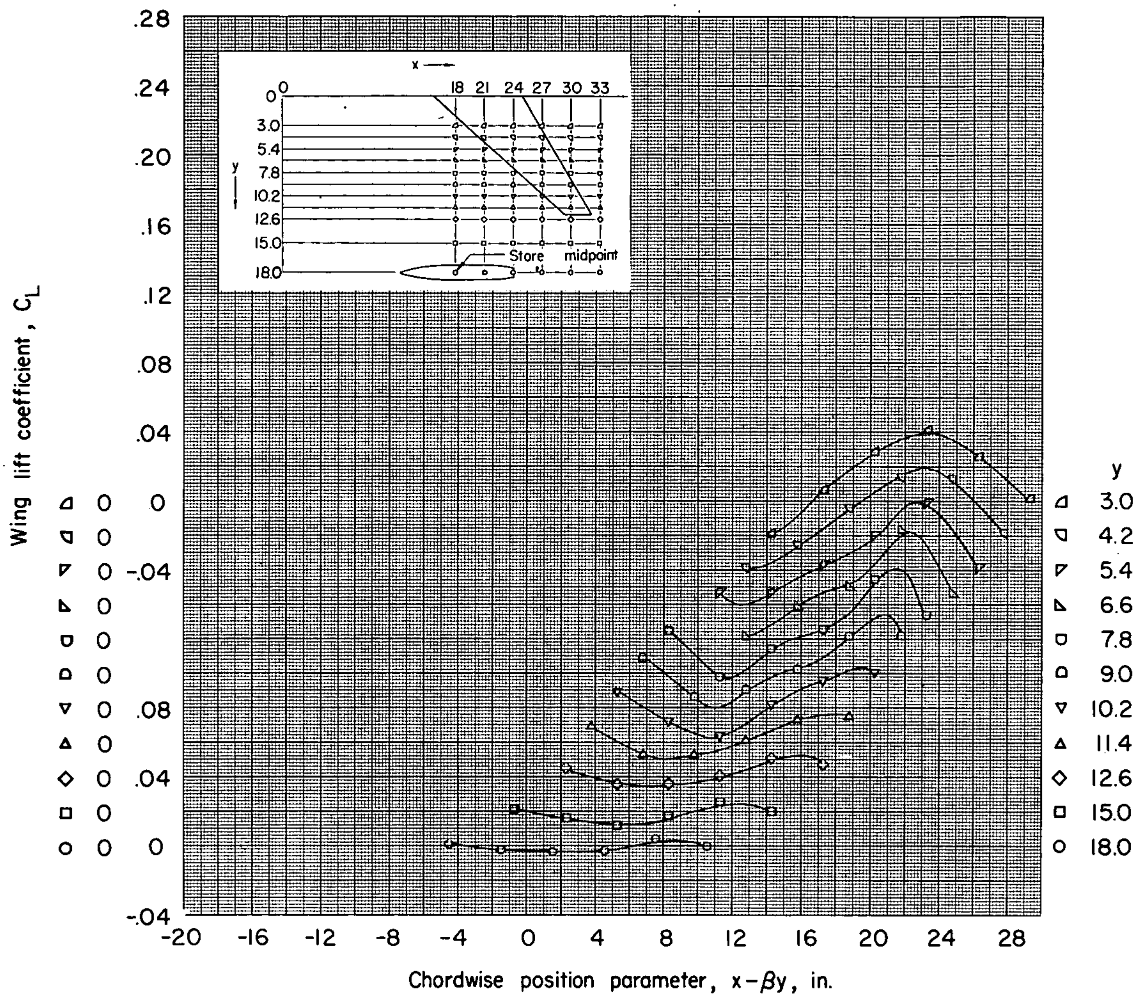
(b) z = 2.09 inches; α = 0°.

Figure 17.- Continued.



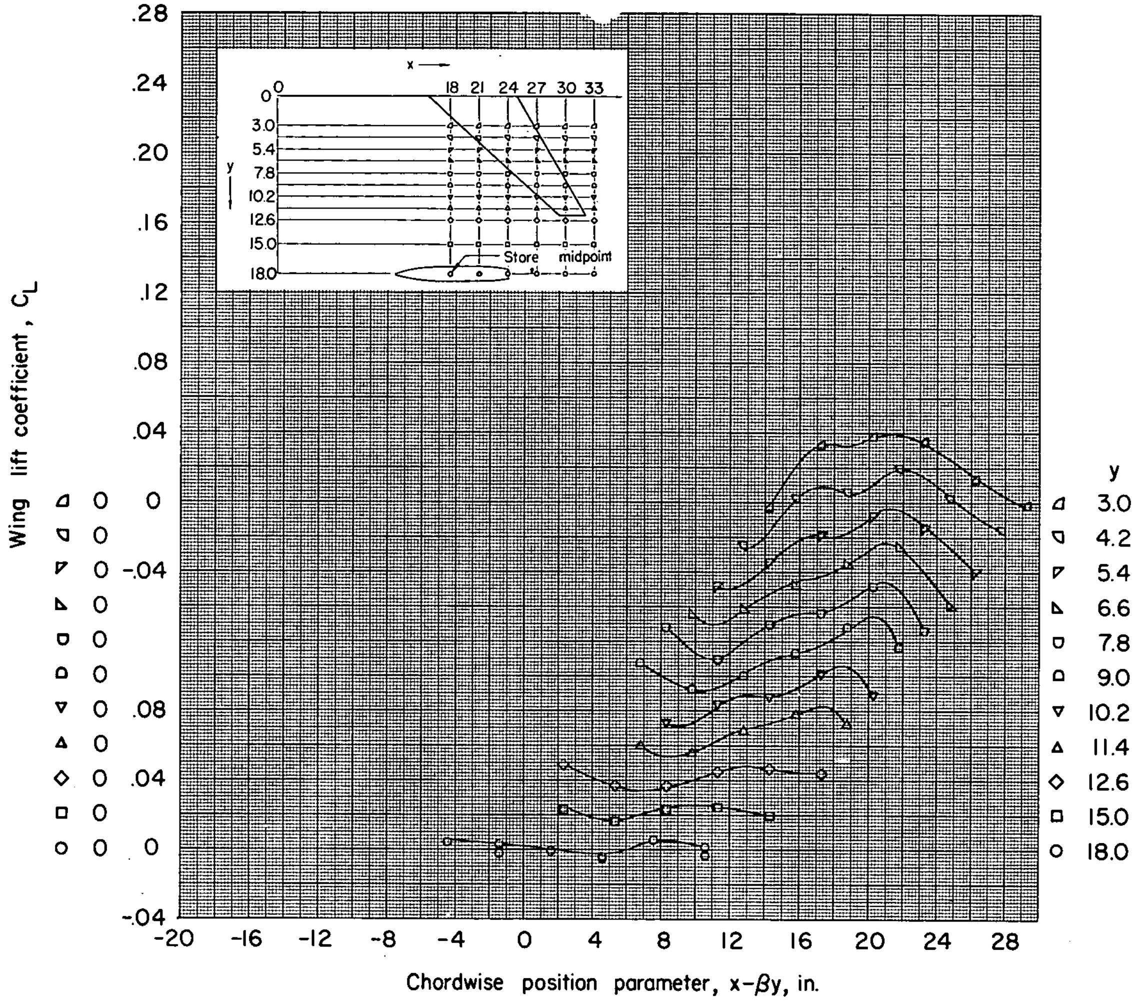
(c) z = 2.09 inches; α = 4°.

Figure 17.- Concluded.



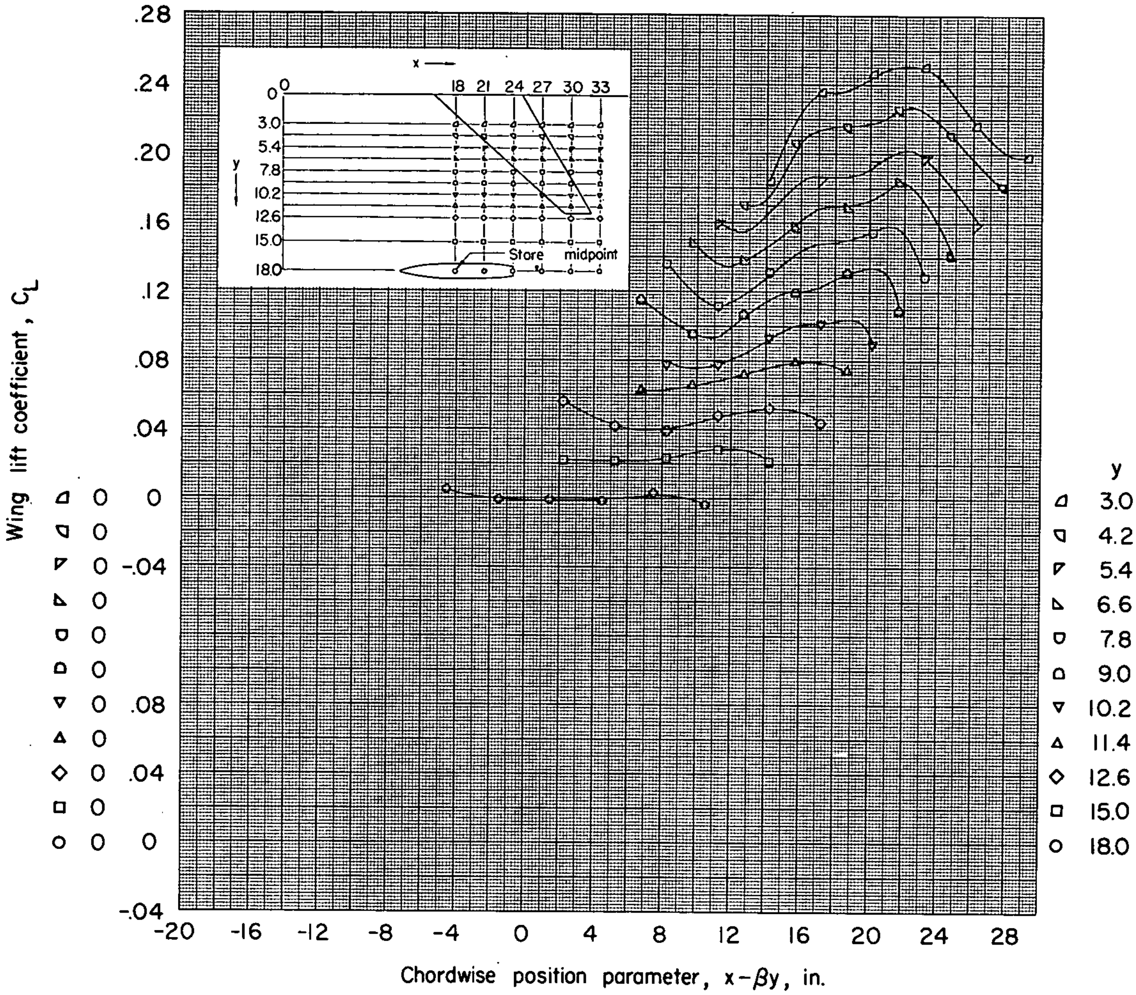
(a) $z = 1.15$ inches; $\alpha = 0^{\circ}$.

Figure 18.- Lift of wing in presence of store.



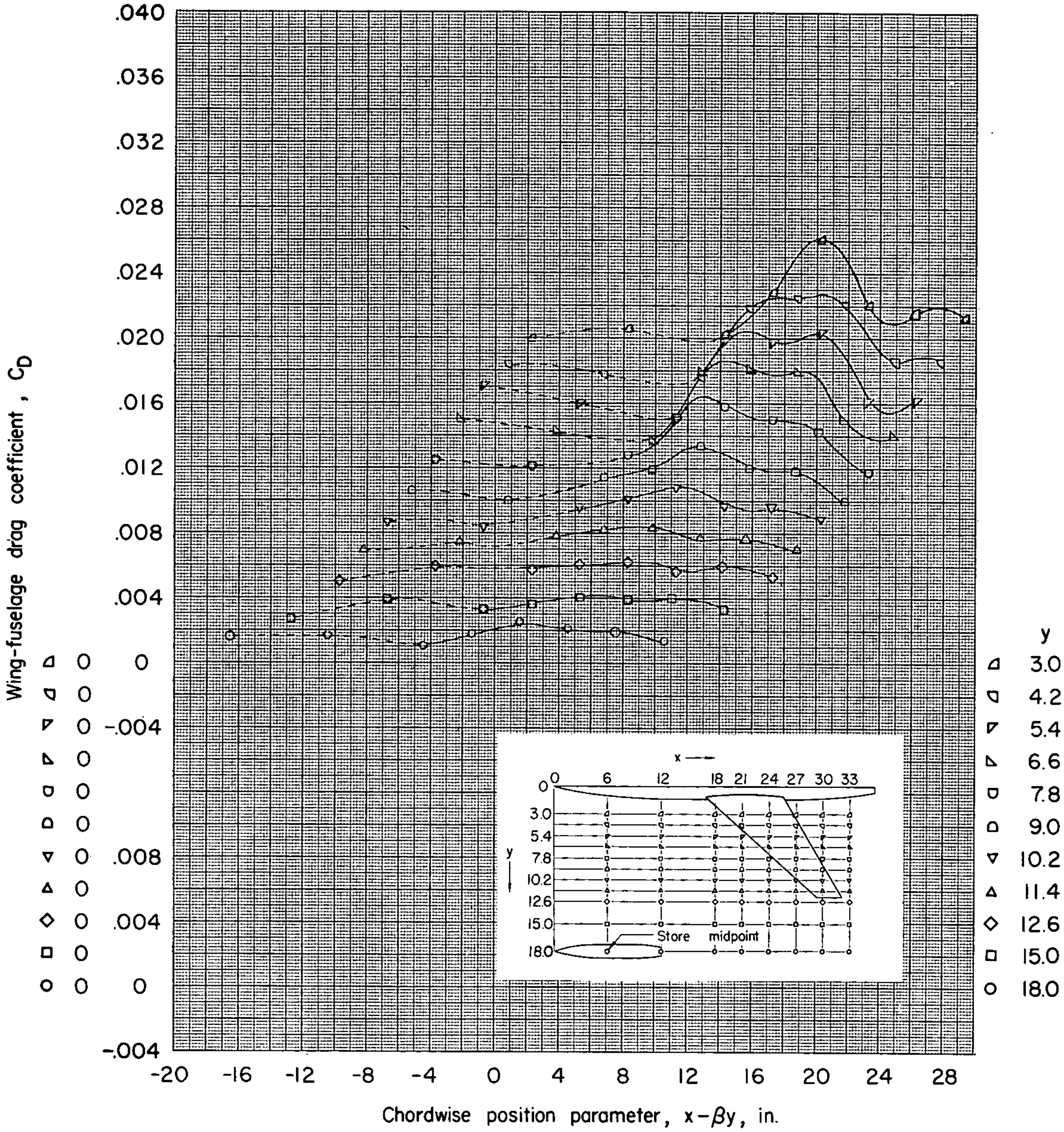
(b) z = 2.09 inches; α = 0°.

Figure 18.- Continued.



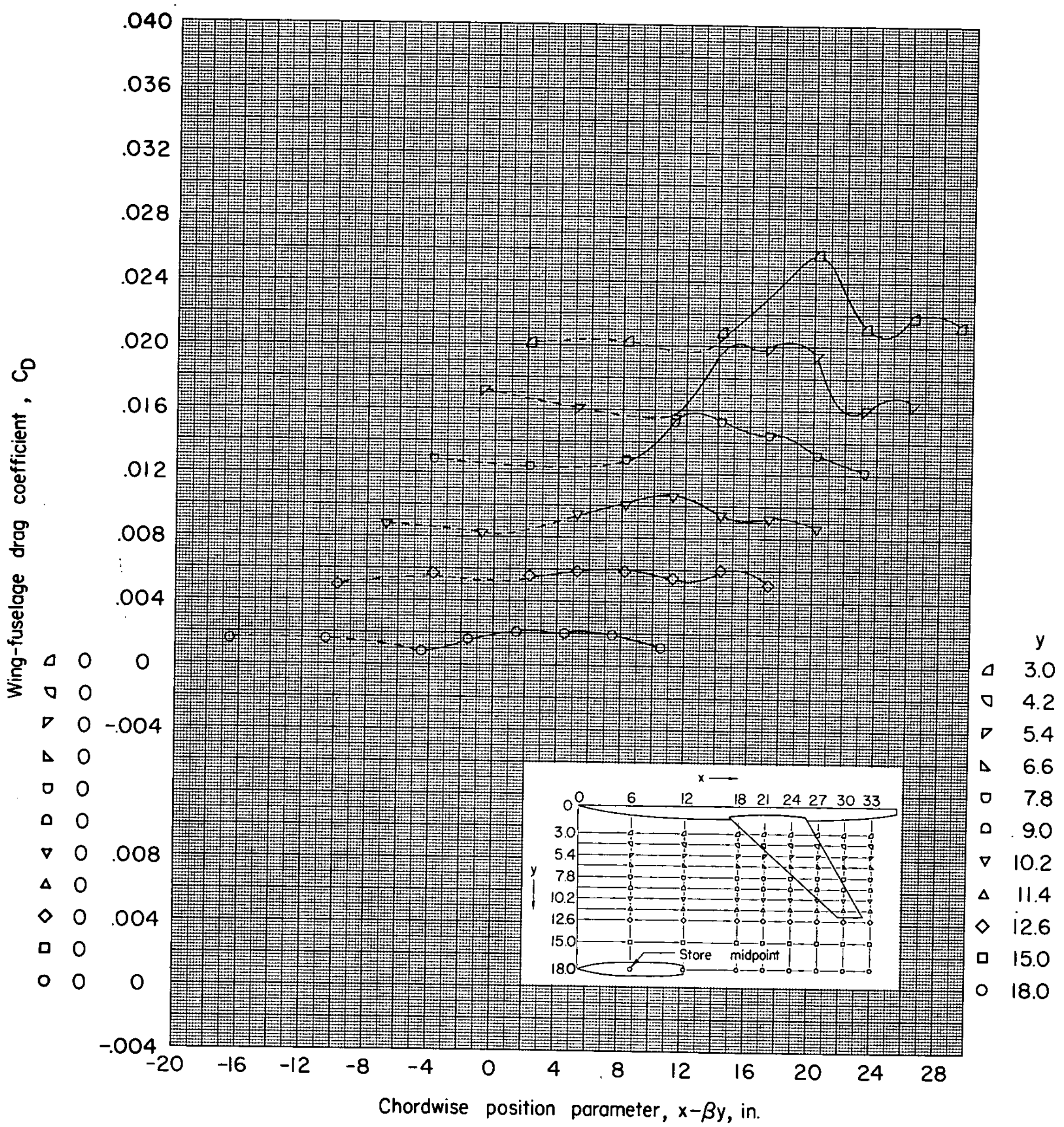
(c) z = 2.09 inches; $\alpha = 4^{\circ}$.

Figure 18.- Concluded.



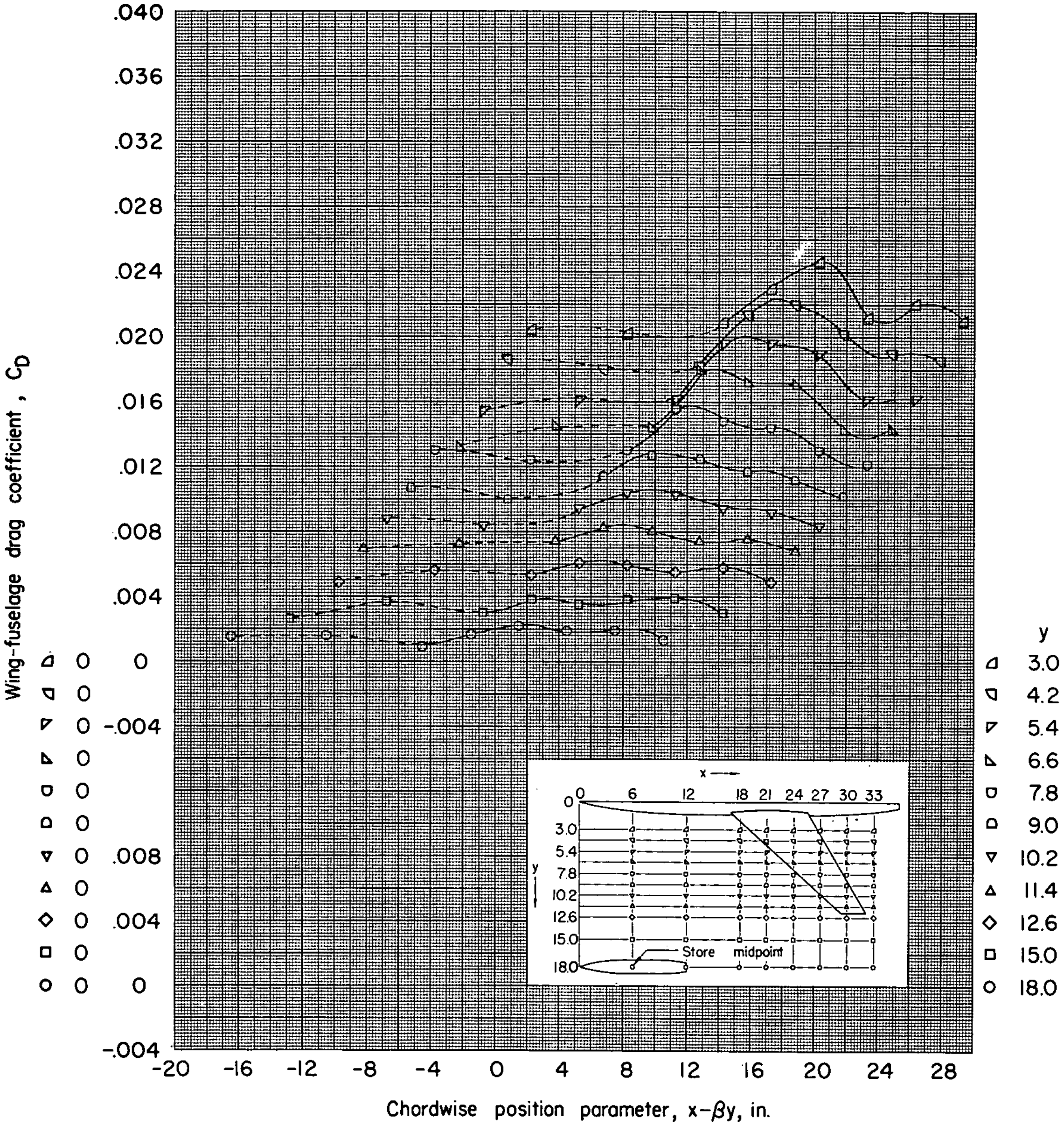
(a) z = 1.15 inches; $\alpha = 0^{\circ}$.

Figure 19.- Drag of wing-fuselage combination in presence of store. Dashed lines indicate presence of interference of store sting.



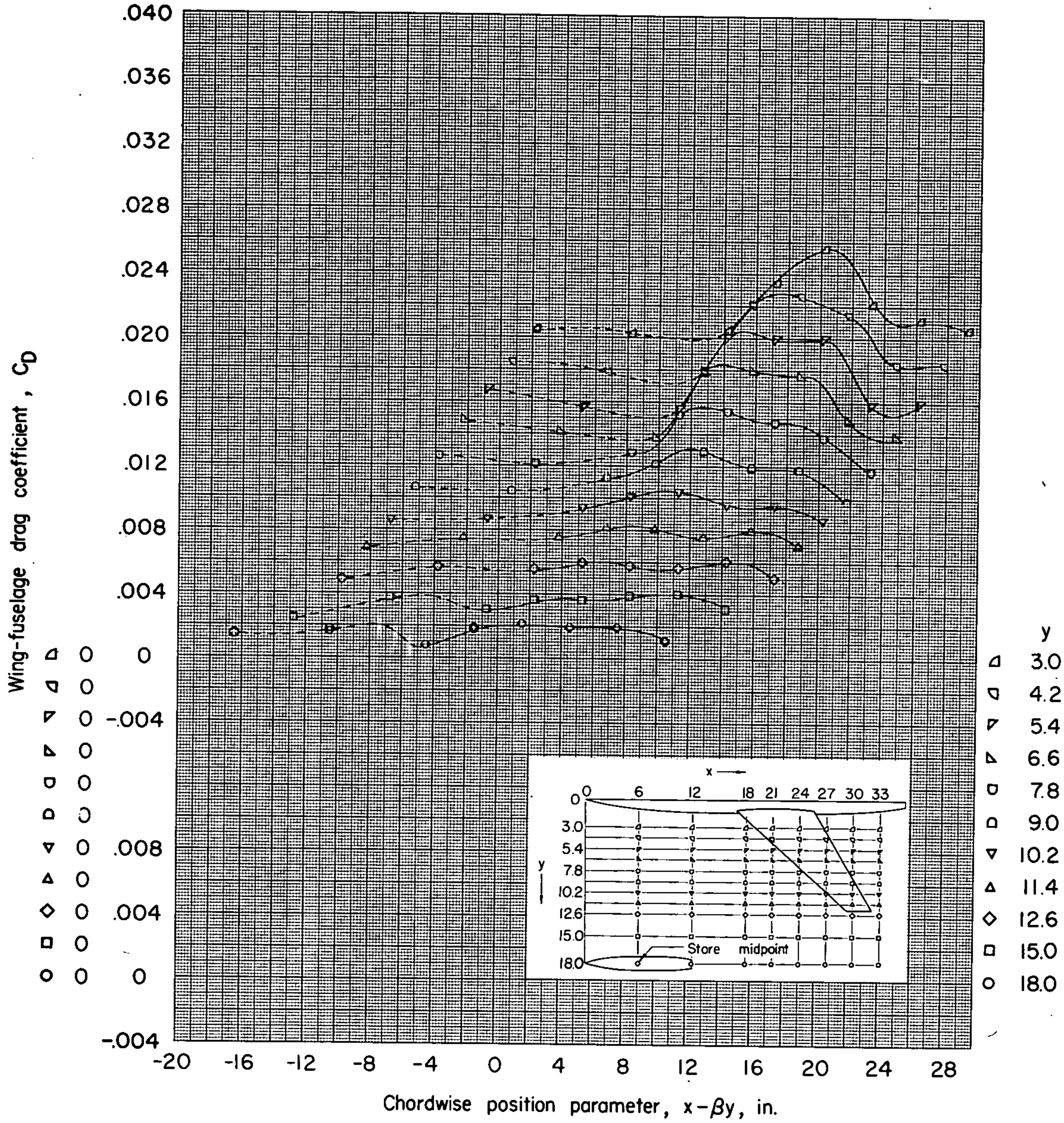
(b) z = 1.67 inches; $\alpha = 0^{\circ}$.

Figure 19.- Continued.



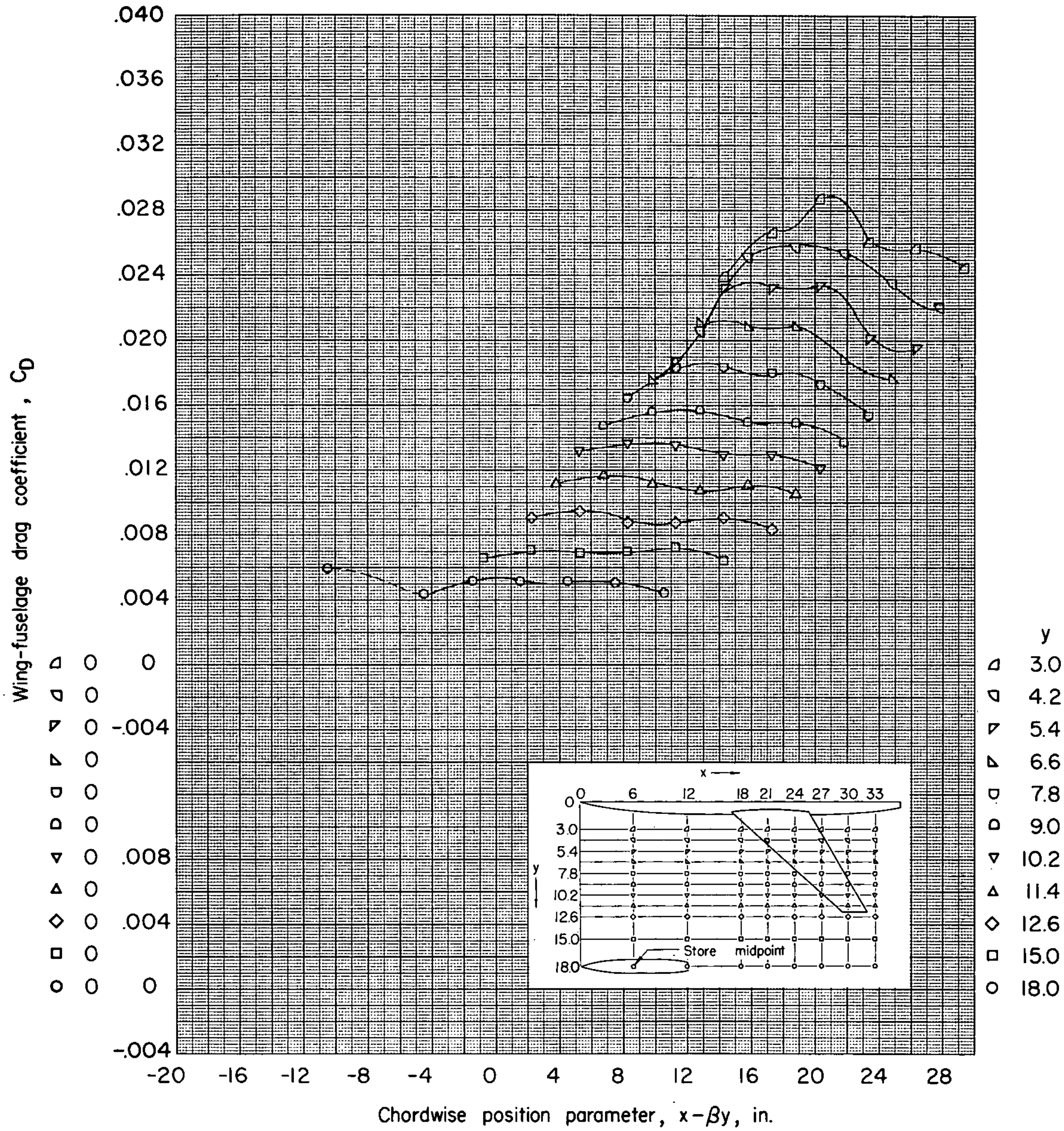
(c) z = 2.09 inches; α = 0°.

Figure 19.- Continued.



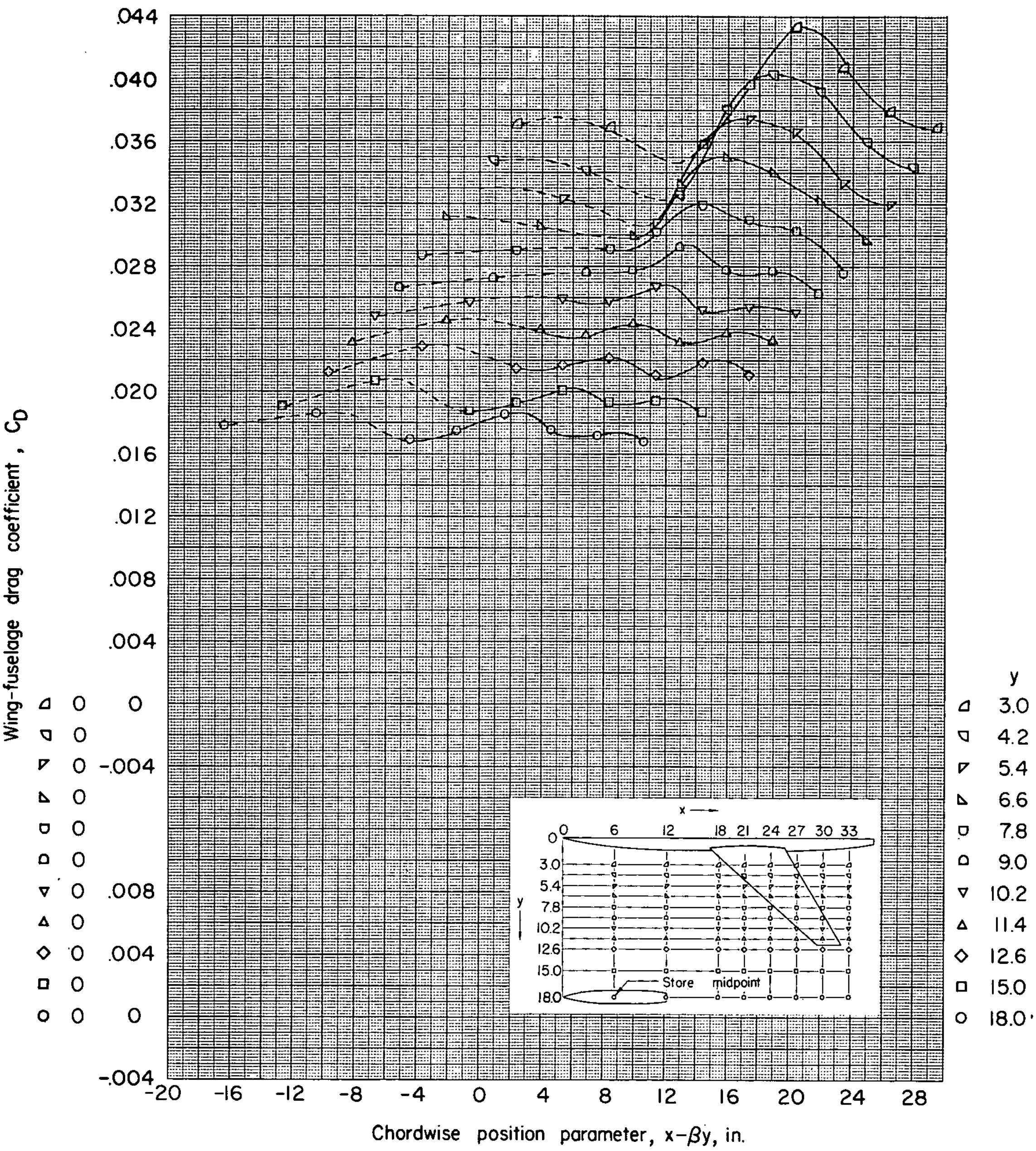
(d) $z = -1.31$ inches; $\alpha = 0^{\circ}$.

Figure 19.- Continued.



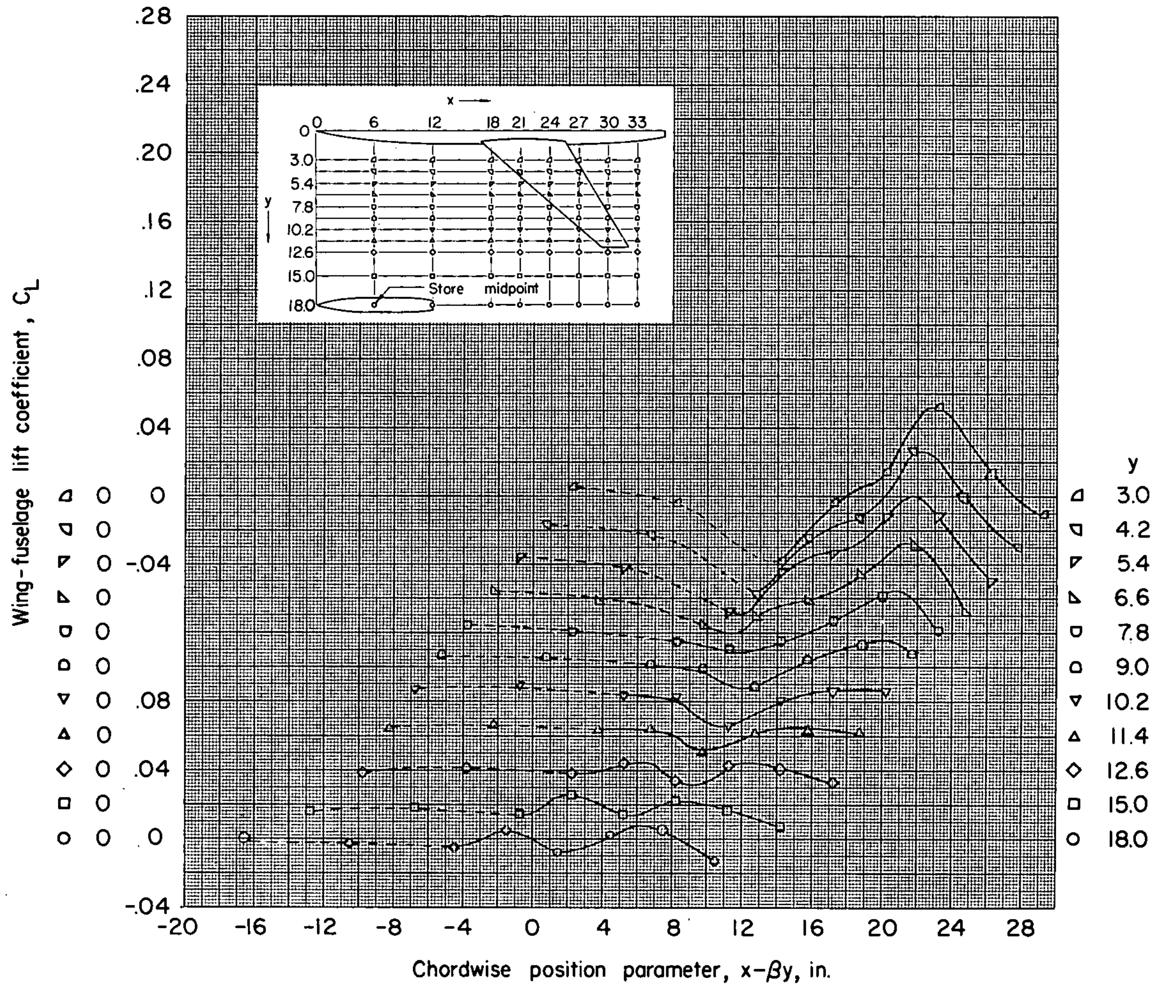
(e) z = 2.09 inches; α = 2°.

Figure 19.- Continued.



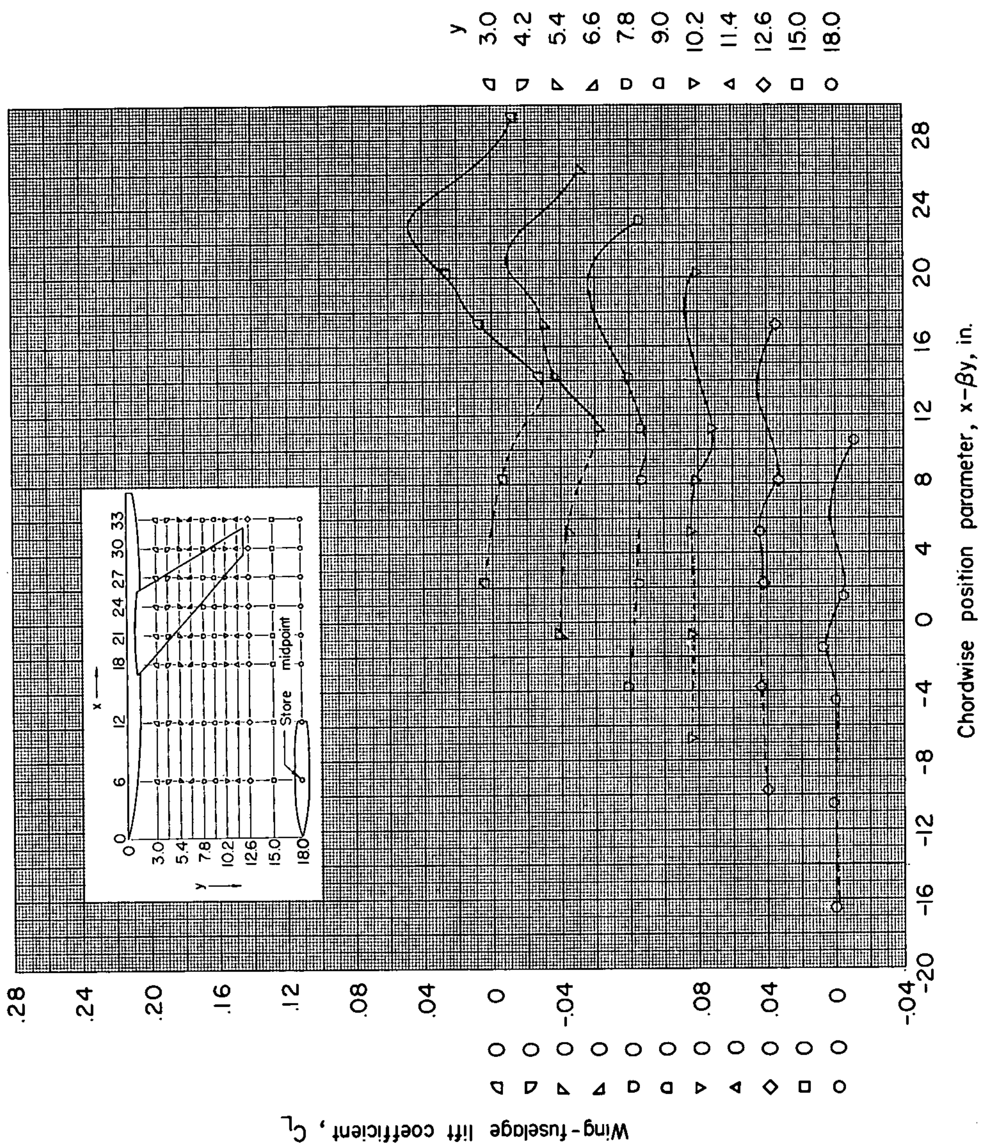
(f) z = 2.09 inches; $\alpha = 4^{\circ}$.

Figure 19.- Concluded.



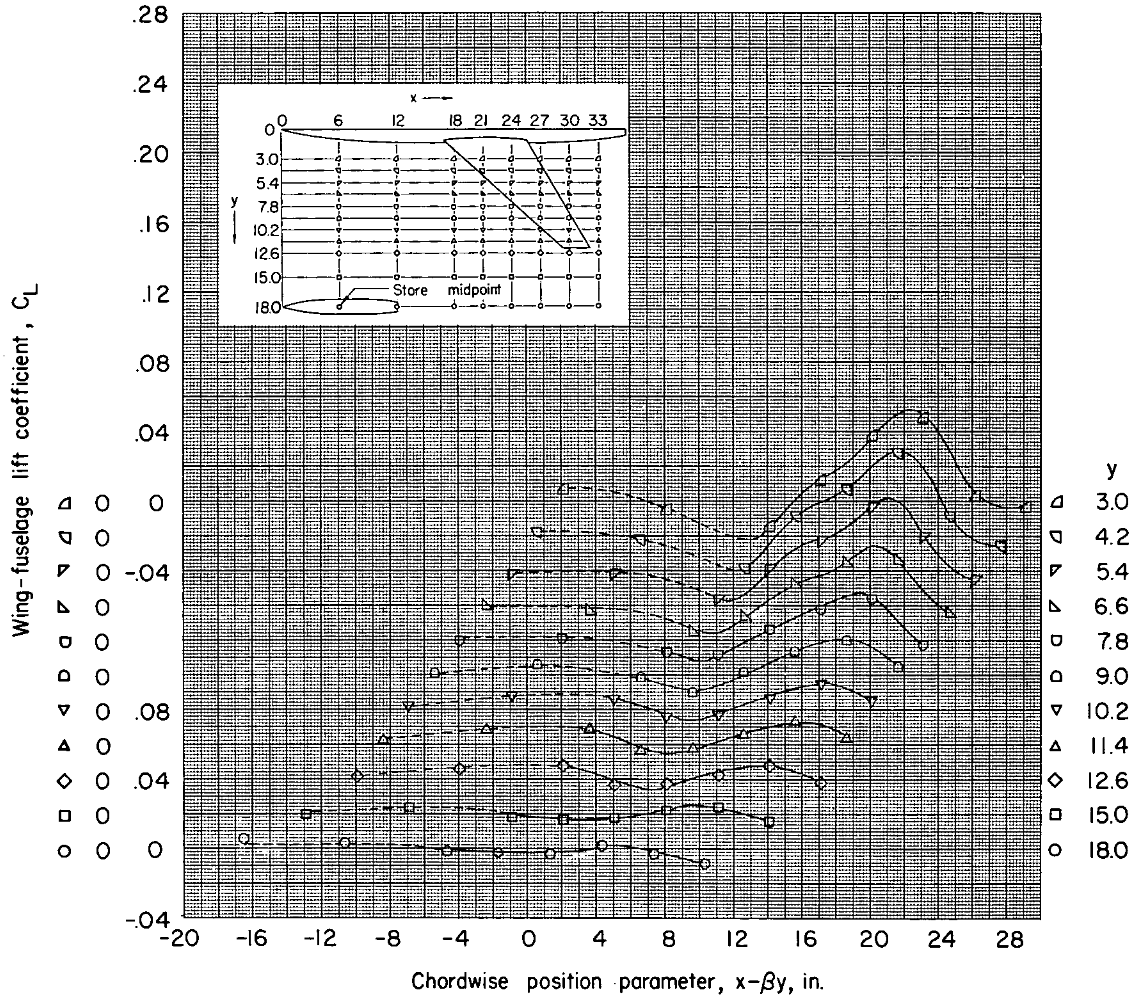
(a) $z = 1.15$ inches; $\alpha = 0^{\circ}$.

Figure 20.- Lift of wing-fuselage combination in presence of store. Dashed lines indicate presence of interference of store sting.



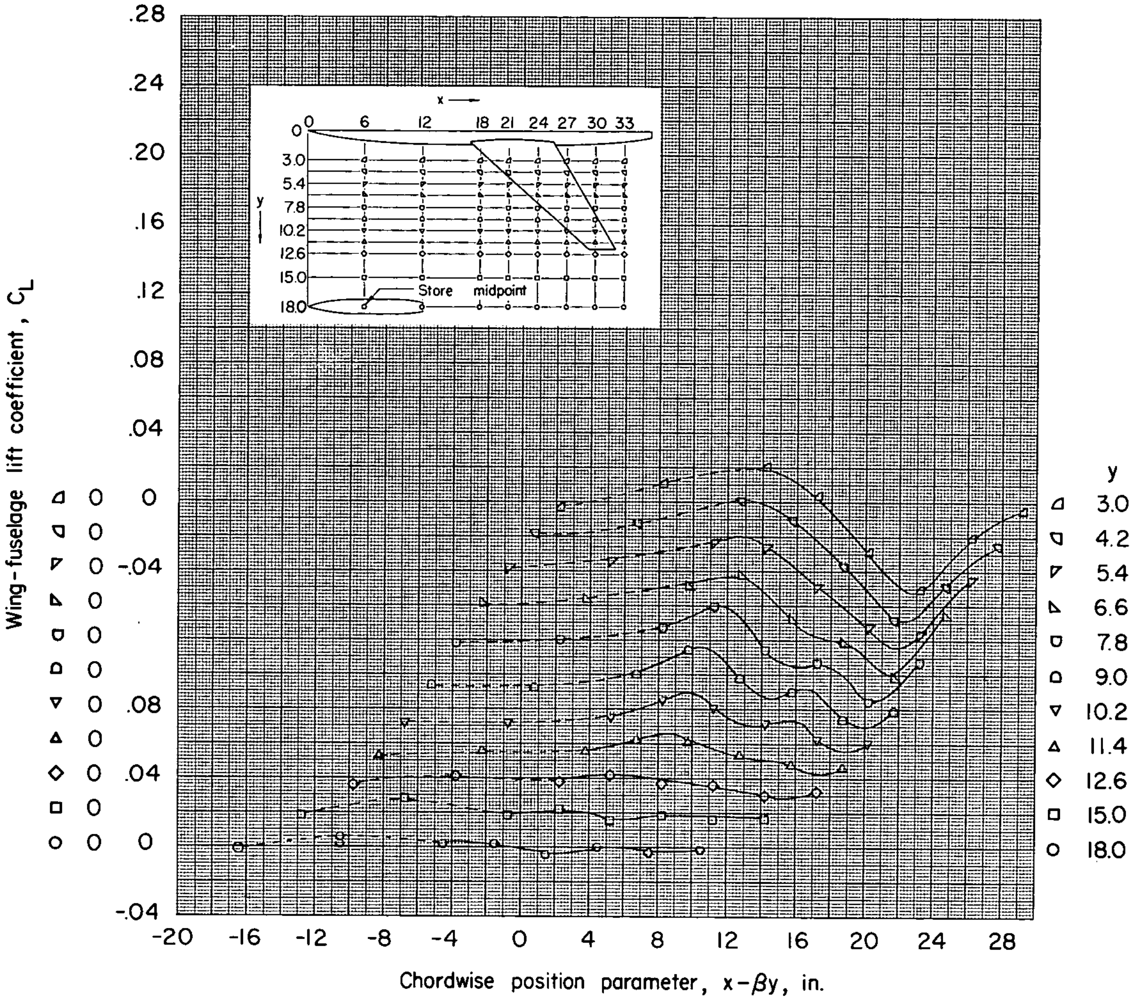
(b) z = 1.67 inches; α = 0°.

Figure 20.- Continued.



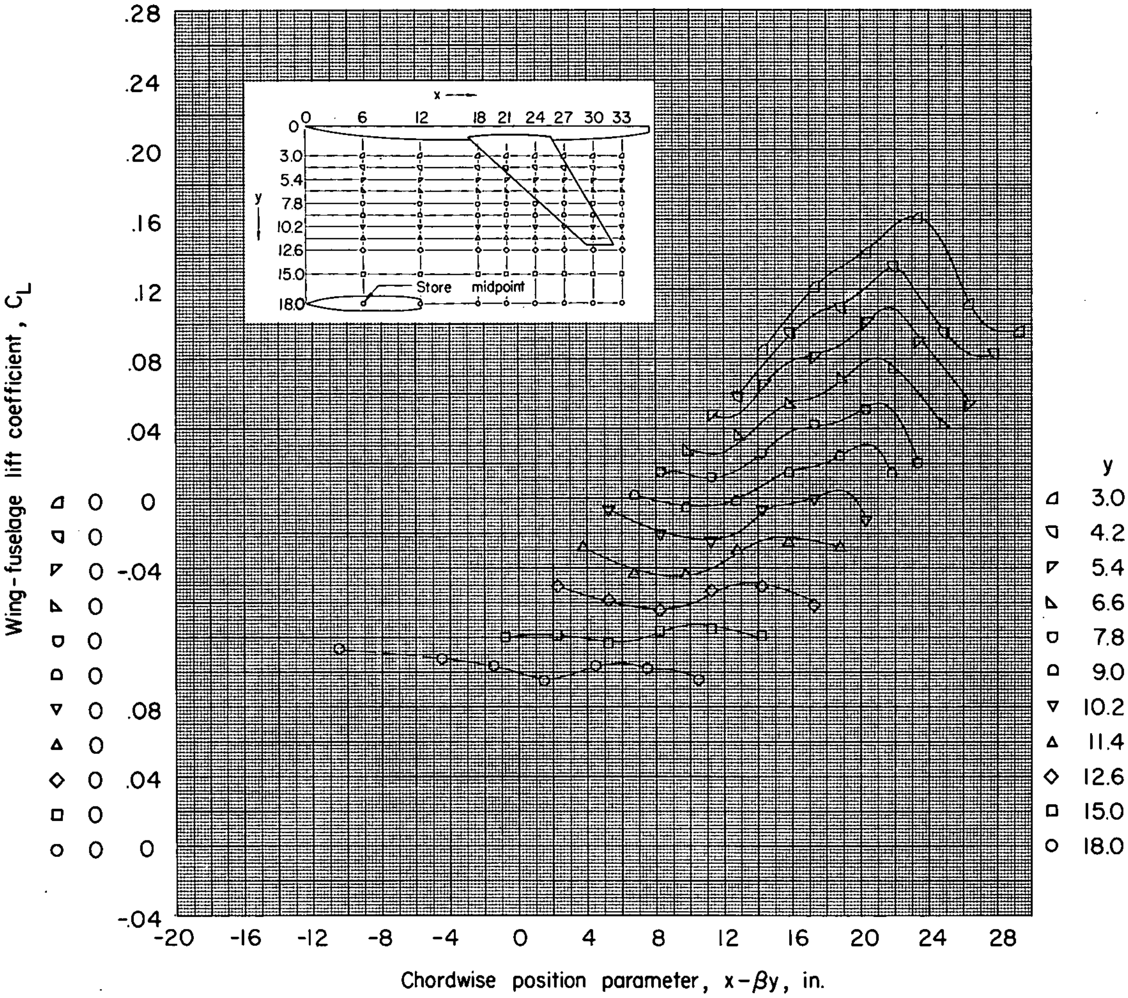
(c) z = 2.09 inches; α = 0°.

Figure 20.- Continued.



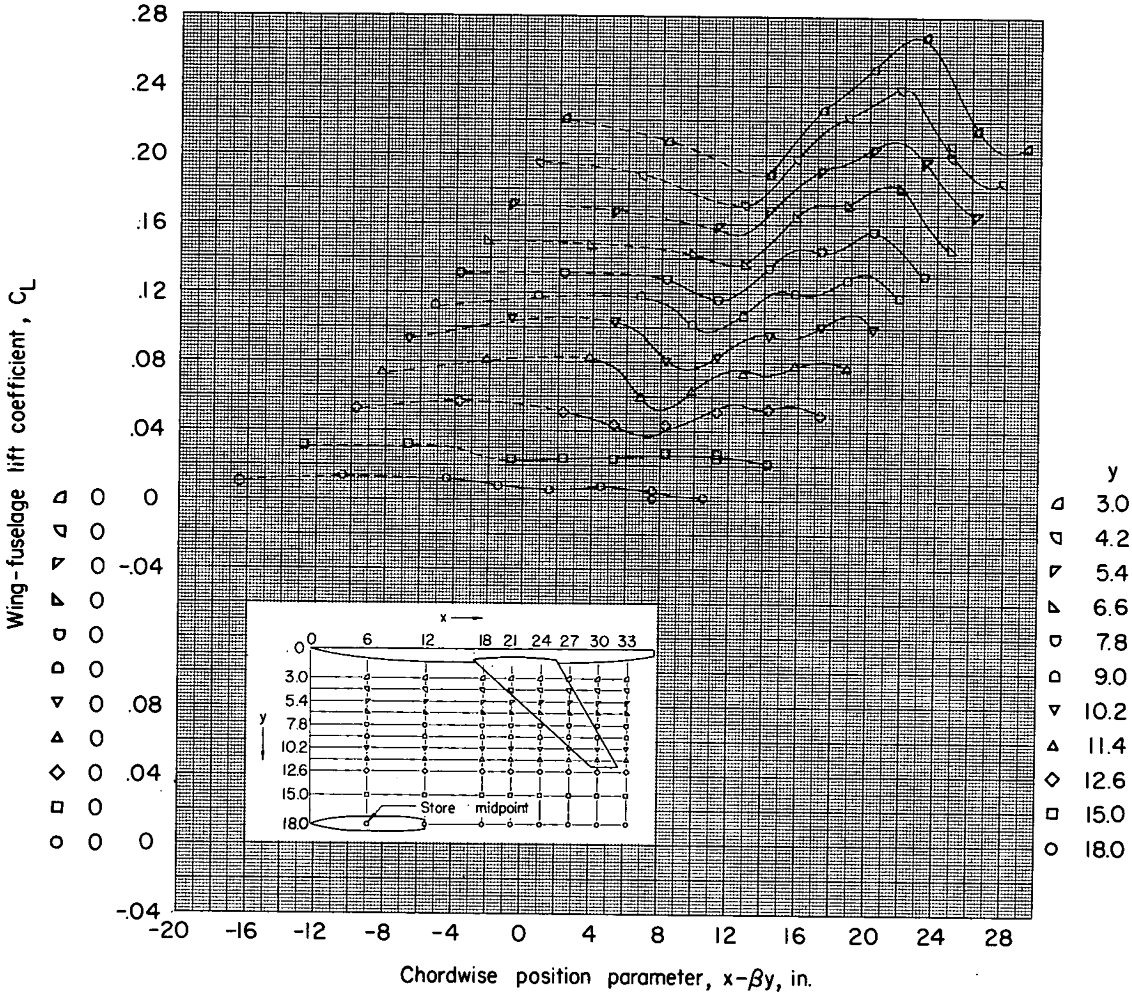
(d) z = -1.31 inches; α = 0°.

Figure 20.- Continued.



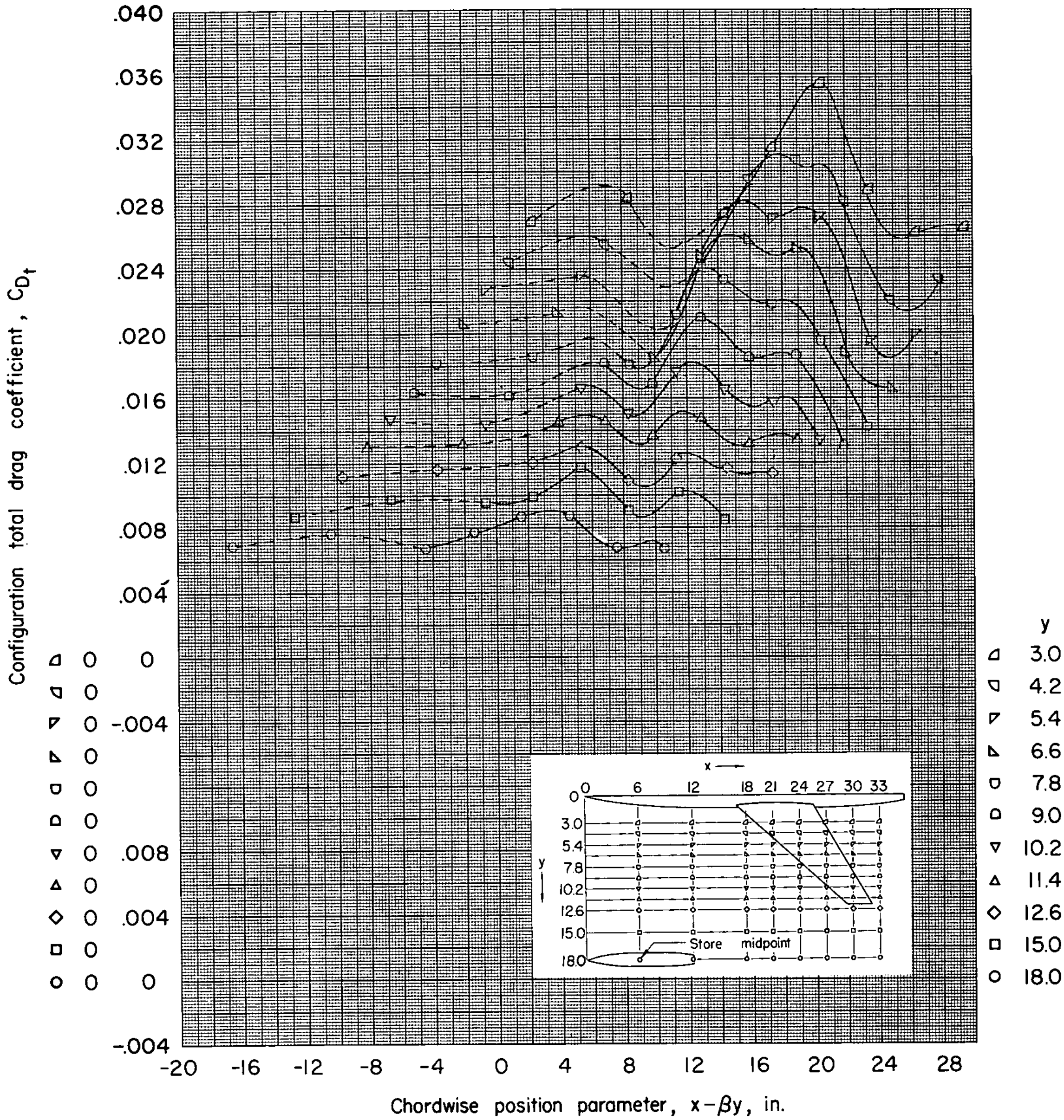
(e) z = 2.09 inches; α = 2°.

Figure 20.- Continued.



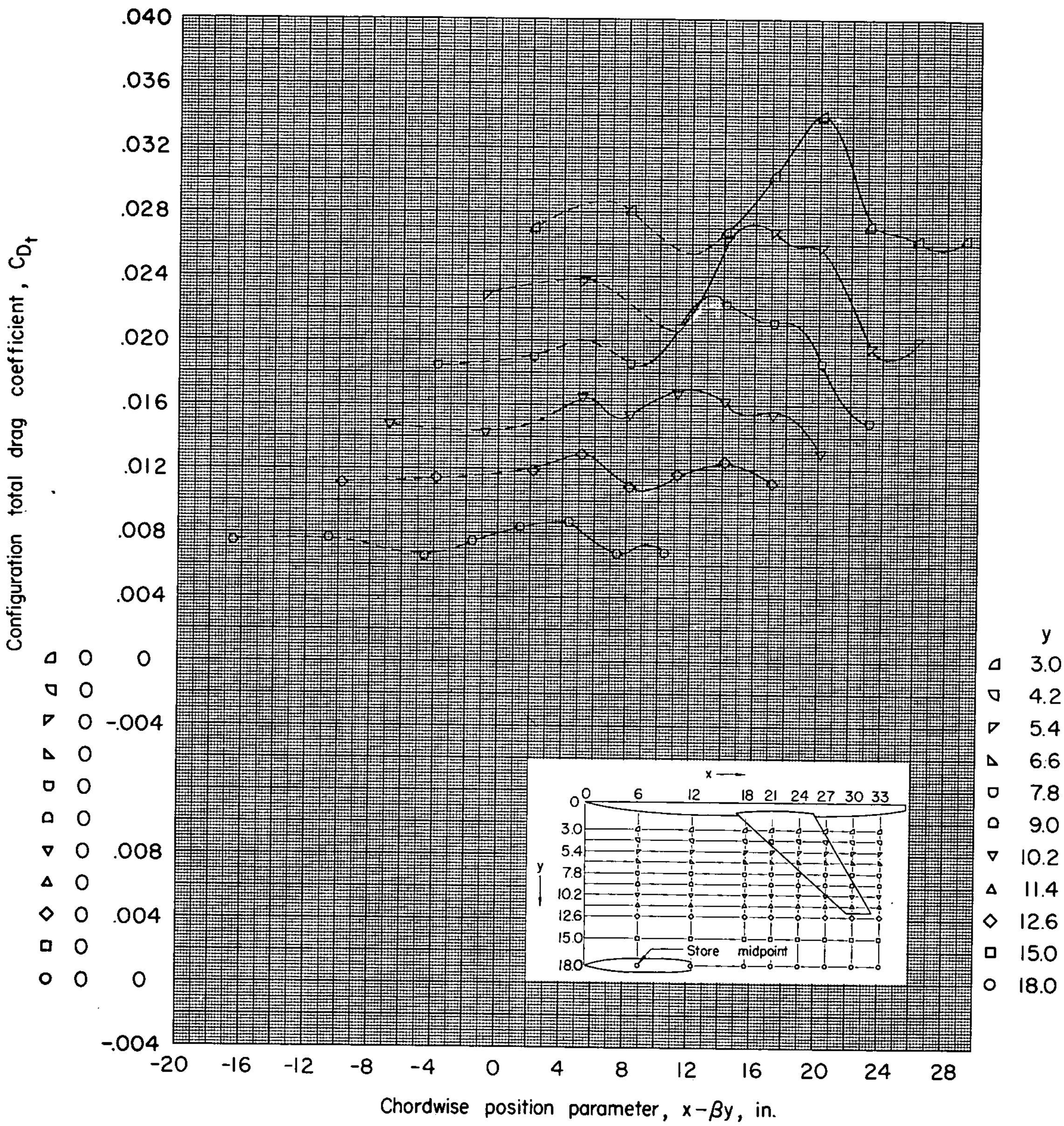
(f) z = 2.09 inches; α = 4°.

Figure 20.- Concluded.



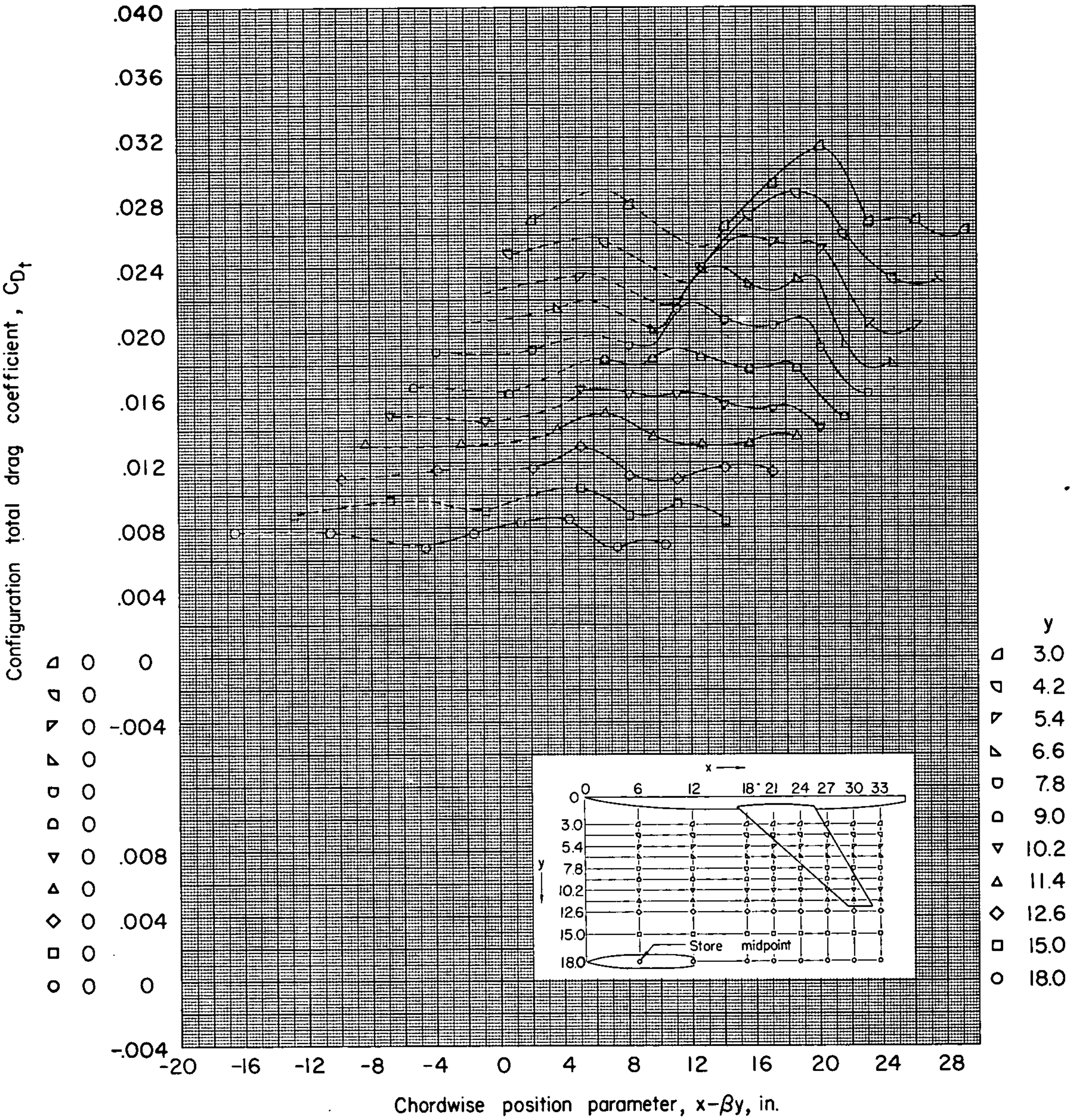
(a) z = 1.15 inches; $\alpha = 0^{\circ}$.

Figure 21.- Total drag of complete configuration (store plus wing-fuselage). Dashed lines indicate presence of interference of store sting.



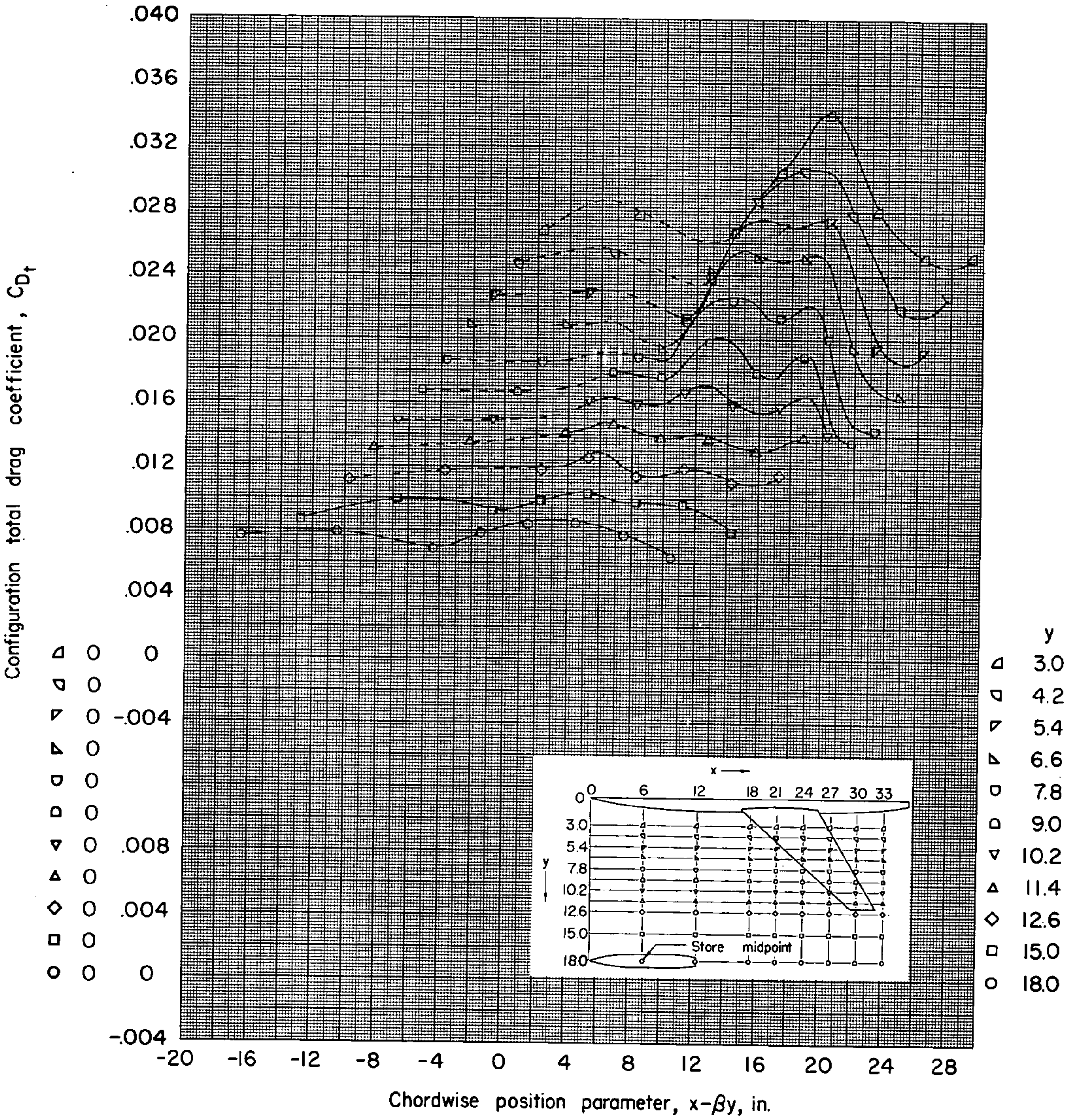
(b) z = 1.67 inches; $\alpha = 0^{\circ}$.

Figure 21.- Continued.



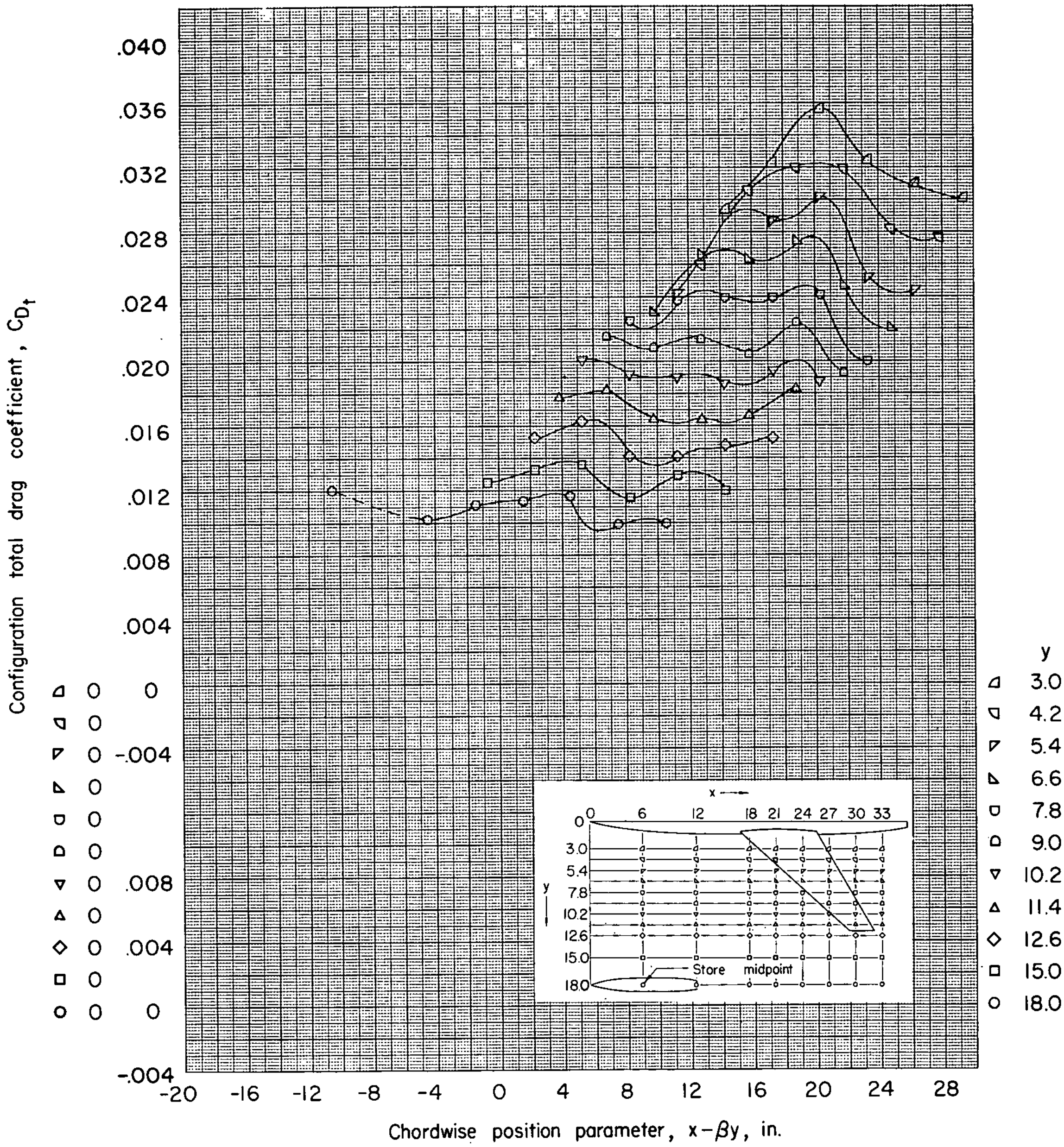
(c) z = 2.09 inches; α = 0°.

Figure 21.- Continued.



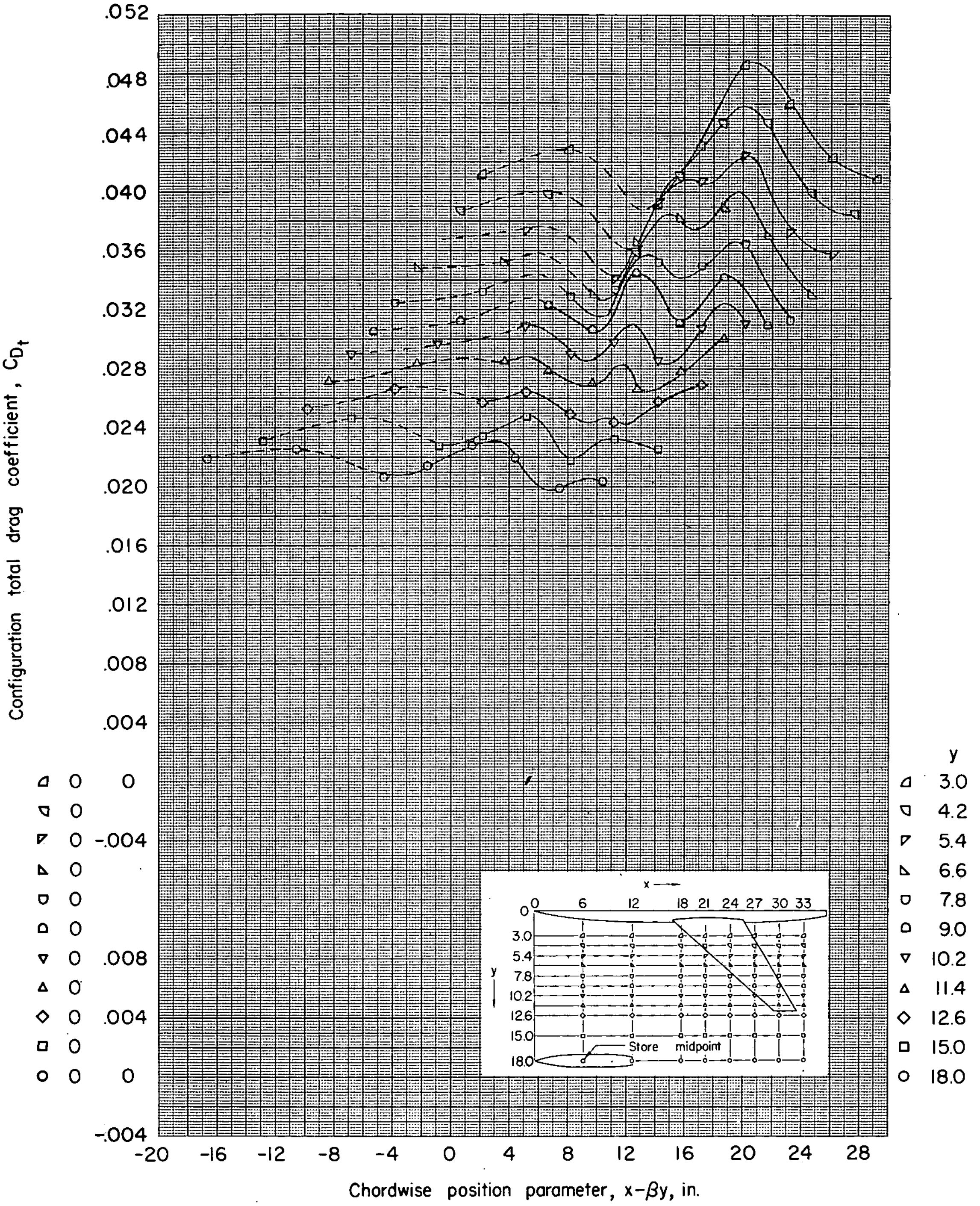
(d) $z = -1.31$ inches; $\alpha = 0^{\circ}$.

Figure 21.- Continued.



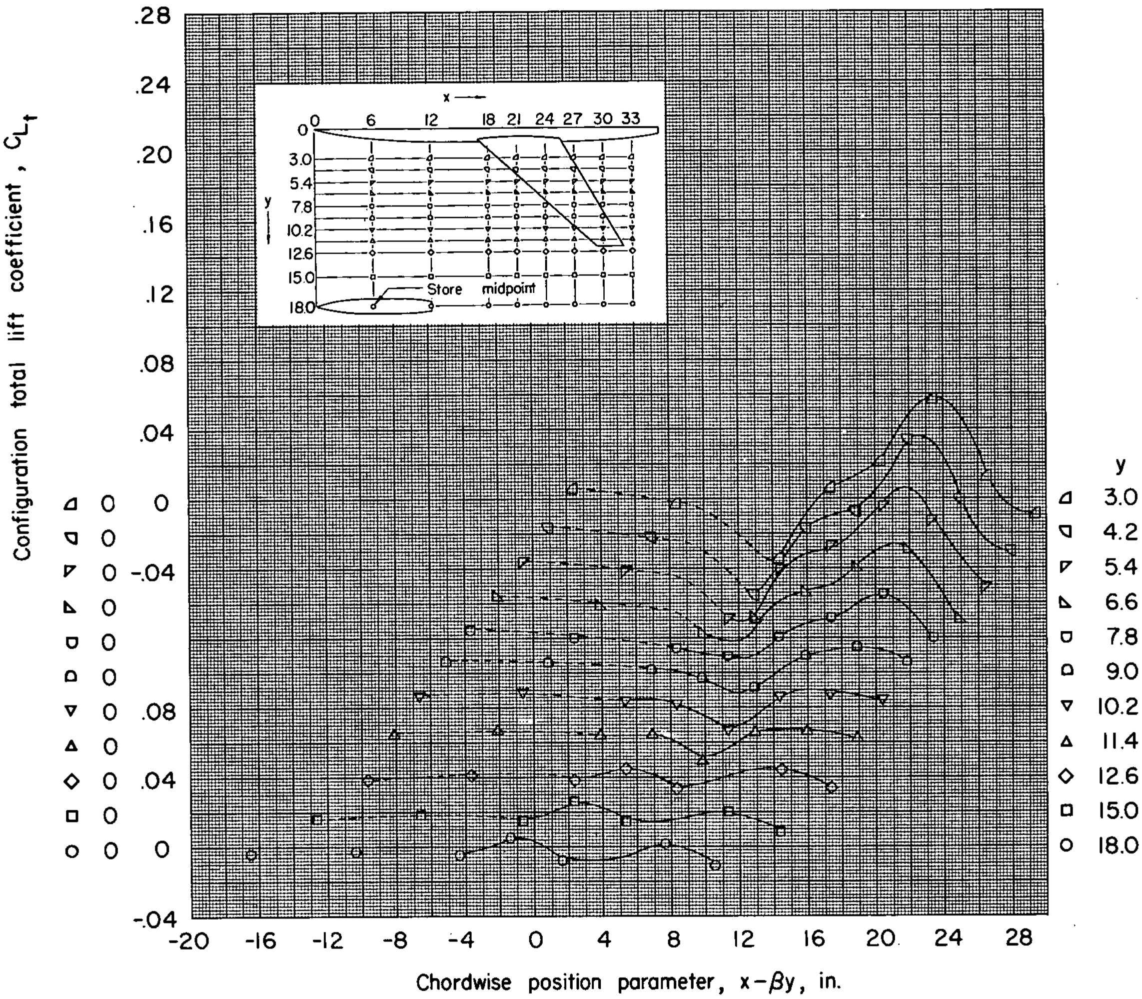
(e) z = 2.09 inches; α = 2°.

Figure 21.- Continued.



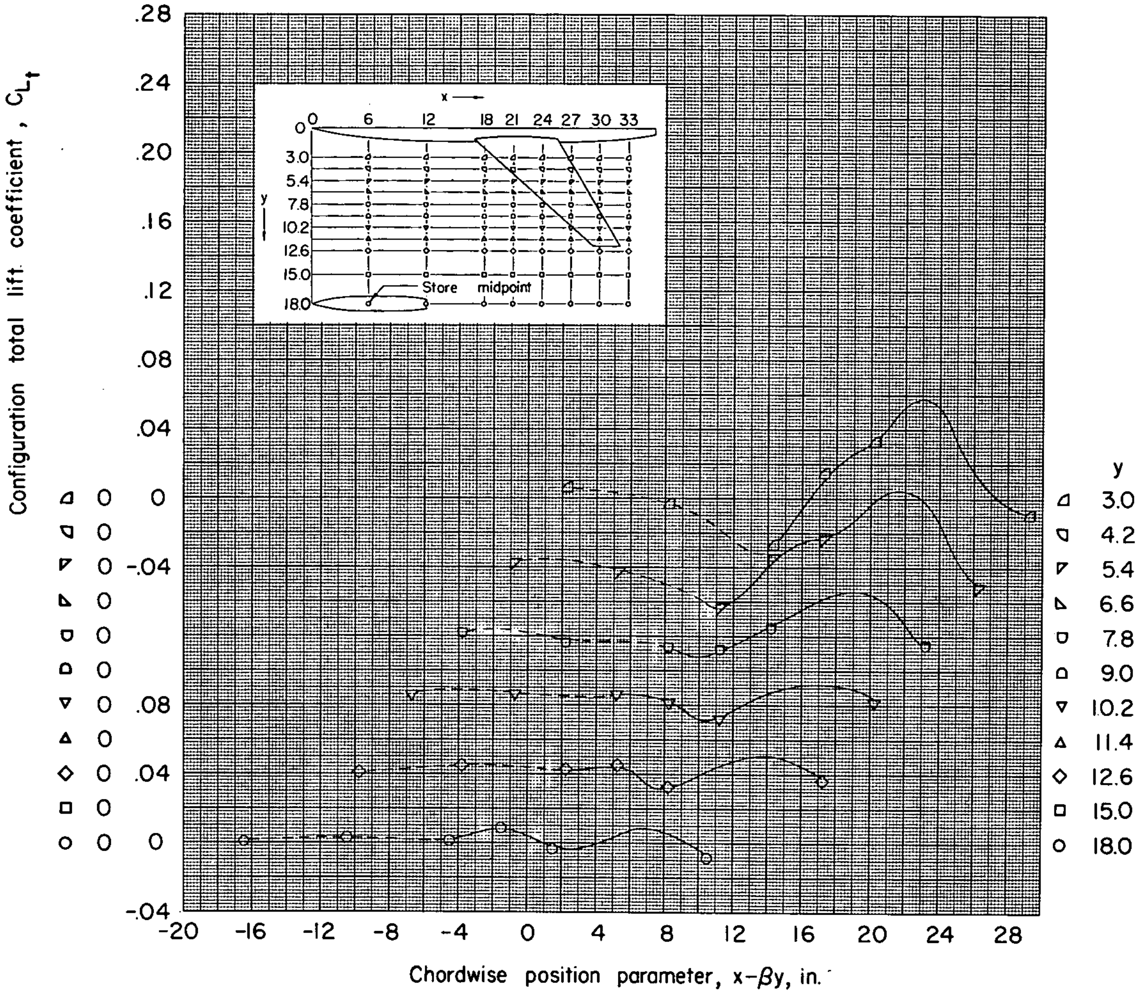
(f) z = 2.09 inches; α = 4°.

Figure 21.- Concluded.



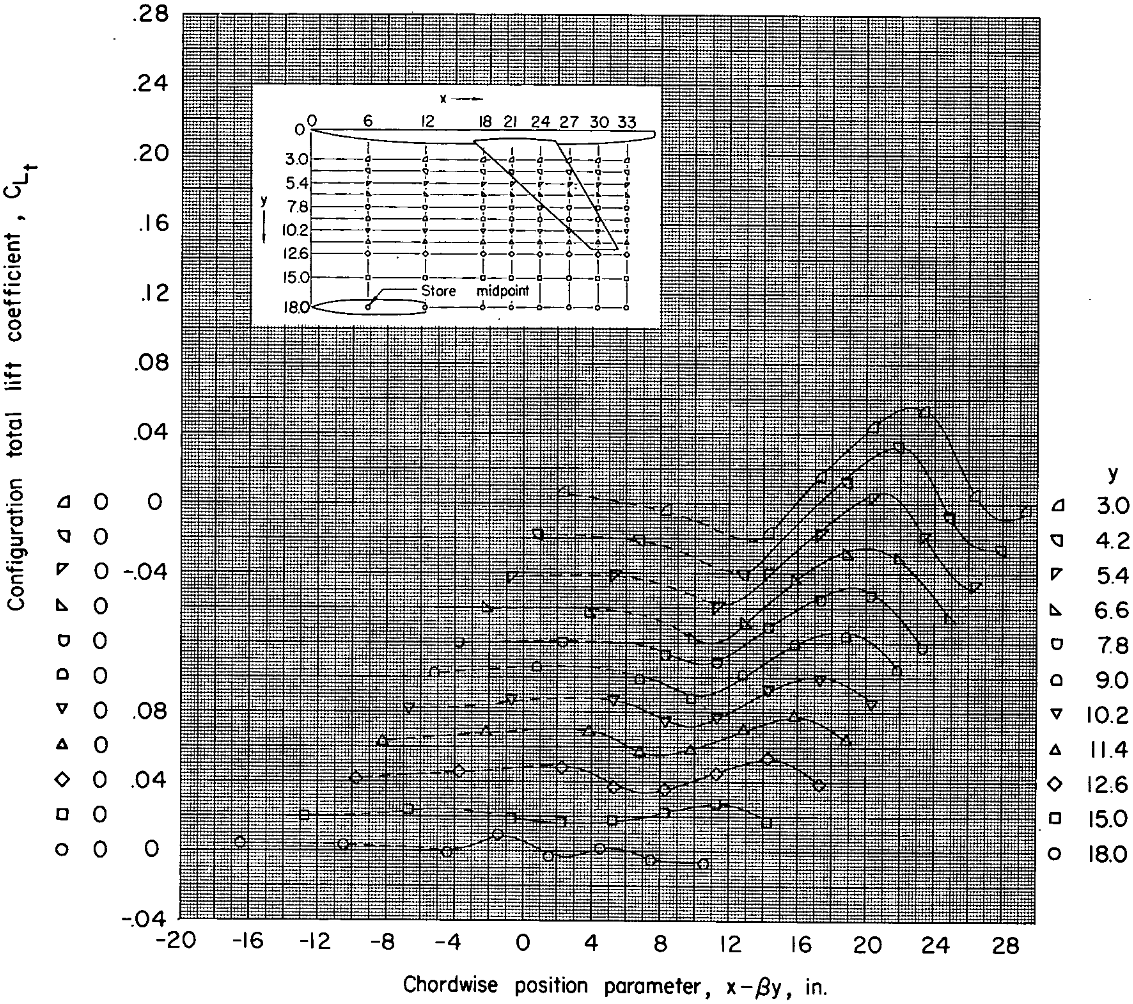
(a) z = 1.15 inches; α = 0°.

Figure 22.- Total lift of complete configuration (store plus wing-fuselage). Dashed lines indicate presence of interference of store sting.



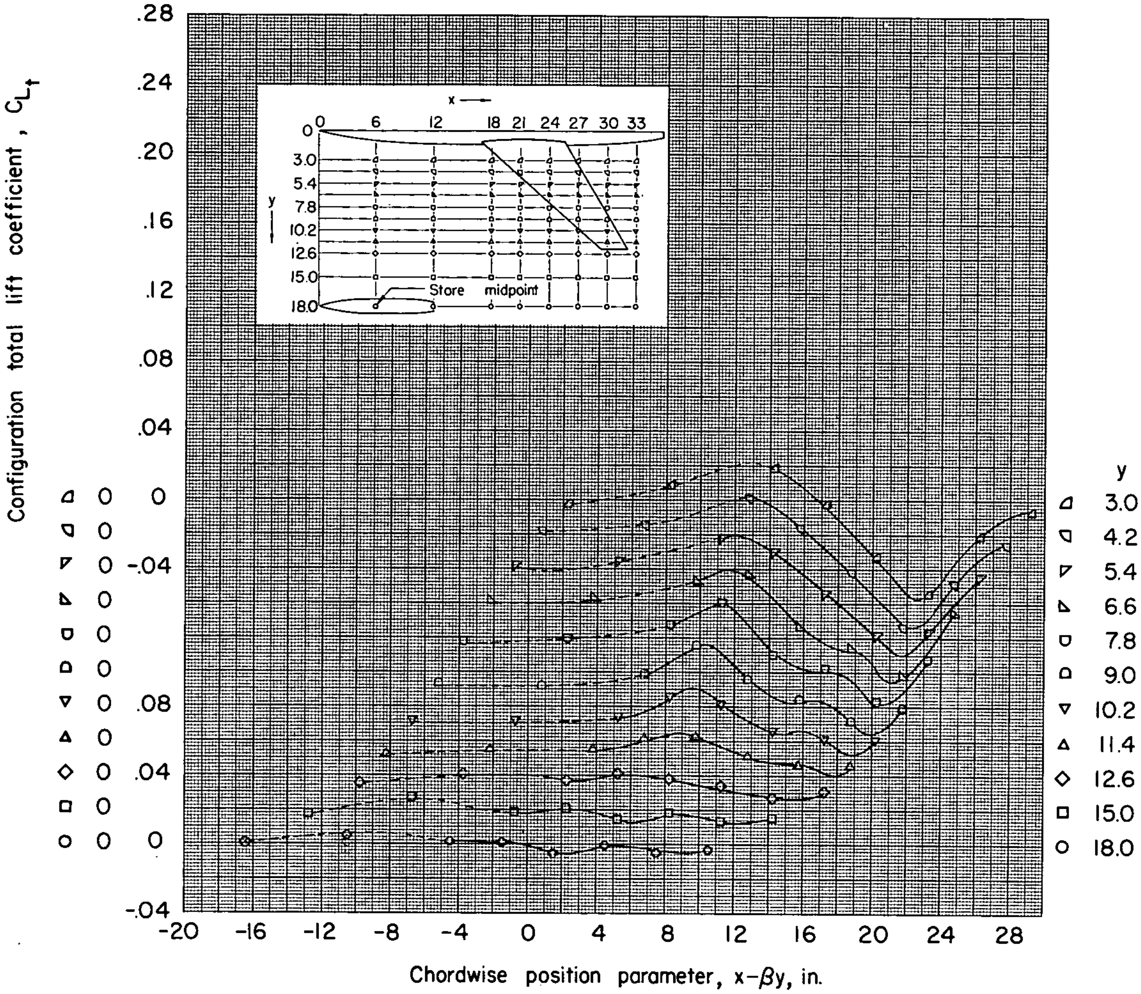
(b) z = 1.67 inches; α = 0°.

Figure 22.- Continued.



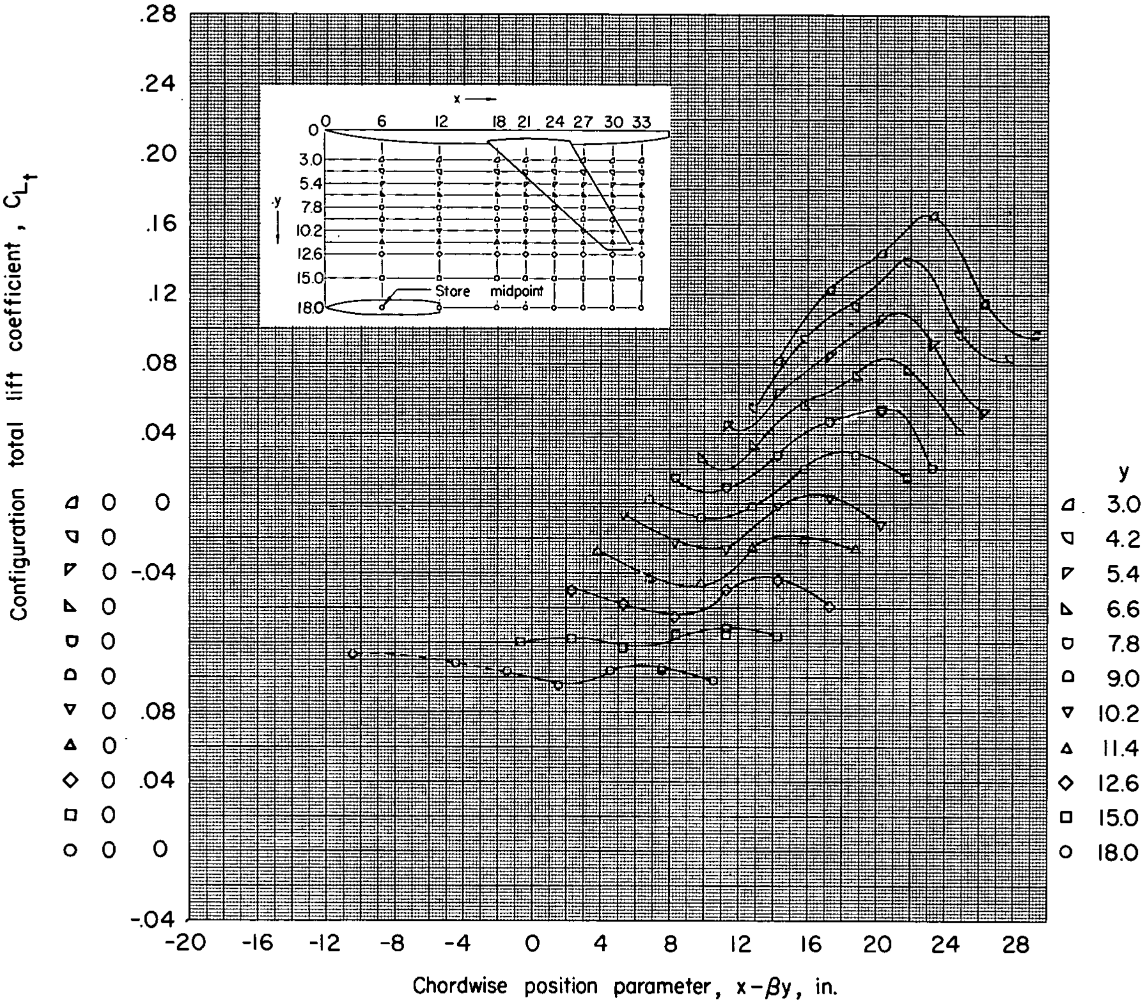
(c) z = 2.09 inches; α = 0°.

Figure 22.- Continued.



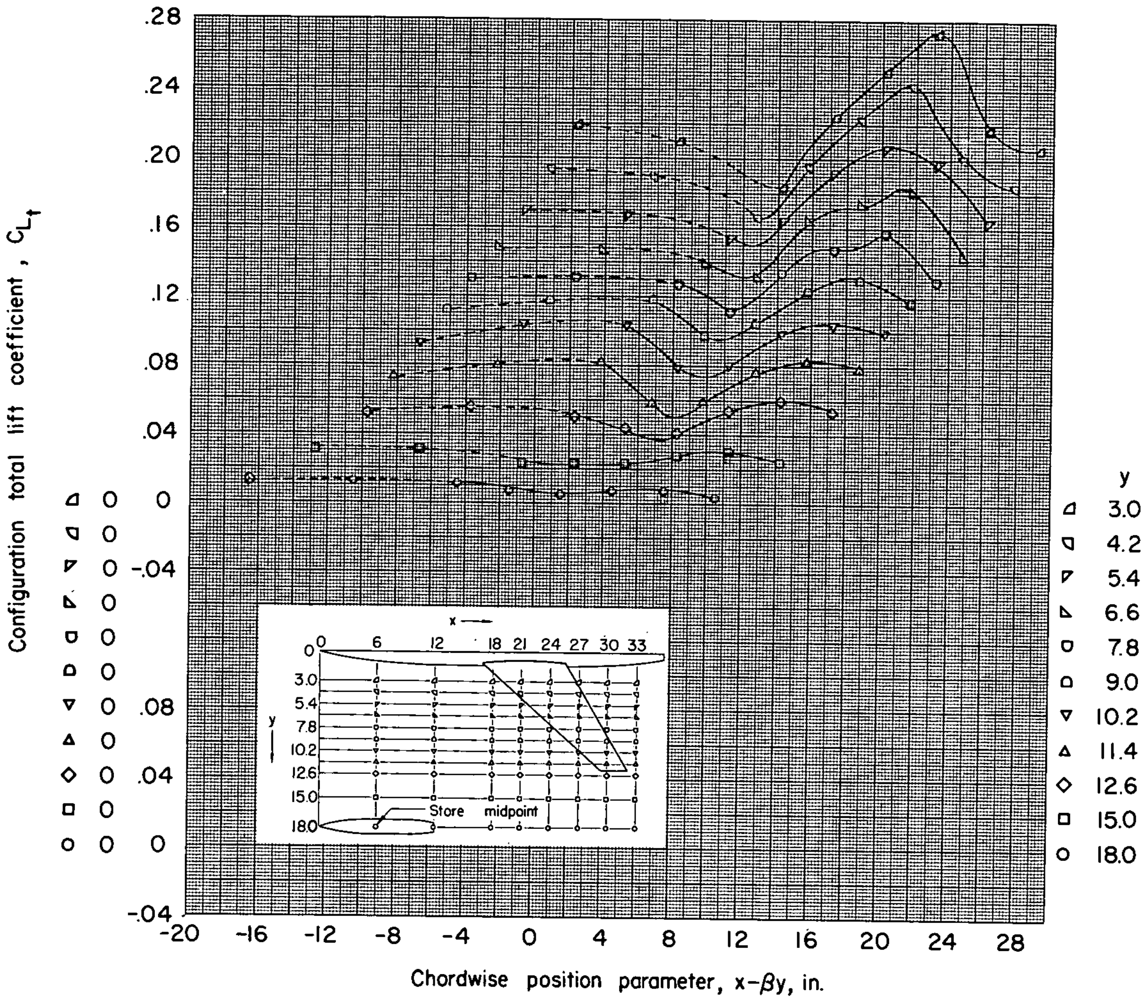
(d) $z = -1.31$ inches; $\alpha = 0^{\circ}$.

Figure 22.- Continued.



(e) z = 2.09 inches; α = 2°.

Figure 22.- Continued.



(f) z = 2.09 inches; $\alpha = 4^{\circ}$.

Figure 22.- Concluded.

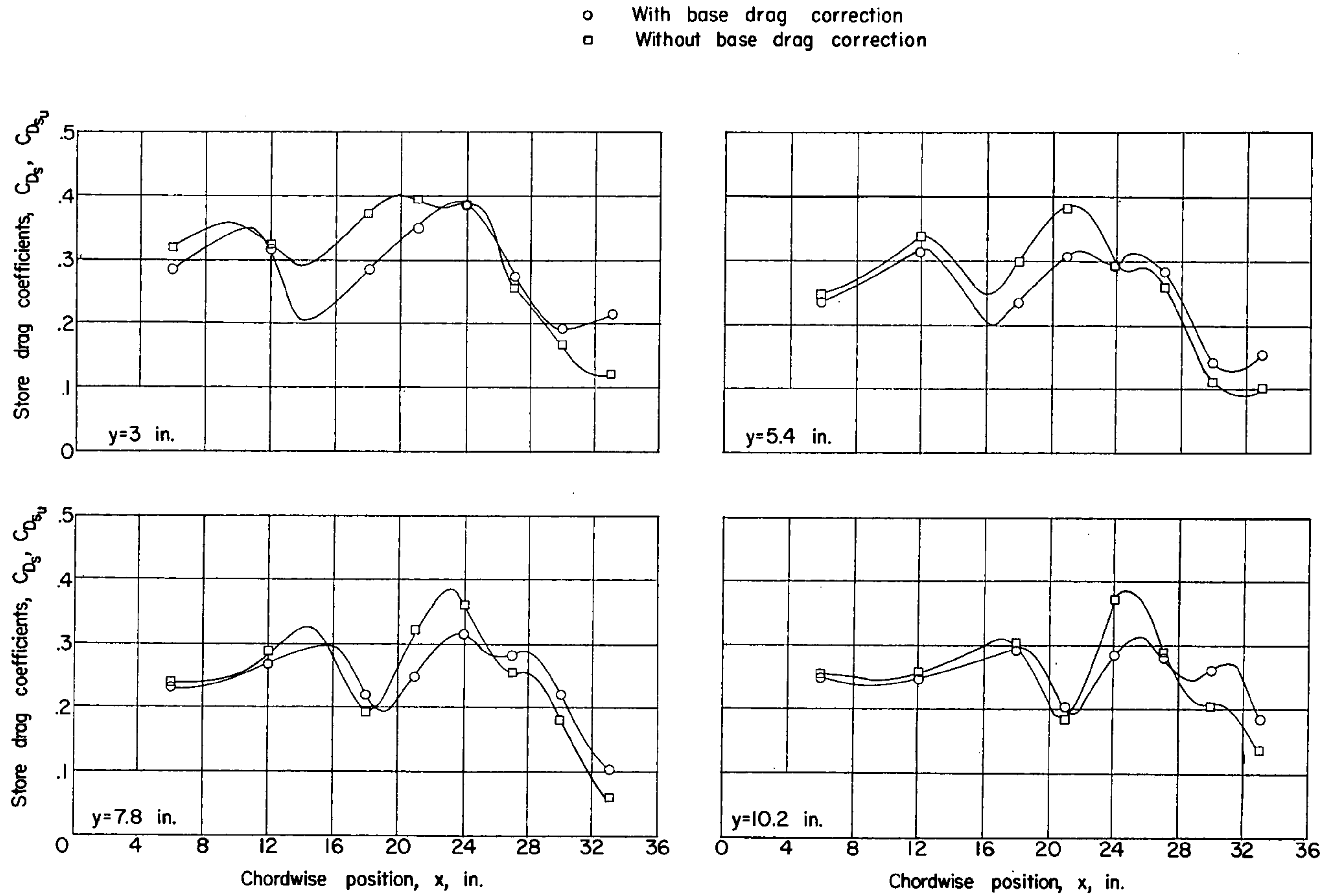
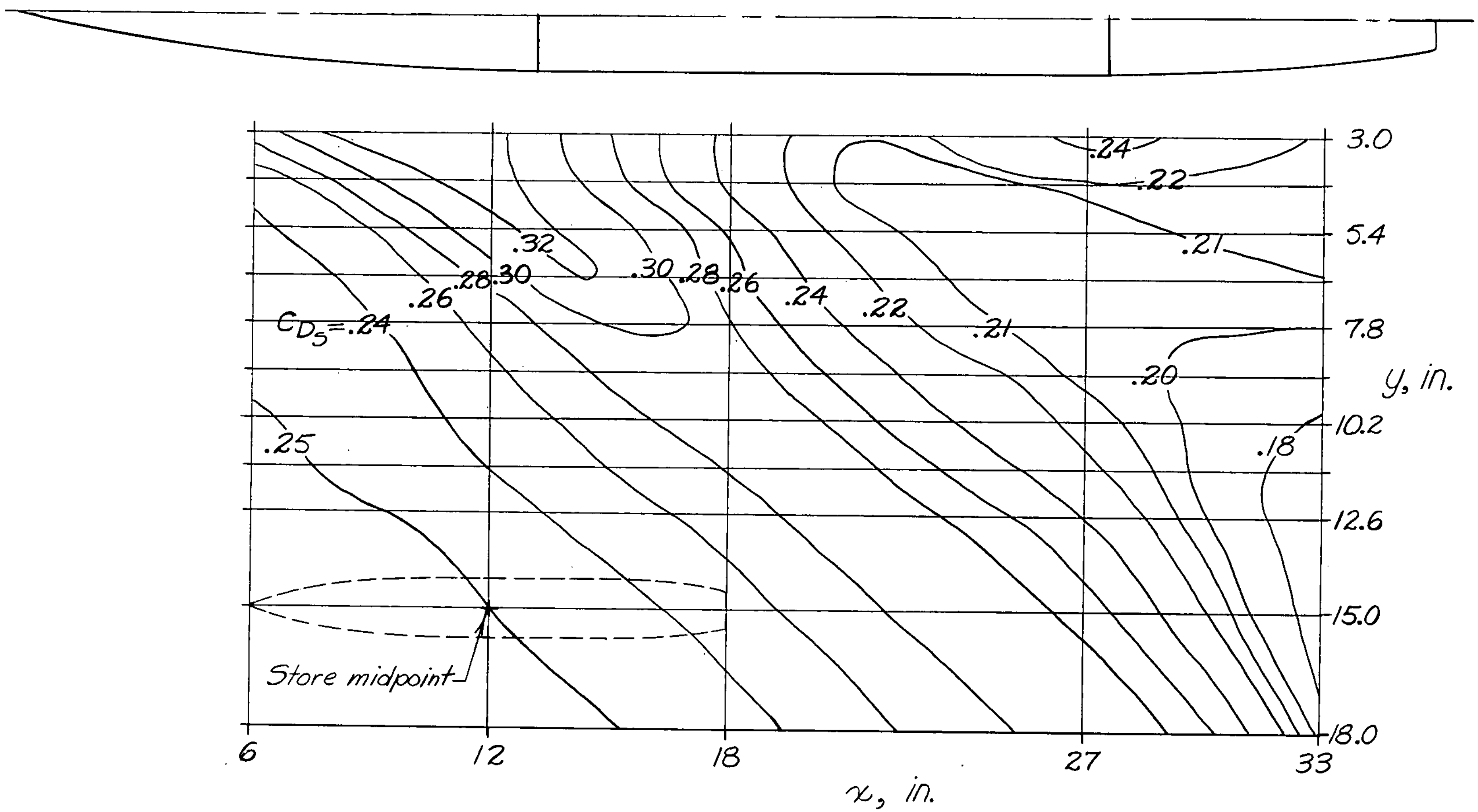
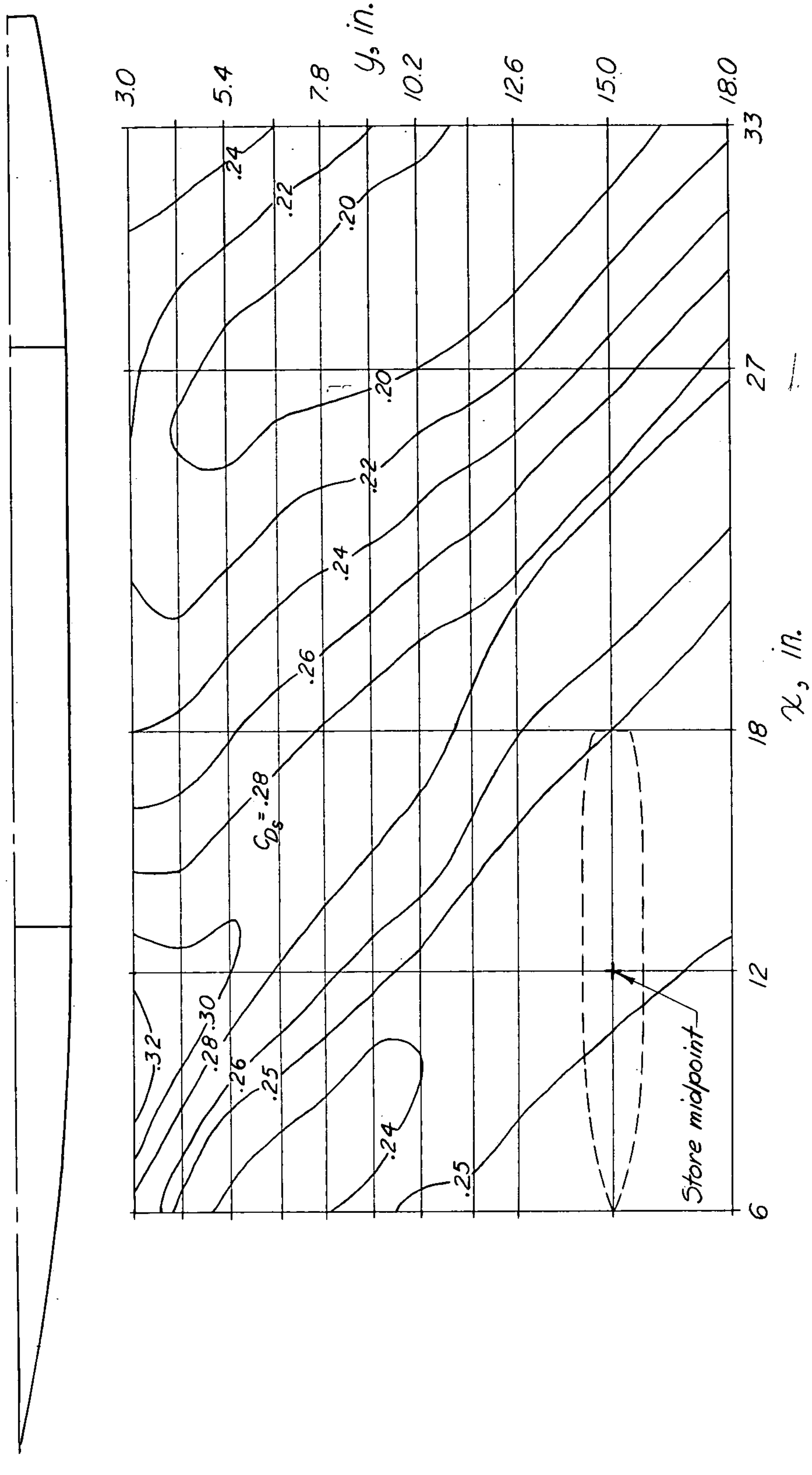


Figure 23.- Comparison of store drags with and without correction for base drag. Store in presence of wing fuselage combination. $z = 1.15$ inches; $\alpha = 0^{\circ}$.



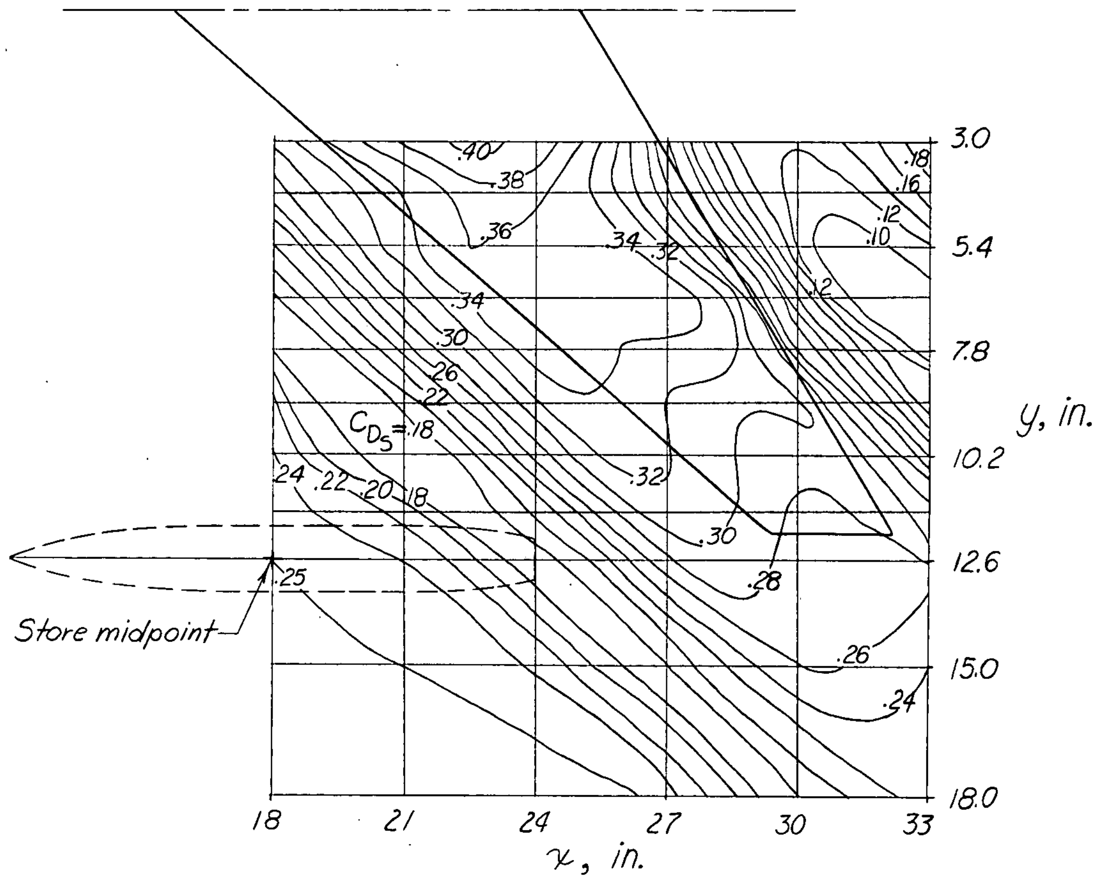
(a) z = 1.15 inches; α = 0°.

Figure 24.- Contour plot of the drag of the store in the presence of the fuselage. Drag coefficient of isolated store is 0.252.



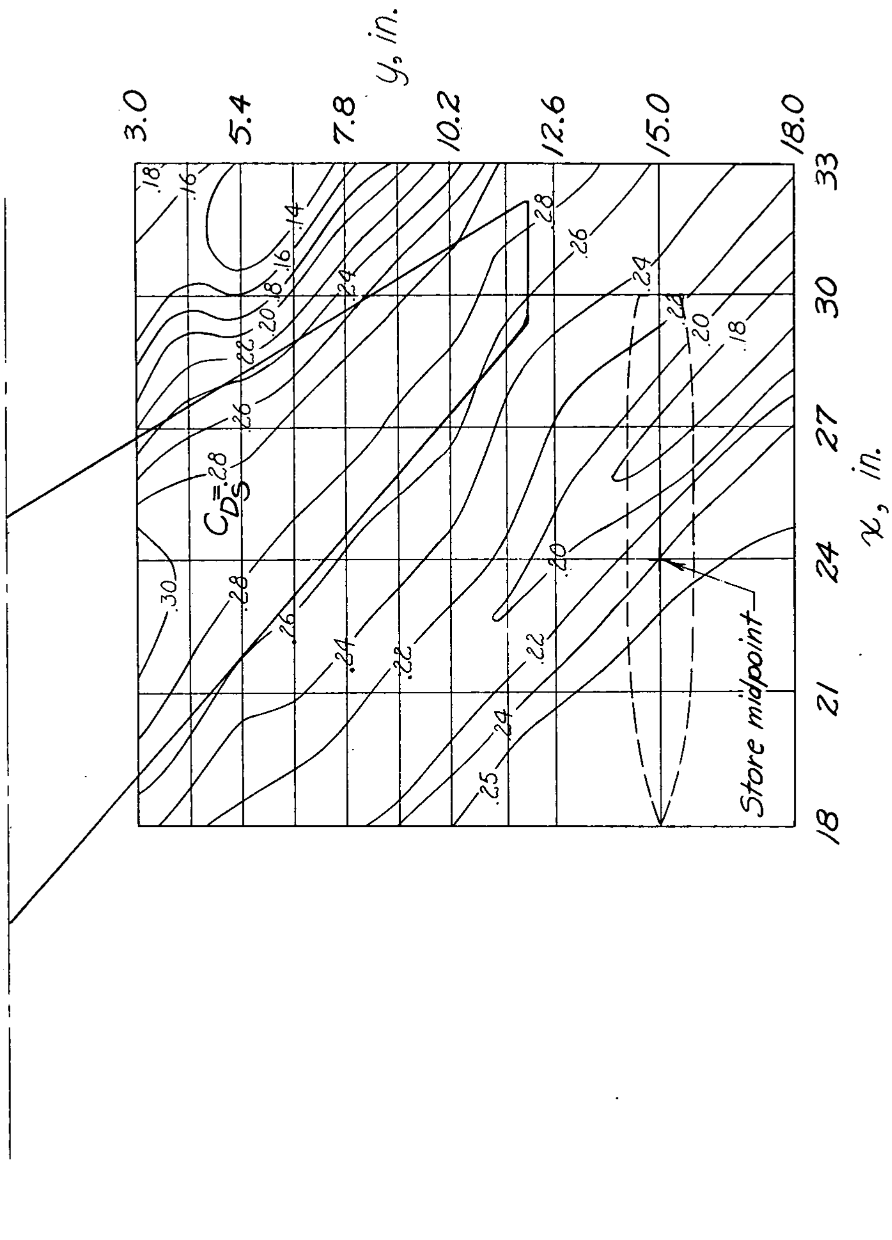
(b) z = 2.09 inches; α = 0°.

Figure 24.- Concluded.



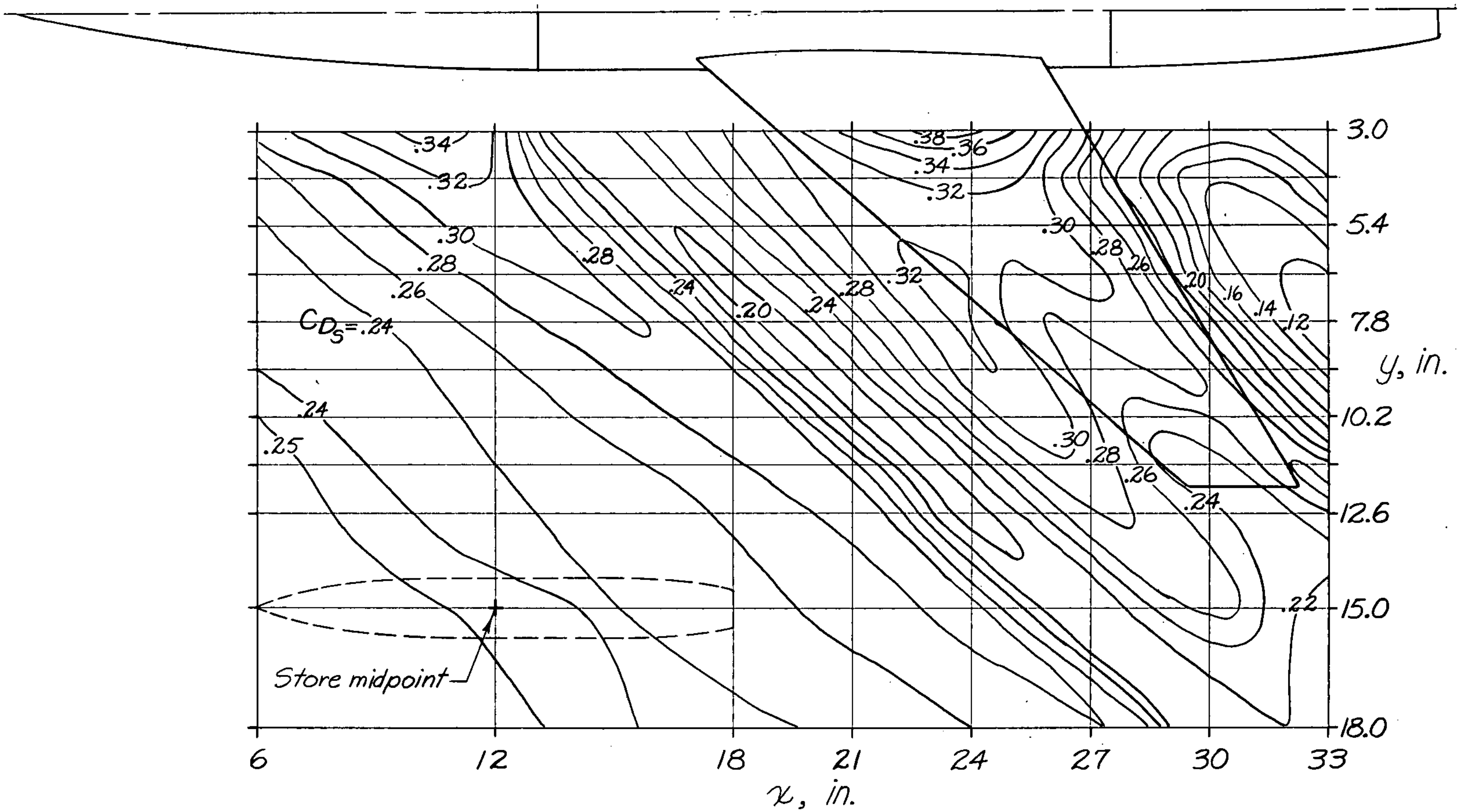
(a) z = 1.15 inches; α = 0°.

Figure 25.- Contour plot of the drag of the store in the presence of the wing. Drag coefficient of isolated store is 0.252.



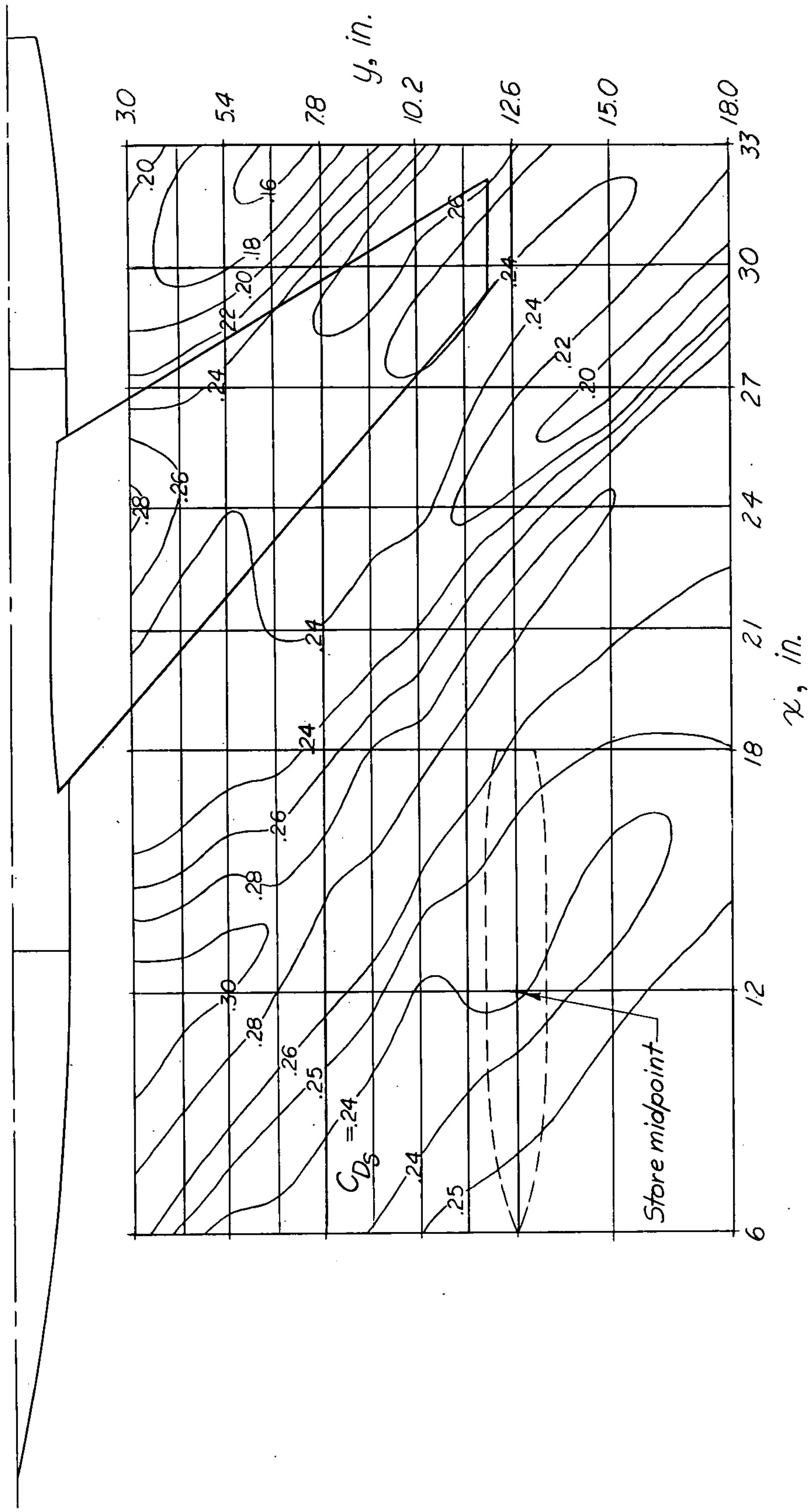
(b) z = 2.09 inches; α = 0°.

Figure 25.- Concluded.



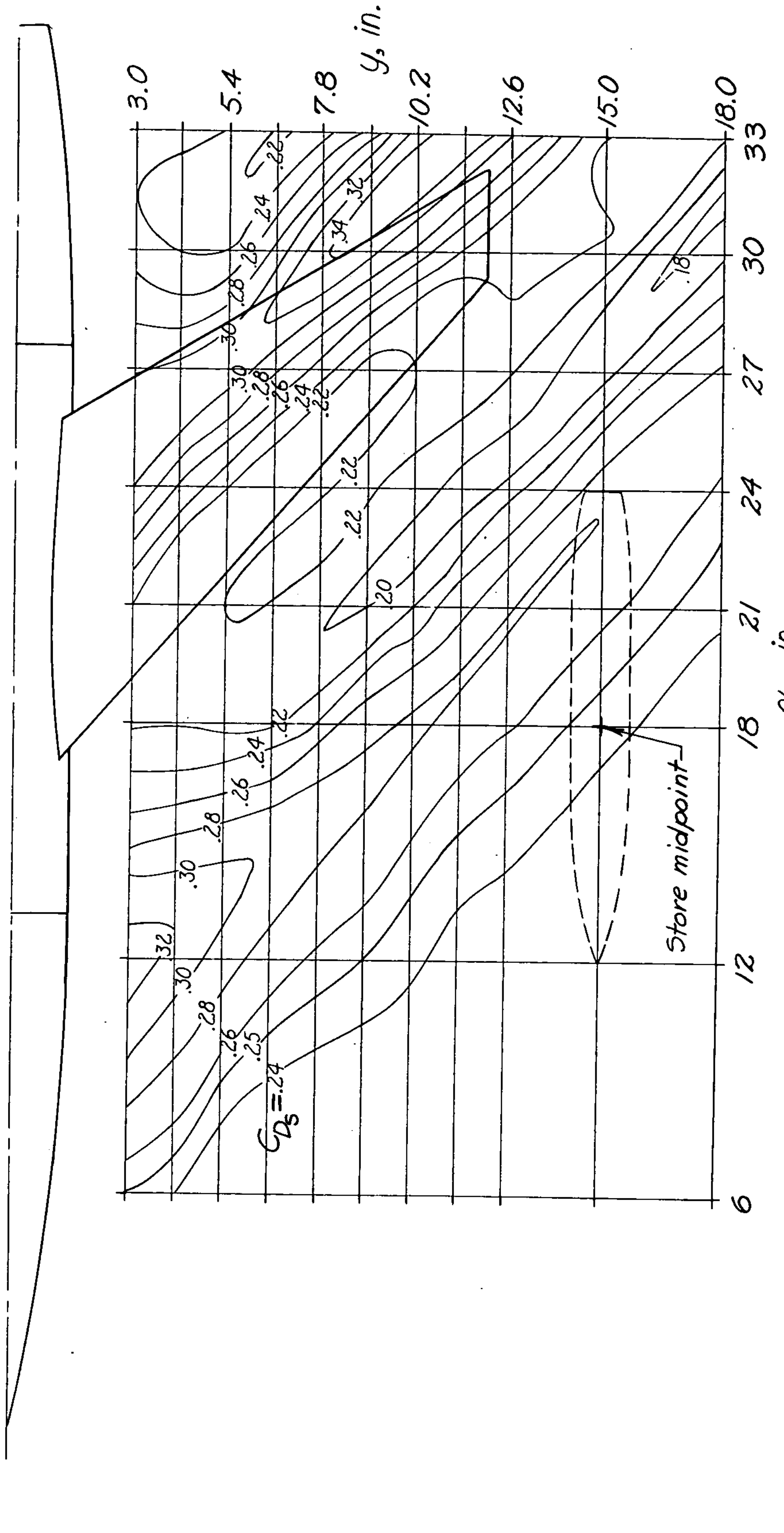
(a) z = 1.15 inches; α = 0°.

Figure 26.- Contour plot of the drag of the store in the presence of the wing-fuselage combination. Drag coefficient of isolated store is 0.252.



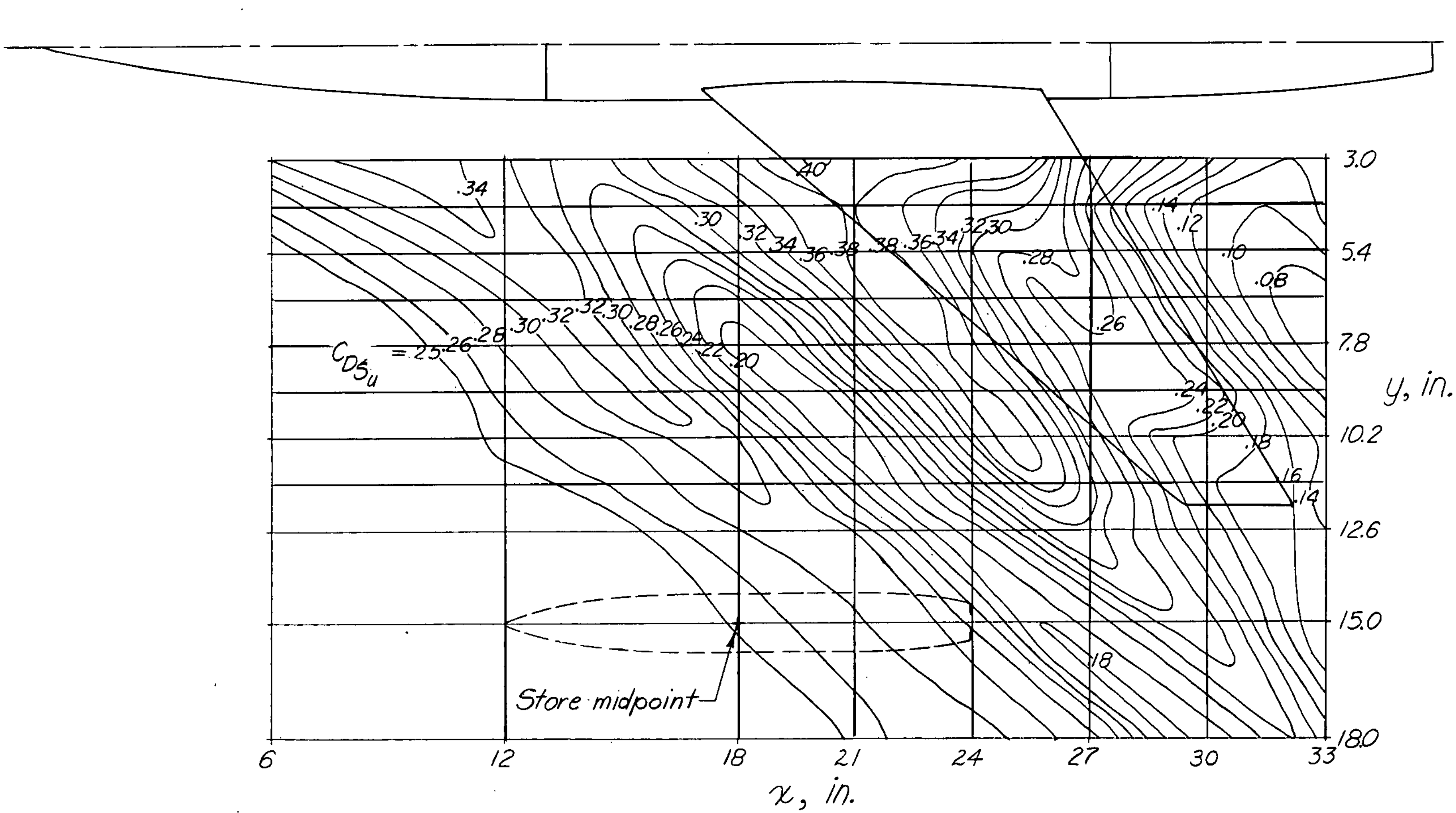
(b) z = 2.09 inches; α = 0°.

Figure 26.- Continued.



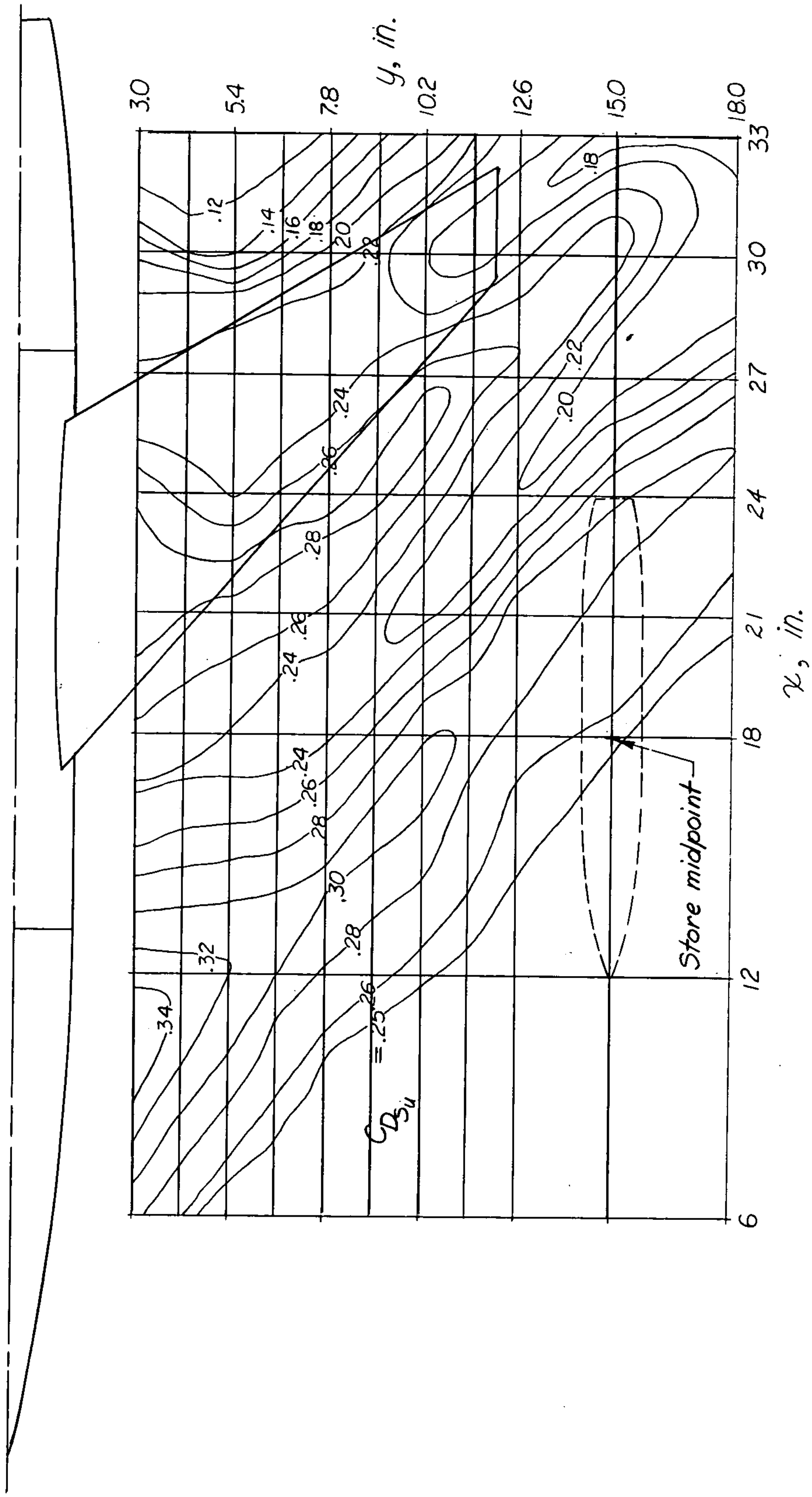
(c) z = 2.09 inches; α = 4°.

Figure 26.- Concluded.



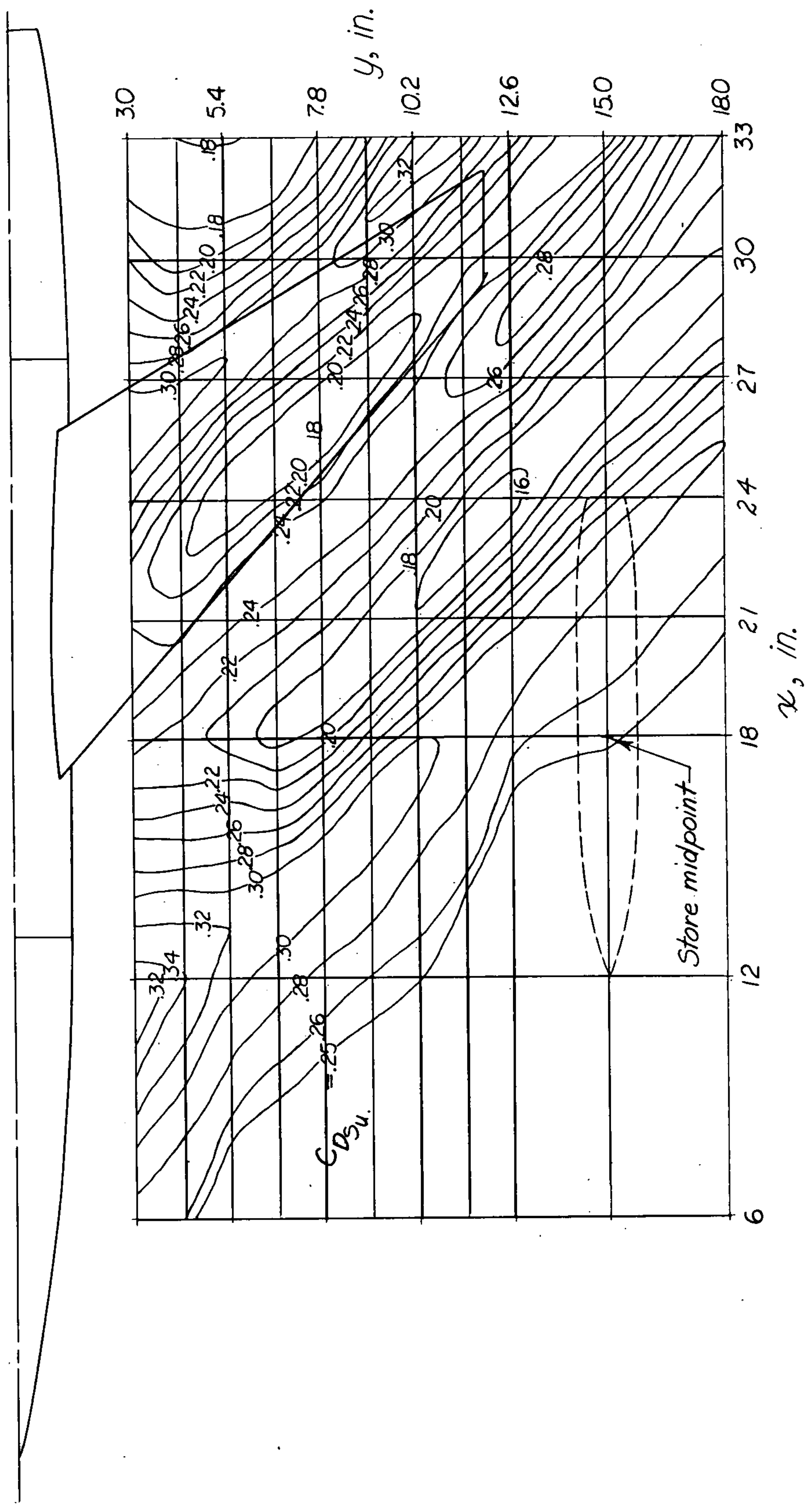
(a) $z = 1.15$ inches; $\alpha = 0^{\circ}$.

Figure 27.- Contour plot of the drag of the store in the presence of the wing-fuselage combination. Drag uncorrected for base pressure. Drag coefficient of isolated store, uncorrected for base pressure is 0.270.



(b) z = 2.09 inches; α = 0°.

Figure 27.- Continued.



(c) z = 2.09 inches; α = 4°.

Figure 27.- Concluded.

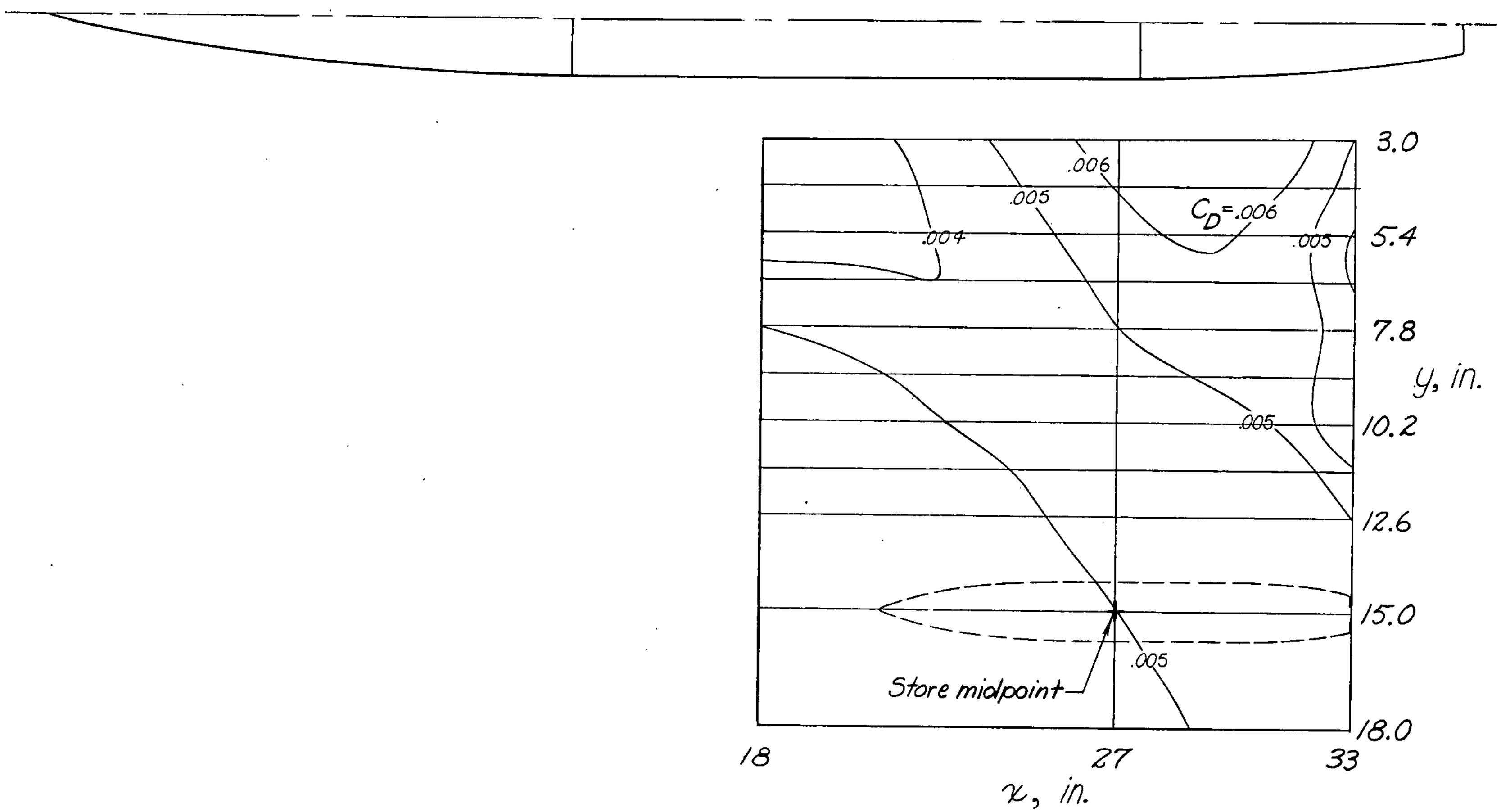


Figure 28.- Contour plot of the drag of the fuselage in the presence of the store. (Contour lines give fuselage drag for store midpoint at any location.) $z = 1.15$ inches; $\alpha = 0^{\circ}$. Drag coefficient of isolated fuselage is 0.005.

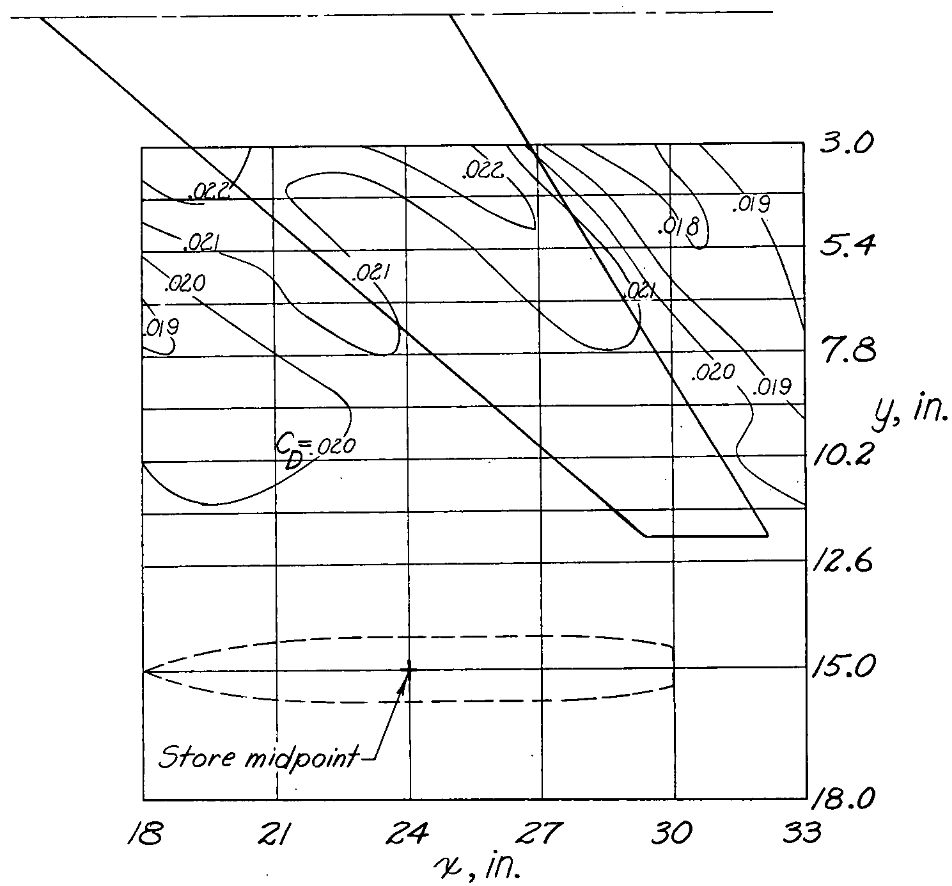
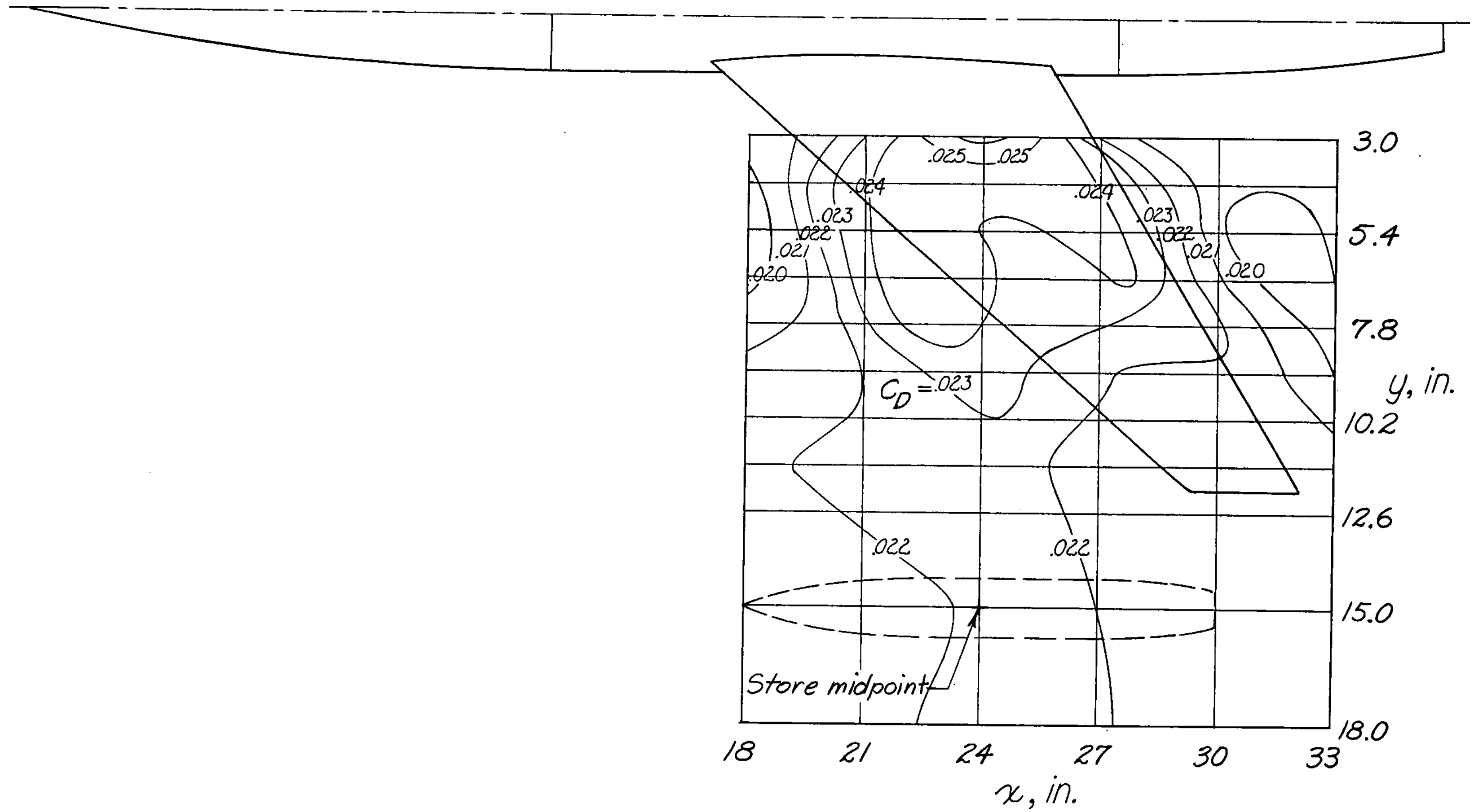
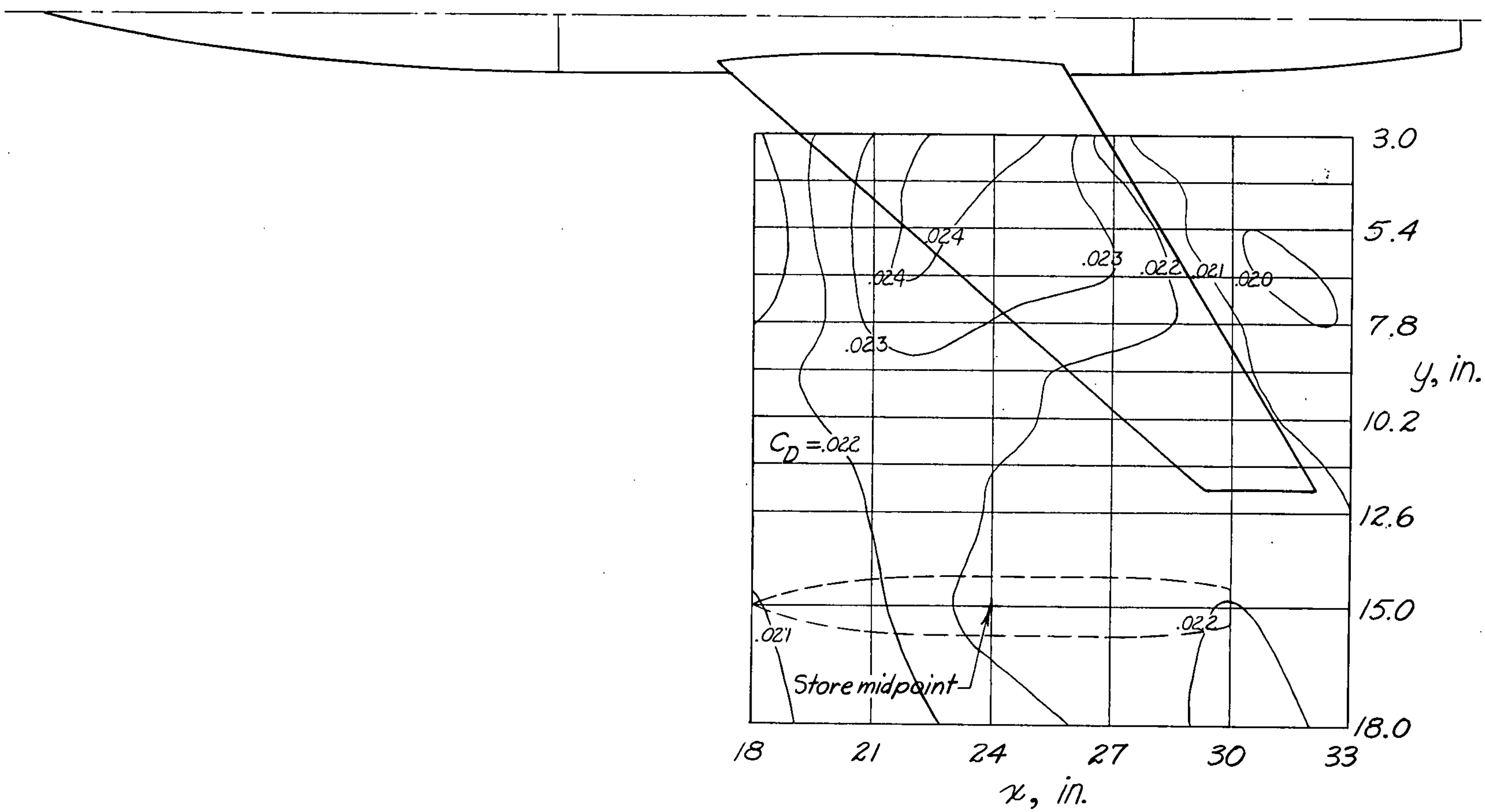


Figure 29.- Contour plot of the drag of the wing in the presence of the store. (Contour lines give wing drag for store midpoint at any location.) $z = 1.15$ inches; $\alpha = 0^{\circ}$. Drag coefficient of isolated wing is 0.020.



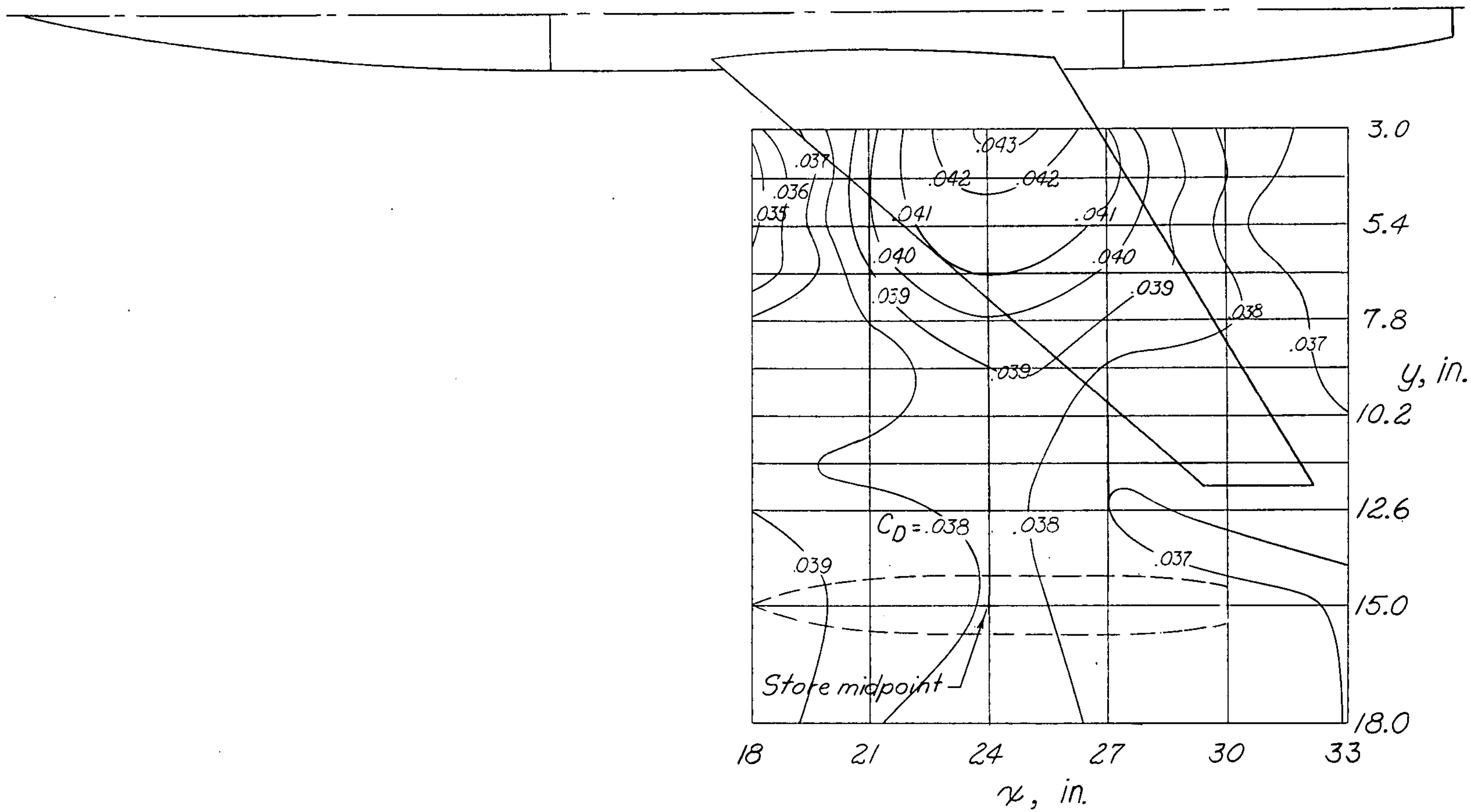
(a) z = 1.15 inches; α = 0°.

Figure 30.- Contour plot of the drag of the wing-fuselage combination in the presence of the store. (Contour lines give wing-fuselage combination drag for store midpoint at any location.) Drag coefficient of isolated wing-fuselage combination is 0.0213.



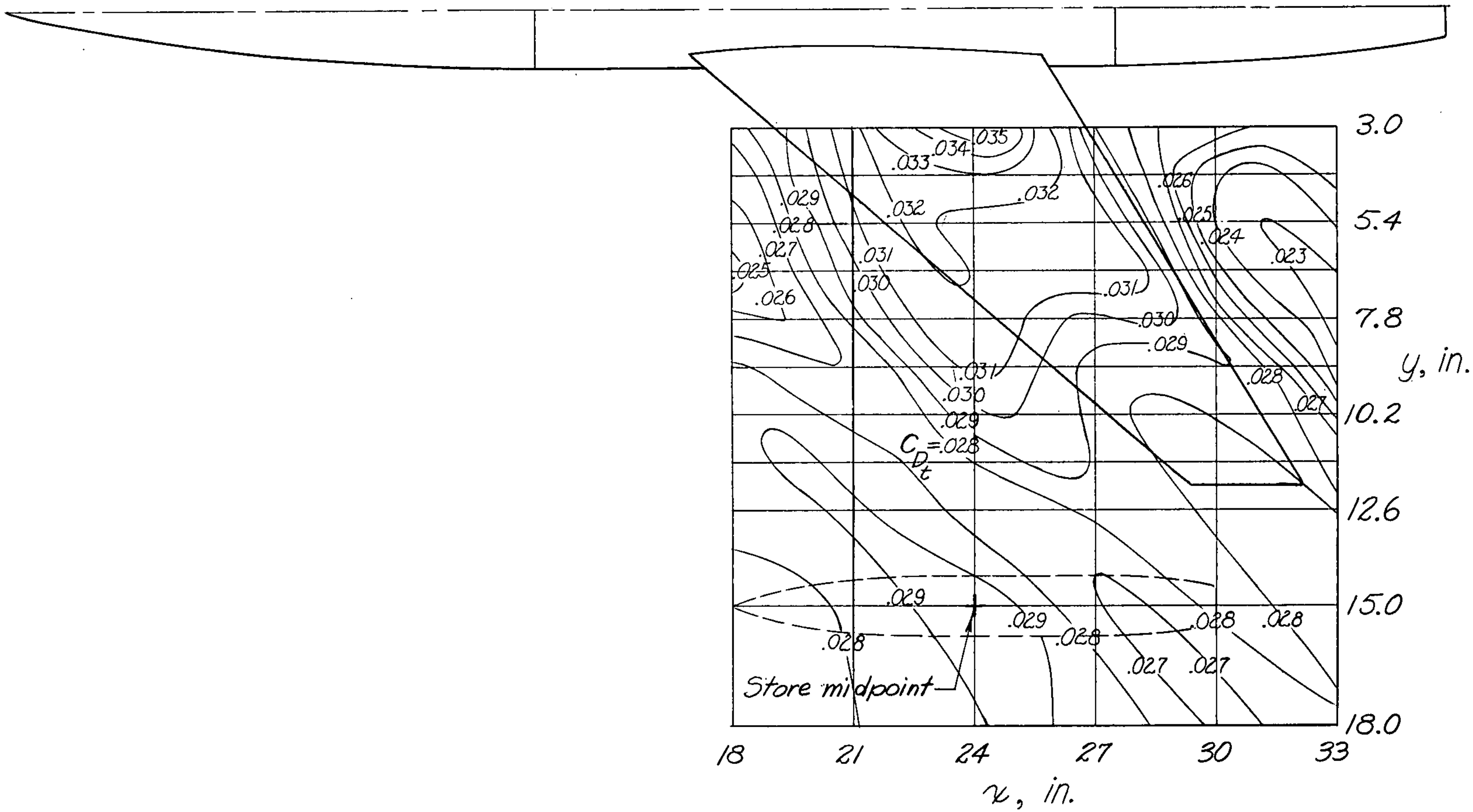
(b) z = 2.09 inches; α = 0°.

Figure 30.- Continued.



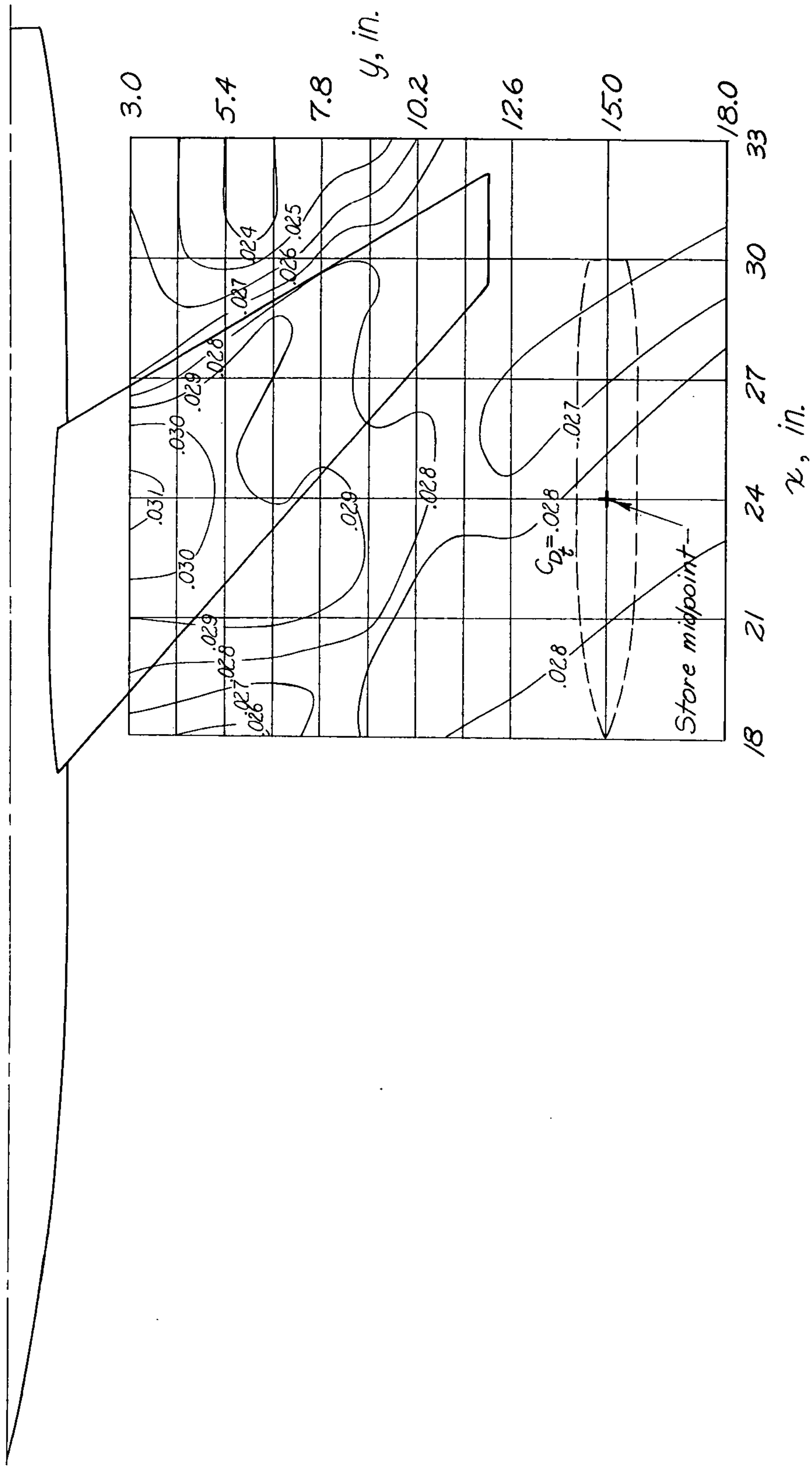
(c) z = 2.09 inches; α = 4°.

Figure 30.- Concluded.



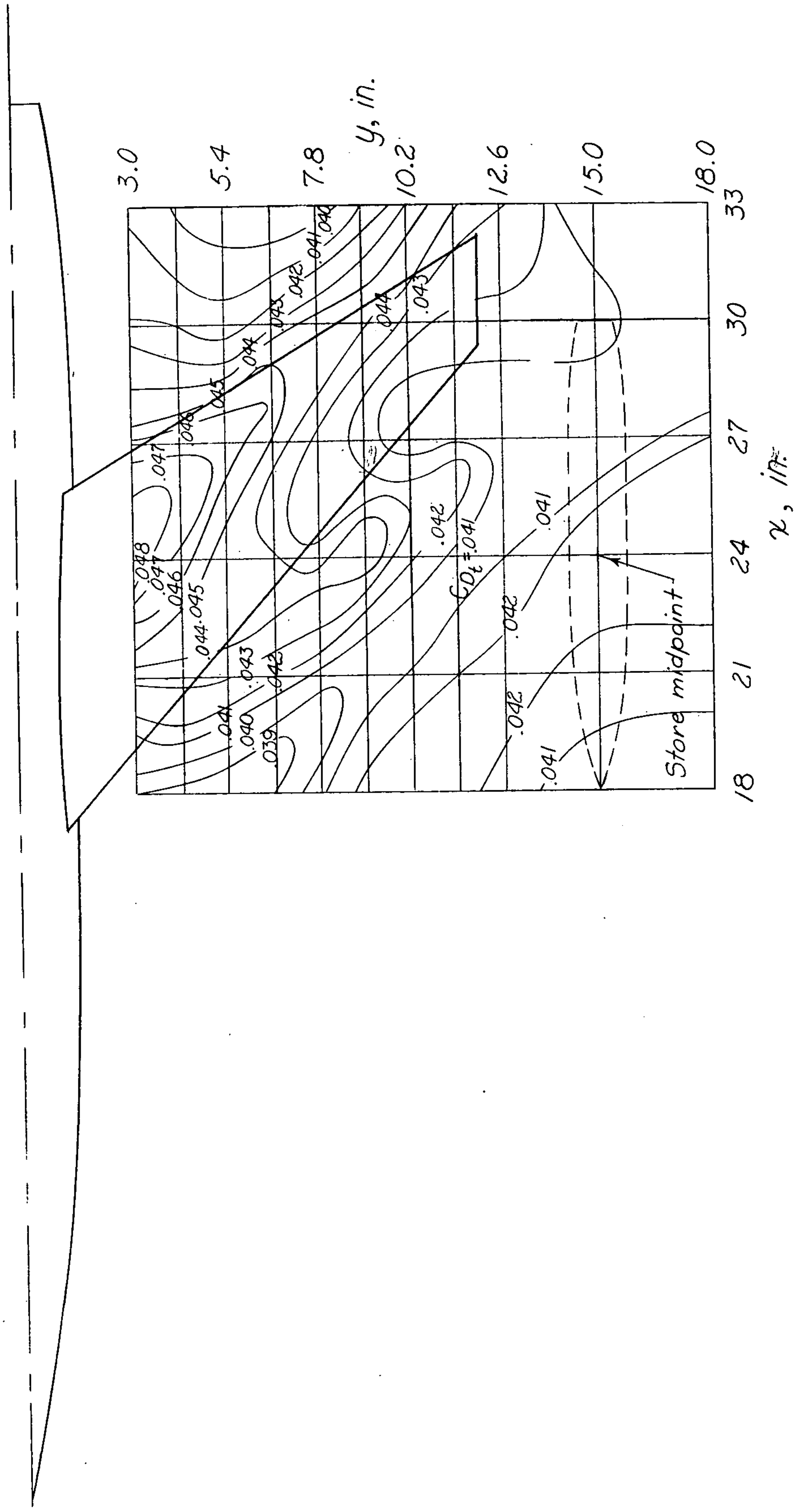
(a) z = 1.15 inches; α = 0°.

Figure 31.- Contour plot of the total drag of the complete (wing fuselage plus store) configuration. (Contour lines give total drag for store midpoint at any location.) Sum of drag coefficients for isolated store and isolated wing-fuselage is 0.0276.



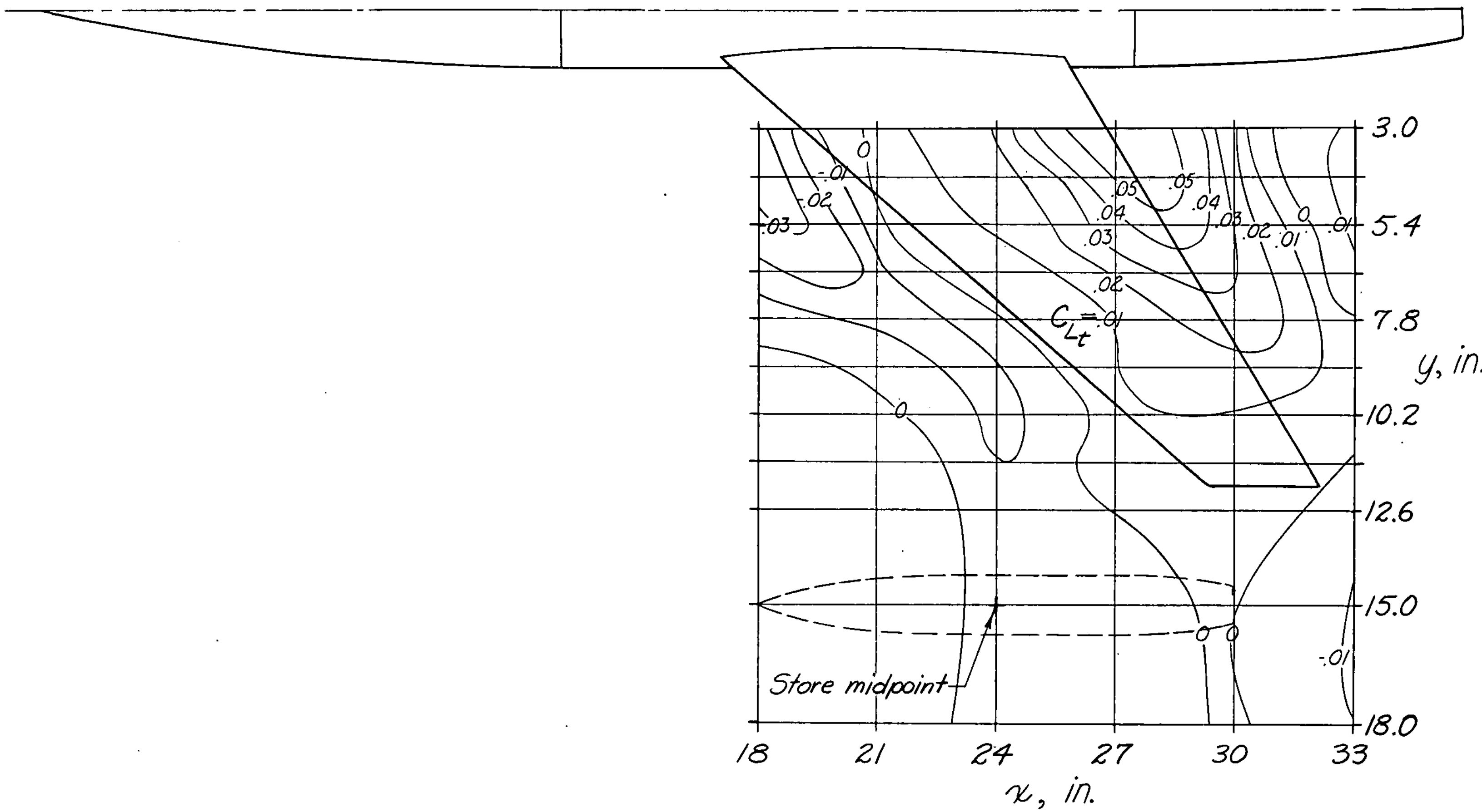
(b) z = 2.09 inches; α = 0°.

Figure 31.- Continued.



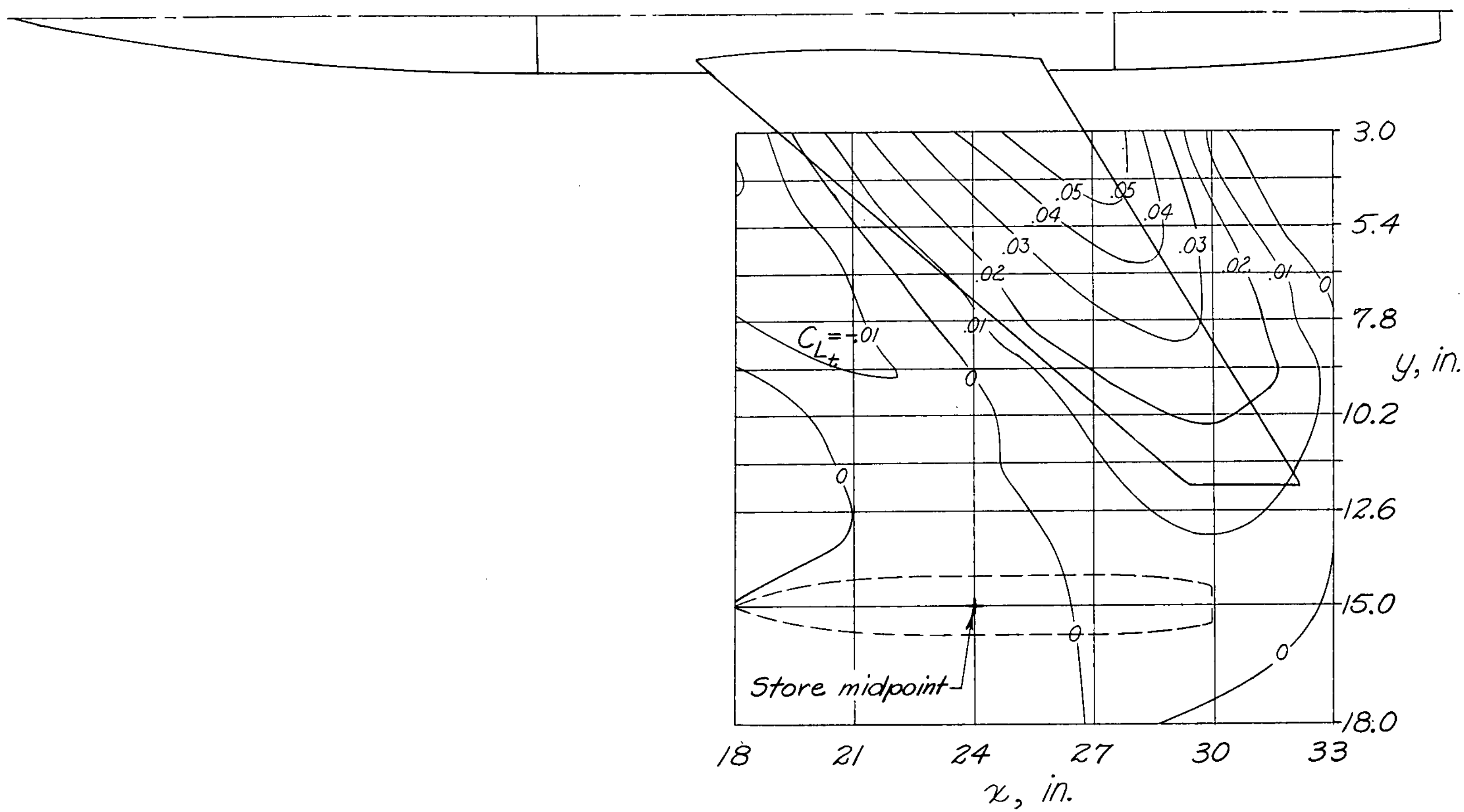
(c) z = 2.09 inches; α = 4°.

Figure 31.- Concluded.



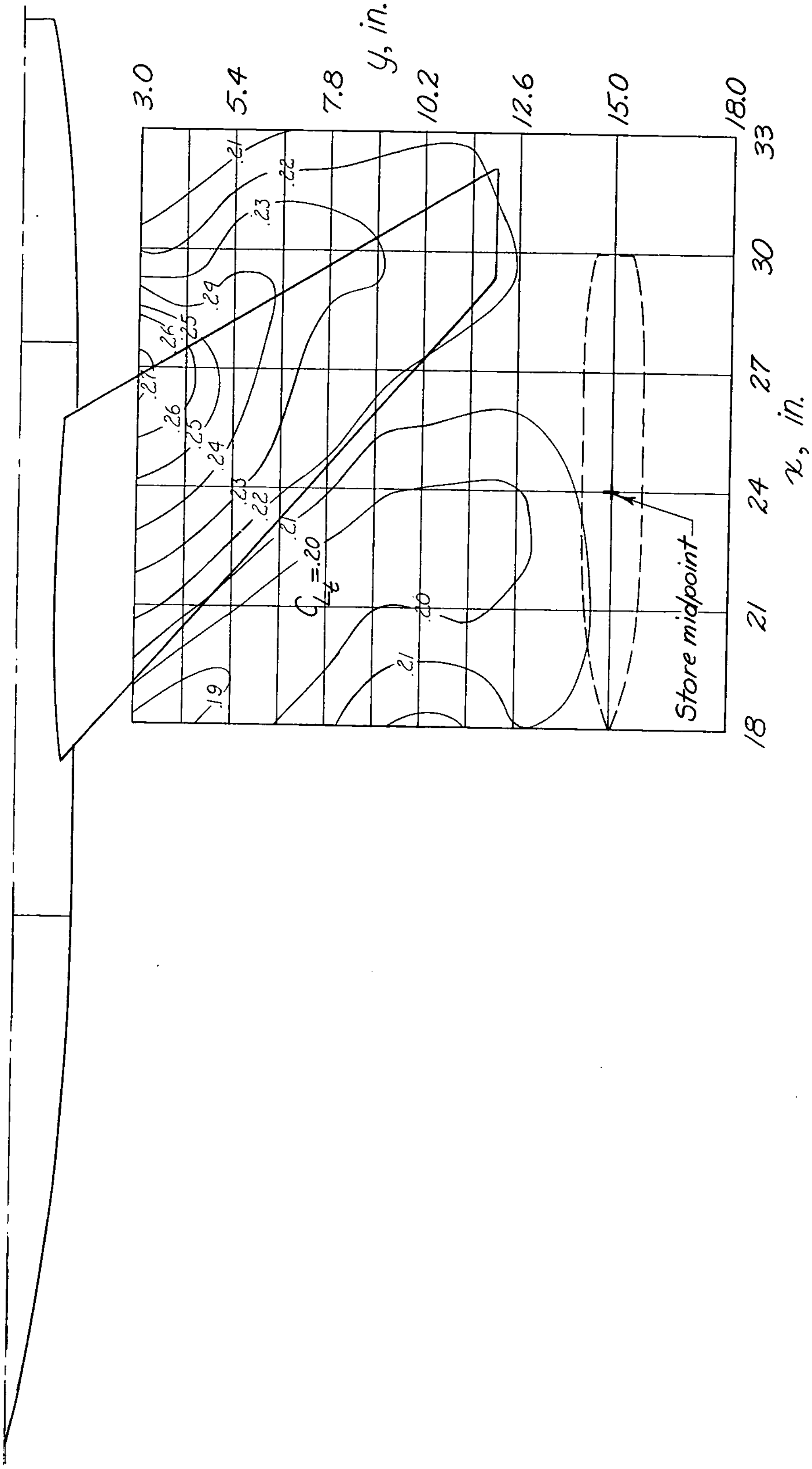
(a) z = 1.15 inches; α = 0°.

Figure 32.- Contour plot of the total lift of the complete (wing fuselage plus store) configuration. (Contour lines give total lift for store midpoint at any location.)



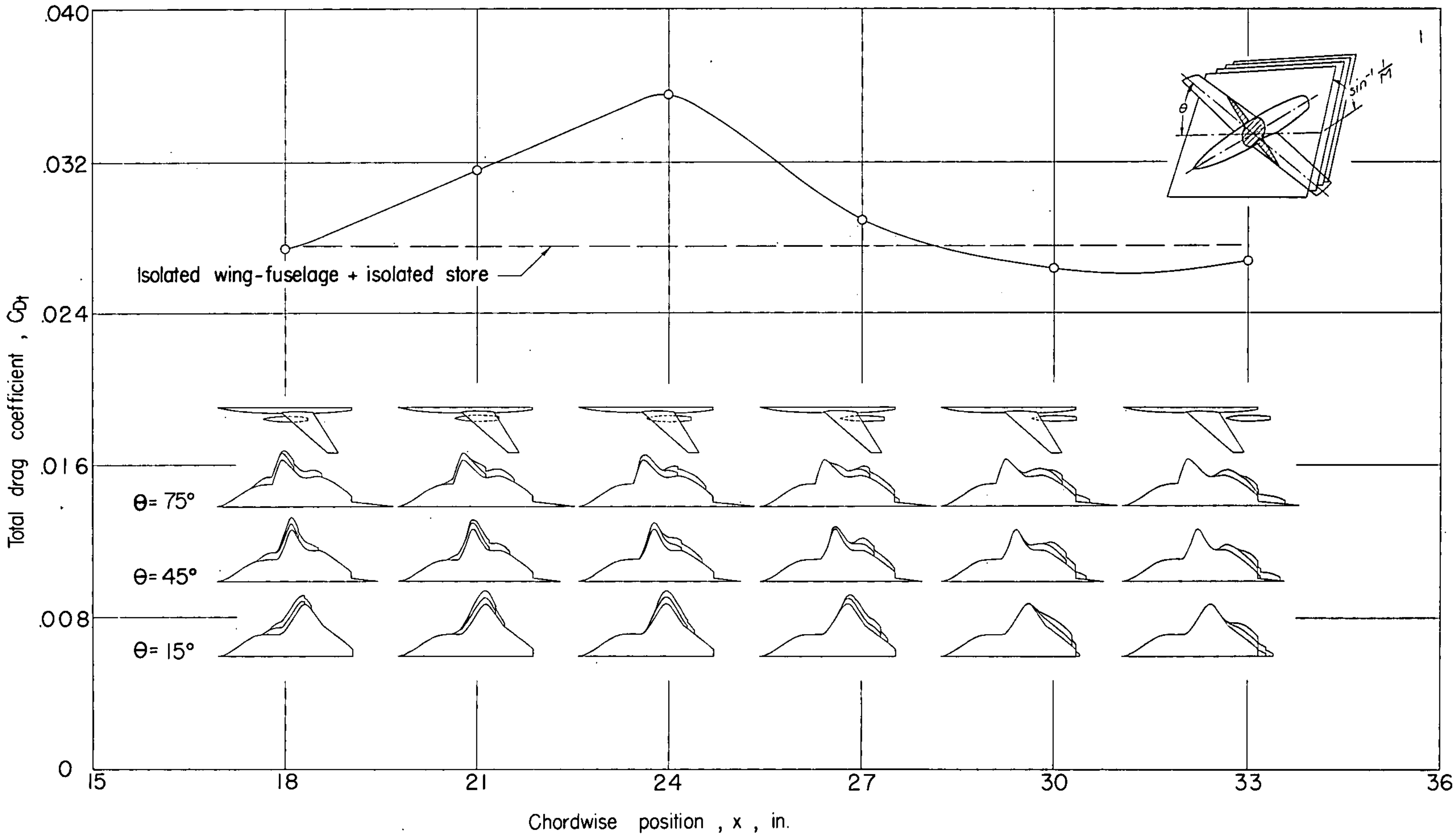
(b) z = 2.09 inches; α = 0°.

Figure 32.- Continued.



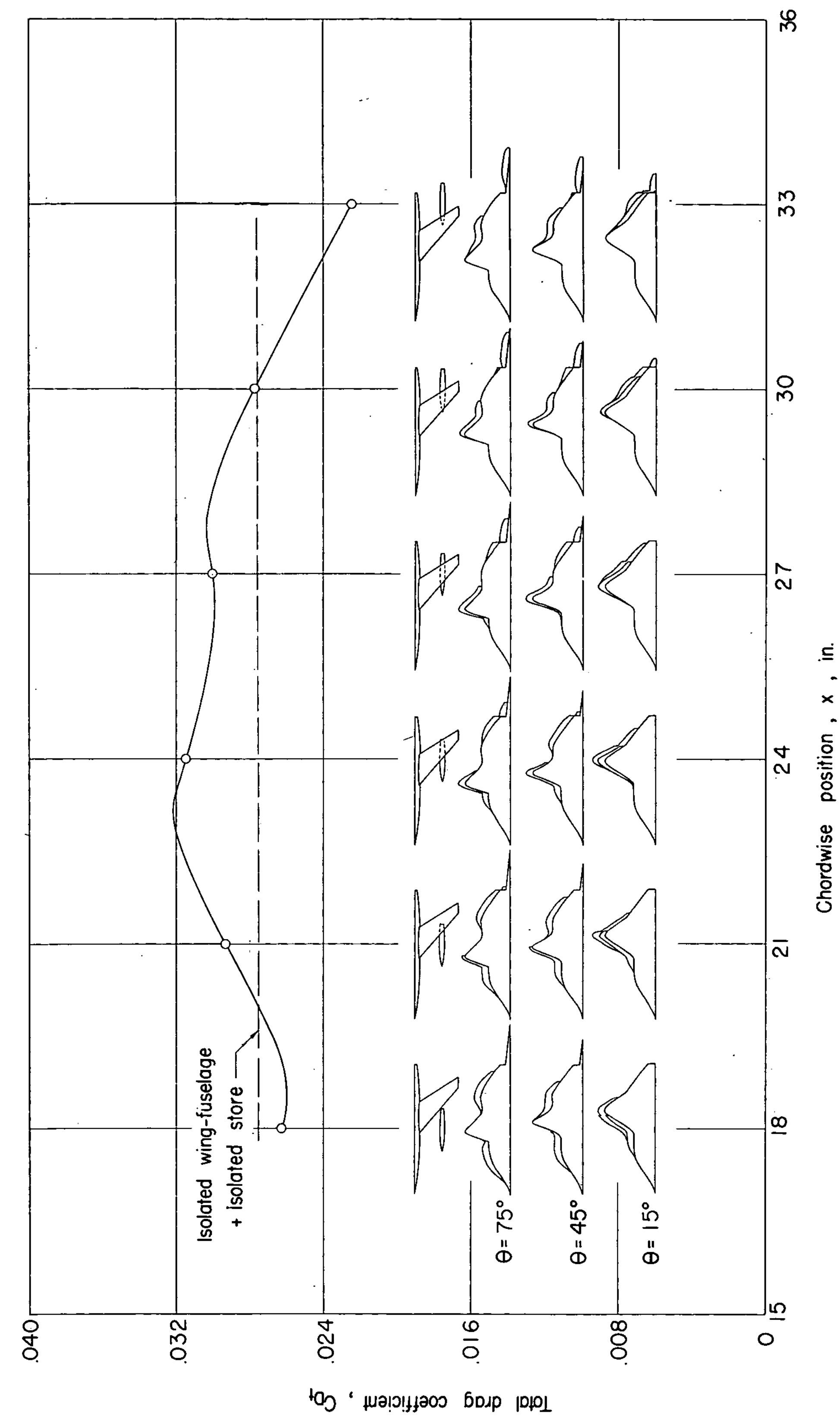
(c) z = 2.09 inches; α = 4°.

Figure 32.- Concluded.



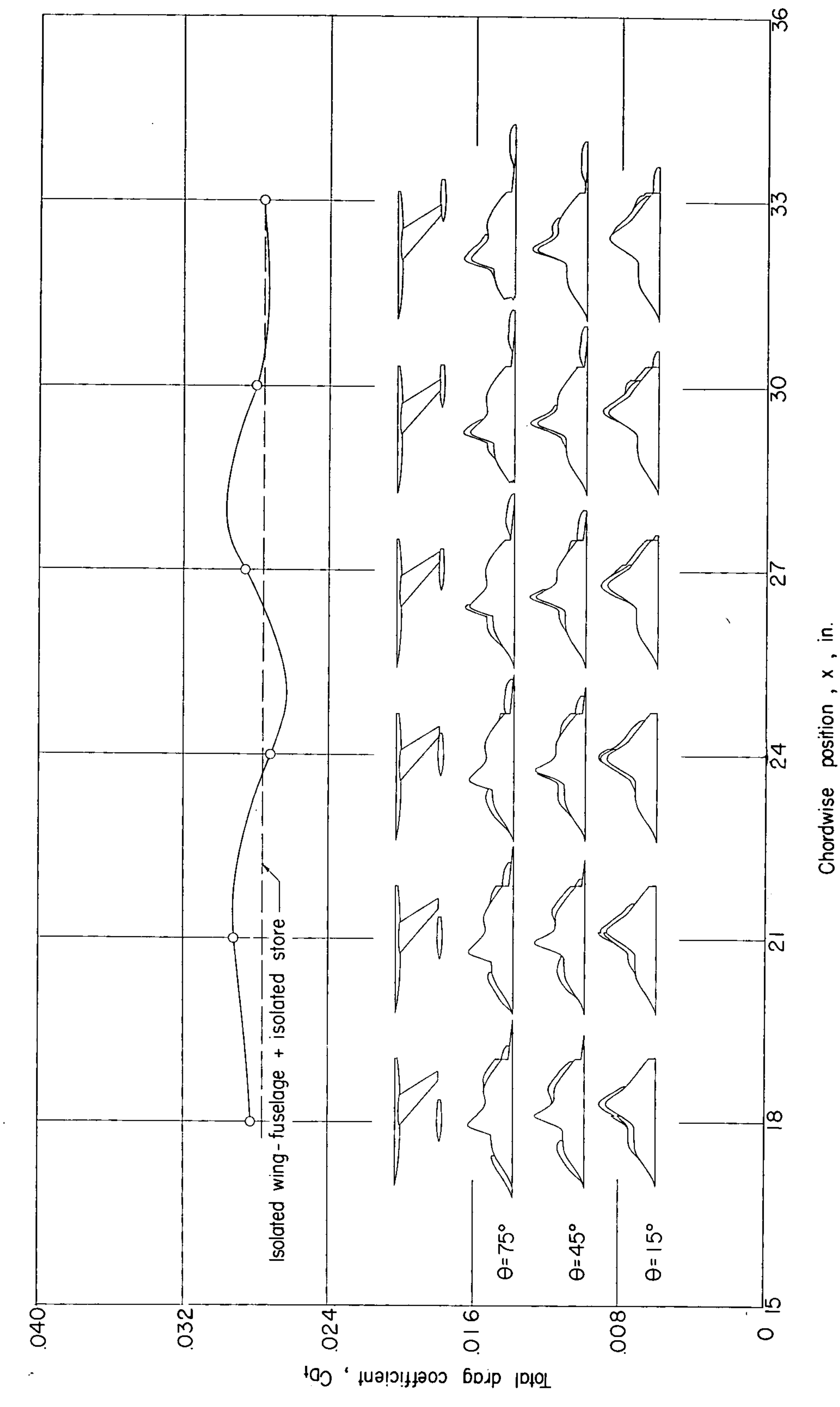
(a) y = 3.0 inches.

Figure 33.- Analysis of configuration total drag (store + wing fuselage) using supersonic area rule considerations. z = 1.15 inches; $\alpha = 0^{\circ}$. (The area diagrams shown are for full-span configuration.)



(b) y = 7.8 inches.

Figure 33.- Continued.



(c) y = 12.6 inches.

Figure 33.- Concluded.

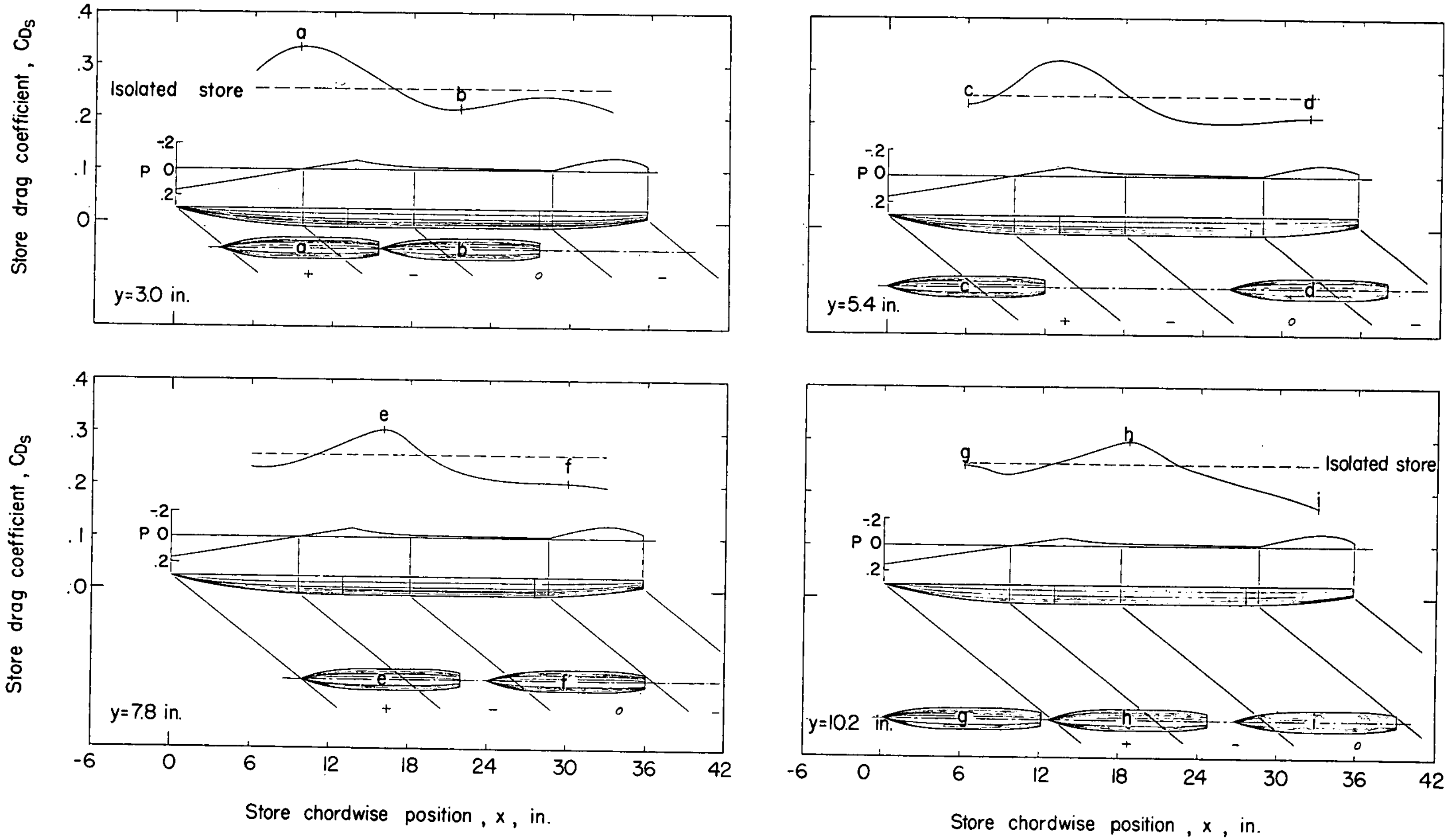


Figure 34.- Effect of fuselage pressure field on drag of store. $z = 1.15$ inches; $\alpha = 0^{\circ}$.

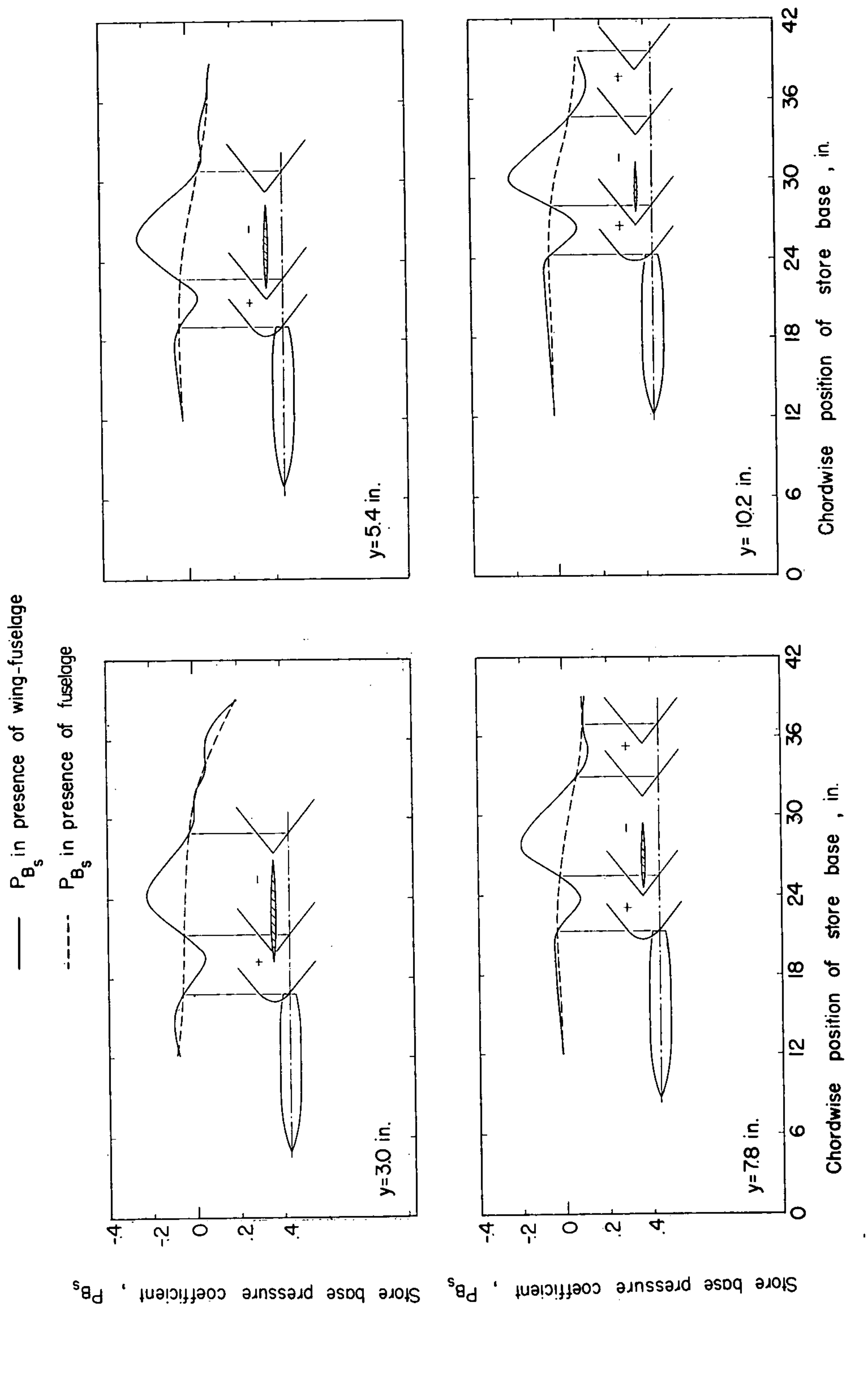


Figure 35.- Mapping of effective pressure field of wing alone by means of store base pressure measurements. z = 1.15 inches; α = 0°.

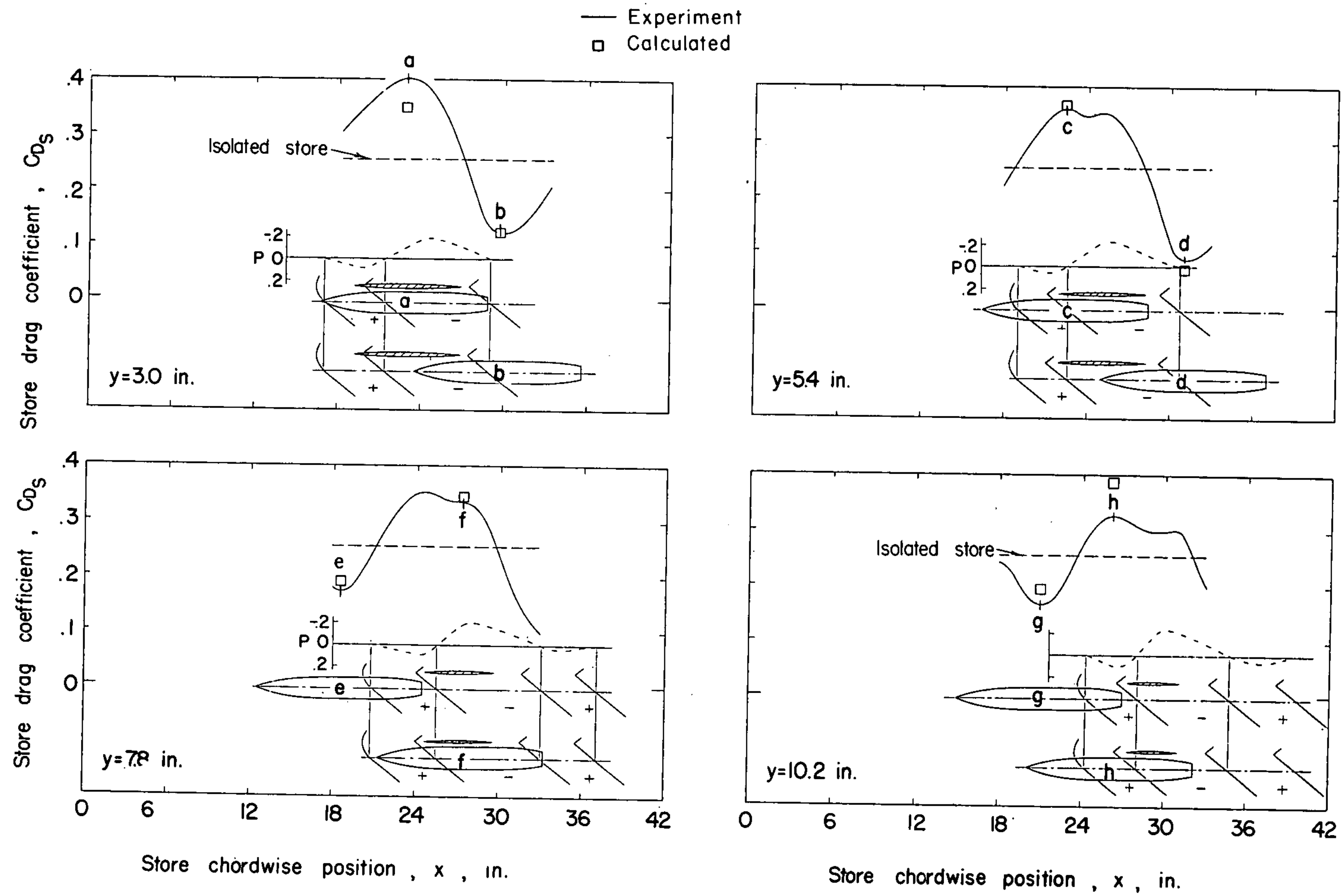


Figure 36.- Effect of wing-alone effective-pressure field on store drag. Wing field determined from store base pressures. $z = 1.15$ inches; $\alpha = 0^{\circ}$.

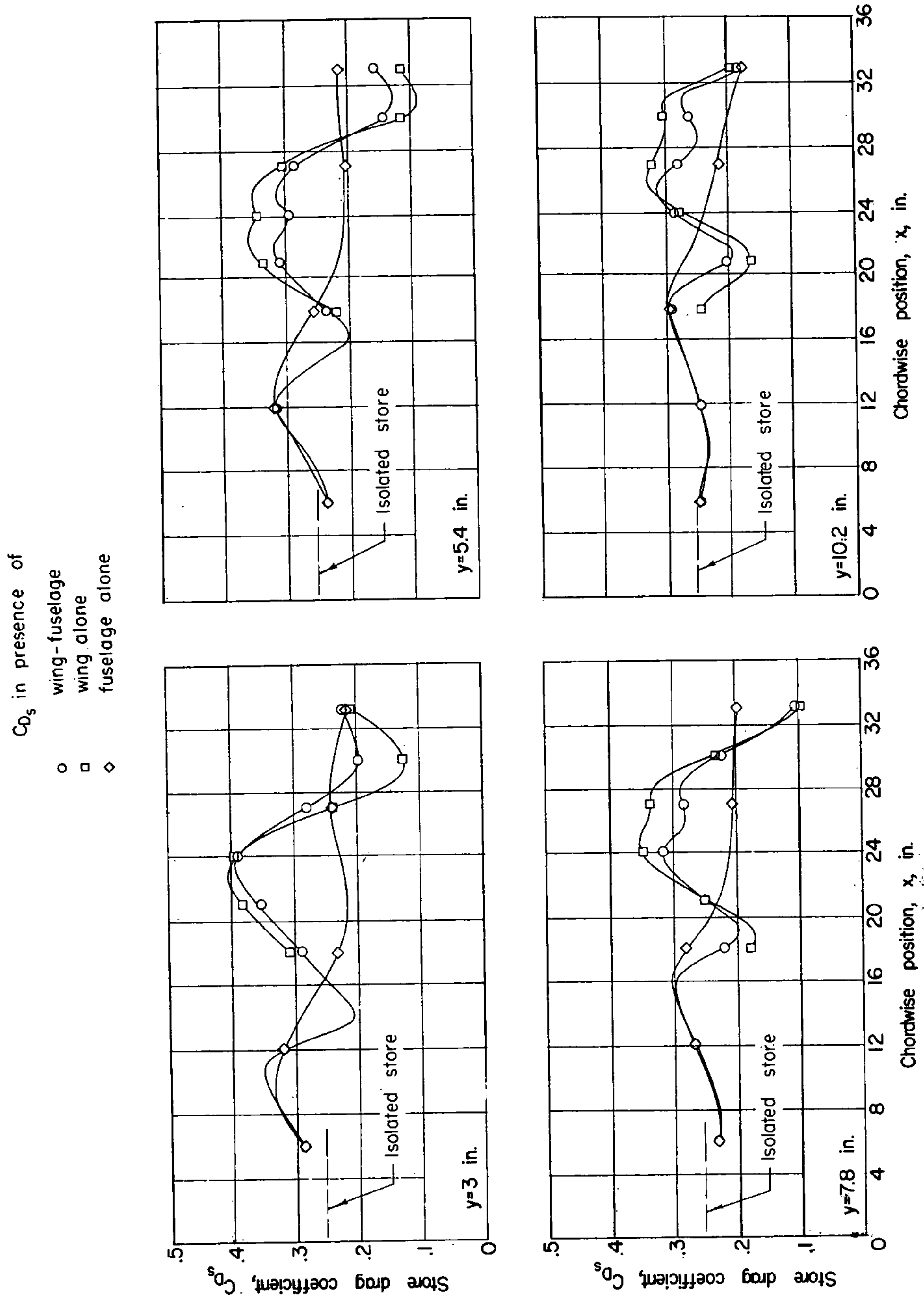


Figure 37.- Comparison of store drags in the presence of the fuselage, wing, and wing-fuselage combination. z = 1.15 inches; $\alpha = 0^{\circ}$.

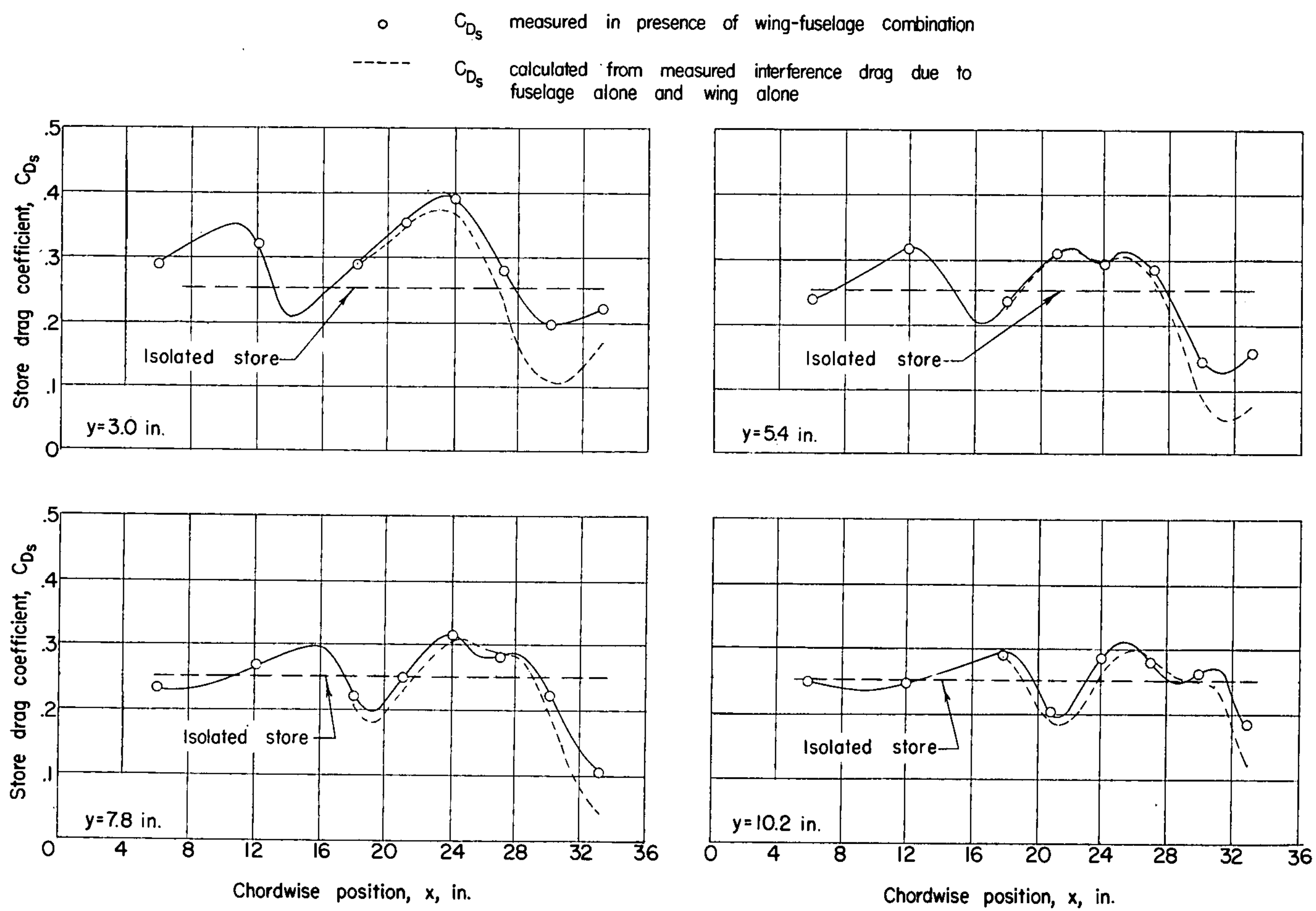


Figure 38.- Comparison of store drag measured in the presence of the wing-fuselage combination with store drag calculated from the drag of the store in the presence of the fuselage alone and in the presence of the wing alone. z = 1.15 inches; $\alpha = 0^{\circ}$.

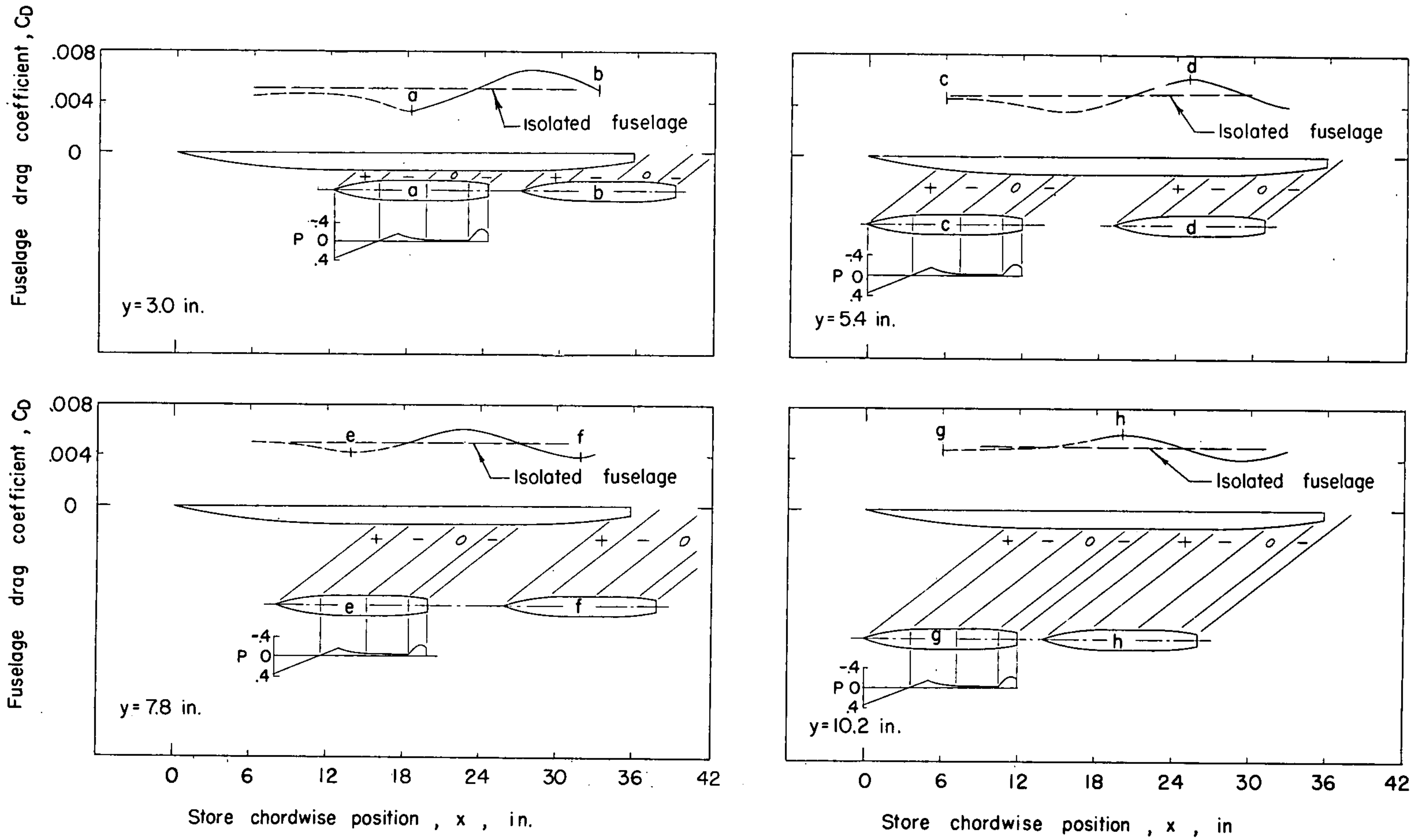


Figure 39.- Effect of store pressure field on drag of the fuselage alone. z = 1.15 inches; α = 0°. Dashed line indicates presence of interference of store sting.

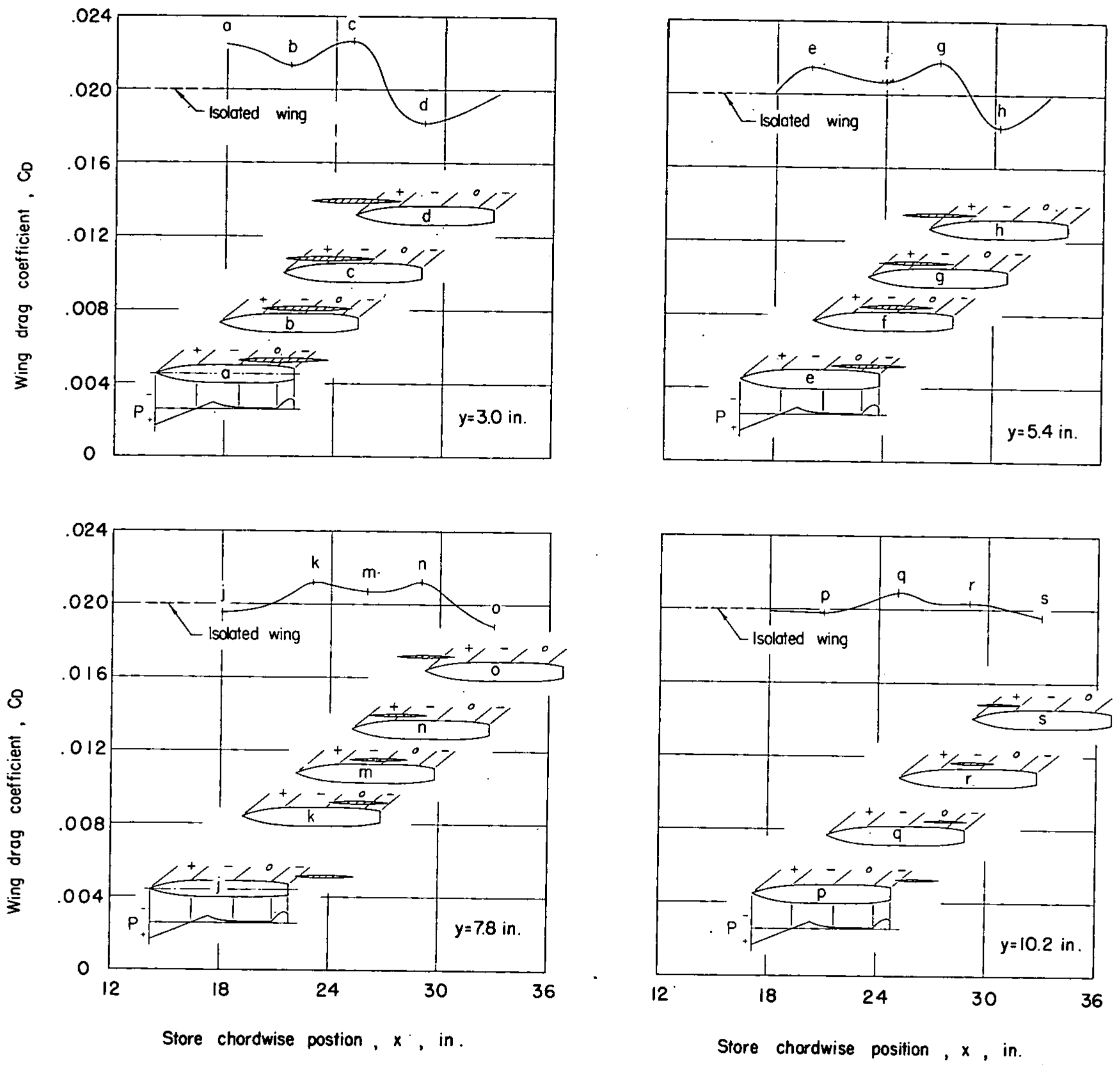


Figure 40.- Effect of store pressure field on drag of the wing alone. z = 1.15 inches; $\alpha = 0^{\circ}$.

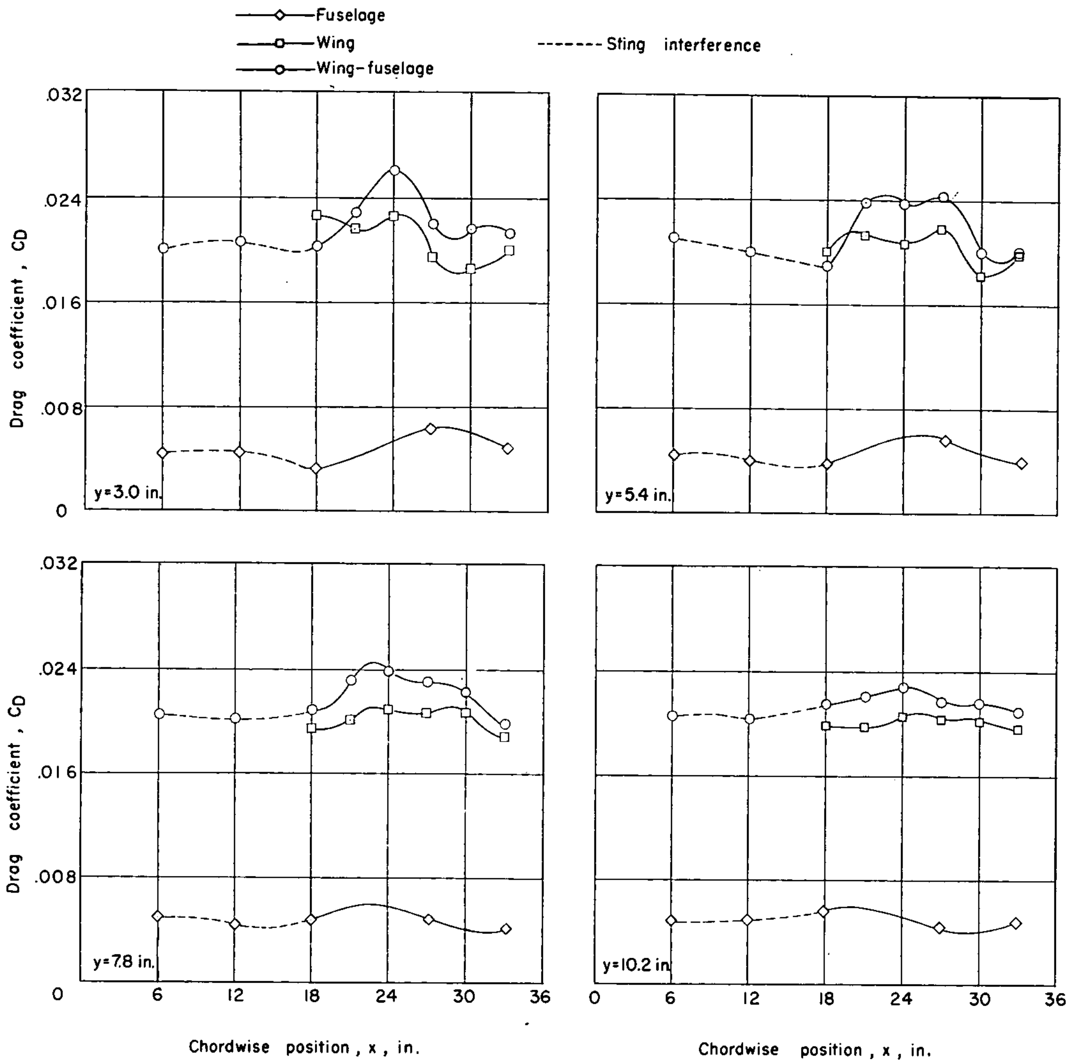


Figure 41.- Comparison of drag of fuselage, wing, and wing-fuselage combination in presence of store. z = 1.15 inches; $\alpha = 0^{\circ}$. Dashed line indicates presence of interference of store sting.

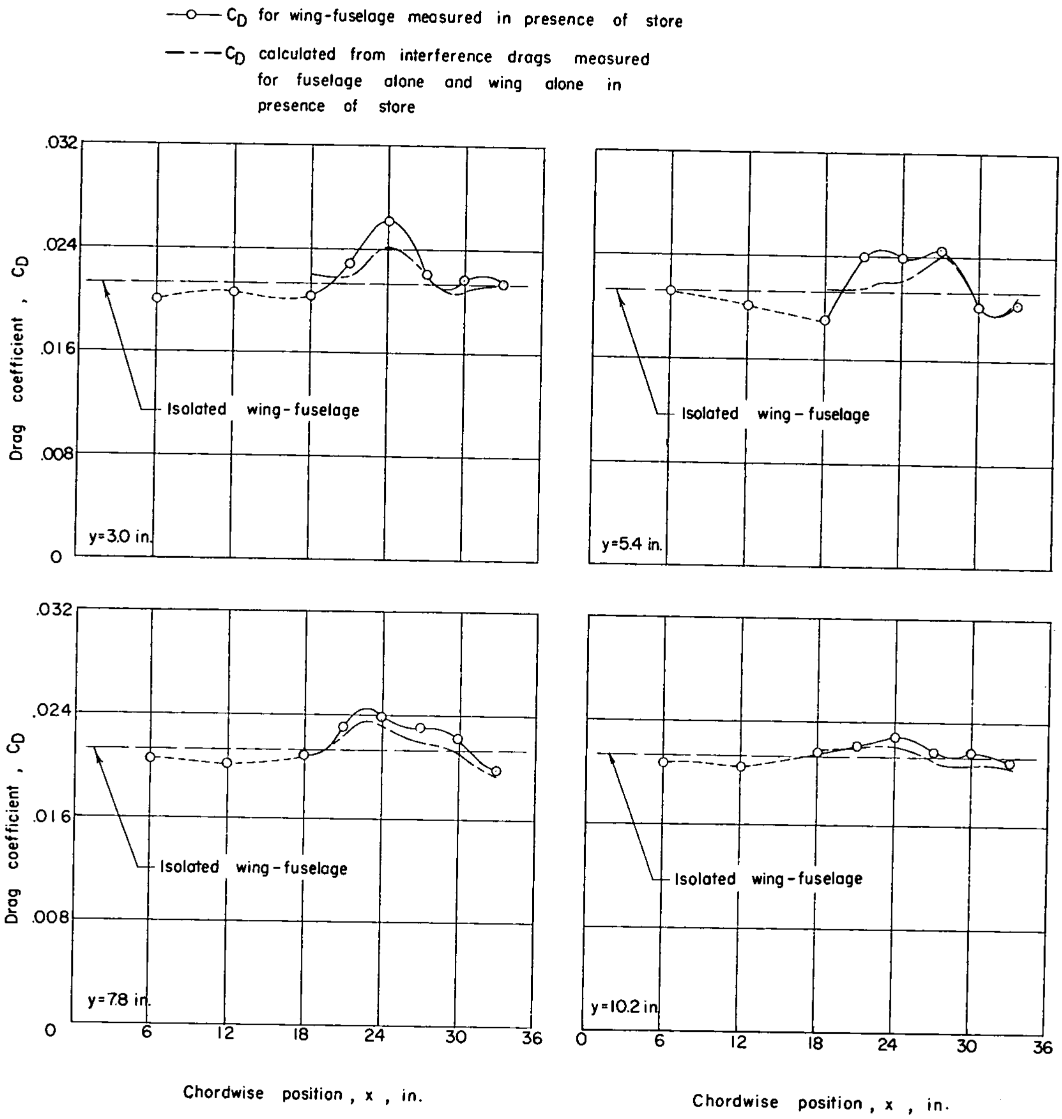


Figure 42.- Comparison of wing fuselage drags measured in the presence of the store with values calculated from the drags of the wing alone and the fuselage alone in the presence of the store. $z = 1.15$ inches; $\alpha = 0^{\circ}$. Short-dashed line indicates presence of interference of store sting.

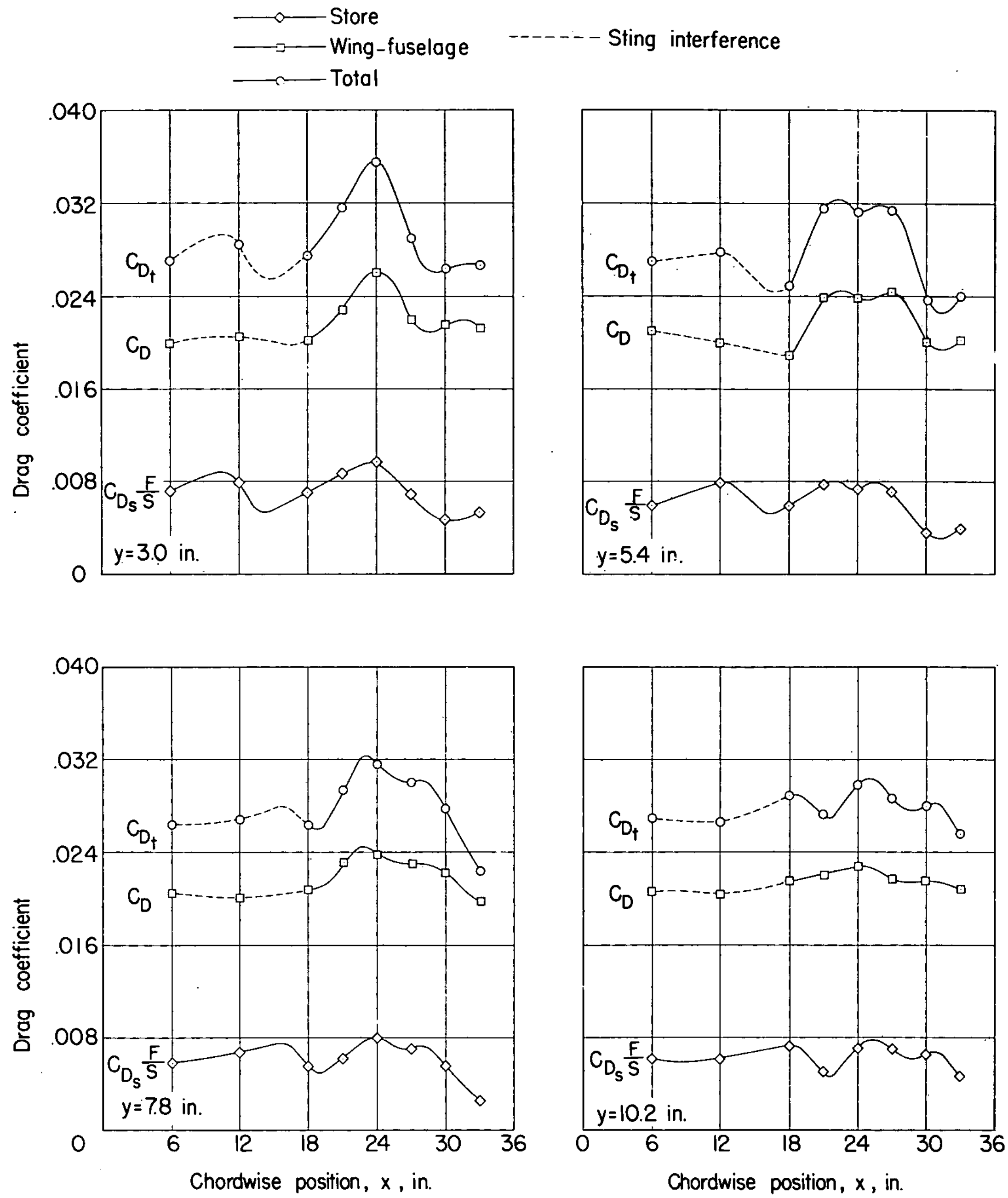


Figure 43.- Relative contribution of store drag and wing-fuselage drag to configuration total drag. Coefficients based on wing area. z = 1.15 inches; $\alpha = 0^{\circ}$. Dashed lines indicate presence of interference of store sting.

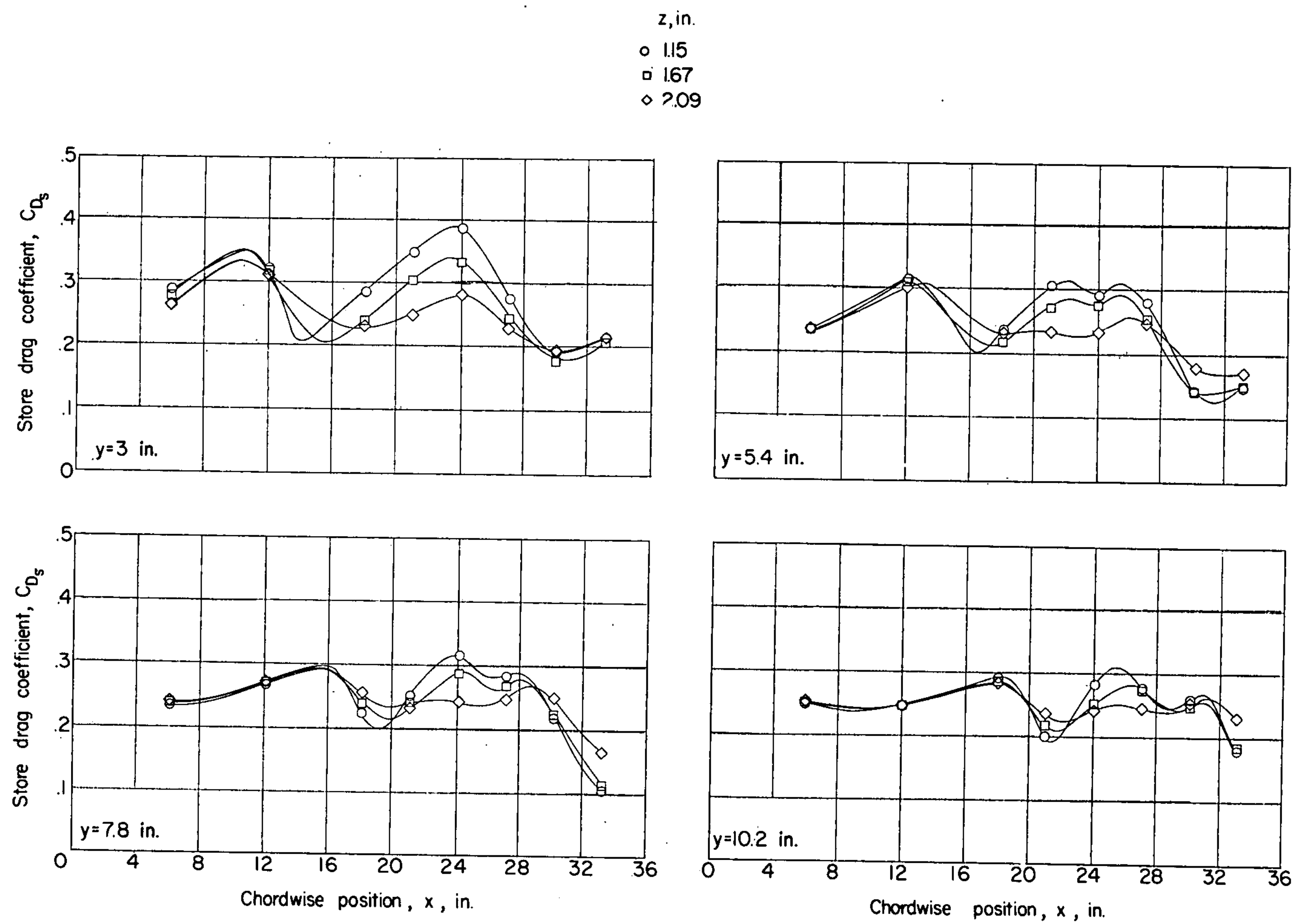


Figure 44.- Effect of store vertical position z on store drag. $\alpha = 0^{\circ}$.

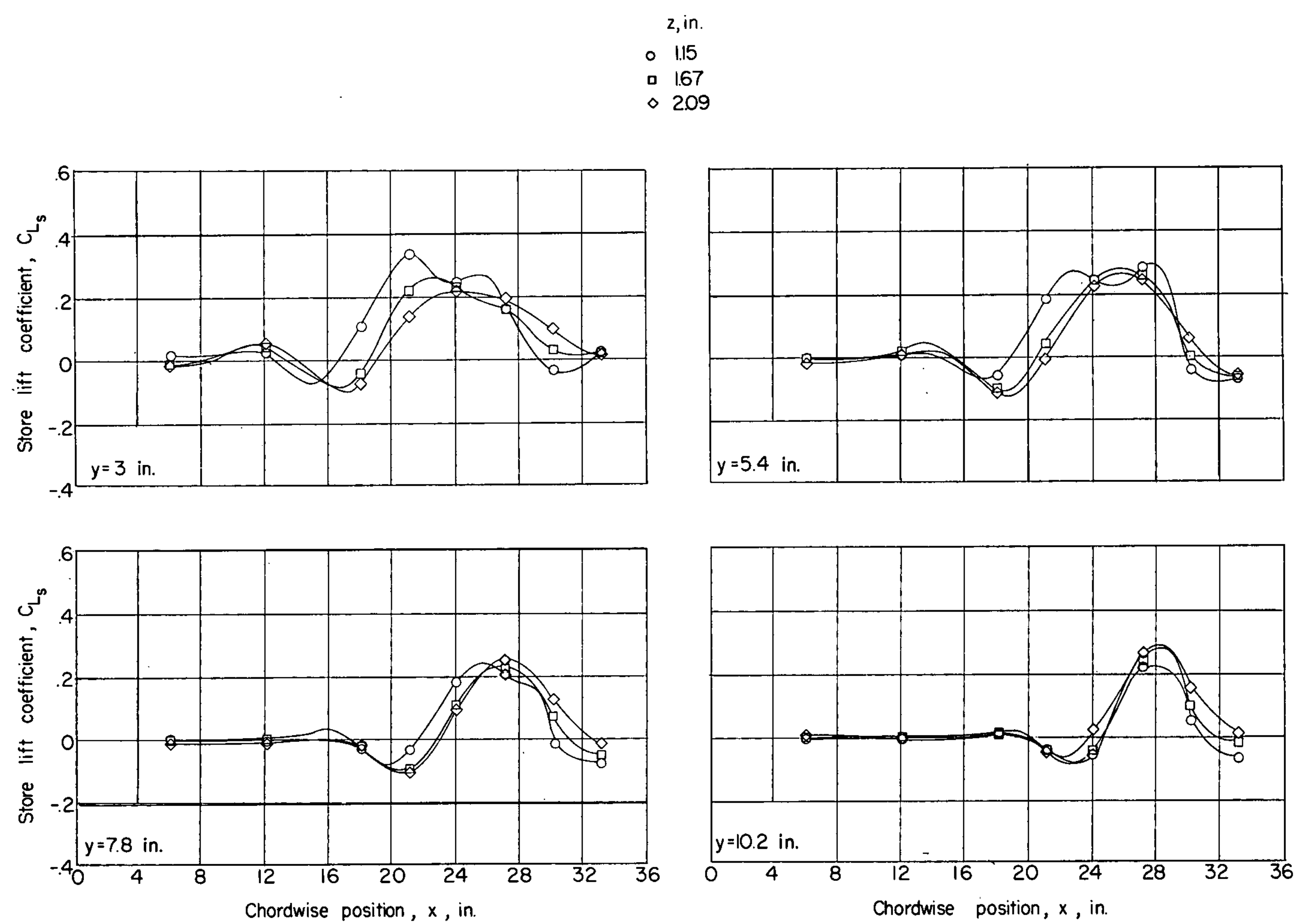


Figure 45.- Effect of store vertical position z on store lift. $\alpha = 0^{\circ}$.

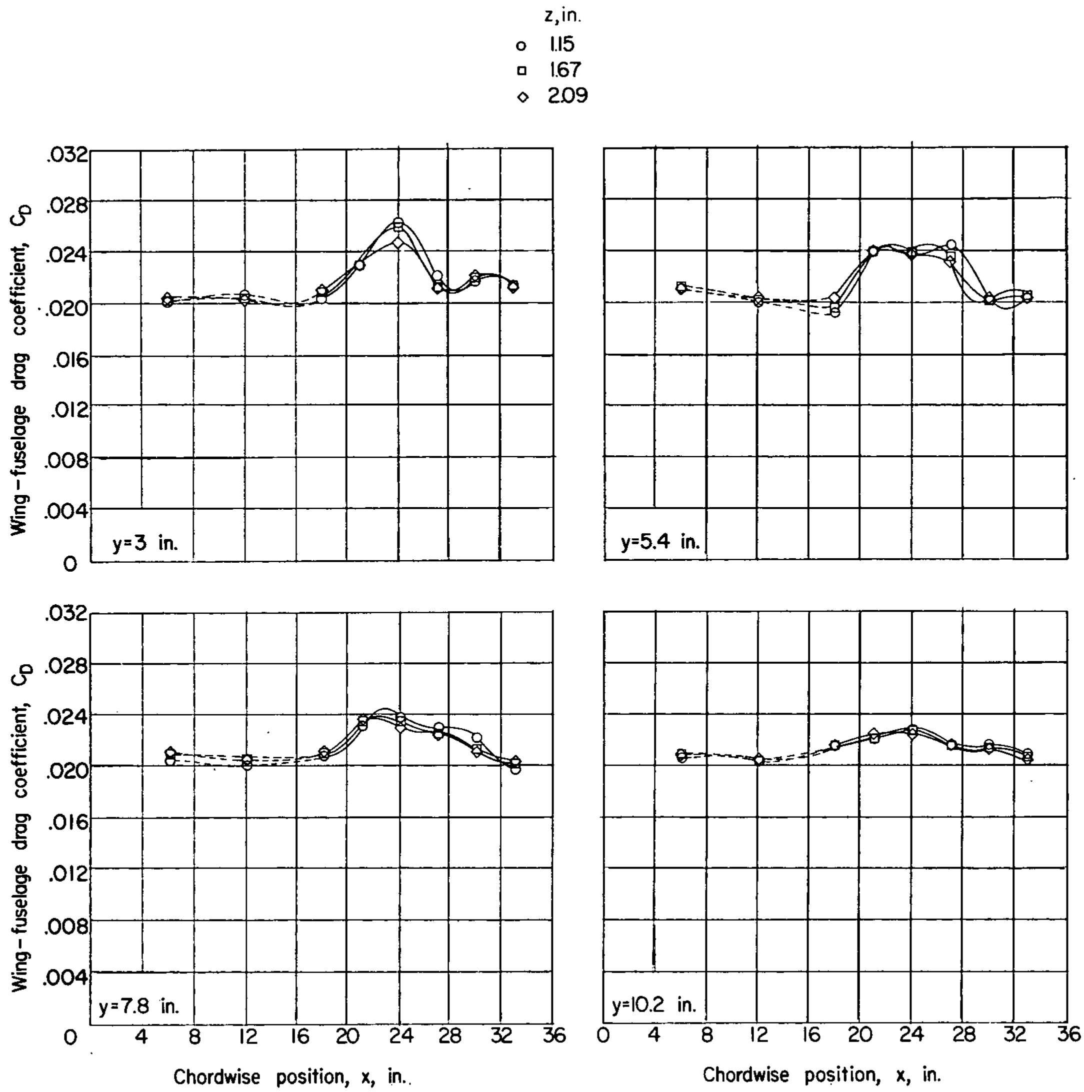


Figure 46.- Effect of store vertical position z on wing fuselage drag. Dashed lines indicate presence of interference of store sting. $\alpha = 0^{\circ}$.

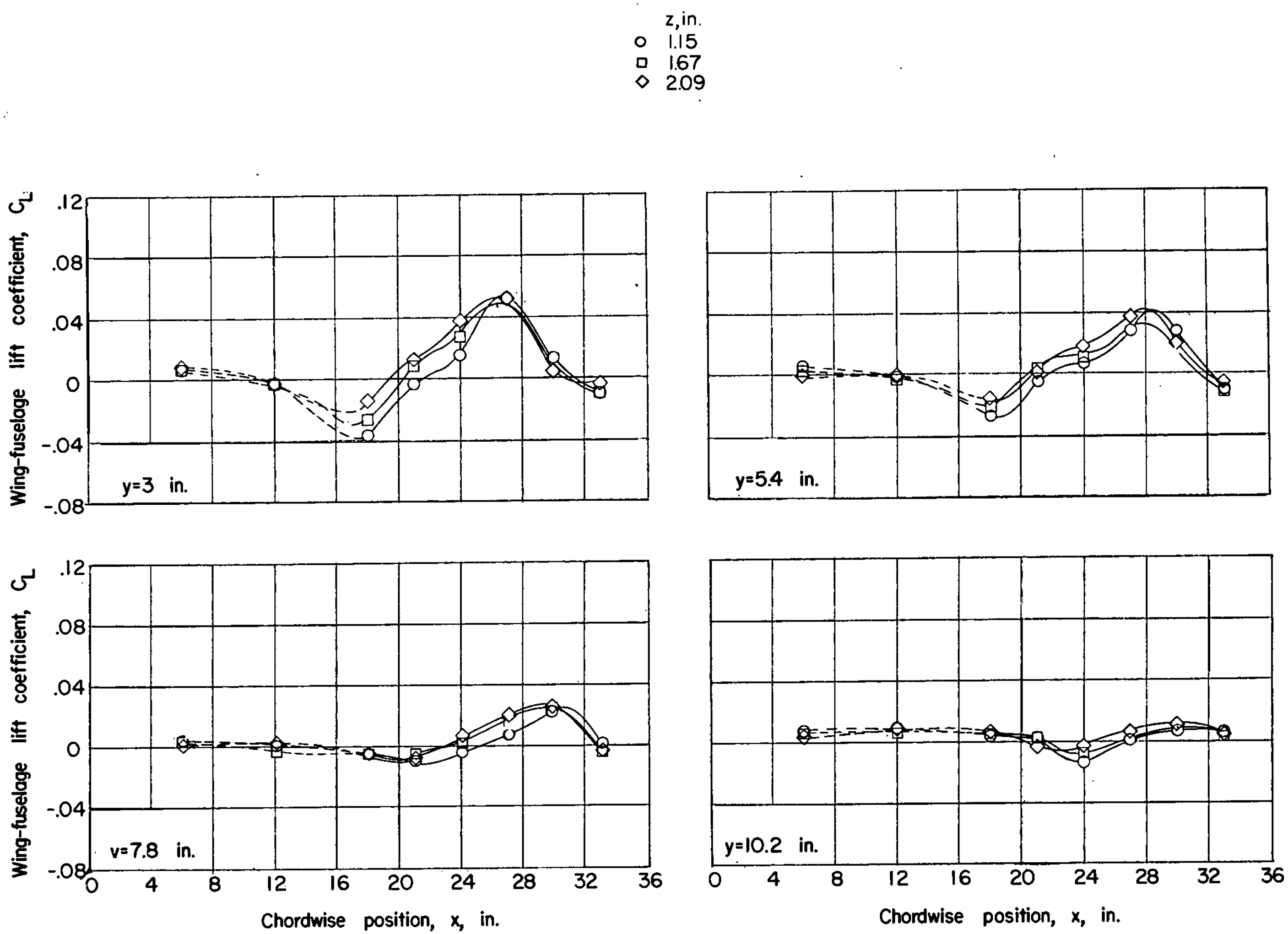


Figure 47.- Effect of store vertical position z on wing-fuselage lift. $\alpha = 0^{\circ}$. Dashed line indicates presence of interference of store sting.

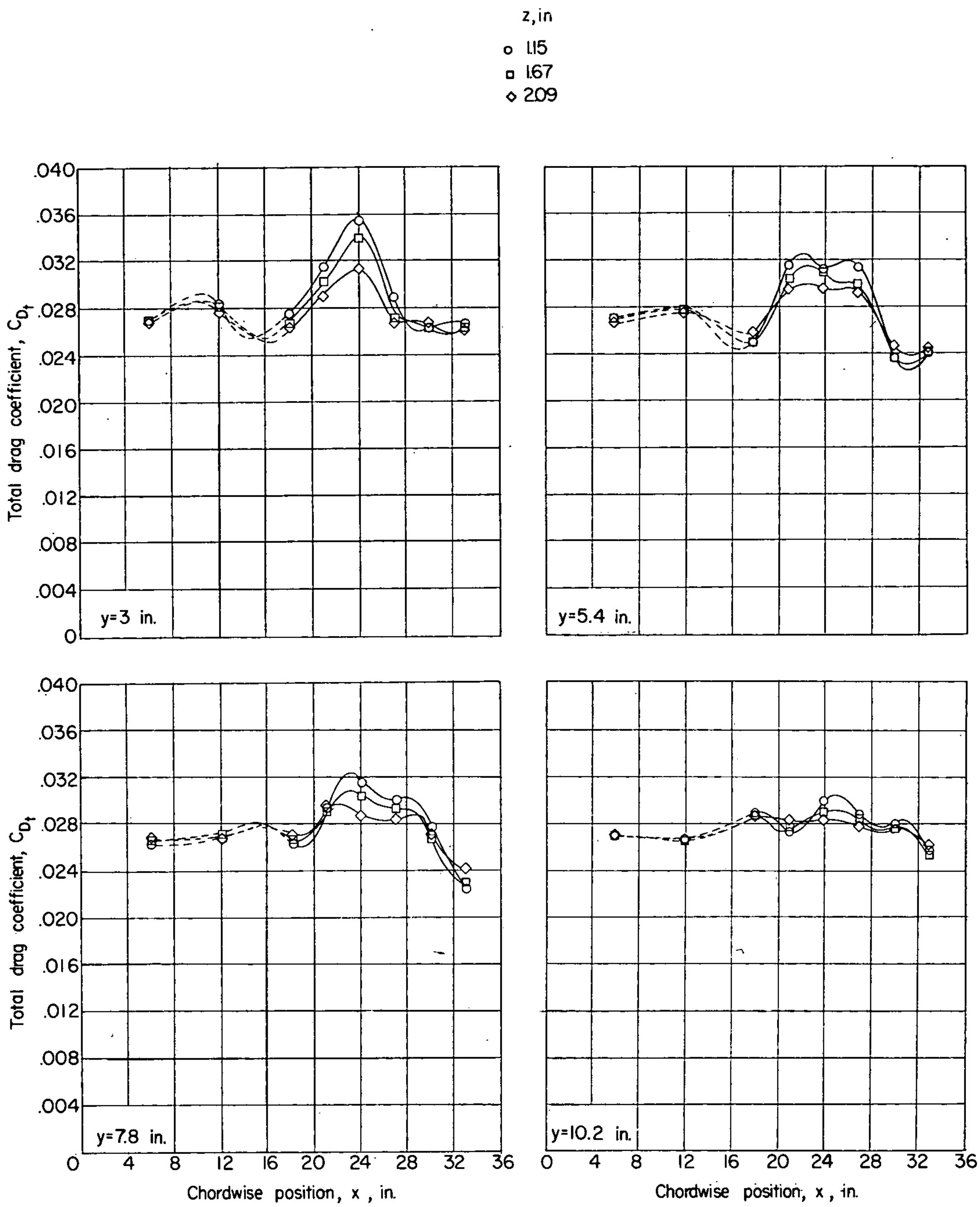


Figure 48.- Effect of store vertical position on total (wing fuselage plus store) drag. Dashed lines indicate presence of interference of store sting. $\alpha = 0^{\circ}$.

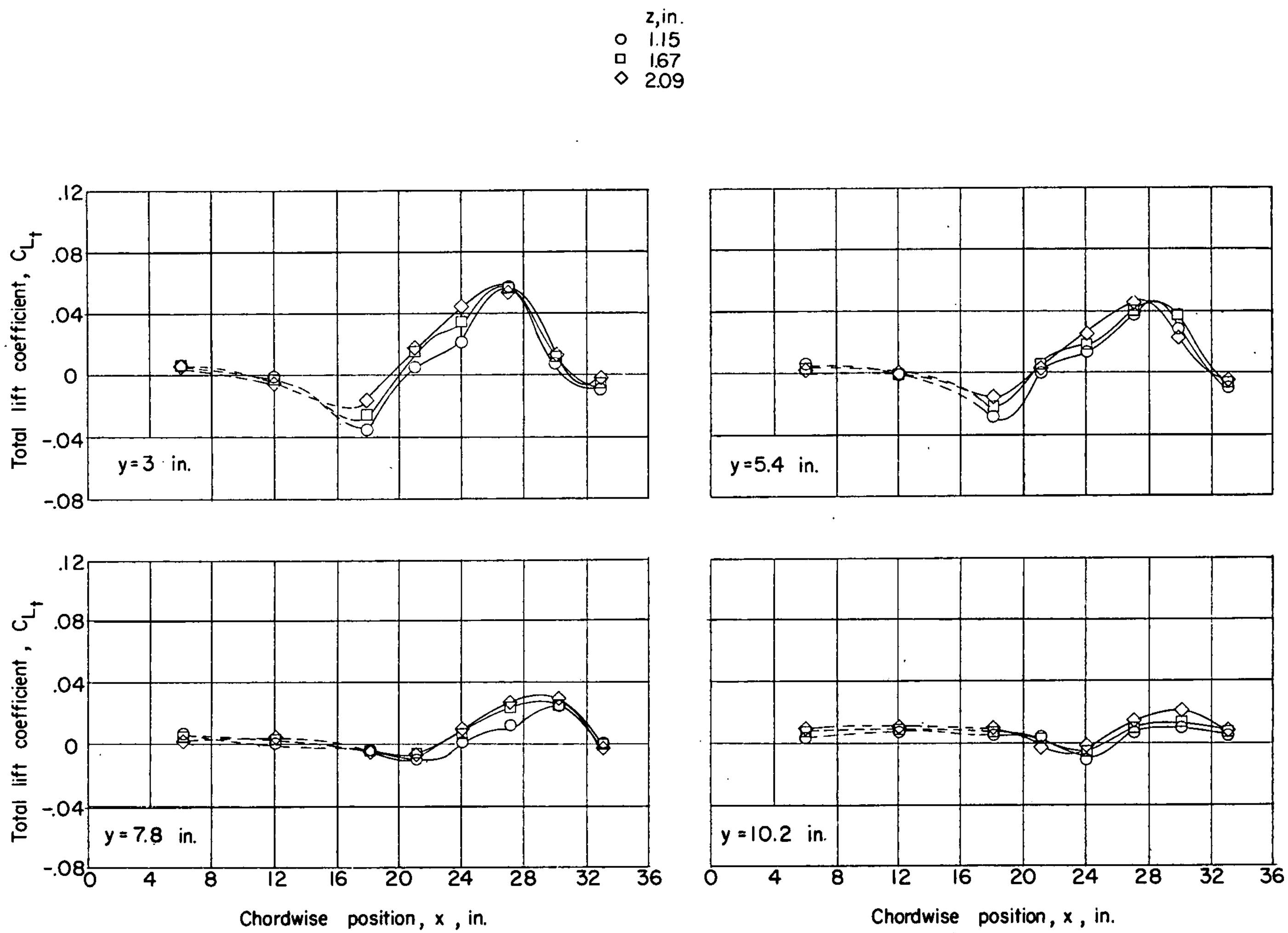


Figure 49.- Effect of store vertical position z on total (wing fuselage plus store) lift. Dashed lines indicate presence of interference of store sting. $\alpha = 0^{\circ}$.

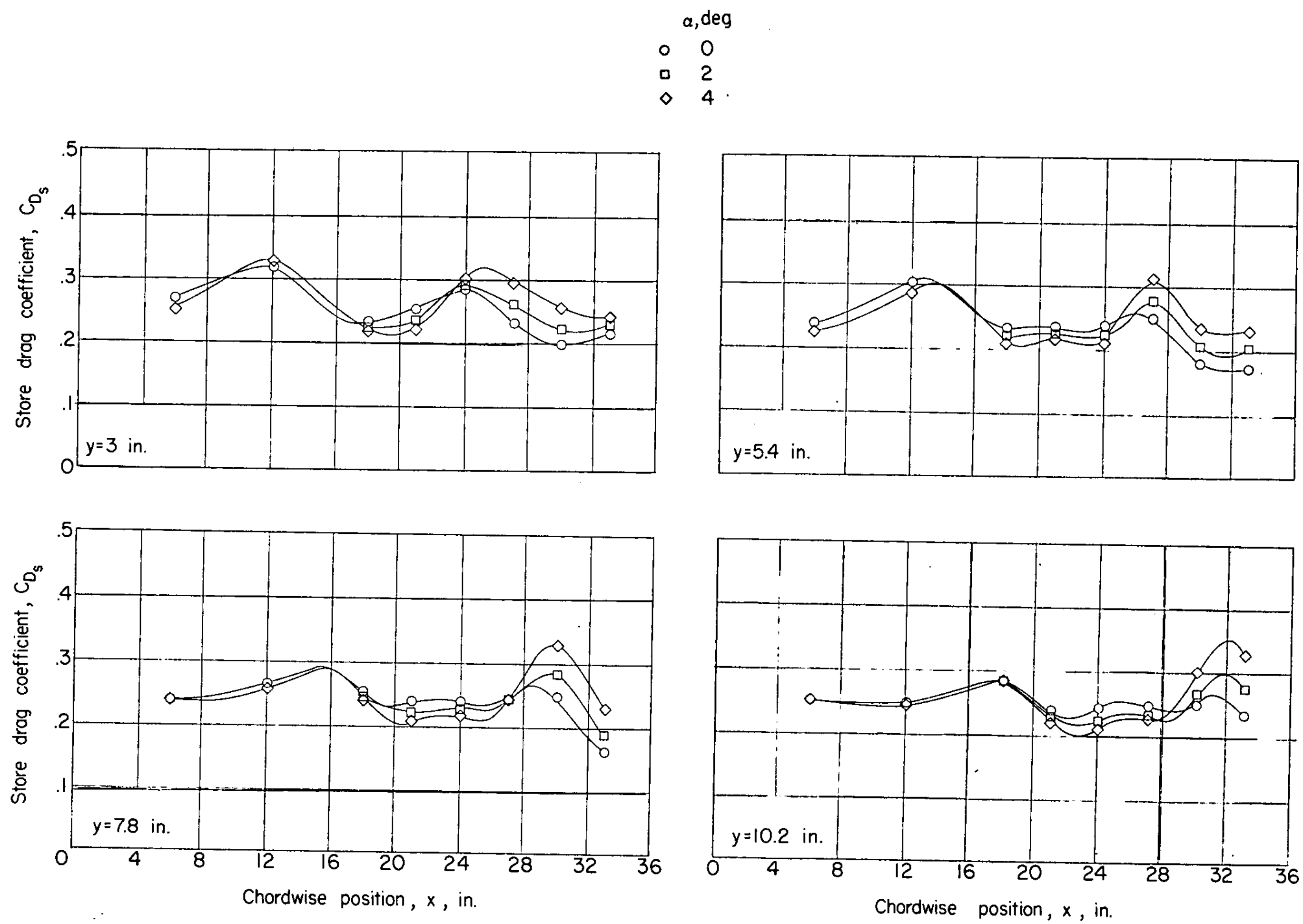


Figure 50.- Effect of angle of attack of wing fuselage combination on store drag. z = 2.09 inches.

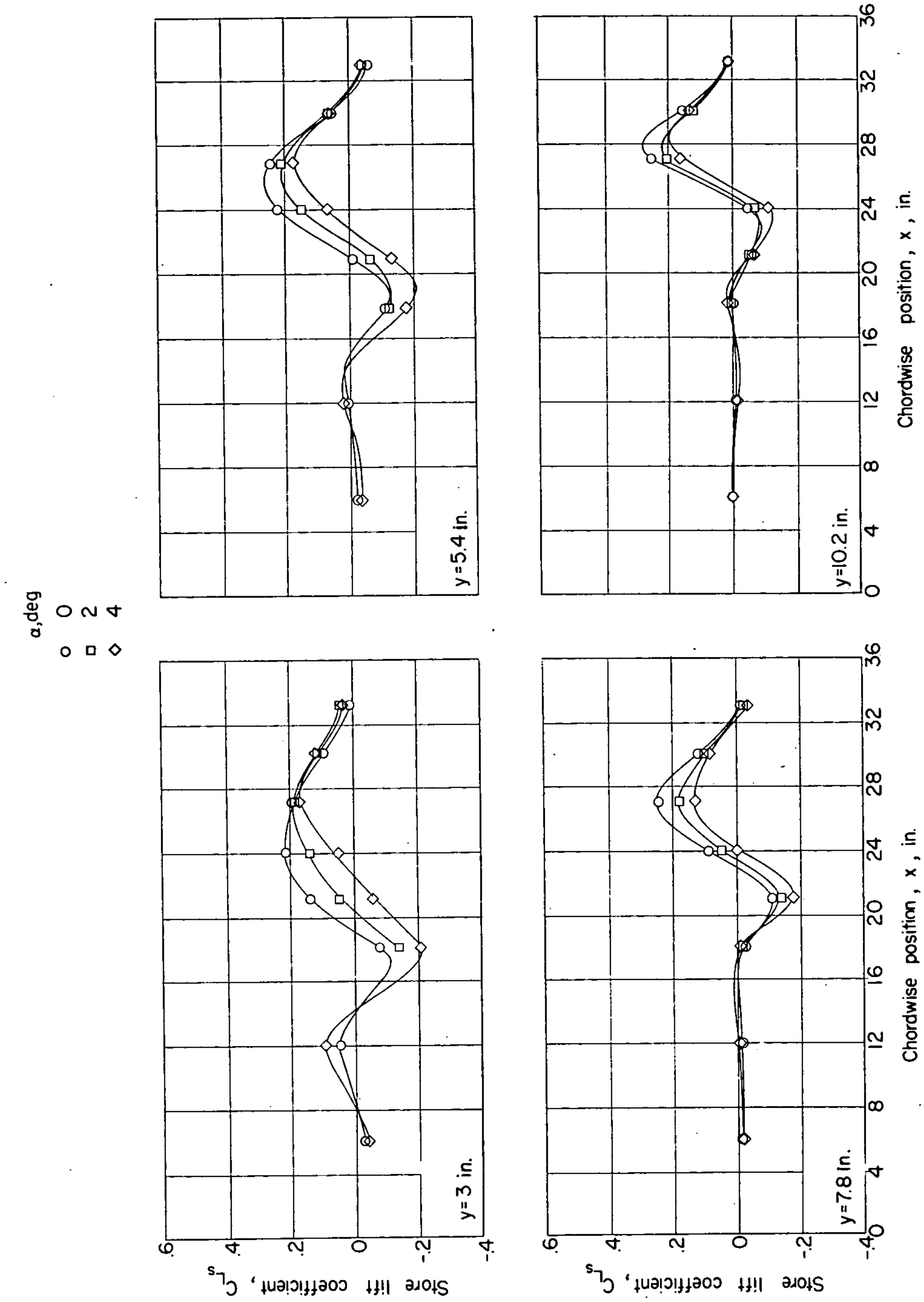


Figure 51.- Effect of angle of attack of wing-fuselage combination on store lift. z = 2.09 inches.

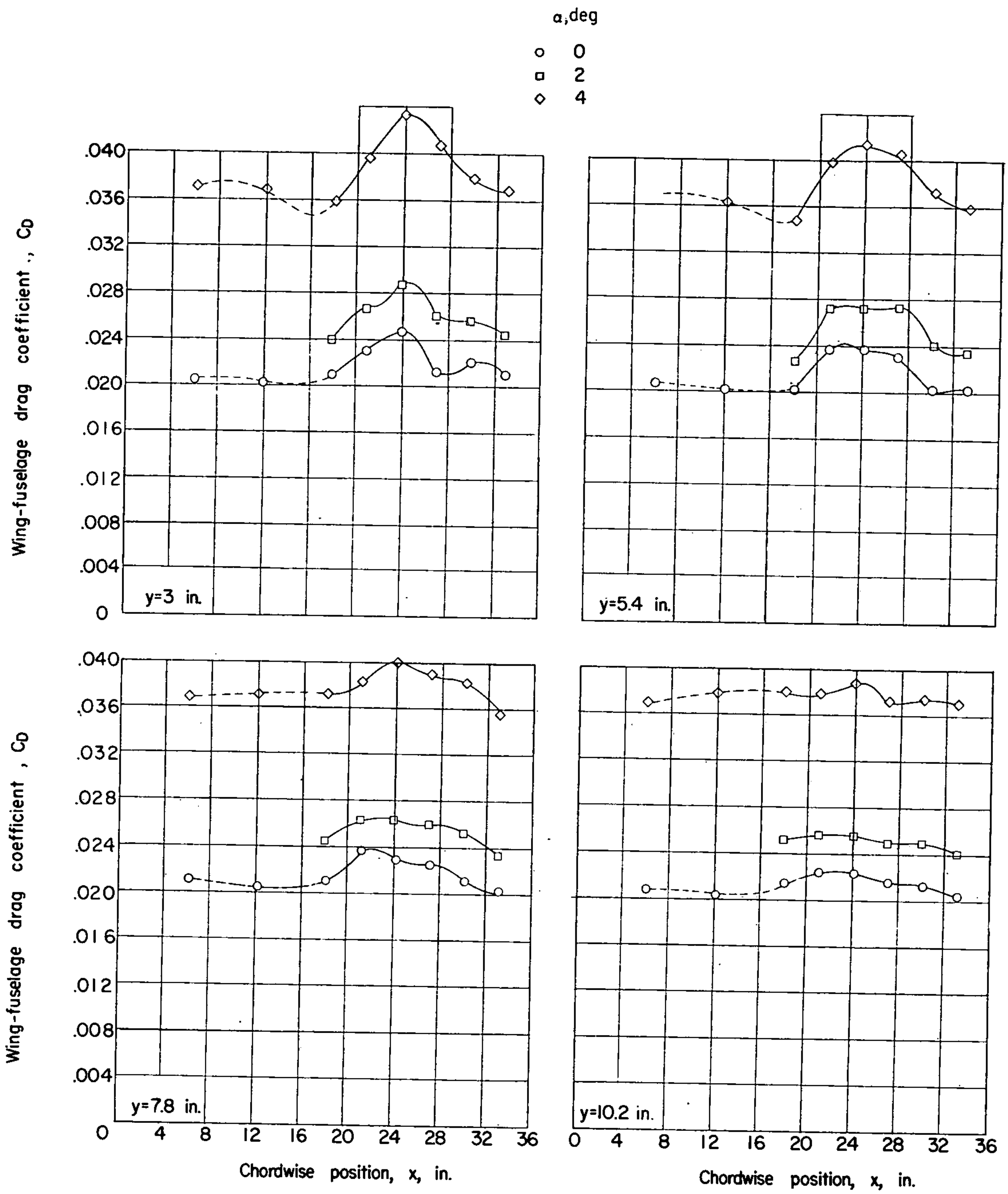


Figure 52.- Effect of angle of attack of wing-fuselage combination on wing-fuselage drag. z = 2.09 inches. Dashed lines indicate presence of interference of store sting.

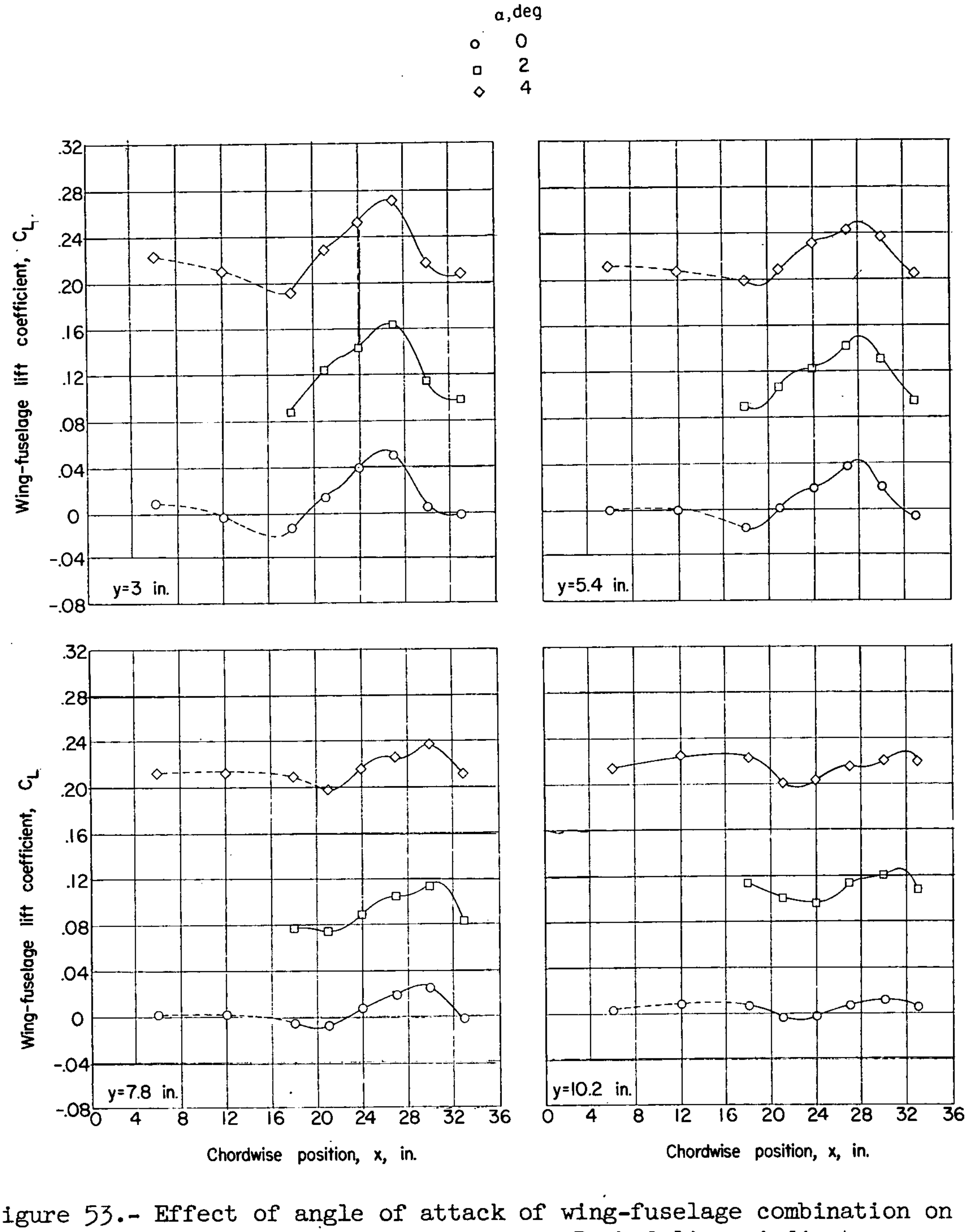


Figure 53.- Effect of angle of attack of wing-fuselage combination on wing-fuselage lift. z = 2.09 inches. Dashed lines indicate presence of interference of store sting.

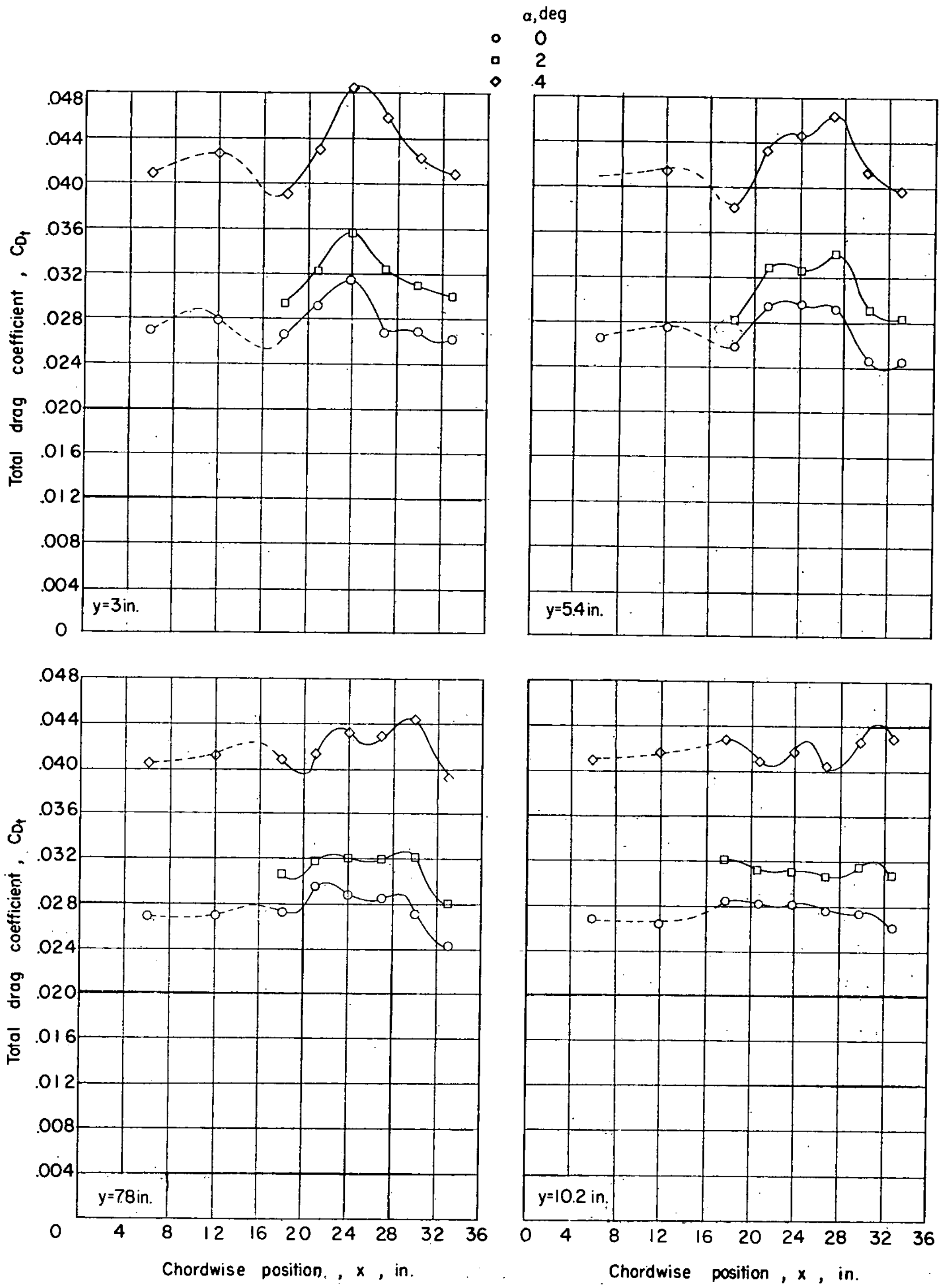


Figure 54.- Effect of angle of attack of wing-fuselage combination on total (wing fuselage plus store) drag. z = 2.09 inches. Dashed lines indicate presence of interference of store sting.

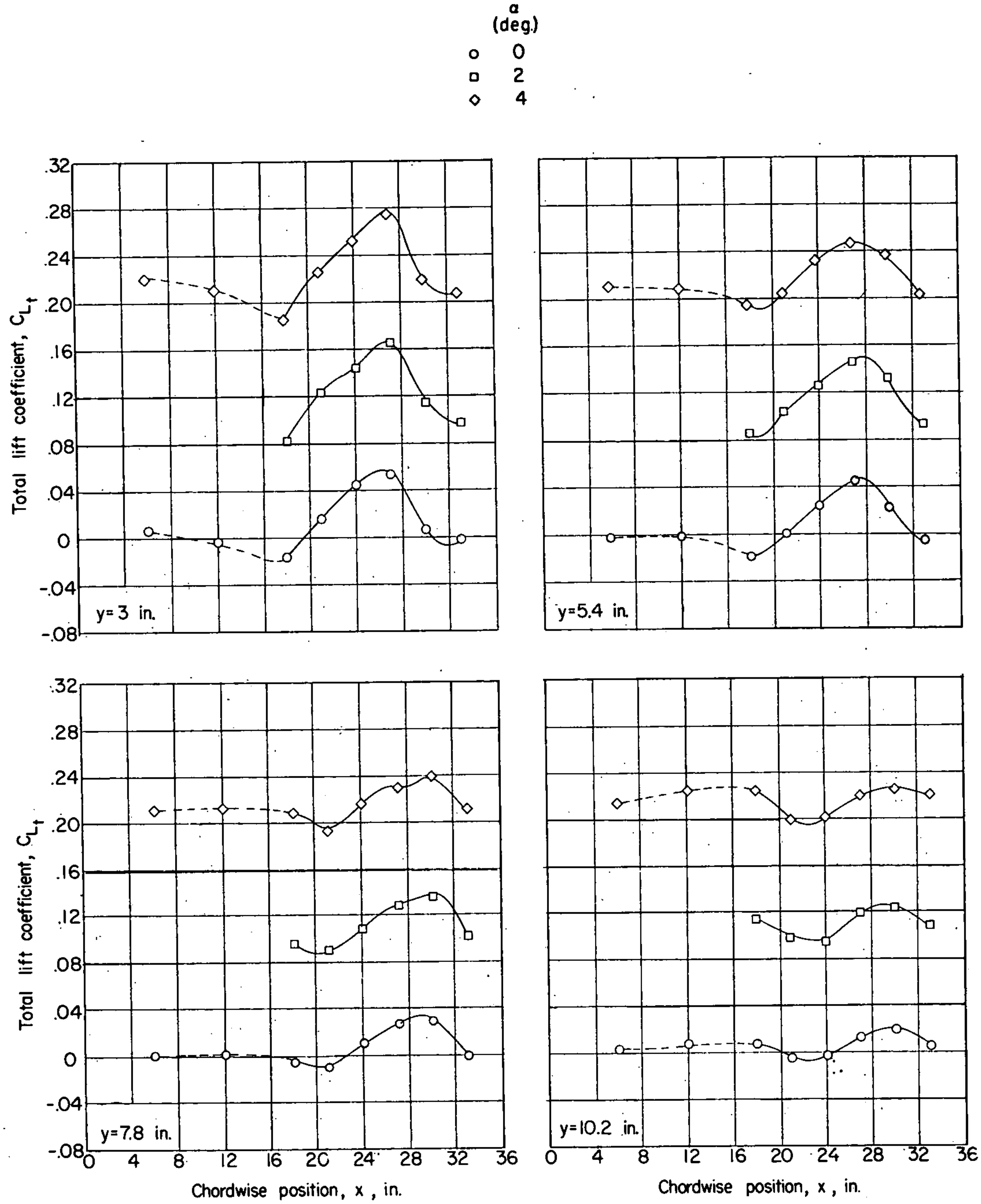


Figure 55.- Effect of angle of attack of wing-fuselage combination on total (wing-fuselage plus store) lift. z = 2.09 inches. Dashed lines indicate presence of interference of store sting.