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RESEARCH MEMORANDUM

MEASUREMENTS OF FLUCTUATING PRESSURES ON THE WINGS AND BODY OF A SWEPTBACK WING-BODY COMBINATION IN THE LANGLEY 16-FOOT TRANSONIC TUNNEL

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

Pressure fluctuations have been measured at eight locations on the body and one location of each wing of a sweptback wing-body combination in the Langley 16-foot transonic tunnel. These tests were made for four model configurations: the basic configuration, the wing-aft configuration for which the wing was effectively shifted about one wing root chord towards the rear of the body, a wing leading-edge chord-extension configuration, and a wing leading-edge slat configuration.

The pressure fluctuations on the body were found to be relatively small for most test conditions at all measuring stations except those in the vicinity of the wings. The effect of the wing position on the body was found to have little effect on the flow fluctuations at the pressure-gage location on the wings (90-percent-semispan, 80-percent-chord station). The over-all effects of the leading-edge devices on the fluctuating flow at the 90-percent-semispan, 80-percent-chord station of the wing were found to be detrimental for the leading-edge chord-extension configuration and beneficial for the leading-edge slat configuration. It is emphasized that the results presented herein concerning the effects of the leading-edge modifications on the pressure fluctuations on the wing are for one gage location only and may not be a true picture of the effect of the leading-edge devices on the flow fluctuations over the entire wing.

Frequency analysis of some of the pressure fluctuations measured on the model indicated that, although pressure fluctuations on the body were larger at some frequencies than at others, this predominant frequency could not be consistently correlated with the test conditions. Pressure fluctuations measured on the wings were found to be random with respect to time with fluctuations of about equal amplitude at all frequencies investigated (from 10 to 1,000 cycles per second).

INTRODUCTION

As part of a program to obtain buffeting information with models designed for general aerodynamic testing, fluctuating pressures were measured at eight locations on the body and one location on each wing for two configurations of a sweptback wing-body combination in the Langley 16-foot transonic tunnel. When tests of the sweptback wing-body combination were extended to obtain aerodynamic information for a number of leading-edge devices, fluctuating pressure measurements were obtained along with the aerodynamic data for each of the various configurations. Because of the sparse instrumentation on the wings of the model, however, the conclusions concerning the effects of the wing leading-edge modifications on the amplitude of the flow fluctuations on the wing are limited.

Measurements of fluctuating pressures similar to those presented herein on a sweptback wing are presented in reference 1 for an unswept wing as another portion of this exploratory program.

SYMBOLS

c local wing chord parallel to plane of symmetry, ft

$\bar{c}$ mean aerodynamic chord of wing, $\frac{2}{S}\int_0^{b/2} c^2 dy$, ft

S wing area including area inboard of fuselage, sq ft

b span, ft

y spanwise distance outboard of plane of symmetry, ft

$\frac{\Delta p}{q}$ pressure fluctuation coefficient

Δp amplitude of pressure variation across diaphragm of electrical pressure gage, lb/sq ft

q dynamic pressure, $\frac{1}{2}\rho V^2$, lb/sq ft

ρ density, slugs/cu ft

V velocity, ft/sec

α	angle of attack of fuselage center line, deg
M	Mach number
R	Reynolds number based on mean aerodynamic chord
f	predominate frequency of pressure fluctuations, cps

APPARATUS AND TESTS

Tunnel

The fluctuating pressure measurements reported herein were made on a model in the Langley 16-foot transonic tunnel. A detailed description of the tunnel, its operation, and calibration are presented in reference 2.

Model

General description.- The wing-fuselage model used in this investigation is the same model used in the investigation of references 3 and 4. The wing has NACA 65A006 airfoil sections parallel to the airstream, a taper ratio of 0.6, an aspect ratio of 4, and a sweep of the quarter-chord line of 45°. The fuselage is a transonic body of revolution of basic fineness ratio 12, but was cut off at the rear in order to attach the model support sting thus giving a fineness ratio of 10. The model is supported near the center of the tunnel on the sting as shown in figures 1 and 2. Details of the support system are given in reference 3.

Basic and wing-aft configurations.- For the basic configuration the wing was mounted to the fuselage with the quarter-chord station of the wing mean aerodynamic chord at the longitudinal station of maximum fuselage diameter, (the 60-percent-fuselage station). In a second configuration, designated the wing-aft configuration, the quarter-chord station of the wing mean aerodynamic chord was located $1.197\bar{c}$ to the rear of the longitudinal station of maximum fuselage diameter (see fig. 1).

Leading-edge modifications.- After completion of tests of the basic and wing-aft configurations, modifications were made to the basic configuration by the addition of leading-edge slats and, later, leading-edge chord-extensions. The leading-edge slats extended from 54 percent wing semispan to 99 percent wing semispan, had 0° deflection with respect to the wing chord, and were extended 9 percent of the wing chord with a 1.1-percent-wing-chord gap. The leading-edge chord-extensions were extended 15 percent of the wing chord from 65 percent wing semispan to

99 percent wing semispan with 0° deflection. Dimensional details of all four configurations are given in figure 1.

Instrumentation

Pressure fluctuations were measured at eight positions on the fuselage and one position on each wing with electrical pressure gages of the type described in reference 5. The gage locations are indicated in figure 1. The measurements on the fuselage were made at station 55 and 88.5 percent of the fuselage length in each quadrant of the body. Those at the 55-percent-fuselage station were each 35° from the vertical plane of symmetry, whereas those at the 88.5-percent-fuselage station were each 45° from the vertical plane of symmetry. Each of the eight electrical pressure gages on the body was referenced to a common steady pressure.

The pressure gages in the wings were located at the 80-percent-chord station at the 90-percent-semispan station and were installed to indicate the variation in pressure between the upper and lower surfaces of the wings at the gage location. The electrical signals from all gages were amplified and recorded by a recording oscillograph.

Reduction of Data

For each test point the visual average of the maximum peak-to-peak pressure fluctuation was determined for each of the 10 electrical pressure gages from the oscillograph records as shown in figure 3 for a typical record. Because pressure fluctuations of about the same amplitude were obtained from pressure gages which were mirror images of each other with respect to a vertical plane through the longitudinal center line of the model, data obtained from such gages were averaged together. The measured pressure fluctuations were converted to nondimensional coefficients by dividing the value of the pressure fluctuation by free-stream dynamic pressure. As discussed in reference 1, errors due to nonlinearity of the galvanometer elements, reading of the records, and calibrations are such that the pressure fluctuation coefficients presented in this paper are believed to be approximately 10 to 20 percent too low. The data are also difficult to repeat because of the unstable nature of the flow over the model when shocks and separation occur.

For some test conditions, frequency analyses were made of the signals from some of the electrical pressure gages. The analyzer and amplifier system as used for these tests had a lower frequency limit of about 10 cycles per second and an upper frequency limit of about 1,000 cycles per second, although usually the frequency analyses were made only over the lower frequency range of from 10 cycles per second to 150 cycles per second. For reasons discussed in reference 1, the amplitude of the root-mean-square pressure fluctuation indicated at any particular frequency by the frequency analyzer may be subject to large errors. No attempts were made to correct these amplitudes because the purpose of making the frequency analyses was to determine if the pressure flucutations at the pressure-gage location were occurring at any particular frequency. The frequency scales on the frequency analysis plots, however, are believed accurate to within ±2 or 3 cycles per second on the 10- to 150-cycles per second frequency range and ±20 or 30 cycles per second on the 100- to 1,000-cycles per second frequency range.

Test Conditions

Data were obtained at 13 Mach numbers, which are believed accurate to ±0.005, over a range from 0.6 to 1.03. At a Mach number of 0.60, data were obtained at 2° increments in angle of attack from -2° to 26°. As the Mach number was increased to 1.03, the upper limit of the angle-of-attack range was reduced to 8° because of load limitations on the model support system. The angles of attack presented are believed accurate to ±0.1° (see ref. 3).

Figure 4 shows the Reynolds number range to be from 4.8×10^6 to 6.7×10^6. These values are based on the wing mean aerodynamic chord of 1.531 feet.

Free-stream relative humidity was calculated for each test point and is believed low enough to have little or no effect on the data presented (see ref. 3).

RESULTS AND DISCUSSION

Pressure Fluctuations

Pressure fluctuations on the body.- The wing was in the same position relative to the fuselage for the basic configuration, the leading-edge slat configuration, and the leading-edge chord-extension configuration. Because the leading-edge modifications were made well outboard on the wing, it is reasonable to expect the amplitude of the pressure fluctuations on the fuselage to be about the same for the three above-mentioned configurations. The differences in the data shown in figure 5 for these three configurations are therefore an indication of the scatter in the data. The data obtained for the leading-edge slat configuration are believed to be more accurate than those obtained for the other configurations when the amplitude of the pressure fluctuations is small. For tests of the leading-edge slat configuration the amplification was adjusted at each test point to keep the deflections on the oscillograph to within certain limits. For tests of other configurations, the amplification was held constant and when the pressure fluctuations were relatively small, the deflections on the oscillograph were too small to be read accurately.

An examination of the data presented in figure 5 indicates that the pressure fluctuations on the fuselage were relatively large only at the forward upper gage location (fig. 5(a)) at Mach numbers from 0.60 to 0.92 with the wing in the forward or normal position (basic, leading-edge slat, and leading-edge chord-extension configurations). These relatively large pressure fluctuations are caused by the presence of the wing as the forward gages on the body were at the 56-percent-wing-root-chord station when the wing was in the normal position (see fig. 1). With the wing in the aft position the pressure fluctuations at the forward upper gage location remained relatively small for all test conditions because the gages were well ahead of the wing. At Mach numbers above 0.92 the pressure fluctuations at the forward upper gage location were relatively low for all four configurations at all angles of attack tested probably because any flow disturbances on the wing near the body had moved rearward of the 56-percent-wing-root-chord station.

The pressure fluctuations on the body at the aft location of the pressure gages (figs. 5(c) and (d)) were usually relatively small for all four model configurations. The location of the wing had no noticeable effect on the pressure fluctuations at the aft location of the pressure gages even though the static pressure diagrams presented in reference 4 for the wing-aft configuration indicated that the static pressures measured at the aft location of the pressure gages were influenced by the presence of the wing for some test conditions.

Pressure fluctuations on the wings.- The peak-to-peak pressure fluctuations measured between the upper and lower surfaces on the wings at one location (80-percent-chord, 90-percent-semispan station) for the four model configurations are presented in figure 6 as a function of angle of attack for various constant Mach numbers. Although the pressure gages were installed on the wings to measure the difference in pressure between the upper and lower surface of the wing at the gage location, it is believed that most of the pressure fluctuations occurred on the upper surface of the wings (see ref. 6). At all Mach numbers at which tests were made the data for the basic and wing-aft configurations are in approximate agreement. The values of angle of attack at which the pressure fluctuations began to increase are in fair agreement with each other and the angle of attack at which the pressure fluctuation coefficients are maximum agree at all but a few Mach numbers.

In reference 1, where pressure fluctuations measured near the trailing edge of an unswept wing are reported, the decrease which occurred in the amplitude of the pressure fluctuation coefficients as the angle of attack was increased beyond the value at which the pressure fluctuation coefficients were maximum was attributed to a forward movement of the shock location. In the present tests, the loading (as indicated by the difference between upper-surface and lower-surface static pressure coefficients) at the pressure-gage location seems to have a greater effect than the shock location on the amplitude of the pressure fluctuations. Pressure distributions presented in reference 4 indicate that at each test Mach number the loading at the pressure-gage location is greater for an angle of attack of 8° than for other angles of attack tested. Similarily, the magnitude of the pressure fluctuations measured in the present tests was usually larger at an angle of attack of 8° than at other angles of attack for the basic and wing-aft configurations (fig. 6).

The fluctuating flow characteristics of the basic wing at the 90-percent-semispan, 80-percent-chord station were generally improved by the addition of the leading-edge slats to the basic configuration, whereas the addition of the leading-edge chord-extension to the basic configuration generally impaired the fluctuating flow characteristics of the basic wing at this one station.

The reason why the leading-edge slat configuration should have a marked advantage over the leading-edge chord-extension configuration in reducing the level of the pressure fluctuations at the low angles of attack and delaying the angle of attack at which the rise in pressure fluctuation occurs is not known. A study of the static pressure diagrams obtained for these two configurations at the outboard stations of the wing does not indicate any large differences in shock location or loading which could account for the noted differences in pressure fluctuation coefficients.

The lift coefficient at which various constant values of pressure fluctuation coefficient occur at the location of the pressure gages on the wings over the test Mach number range is plotted in figure 7. These intensity plots further emphasize the differences in pressure fluctuation coefficients at the gage locations for the various configurations. At the lower Mach numbers, as the lift coefficient is increased, a given value of pressure fluctuation coefficient occurs first for the leading-edge chord-extension configuration, at a slightly higher lift coefficient for the basic and wing-aft configurations and at a considerably higher lift coefficient for the leading-edge slat configuration. As the Mach number is increased, the differences in pressure fluctuation coefficient for the various configurations decrease and consistent differences disappear at the highest Mach numbers.

It is emphasized that the results presented herein concerning the effects of the leading-edge modifications on the pressure fluctuations on the wing are for one gage location only and may not be a true picture of the effect of the leading-edge devices on the flow fluctuations over the entire wing.

Contrary to the findings reported in reference 1, the shapes of the intensity plots shown in figure 7 are not similar to the shapes of airplane buffet-boundary curves. While it is realized that the chances of obtaining aerodynamic forcing functions for a wing with only one measuring station are nil, it was believed that the intensity plots should bear some resemblance to airplane buffet-boundary curves and buffet-intensity curves. It appears, however, that, perhaps due to the complex flow which occurs on swept wings (particularly at the outboard stations), measurements at the location of the gage in the present tests are not at all representative of the flow occurring elsewhere on the wing. It is obvious that if representative aerodynamic forcing functions are to be measured on three-dimensional models, a relatively large number of electrical pressure gages are required so that localized flow disturbances are properly weighed.

Frequency Analyses

Pressure fluctuations on the body.- Shown in figure 8 are representative frequency analyses of the pressure fluctuations which occurred on the body during the tests described herein. Both frequency analyses were obtained at a Mach number of 0.80 and at an angle of attack of 8° for the basic model. The ordinate scale is logarithmic with each small division representing 1 decibel. The value of root-mean-square pressure fluctuation for any line on the ordinate scale can be determined from

$$\Delta p_1 = \Delta p_0 (10)^{n/20}$$

where Δp_1 is the amplitude of the root-mean-square pressure fluctuation n decibels above the base line and Δp_0 is the amplitude of the root-mean-square pressure fluctuation indicated for the base line on each frequency analysis.

Although the frequency analyses shown in figure 8 are typical of those obtained from pressure fluctuations on the body during the present investigation, the maximum amplitude at any gage location did not always occur at the same frequency as the test conditions were varied. A study made of the frequency analyses of the pressure fluctuations on the body indicated that there was no apparent correlation between the frequency at which the pressure fluctuations were maximum and Mach number or angle of attack. Instead, the frequency at which the pressure fluctuations were maximum varied from 10 cycles per second to 150 cycles per second in a random fashion in regard to Mach number or angle of attack.

A study of the pressure fluctuations measured on the tunnel wall during calibration of the tunnel indicated that at Mach numbers up to 0.80 the variation of predominate frequency of pressure fluctuations at the tunnel wall with Mach number was about linear with a relation

$$f \approx 50M$$

being applicable. At Mach numbers of 0.85 and above, the predominate frequency was usually between 55 and 70 cycles per second.

A study of approximately 150 frequency analyses of pressure fluctuations on the body indicated that for about one-half of these analyses the predominate frequencies at which pressure fluctuations were occurring on the body were in approximate agreement with those previously measured on the tunnel wall. This agreement could not be predicted from the test conditions, for at any Mach number predominate frequencies measured on the body were spread over a wide range and did not follow any set pattern. The pressure fluctuations measured on the tunnel wall during the present tests were always smaller than those measured on the body but were in some cases as large as about 80 percent of the smaller pressure fluctuations measured on the body.

It is believed though that the effects of fluctuations in the tunnel stream on the fluctuations on the body are small because pressure fluctuations measured in the center of the tunnel stream with the model removed were found to be only about 1/5 the magnitude of those measured on the tunnel wall. Also if the pressure fluctuations in the stream were large enough to greatly affect the measurements on the body, agreement between the frequencies measured on the wall and on the model would be expected to occur with more regularity than it did in the present tests.

The natural frequency of the model and internal balance on the support system was of the order of 10 cycles per second. As a predominate frequency of 10 cycles per second was not consistently noted, the effects of the model shaking on the support system on the pressure fluctuations on the models must be small.

Pressure fluctuations on the wings.- Presented in figure 9 are typical frequency analyses of pressure fluctuations which occurred on the wings of the model during the present tests. As was found in reference 1, pressure fluctuations on the wings at the location of the pressure gages were random with respect to time with pressure fluctuations occurring at all frequencies within the range of the analyzing equipment (10 to 1,000 cycles per second). The only changes noted in the frequency analyses as the test conditions were varied were an increase or decrease in the general level of the data. This variation in general level of the data was in agreement with data presented in figure 6, as would be expected.

Varying the model configuration from that of the basic model similarly had no effect on the frequency analyses except to change the level of the data in agreement with results shown in figure 6.

CONCLUSIONS

From a study of the pressure fluctuations measured on the wings and body of four configurations of a sweptback wing-body combination in the Langley 16-foot transonic tunnel, the following conclusions can be made.

1. The pressure fluctuations measured on the body were usually relatively small for all test conditions except at the forward upper gage location when these gages were in the influence of the flow over the wing (all configurations except wing aft). The fluctuating flow which is believed to be the cause of buffeting therefore acts not only on the exposed wing area, but also on the fuselage in the vicinity of the wing.

2. The position of the wing on the fuselage had little effect on the flow fluctuations measured well outboard on the wing near the wing trailing edge (90-percent-semispan, 80-percent-chord station).

3. The fluctuating flow characteristics of the basic wing at the 90-percent-semispan, 80-percent-chord station were generally improved by the addition of the leading-edge slats to the basic configuration, whereas the addition of the leading-edge chord-extensions to the basic configuration generally impaired the fluctuating flow characteristics of the basic configuration at this station. Because the flow fluctuations were measured at only one station on the wings, the results obtained may not be indicative of the effect of leading-edge devices on the fluctuating flow over the entire wing surfaces.

4. Pressure fluctuations on the body usually occurred at some predominate frequency which, however, could not be consistently correlated with the test conditions.

5. Pressure fluctuations on the wings were found to be random with respect to time with pressure fluctuations of about equal amplitude occurring at all frequencies investigated (10 to 1,000 cycles per second).

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

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1. Habel, Louis W., and Steinberg, Seymour: Measurements of Fluctuating Pressures on a 1/4-Scale Model of the X-1 Airplane With a 10-Percent-Thick Wing in the Langley 16-Foot Transonic Tunnel. NACA RM L52J31, 1953.

2. Ward, Vernon G., Whitcomb, Charles F., and Pearson, Merwin D.: Air-Flow and Power Characteristics of the Langley 16-Foot Transonic Tunnel With Slotted Test Section. NACA RM L52E01, 1952.

3. Hallissy, Joseph M., and Bowman, Donald R.: Transonic Characteristics of a 45° Sweptback Wing-Fuselage Combination. Effect of Longitudinal Wing Position and Division of Wing and Fuselage Forces and Moments. NACA RM L52K04, 1953.

4. Solomon, William, and Schmeer, James W.: Effect of Longitudinal Wing Position on the Pressure Characteristics at Transonic Speeds of a 45° Sweptback Wing-Fuselage Model. NACA RM L52K05a, 1953.

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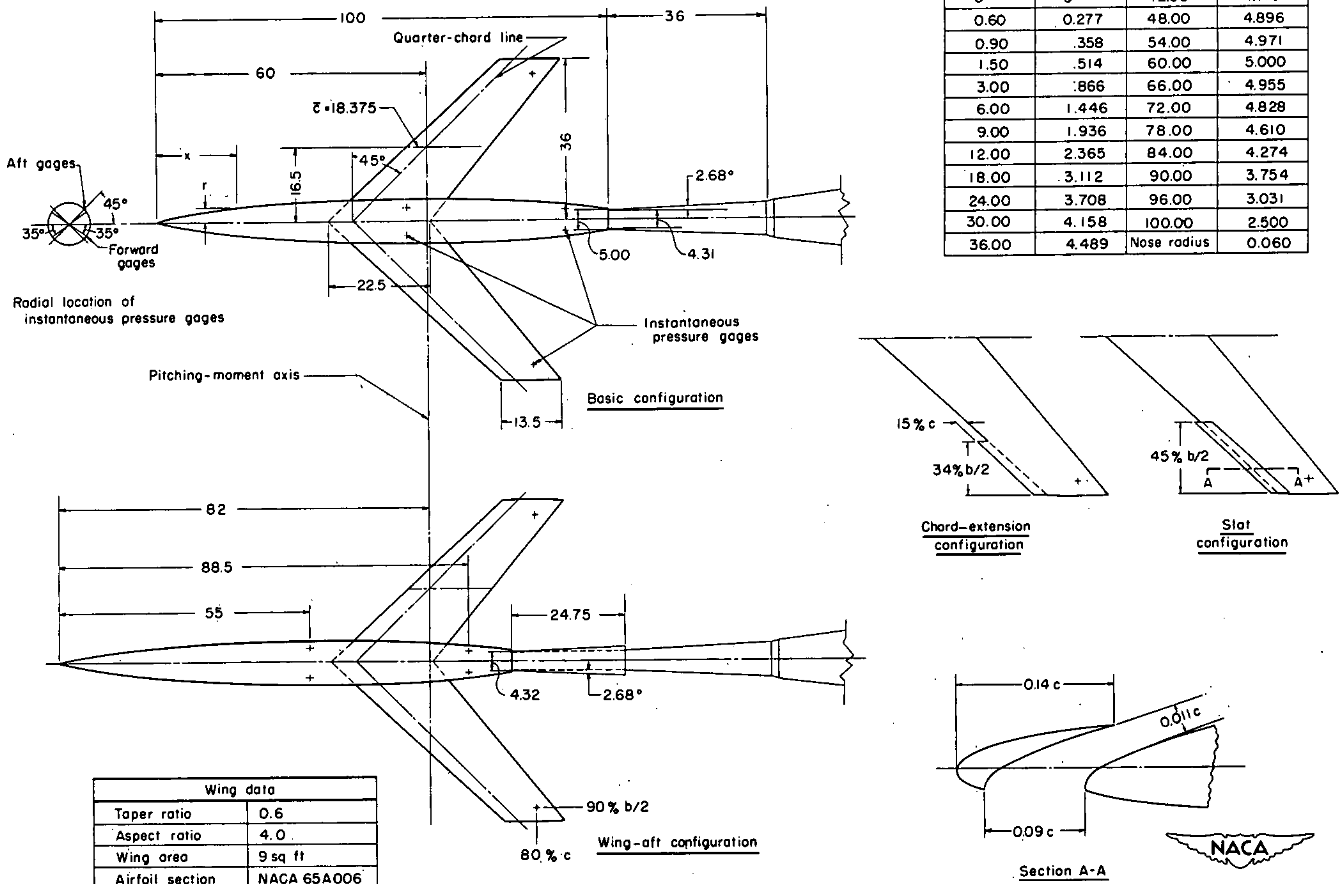

Fuselage ordinates			
x	r	x	r
0	0	42.00	4.719
0.60	0.277	48.00	4.896
0.90	.358	54.00	4.971
1.50	.514	60.00	5.000
3.00	.866	66.00	4.955
6.00	1.446	72.00	4.828
9.00	1.936	78.00	4.610
12.00	2.365	84.00	4.274
18.00	3.112	90.00	3.754
24.00	3.708	96.00	3.031
30.00	4.158	100.00	2.500
36.00	4.489	Nose radius	0.060

Wing data	
Taper ratio	0.6
Aspect ratio	4.0
Wing area	9 sq ft
Airfoil section	NACA 65A006 parallel to plane of symmetry

Figure 1.- Model dimensions and arrangement. Basic, wing-aft, leading-edge chord-extension, and leading-edge slat configurations. All dimensions are in inches.

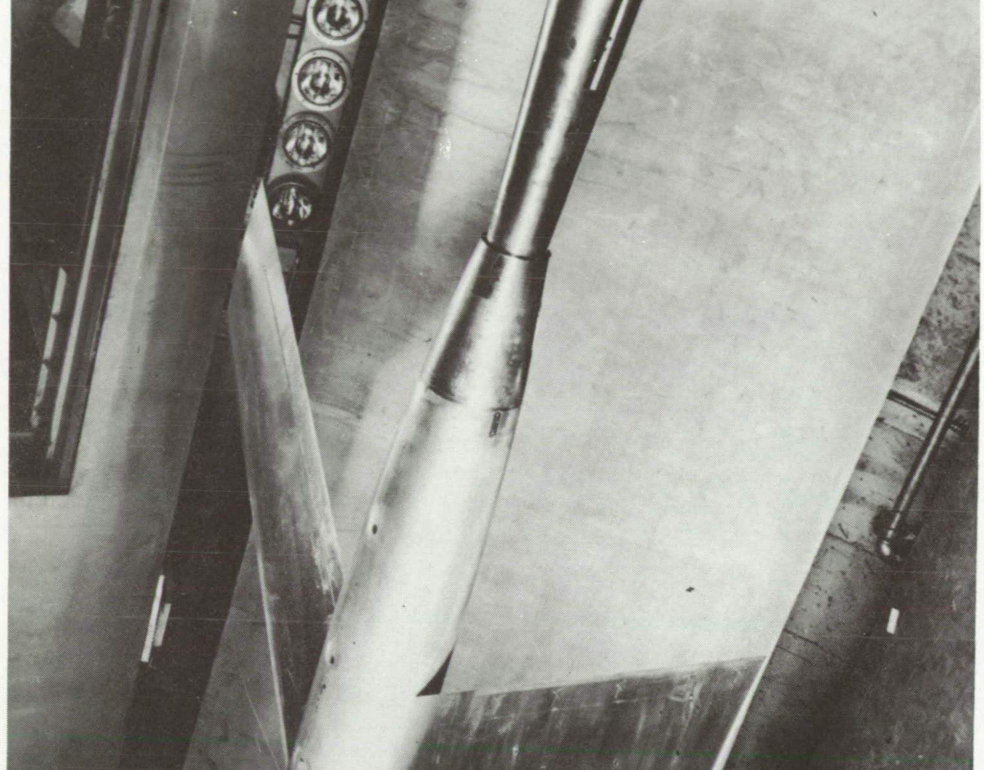

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Figure 2.- Basic model installed in the Langley 16-foot transonic tunnel test section.

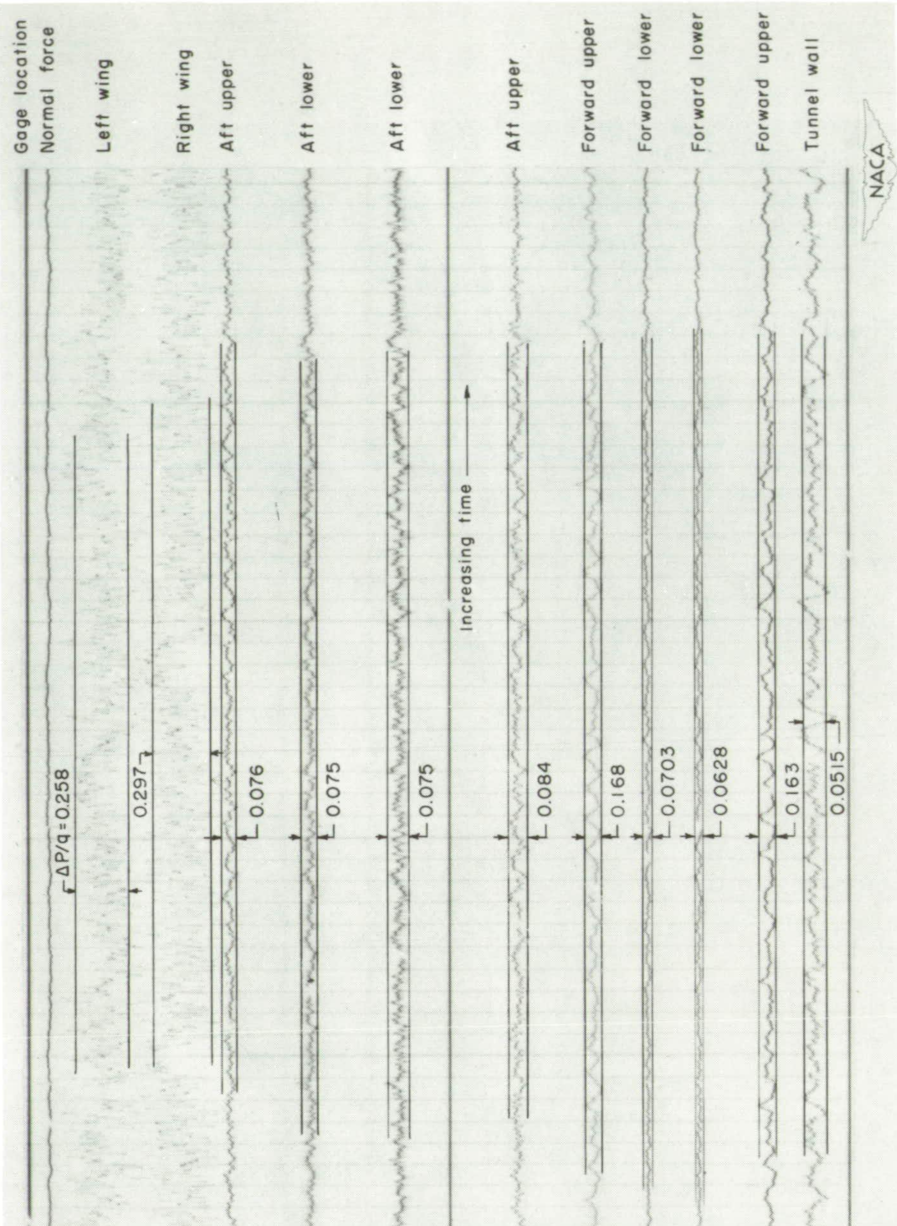


Figure 3.- Portion of typical oscillograph record. Basic configuration; angle of attack, 8°; Mach number, 0.80.

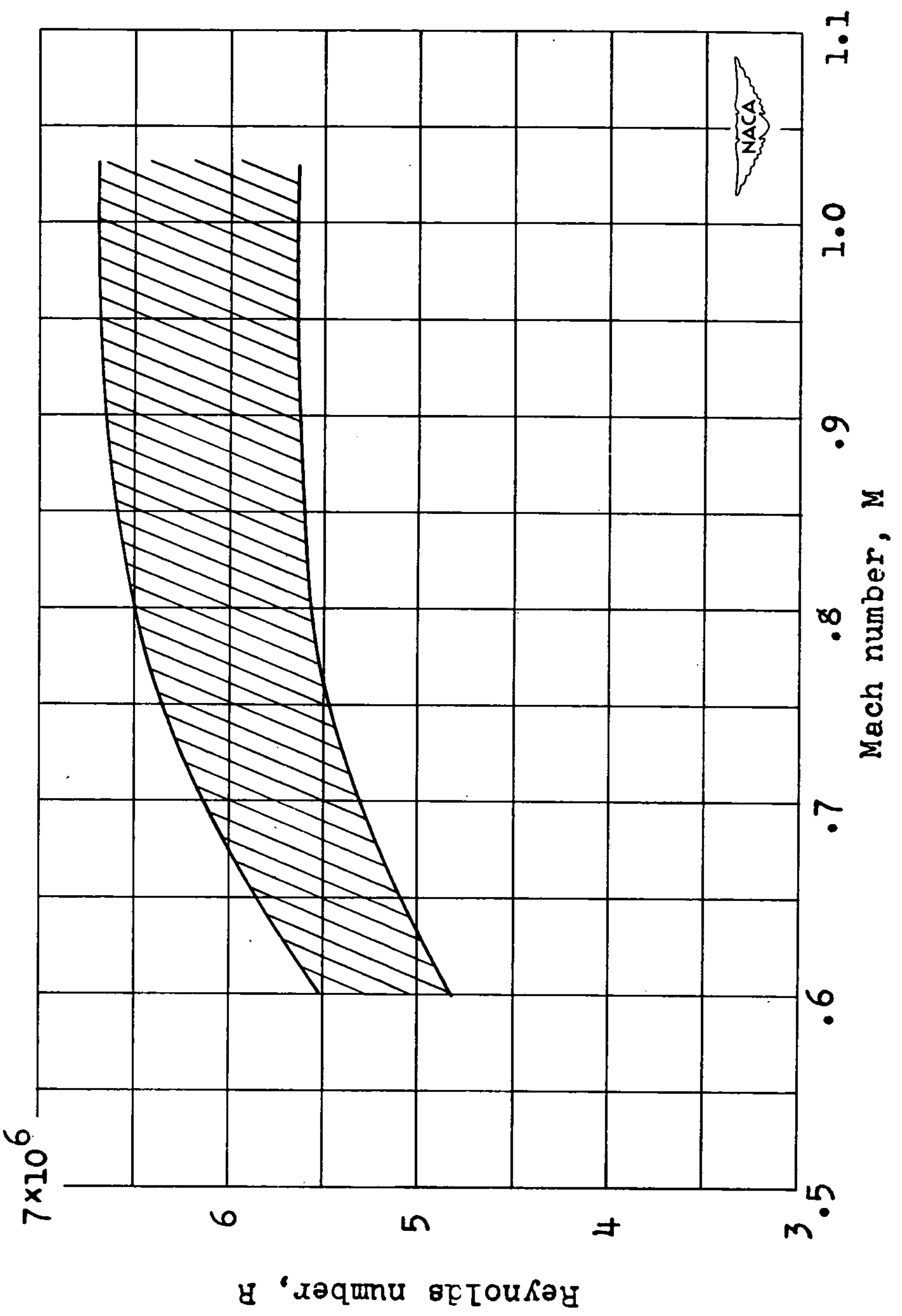
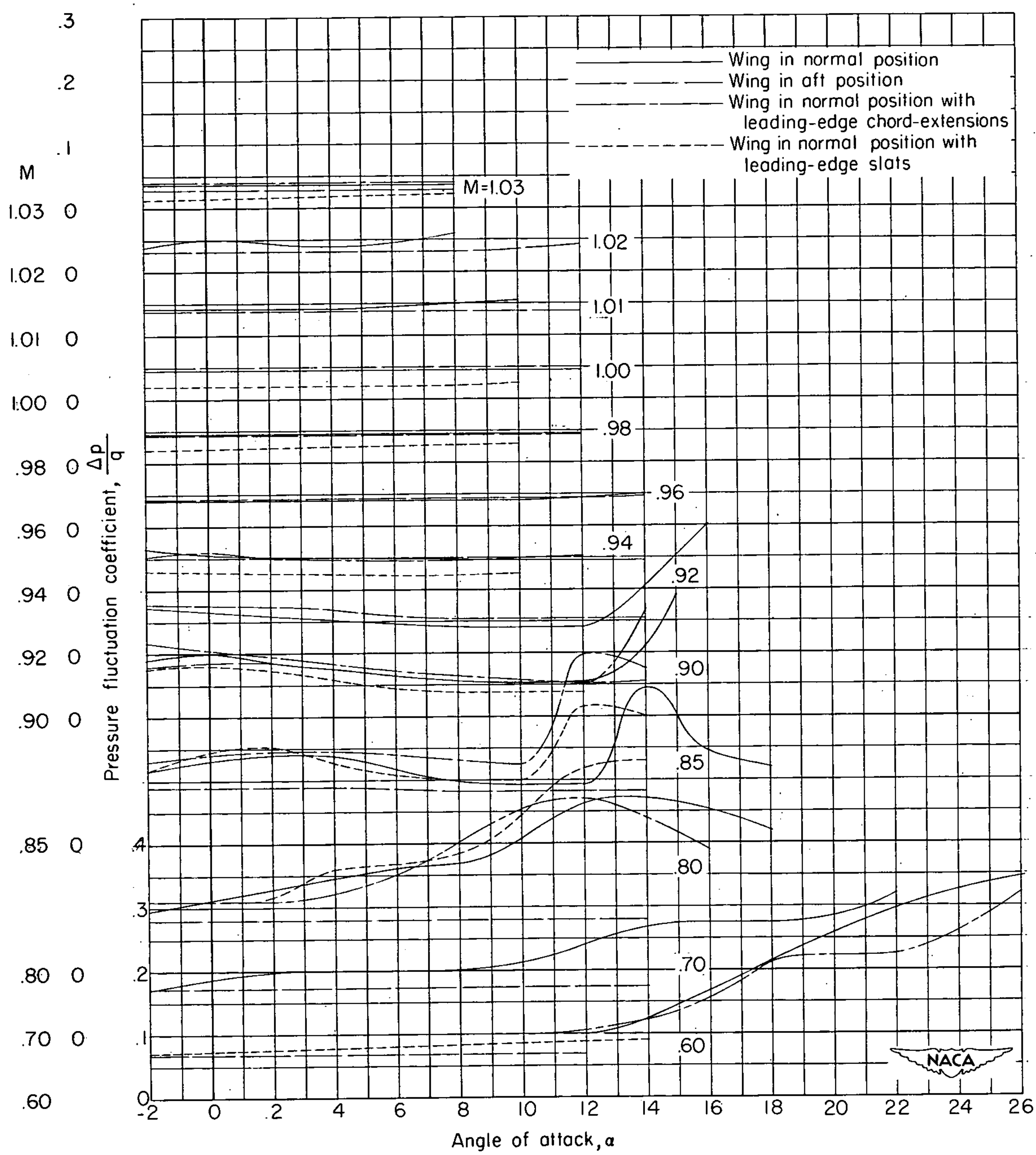
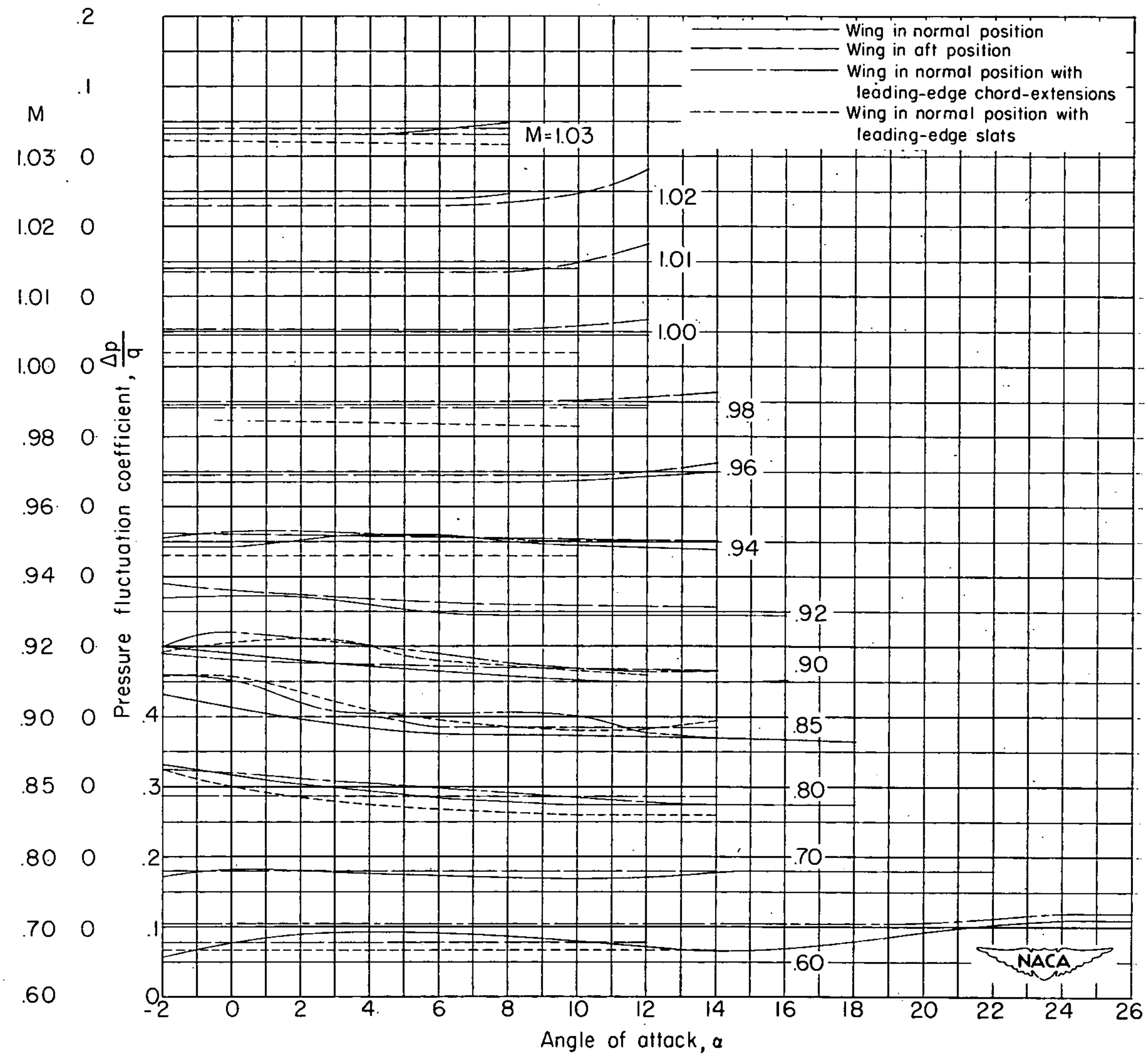


Figure 4.- Reynolds number range based on the wing mean aerodynamic chord.



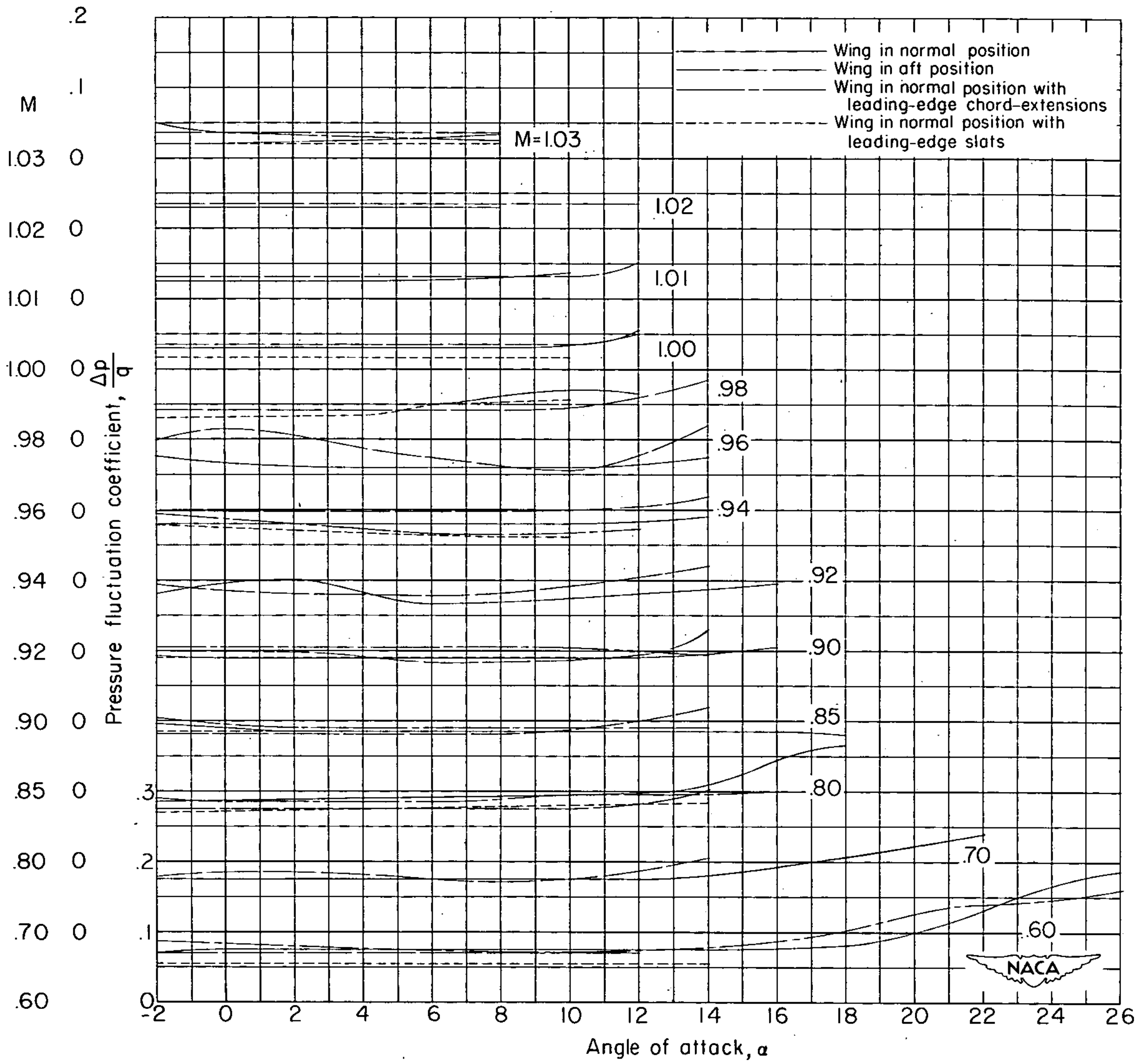
(a) Forward upper gage location.

Figure 5.- Variation of pressure fluctuation coefficient on the body with model angle of attack at constant Mach numbers.



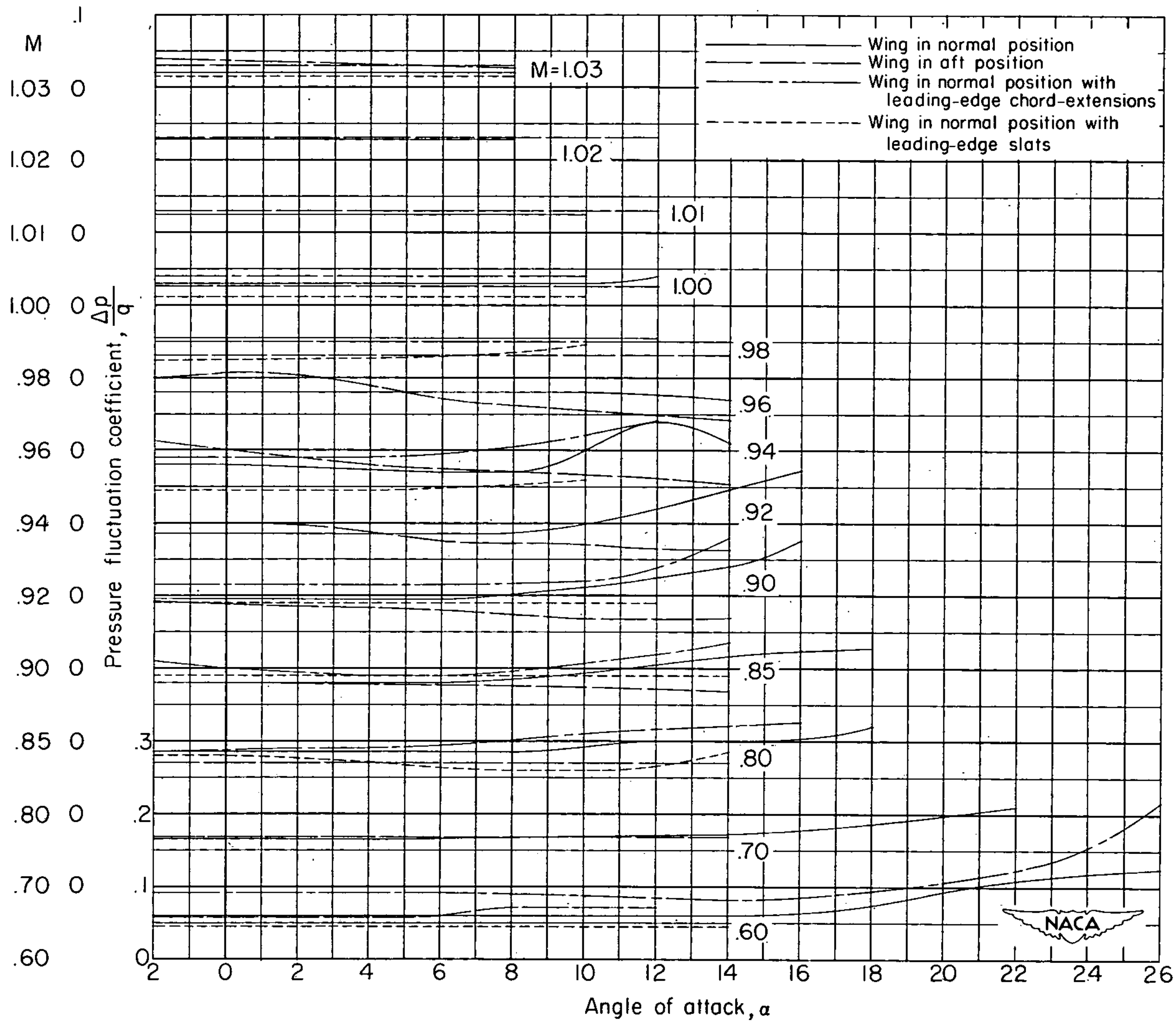
(b) Forward lower gage location.

Figure 5.- Continued.



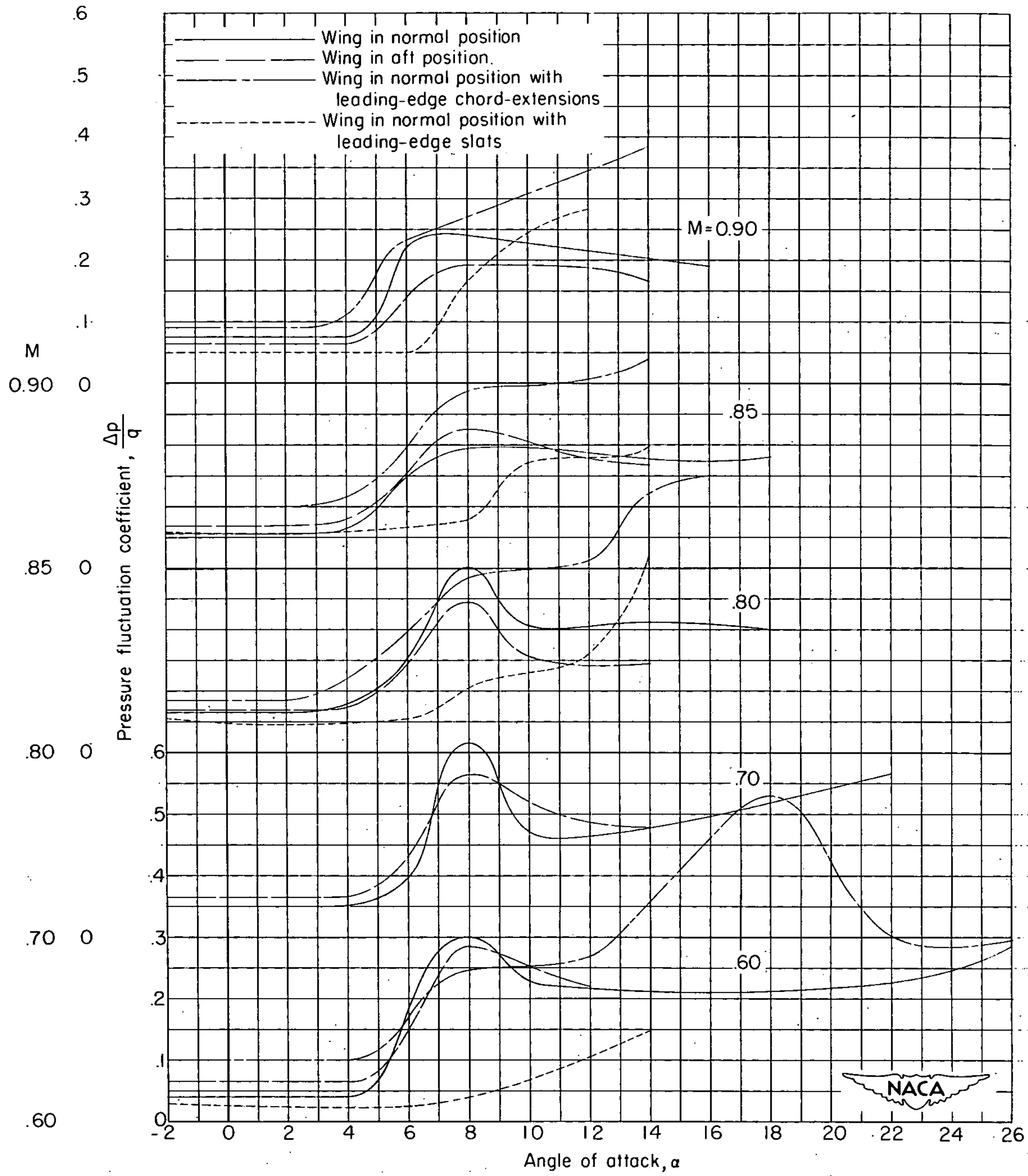
(c) Aft upper gage location.

Figure 5.- Continued.



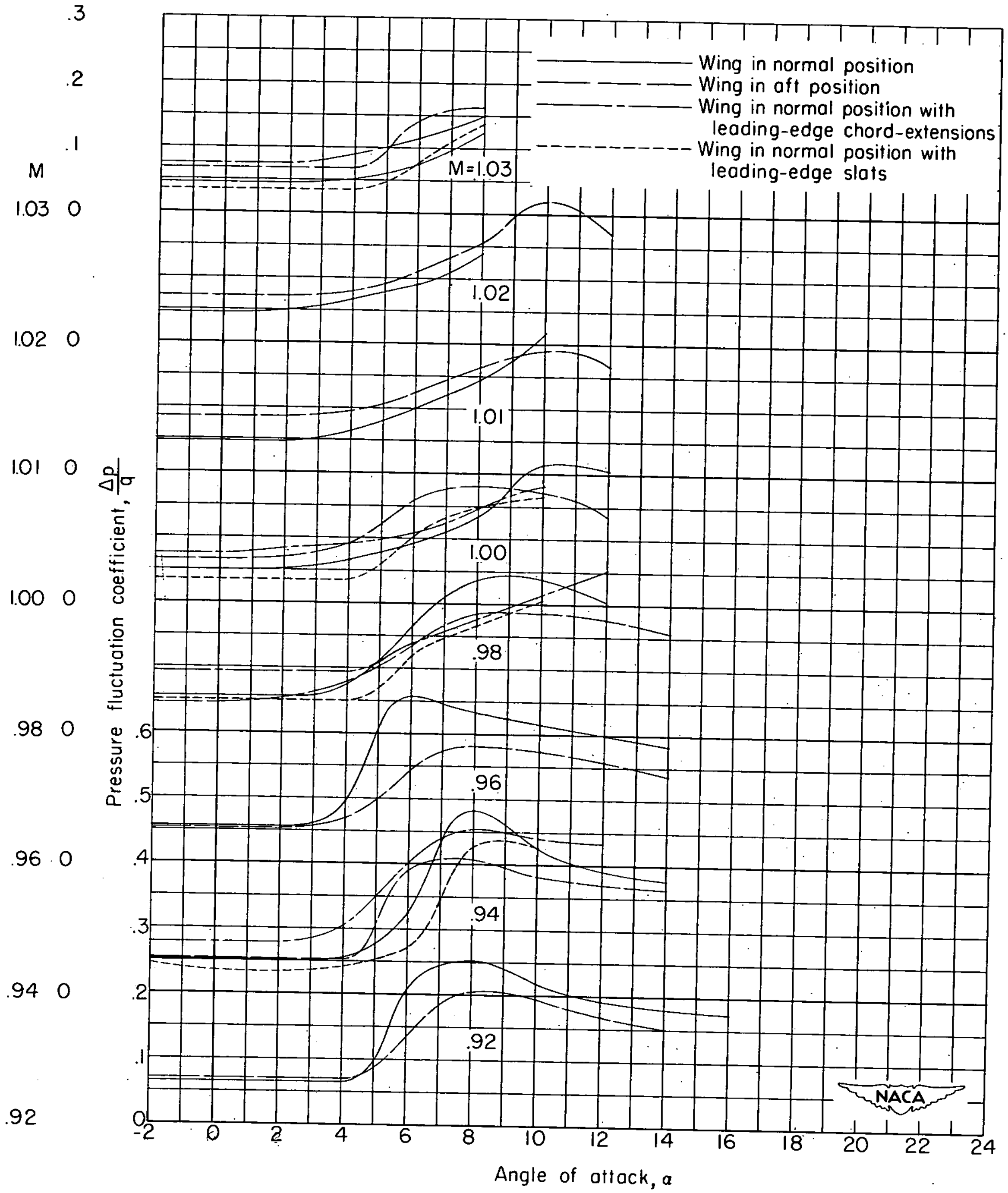
(d) Aft lower gage location.

Figure 5.- Concluded.



(a) Mach numbers from 0.60 to 0.90.

Figure 6.- Variation of pressure fluctuation coefficient at one point on the wing with model angle of attack at constant Mach numbers.



(b) Mach numbers from 0.92 to 1.03.

Figure 6.- Concluded.

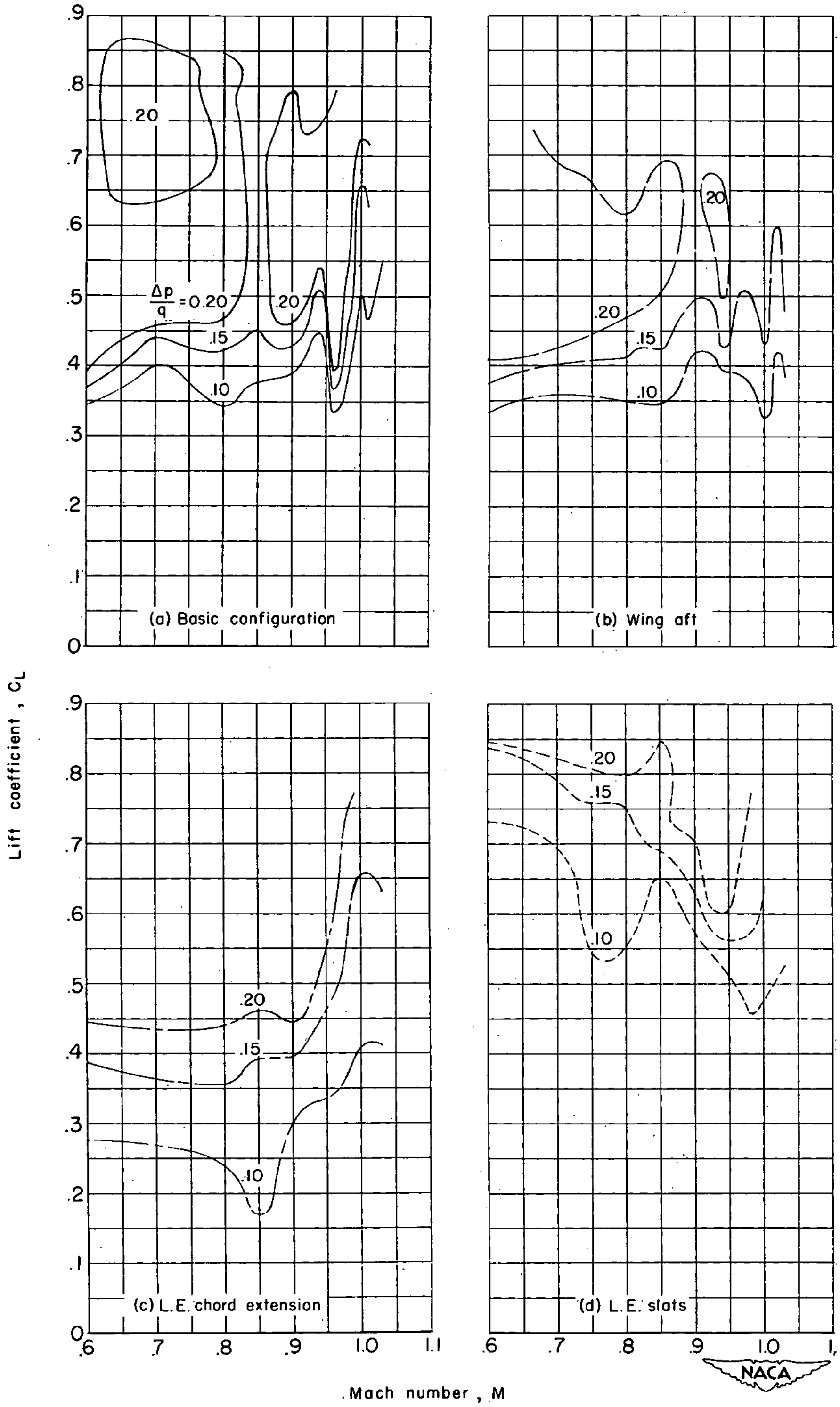
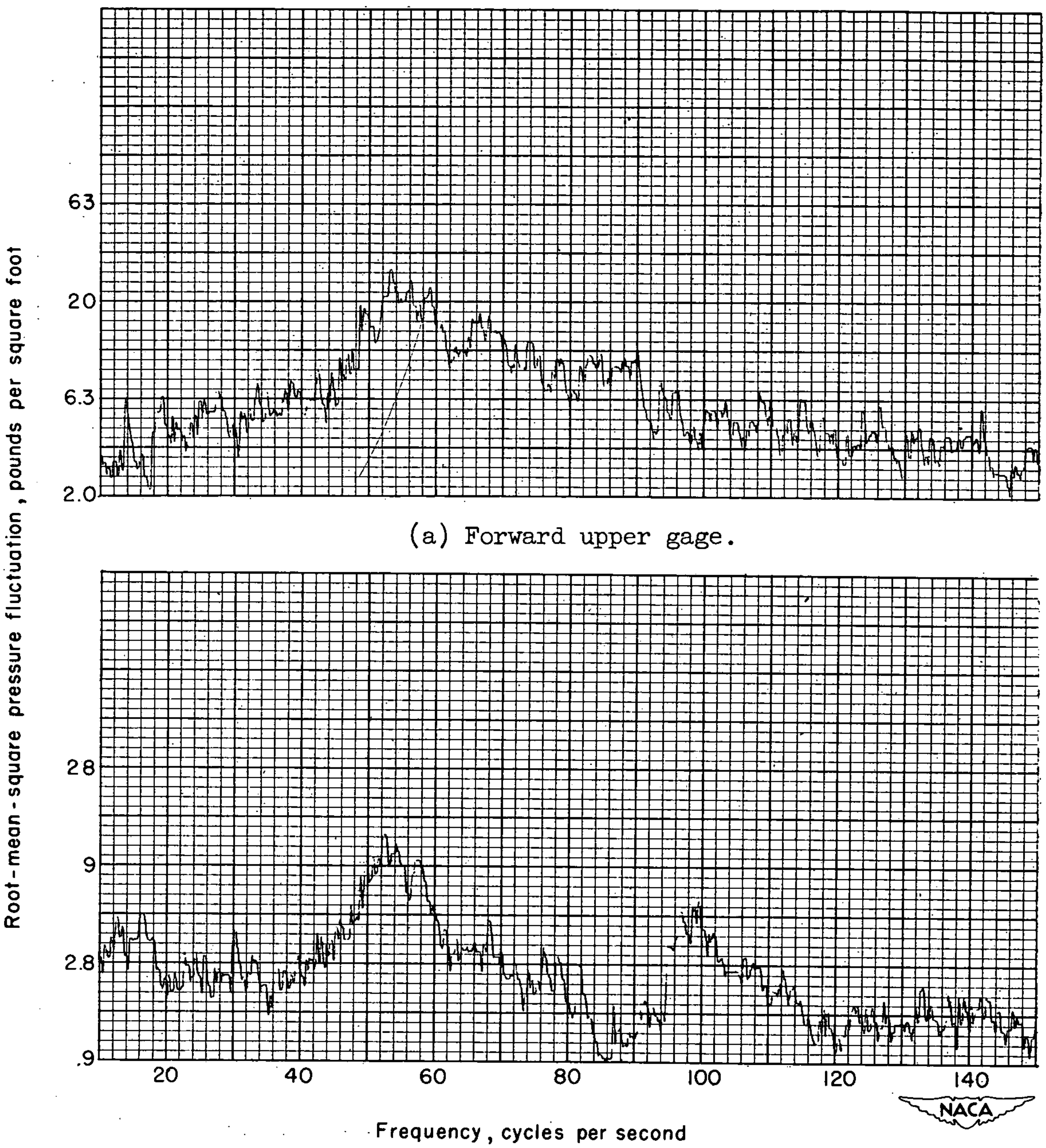


Figure 7.- Variation of lift coefficient with Mach number for constant values of pressure fluctuation coefficient at the location of the wing gage.



(a) Forward upper gage.

(b) Aft upper gage.

Figure 8.- Typical frequency analyses of pressure fluctuations on the body for the basic configuration. Angle of attack, 8°; Mach number, 0.80.

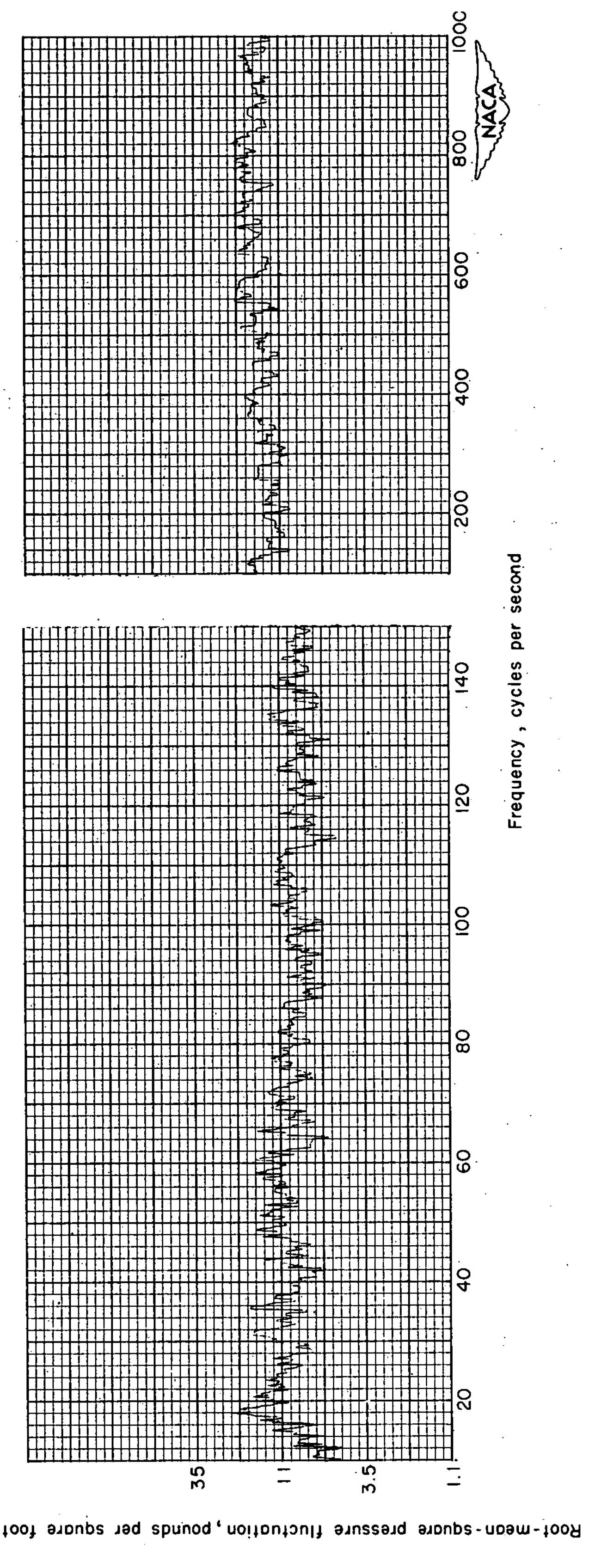


Figure 9.- Typical frequency analysis of pressure fluctuation on the wing for the basic configuration. Angle of attack, 8°; Mach number, 0.80.

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