NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3705

AN INVESTIGATION OF FORWARD-LOCATED FIXED SPOILERS AND DEFLECTORS AS GUST ALLEVIATORS ON AN UNSWEPT-WING MODEL

By Delwin R. Croom, C. C. Shufflebarger, and Jarrett K. Huffman

Langley Aeronautical Laboratory
Langley Field, Va.

Washington
June 1956

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

TECHNICAL NOTE 3705

AN INVESTIGATION OF FORWARD-LOCATED FIXED SPOILERS AND DEFLECTORS AS GUST ALLEVIATORS ON AN UNSWEPT-WING MODEL

By Delwin R. Croom, C. C. Shufflebarger,
and Jarrett K. Huffman

SUMMARY

An investigation was made in the Langley 300 MPH 7- by 10-foot tunnel and the Langley gust tunnel to determine the static longitudinal aerodynamic characteristics and the gust-alleviation capabilities of forward-located (at 12 percent chord) fixed spoilers, deflectors, or a spoiler-deflector combination on a simulated transport airplane model having an unswept wing.

The lift-curve slopes are fairly linear and are substantially reduced by the addition of either the spoiler or deflector configuration; however, the lift-curve slope was nonlinear for the spoiler-deflector combination. Extending the deflectors necessitates only small changes in attitude and trim in order to maintain a given lift coefficient, whereas extending the spoiler or the spoiler-deflector combination requires large changes.

Both the spoiler and the deflector configurations appear to be effective in reducing the normal acceleration in both an up gust and a down gust. It would appear from the gust-tunnel and wind-tunnel tests reported herein that a forward-located fixed deflector would be a practicable and effective alleviator of gust loads on an airplane having unswept wings when turbulence is encountered inasmuch as it reduces the normal accelerations, aids in slowdown to rough-air speed, and requires only small trim changes.

Preliminary results obtained in the Langley 300 MPH 7- by 10-foot tunnel on a model having a 35° sweptback wing have indicated that deflectors, to have the same effectiveness as reported for the unswept-wing model, would have to be located more rearward on the swept wing and would possibly require larger projections.

INTRODUCTION

One approach to gust alleviation in flight through rough air is to slow down to what is called the "rough-air speed," inasmuch as the magnitude of the normal acceleration varies directly with the forward speed of the airplane. The newer high-speed transports, which are aerodynamically cleaner and, moreover, have a large spread between the cruising speed and the rough-air speed, require considerable time to slow down to the rough-air speed. (See ref. 1.) Inasmuch as extremely rough air may be encountered during the slowdown, it is desirable from a structural and a passenger-comfort point of view to reduce the normal accelerations due to the rough air both during the slowdown and after the rough-air speed has been reached.

One of the many devices that has been proposed for use in reducing the acceleration effects of rough air is the spoiler. If the spoiler is located near the wing leading edge, it should be capable of reducing the acceleration because of the reduction in lift-curve slope. This loss in lift-curve slope is associated with the insensitivity of the separated region rearward of the spoiler to change in angle of attack. This assumption has been verified by inspection of the pressure-distribution data available for spoilers on unswept wings. If the spoiler is located outboard on the wing, it should reduce the wing root bending moment by shifting the center of load inboard. In addition, spoilers have been shown to be powerful speed brakes (ref. 2) and should be useful in slowing down to rough-air speeds and in rapid descents.

An evaluation of a fixed spoiler as a means of reducing the normal acceleration due to a gust was made in the Langley gust tunnel and is reported in reference 3. Only one spoiler configuration, which had a small projection, was tested. The spoiler investigated extended along 90 percent of the wing span, was located along the 12-percent-chord line, and projected 2.5 percent chord. The results presented in reference 3 indicate that the reduction in lift-curve slope realized for a forward-located fixed spoiler reduced the maximum acceleration by about 30 percent in a representative gust of 12-chord gradient distance. However, there was no reduction in maximum acceleration in a nonrepresentative sharp-edge gust. The ineffectiveness in the sharp-edge gust probably resulted either from a large lag in effectiveness associated with forward-located spoilers (refs. 3 and 4) or from the nonlinear lift-curve slopes associated with spoilers of small projection located well forward on the wing.

The present paper reevaluates the problem by using spoilers of sufficient projection (7.5 percent chord) to assure a near-linear lift-curve slope and by using lower-surface spoilers (hereinafter referred to as deflectors). The deflectors exhibit about the same reduction in lift-curve slope as the spoilers but, as shown in reference 4, should have small lag. The investigation has been conducted in the Langley 300 MPH 7- by 10-foot tunnel and the Langley gust tunnel on a simulated transport airplane model to determine the aerodynamic characteristics in pitch and the gust-alleviation capabilities of the forward-located fixed spoilers and deflectors.

COEFFICIENTS AND SYMBOLS

The results of the tests are presented as standard coefficients of forces and moments about the wind axes.

C_D drag coefficient, $\frac{\text{Drag}}{qS}$

ΔC_D jet-boundary correction applied to drag coefficient

C_L lift coefficient, $\frac{\text{Lift}}{qS}$

C_m pitching-moment coefficient, referred to $0.25\bar{c}$, $\frac{\text{Pitching moment}}{qS\bar{c}}$

Δa_n acceleration increment due to gust, g units

$\Delta a_{n,max}$ maximum acceleration increment due to gust, g units

b wing span, 5.96 ft

c wing local chord, ft

$\bar{c}$ wing mean aerodynamic chord, 0.69 ft

g acceleration due to gravity, ft/sec^2

i_t horizontal-tail incidence, positive when trailing edge deflected downward, deg

q dynamic pressure, lb/sq ft

r fuselage radius, in.

S wing area, 3.73 sq ft

s distance penetrated into gust by leading edge of wing mean aerodynamic chord, chords

U gust velocity, ft/sec

V	velocity, ft/sec
$\frac{y_i}{b/2}$	inboard end of control, fraction of wing semispan
$\frac{y_o}{b/2}$	outboard end of control, fraction of wing semispan
α	angle of attack, deg
$\Delta\alpha$	jet-boundary correction applied to angle of attack
$\Delta\theta$	pitch-angle increment due to gust, deg

MODEL AND APPARATUS

The model used in the present investigation simulated a transport airplane with unswept wings. A three-view drawing and the physical characteristics of the model are shown in figure 1. The model was equipped with fixed spoilers, deflectors, or a spoiler-deflector combination, which had a projection of 0.075c perpendicular to the surface, attached at the 12-percent-chord line as shown in figure 1.

The spans of the various configurations tested were as follows:

	$\frac{y_i}{b/2}$	$\frac{y_o}{b/2}$
Spoiler	0.31	0.98
Deflector	0.31	0.98
	0.51	0.98
Spoiler-deflector combination	0.51	0.98

The controls measured from 0.31b/2 to 0.98b/2 and from 0.51b/2 to 0.98b/2 are hereinafter referred to as 2/3-span and 1/2-span controls, respectively.

The model had an all-movable horizontal tail which pivoted about the 25-percent-chord point of the tail root. The static longitudinal aerodynamic characteristics of the model were obtained on the single-strut support system in the Langley 300 MPH 7- by 10-foot tunnel. (See fig. 2.)

The Langley gust tunnel and its equipment are described in references 5 and 6. For investigations in the gust tunnel the model was fitted with a recording accelerometer located at the model center of gravity and had small lights in the nose and tail from which the speed, the flight path, and the attitude of the model could be determined. The velocity distributions measured in the gust tunnel, corresponding to the test conditions, are shown in figure 3 as a function of mean-aerodynamic-chord penetration.

TESTS

The tests to determine the static aerodynamic characteristics of the model in pitch were made on the single-strut support system in the Langley 300 MPH 7- by 10-foot tunnel. These tests were made at a dynamic pressure of approximately 12.5 pounds per square foot, corresponding to an airspeed of about 100 feet per second. Reynolds number for this airspeed, based on the mean aerodynamic chord of the model ($\bar{c}$ = 0.69 foot), was approximately 0.4×10^6.

The dynamic tests to determine the normal acceleration and pitching behavior of the various model configurations in a sharp-edge gust were made in the Langley gust tunnel. Most of the tests in the gust tunnel were made at a lift coefficient of about 0.38, which corresponds to a model forward speed of approximately 98 feet per second. The plain wing and wing with deflectors were tested at gust velocities of 0, 10, and 15 feet per second. The spoiler and spoiler-deflector combination were tested at gust velocities of 0 and 15 feet per second.

A minimum of five successful flights through the gust was made for each of the test conditions. Measurements of forward speed, gust velocity, normal-acceleration increment, and pitch-angle increment were made for each flight. In addition, a few flights of the basic model (model with no spoilers) and the 2/3-span spoiler configuration were made at a lift coefficient of about 0.23, which corresponds to a forward speed of 120 feet per second, at gust velocities of 0 and 10 feet per second.

CORRECTIONS

Data Obtained in Langley 300 MPH 7- by 10-Foot Tunnel

The values for angle of attack and drag, which were obtained in the Langley 300 MPH 7- by 10-foot tunnel, have been corrected for jet-boundary effects by the method of reference 7. Jet-boundary corrections applied are as follows:

$$\Delta\alpha = 0.342C_L$$

$$\Delta C_D = 0.006{C_L}^2$$

The data have been corrected for tunnel air-flow misalinement, tunnel blockage, and longitudinal pressure gradient in the tunnel. Tare corrections for the single-support strut have been applied to these data.

Data Obtained in Langley Gust Tunnel

The acceleration histories, which were obtained in the Langley gust tunnel, were corrected for minor variations of the air density, gust velocity, and model weight from the specified test conditions on the assumption that the values of acceleration are directly proportional to the air density and gust velocity and inversely proportional to the model weight. The pitch-angle histories have not been corrected for the small variations from the specified test conditions because these corrections are within the accuracy of the pitch-angle measurements.

RESULTS AND DISCUSSION

Static or Force Test

The aerodynamic characteristics in pitch of the model were obtained in the Langley 300 MPH 7- by 10-foot tunnel and are presented in figure 4. The variation of lift coefficient with angle of attack was fairly linear and the lift-curve slopes were substantially reduced from those obtained for the basic configuration (fig. 4(a)) by the addition of either the deflector (figs. 4(b) and 4(c)) or the spoiler (fig. 4(d)). In contrast, the spoiler-deflector configuration had large nonlinearities throughout the lift-coefficient range (fig. 4(e)). A comparison of the aerodynamic characteristics in pitch of the configurations tested is presented in figure 5. The tail settings used for these tests were approximately the same as those used in the gust-tunnel tests. It is of particular interest to note that projection of the deflector required, in general, only small changes in angle of attack to maintain a given lift coefficient, whereas projection of either the spoiler or the spoiler-deflector combination required large changes in angle of attack.

The tail effectiveness dC_m/di_t was decreased by the addition of either the deflector or the spoiler. The greatest decrease in effectiveness was noted for the spoiler configuration, which also gave the largest change in longitudinal trim. The longitudinal stability dC_m/dC_L was increased by addition of all the devices except the spoiler-deflector combination.

Only the 2/3-span spoiler configuration caused a substantial change in drag coefficient as the lift coefficient changed; however, all spoiler and deflector configurations increased the drag coefficient considerably, especially the spoiler and spoiler-deflector combination. At a lift coefficient of 0.38, the ratio of lift to drag for the basic model was approximately 16, for the deflector configurations, approximately 6, and for the spoiler configuration, approximately 2; therefore, any of the devices would be effective as an aerodynamic brake.

Preliminary results obtained in the Langley 300 MPH 7- by 10-foot tunnel indicate that deflectors, to have the same effectiveness on a 35° sweptback wing as on the unswept wing of the present investigation, would need to be located at a more rearward position on the swept wing and would possibly require larger projections.

Dynamic or Gust-Tunnel Test

The records for each flight were evaluated to obtain time histories of the normal-acceleration increment and the pitch-angle increment in the sharp-edge gusts. In order to obtain the effect of the gust, the pitch angles and normal accelerations used in this investigation are the difference between the average values obtained during flights with gusts and with no gusts.

For all tests there were oscillations in the acceleration histories. (For example, see fig. 6.) These oscillations were of the same frequency as the first bending mode of the wing; consequently, the records were faired as shown in figure 6 to obtain the variations of acceleration with distance traveled. These oscillations were not present in the pitch histories.

For all configurations tested, a minimum of five successful flights was made and the results of these flights were averaged. The average corrected and faired values of the normal-acceleration increment and the pitch-angle increment as a function of gust penetration are presented in figures 7 to 9.

A comparison of the values of the estimated maximum accelerations (determined from eq. (2) of ref. 6 by using the experimental lift-curve slope) and measured maximum accelerations is given in figure 10. The acceleration histories (fig. 7) and the maximum acceleration increments (fig. 10) indicate that both the 1/2- and 2/3-span deflector configurations were effective in reducing the maximum normal-acceleration increment in the sharp-edge gust by approximately 20 to 40 percent. This reduction is in good agreement with the expected reduction in normal-acceleration increment based on the reduction in lift-curve slope (fig. 4). Inspection of the pitch-angle histories (fig. 7) indicates also that, although the pitching action in the gust was changed by the addition of the deflector, the changes were small.

The acceleration histories (fig. 8) together with the comparison between calculated and experimental data (fig. 10) indicate that both the spoiler and the spoiler-deflector combination were effective in reducing the normal-acceleration increment in the sharp-edge gust. The flights made at a forward speed of 120 feet per second through a gust having a velocity of 10 feet per second (fig. 9) indicate substantially the same reduction in normal-acceleration increment as did the results presented in figure 8. The pitch-angle histories indicate that the spoiler configurations cause a greater change in pitch angle than do the deflector configurations; however, the pitch effects are still relatively small, at least until maximum acceleration is reached.

Although the results in figures 7 to 9 are for a sharp-edge gust, the effectiveness of the control in other gusts can be estimated. The effectiveness of the controls in gusts with gradient distances up to 20 chords is fairly evident inasmuch as time histories for the wing with controls show approximately a constant percentage reduction for all penetrations up to the limit of the tests. Inasmuch as this reduction amounts to an overall reduction in response for all inputs up to 20 chords, superposition theory would yield the same reduction both for gusts with gradient distances up to 20 chords and for sharp-edge gusts.

Because both the spoiler and deflector configurations appear effective in an up gust, it might be expected that the controls would also be effective in a down gust. Inasmuch as exit from the sharp-edge gust corresponds to entry into a down gust, a few flights were made with the 2/3-span deflector configuration and data were recorded for some distance after exit from the gust profile shown in figure 3. These data are presented in figure 11. By adding the acceleration and pitch-angle increments at gust entry to the time history at gust exit, the time history for a continuous sharp-edge gust was constructed as shown by the dashed line in figure 11. Although the results are only approximate, they indicate that substantially the same alleviation could be expected for a down gust as for an up gust.

The results from the flights of the model through sharp-edge gusts indicate that, for the conditions of the tests, the effectiveness of either the spoiler or the deflector was not appreciably affected by lag. This fact may mean that the lag in effectiveness of a spoiler as obtained from abrupt deflections (ref. 4) may not be representative of the lag associated with an abrupt change in angle of attack of the wing with spoiler deflected. Because the basic model requires 8 chord lengths to obtain maximum acceleration, it is not possible from these test results to evaluate completely the effects of spoiler lag. Additional information on the effect of sudden angle-of-attack changes on wings with fixed spoilers must be obtained before any definite statement can be made regarding the effect of spoiler lag on the response of an airplane entering a sharp-edge gust. It would appear, however, that airplanes with response characteristics similar to those of the model used in this investigation would give satisfactory gust alleviation with a forward-located fixed spoiler. If the spoiler is planned to be used where rapid control response is required, the lag results presented in reference 4 would indicate that the spoiler would require as much as 8 chord lengths after deflection before full effectiveness would be realized; however, the deflector would obtain full effectiveness in approximately 1 chord length.

Short-Period Frequency and Damping

For continuous turbulence, the effect of any control on the short-period frequency and damping may be important and a reduction in frequency or damping may be expected to increase the loads in gusts. Calculations for the basic model and the 2/3-span deflector configuration indicated no substantial change in the period (frequency of motion) due to adding the control on the test model and showed that the control reduced the damping (time to damp to one-half amplitude) from 8.4 chords for the basic model configuration to 9 chords for the 2/3-span deflector configuration. This reduction indicates only a very slight decrease in damping and the alleviation of gusts as obtained from gust-tunnel test results is about the alleviation that would be expected in flight.

CONCLUDING REMARKS

Results have been presented of an investigation in the Langley 300 MPH 7- by 10-foot tunnel and the Langley gust tunnel to determine the effectiveness of fixed spoilers and deflectors at the 12-percent-chord line as gust alleviators on a simulated transport airplane model having an unswept wing.

The lift-curve slopes for this configuration with either the spoiler or the deflector were fairly linear and were substantially reduced from the slopes for the plain wing; however, use of the spoiler and deflector in combination caused nonlinearities in the lift-curve slope. Extending the deflectors required only small changes in attitude and trim for maintenance of a given lift coefficient, whereas extending the spoiler or spoiler-deflector combination required large changes.

These gust- and wind-tunnel studies indicate that a fixed deflector placed near the leading edge of an unswept wing would be a practicable and effective alleviator of gust loads when turbulence is encountered inasmuch as it reduces the normal accelerations, aids in slowdown to rough-air speed, and requires only small trim changes.

Results of a limited study of deflectors as gust alleviators on a 35° sweptback-wing model in the Langley 300 MPH 7- by 10-foot tunnel indicate that, in order to obtain the same effectiveness as obtained with the unswept wing, the deflector would have to be located more rearward from the leading edge and would possibly require larger projections.

Langley Aeronautical Laboratory
National Advisory Committee for Aeronautics,
Langley Field, Va., March 15, 1956.

REFERENCES

1. Davis, Don D., Jr.: The Problem of Reducing the Speed of a Jet Transport in Flight. NACA TN 3613, 1955.

2. Fischel, Jack, and Watson, James M.: Investigation of Spoiler Ailerons for Use as Speed Brakes or Glide-Path Controls on Two NACA 65-Series Wings Equipped With Full-Span Slotted Flaps. NACA Rep. 1034, 1951. (Supersedes NACA TN 1933.)

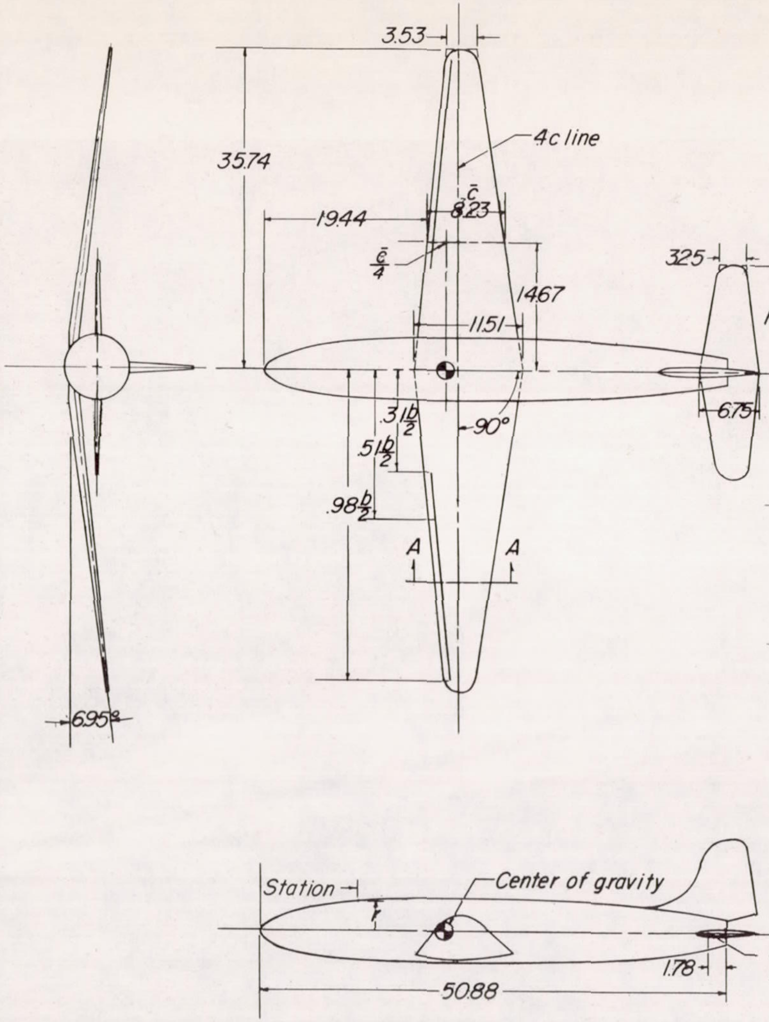
3. Mickleboro, Harry C.: Evaluation of a Fixed Spoiler as a Gust Alleviator. NACA TN 1753, 1948.

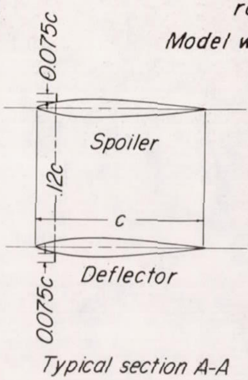
4. Wenzinger, Carl J., and Rogallo, Francis M.: Wind-Tunnel Investigation of Spoiler, Deflector, and Slot Lateral-Control Devices on Wings With Full-Span Split and Slotted Flaps. NACA Rep. 706, 1941.

5. Donely, Phillip: Summary of Information Relating to Gust Loads on Airplanes. NACA Rep. 997, 1950. (Supersedes NACA TN 1976.)

6. Pierce, Harold B.: Tests of a 45° Sweptback-Wing Model in the Langley Gust Tunnel. NACA TN 1528, 1948.

7. Gillis, Clarence L., Polhamus, Edward C., and Gray, Joseph L., Jr.: Charts for Determining Jet-Boundary Corrections for Complete Models in the 7- by 10-Foot Closed Rectangular Wind Tunnels. NACA WR L-123, 1945. (Formerly NACA ARR L5G31.)





TABULATED MODEL DATA

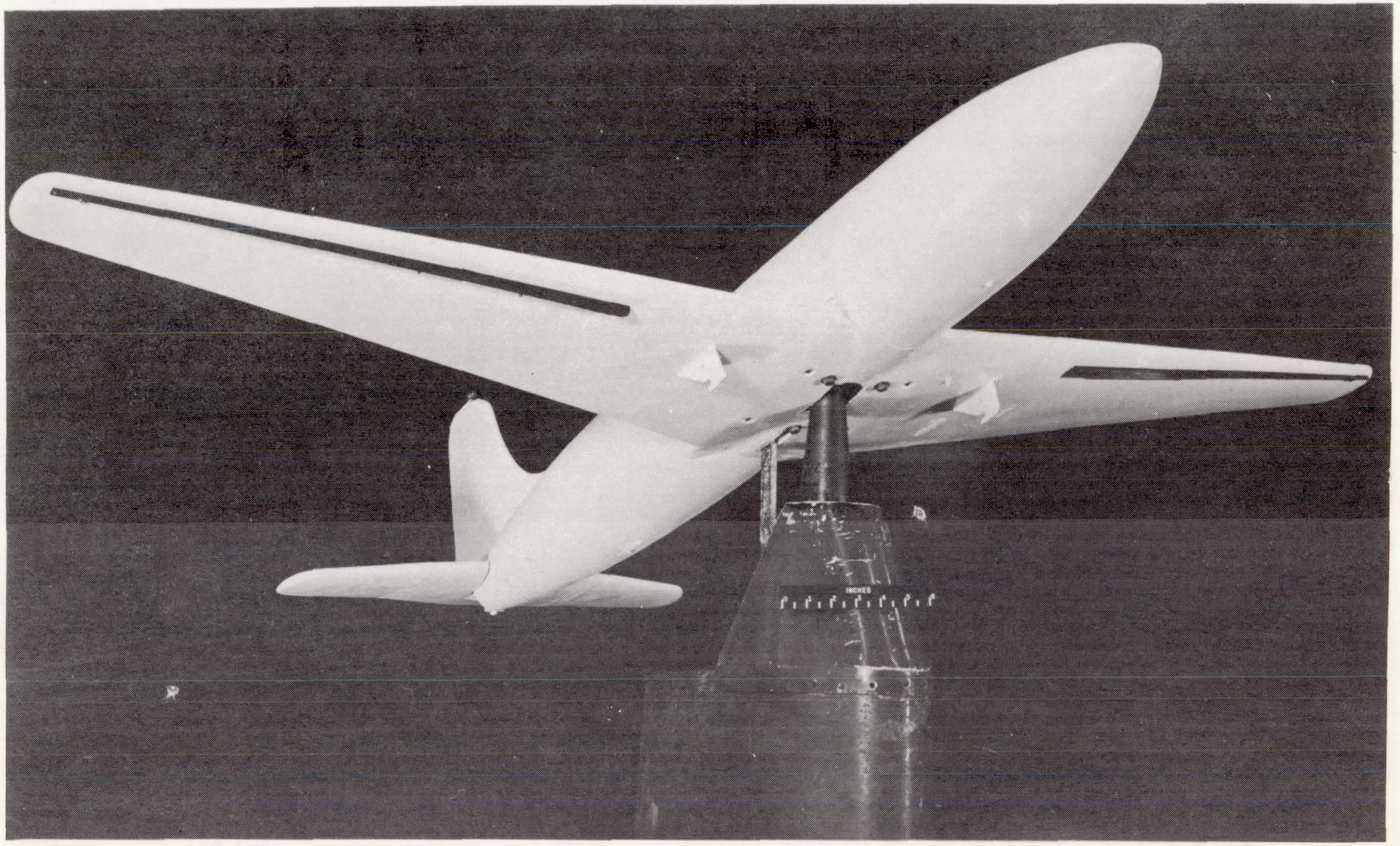
Wing	
Area, sq ft	3.73
Span, ft	5.96
Mean aerodynamic chord, ft	0.69
Aspect ratio	9.52
Taper ratio	0.31
Dihedral, deg	6.95
Incidence, deg	3.98
Airfoil section parallel to free airstream	NACA 0015
Horizontal tail	
Span, ft	1.81
Area, sq ft	0.82
Pivot point, percent tail root chord	25
Model weight, lb	18.00

Fuselage coordinates

Station, in.	Radius, in.
0	0
0.85	0.93
3.35	2.02
6.05	2.74
8.74	3.20
12.05	3.42
15.20	3.45
28.15	3.45
33.20	3.40
38.30	3.15
43.05	2.65
47.80	1.87
50.88	1.20

Nose radius 0.48 in.

Figure 1.- Three-view drawing of the model. (All dimensions are in inches except where noted.)



L-90904

Figure 2.- Photograph of model mounted on the single-strut support system.

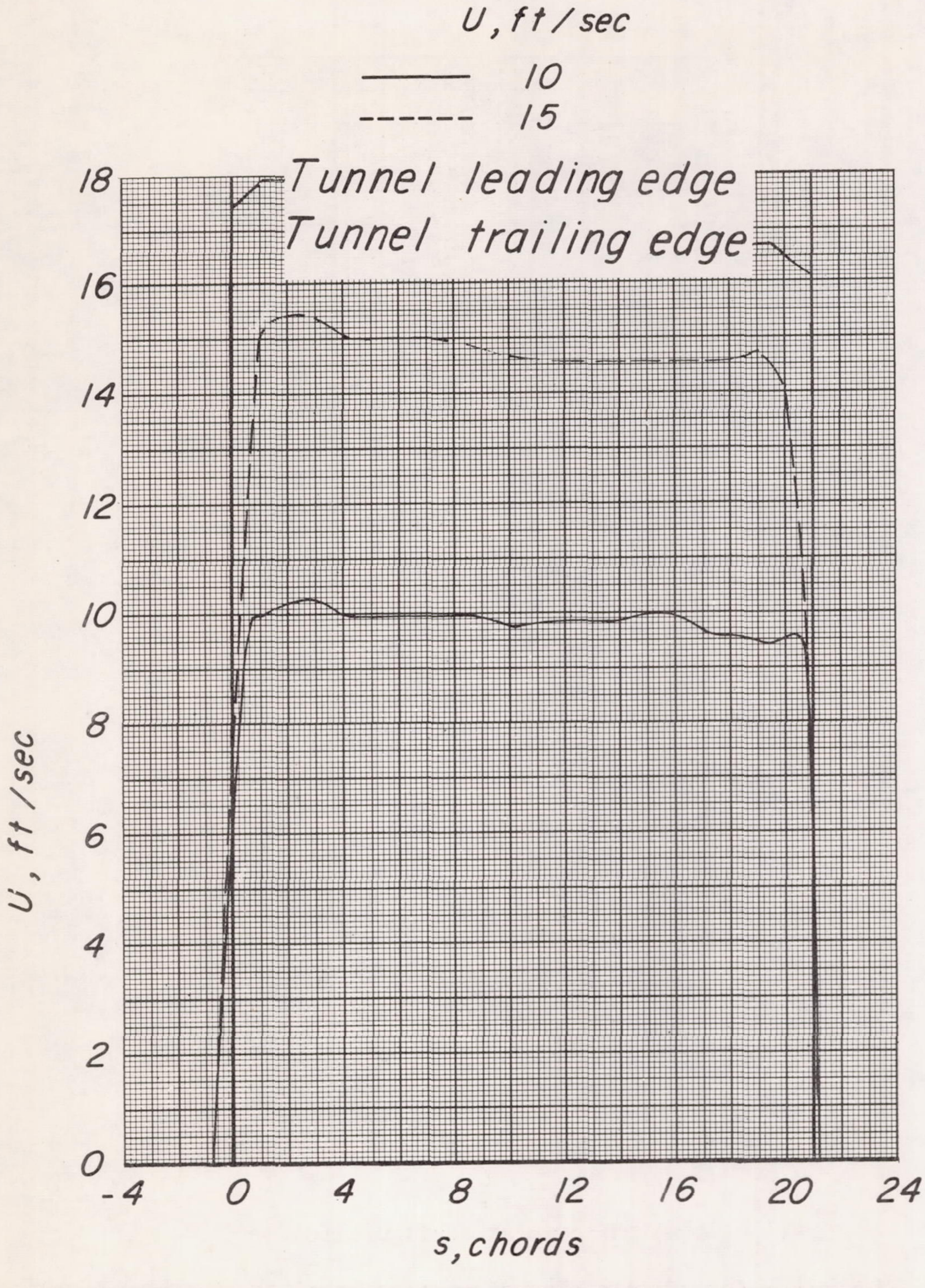
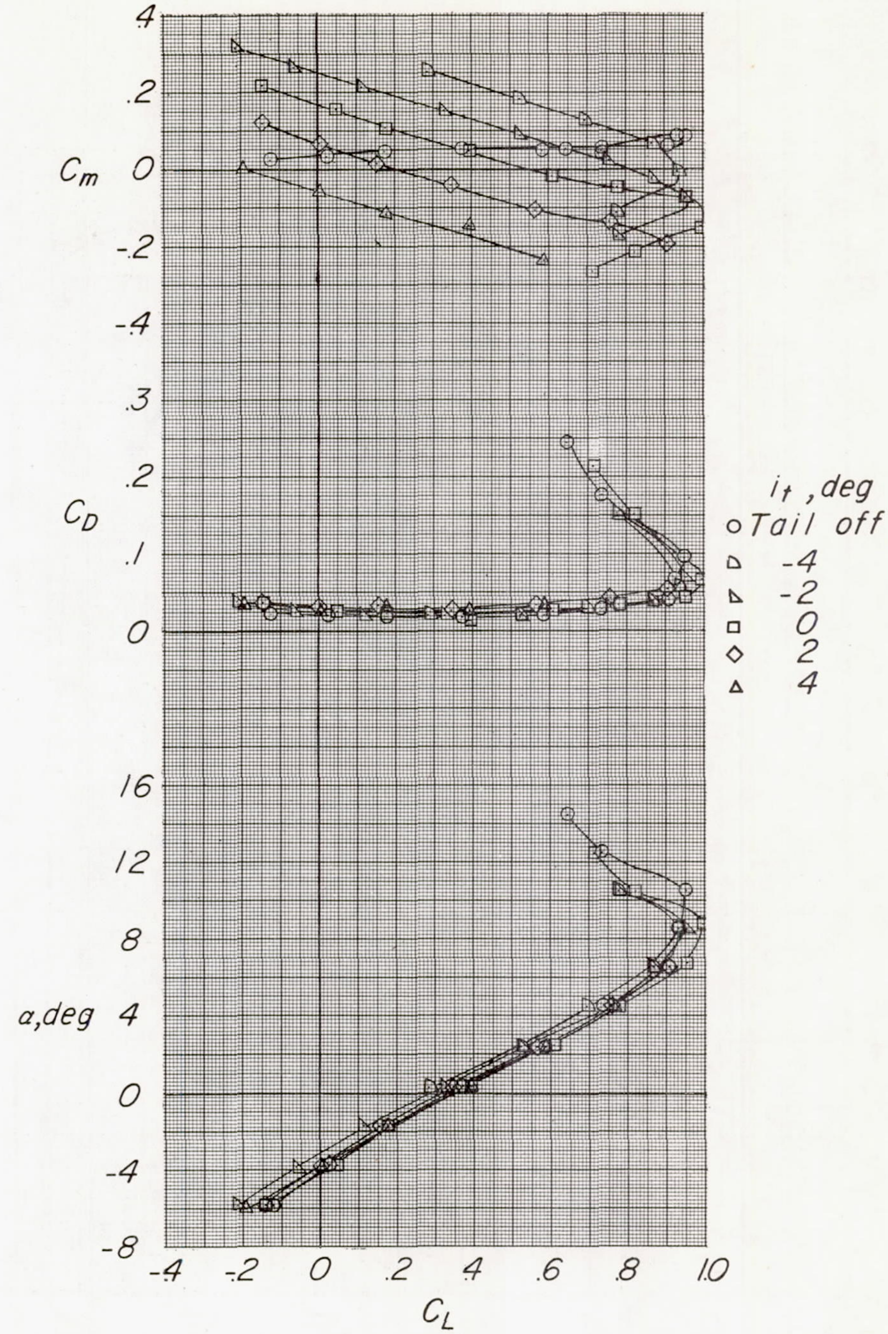
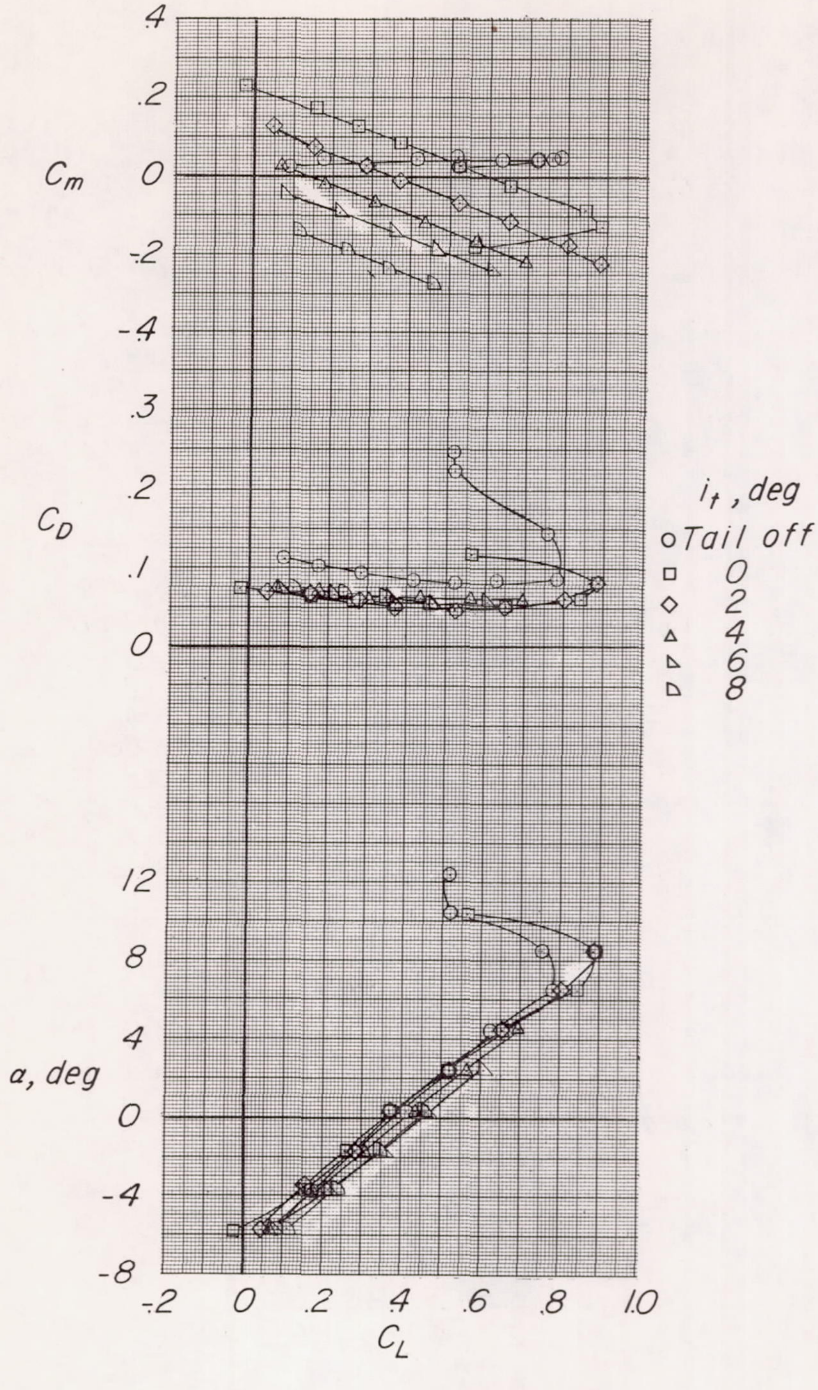


Figure 3.- Velocity distribution of test gusts.



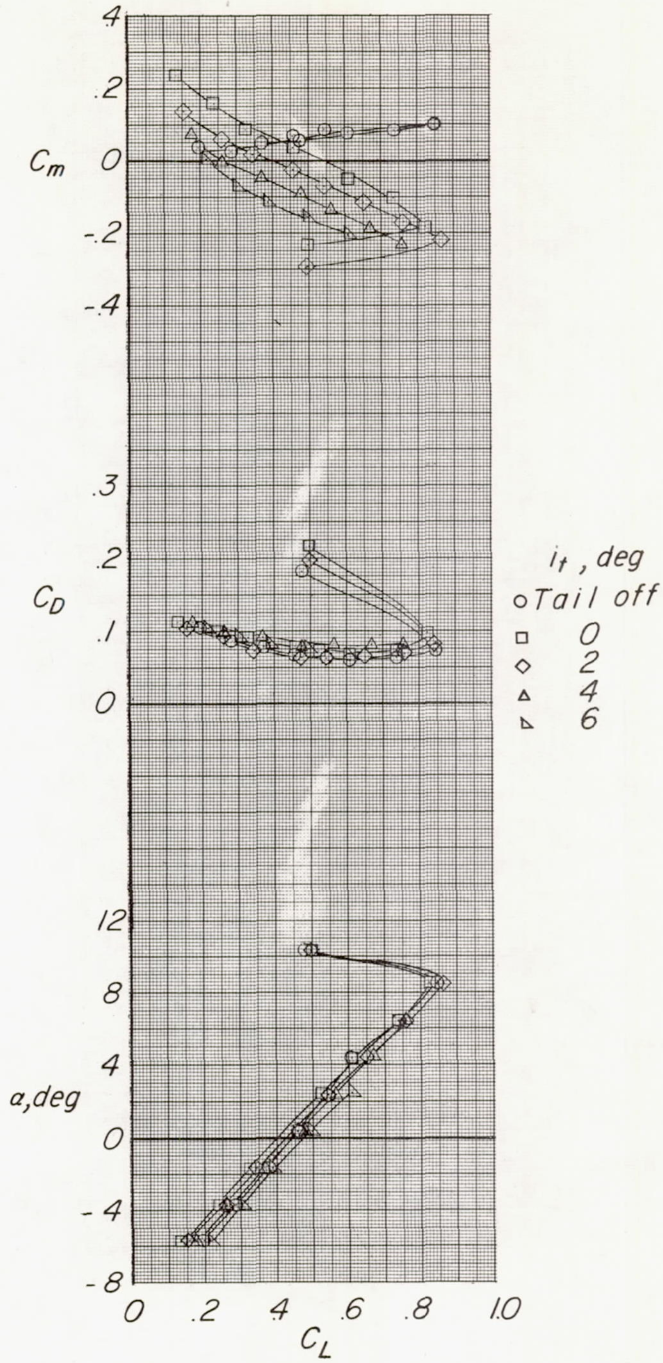
(a) Basic model configuration.

Figure 4.- Aerodynamic characteristics in pitch of the model.



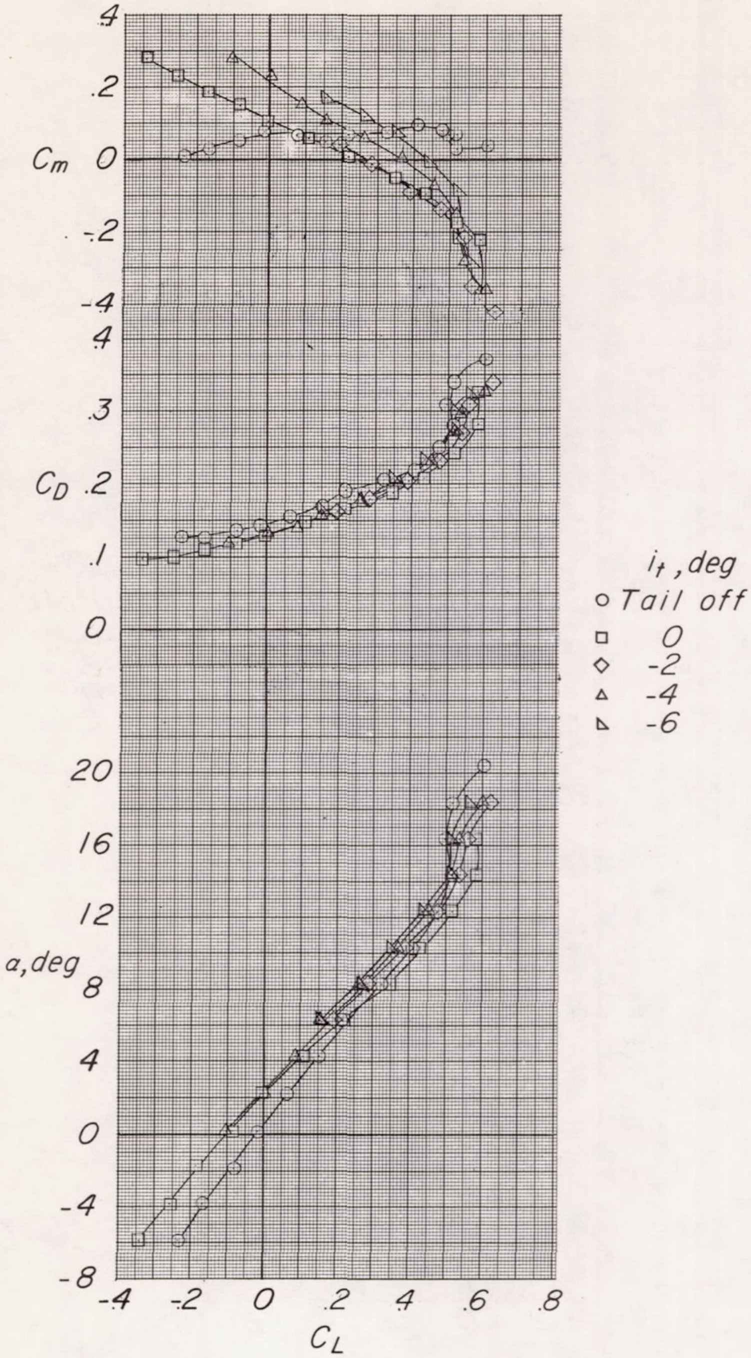
(b) 1/2-span deflector configuration.

Figure 4.- Continued.



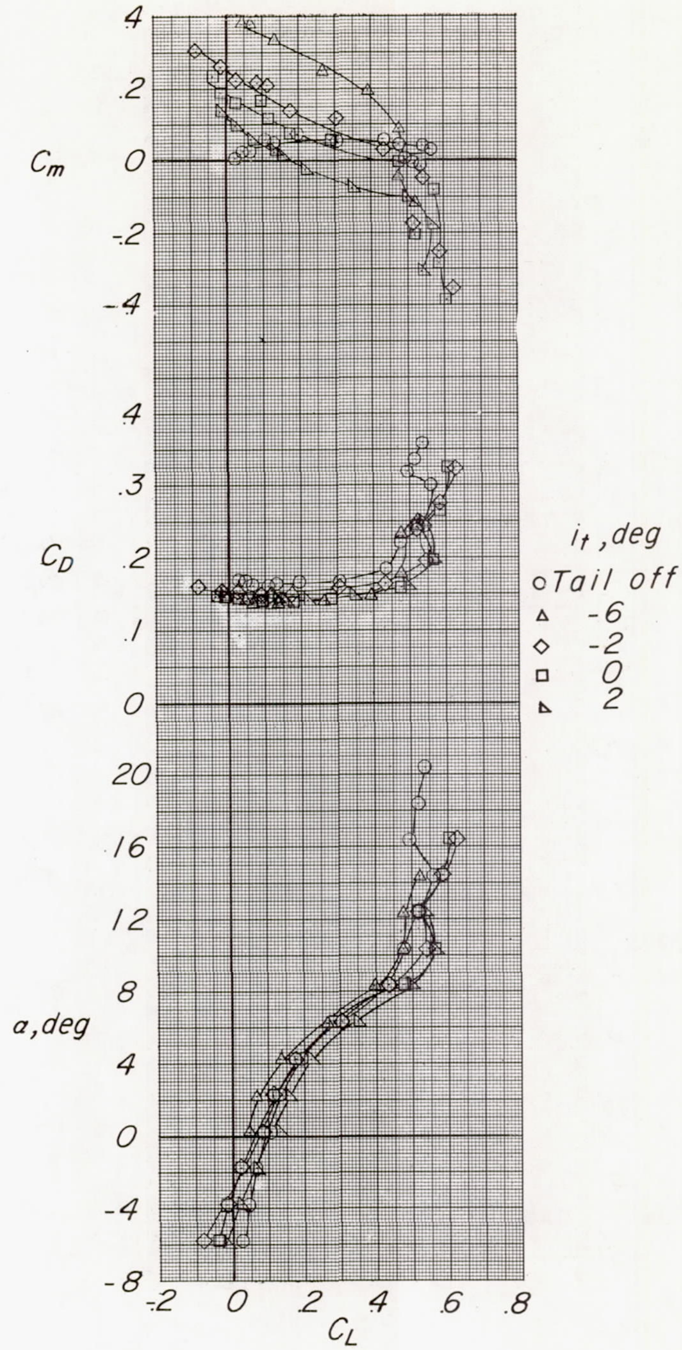
(c) 2/3-span deflector configuration.

Figure 4.- Continued.



(d) 2/3-span spoiler configuration.

Figure 4.- Continued.



(e) Combination 1/2-span spoiler and deflector configuration.

Figure 4.- Concluded.

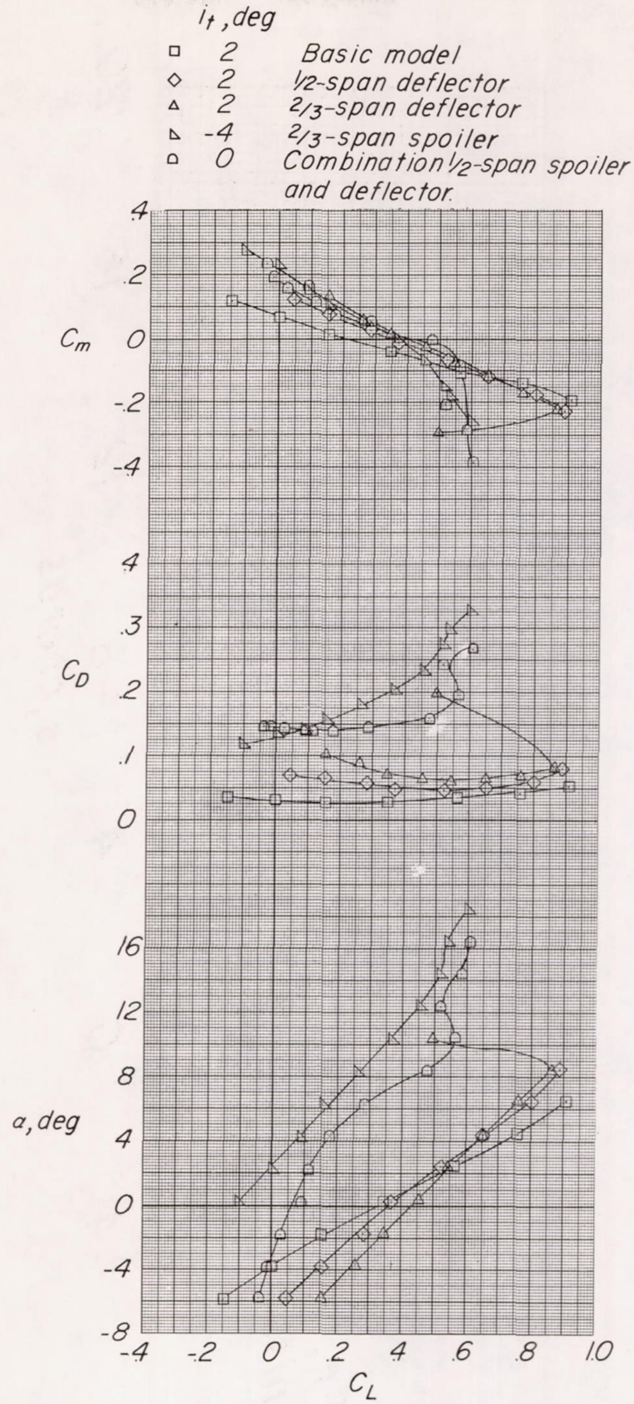


Figure 5.- Aerodynamic characteristics in pitch of basic model and various spoiler and deflector configurations.

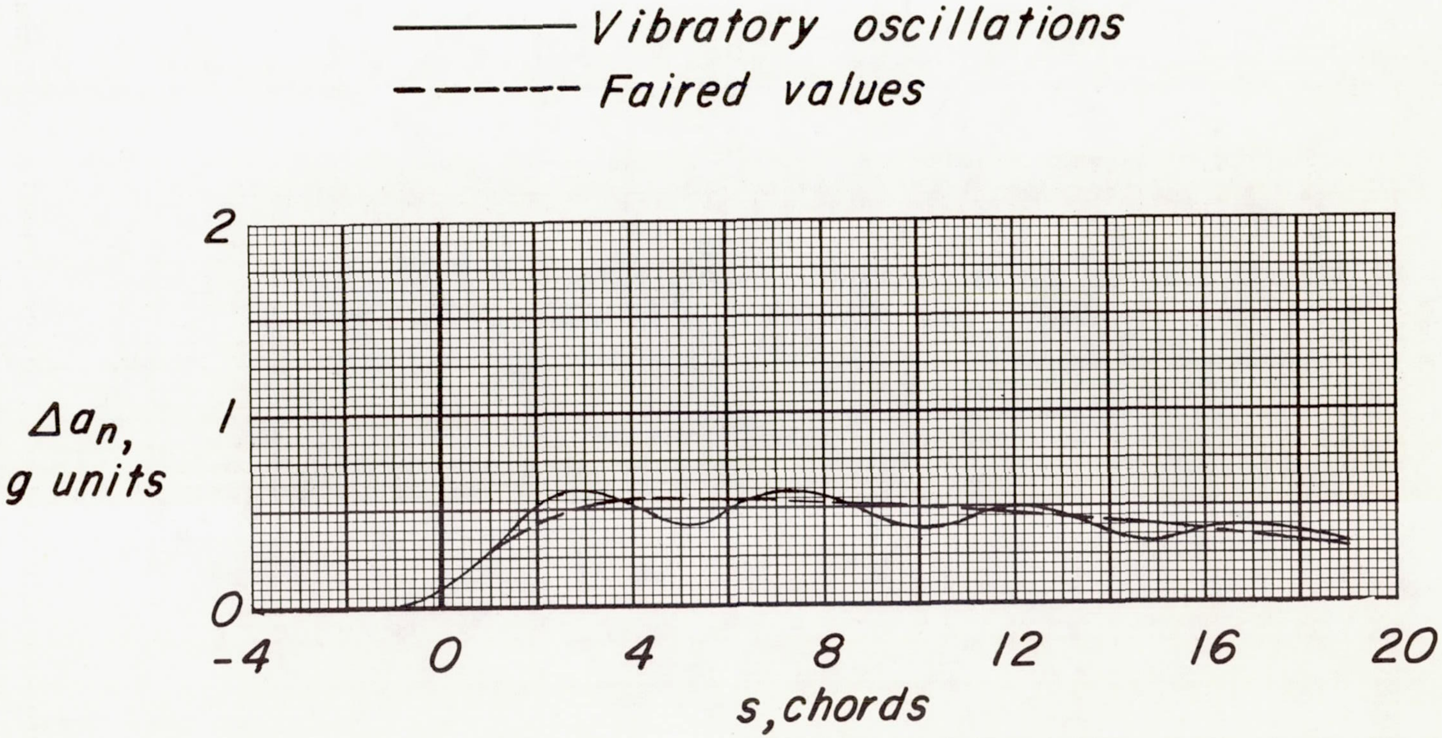
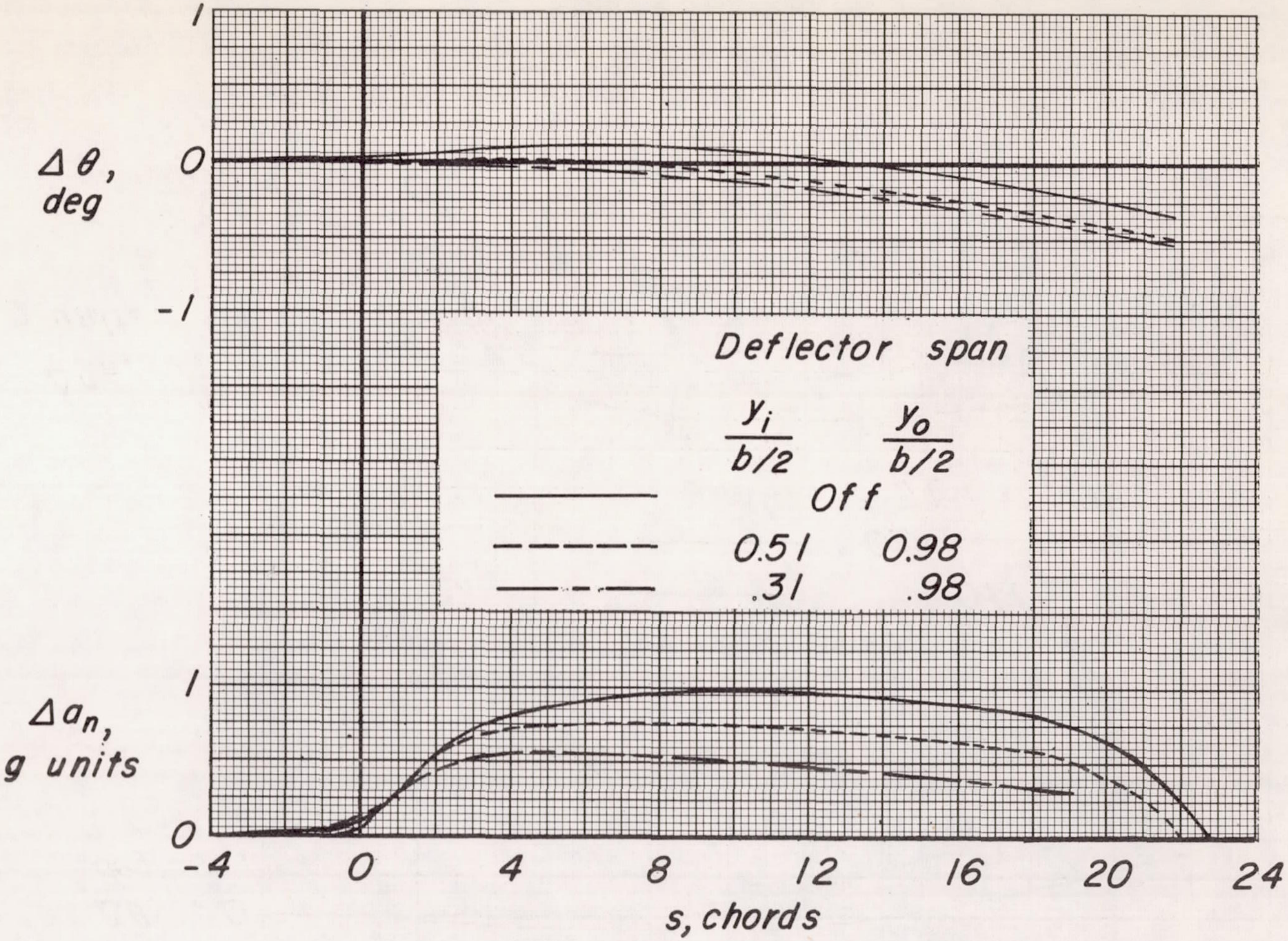
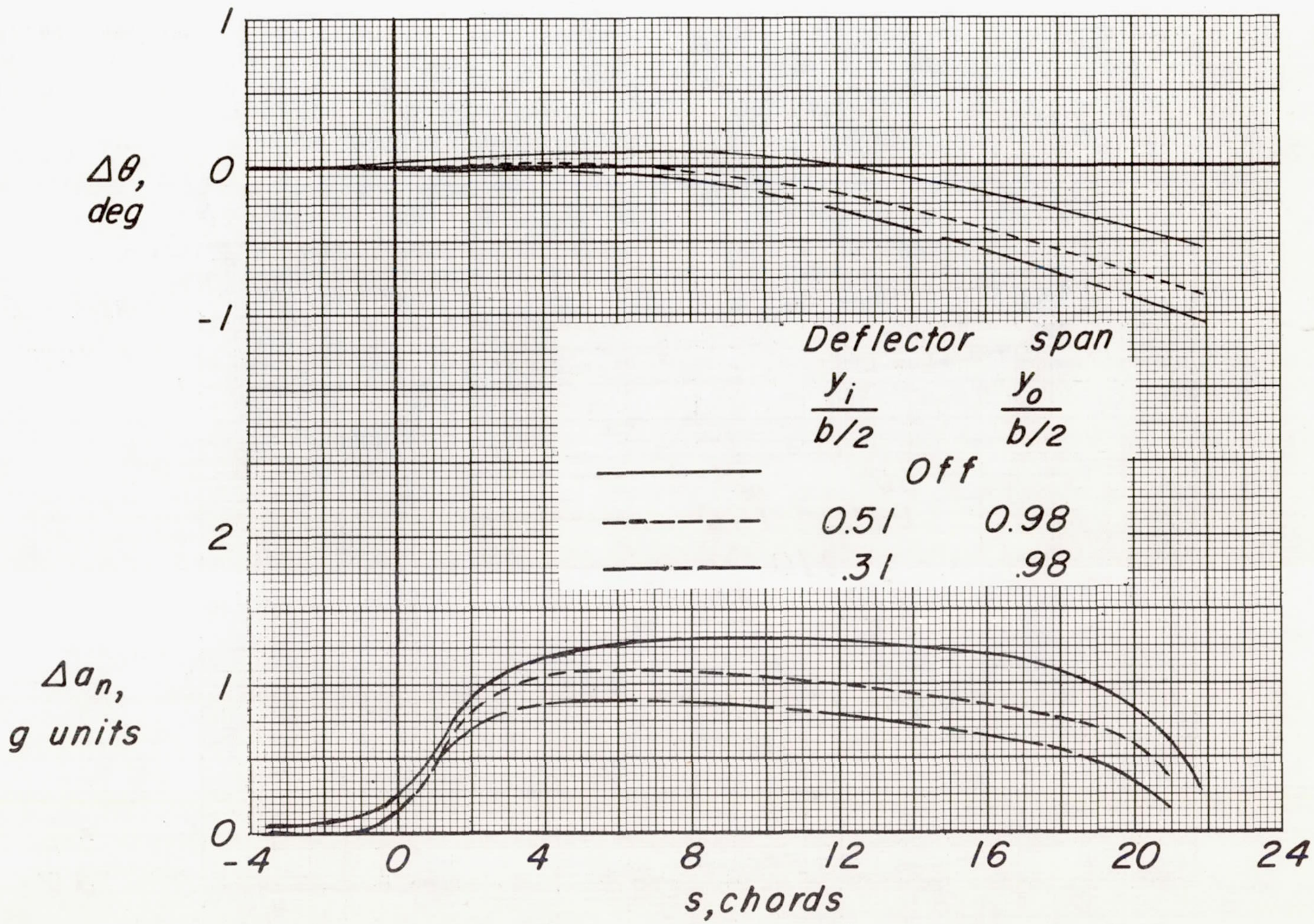


Figure 6.- Variation of incremental normal acceleration with gust penetration for the 2/3-span deflector configuration. U = 10 feet per second; V = 98 feet per second.



(a) U = 10 feet per second; V = 98 feet per second.

Figure 7.- Variation of incremental pitch angle and normal acceleration with gust penetration for the deflector configurations.



(b) U = 15 feet per second; V = 98 feet per second.

Figure 7.- Concluded.

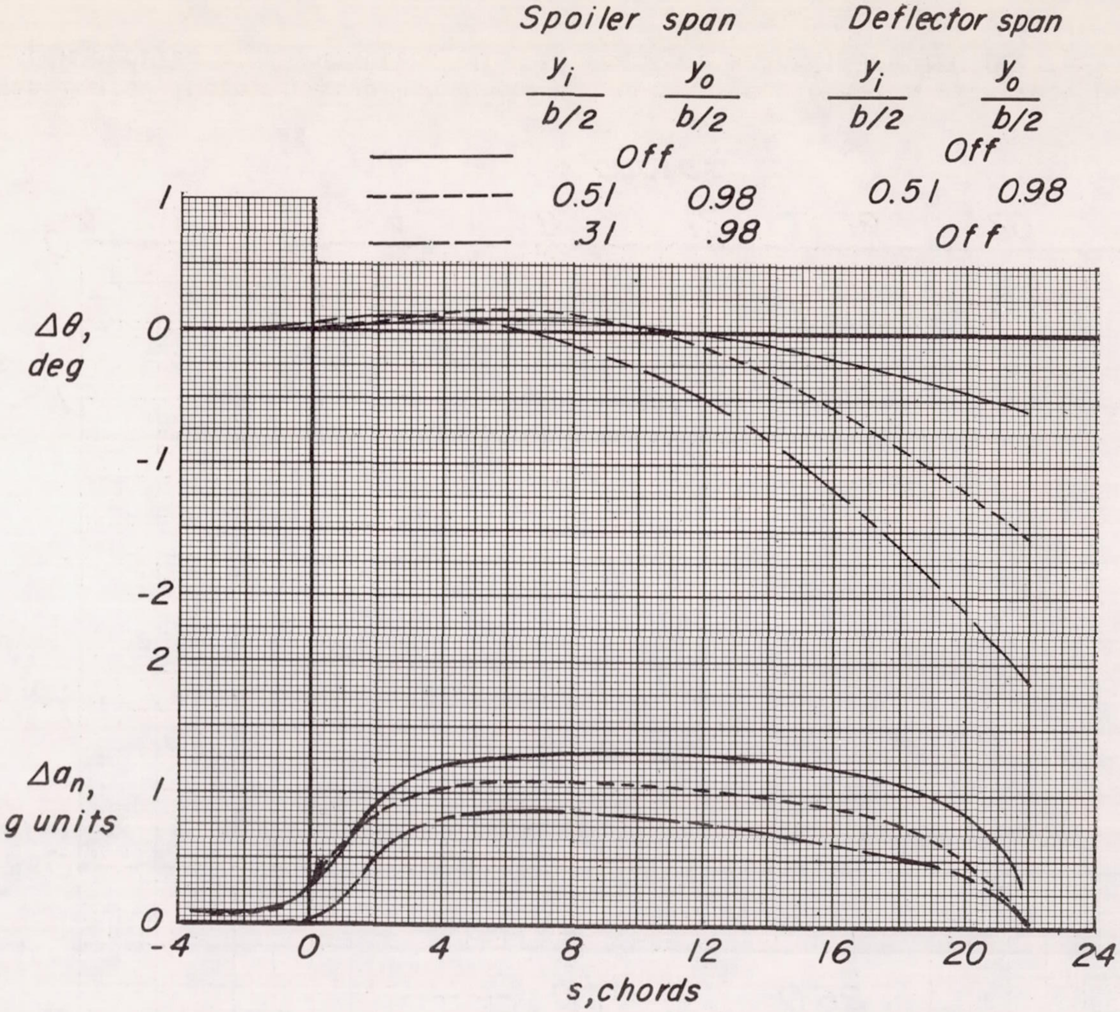


Figure 8.- Variation of incremental pitch angle and normal acceleration with gust penetration for the spoiler and spoiler-deflector configurations. U = 15 feet per second; V = 98 feet per second.

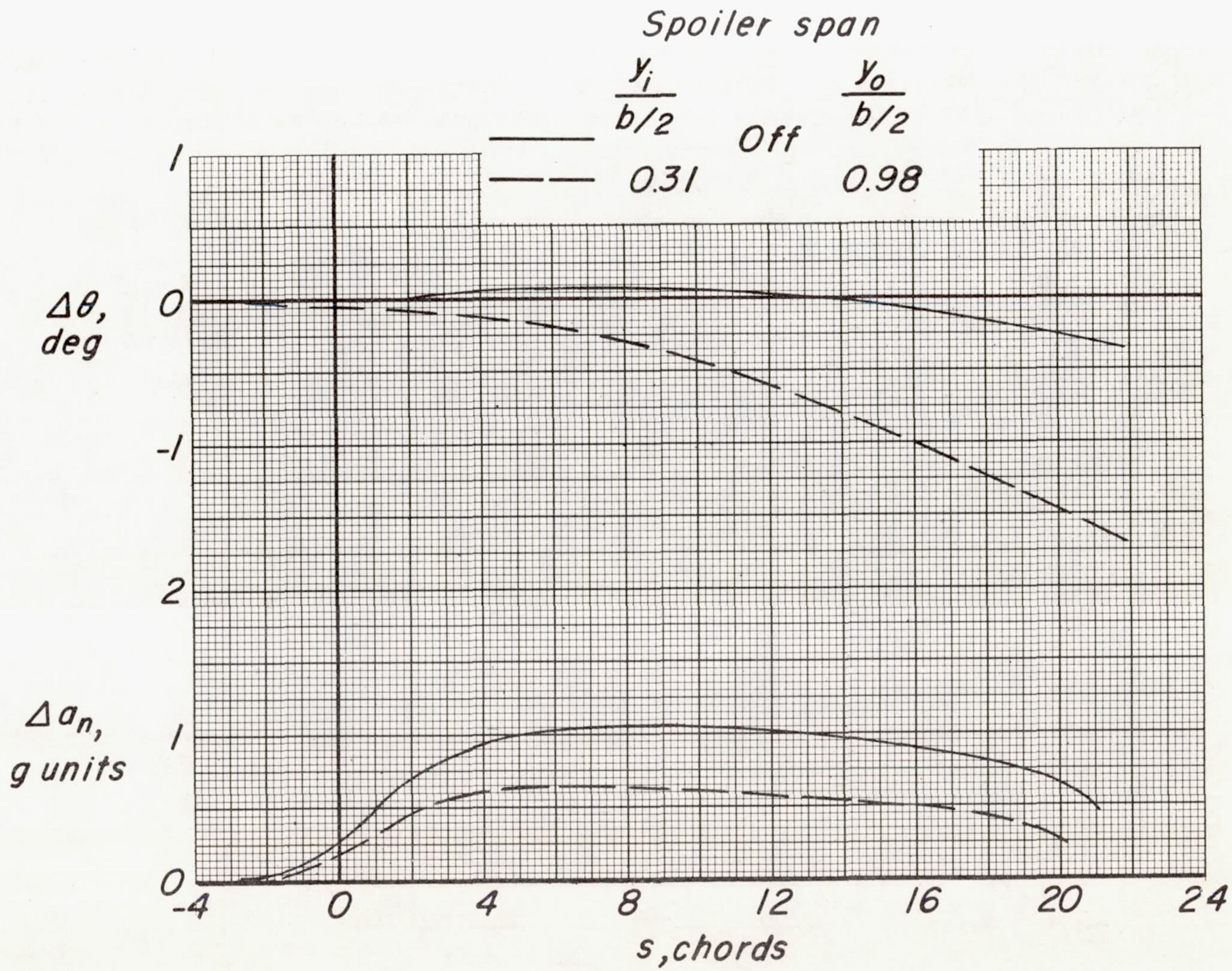


Figure 9.- Variation of incremental pitch angle and normal acceleration with gust penetration for the 2/3-span spoiler configuration. U = 10 feet per second; V = 120 feet per second.

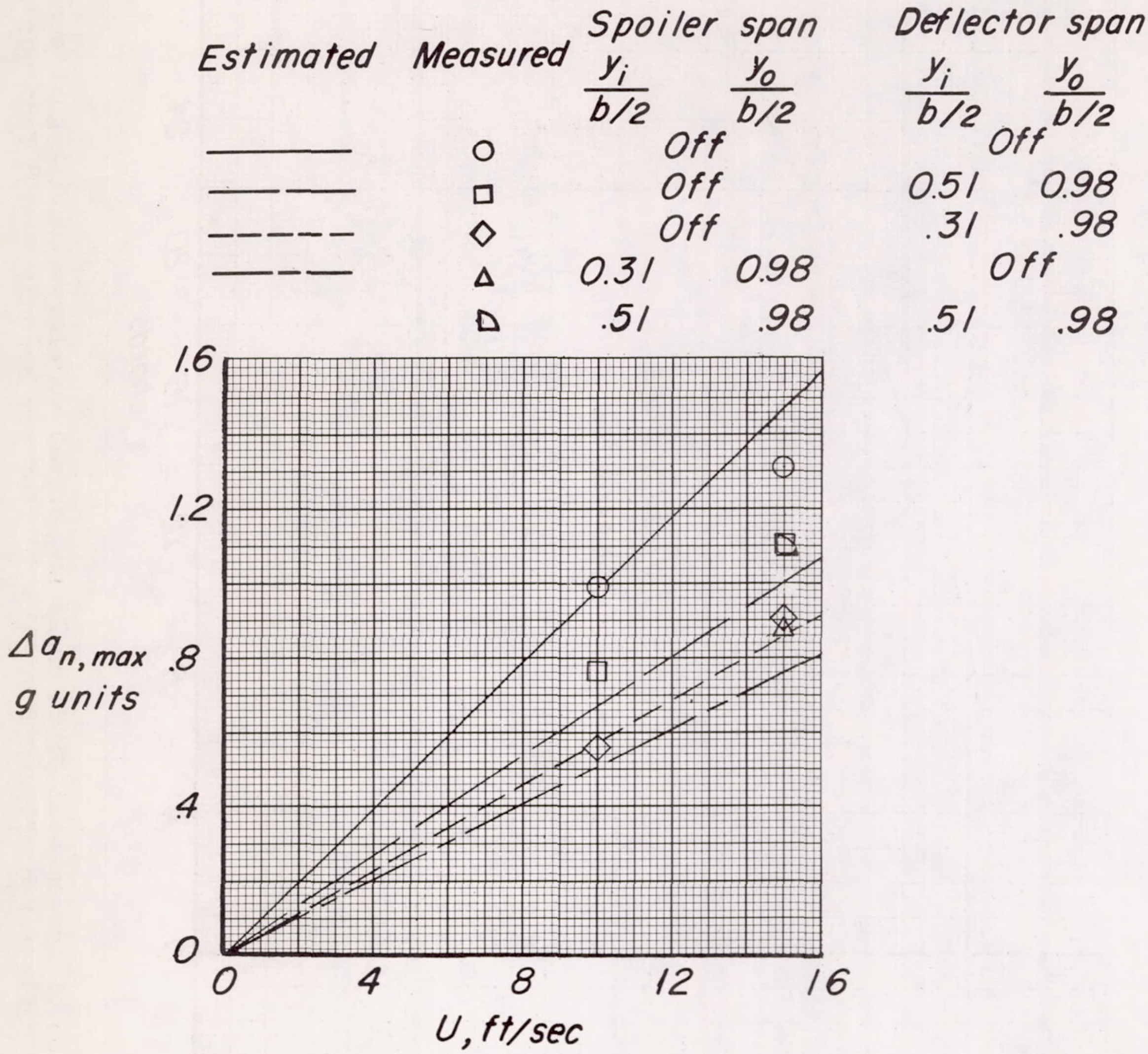


Figure 10.- Variation of the estimated and measured maximum incremental normal accelerations with gust velocity.

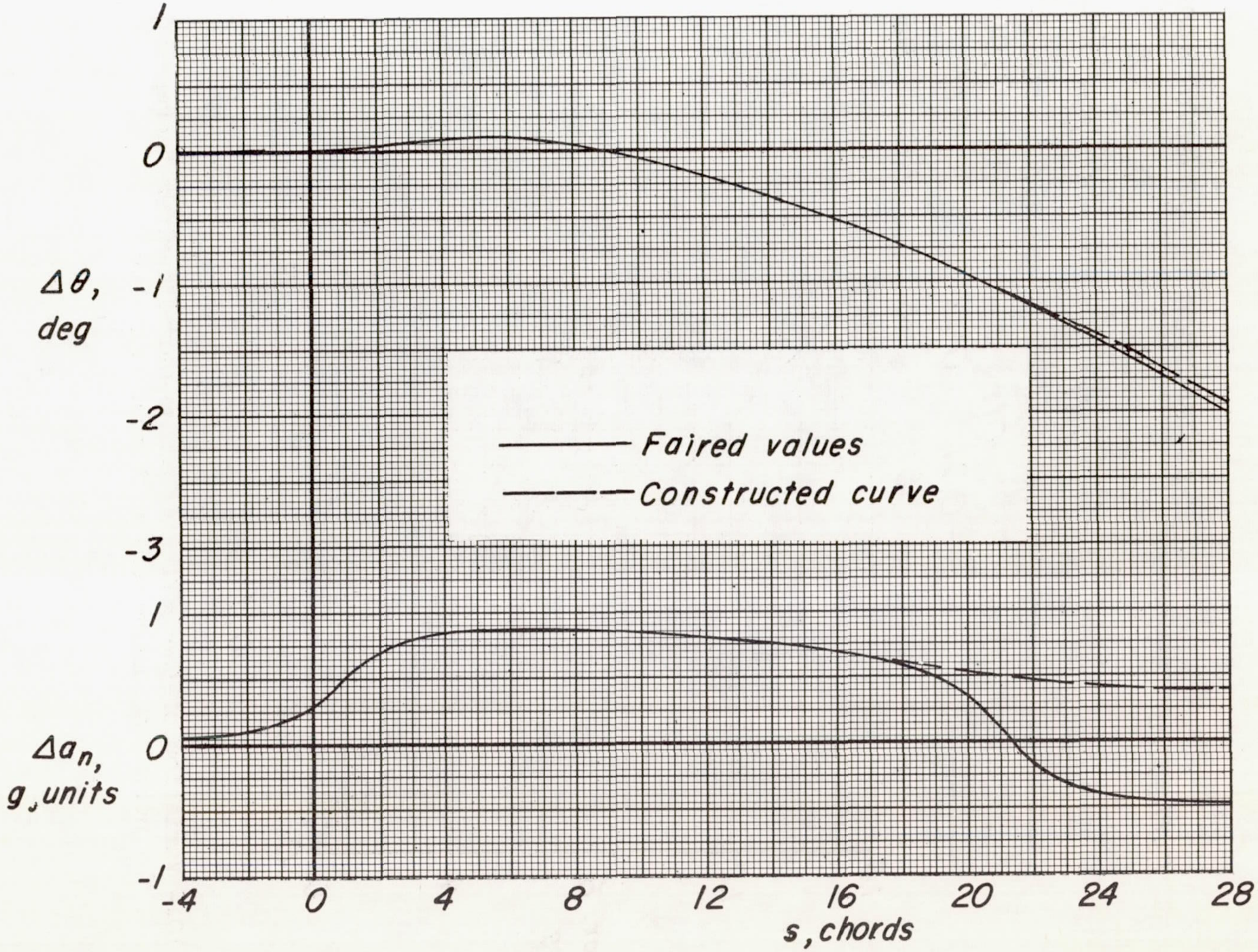


Figure 11.- Variation of incremental pitch angle and normal acceleration with gust penetration for the 2/3-span deflector configuration. U = 15 feet per second; V = 98 feet per second.