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RESEARCH MEMORANDUM

GUST-TUNNEL INVESTIGATION TO DETERMINE EFFECTS OF CENTER-OF-GRAVITY POSITION ON THE GUST LOADS OF A DELTA-WING MODEL WITH LEADING EDGE SWEPT BACK 60°

By Thomas D. Reisert and Domenic J. Maglieri

Langley Aeronautical Laboratory
Langley Field, Va.

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SUMMARY

A gust-tunnel investigation to determine the effects of center-of-gravity position on the gust loads of a delta-wing model with the leading edge swept back 60° was made over a range of center-of-gravity positions from 4 percent ahead of to 11 percent behind the leading edge of the mean geometric chord. This investigation indicated that a 1-percent rearward movement of the center-of-gravity position increased the acceleration increment in the sharp-edge gust by 0.5 percent. In a gust with a gradient distance of 6.5 chords, the acceleration increment was increased by approximately 2 percent for the same movement of the center of gravity. Comparison of these results with those for a conventional airplane model indicates that the change in load for both configurations would be nearly the same in a sharp-edge gust, but in a gust with a gradient distance of 6.5 chords, the change in load for a given change in center-of-gravity position would be approximately twice as great for the delta-wing model as for the conventional airplane model.

INTRODUCTION

The results of a previous investigation of the gust loads on a delta-wing model (ref. 1), as compared with those on a conventional airplane model (table XI and p. 30 of ref. 2), indicated that the amount of pitch due to gusts was greater for the tailless delta-wing model than would be expected for conventional configurations. These results, together with the analyses of references 3 and 4 and the fact that a tailless configuration inherently has low damping in pitch, led to concern that gust loads on tailless delta-wing airplanes would be significantly affected by center-of-gravity position.

In accordance with the foregoing, the investigation of reference 1 has been extended to determine the influence of center-of-gravity position on the gust loads due to penetration into a sharp-edge and a gradient gust. This report presents the results of a gust-tunnel investigation of the effect of center-of-gravity position on the gust loads on a tailless delta-wing model with the leading edge swept back 60°.

APPARATUS AND TESTS

The 60° delta-wing model used in the tests is the model of reference 1. A photograph of the model is shown in figure 1, and the plan-view drawing is shown in figure 2. The characteristics of the model and the test conditions are listed in table I. The airfoil had an NACA 65-006 section at the root and was tapered to an NACA 65_1-012 section at a point 1.5 inches from the tip. The construction of the model was such that it could be considered a rigid body for the tests. An accelerometer was mounted under the forward part of the fin at zero percent of the mean geometric chord, a point which coincided with 50 percent of the root chord. Two lights were mounted on the model for pitch measurements in free flight.

The gust tunnel and its equipment are described in reference 2. The profiles of the sharp-edge gust and of a gust with a gradient distance of 6.5 chords are shown in figure 3, where the ratio of the local gust velocity to the average maximum gust velocity is plotted as a function of penetration measured in mean geometric chords.

The tests consisted of 8 flights through the sharp-edge gust and 16 flights through the gust with a gradient distance of 6.5 chords for each of the three center-of-gravity positions of -4, +6, and +11 percent of the mean geometric chord of the model. Negative center-of-gravity positions are located ahead of the leading edge of the mean geometric chord and positive center-of-gravity positions are located behind the leading edge of the mean geometric chord. Measurements of forward velocity, gust velocity, normal-acceleration increment, and pitch-angle increment were made for each flight. Experience has shown that the dispersion of data is generally greater for tests in a gradient gust than for tests in a sharp-edge gust. Therefore, two completely separate tests of eight flights each, for each center-of-gravity position, were made in the gradient gust to obtain a better average value of maximum acceleration increment. Comparison of the results of the two tests indicated they were in good agreement. The difference in the average values of maximum acceleration increment was generally less than 3 percent, although in one case it was somewhat larger.

PRECISION

The measured quantities are estimated to be accurate within the following limits for any test or run:

Normal-acceleration increment, Δn, g units	±0.05
Forward velocity, ft/sec	±0.5
Gust velocity, ft/sec	±0.1
Pitch-angle increment, $\Delta\theta$, deg	±0.1

RESULTS

The records for all flights were evaluated to obtain histories of the normal-acceleration increment and pitch-angle increment during traverse through the gust. The maximum acceleration increment was determined for each test flight. Since minor variations in forward speed and gust velocity occur from flight to flight, the maximum acceleration increments were corrected to a forward speed of 88 feet per second and a gust velocity of 10 feet per second on the assumption that the acceleration increment is directly proportional to forward speed and gust velocity. The measured accelerations were also corrected for the effects of angular acceleration by the method of reference 5, since the accelerometer was not mounted exactly at the center of gravity. The average values of the corrected maximum acceleration increments, together with the values reduced to zero pitching motion by the approximate method of reference 6, for each gust shape and each of the three center-of-gravity positions are given in table II. Changing the center of gravity of the model for a constant model weight resulted in a change in the pitching moment of inertia of the model. The results obtained therefore include some effect of inertia, but rough calculations indicated that the effect of inertia is small.

Representative histories of acceleration increment and pitch increment are shown in figure 4. The average values of maximum acceleration increment are shown in figure 5 plotted against the center-of-gravity position. In figure 6, the maximum acceleration increment including the effect of pitch divided by the maximum acceleration increment corrected to zero pitch is shown as a function of center of gravity.

DISCUSSION

Inspection of figure 4 indicates that, as for the conventional airplane, rearward movement of the center-of-gravity position tends to increase the gust load and the airplane pitch. The pitch-increment curves of figure 4 indicate that (as the restoring moment decreases) with rearward movement of the center-of-gravity position, the stabilizing pitching motion decreases. This decrease in nose-down pitch causes a corresponding change in the characteristic shapes of the acceleration-increment curves. The curves of figure 4 further indicate that in the sharp-edge gust the effect of pitch at the point of maximum acceleration is adverse for all center-of-gravity positions (positive pitch increases the load), whereas in the gradient gust, where the penetration effect has been partially overcome by the static stability, the effect of pitch, at least for forward center-of-gravity positions, is favorable. The time histories of figure 4 wherein the pitch curves include both positive and negative pitch indicate that the phase relation between the load and pitch histories would be very significant. The point of zero pitch may vary along the time axis and the prediction of the effect of pitch would require close estimation of that point.

Figure 5 shows that a 15-percent rearward movement of center-of-gravity position increased the acceleration increment in the sharp-edge gust by 0.08g or approximately 7.5 percent and increased it in the gust with a gradient distance of 6.5 chords by 0.24g or 35 percent. Comparison of these results for the delta-wing model with those of reference 2 (p. 30) for a conventional airplane configuration indicates that in a sharp-edge gust the effect of center-of-gravity travel is minor for both configurations (0.5-percent increase in gust load for a 1-percent change in center-of-gravity position) but in a gust with a gradient distance of about 6 chords the gust load on the delta wing increased about 2 percent for each 1-percent rearward movement of center-of-gravity position. Since a 2-percent increase is twice that indicated in reference 2 for the straight-wing conventional configuration, the lack of damping in pitch is apparently having a significant effect. A similar conclusion could be drawn from the results presented in reference 2 (p. 30) for another tailless configuration, where a $1\frac{1}{2}$-percent change in load was obtained for a 1-percent change in center-of-gravity position.

The data in table II for the acceleration increment for zero pitch indicate an anomaly for the gradient gust in that the gust load varies with center-of-gravity position. If the corrections and assumptions were all correct, the zero-pitch gust load would be expected to be independent of center-of-gravity position. Since, in figure 4, the acceleration and pitch-angle histories vary in a consistent and orderly fashion, two possible explanations for the anomaly are: (1) the pitch correction of reference 6 is not adequate for delta-wing airplanes and (2) some other factor associated with center-of-gravity position is modifying the load. Consideration of the plan form, together with the fact that the pitch tends to become more important for the longer gust-gradient distances, indicates that some of the discrepancy can be reasonably ascribed to the pitch correction, the adequacy of which cannot be assessed.

If the pitch correction is assumed to be adequate, figure 6 indicates that a 15-percent rearward movement of the center-of-gravity position increases the load due to pitch by 5 percent for the sharp-edge gust and by 12 percent for the gust with a gradient distance of 6.5 chords. These results are similar to those obtained for the conventional airplane of reference 2 (p. 30), for which a 1-percent change in center of gravity gave about a 0.5-percent change in load in a sharp-edge gust and about a 1-percent change in load in a gust with a gradient distance of about 6 chords.

For a single gust, therefore, the center-of-gravity position is apparently an important factor in determining the magnitude of the gust load for delta wings. Since it is not possible to study a complete oscillation subsequent to the gust penetration, no concrete observations can be made concerning the damping in pitch or behavior in continuous rough air.

CONCLUDING REMARKS

Results of a gust-tunnel investigation of a delta-wing model with the leading edge swept back 60° have indicated that a 15-percent change in center-of-gravity position on the mean geometric chord gave a 7.5-percent change in load for the model in a sharp-edge gust and approximately a 35-percent change in load in a gust with a gradient distance of 6.5 chords. The change in load for the sharp-edge gust could be largely accounted for by the effect of pitching motion. In the gust with a gradient distance of 6.5 chords, however, the correction for pitching motion accounted for about one-third of the change in load. When the results for the delta-wing configuration were compared with those for a conventional airplane model the results were as follows: (1) in the sharp-edge gust the variation of load with center-of-gravity position was the same for both airplanes and (2) in the gust with a gradient distance of about 6.5 chords the change in loads for a given change of center-of-gravity position was twice as great for the delta-wing model as for the conventional airplane.

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

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TABLE I

CHARACTERISTICS OF THE MODEL AND TEST CONDITIONS

Center-of-gravity location, percent M.G.C.	-4	+6	+11
Weight, lb	15	15	15
Wing area, sq ft	6.92	6.92	6.92
Wing loading, lb/sq ft	1.69	1.69	1.69
Span, ft	4.00	4.00	4.00
Mean geometric chord measured parallel to plane of symmetry, Area/Span, ft	1.73	1.73	1.73
Aspect ratio	2.33	2.33	2.33
Root chord, ft	3.46	3.46	3.46
Slope of lift curve determined by steady-flow force tests, per radian	2.4	2.4	2.4
Gust velocity, fps	10	10	10
Forward velocity, fps	88	88	88
Pitching moment of inertia, slug-ft^2	0.436	0.309	0.266

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TABLE II

AVERAGE MAXIMUM VALUES OF ACCELERATION INCREMENT

CORRECTED FOR FORWARD SPEED AND GUST VELOCITY

Gradient distance, mean chords	Center-of-gravity location, percent M.G.C.	Corrected Δn_{max}, g units	Corrected Δn_{max} reduced to zero pitch, g units
0	-4	1.07	1.03
	+6	1.16	1.10
	+11	1.15	1.06
6.5	-4	.68	.72
	+6	.81	.83
	+11	.92	.86

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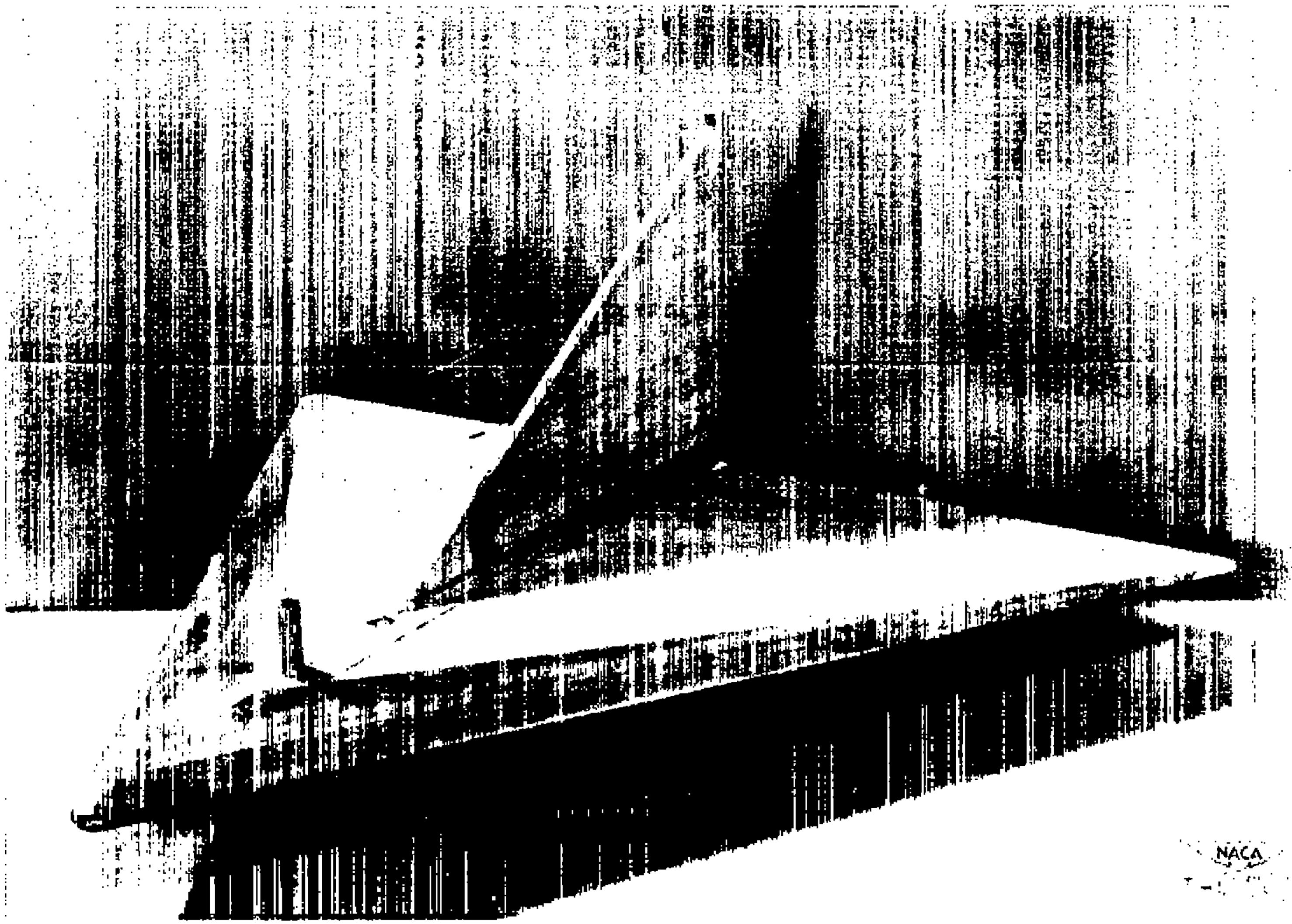


Figure 1.- Photograph of 60° delta-wing model.

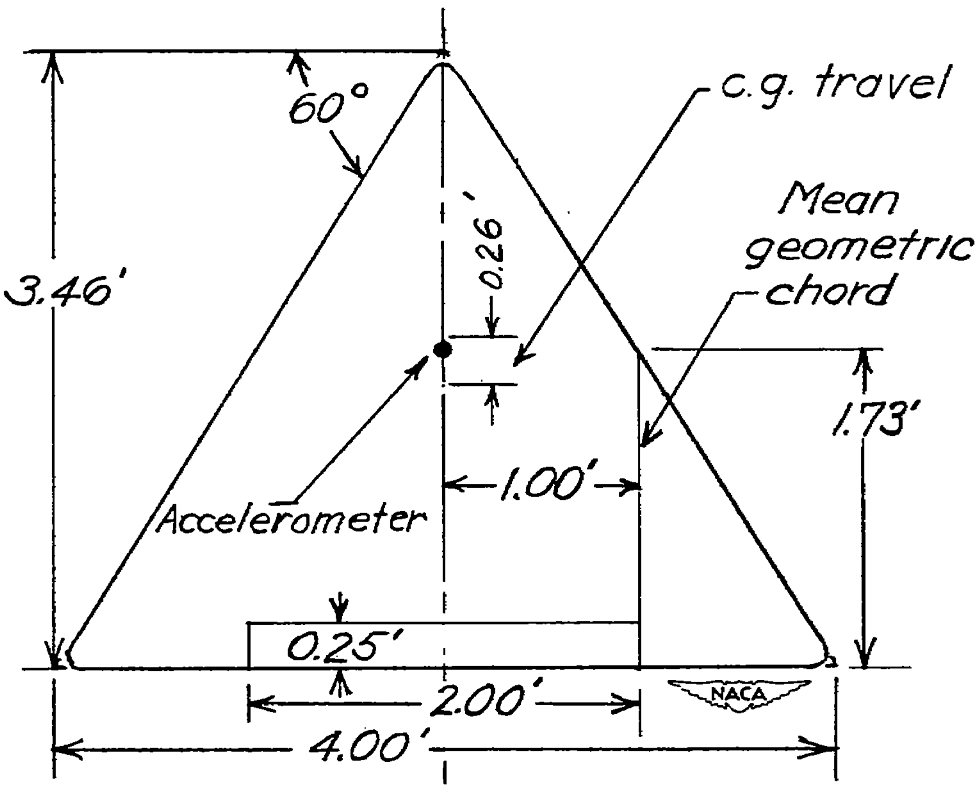


Figure 2.- Plan form of 60° delta-wing model.

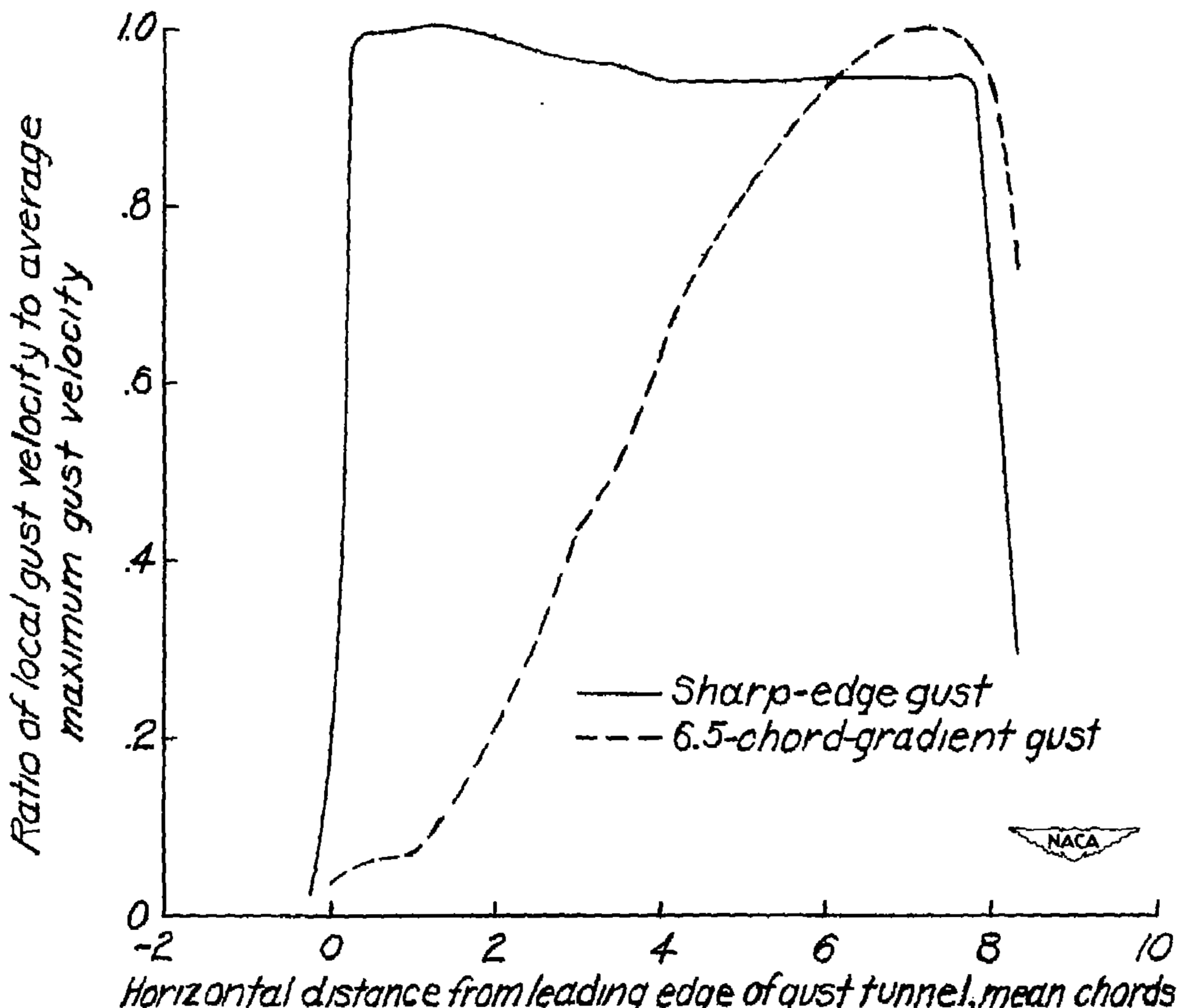
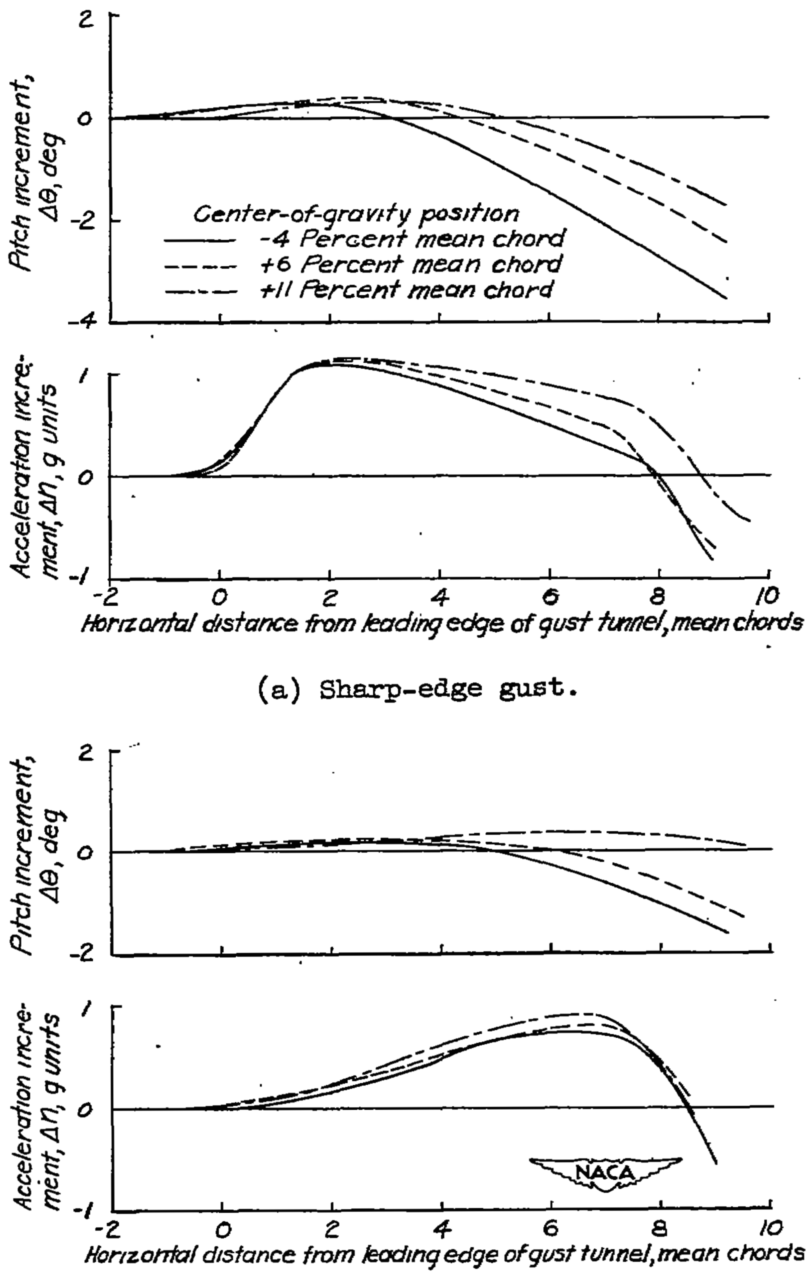


Figure 3.- Velocity distribution through gust-tunnel jet.



(b) 6.5-chord-gradient gust.

Figure 4.- Comparison of histories in test gusts.

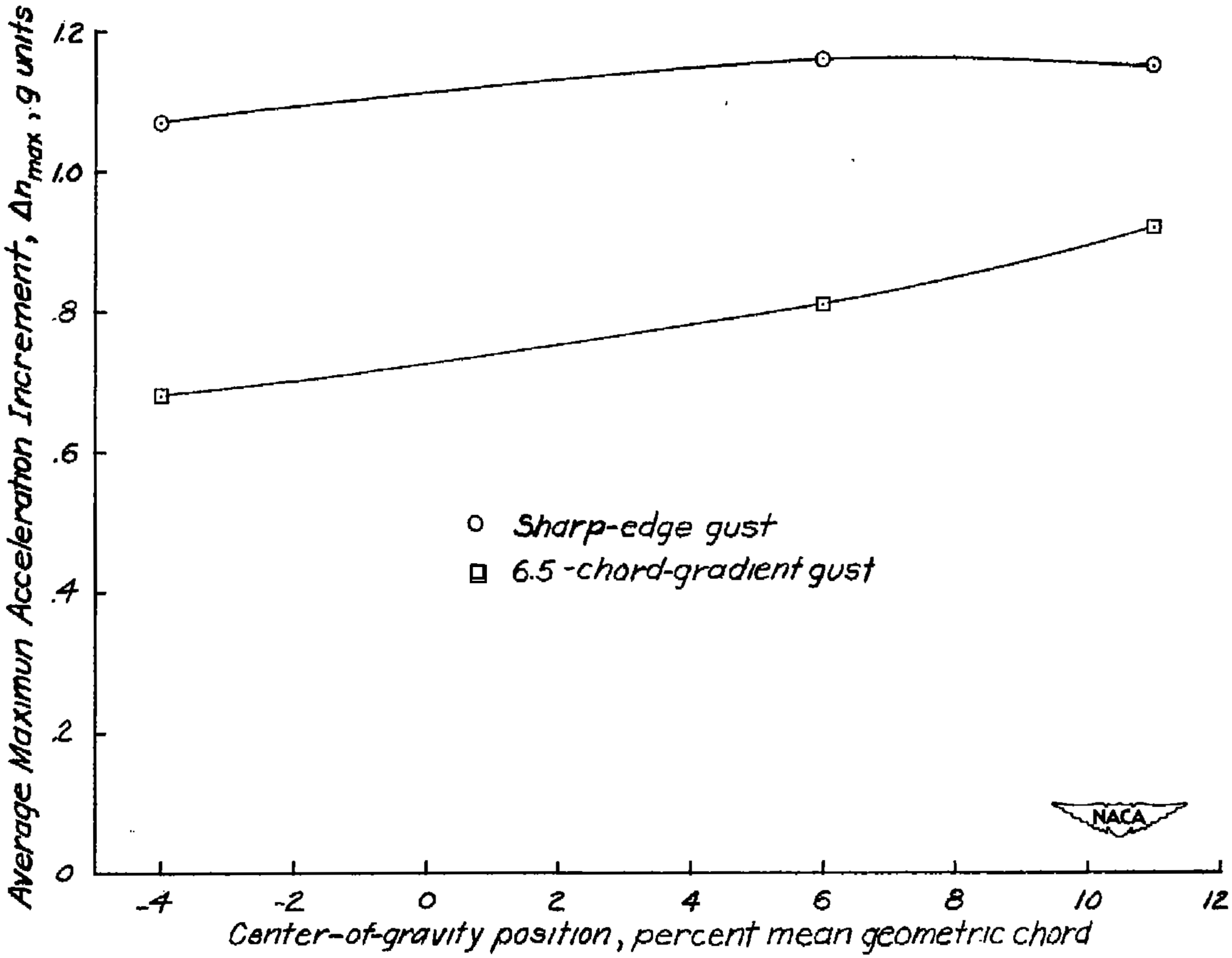


Figure 5.- Variation of maximum acceleration increment with center-of-gravity position.

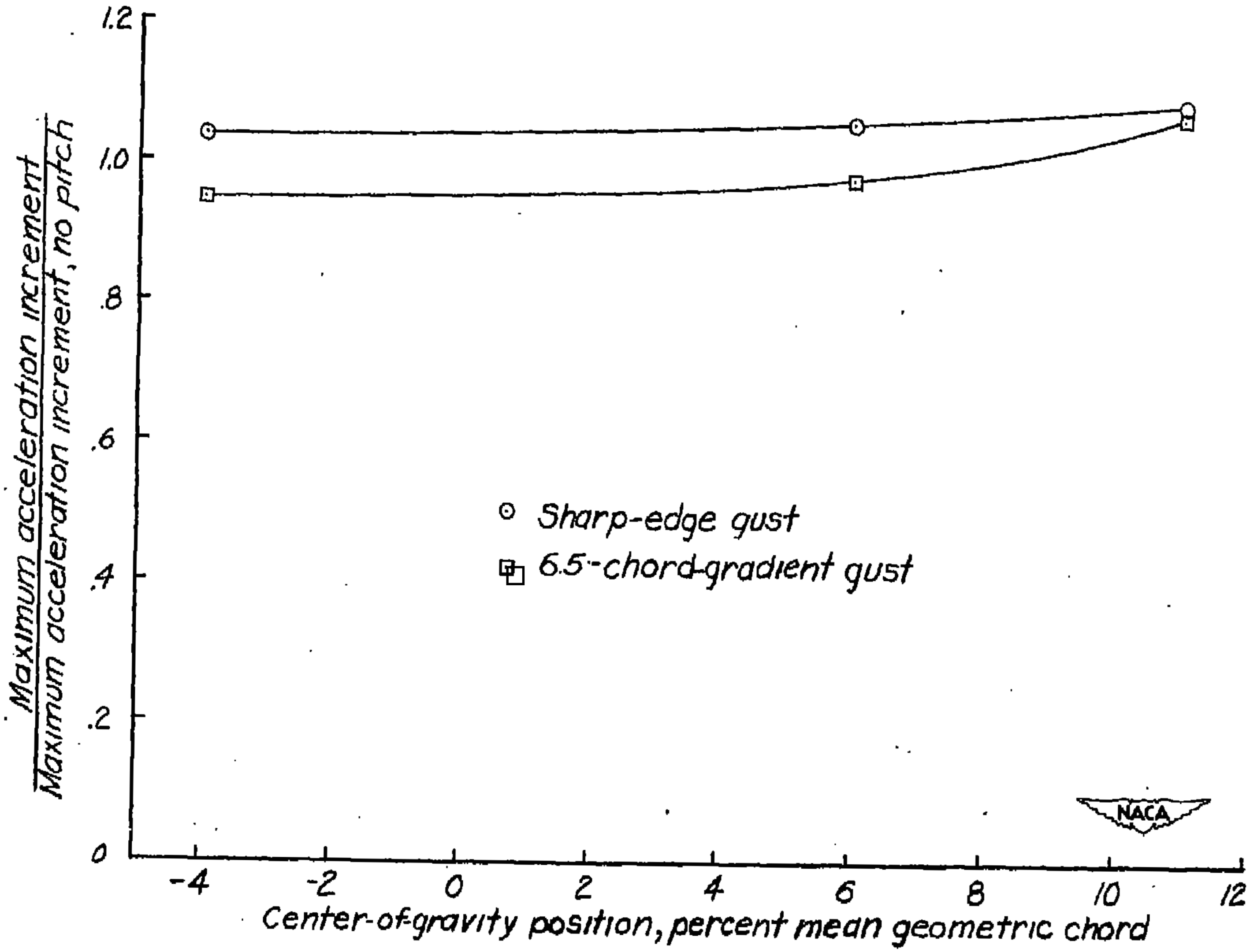


Figure 6.- Ratio of maximum acceleration increment to maximum acceleration increment corrected to zero pitch, as a function of center of gravity.