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SOME BUFFET RESPONSE CHARACTERISTICS OF A TWIN-VERTICAL-TAIL CONFIGURATION

By

Stanley R. Cole, Steven W. Moss, and Robert V. Doggett, Jr.

SUMMARY

A rigid, 1/6-size, full-span model of an F-18 airplane was fitted with flexible vertical tails of two different levels of stiffness. These tails were buffet tested in the Langley Transonic Dynamics Tunnel. Vertical-tail buffet response results that were obtained over the range of angles of attack from -10° to +40° degrees, and over the range of Mach numbers from 0.30 to 0.95 are presented. These results indicate the following: (1) the buffet response occurs in the first bending mode; (2) the buffet response increases with increasing dynamic pressure, but changes in response are not linearly proportional to the changes in dynamic pressure; (3) the buffet response is larger at M=0.30 than it is at the higher Mach numbers; (4) the maximum intensity of the buffeting is described as heavy to severe using an assessment criteria proposed by another investigator; and (5) the data at different dynamic pressures and for the different tails correlate reasonably well using the buffet excitation parameter derived from the dynamic analysis of buffeting.

INTRODUCTION

Randomly varying pressures produced by such phenomena as separated flow, shock wave boundary layer interaction, and wake flows can produce significant buffeting structural response of an airplane empennage. The internal structural loads resulting from these responses are important for two reasons. First, the magnitude of the loads when added to loads from other sources can approach limiting values. Second, the random nature of the loading can adversely affect the fatigue life of the structure.

There has been considerable interest in empennage buffeting over the years, beginning with the crash of the Junkers F13 low-wing monoplane at Meopham, England, on a blustery July 21, 1930. British scientists blamed this accident on horizontal tail buffeting[1] whereas independent German studies cited wing failure due to excessive dynamic loads produced by gust and/or an abrupt pull-up maneuver.[2] During the 1930's there was considerable interest in empennage buffeting in Europe[3,4,5,6] and in the United States.[7,8] (The references cited in this paragraph are intended to be only a representative sample of what is available in the open literature.) A lot of this interest was apparently precipitated by the Junkers crash. During World War II there were a number of empennage buffeting studies conducted. Most of these were devoted to understanding and curing the empennage buffeting problems that had been identified for a variety of fighter airplanes.[9,10] At the conclusion of the war buffeting studies were refocused on research although wind-tunnel tests and flight tests of specific airplanes still played a significant role.[11,12,13,14,15] Even though a large proportion of empennage buffeting studies have focused on military airplanes, that does not mean that it is something that can be ignored for commercial airplanes as the tail damage due to buffeting that occurred for a DC-10 so emphatically attests.[16]

Although horizontal tail buffeting has been a significant focus in the past, operational experiences with twin-vertical-tail fighter airplane configurations of United States design have resulted in significant buffet-like response of the vertical tails. Consequently there is considerable current interest in gaining a better understanding of this type of buffeting. The buffet response of twin vertical tails appears to fit into two different categories. The first category is buffeting response produced by wake flows emanating from the upstream fuselage and wing. This type of buffet excitation is somewhat similar to the horizontal tail buffeting observed in the past in that the vertical tail is submerged, so to speak, in a wake of turbulent flow produced by deterioration of the flow as it passes over the forward fuselage and wing. Buffeting of the vertical tails of F-15 fits into this category as does that of the F-14. (Although there are no F-14 buffet data available in the open literature, the authors are aware of some unpublished wind-tunnel and flight test results.) In papers by Triplett[17,18] some measured unsteady pressures on the vertical tails of a wind-tunnel model of the F-15 airplane are presented. This study was undertaken because of some in flight buffet experiences with the F-15. Triplett notes that this airplane experienced large vibrations of the vertical tail during simulated combat maneuvers at high angles of attack. The response of the tails was primarily in the first torsion mode with the maximum response occurring at about 22° angle of attack.

The second category is buffet response produced by vortices emanating from highly swept leading edge extensions of the wing. Because at some flight conditions these vortices burst prior to reaching the vertical tails, the tails are bathed in a wake of very turbulent swirling flow. Buffeting of the vertical tails of the F-18 fits into this category. Relatively large vibrations have been observed during flight operations of this airplane. To assist in understanding better the flow field in the vicinity of the tails of twin vertical tail airplanes susceptible to bursting vortex buffeting, Sellers et al.[19] conducted some three-component velocity surveys for a YF-17 model (a configuration similar to the F-18) at low speeds by using a laser Doppler velocimeter. Their results clearly show that at 25° angle of attack the vortex produced by the wing leading edge extension has clearly burst and that there are large fluctuations in the velocity in the vicinity of the vertical tails. They measured root-mean-square fluctuations as high as 40 percent of the free stream velocity. Some water tunnel studies conducted by Wentz (presented in appendix of ref. 20) using an F-18 model also showed that the vortex produced by the leading edge extension of the wing burst forward of the vertical tails at angles of attack of 25° and higher. If these flows contain substantial energy at frequencies corresponding to the lower modes of vibration of the tail structure, significant structural response can result. A limited amount of F-18 flight data and some wind-tunnel model results are published in reports by Zimmerman, Ferman, et al.[21,22] wherein they discuss the applicability of two methods based on wind-tunnel model measurements that can be used to predict full-scale buffet response. Data presented in these two references show that the buffet response of the F-18 vertical tails was in the first bending (about 15 Hz) and the first torsion (about 45 Hz) modes. The relative individual contributions of the two modes to the total response depends on flow conditions, for example, dynamic pressure. The maximum responses observed occurred at about 30° angle of attack.

Because wind-tunnel model studies have played a significant role in leading to a better understanding of buffeting phenomena,[23,24,25] a wind-tunnel model study was undertaken to provide some buffet response data for a twin tail fighter airplane configuration. To this end a rigid F/A-18 free flight drop model was fitted with elastic vertical tails and wind-tunnel tested in the Langley Transonic Dynamics Tunnel at low speeds as well as at transonic speeds. Two flexible vertical tails of differing stiffness were studied. Although the elastic vertical tails were not dynamically scaled aeroelastic representations of the full scale tails their properties were chosen to be representative of scaled full scale designs. Buffet response data were acquired over the angle of attack range from -10 to +40 degrees at Mach numbers from 0.30 to 0.95. Although low speed twin-tail buffet response data have been published previously by other investigators,[21,22] the transonic results presented herein are believed to be the first publication of transonic buffet response data for an F-18 configuration.

WIND TUNNEL

The wind-tunnel tests were conducted in the Langley Transonic Dynamics Tunnel (TDT). This wind tunnel is used almost exclusively for aeroelastic testing. The TDT is of the single return type, and its speed and stagnation pressure are continuously controllable over a range of Mach numbers from near zero to 1.2 and over a range of pressures from near vacuum to about one atmosphere. Either air or a heavy gas, R12, can be used as the test medium. The gas R12 was used for the present test.

The well known British buffet authority Dennis Mabey[26] has developed a criteria for assessing the suitability of a particular wind tunnel for buffet testing. A wind tunnel with rough flow is less suitable than a wind tunnel with smooth flow. His criteria has been applied to the TDT and the results are presented in figure 1 for the two frequencies at which significant buffet response was obtained in the present study. The ordinate $\sqrt{fF(f)}$ is a nondimensional form of the autospectrum of the randomly varying pressure in the wind tunnel at important natural frequencies of the model being studied. The variable f is the frequency of interest, and the function F(f) is the autospectrum of the unsteady pressure divided by the dynamic pressure squared. Also indicated on the ordinate are adjectives that characterize the suitability of the wind tunnel for two levels of buffeting, light and heavy. These results, when compared to the levels of buffet response presented later, indicate that the wind tunnel is suitable for the present study.

MODEL

The model tested was a 1/6-size model of the F-18 airplane. The primary geometry difference between the model and the airplane is that the model did not have flow thru engine nacelles. A photograph of the model mounted in the wind tunnel is presented in figure 2. The basic model was originally designed for use as a remotely controlled, free-flight drop model to be released from a helicopter. Consequently it was designed to be very stiff because its intended use was for stability and control purposes. In the context of the present study the model can be considered to be "rigid." The original model was modified to make it suitable for the present study by adding internal bracing to increase the model strength (the wind-tunnel loads would be higher than the flight loads) by providing a means for attaching the fuselage to a pylon strut so that the model could be attached to the wind-tunnel sting, and by providing a means for replacing the original rigid vertical tails with flexible tails. Two different flexible vertical tails were built. These flexible tails had the same planform geometry as the original tails, but were not dynamically scaled aeroelastic representations of the full scale F-18 tails. The geometry of the tails is given in figure 3. The difference in the two tails was in stiffness and mass. For convenience the stiffer tail will be referred to hereafter as Tail A; the less stiff tail will be referred to as Tail B.

Construction

Each tail was constructed of a constant thickness aluminum alloy plate that was covered with balsa wood that was shaped to the desired airfoil section, a NACA 65A005 airfoil section at the root linearly tapering to a NACA 65A003 section at the tip. This fabrication concept is illustrated in figure 3. A portion of the aluminum plate was extended inboard of the model root to provide a means for cantilever mounting the tail to the fuselage. Near the leading and trailing edges and near the tip it was necessary to contour the aluminum alloy plate to obtain the desired airfoil section. The thickness of the plate used for Tail A was 0.25 inches; the thickness of the plate used for Tail B was 0.125 inches.

Natural Vibration/Physical Characteristics

Natural frequencies and node lines of the first three modes for both vertical tails were measured. These data are presented in figure 4. The structural damping ratio for all of these modes was a nominal 0.015. Because the node lines for the two tails were virtually identical only the node lines for Tail A are shown. Natural frequencies of other components of the model, for example wing bending, were also determined to ensure that there was no coincidence with the tail modes that would adversely affect the buffet results. These results, although not shown here, indicated that all of the other frequencies were well separated from the tail frequencies. Tail A weighed 5.00 lbs; Tail B weighed 3.34 lbs. These weights do not include the weight of the clamping block.

Instrumentation/Data Acquisition

Each tail was instrumented with a four-active-arm, resistance wire strain gage bridge mounted on the aluminum plate near the root. The gages were calibrated in terms of bending moment. The output signals from the gages was routed to strip chart recorders for visual display, to analog tapes for recording for use in post test analysis, and to a transfer function analyzer for on-line, real-time analysis and display. The transfer function analyzer was used during the test and post test to determine autospectra and root-mean-square values.

TEST CONDITIONS/CONFIGURATIONS

The matrix of test conditions is shown in figure 5 in terms of dynamic pressure q and Mach number M. Contours of constant Reynolds number R_N based on the mean geometric chord are also shown on the figure. The solid circle symbols indicate the test conditions for Tail A. The symbols with the flags denote conditions at which data were acquired for Tail B as well. At each of the conditions buffet response data were acquired in terms of tail root bending moment at each of a number of specific angles of attack. At most of the conditions data were acquired from 10 to 40 degrees angle of attack. At some conditions data were acquired from -10 to 40 degrees angle of attack in two stages, namely, from -10 to +20 degrees and from +10 to +40 degrees. A single continuous variation in angle of attack from -10 to +40 degrees could not be obtained because of the characteristics of the wind-tunnel sting mechanism.

For all tests the ailerons on the wing were locked at the undeflected position. The horizontal tails were set at 8° nose down. A few tests were conducted with the horizontal tails removed. For the angle of attack sweeps from -10 to +20 degrees the leading edge flaps on the wing were set to zero degrees. For the angle of attack sweeps from +10 to +40 degrees the wing leading edge flaps were set to 25° leading edge down. The two different flap setting were used to approximate settings that might be expected to be used for the full-scale airplane.

RESULTS AND DISCUSSION

The buffet response data are presented in terms of the variations with angle of attack of the root-mean-square (rms) bending moment σ and of the buffet excitation parameter β. The parameter β is a direct result of applying the techniques of generalized harmonic analysis to buffet analysis and has been developed by a number of investigators. For instance, see refs. 24 and 27. Mabey[28] has suggested that β be adopted as the AGARD standard in displaying buffet response data. The parameter β is defined by the relationship

$$\beta = \frac{2}{\sqrt{\pi}} \frac{m \ddot{z}}{q S} \zeta^{1/2}$$

where

m = generalized mass,

$\ddot{z}$ = root-mean-square (rms) tip acceleration,

S = reference area,

and

ζ = total (aerodynamic plus structural) critical damping ratio.

Because the tip displacement was not measured directly in the present study it was necessary to calculate the relationship between root bending moment and tip acceleration. Furthermore, because the damping term ζ contains both structural and aerodynamic damping components and the aerodynamic damping was not measured, it was necessary to calculate the aerodynamic damping ratio. The aerodynamic damping ratio was calculated by using the equation for the damping ratio given in Appendix D of ref. 29 with the exception that Theodorsen's incompressible F-function was replaced with compressible values obtained by interpolating values from the curves in figure 41 of ref. 30. (It is recognized, of course, that there are more sophisticated methods available for calculating the aerodynamic damping, but it is believed, however, that the relatively simple approach used here is sufficient for the purposes of the present study.)

General Characteristics

The general character of the buffet characteristics of both tails was the same. In each case the buffet response was concentrated at the frequency of the first bending mode. This is clearly shown by the typical autospectra of the response presented in figure 6. The large peak that occurs for each of the tails is at the frequency f of the first bending mode. A typical variation of the rms root bending moment σ with angle of attack is presented in figure 7. Data are given for both tails. At the lower angles of attack, -10 to +10 degrees, the response is nearly constant and has a low value compared to the maximum value obtained. Beginning at about +10° the response begins to increase rapidly as α is increased until a maximum value of σ is reached in the α = 30 to 40 degrees range. After the peak value is reached the response generally begins to decrease. In some cases however the response tends to level out or to continue a gradual increase in value. The different variations of the trend of the change in σ with changes in α in the region of maximum buffet response can be seen in the data presented in subsequent figures.

The variations of σ with α observed in the present study are similar to those observed by other investigators for a similar configuration[21,22], but the frequency content is not similar. Autospectra presented in refs. 21 and 22 show that the buffet response contains major contributions from the first (bending) and second (torsion) natural modes of the vertical tail (The relative contributions vary with flow conditions) in contrast to the present study where the response was primarily in the first (bending) mode.

Horizontal Tail Effects

For Tail A some data were obtained at M= 0.30, 0.60, and 0.80 with the horizontal tails both on and off. The M=0.30 and M=0.60 results (The M=0.80 results were similar to the M=0.60 results.) are presented in figure 8. For the M=0.30 case the maximum moment is higher with the tail off. At M=0.60 the data are essentially the same whether the horizontal tail is present of not. The reason why the results are different at the two Mach numbers is not fully understood, nor is it clear why the absence of the tail increased the bending moment at the lower Mach number.

Wing Leading-Edge Flap Effects

Although no extensive study was made of the effects of wing leading edge flap setting on the buffeting response, a small effect of flap setting can be seen in the $+10° < \alpha < +20°$ range for the data presented in figure 8. (Data were acquired in this range for both flap settings because of the test procedure used. See discussion in the TEST CONDITIONS/CONFIGURATIONS Section.) The rms bending moment is generally slightly higher for the case where the flaps were set to zero degrees (square symbols) than it is for the case where the flaps were set to 25° leading edge down (circle symbols), although the values are essentially the same at the ends of the range. Because there is so little difference in the two sets of data and the levels are relatively low compared to the maximum values that occur at higher angles of attack, there is no distinction made in subsequent figures between data in this overlap region of angle of attack for the two flap settings. Average values of the data are presented in this angle of attack range whenever full α sweep data, -10 to +40 degrees, are presented.

Dynamic Pressure Effects

The variation of σ with α for Tail A are presented in figure 9 for M= 0.30, 0.60, 0.88 and 0.95. Generally speaking, and as would be expected, the buffet response increases with increasing dynamic pressure. However, the change in buffet response from one value of q to another does not appear to be in direct proportion to the change in q.

Mach Number Effects

By comparing the data at the different Mach numbers presented in figure 9 it is clear that for constant values of q the buffet response is larger at M=0.30 than it is at the higher Mach numbers. For example, a comparison of the data for two of the higher dynamic pressures, q=50 (x symbols) and q=60 (+ symbols), shows that the maximum value of the response is about the same at the three higher Mach numbers, but that this value is only about two-thirds of the maximum value obtained at M=0.30. Apparently the buffet input forces are either more severe at the lower Mach number or there is a better tuning of the frequency of the buffeting forces with the frequency of the first bending mode. Interestingly, Huston and Skopinski[12] observed a decrease in buffet intensity with increasing Mach number for horizontal tail buffeting.

Response Parameter Results

The buffet response data presented in figure 9 have been converted to the buffet excitation parameter β and replotted versus α in figure 10. The data for the different values of dynamic pressure are brought together reasonably well at the three higher Mach numbers by the use of this parameter. For the M=0.30 case, however, the data are not brought together as well. At this Mach number it appears that the data for $q < 20$ psf correlate well and the data for $q > 20$ psf do correlate but not nearly as well.

Severity of Buffeting

Mabey[24] has suggested that an adjective description can be applied to the buffeting intensity depending of the value of β. He has proposed the following:

$\beta = 0.00075$, Light Buffeting
$\beta = 0.00150$, Moderate Buffeting
$\beta = 0.00300$, Heavy Buffeting

The maximum buffet response obtained in the present study at the higher Mach numbers fall into the heavy buffeting category. The response at M=0.30 (See figure 10.) is considerably larger than the heavy value which suggests that there should perhaps be a fourth category characterized by the adjective "severe," namely, $\beta = 0.00600$, Severe Buffeting. From what the authors understand of flight buffeting experiences of the F-18 it appears that the term severe is appropriate. It should be noted that Mabey has used wing buffet data for the most part in developing his buffet severity characterization.

Correlation of Tail A and Tail B Results

The buffet excitation parameter has been used to correlate data obtained for the two tails. The variations of β with α at q=30 for M=0.30, 0.60, 0.80, and 0.88 are presented in figure 11. Generally speaking the two data sets agree reasonably well thus indicating the usefulness of the parameter β in correlating the buffet response data for the two tails. These results show the same Mach number effects previously discussed for the rms bending moment, namely, the largest value occurs at the lower Mach number.

Something about the frequency content of the buffeting flows can be inferred indirectly from these results. Because the data correlate as well as they do, it appears that the energy in the buffeting flow at the frequency of response for Tail A, about 27 Hz, is about the same as it is at the frequency of response for Tail B, about 15 Hz.

CONCLUDING REMARKS

Buffet response results have been presented over a range of angles of attack from -10° to +40° degrees, and over a range of Mach numbers from 0.30 to 0.95 for the twin vertical tails of a 1/6-size model of the F-18 airplane. The data were obtained by conducting a wind-tunnel test in the Langley Transonic Dynamics Tunnel. The results obtained indicate the following:

(1) The buffet response occurred in the first bending mode.

(2) The buffet response increased with increasing dynamic pressure, but changes in response are not linearly proportional to the changes in dynamic pressure.

(3) The buffet response was larger at M=0.30 than it was at the higher Mach numbers.

(4) The intensity of the buffeting is described as heavy to severe.

(5) The data at different dynamic pressures and for the different tails correlated reasonably well using the buffet excitation parameter.

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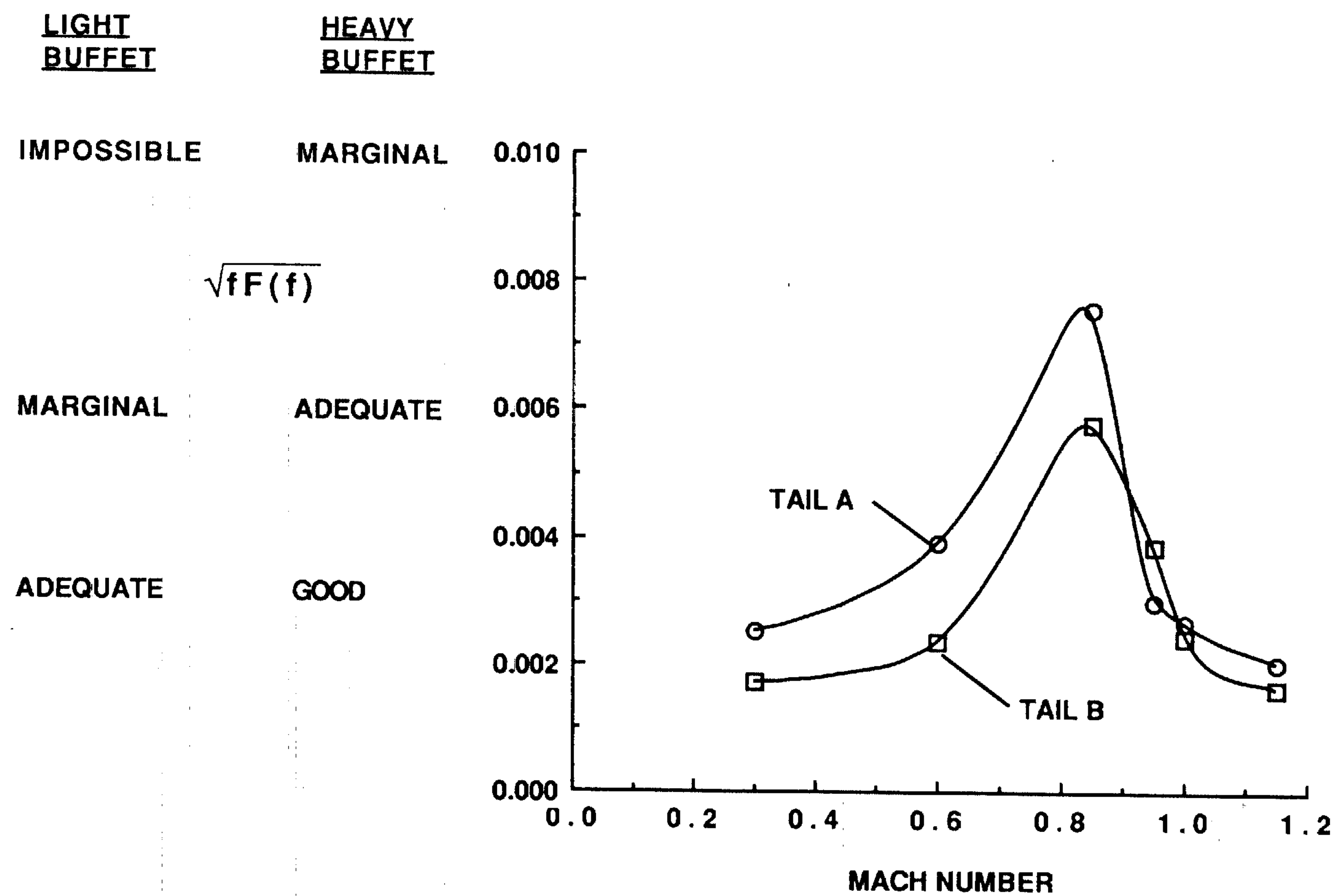

Figure 1.- Suitability of wind tunnel for buffet testing.

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Figure 2.- Photograph of model mounted in wind tunnel.

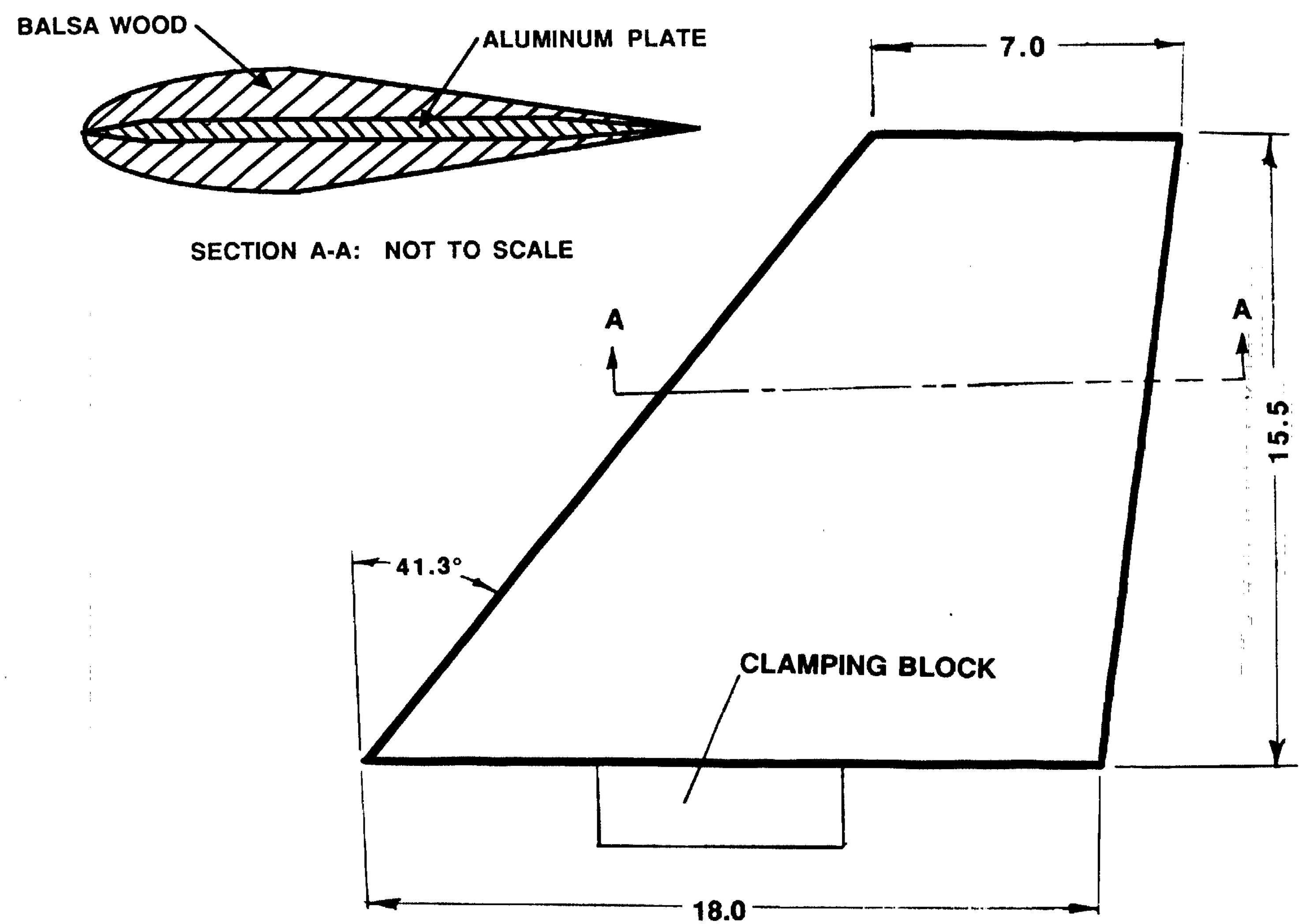

Figure 3.- Geometry and construction details of vertical tail. Linear dimensions are in inches.

VERTICAL TAIL NATURAL FREQUENCIES, HZ

	TAIL A	TAIL B
FIRST BENDING	27.0	14.6
FIRST TORSION	96.3	53.5
SECOND BENDING	132.3	73.5

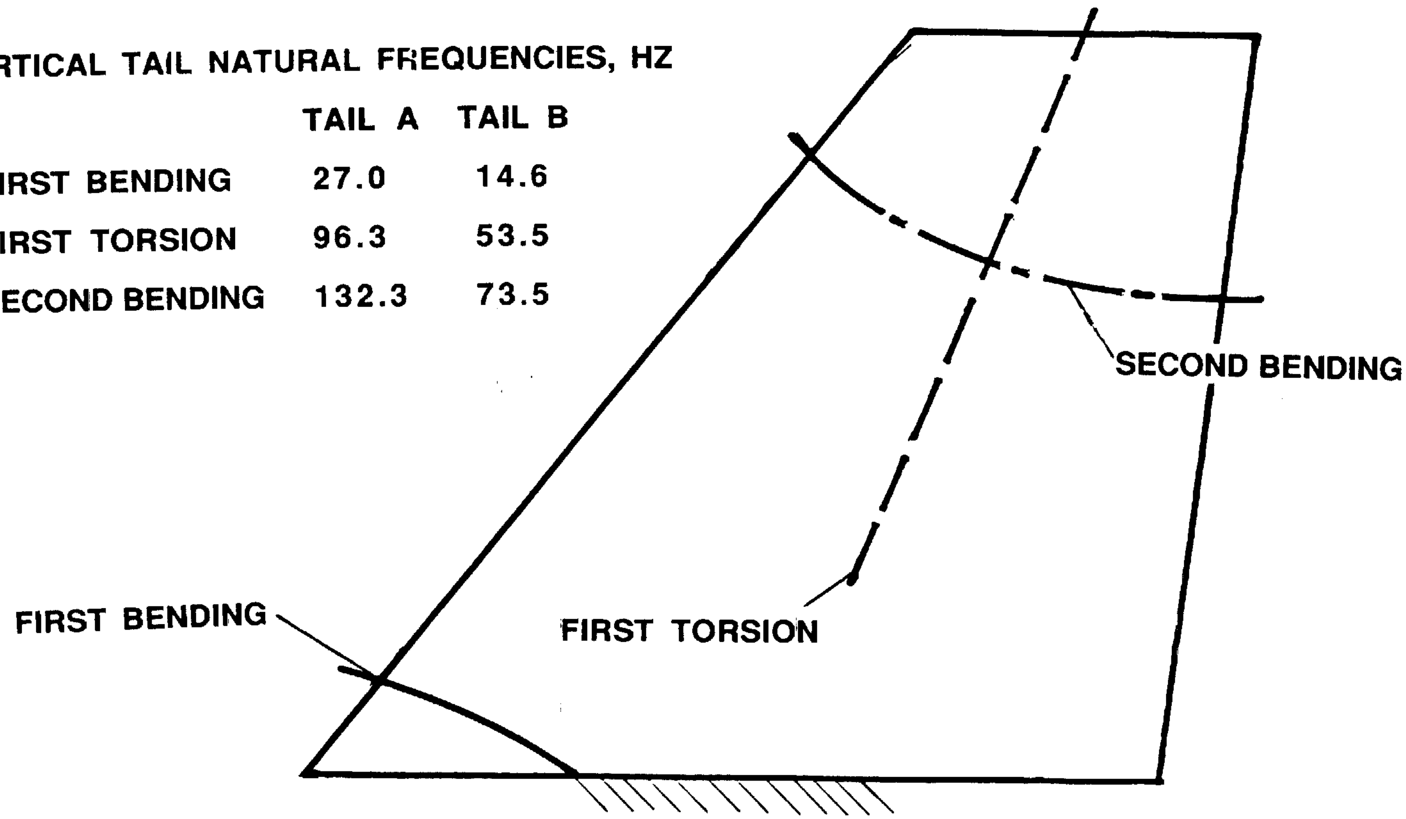

Figure 4.- Measured natural frequencies and node lines for vertical tails.

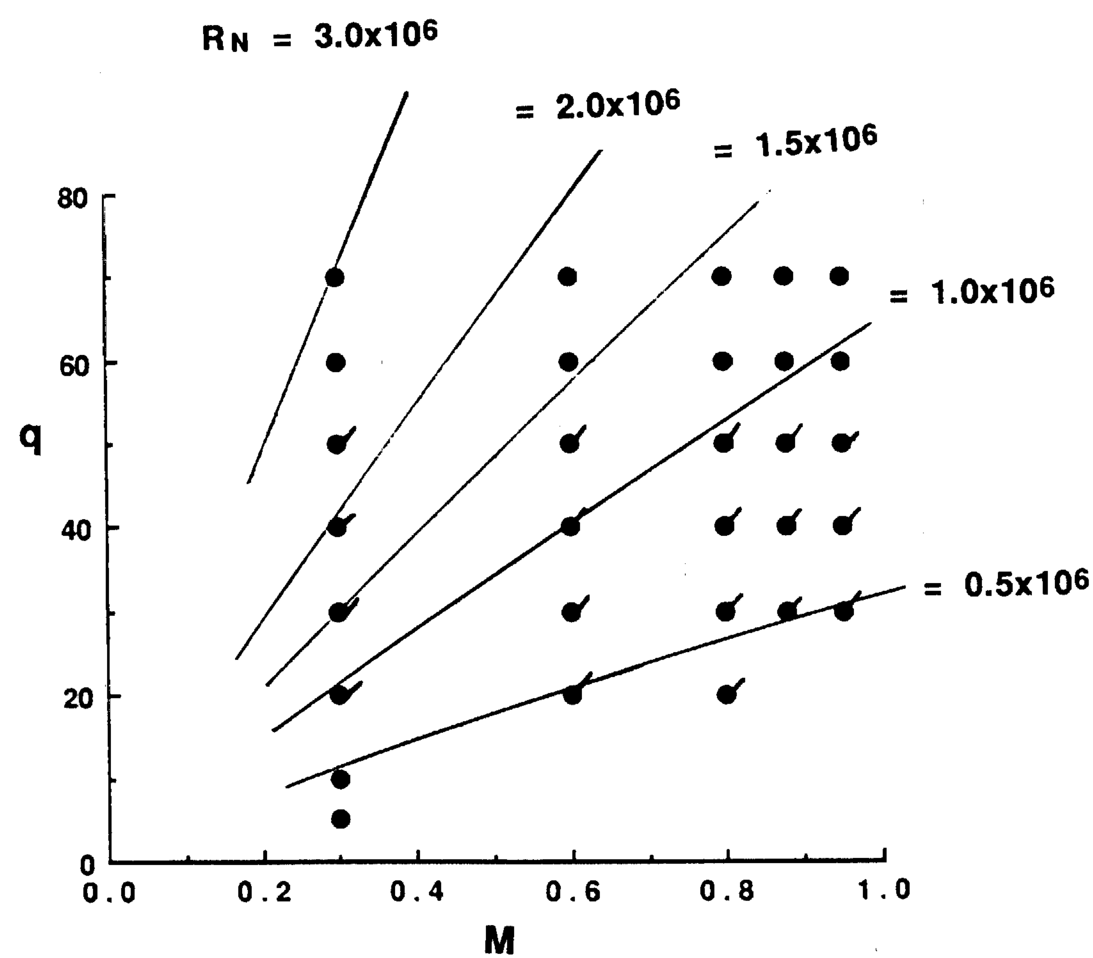

Figure 5.- Matrix of wind-tunnel test conditions.

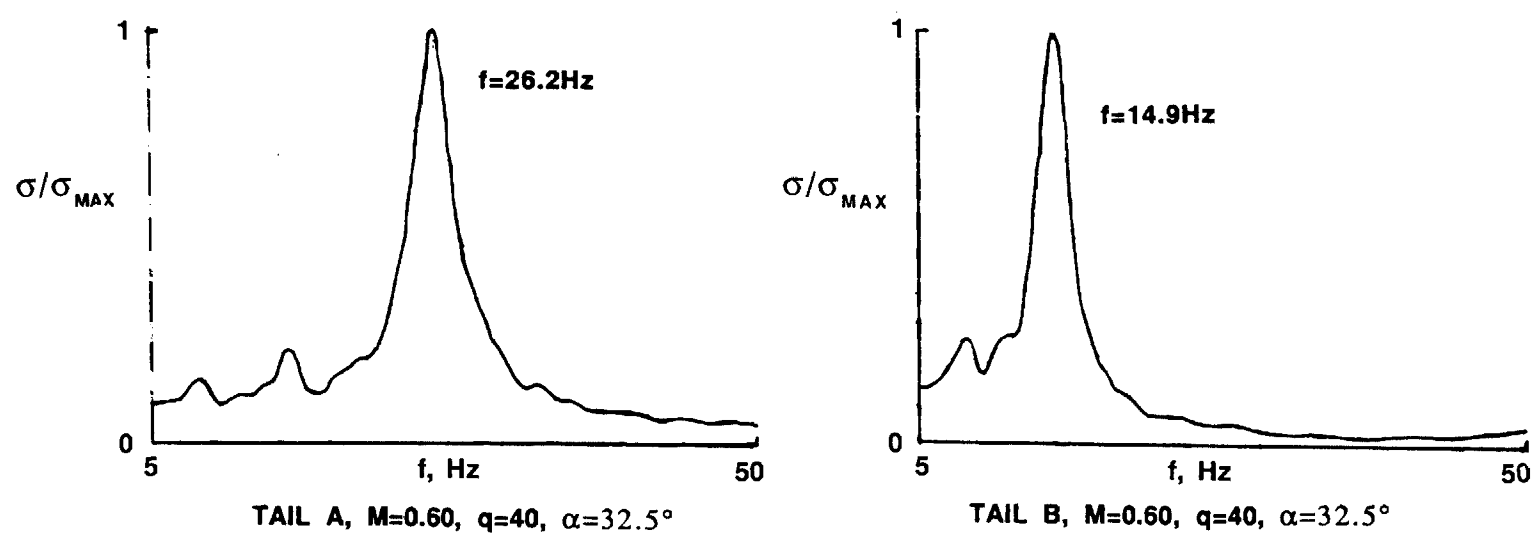

Figure 6.- Typical autospectra of buffet response.

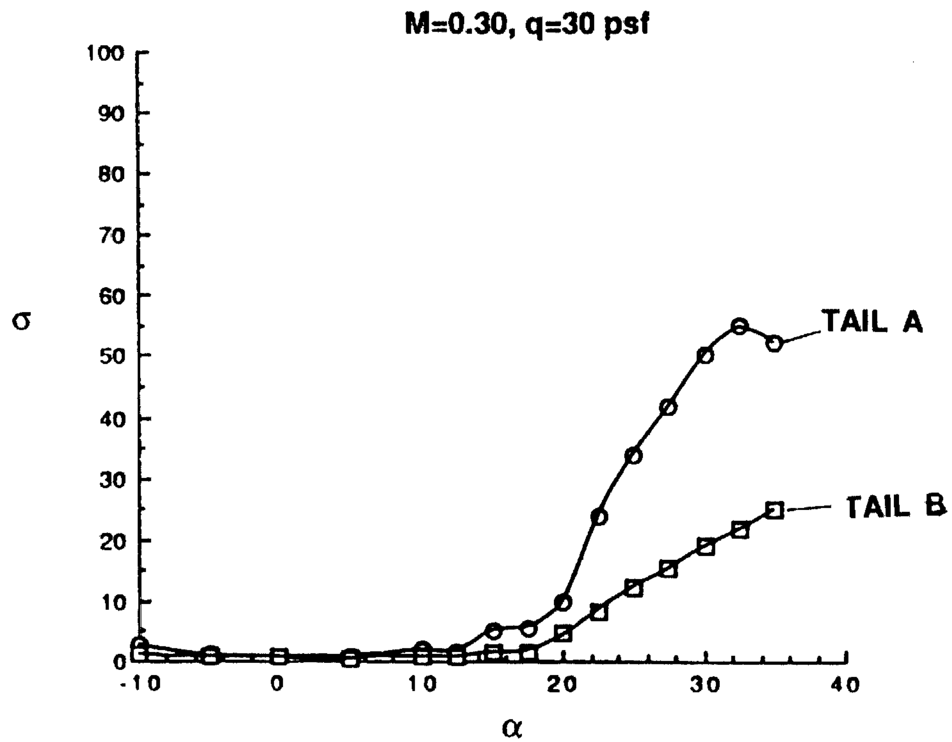

Figure 7.- Typical variations of rms buffet bending moment with angle of attack.

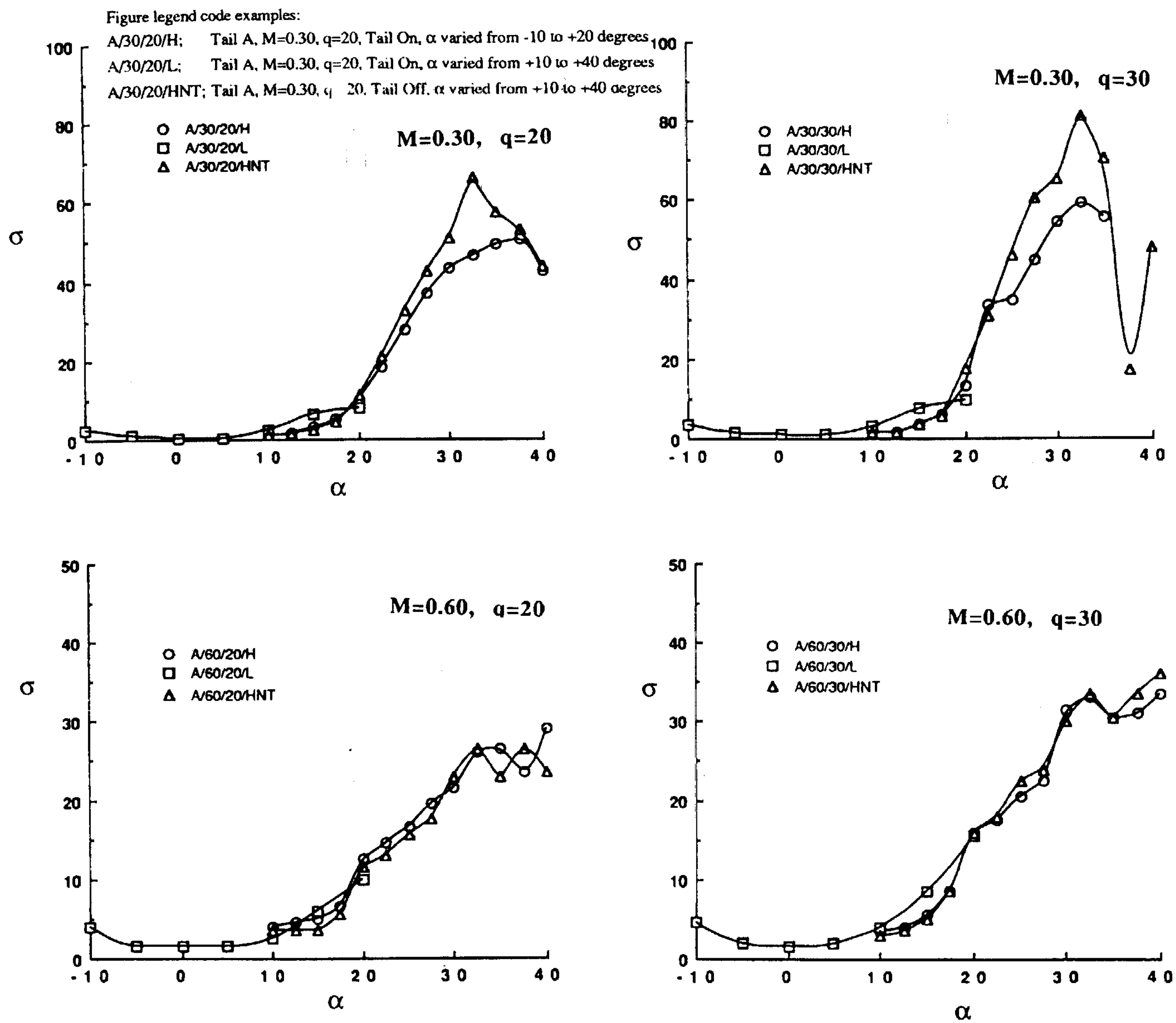

Figure 8.- Comparison of horizontal tail-off and horizontal tail-on buffet response for Tail A.

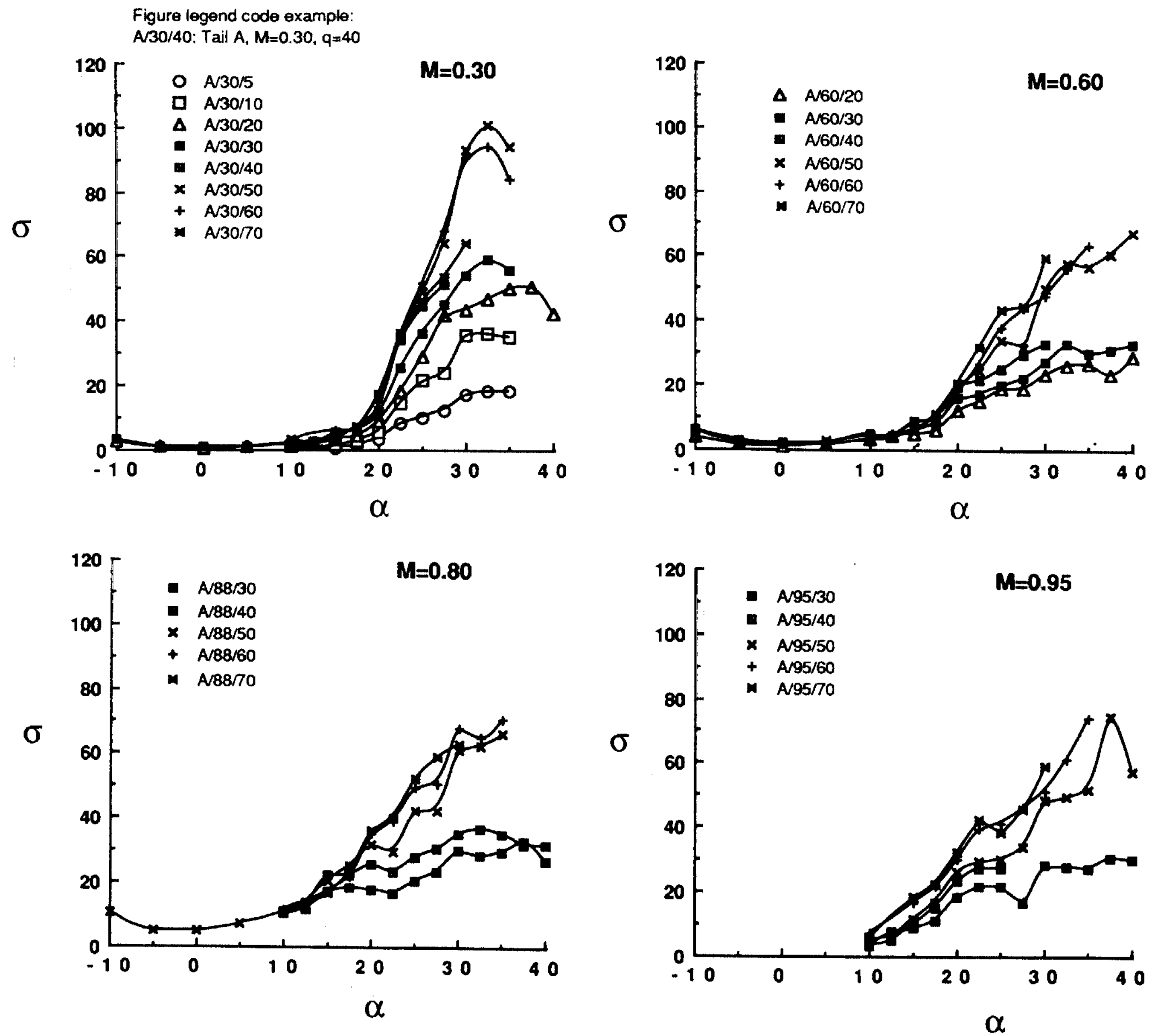

Figure 9.- Variation of rms buffet bending moment with angle of attack at several Mach numbers for Tail A.

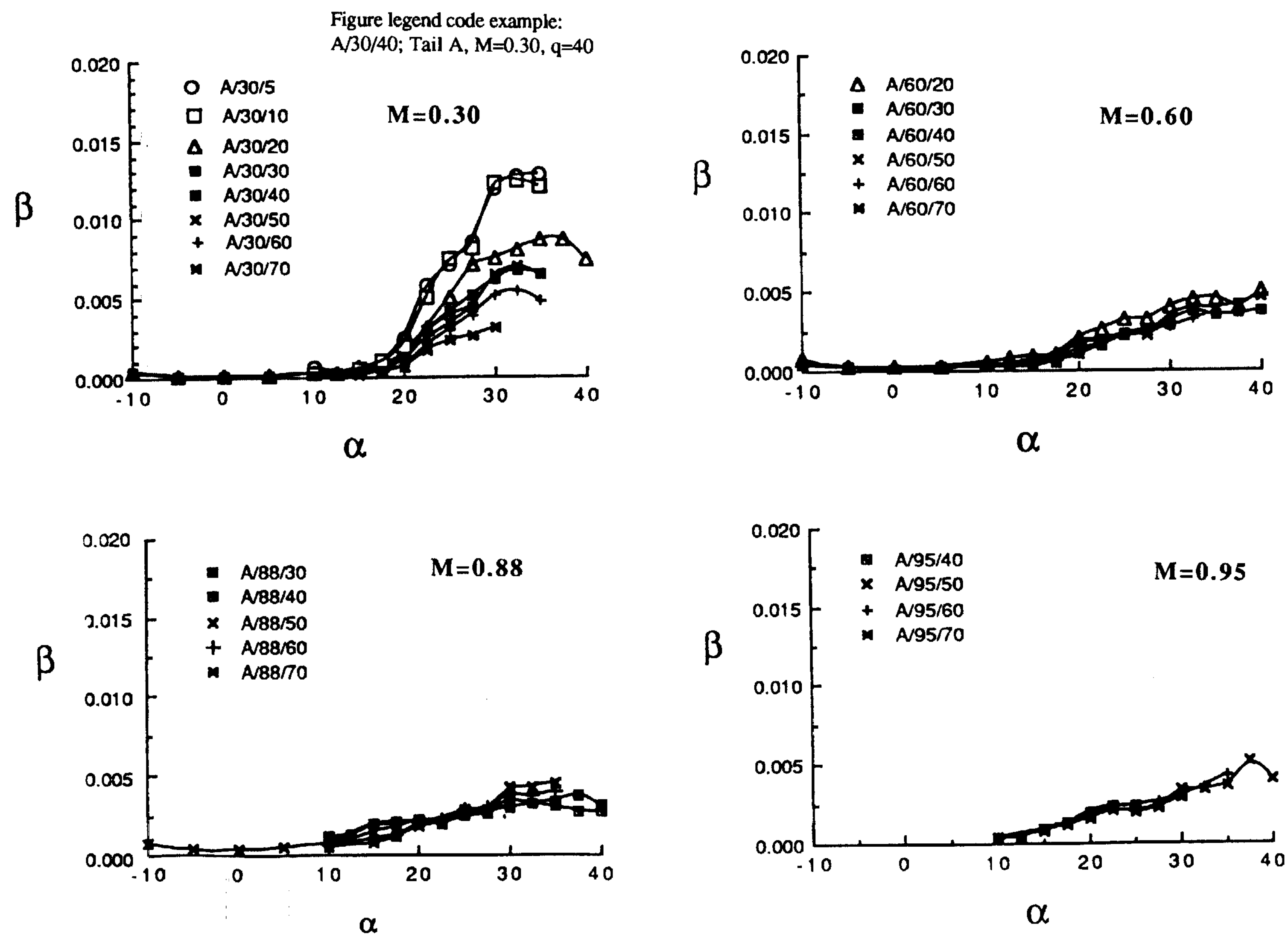

Figure 10.- Variation of buffet excitation parameter with angle of attack at several Mach numbers for Tail A.

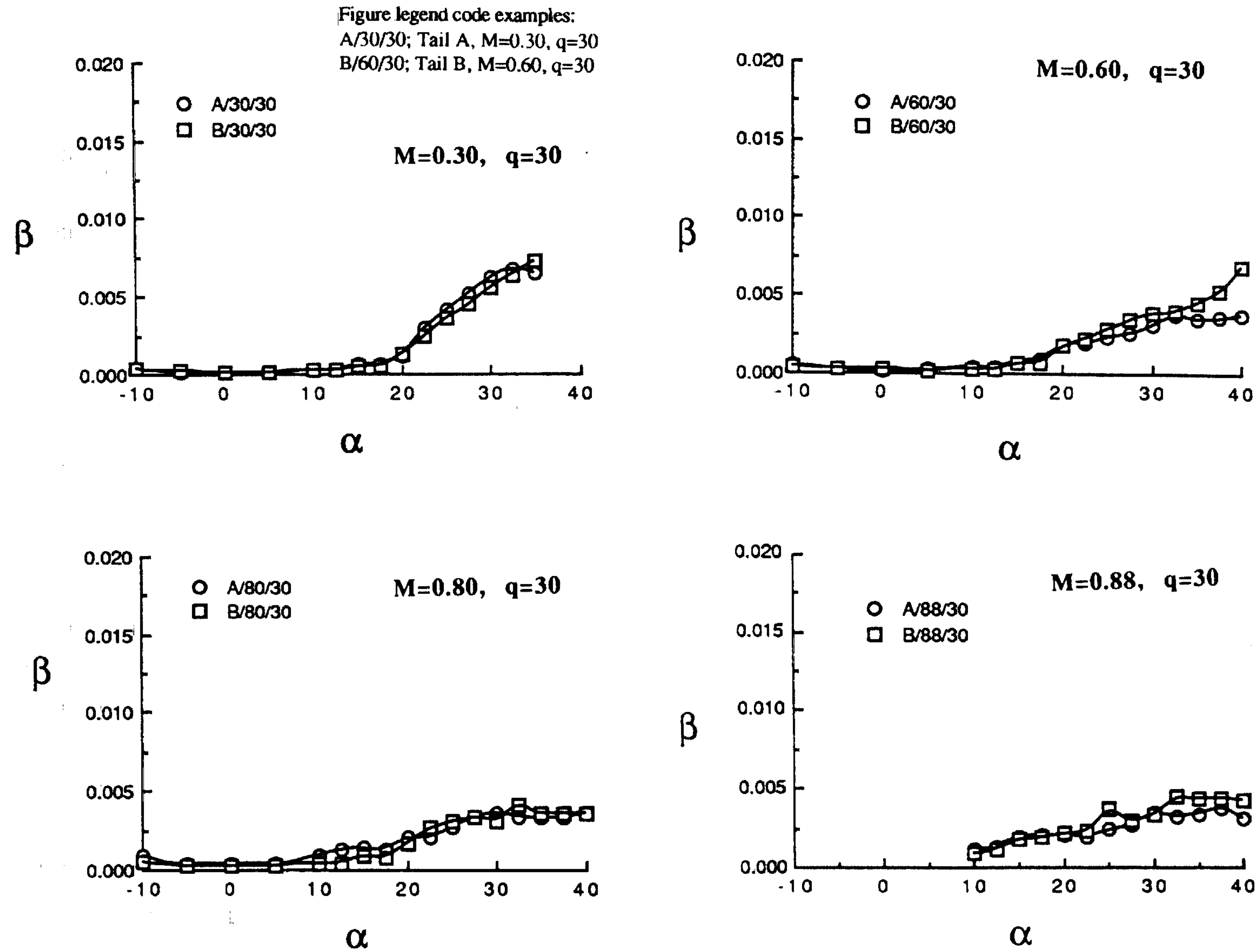

Figure 11.- Correlation of buffet response of Tails A and B using buffet excitation parameter.

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15. Supplementary Notes

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16. Abstract

A rigid, 1/6-size, full-span model of an F-18 airplane was fitted with flexible vertical tails of two different levels of stiffness that were buffet tested in the Langley Transonic Dynamics Tunnel. Vertical-tail buffet response results that were obtained over the range of angles of attack from -10 to +40 degrees, and over the range of Mach numbers from 0.30 to 0.95 are presented. These results indicate the following: (1) the buffet response occurs in the first bending mode; (2) the buffet response increases with increasing dynamic pressure, but changes in response are not linearily proportional to the changes in dynamic pressure; (3) the buffet response is larger at M=0.30 than it is at the higher Mach numbers; (4) the maximum intensity of the buffeting is described as heavy to severe using an assessment criteria proposed by another investigator; and (5) the data at different dynamic pressures and for the different tails correlate reasonably well using the buffet excitation parameter derived from the dynamic analysis of buffeting.

17. Key Words (Suggested by Author(s))
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