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# RESEARCH MEMORANDUM

## MEASURED DATA PERTAINING TO BUFFETING AT SUPERSONIC SPEEDS OF THE DOUGLAS D-558-II RESEARCH AIRPLANE


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RESEARCH MEMORANDUM

# MEASURED DATA PERTAINING TO BUFFETING AT SUPERSONIC SPEEDS OF THE DOUGLAS D-558-II RESEARCH AIRPLANE

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## SUMMARY

Normal-force coefficients greater than 1.5 have been attained by the Douglas D-558-II airplane during maneuvers at supersonic Mach numbers up to 1.15. Buffeting was encountered at normal-force coefficients greater than about 0.7 in the Mach number range from 0.96 to 1.27 but at Mach number of 1.57, a peak normal-force coefficient of 0.80 was attained with no indication of buffeting. The increase in buffet intensity with lift is very gradual at supersonic speed compared with the buffet intensity-lift variation at subsonic Mach numbers. High-intensity buffeting has not been encountered at Mach numbers greater than 0.925, but gust-induced-acceleration fluctuations of intensity equivalent to high-intensity buffeting have been experienced during flight in turbulent air at supersonic speed.

## INTRODUCTION

A limited amount of data have been obtained at high lift and supersonic speeds with the Douglas D-558-II research airplane. It is the purpose of this paper to present such of these data as are pertinent to buffeting in order to establish a measure of the buffet-free operational region for the airplane at supersonic speeds and to compare supersonic buffet intensities with subsonic data.

The airplane used for this investigation is an air-launched, rocket-powered version of the D-558-II research airplanes which were procured by the Bureau of Aeronautics, Department of the Navy, for use of the National Advisory Committee for Aeronautics as part of the cooperative NACA-Navy transonic flight research program. This research program is being conducted by the NACA High-Speed Flight Research Station at Edwards Air Force Base, Calif. The results of previous investigations of buffeting utilizing the D-558-II airplanes are given in references 1 and 2 and present data in the Mach number range from 0.5 to 0.95, and 0.85 to about 1.10, respectively.

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## SYMBOLS

| | |
|---|---|
| $A_Z$ | normal acceleration at airplane center of gravity, g units |
| a | velocity of sound, ft/sec |
| $C_{N_A}$ | airplane normal-force coefficient, $nW/qS$ |
| $C_{N_{WP}}$ | wing-panel normal-force coefficient, $L_{WP}/qS_{WP}$ |
| $\Delta C_{A_Z}$ | incremental coefficient of normal acceleration due to buffeting, $W\Delta A_Z/qS$ |
| $dC_{N_A}/d\alpha$ | slope of airplane normal-force coefficient curve, per degree |
| $dC_{N_{WP}}/d\alpha$ | slope of wing-panel normal-force coefficient curve, per degree |
| g | acceleration due to gravity, 32.2 ft/sec$^2$ |
| $H_o$ | total pressure at nose boom, lb/sq ft |
| $H_T$ | total pressure at horizontal tail, lb/sq ft |
| $h_p$ | pressure altitude, ft |
| $L_{WP}$ | wing-panel aerodynamic load, lb |
| M | Mach number, $V/a$ |
| n | airplane normal load factor |
| q | free-stream dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft |
| S | wing area, 175 sq ft |
| $S_{WP}$ | wing-panel area outboard of wing station at 33 inches, 63.8 sq ft |
| V | free-stream velocity, ft/sec |
| $V_i$ | indicated airspeed, ft/sec |

$W$ airplane gross weight, lb

$\alpha$ airplane angle of attack, deg

$\Delta A_Z$ incremental fluctuation of normal acceleration at airplane center of gravity due to buffeting, $\pm g$ units

$\Delta H$ loss in total pressure at horizontal tail, $H_o - H_T$, lb/sq ft

$\Delta\tau_T$ incremental horizontal tail-spar shear stress, $\pm$lb/sq in

$\Delta\tau_W$ incremental wing-spar shear stress, $\pm$lb/sq in

$\rho$ mass density of air, slugs/cu ft

## AIRPLANE AND INSTRUMENTATION

The D-558-II airplanes have sweptback wing and tail surfaces and were originally designed for a combination of turbojet and rocket power. The airplane used in the present tests, however, has the turbojet engine removed, has no air inlet or exhaust ducts, and is powered solely with a rocket engine exhausting from the rear of the fuselage. A photograph of the airplane is shown in figure 1 and a three-view drawing is shown in figure 2. Pertinent airplane dimensions and physical characteristics are listed in table I. The airplane is equipped with an adjustable stabilizer and both leading-edge slats and stall-control fences are incorporated on the wings. The wing slats can be locked in the closed position or can be unlocked.

Standard NACA recording instruments, synchronized by a common timer, were used to measure airspeed, altitude, normal acceleration, angle of attack, and tail total pressure. Strain gages are installed at the roots of both sides of the wing and horizontal tail to measure steady loads and spar shear and bending stresses. The strain gages could not be used to measure buffet loads, however. The wing strain gages are located along a station 3 inches outboard of the fuselage. The tail strain gages are located along a station 6 inches on each side of the airplane center line. The outputs of the strain gages were recorded on a 36-channel recording oscillograph which had a frequency response flat to 60 cycles per second. The airspeed system was calibrated at all Mach numbers by the NACA radar phototheodolite method (ref. 3). The accuracy of the Mach numbers presented herein is estimated as ±0.025. Tail total pressure was measured at a station 48 inches from the airplane center line with an NACA type A-6 total head tube projecting 5.5 inches forward of the leading edge of the horizontal tail (see fig. 2). No errors induced by flow angle exist in the measurements of total pressure made at the nose boom or at the tail. The difference between total pressure measured at the nose boom, using the airspeed system, and tail total pressure is presented in this paper. No corrections have been made to total pressure measurements for loss through a normal shock wave.

The accelerometer used for buffet-intensity determination is an air-damped instrument having a natural frequency of 10.5 cycles per second. The response of this instrument varies with air density and forcing frequency. It is realized that the use of a low natural frequency, air-damped, accelerometer in evaluating buffet-induced accelerations is somewhat questionable; however, in the interest of providing some information on buffeting at supersonic speeds as soon as possible, available instrumentation was utilized. The incremental-acceleration data presented herein have been corrected insofar as possible for forcing frequency (12.5 cps) and variation in air density. No frequency or damping corrections to fluctuating stress data were necessary.

## TESTS, RESULTS, AND DISCUSSION

The data presented in this paper were obtained at altitudes varying from 35,000 to 60,000 feet in the Mach number range from 0.95 to 1.28. The Reynolds number varied from $6 \times 10^6$ to $20 \times 10^6$. The data were taken with the airplane in the clean (slats-locked-closed) condition during turns and pull-ups. No significant difference was found between power-on and power-off data that could be attributed to the presence or absence of power.

Buffeting was encountered at supersonic speeds during maneuvering flight. Buffet-induced fluctuations in normal acceleration, at the airplane center of gravity, are considered to represent the summation of buffet-induced vibrations of all the components. The incremental stress values shown subsequently for the wing and tail are indicative of the magnitude of vibration of each component, although specific values of incremental stress are peculiar to the particular strain-gage location.

Measurements of quantities pertinent to buffeting are presented in figure 3. These data were obtained during a typical power-off turn in smooth air. It may be seen in figure 3(a) that a decrease in $dC_{N_A}/d\alpha$ and $dC_{N_{WP}}/d\alpha$ occurs at an angle of attack of 11° and is coincidental with the occurrence of a definite loss in total pressure at the tail. Airplane and wing buffeting started at an angle of attack of 10.3° (fig. 3(b)) but no tail buffeting was apparent until an angle of attack of 11.8°. For all practical purposes, however, the start of buffeting, a decrease in lift-curve slope, and a loss in tail total pressure can be said to occur at the same angle of attack for this airplane at supersonic speeds. No exact relationship can be shown to exist between the intensity of buffeting and the loss in lift due to flow separation or the loss of total pressure at the tail. However, it is apparent in figure 3 that as separation, indicated by the decrease in lift-curve slope and the rise in tail total-pressure loss, increases, the intensity of buffeting, in general, increases. The negative values of total-pressure difference shown at low angles of attack in figure 3(a) are believed to result from the existence of an oblique shock extending out from the airplane ahead of the tail. References 4 and 5 present typical results of wind-tunnel investigations of the relation between flow phenomena and buffeting.

As a matter of interest, peak structural loads imposed during the turn of figure 3 ($M \approx 1.2$, $h_p \approx 52,000$ feet) were 14,280 pounds on the left wing and a down load of 1,466 pounds on the left horizontal tail. The shearing stresses resulting from these loads were 1,290 pounds per square inch for the rear spar of the wing and 540 pounds per square inch for the rear spar of the tail. The peak fluctuating buffet stresses in the wing rear spar were 4.7 percent of the steady stress. The peak tail buffet stress in the rear spar was 27 percent of the steady stress. During previous tests at a Mach number of about 0.9 at 36,000 feet, buffet stresses in the rear wing spar of 17 percent of the steady stress and in the rear spar of the horizontal tail of 67 percent of the steady stress were observed. (The values of steady stress due to structural load were 1250 pounds per square inch in the rear wing spar and 615 pounds per square inch in the rear spar of the horizontal tail.) Thus, at supersonic speeds, wing buffeting for this airplane is of small practical importance and tail buffeting, compared to that at subsonic speed, is not serious.

Such buffet-intensity data as have been obtained at supersonic Mach numbers are summarized in figure 4 and compared with similar subsonic data from reference 1. In order to minimize the effect of altitude variation, incremental values of normal acceleration at the center of gravity were converted to coefficient form $\Delta C_{A_Z}$ by dividing $\Delta A_Z$ by free-stream dynamic pressure $q$ and multiplying by wing loading $W/S$. No data exist as to the correctness of the assumption that buffet-induced acceleration fluctuations are directly proportional to free-stream dynamic pressure and it should be noted that the data of the present tests were obtained at altitudes varying from 35,000 to 60,000 feet, whereas those of reference 1 were obtained at altitudes varying from 20,000 to 35,000 feet. The various buffet intensity points of the present tests are not sufficient to establish contours, or limits, of the intensities but are connected by straight lines to aid in their identification. Some of the nonuniformity of the data is thought to be caused by flight in turbulent air, which is discussed subsequently. The buffet boundary determined in the present tests and shown in figure 4 is based on the start of high-frequency (45 cps) fluctuations of wing shear stress. This procedure was necessary in order to distinguish between turbulent air, which did not appear to excite high-frequency structural vibrations, and buffeting. Some scatter exists in the buffet-boundary points of figure 4 but the data clearly show that buffeting does not exist below a normal-force coefficient of 0.65 at supersonic speed. The highest Mach number at which a buffet-boundary point was obtained was 1.265 at a normal-force coefficient of 0.74; however, a normal-force coefficient of 0.80 was attained at $M = 1.57$ with no indication of buffeting. During preliminary investigations with this airplane (ref. 2) very low-intensity buffeting was reported to exist, intermittently, at low and moderate values of lift during flight at supersonic speed. This intermittent low-intensity "buffeting" has been determined to be gust-induced acceleration fluctuations resulting from flight in turbulent air.

Comparison of the buffet intensities of the present tests with those of reference 1 shows that even though buffeting is encountered at supersonic speeds, the increase in intensity with lift is, in general, very gradual and that high values of normal-force coefficient must be attained before other than low-intensity buffeting is experienced. In reference 1 low-intensity buffeting was regarded as that equivalent to values of $\Delta C_{A_Z}$ less than $\pm 0.02$ and intensities greater than about $\Delta C_{A_Z} = \pm 0.05$ were considered high-intensity buffeting. High-intensity buffeting has not been encountered at Mach numbers greater than 0.925 within the lift range covered (see fig. 4).

Buffet frequencies were determined from stress fluctuations at the roots of the wing and tail. The predominant wing buffet frequencies corresponded to the first modes of natural structural wing bending and wing torsion, 12.5 and 45 cycles per second, respectively. Predominant tail buffet frequencies were on the order of 10 cycles per second and appeared to be stabilizer rocking. In addition to the predominant buffet frequencies of the wing and tail, low amplitude stress fluctuations at frequencies above 60 cycles per second were observed for both components. Acceleration fluctuations at the airplane center of gravity were recorded at a frequency on the order of 12.5 cycles per second. The response of the accelerometer at higher frequencies was negligible because of its poor frequency-response characteristics.

During most of the flights from which the data presented in this paper were obtained, the airplane encountered clear-air turbulence from time to time and some difficulty was experienced in distinguishing between rough air and buffeting. However, frequency analysis of the strain-gage data showed that the first natural mode of structural vibration predominated during flight in turbulent air, whereas the higher structural modes were also excited noticeably during buffeting. As an example of flight in turbulent air, records of airspeed and normal acceleration were reproduced in figure 5. For the time range shown, Mach number increased from 1.22 to 1.30 and altitude decreased from 43,100 to 42,800 feet. Turbulent air was first encountered by the airplane at 42,600 feet and persisted to the maximum altitude attained during the flight, 43,900 feet. Upon descent, the turbulence ceased at 42,800 feet as shown at the right side of figure 5. A survey of atmospheric conditions over Edwards Air Force Base, Calif., at about the time of the flight showed that a normal temperature lapse rate existed to 57,000 feet with the exception of a 3° C inversion at 43,000 feet. The atmosphere was clear with no clouds.

The peak incremental acceleration experienced in the portion of the flight for which the records are reproduced was ±0.29g (corrected for instrument damping and forcing frequency). This value is equivalent to a $\Delta C_{A_Z}$ of 0.053 and is of greater magnitude than any buffeting intensity so far encountered at Mach numbers greater than 0.925. Normal-acceleration fluctuations are considered induced by the vertical components of gusts but the fluctuations in airspeed are indicative of longitudinal gust velocity. It has been shown in reference 6 that maximum values of horizontal and vertical gust velocities in the same traverse are essentially equal. No analysis of data taken in turbulent air has been made, but it is clear from the comparison of gust-induced accelerations with buffet-induced accelerations that some investigation of the effects of turbulent air on flight characteristics at supersonic speed is in order.

## CONCLUDING REMARKS

Normal-force coefficients greater than 1.5 have been attained by the Douglas D-558-II airplane during maneuvers at supersonic Mach numbers up to 1.15. Buffeting was encountered at normal-force coefficients greater than about 0.7 in the Mach number range from 0.96 to 1.27 but at a Mach number of 1.57, a peak normal-force coefficient of 0.80 was attained with no indication of buffeting. The increase in buffet intensity with lift is very gradual at supersonic speed compared with the buffet intensity-lift variation at subsonic Mach numbers. High-intensity buffeting has not been encountered at Mach numbers greater than 0.925, but gust-induced acceleration fluctuations of intensity equivalent to high-intensity buffeting have been experienced during flight in turbulent air at supersonic speed.

Langley Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., November 23, 1953.

## REFERENCES


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2. Baker, Thomas F.: Some Measurements of the Buffet Region of a Swept-Wing Research Airplane During Flights to Supersonic Mach Numbers. NACA RM L53D06, 1953.

3. Zalovcik, John A.: A Radar Method of Calibrating Airspeed Installations on Airplanes in Maneuvers at High Altitudes and at Transonic and Supersonic Speeds. NACA Rep. 985, 1950. (Supersedes NACA TN 1979.)

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5. Sorenson, Robert M., Wyss, John A., and Kyle, James C.: Preliminary Investigation of the Pressure Fluctuations in the Wakes of Two-Dimensional Wings at Low Angles of Attack. NACA RM A51G10, 1951.

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

TABLE I

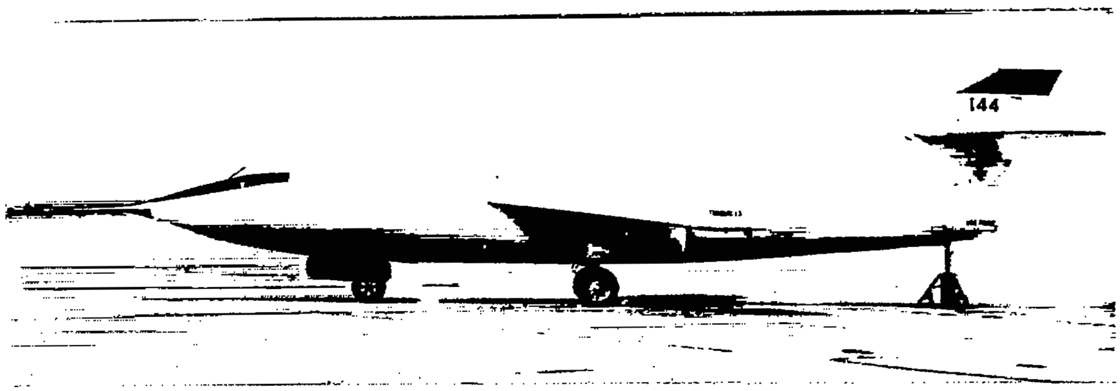
PHYSICAL CHARACTERISTICS OF THE DOUGLAS D-558-II AIRPLANE

| | |
|---|---|
| Wing: | |
| Root airfoil section (normal to 0.30 chord) | NACA 63-010 |
| Tip airfoil section (normal to 0.30 chord) | NACA $63_1$-012 |
| Total area, sq ft | 175.0 |
| Span, ft | 25.0 |
| Mean aerodynamic chord, in. | 87.301 |
| Root chord (parallel to plane of symmetry), in. | 108.51 |
| Tip chord (parallel to plane of symmetry), in. | 61.18 |
| Taper ratio | 0.565 |
| Aspect ratio | 3.570 |
| Sweep at 0.30 chord, deg | 35.0 |
| Incidence at fuselage center line, deg | 3.0 |
| Dihedral, deg | -3.0 |
| Geometric twist, deg | 0 |
| Total aileron area (aft of hinge), sq ft | 9.8 |
| Aileron travel (each), deg | ±15 |
| Total flap area, sq ft | 12.58 |
| Flap travel, deg | 50 |
| Horizontal tail: | |
| Root airfoil section (normal to 0.30 chord) | NACA 63-010 |
| Tip airfoil section (normal to 0.30 chord) | NACA 63-010 |
| Area (including fuselage), sq ft | 39.9 |
| Span, in. | 143.6 |
| Mean aerodynamic chord, in. | 41.75 |
| Root chord (parallel to plane of symmetry), in. | 53.6 |
| Tip chord (parallel to plane of symmetry), in. | 26.8 |
| Taper ratio | 0.50 |
| Aspect ratio | 3.59 |
| Sweep at 0.30 chord line, deg | 40.0 |
| Dihedral, deg | 0 |
| Elevator area, sq ft | 9.4 |
| Elevator travel, deg | |
| Up | 25 |
| Down | 15 |
| Stabilizer travel, deg | |
| Leading edge up | 4 |
| Leading edge down | 5 |

TABLE I - Concluded

PHYSICAL CHARACTERISTICS OF THE DOUGLAS D-558-II AIRPLANE

| | |
|---|---|
| Vertical tail: | |
| Airfoil section (normal to 0.30 chord) | NACA 63-010 |
| Area, sq ft | 36.6 |
| Height from fuselage center line, in. | 98.0 |
| Root chord (parallel to fuselage center line) | 146.0 |
| Tip chord (parallel to fuselage center line), in. | 44.0 |
| Sweep angle at 0.30 chord, deg | 49.0 |
| Rudder area (aft hinge line), sq ft | 6.15 |
| Rudder travel, deg | ±25 |
| Fuselage: | |
| Length, ft | 42.0 |
| Maximum diameter, in. | 60.0 |
| Fineness ratio | 8.40 |
| Speed-retarder area, sq ft | 5.25 |
| Power plant: | |
| Rocket | Reaction Motors |
| Airplane weight (full rocket fuel), lb | 15,787 |
| Airplane weight (no fuel), lb | 9,421 |
| Center-of-gravity locations: | |
| Full rocket fuel (gear up), percent mean aerodynamic chord | 24.6 |
| No fuel (gear up), percent mean aerodynamic chord | 27.3 |
| No fuel (gear down), percent mean aerodynamic chord | 26.7 |
| Moments of inertia (no fuel): | |
| About normal axis, slug-ft$^2$ | 38,100 |
| About longitudinal axis, slug-ft$^2$ | 5,025 |
| About lateral axis, slug-ft$^2$ | 34,500 |

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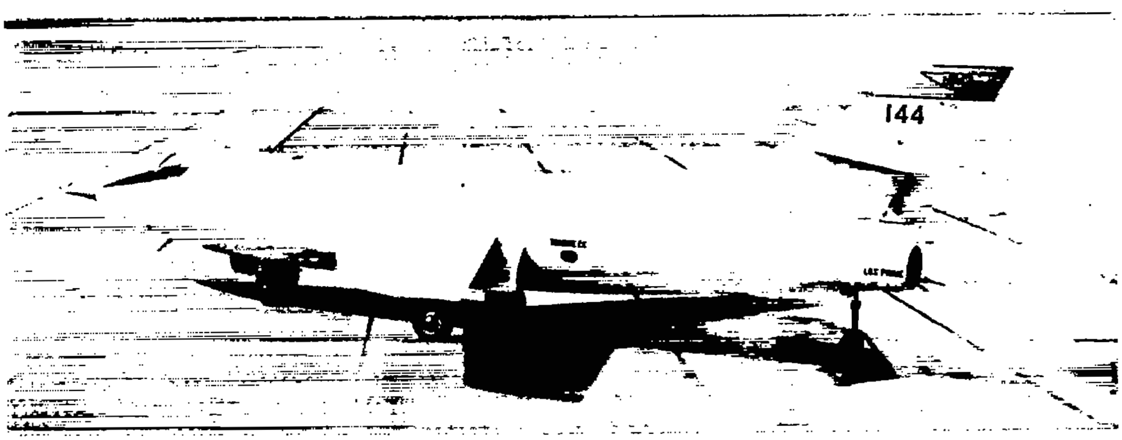
(a) Side view.

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(b) Three-quarter rear view.

Figure 1.- Photographs of the Douglas D-558-II research airplane.

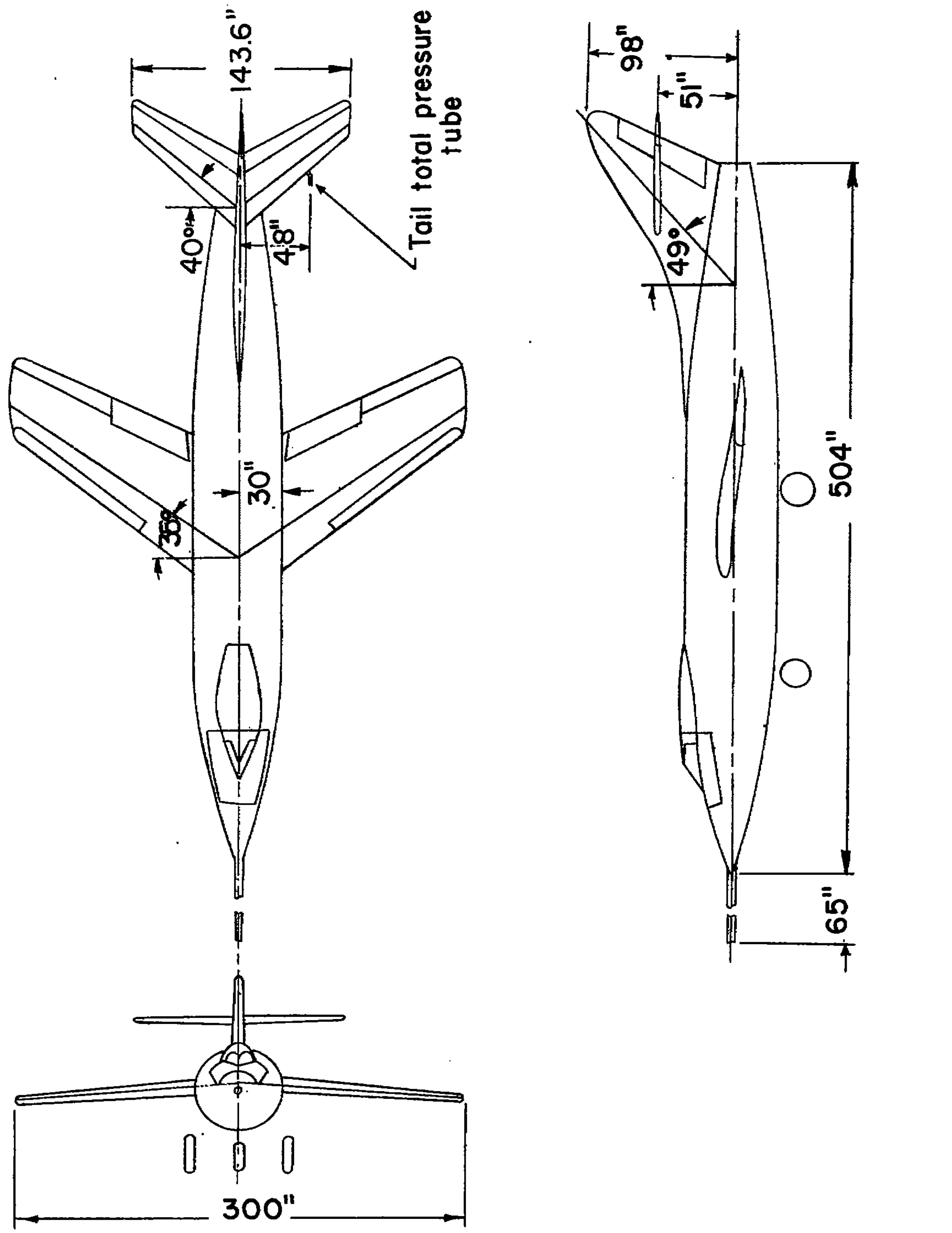
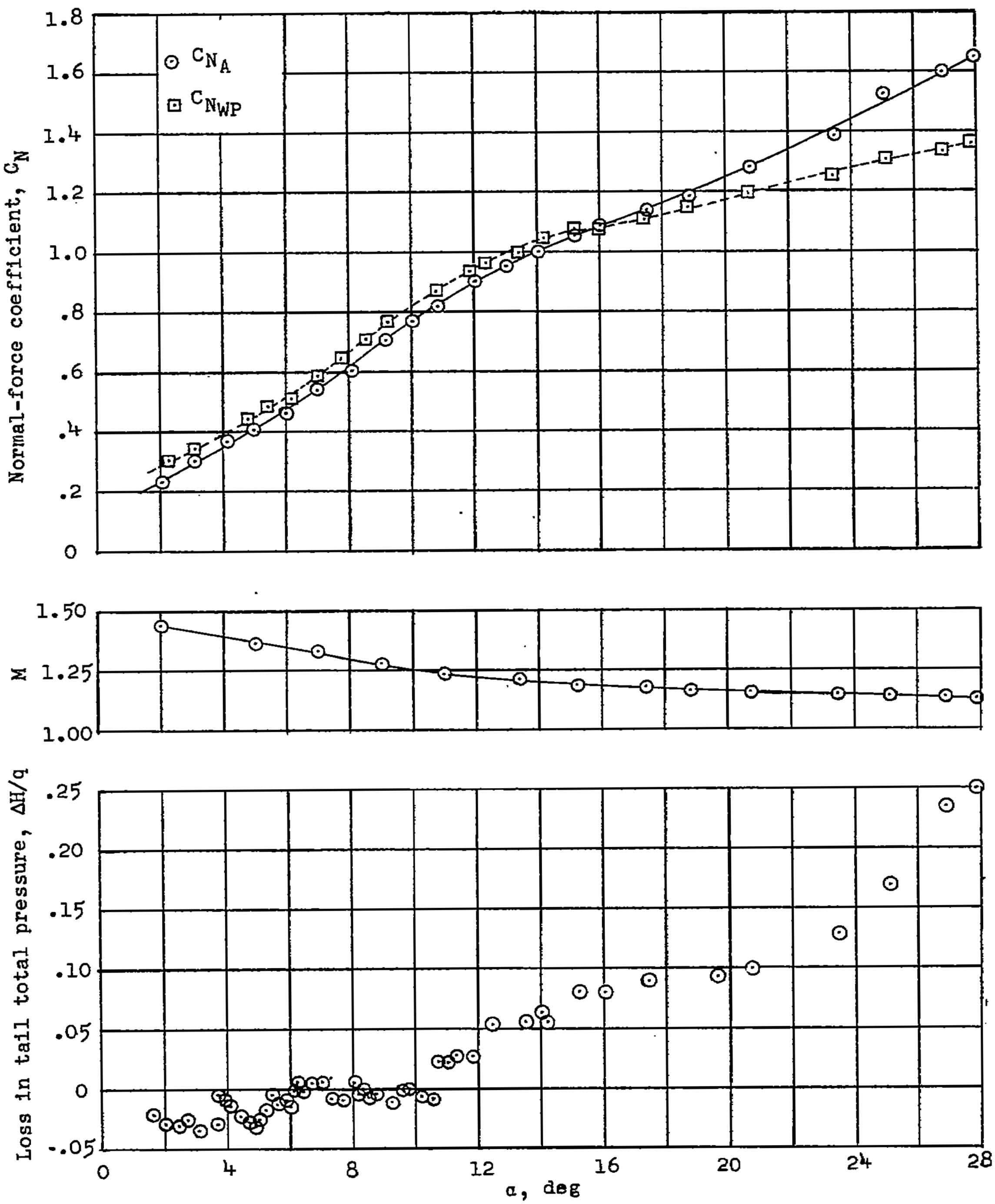



Figure 2.- Three-view drawing of the Douglas D-558-II airplane showing location of tail total pressure tube.




(a) Steady aerodynamic quantities.

Figure 3.- The variation with angle of attack of various quantities measured during a turn at supersonic speed. $h_p \approx 52{,}000$ feet.

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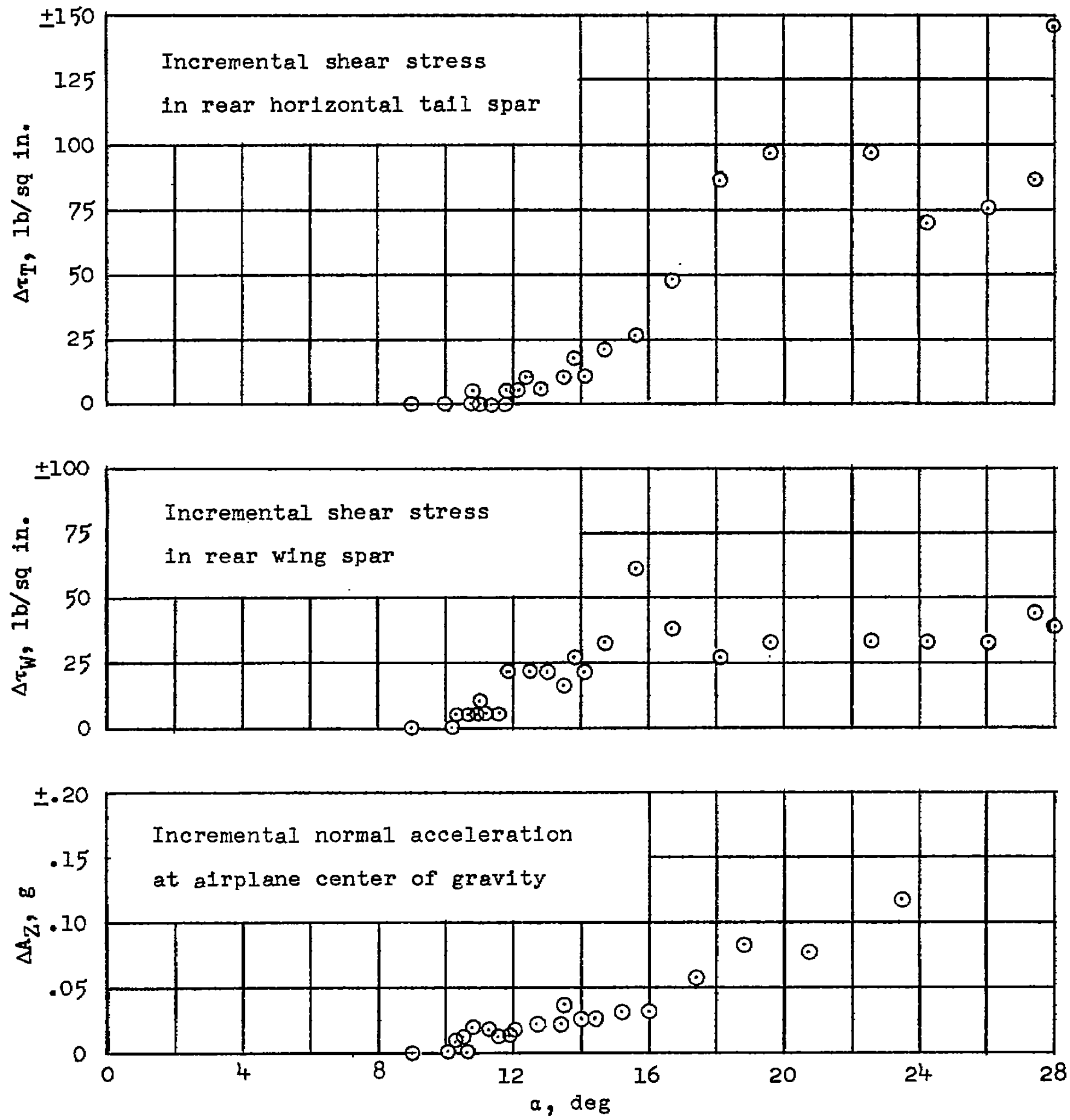


(b) Buffeting quantities.

Figure 3.- Concluded.

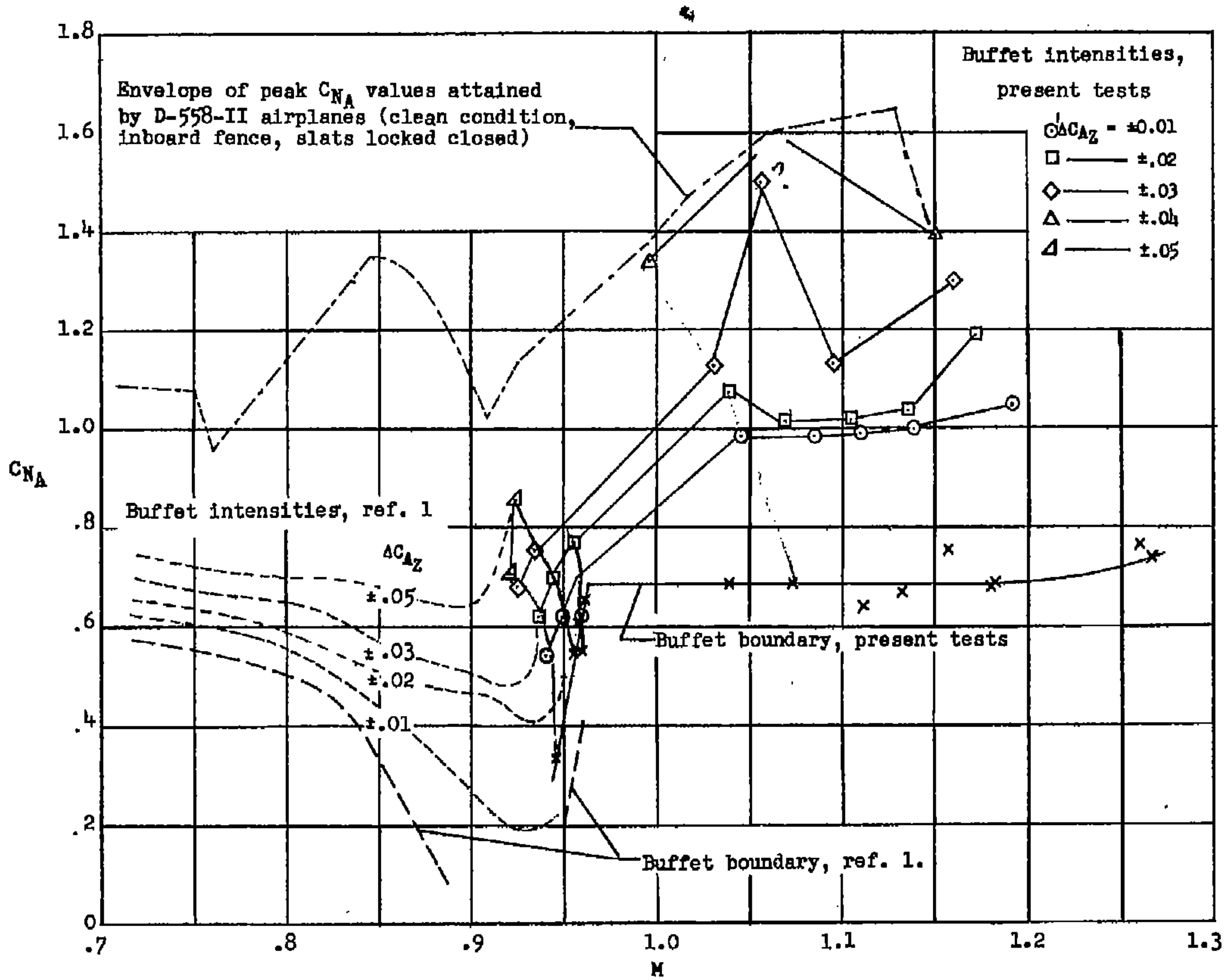


Figure 4.- Summary plot of buffet intensities measured during the present tests and comparison with similar data taken at subsonic speed during previous tests.

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