RM A50I27

NACA RM A50I27

NACA

RESEARCH MEMORANDUM

FLIGHT-DETERMINED BUFFET BOUNDARIES OF TEN AIRPLANES AND COMPARISONS WITH FIVE BUFFETING CRITERIA

By Burnett L. Gadeberg and Howard L. Ziff

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS
WASHINGTON

January 5, 1951
Declassified July 28, 1958

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

FLIGHT-DETERMINED BUFFET BOUNDARIES OF TEN AIRPLANES AND COMPARISONS WITH FIVE BUFFETING CRITERIA

By Burnett L. Gadeberg and Howard L. Ziff

SUMMARY

The flight-determined buffet boundaries of ten airplanes are presented. Comparisons are made with five possible buffeting criteria which are related to airfoil-section characteristics. The general conformity of the trend of the buffet boundaries (in terms of lift coefficient and Mach number) with that of the criteria for seven of the eight straight-wing airplanes indicates that the wing was probably the primary cause of the buffeting. A reasonable estimate of the buffet boundary of a straight-wing airplane may be obtained from the criteria discussed.

INTRODUCTION

One of the first factors of concern in the study of buffet characteristics of airplanes is the establishment of conditions of lift coefficient and Mach number at which airplane buffeting occurs (detectable by the pilot or by suitable instrumentation); a second factor is the relation of the buffet boundaries so determined to some criterion which will define the occurrence of a flow change on some major component of the airplane.

It appeared likely that information on the above two points could be obtained from a study of existing flight records which originally had been obtained and analyzed for purposes other than a study of buffeting characteristics. Such an examination of flight data on file at Ames Aeronautical Laboratory resulted in sufficient information on six airplanes to establish the buffet boundaries. To supplement these results, data on four other airplanes were obtained; one from tests conducted at Langley Aeronautical Laboratory and three from tests at the NACA High-Speed Flight Research Station.

This report presents the flight-determined buffet boundaries of these ten airplanes and compares them with five criteria based on airfoil-section characteristics.

SYMBOLS

A	wing aspect ratio $\left(\frac{b^2}{S}\right)$
A_Z	the ratio of the net aerodynamic force along the airplane Z axis (positive when directed upward, as in normal level flight), to the weight of the airplane
b	wing span, feet
C_L	airplane lift coefficient $\left(\frac{WA_Z}{qS}\right)$
c_r	wing root chord, feet
h_t	average height of stabilizer root chord above wing root chord, feet
M	free-stream Mach number
M_b	lift-divergence Mach number (free-stream Mach number at initial inflection point of curves of section lift coefficient versus Mach number at constant angle of attack)
M_p	force-peak Mach number (free-stream Mach number at peak of curves of section lift coefficient versus Mach number at constant angle of attack)
M_{cr}	critical Mach number of airfoil section
M_β	free-stream Mach number at which flow at airfoil crest first reaches sonic velocity
M_δ	free-stream Mach number based on empirical buffeting criterion
$\overline{\Delta M}$	average Mach number difference between buffet boundaries and criterion
ΔM_b	difference in Mach number between buffet boundary and M_b
ΔM_p	difference in Mach number between buffet boundary and M_p
ΔM_{cr}	difference in Mach number between buffet boundary and M_{cr}
ΔM_β	difference in Mach number between buffet boundary and M_β
ΔM_δ	difference in Mach number between buffet boundary and M_δ
q	dynamic pressure $\left(\frac{1}{2}\rho V^2\right)$, pounds per square foot

S wing area, square feet

V true airspeed, feet per second

W airplane weight, pounds

δ angle between flight path and line through trailing edge and 70-percent-chord point of wing upper surface

ρ atmospheric density at altitude, slugs per cubic foot

Λ angle of wing sweepback, degrees

DESCRIPTION OF THE AIRPLANES

All the test vehicles were single-engine, single-place airplanes, the major differences of which can be determined from the following grouping:

Airfoil sections	Wing	Airplane	Engine / inlets	Propulsion
Conventional airfoil sections	Straight, low wing	F8F-1	Air-cooled engine	Propeller driven
Conventional airfoil sections	Straight, low wing	P-39N	Liquid-cooled engine	Propeller driven
Low-drag airfoil sections	Straight, low wing	F-51D	Liquid-cooled engine	Propeller driven
Low-drag airfoil sections	Straight, low wing	F-51H	Liquid-cooled engine	Propeller driven
Low-drag airfoil sections	Straight, low wing	F-80A	Wing-root inlets	Jet propelled
Low-drag airfoil sections	Straight, low wing	YF-84A	Nose inlet	Jet propelled
Low-drag airfoil sections	Straight, low wing	D-558-1	Nose inlet	Jet propelled
Low-drag airfoil sections	Swept, low wing	F-86A	Nose inlet	Jet propelled
Low-drag airfoil sections	Swept, mid-wing	D-558-2	Flush inlets	Jet propelled
Low-drag airfoil sections	Straight, mid-wing	X-1		Rocket propelled

Figure 1 shows two-view drawings and some specifications (including h_t/c_r) of the airplanes, and figure 2 shows wing-root airfoil-section contours. More detailed particulars may be obtained from the references listed as follows:

Airplane	Reference
F8F-1	1 (airplane 2)
P-39N	2
F-51D	3
F-51H	4
F-80A	5
YF-84A	
X-1	6
D-558-1	7
D-558-2	8
F-86A	9

INSTRUMENTATION

All the airplanes tested were equipped with standard NACA photographically recording instruments for measuring airspeed, altitude, and normal acceleration as functions of time. Airspeeds were corrected for position error in all cases except for those installations where the error was considered negligible. In addition to the afore-mentioned instruments, the D-558-1, D-558-2, and X-1 airplanes were equipped with strain gages installed in the wing roots.

TEST PROCEDURE

Because the tests were performed at different times and places, the test procedures varied and are described individually.

F8F-1

Flight tests were made at Mach numbers ranging from 0.50 to the maximum practicable, and for normal accelerations ranging from those of steady flight to values corresponding to lift coefficients of about 1.10. The test altitude was 20,000 feet ±6,000 feet. Data were obtained in steady dive pull-outs, during which the pilot tried to hold constant acceleration while allowing the Mach number to vary.

P-39N

Tests were run at Mach numbers from 0.60 to 0.80 at altitudes ranging from 4,000 to 12,000 feet. Data were obtained by gradually increasing the acceleration (from values corresponding to a lift coefficient of almost zero to those for a lift coefficient of 0.80) while holding the other conditions approximately constant.

F-51D

Abrupt stalls were made at altitudes of 10,000, 20,000, and 30,000 feet, and at Mach numbers from 0.50 to 0.63 by pulling the airplane up as sharply as possible, with inertia, control power, and stability as limiting factors. Gradual stalls in turns were also made at 30,000 feet and at Mach numbers from 0.50 to 0.65, and pull-ups through the buffet boundary were made within the Mach number range from 0.64 to 0.80 until vibration of the airplane became objectionable to the pilot. The lift coefficients ranged from approximately 0.15 to 1.10.

F-51H

Test procedures for this airplane were similar to those for the F8F airplane.

F-80A

The airplane was first stabilized in steady straight runs, and then rolled into gradually tightening turns, keeping the airspeed approximately constant until the stall, or to the highest safe acceleration. This technique was used at Mach numbers below 0.78. Data for higher Mach numbers (up to 0.86) were obtained during pull-ups from shallow dives. The test altitudes varied from 20,000 to 35,000 feet, and the normal accelerations ranged from that for steady flight to that for a lift coefficient of 1.10.

YF-84A

Tests were made in steady turns at 35,000 feet at various accelerations and airspeeds, for the lower Mach number range (below 0.80), and in pull-ups at that altitude for the higher Mach numbers (from 0.80 to the maximum attained). The lift coefficients obtained varied from 0 to 0.85. The zero lift coefficients were obtained in push-over maneuvers.

X-1

Data were obtained by diving the airplane. The boundary was penetrated at various airspeeds by varying the normal acceleration in pull-ups from steady flight values to those for lift coefficients of approximately 0.90.

D-558-1

Buffet-boundary points below a Mach number of 0.81 were obtained during accelerated turns, whereas those above 0.81 were obtained during pull-ups from dives. The lift coefficients ranged from 0.10 to 0.90.

D-558-2

Data were obtained, with slats closed, in stalls and turns at altitudes varying from 10,000 to 25,000 feet. The Mach number was varied from 0.60 to 0.90, and the lift coefficient ranged from 0.10 to 0.90.

F-86A

Below a Mach number of 0.92, data were obtained in pull-ups from level flight at an altitude of approximately 35,000 feet. In the higher Mach number range (above 0.92), the airplane was dived to attain the desired speed, then pulled up through the buffet boundary at about the same altitude. Lift coefficients varied from approximately 0 to 1.20. The zero lift coefficients were obtained in push-over maneuvers similar to those performed with the YF-84A airplane.

DETERMINATION OF BUFFET BOUNDARIES

For the purposes of this report, buffeting was considered to be first encountered by an airplane when the acceleration oscillations at the center of gravity underwent a noticeable increase in amplitude from that normally encountered. A typical time-history recording of such acceleration changes is shown in figure 3.

The point at which an airplane can be said to start buffeting will be determined by the least noticeable increase in the width of the recorded accelerometer line. It has been found from experience that the least change in line width that can be detected consistently is approximately ±0.005 inch. (An error of as much as 25 percent in the determination of this change in line width would cause but a negligible change in the buffet boundary.) Changes in acceleration as low as ±0.03g were determined from records from typical NACA recording accelerometers of the type used to obtain most of the data presented herein. Buffet boundaries thus determined define the lowest limit at which an unsteadiness in the lift force occurs and do not necessarily indicate operational limits of the aircraft.

Since there has been some question as to the difference between pilots' opinions of beginning of buffet, and the boundary indicated by instruments, the pilot of the F8F-1 airplane was supplied with a means of marking the photographic records at will, and was requested to indicate the point at which he considered buffeting to start. A comparison of points thus selected and those indicated by the accelerometer is presented in figure 4. For this particular combination of pilot and airplane, the two buffet boundaries are almost identical. Similar results have been noted with the F-86A and D-558-2 airplanes (reference 8). It has been shown that the minimum normal acceleration detectable by a pilot is approximately ±0.04g (reference 10), which is comparable to the minimum normal acceleration detectable on the NACA accelerometer records, so it might be expected that the agreement should be good except for a slight time lag in the pilot's reactions.

The airplane lift coefficients and Mach numbers corresponding to the beginning of buffet, as defined above, were considered to define the buffet boundary. These lift coefficients were calculated from the equation

$$C_L = \frac{WA_Z}{qS}$$

It is seen from the equation that the lift was assumed equal to the normal force, WA_Z. Although this is not rigorous, since the lift is a function of the normal and longitudinal accelerations as well as the angle of attack of the airplane, it was determined that the maximum deviation was only of the order of 5 percent. It was realized that the total airplane lift thus determined included those portions contributed by the propeller, fuselage, and tail; however, this total airplane lift was used as a reasonable approximation of the wing lift for the purpose of comparing the buffet boundaries with the various buffeting criteria.

The buffet boundary of the F-51D, determined in a similar manner, was obtained from reference 3. The boundaries for the D-558-1, X-1, and D-558-2 airplanes were obtained from reference 8. Time-history recordings of load fluctuations, as indicated by strain gages mounted on the wing roots, were used in addition to accelerometer records to indicate points of incipient buffeting for the latter three airplanes. (Boundary points obtained from the two records coincided.)

TEST RESULTS

In figure 5, experimentally obtained points of incipient buffeting are presented in terms of lift coefficient as a function of Mach number, for the eight airplanes for which these points were available. Also shown are the buffet boundaries which have been faired through these points. It should be noted that there is considerable scatter in the test points (the amount varying from airplane to airplane), which perhaps is due to other variables, such as rate of change of Mach number, pitching velocity, minute changes in wing surface, etc. These effects may be such as to alter the lift coefficients at which buffeting begins, so that the scatter shown may not necessarily be due to experimental inaccuracies. This fact should be borne in mind when the buffet boundaries are compared with the various computed criteria in the comparisons section of this report.

The buffet boundary of the YF-84A (fig. 5(f)) shows a rapid change in slope at low lift coefficients. Whether or not this indicates that the buffet boundary for this airplane does not extend to zero lift coefficient is not known; however, no apparent buffeting was obtained at zero lift coefficient for Mach numbers as high as 0.84.

The dashed portion of the F-86A buffet boundary (fig. 5(h)) should be noted. This is an extension where boundary points were not obtained but definite buffeting points were determined beyond the boundary at a lift coefficient as low as 0.081, above a Mach number of 0.97.

Also shown in figure 5 are the limits of penetration beyond the buffet boundaries obtained during the course of the flight tests. The penetrations were not normally limited by buffeting intensities since the tests were not conducted for the purpose of exploring the maximum tolerable buffeting. However, the conditions for which elevator structural failure imposed an upper limit on the lift coefficient attainable are noted in two of the figures.

DETERMINATION OF BUFFETING CRITERIA

The selection and application of the buffeting criteria discussed herein were based on several simplifying assumptions. The basic assumption made was that the source of the buffeting was some characteristic of the airfoil. Thus all the criteria considered are more or less based on airfoil-section characteristics that might promote this buffeting. Another assumption was that the initial buffeting occurred at the wing-fuselage junction, so that on a wing with varying profile from root to tip, only the root profile was considered. The root-section lift coefficient was assumed to be equal to the total airplane normal-force coefficient. This assumption was justified in part by the fact that the theoretical span loading distribution (reference 11) for all the straight wings was such that the root section lift coefficient varied by no more than 6 percent from the average lift coefficient over the span. For the criteria which are based directly on angle of attack (M_β and M_δ), the lift-curve slope was estimated by use of the aspect-ratio correction described below. Further possible refinements such as the effect of the induced velocity of the fuselage, or the increment of velocity in the slipstream, were not considered.

The foregoing applies to the use of the several criteria on the straight-wing airplanes. Application of the criteria to the swept-wing airplanes is discussed in the comparisons section of this report. The sources of the data used (references 12 to 20) are noted in table I. For those cases where data were not available for the exact airfoil sections, the closest sections for which data were available are indicated.

Critical Mach number.- Since the critical Mach number (M_{cr}) represents the speed at which sonic velocity is first reached on an airfoil, it should be expected to be only an approximate measure of the onset of buffeting. Parenthetically, it may be noted that there is a break in the critical Mach number curve as it is usually presented, which is due to the fact that there are two regions on the airfoil section where sonic velocity can be reached - near the nose and over the mid-portion of the chord.

The variation of critical Mach number of an airfoil with lift coefficient is fairly readily calculable without the aid of wind-tunnel data (reference 12). This procedure is useful on occasion when sufficient data are not available for use of more accurate methods of defining conditions of flow change.

Mach number of sonic flow at crest.- A somewhat more refined indication of flow conditions over the airfoil may be the Mach number at which sonic velocity is first reached at the crest of the airfoil (herein called M_β). As shown in reference 13, there is a correlation between this criterion and the Mach number of drag divergence, a phenomenon which may also be associated with the imminence of buffeting.

This criterion also can be used without recourse to wind-tunnel data. Its application requires an estimate of not only the pressure distribution, but also the angle of attack, since the crest of the airfoil is defined as the point where the upper surface is tangent to the free-stream direction. In the evaluation of M_β for this report, the angle of attack for an arbitrary crest point was first determined. Then the low-speed lift-curve slope was estimated from reference 21, taking into account the aspect ratio. With those two quantities, the low-speed lift coefficient was obtained, which in turn, allowed the determination of the theoretical pressure coefficient at the crest. As is shown in reference 13, the value of M_β can then be determined directly from the low-speed pressure coefficient. A new lift-curve slope was found using the aspect ratio corrected for compressibility effects, and a second Mach number was calculated. Since these successive approximations showed rapid convergence, only two were made. Finally, the low-speed lift coefficient was corrected by the Prandtl-Glauert factor.

Lift-divergence Mach number.- It is normal for the lift coefficient at a constant angle of attack to increase with Mach number at a progressively greater rate until an inflection point is reached at a Mach number somewhat higher than M_{cr}, and then to increase at a progressively decreasing rate until a peak is reached. This inflection point on the curve is defined (reference 14) as the Mach number of lift-divergence and is referred to herein as M_b. Since this is the point at which the lift characteristics of an airfoil began to change, this lift-divergence Mach number may serve as a useful buffeting criterion.

Lift-peak Mach number.- It may be reasoned that the buffeting of an airplane will be of minor magnitude until drastic flow changes have occurred. Such a condition will be defined by the peak of the lift curves previously mentioned and the Mach number of this point will be referred to as M_p. The same wind-tunnel data may be used to evaluate the lift-peak buffeting criterion as that used for the lift-divergence criterion.

Empirical buffeting criterion.- The last criterion for the determination of the buffet boundary, compared with flight data herein, is that obtained by the method suggested in reference 15. In the reference, it is shown that the pressure distributions over the aft 30 percent of a number of airfoils are almost constant up to a particular Mach number, and then deviate widely with increasing Mach number. Since this deviation with increasing Mach number is due to the adverse pressure gradient which is a partial function of the slope of the aft portion of the airfoil, it was reasoned that the Mach number at which buffeting begins should be a function of the slope of the aft portion of the airfoil. An empirical relation was found, for a number of airplanes, between the Mach number of incipient buffeting and the angle δ between the line of flight and a line drawn between the trailing edge and the 70-percent-chord point of the upper surface.

The criterion (referred to as M_δ) was evaluated by determining the angle δ, for various airplane angles of attack, and using it in conjunction with the empirical curve of reference 15 to establish the Mach number at which buffeting starts. The corresponding lift coefficient was found by estimating the lift-curve slope (using reference 21),[1] multiplying it by the angle of attack, and correcting the resulting low-speed lift coefficient by the Prandtl-Glauert factor.

COMPARISONS OF BUFFET BOUNDARIES WITH CRITERIA

The flight-determined buffet boundaries as defined by the faired curves of figure 5 are presented with the various buffeting criteria in figure 6 for the eight straight-wing airplanes,[2] and in figure 7 for the two swept-wing airplanes. The M_b and M_p criteria have been omitted from figures 6(c) and 6(f) for the F-51D and YF-84A airplanes because insufficient wind-tunnel data were available to permit their evaluation. (See table I.)

Straight-Wing Airplanes

A comparison of the buffet boundaries with the buffeting criteria for the straight-wing airplanes (fig. 6) discloses the outstanding characteristic of the general conformity of the trend of the buffet boundaries with that of the criteria for all the airplanes except the F-51H. This observation trends to confirm the validity of the initial assumption that some characteristic of the wing was the primary cause of the buffeting, but does not obviate the possibility that the tail surfaces may be contributing to the buffeting. Further confirmation of this assumption may be obtained by a comparison of the buffet boundaries of the X-1 and D-558-1 airplanes (figs. 6(g) and 6(h)) which shows that they are almost identical for these two airplanes having identical wing sections.

---

[1]The airplane effective aspect ratio was also adjusted for compressibility as suggested in this reference.

[2]The buffet boundaries and criteria for the two airplanes for which boundary points were not available, and which were therefore not shown in figure 5, are presented in figure 6.

The buffet boundary of the F-51H airplane (fig. 6(d)) differs from that of the other straight-wing airplanes in that it lacks the general parallelism with, and intersects, all the buffeting criteria. This implies that the initial buffeting was caused by something other than the wing. As a consequence, the F-51H airplane is not considered in the subsequent discussion of straight-wing airplanes.

The Mach number differences between the buffet boundaries of the straight-wing aircraft and the various criteria have been plotted as a function of lift coefficient in figure 8. This figure indicates, as anticipated, that the M_{cr} criterion[3] is not only the most conservative, but bears the least consistent relation to the buffet boundaries. The closer approximation attained by use of the crest-line criterion is evident in figure 8(b). The Mach number differences for this criterion vary from +0.11 to +0.03.

One of the most consistent relationships to the buffet boundaries is that of the lift-divergence criterion, M_b. It is conservative for every case evaluated, by a ΔM_b variation from +0.09 to +0.02.[4] The lift-peak criterion M_p has a somewhat greater spread in ΔM_p (+0.07 to -0.02). The M_δ criterion shows the least difference, on the average, between it and the buffet boundaries, but ΔM_δ varies from +0.03 to -0.14.

From the foregoing results it appears that a reasonably close estimate of the buffet boundary for straight-wing airplanes may be obtained if it is assumed that the boundary will have the following relations to the buffeting criteria:

Criterion	$\overline{\Delta M}$	Maximum deviation from $\overline{\Delta M}$
M_{cr}	+0.09	+0.10 -0.08
M_β	+0.06	+0.05 -0.03
M_b	+0.06	+0.03 -0.04
M_p	+0.02	+0.05 -0.04
M_δ	0.00	+0.03 -0.14

[3]It should be noted that the curves of figure 8(a) were obtained by utilizing only those parts of the critical Mach number curves (or their extensions) derived from the pressure distributions over the central portion of the upper surface of the airfoil.

[4]This criterion was evaluated for only five of the straight-wing airplanes due to the limited test data available. (Continued on p. 13)

The evaluation of a buffeting criterion for a swept-wing airplane may be carried out by two methods. For one method the free-stream velocity would be used in conjunction with the section characteristics of the streamwise airfoil section. For the other, the velocity component normal to the swept reference line would be used in conjunction with the airfoil data for the section normal to that line. The free-stream Mach numbers and airplane lift coefficients for the latter case should then be determined by dividing the normal Mach numbers by the cosine of the sweep angle and multiplying the lift coefficients by the square of the cosine of the sweep angle, as indicated by simple swept-wing flow theory.

Since the buffet boundaries of only two swept-wing airplanes were available and any generalizations drawn from comparisons with the buffeting criteria could not be considered conclusive, only the M_b criterion has been presented for these airplanes. The M_b criterion was chosen because it afforded one of the most consistent predictions of the buffet boundaries for the straight-wing airplanes.

With figure 7, comparisons may be made between the buffet boundaries and the M_b criterion, as evaluated by the two methods mentioned previously, for the two swept-wing airplanes. A comparison of the buffet boundaries for the D-558-2 and F-86A airplanes indicates that an anomaly apparently exists. The boundary for the thicker wing airplane (F-86A) occurs at approximately 0.07 higher Mach number on the average than that for the thinner wing airplane (D-558-2). Whether or not this is due to buffeting originating on some portion of the D-558-2 airplane other than the wing is not known; however, reference 8 mentions that the trailing edge of the slats when locked closed deflect upward in flight which may be a contributing factor. As a consequence, only the M_b criterion has been evaluated and no conclusions have been drawn relative to the prediction accuracy of the criterion for swept-wing airplanes by either of the methods of calculation.

CONCLUDING REMARKS

From the comparisons of the five buffeting criteria with the flight-determined buffet boundaries of seven straight-wing airplanes, it is apparent that a reasonable estimate of the buffet boundary of a straight-wing airplane may be obtained from the criteria discussed herein.

---

[4](Concluded.) If the M_β criterion (fig. 8(b)) is reconsidered for those same airplanes used for the M_b criterion (fig. 8(c)), ΔM_β varies from only +0.04 to +0.10. Moreover, the remaining curves show approximately the same degree of parallelism with the buffet boundaries as do those for the M_b criterion. As a consequence it is difficult to recommend one more highly than the other.

The M_β and M_b criteria afforded the most consistent predictions. The choice of one or the other would depend upon the test data available. If wind-tunnel data for the particular airfoil section (or a reasonably similar section) were available, the use of the M_b criterion would permit the quickest and easiest prediction of the buffet boundary. If no test data were available, the boundary could be calculated by the use of the M_β criterion.

Ames Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Moffett Field, Calif.

REFERENCES

1. White, Maurice D., Sadoff, Melvin, Clousing, Lawrence A., and Cooper, George E.: A Flight Investigation of the Effect of Flap Deflection on High-Speed Longitudinal-Control Characteristics. NACA RM A9D08, 1949.

2. Clousing, Lawrence A., Turner, William N., and Rolls, L. Stewart: Measurements in Flight of the Pressure Distribution on the Right Wing of a P-39N-1 Airplane at Several Values of Mach Number. NACA TR 859, 1946.

3. Mayer, John P.: Effect of Mach Number on the Maximum Lift and Buffeting Boundary Determined in Flight on a North American P-51D Airplane. NACA RM L6I10, 1947.

4. Gadeberg, Burnett L.: The Effect of Rate of Change of Angle of Attack on the Maximum Lift Coefficient of a Pursuit Airplane. NACA RM A8I30, 1949.

5. Kidder, R. C.: Dynamic Longitudinal Stability Flight Tests of an F-80A Airplane by the Forced Oscillation and Step Function Response Methods Including Measured Horizontal Tail Loads. USAF Tech. Rept. 5995, Wright-Patterson Air Force Base, Dayton, Ohio, May 1950.

6. Williams, Walter C., Forsyth, Charles M., and Brown, Beverly P.: General Handling-Qualities Results Obtained During Acceptance Flight Tests of the Bell XS-1 Airplane. NACA RM L8A09, 1948.

7. Williams, Walter C.: Limited Measurements of Static Longitudinal Stability in Flight of Douglas D-558-1 Airplane (BuAero No. 37971). NACA RM L8E14, 1948.

8. Mayer, John P., and Valentine, George M.: Flight Measurements With the Douglas D-558-II (BuAero No. 37974) Research Airplane Measurements of the Buffet Boundary and Peak Airplane Normal-Force Coefficients at Mach Numbers up to 0.90. NACA RM L50E31, 1950.

9. Thompson, Jim Rogers, Bray, Richard S., and Cooper, George E.: Flight Calibration of Four Airspeed Systems on a Swept-Wing Airplane at Mach Numbers up to 1.04 by the NACA Radar-Theodolite Method. NACA RM A50H24, 1950.

10. Anderson, Seth B.: Correlation of Pilot Opinion of Stall Warning With Flight Measurements of Various Factors Which Produce the Warning. NACA TN 1868, 1949.

11. Glauert, H.: The Elements of Aerofoil and Airscrew Theory. Cambridge University Press, 1943, p. 155.

12. Abbott, Ira H., von Doenhoff, Albert E., and Stivers, Louis S., Jr.: Summary of Airfoil Data. NACA Rep. 824, 1945.

13. Nitzberg, Gerald E., Crandall, Stewart M., and Polentz, Perry P.: A Preliminary Investigation of the Usefulness of Camber in Obtaining Favorable Airfoil-Section Drag Characteristics at Supercritical Speeds. NACA RM A9G20, 1949.

14. Graham, Donald J., Nitzberg, Gerald E., and Olson, Robert N.: A Systematic Investigation of Pressure Distributions at High Speeds Over Five Representative NACA Low-Drag and Conventional Airfoil Sections. NACA Rep. 832, 1945.

15. Outman, Vernon, and Lambert, Arthur A.: Transonic Separation. Jour. Aero, Sci., vol. 15, no. 11, November 1948, pp. 671-674.

16. Allen, H. Julian: General Theory of Airfoil Sections Having Arbitrary Shape or Pressure Distribution. NACA Rep. 833, 1945.

17. Ganzer, Victor M.: High-Speed Two-Dimensional Wind-Tunnel Tests of a Series of Related Airfoils. Boeing Aircraft Co. Document No. D-7052, 1945.

18. Berggren, Robert E., and Graham, Donald J.: Effects of Leading-Edge Radius and Maximum Thickness-Chord Ratio on the Variation with Mach Number of the Aerodynamic Characteristics of Several Thin NACA Airfoil Sections. NACA A50D04, 1950.

19. Ferri, Antonio: Completed Tabulation in the United States of Tests of 24 Airfoils at High Mach Numbers. NACA ACR L5E21, 1945.

20. Summers, James L., and Graham, Donald J.: Effects of Systematic Changes of Trailing-Edge Angle and Leading-Edge Radius on the Variation with Mach Number of the Aerodynamic Characteristics of a 10-Percent-Chord Thick NACA Airfoil Section. NACA RM A9G18, 1949.

21. DeYoung, John, and Harper, Charles W.: Theoretical Symmetric Span Loading at Subsonic Speeds for Wings Having Arbitrary Plan Form. NACA Rep. 921, 1948.

TABLE I.- SOURCES OF DATA

Airplane	Wing Root Airfoil Section	Figure Number	Buffet Boundary (Flight)	M_{cr}	M_β	M_b	M_p	M_δ
F8F-1	23018	6(a)	a	12	13c	14 (23015)	14 (23015)	15c
P-39N	0015	6(b)	a	14	13c	14	14	15c
F-51D	NAA-NACA	6(c)	3	12b,c	13b,c	d	d	15c
F-51H	66,2-(1.8)(15.5) a=0.6	6(d)	a	14 (66,2-215 a=0.6)	13c	14 (66,2-215 a=0.6)	14 (66,2-215 a=0.6)	15c
F-80A	65_1-213 a=0.5	6(e)	a	12c	13c	a	a	15c
YF-84A	R-4 45-1512-9	6(f)	a	13c (66,1-112)	13c (66,1-112)	d	d	15c
X-1	65_1-110	6(g)	8	12c	13c	17 (65,1-010)	17 (65,1-010)	15c
D-558-1	65_1-110	6(h)	8	12c	13c	17 (65,1-010)	17 (65,1-010)	15c
D-558-2 (Normal section)	63-010	7(a)	8	--	--	17 (63,1-010)	--	--
D-558-2 (Streamwise section)	63-008 (Approx.)	7(b)	8	--	--	18 (0008-64)	--	--
F-86A (Normal section)	0012-64 Modified	7(c)	a	--	--	19	--	--
F-86A (Streamwise section)	0010-64 (Approx.)	7(d)	a	--	--	20	--	--

NOTE: Numbers in body of table indicate references from which data have been obtained, except those in parentheses which designate the closest airfoil sections for which data were available.

(a) Previously unpublished data obtained at the Ames Aeronautical Laboratory.
(b) Theoretical pressure distributions calculated by method of reference 16.
(c) Calculated by method described in text of this report, using reference listed.
(d) Data available were insufficient to evaluate this criterion.

NACA

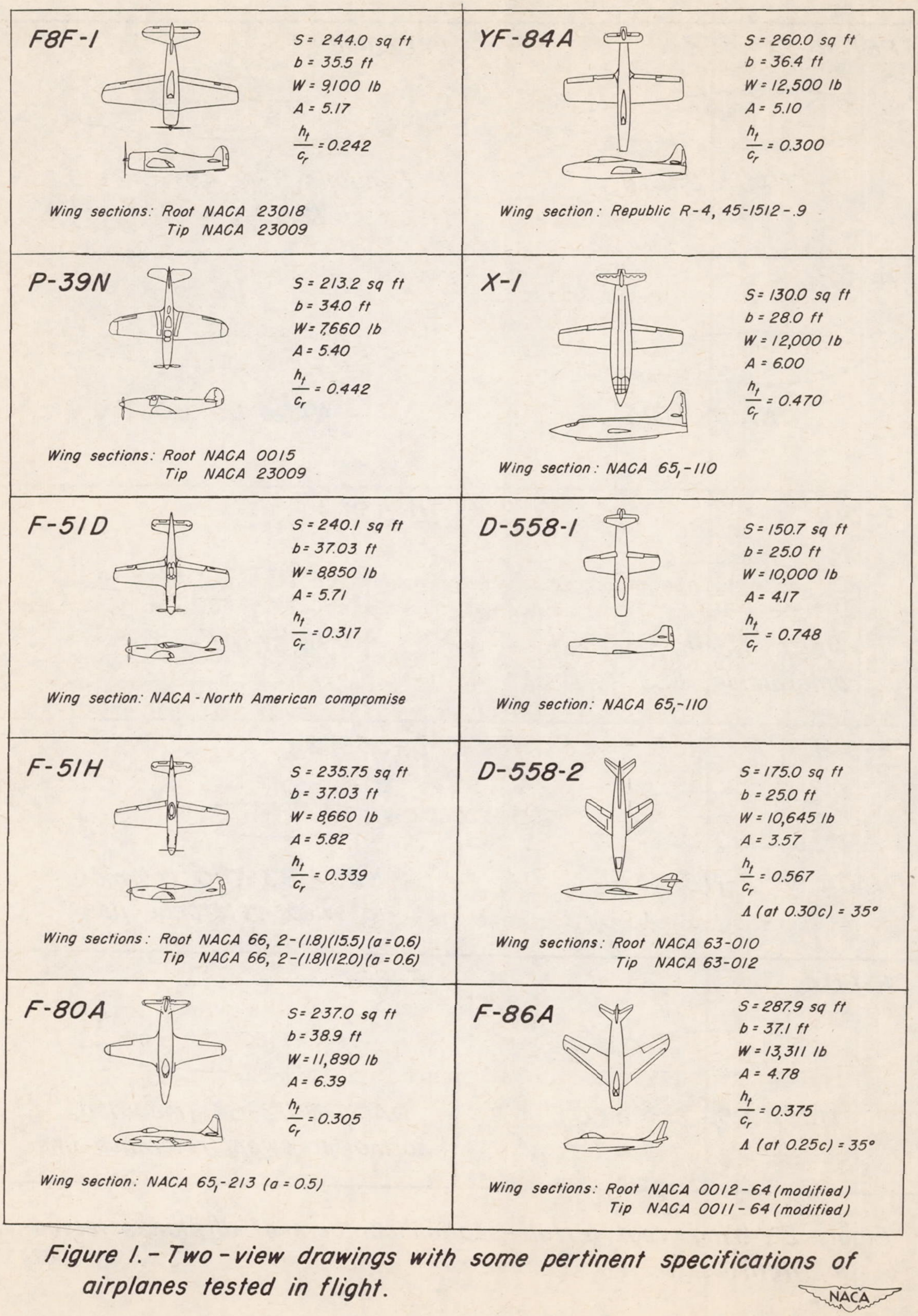


Figure 1.- Two-view drawings with some pertinent specifications of airplanes tested in flight.

NACA

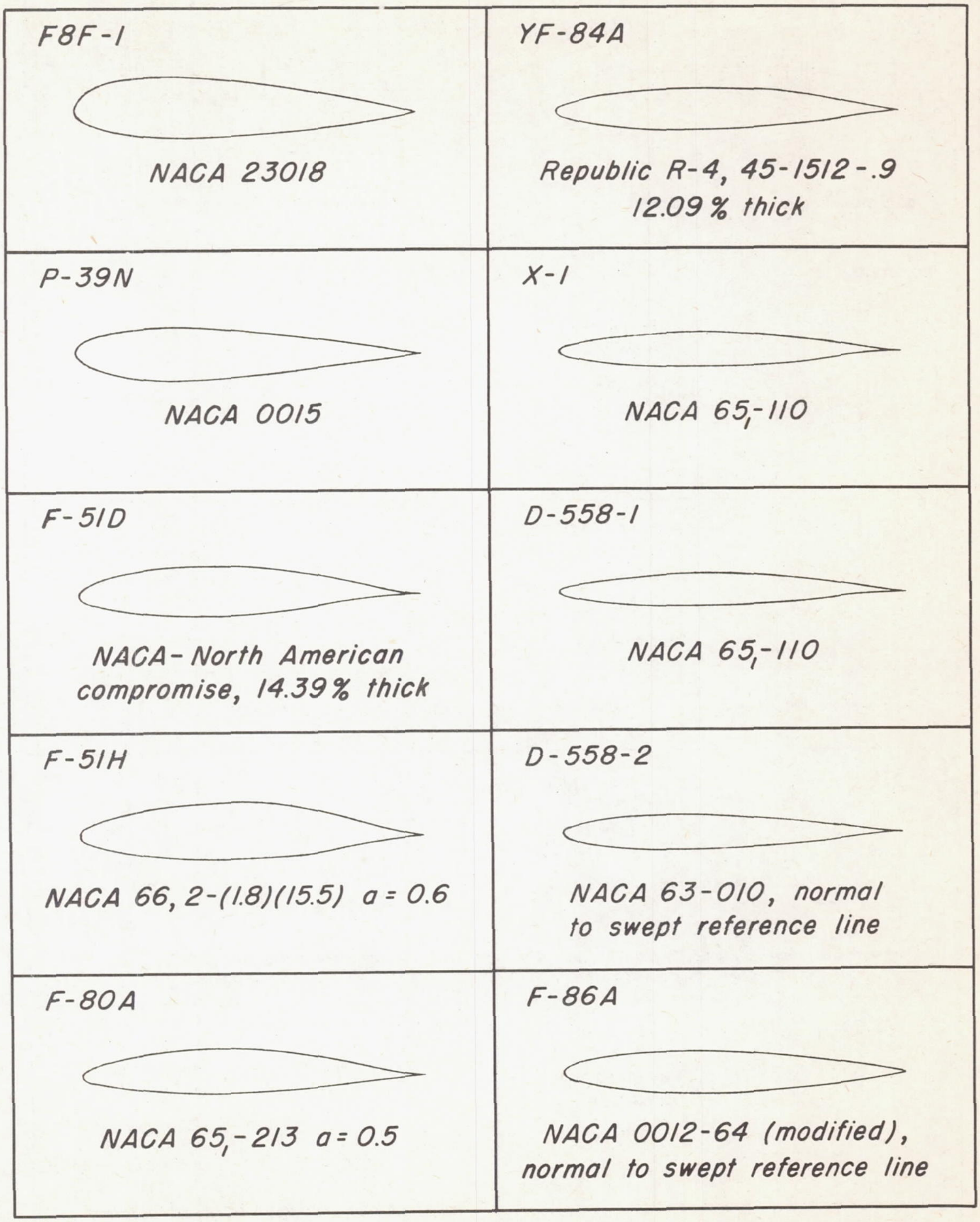


Figure 2.- Wing-root airfoil-section contours of airplanes tested in flight.

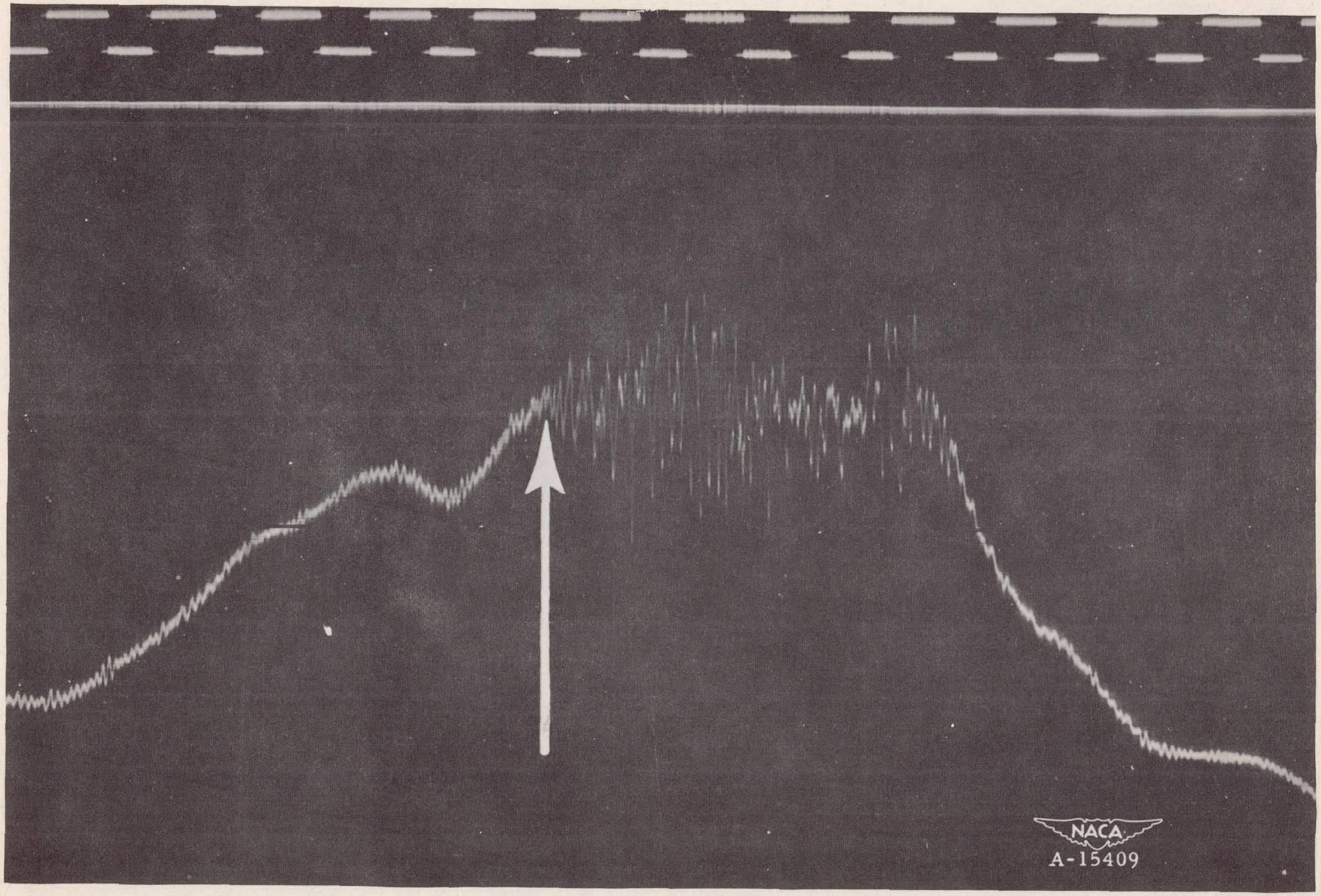


Figure 3.- Typical time history of normal acceleration at the center of gravity (arrow shows point of incipient buffeting).

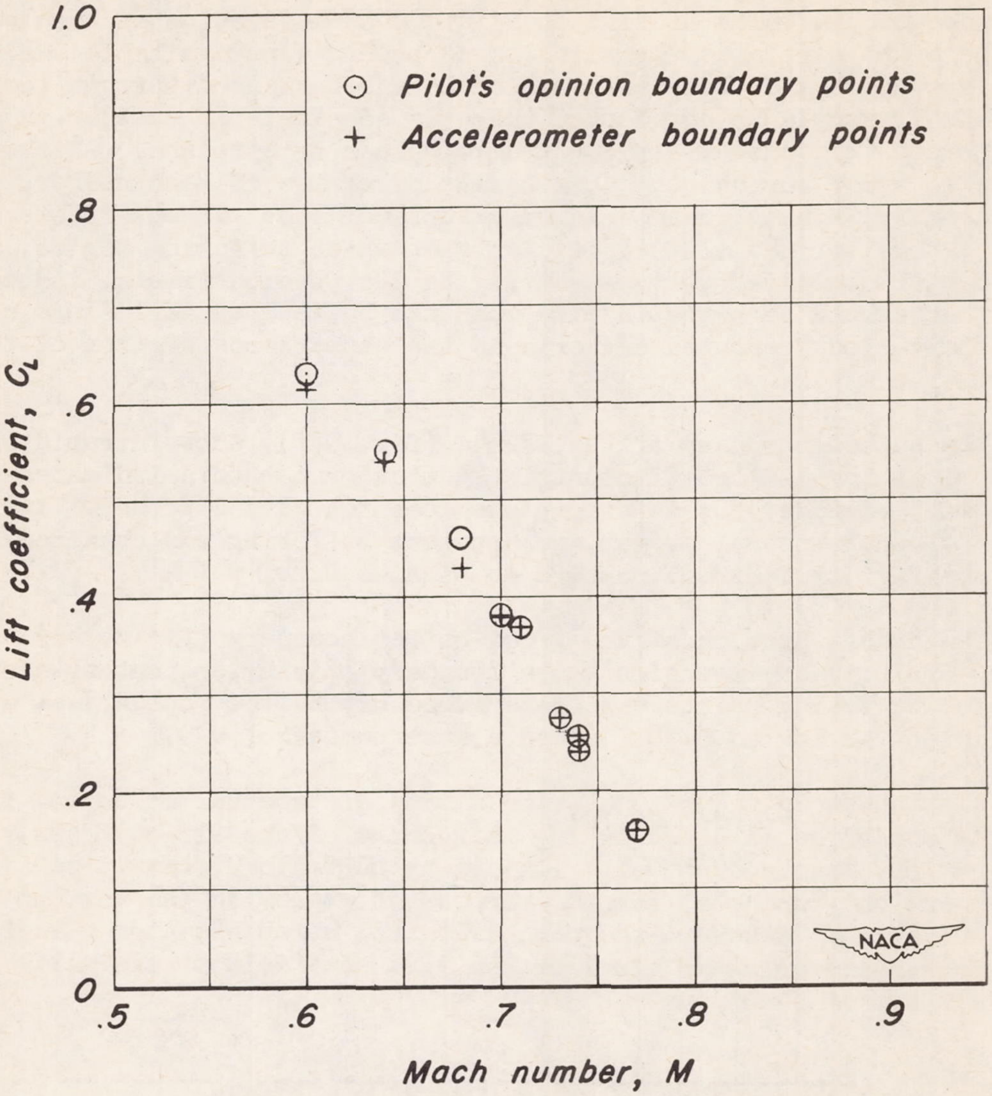
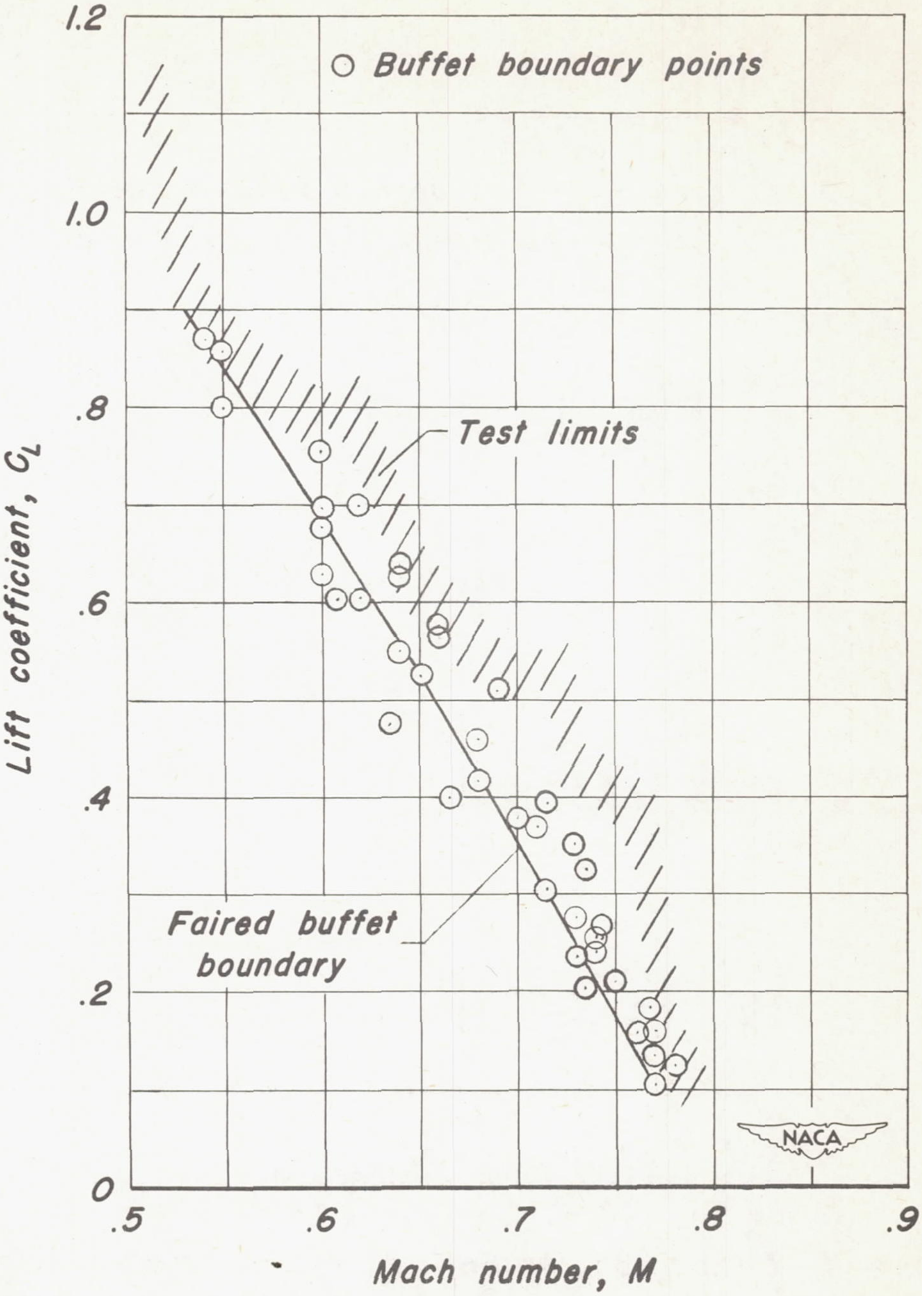
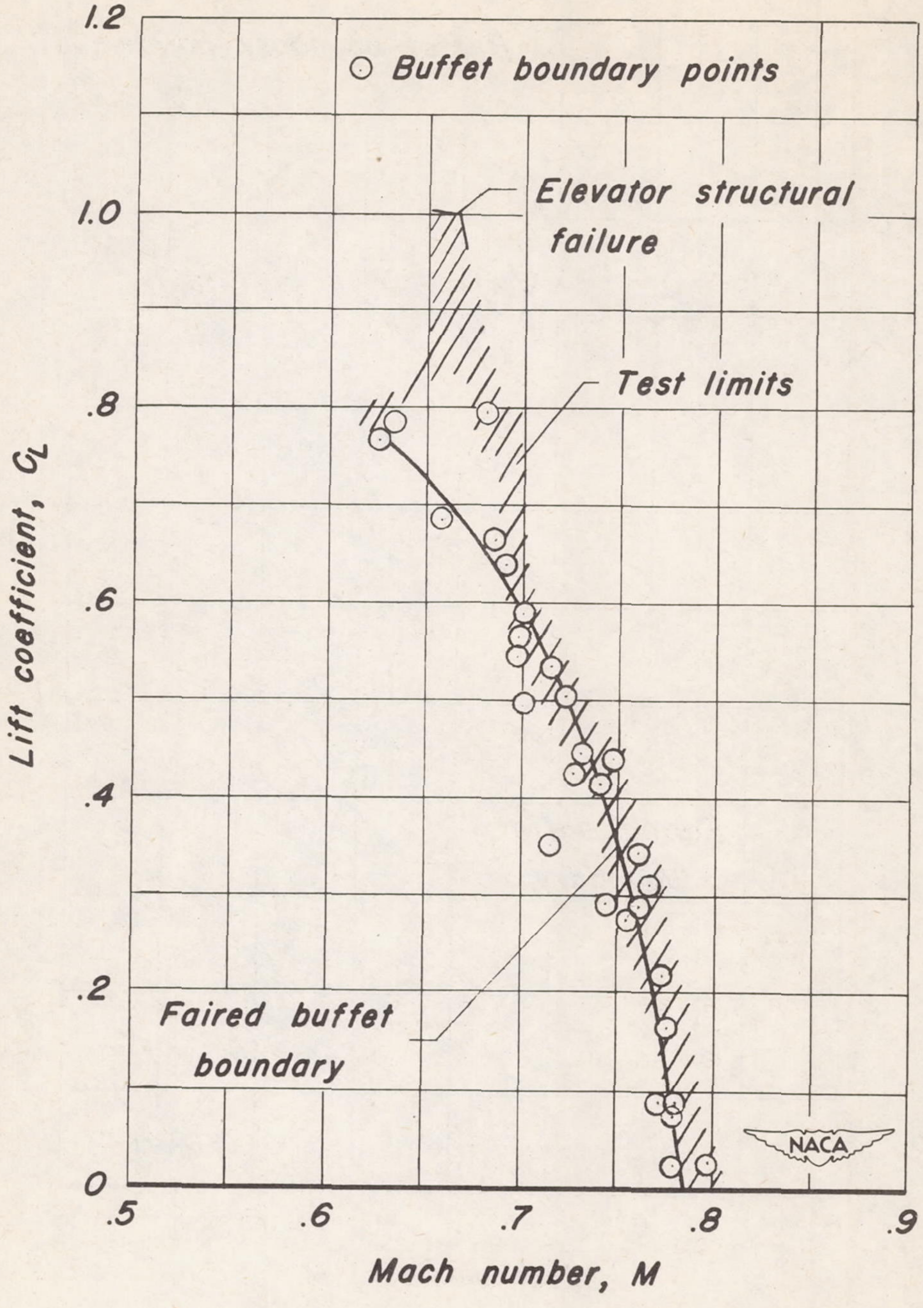


Figure 4.- Comparison for F8F-1 airplane between buffet boundary points determined from accelerometer record and those indicated by pilot.



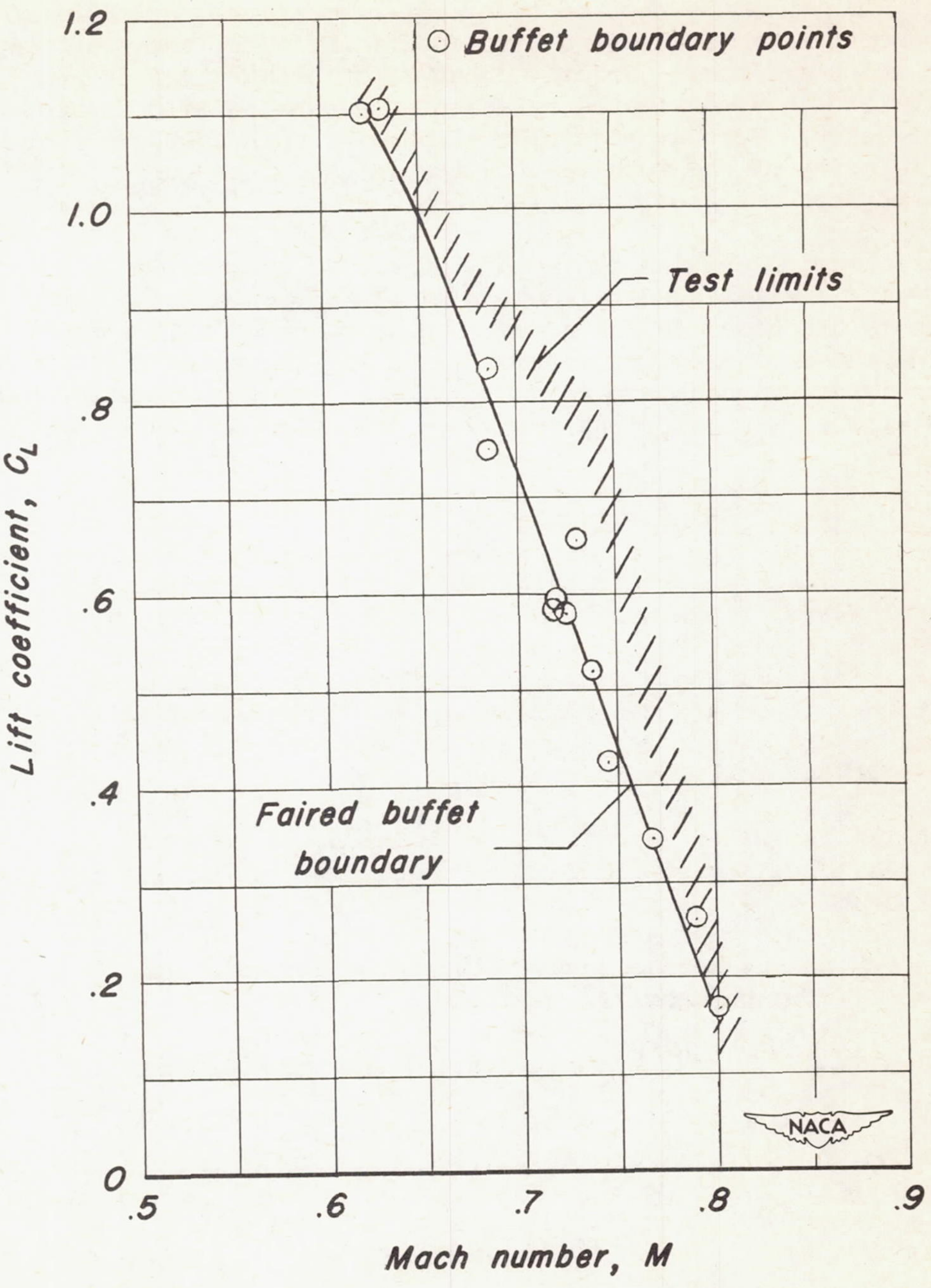
(a) F8F-1 airplane.

Figure 5.– Buffet boundary points, faired buffet boundaries, and penetration limits.



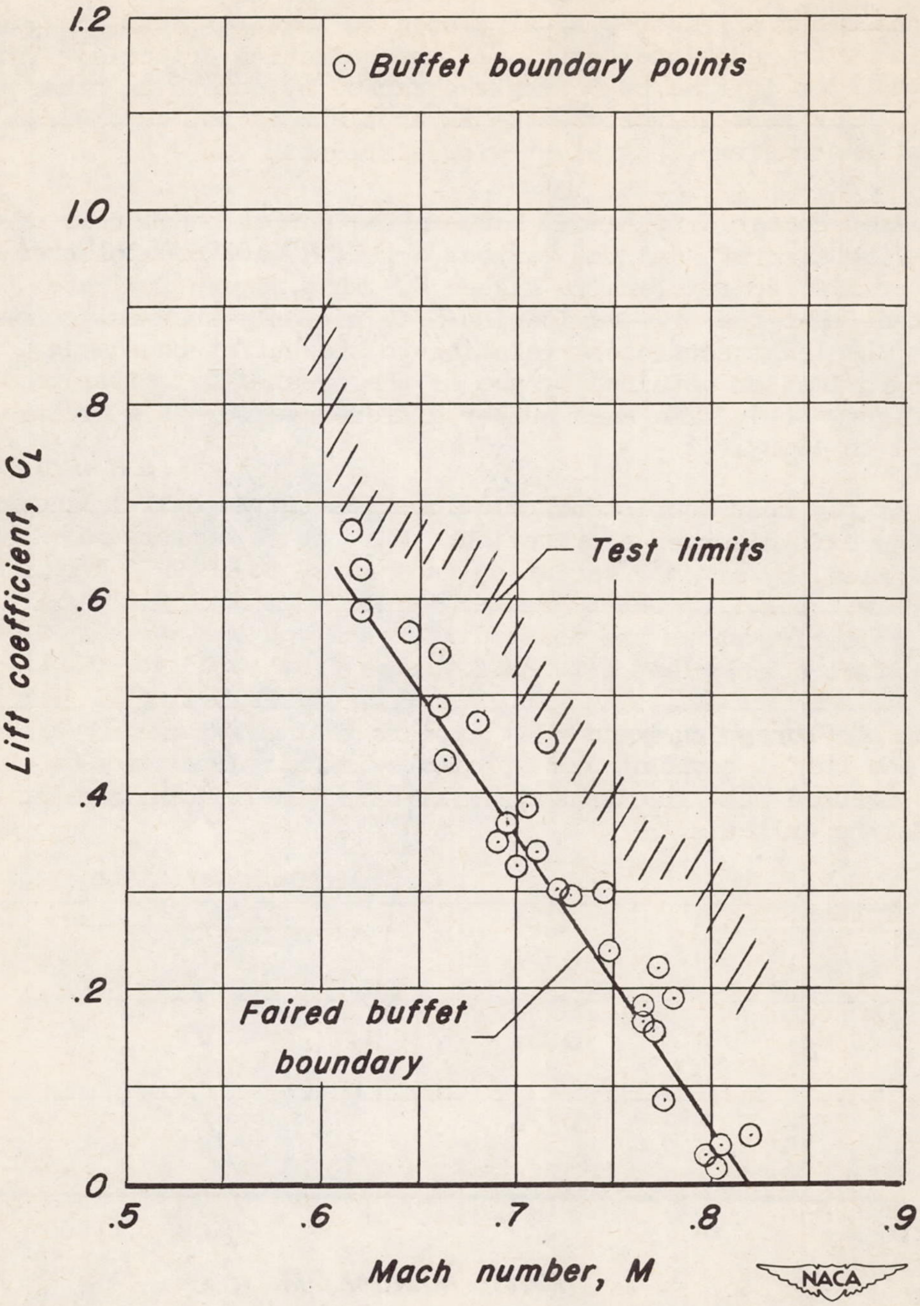
(b) P-39N airplane.

Figure 5.- Continued.



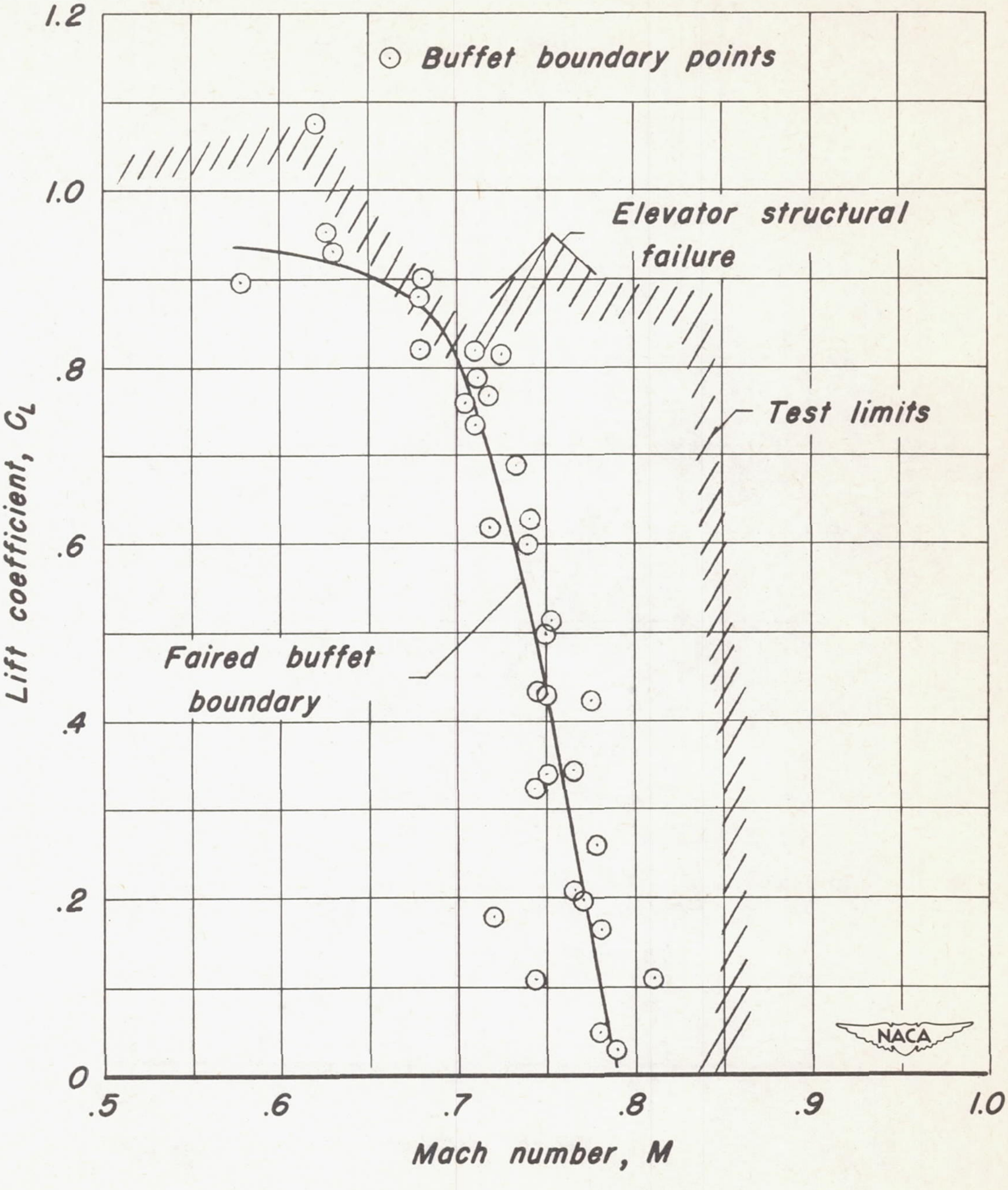
(c) F-51D airplane.

Figure 5.- Continued.



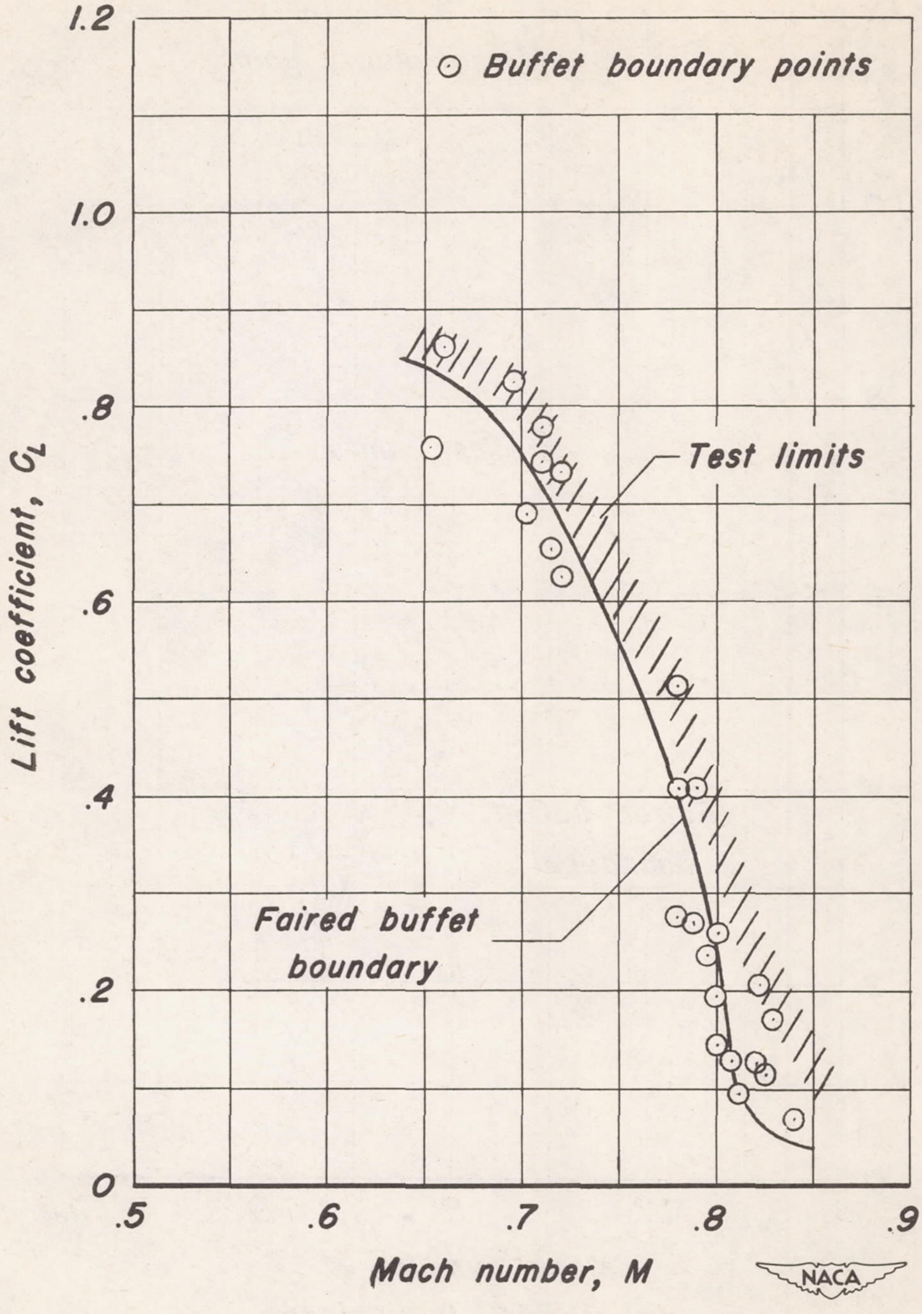
(d) F-51H airplane.

Figure 5.– Continued.



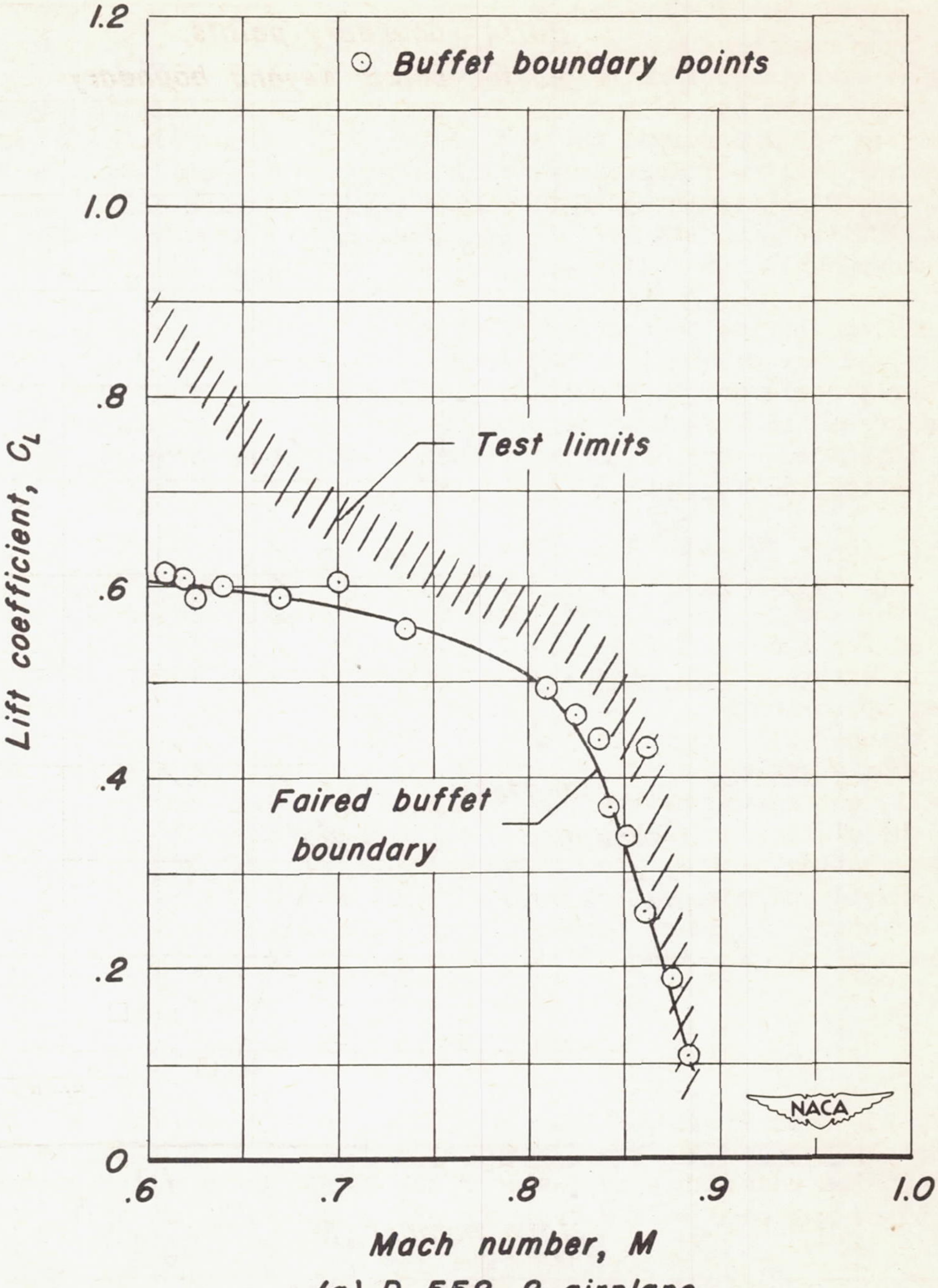
(e) F-80A airplane

Figure 5.- Continued.



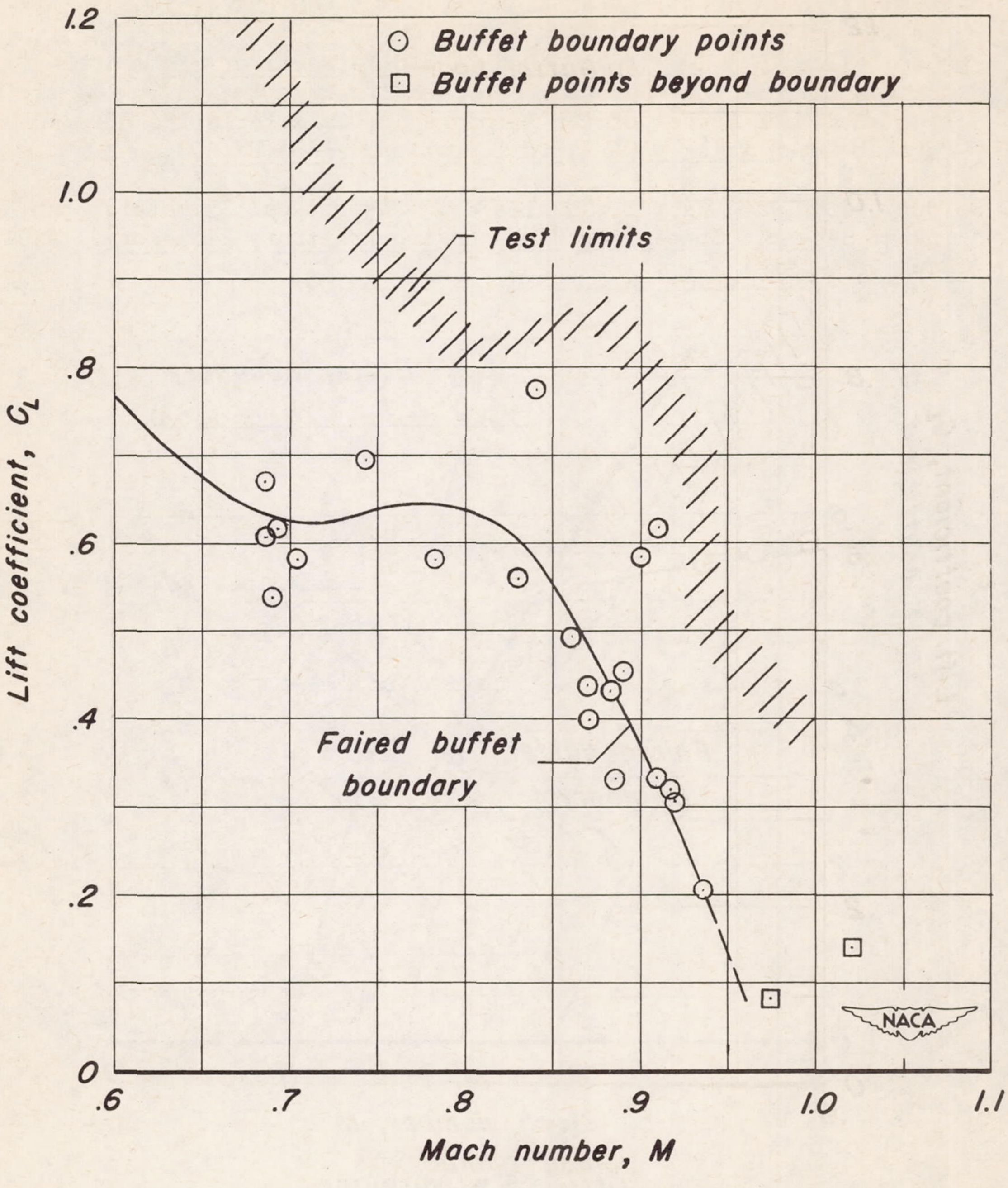
(f) YF-84A airplane.

Figure 5.- Continued.



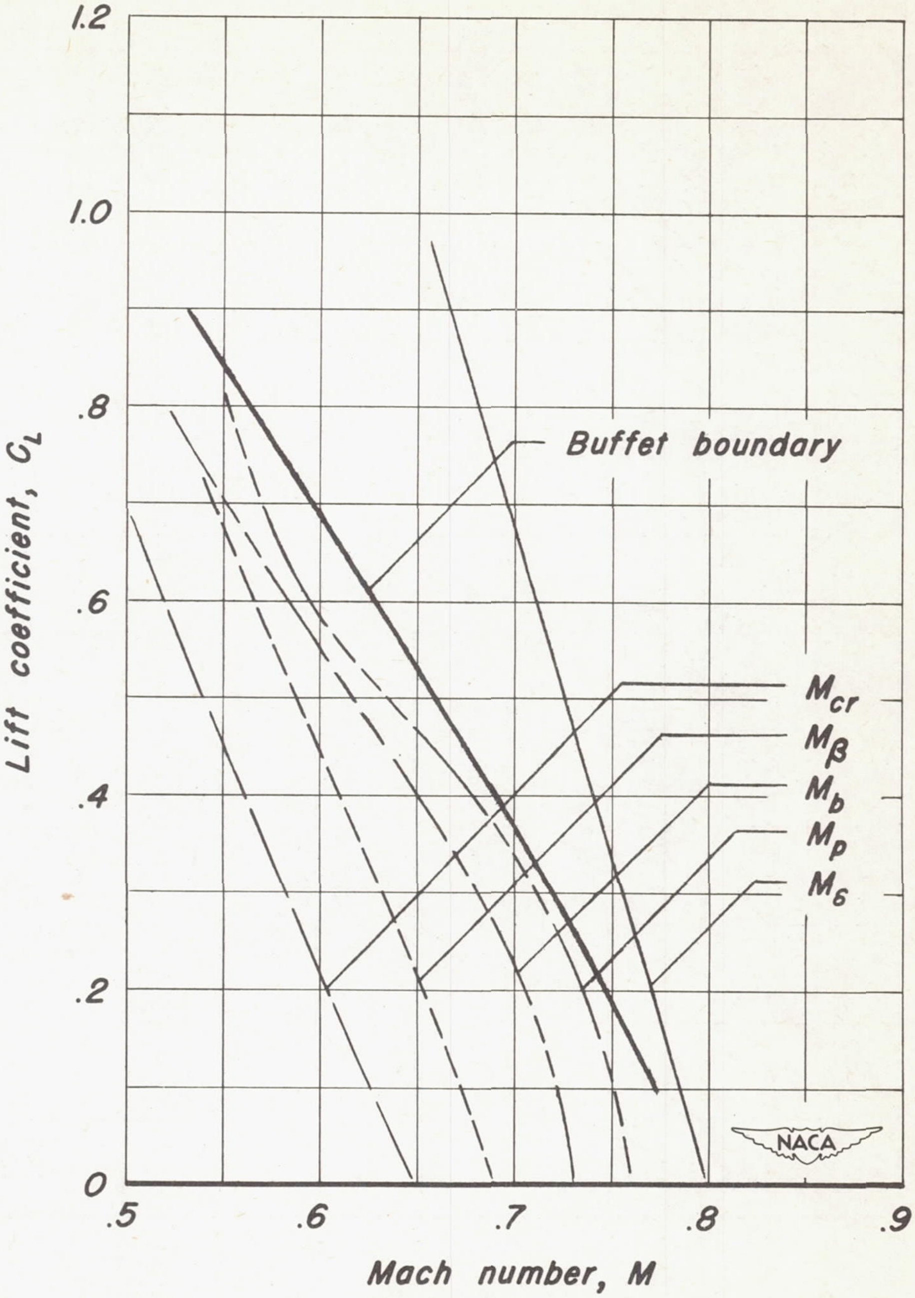
(g) D-558-2 airplane.

Figure 5.- Continued.



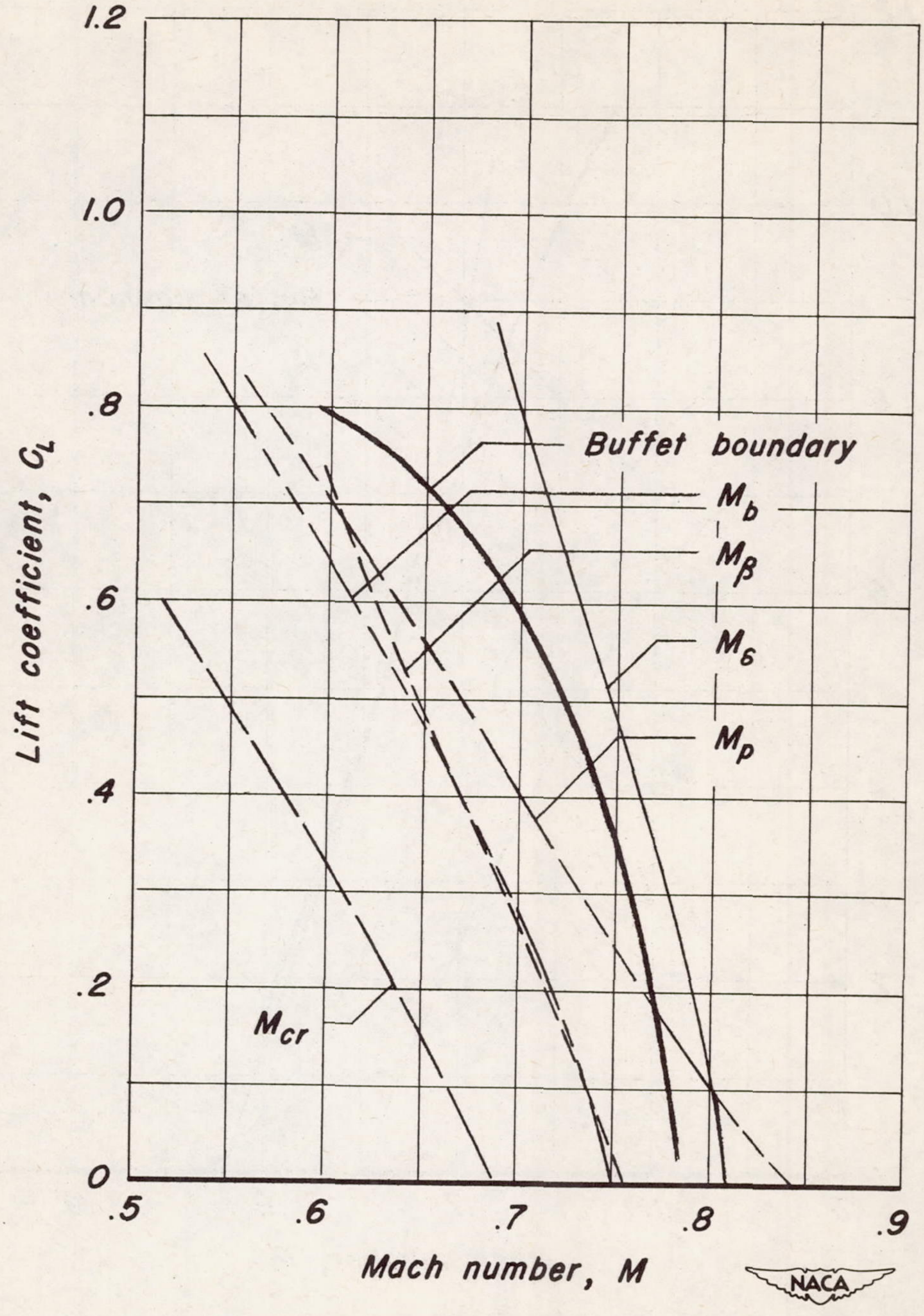
(h) F-86A airplane.

Figure 5.- Concluded.



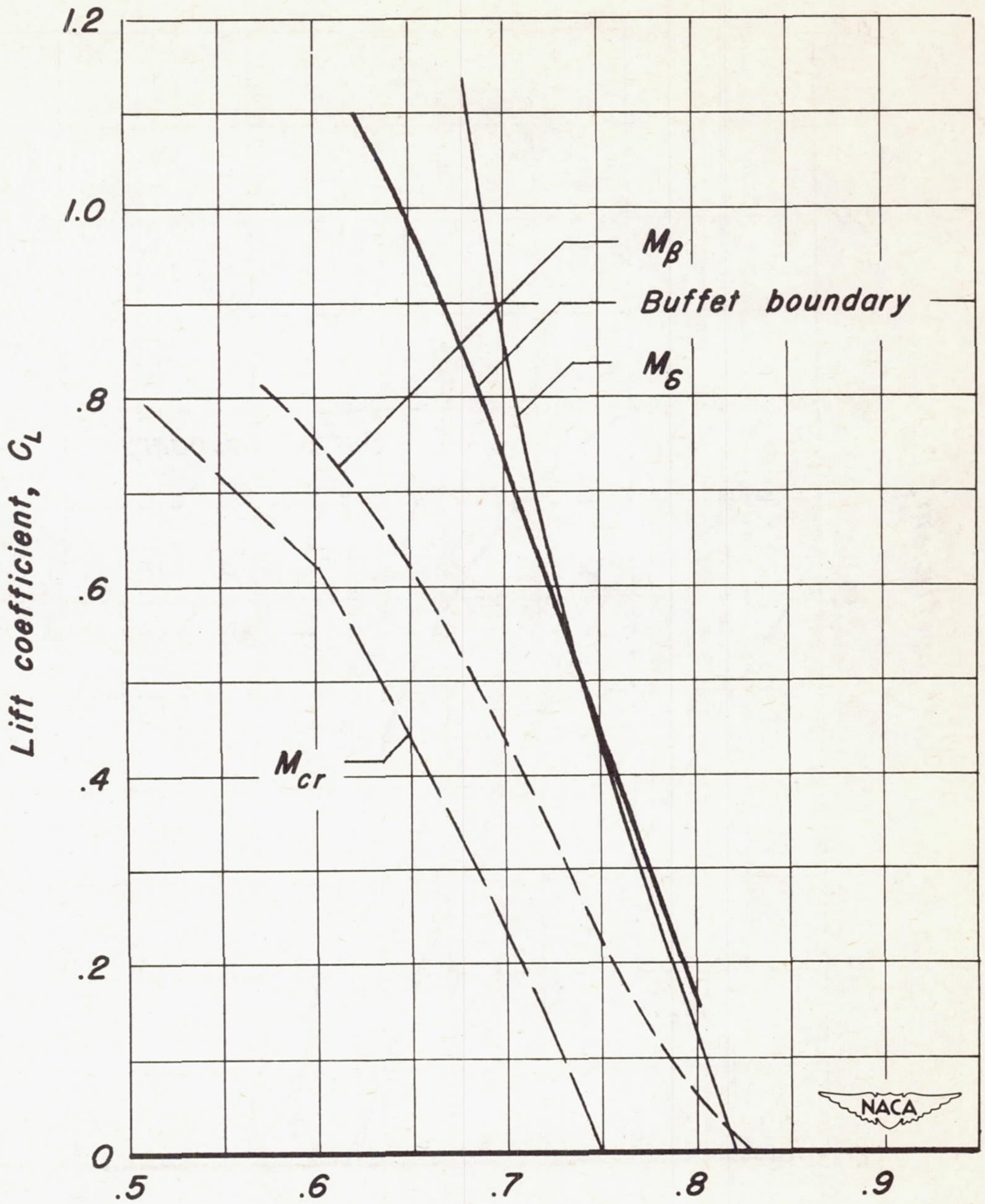
(a) F8F-1 airplane.

Figure 6.– Buffet boundaries and various buffeting criteria for eight straight-wing aircraft.



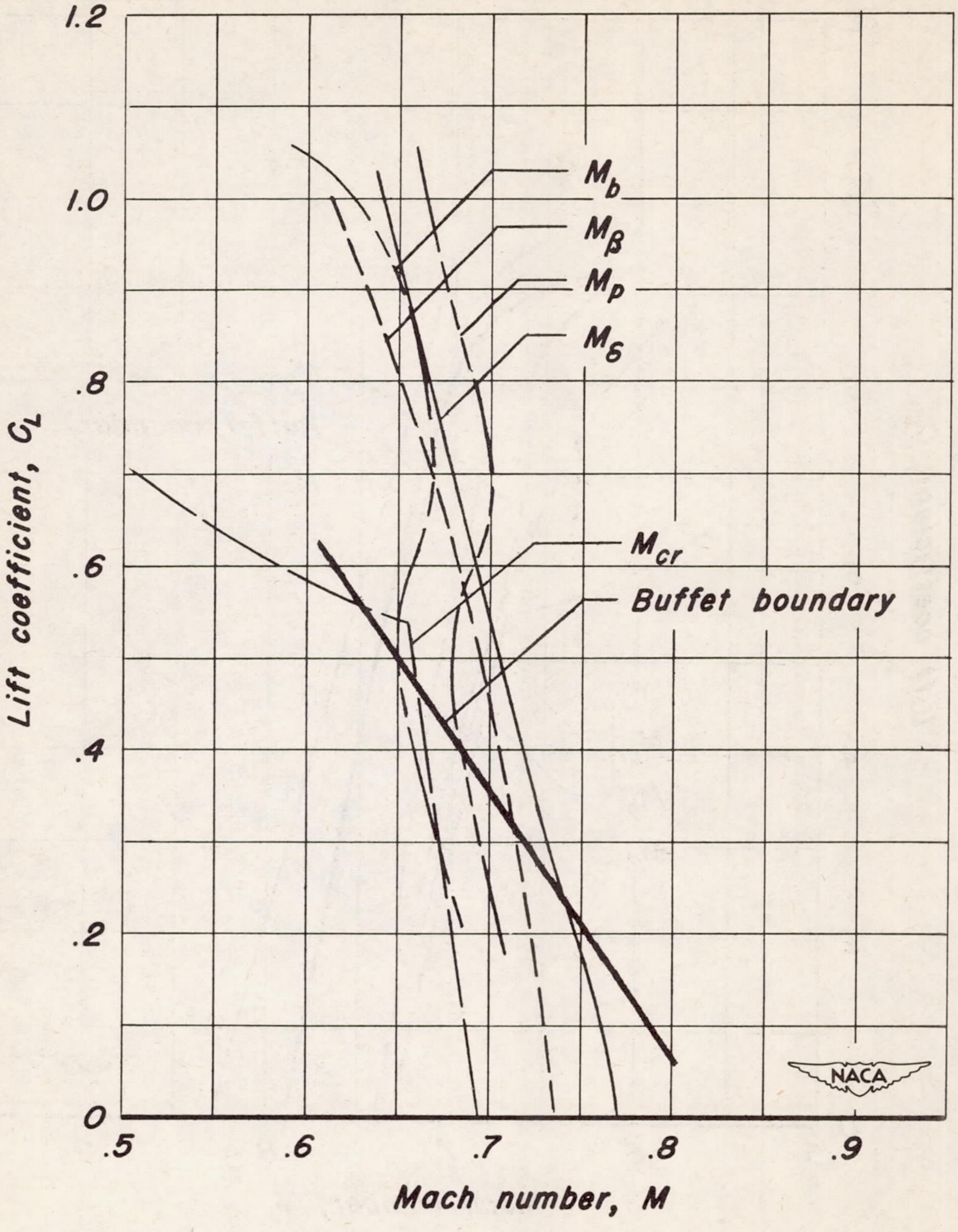
(b) P-39N airplane.

Figure 6.- Continued.



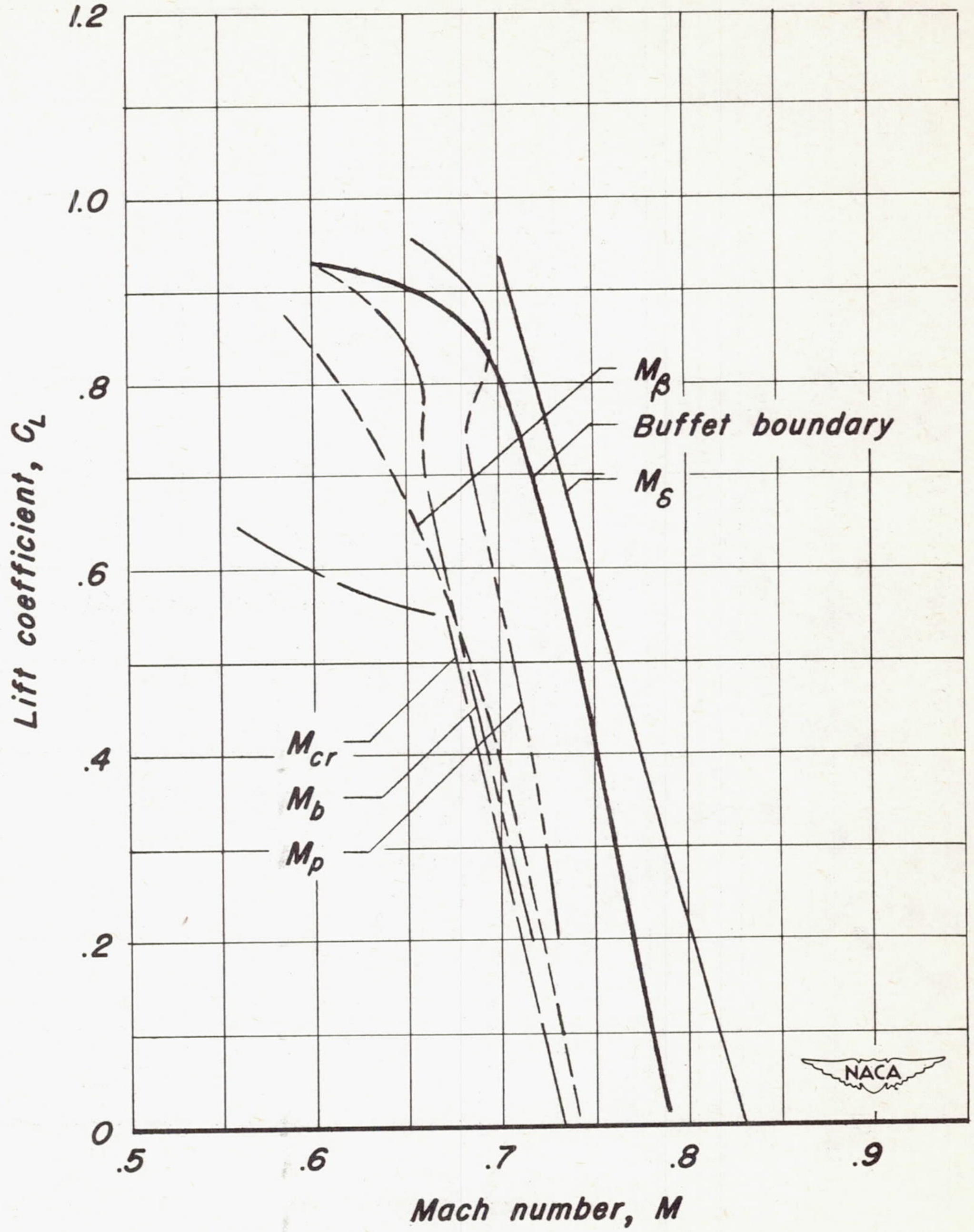
(c) F-51D airplane.

Figure 6.– Continued.



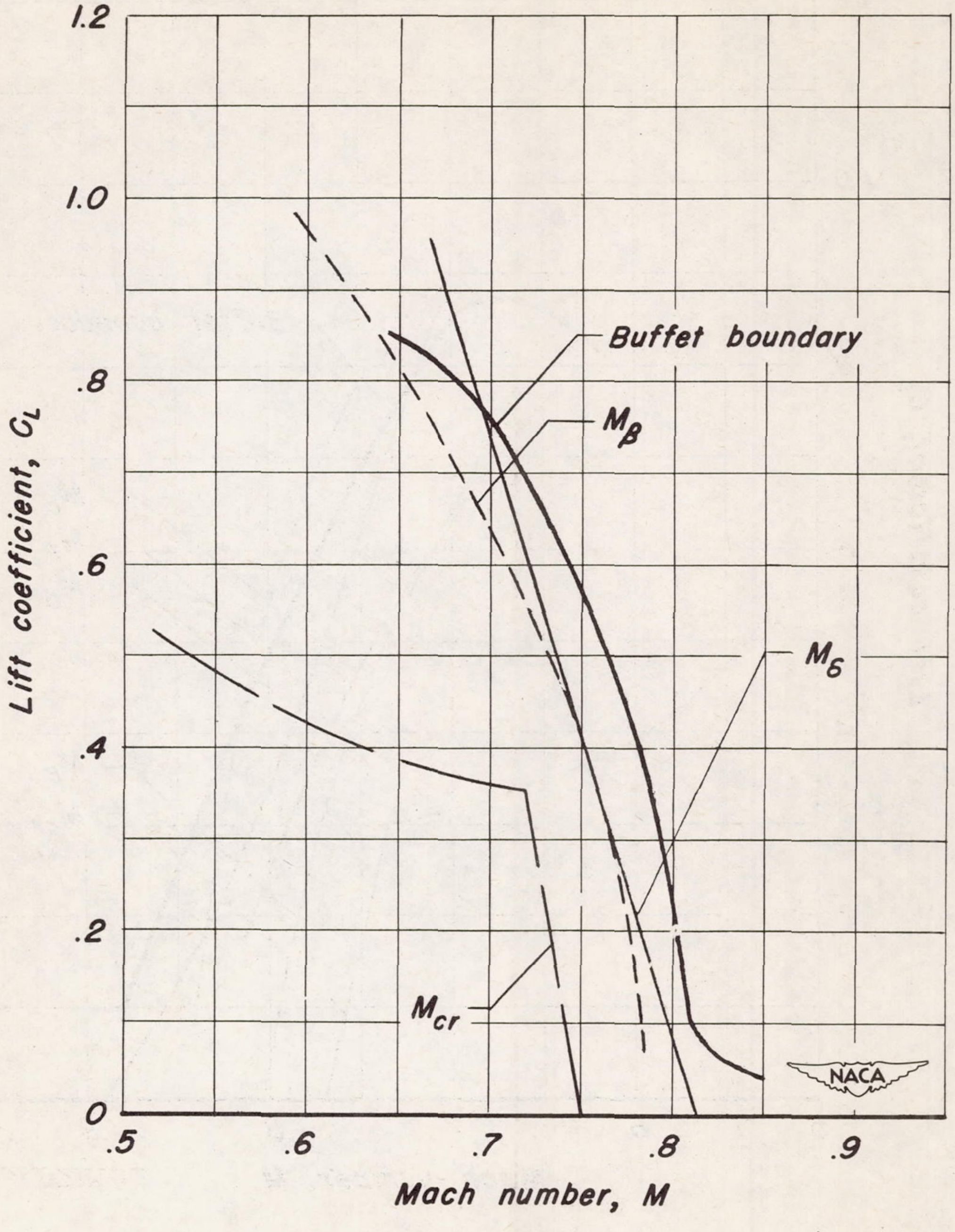
(d) F-51H airplane.

Figure 6.- Continued.



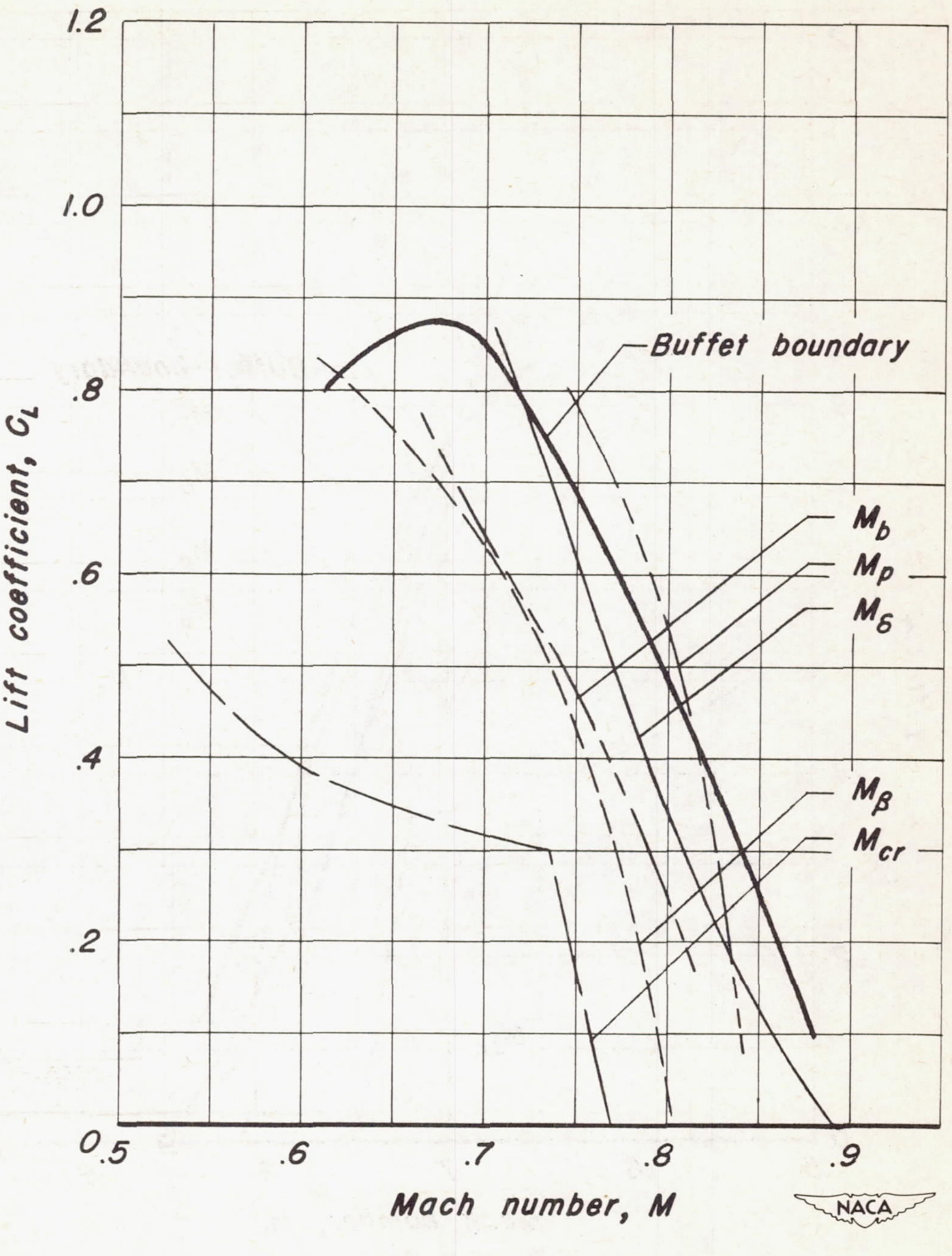
(e) F-80A airplane.

Figure 6.– Continued.



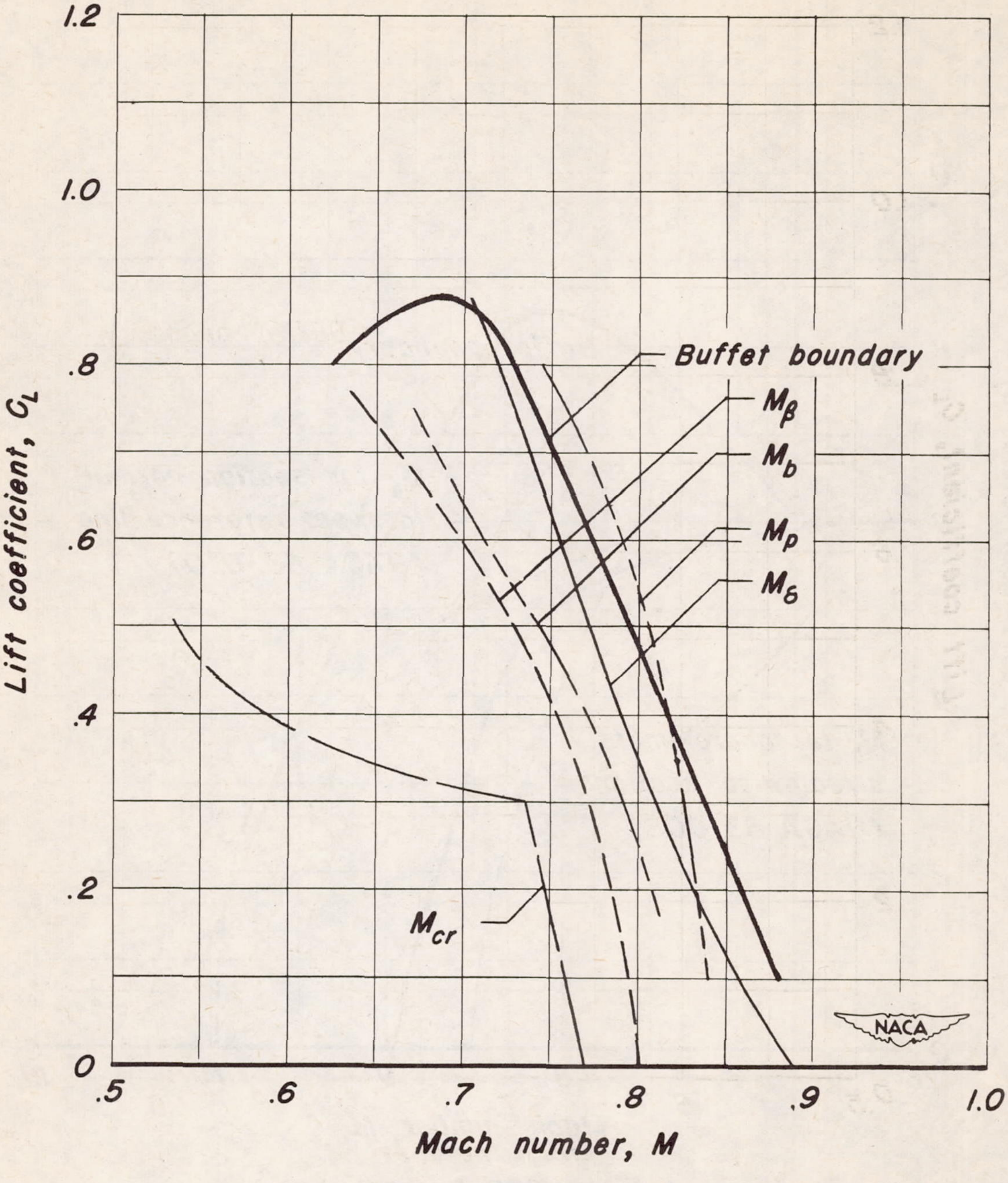
(f) YF-84A airplane.

Figure 6.- Continued.



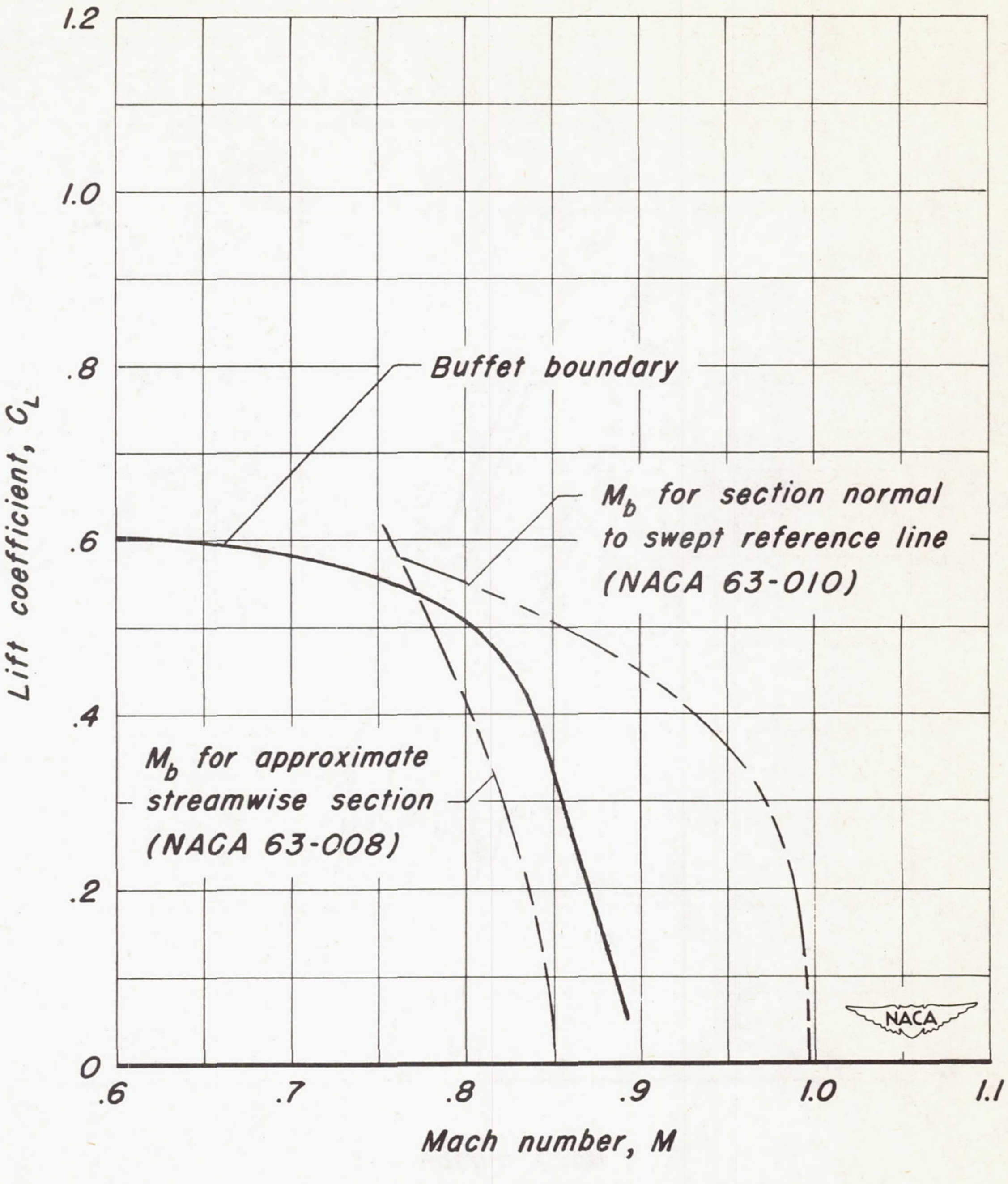
(g) X-1 airplane.

Figure 6.- Continued.



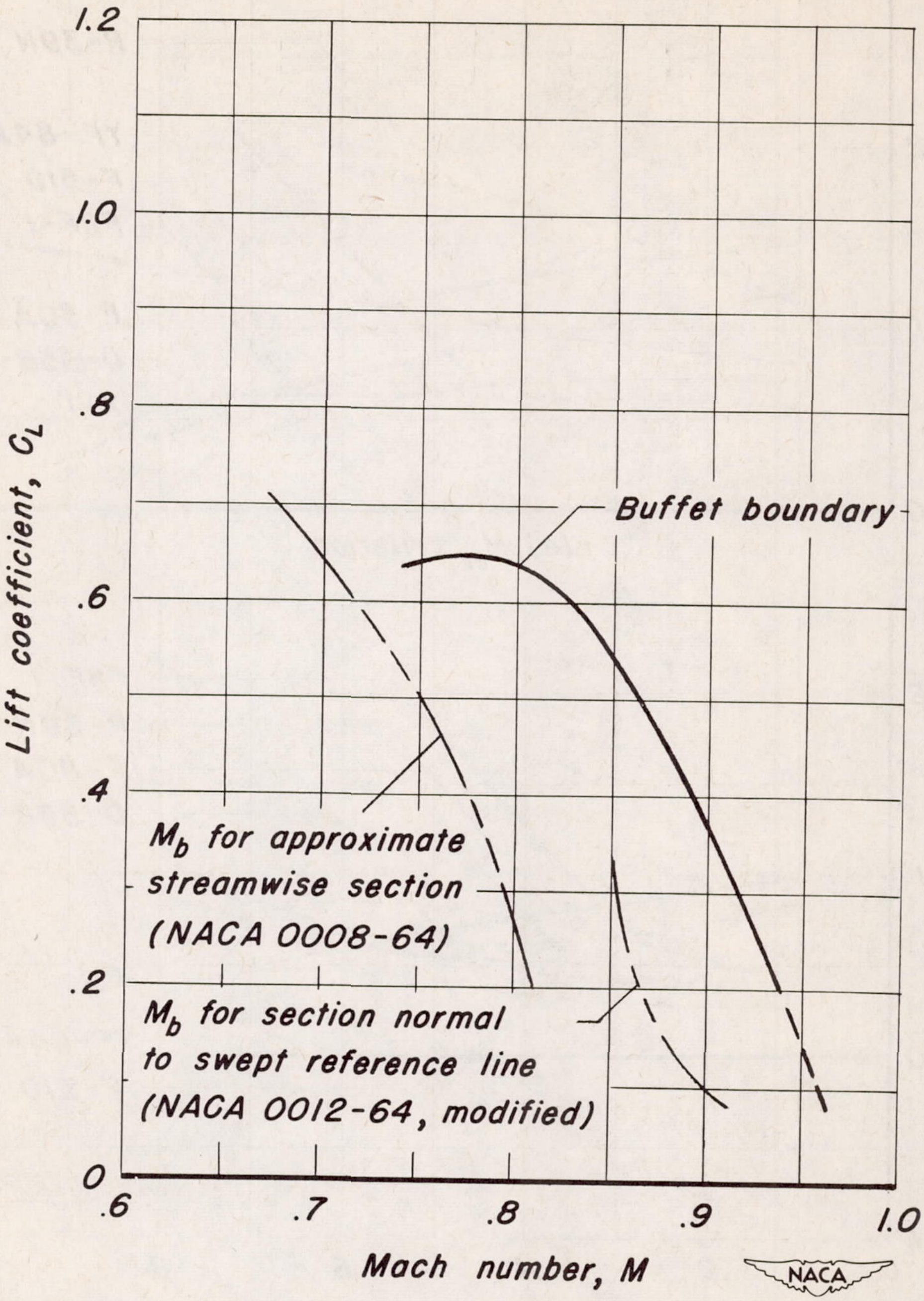
(h) D-558-I airplane.

Figure 6.– Concluded.



(a) D-558-2 airplane.

Figure 7.- Buffet boundaries and the M_b buffeting criterion for two swept-wing aircraft.



(b) F-86A airplane.

Figure 7.- Concluded.

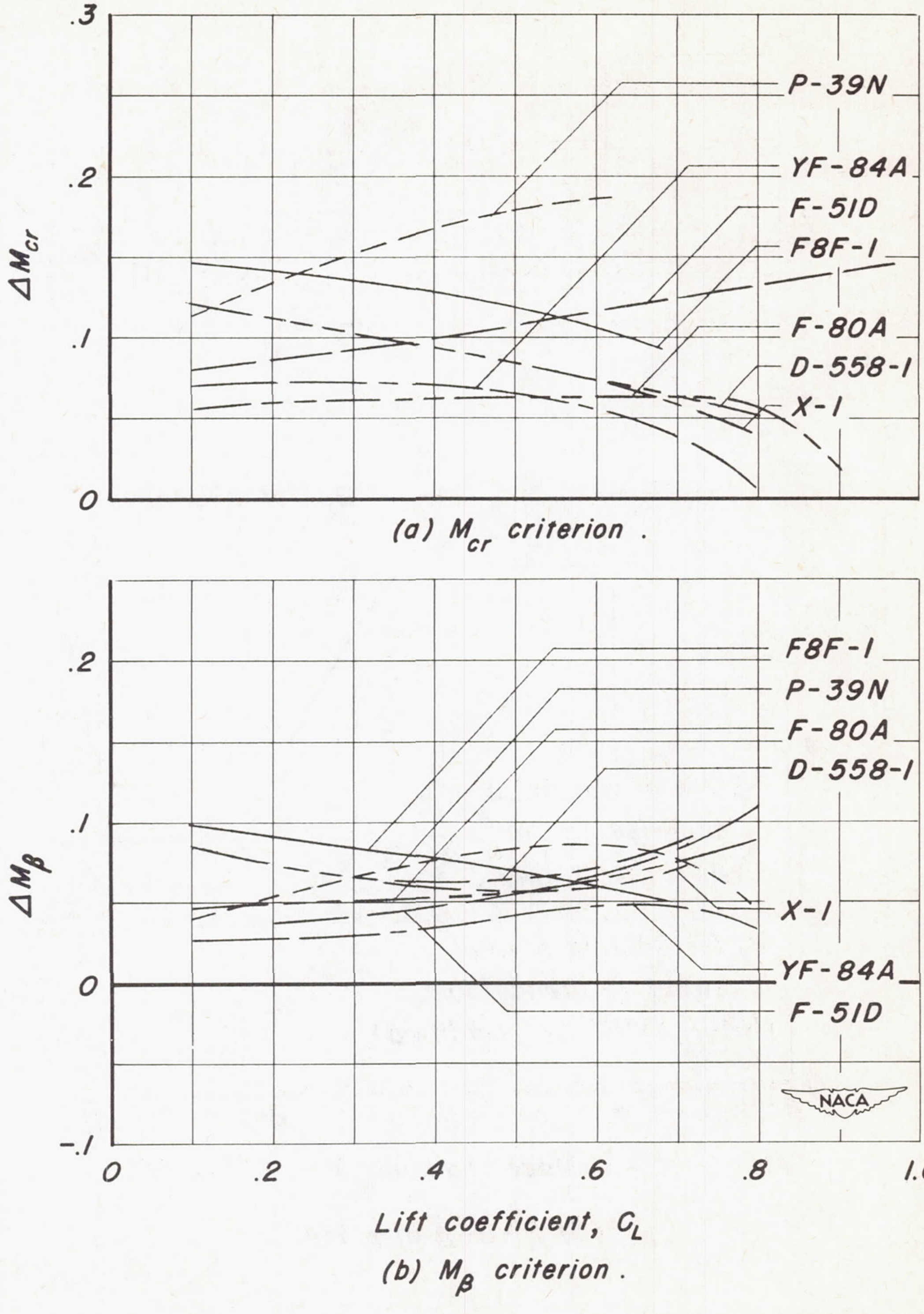
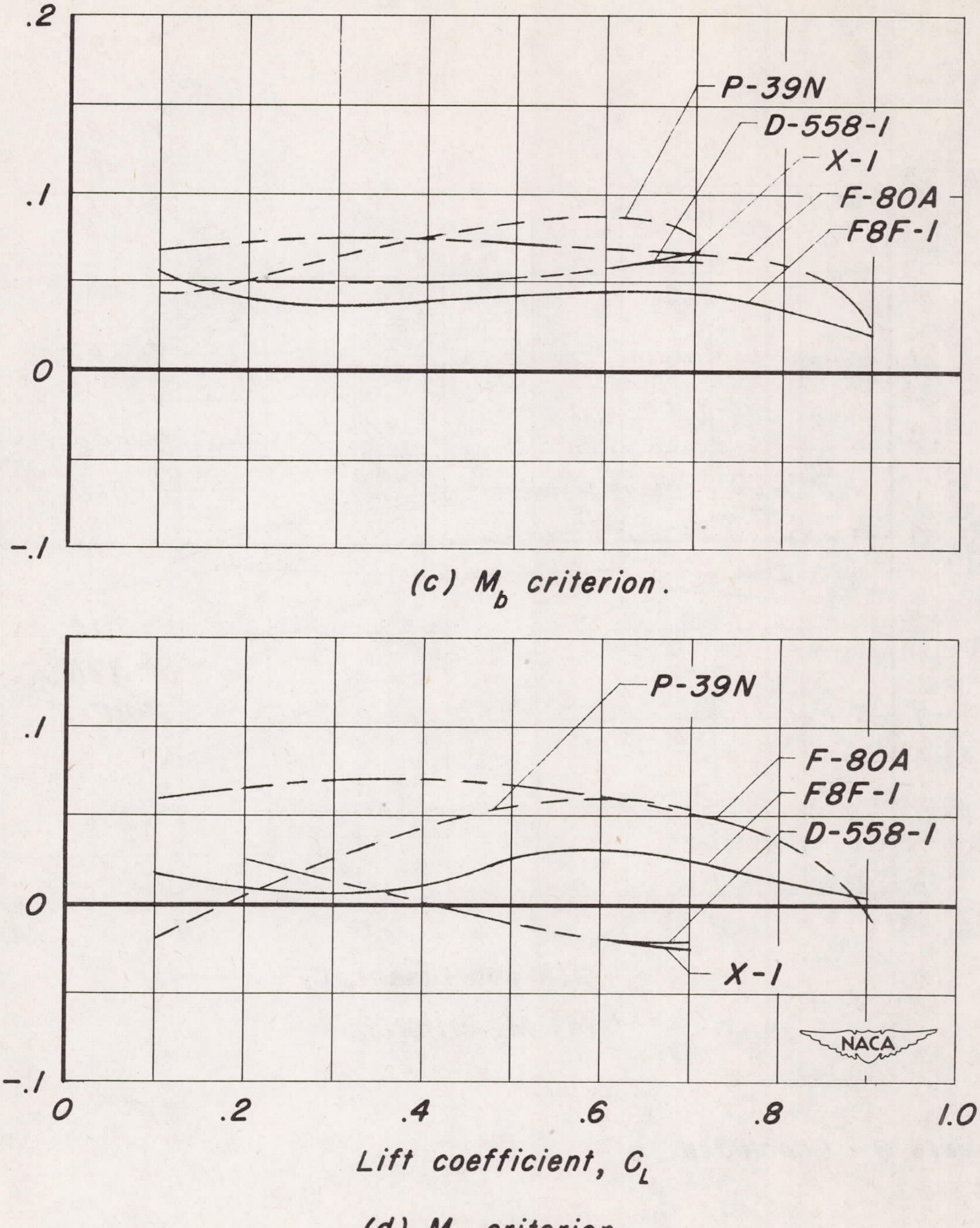
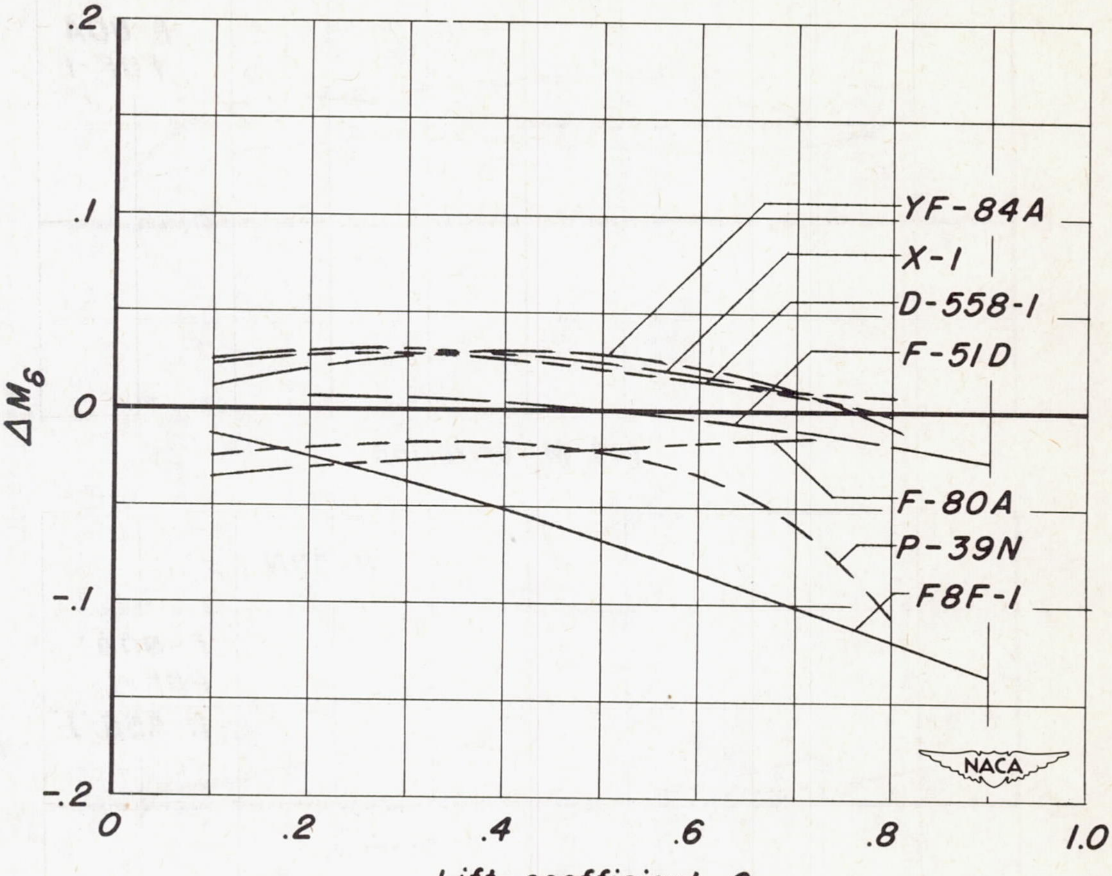


Figure 8.- Differences in Mach number between buffet boundaries and buffeting criteria.



(d) M_p criterion.

Figure 8.– Continued.



(e) M_δ criterion.

Figure 8.- Concluded.