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PRELIMINARY REPORT ON CANDIDATES FOR AGARD STANDARD AEROELASTIC CONFIGURATIONS FOR DYNAMIC RESPONSE

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ABSTRACT

At the request of the Aeroelasticity Subcommittee of the AGARD Structures and Materials Panel, a survey of member countries has been conducted to seek candidates for a prospective set of standard configurations to be used for comparison of calculated and measured dynamic aeroelastic behavior with emphasis on the transonic speed range. This set is a sequel to that established several years ago for comparisons of calculated and measured aerodynamic pressures and forces. Approximately two dozen people in the United States and more than three dozen people in the other member countries were contacted. This preliminary report presents the results of the survey and an analysis of those results along with recommendations for the initial set of standard configurations and for additional experimental work needed to fill significant gaps in the available information.

INTRODUCTION

The desirability of establishing a set of standard configurations for comparisons of calculated and measured dynamic aeroelastic behavior was discussed at the September 1984 meeting of the Aeroelasticity Subcommittee of the AGARD Structures and Materials Panel. Several years ago the SMP selected two-dimensional and three-dimensional standard lifting-surface configurations (refs. 1 and 2) to provide a common basis for comparison of pressures and forces calculated by the emerging transonic unsteady aerodynamic codes in order to assess how well these methods model the essential flow physics. It is appropriate now to designate a similar set of configurations as "standard" for the comparison of transonic flutter characteristics and dynamic response (either forced or turbulence-excited) in order to assess how well these codes do the job for which they were intended, namely, predict aeroelastic behavior.

In order to assess the suitability of configurations already tested and the associated data for designation as "standard", a survey of AGARD member countries has been conducted to seek candidates for the prospective set. In the United States approximately two dozen people within NASA, other government agencies, universities, and the aerospace industry were contacted. In addition, input was solicited from more than three dozen people in the other member countries. A copy of the letter of inquiry is included as an appendix, and a list of the organizations contacted is given in Table 1. This preliminary report presents the results of the survey and an analysis of those results along with the author's recommendations for the initial set of standard configurations and for additional experimental work needed to fill significant gaps in the available information.

RESPONSE TO SURVEY

The nature and scope of the survey, along with some preliminary considerations, are set forth in the letter of inquiry (Appendix). Within the guidelines thus established, twelve of the organizations queried recommended consideration of specific configurations. These are evaluated and discussed in a subsequent section of this report.

It may be said in general that the survey produced no particular surprises in terms of the unexpected abundance or deficiency of specific kinds of data and information. Rather, it is hoped that the results of the survey and the assessment and recommendations based on it presented herein will serve to bring into sharper focus and in a sense quantify that which is available as well as that which is needed. It was no surprise, for example, that suitable data do not appear to be available from the industry. Very little testing of research models was mentioned, and the associated data are quite sparse. Nor has design-related testing produced data suitable for present purposes. The high-aspect-ratio transport-type wings that have been flutter tested generally had pylon-mounted nacelles attached and hence are not considered suitable and were not proposed for the initial set of standard configurations. Similarly, the low-aspect-ratio fighter-type models generally had stores attached. Clean-wing configurations have been tested for flutter clearance but were not often taken to hard flutter points in order to preserve the model for subsequent tests with a variety of store configurations. Finally, a number of configurations were ruled out by security classification, proprietary constraints, or other limitations on availability of data.

GUIDELINES FOR PRELIMINARY ASSESSMENT

Preliminary considerations and guidelines for this assessment are given in the letter of inquiry (Appendix). Since emphasis is on the transonic speed range, special importance is placed on configurations for which available data are sufficient to define accurately a transonic flutter boundary. Only configurations with clean smooth surfaces are considered suitable. Segmented models or models with surface-slope discontinuities (e.g., beveled flat plate) are inappropriate. Excluded also, in general, are configurations and data sets that involve behavior that is uncertain or not well understood, uncertain model properties, or known sensitivities to small variations in model properties. These may represent challenging research opportunities but do not seem appropriate as standard configurations. Within these limitations admissible configurations/data sets seem to fall into three categories:

Category 1 includes good concise (little scatter) complete data sets for relatively simple configurations (e.g., isolated wings) with fully and accurately defined and validated model properties.

Category 2 includes configurations with properties that are not concisely defined or with limited or scattered data. These configurations are considered favorably only if there are special features or special purposes that make them of interest or if the model still exists and is available for further measurements and testing.

Category 3 includes configurations with more complicated shapes (e.g., winglets, stores, nacelles, interacting wings) or behavior (e.g., significant shock/vortex interactions). These are considered to be more appropriate for consideration at a later time.

The configurations and data sets proposed in the course of this survey have been assessed and evaluated in accordance with these guidelines.

RESULTS

Configurations Recommended

The examination and assessment of configurations and data sets suggested in the course of the survey have led to the delineation of seven configurations which appear to be suitable for use as AGARD standards. Some information concerning these configurations and associated data is summarized in Table 2 and discussed in this section. All of the configurations are isolated clean wings tested in slotted-throat tunnels. With the exception of the tunnel-spanning two-dimensional configuration, all were side-wall-mounted semispan models. No significant flow separation appears to have occurred during the tests, and the angles of attack, static deformations, and motions were small enough to minimize that concern.

Wing 445.6.- Wing 445.6 (fig. 1) identifies the shape of a set of swept-back, tapered research models which were flutter tested in both air and Freon-12 gas in the 16 foot x 16 foot NASA Langley Transonic Dynamics Tunnel (ref. 3). The first digit of this numerical designation is the aspect ratio; the second and third digits indicate the quarter-chord sweep angle, and the last digit is the taper ratio. These wings had a revolved tip shape, had no twist nor camber, and were tested at zero angle of attack (fully symmetrical conditions). They were of solid homogeneous construction. For testing, each wing was cantilever-mounted from the tunnel wall with no simulated fuselage and no boundary-layer trip. The wing root was thus immersed in the wall boundary layer. Since the model was cantilevered, however, little motion occurred near the root so that portion of the wing contributed very little to the generalized aerodynamic forces driving the flutter motion. Consequently, the effect of wall boundary layer on measured flutter characteristics should not be significant as long as the boundary-layer thickness is a small fraction of the model span, as it was for these tests.

This configuration and associated data are recommended for several reasons: (1) the tests in air and freon covered a very wide range of mass ratio (8.5 to 260 overall as shown in fig. 2). At Mach number 1.0, mass-ratio values were about 12, 34,and 250, the last two values being for models of uniformly reduced stiffness. (2) The transonic dip (fig. 3) is defined, including the supersonic side, and data extend also well into the subsonic range. (3) Very good repeatability of data was shown. (4) Flow over the wing was not complicated by the interference effect of a simulated fuselage. Moreover, since the model and flow were fully symmetrical, the flutter data are not complicated by the effects of static aeroelastic deformation. Finally, note that a limited amount of data was obtained with models of different sizes and with a sting-mounted full-span model but only in the low subsonic range.

On the negative side, one significant gap exists in the definition of model properties. Only the node lines (fig. 1) and frequencies of the first four natural modes were measured. Mode shapes were not measured. However, the models were solid, essentially homogeneous, and their total masses are known, so the mode shapes could be readily calculated by a structural finite-element analysis. The resulting mode shapes should suffice because flutter calculations that have been made for these and similar models gave results that were not particularly sensitive to variations in mode shapes or in modal damping. If the modal calculations are made, wing 445.6 should be a category 1 configuration.

TF-8A Wing.- The TF-8A airplane was a proof-of-concept flight demonstrator for supercritical wing technology. Models of the wing of this airplane, which was designed for cruise Mach number near 0.99, were flutter tested in air and in Freon-12 gas in the 16 foot x 16 foot NASA Langley Transonic Dynamics Tunnel (refs. 4 and 5). Two models tested were as nearly identical as possible except the airfoil shape and associated twist distribution (fig. 4). One model had the TF-8A supercritical airfoil and twist; the other had a conventional airfoil with a twist distribution that would produce the same deflection shape as the supercritical wing when both were at scaled design cruise Mach number and dynamic pressure. For testing, the wings were cantilever-mounted on a half fuselage that represented the shape of the TF-8A airplane (fig. 5). The fuselage, in turn, was mounted on a turntable in the tunnel wall that permitted several degrees variation in angle of attack. The conventional wing was tested with and without boundary-layer transition strips with very little difference in results. The supercritical wing had transition strips throughout its tests.

Bending and torsional stiffnesses for these models were measured, and generalized masses were determined by the method of displaced frequencies. Six well-defined natural vibration modes were measured. Six uncoupled bending modes and six uncoupled torsional modes as well as twelve coupled modes were calculated by NASTRAN. Although the structural properties of these models are well defined, the external shape is not. Design ordinates for the supercritical wing are available, but actual values for the models are not. The models still exist, however, so that the ordinates could be readily measured. If this is done, these models would be considered to constitute a category 1 configuration.

The data obtained in freon for both wings for angles of attack near zero (fig. 6) from reference 4 show little scatter, extend well into the subsonic range, and include a well-defined transonic dip. The detrimental effect of the supercritical airfoil on transonic flutter is clearly shown. Moreover, a limited amount of flutter data obtained in air for the supercritical wing (fig. 7) from reference 5 shows a drastically detrimental effect of angle of attack, even at only one or two degrees. As indicated in reference 5, there are indications that this effect of angle of attack, including the backward-turning transonic flutter boundary, is associated with static aeroelastic deformation. The basic data of reference 4 should be considered the "standard" set, but the data of reference 5 are available for comparison with more ambitious calculations.

Supercritical Transport Wing.- The high-aspect-ratio supercritical transport-type wing shown in figure 8 has been studied extensively in the 1.6 m x 2.0 m HST at NLR Amsterdam (refs. 6 and 7). This research wing was tested in the presence of a simulated fuselage but was attached at the root to an

X-section flexure which added a pitch degree of freedom to the usual deformations of the wing itself. The flexure, in turn, was attached to a turntable in the tunnel wall which permitted changes in angle of attack. The torsional stiffness of the wing itself appears to be sufficiently high to avoid twisting deformations large enough to cause any significant amount of flow separation. Tests were run with both fixed and natural transition of the boundary layer. Although full geometrical description of the model is not contained in references 6 and 7, the information, including wing-surface ordinates, does exist. It is not known whether stiffness distributions are available.

The flutter tests of this wing were performed with great care and precision. A considerable amount of subcritical-response data appears to have been taken during the approach to flutter conditions. The exceptionally large number of flutter points obtained show very little scatter and are sufficient to define with great accuracy the transonic flutter boundaries for nominal angles of attack of -0.35°, 0.85°, and 2.05° (fig. 9). It is particularly noted that the double transonic dip shown for 2.05° is remarkably like that calculated for the TF-8A wing at 2.00° (ref. 5). The flutter boundaries in figure 9, however, do not show the backward turn which was found experimentally for the TF-8A wing at positive angles of attack.

If full shape and stiffness information can be made available for the supercritical transport wing, it certainly would be regarded as a category 1 configuration.

Modified F-16 Wing.- The modified F-16 wing model shown in figure 10 was flutter tested in Freon-12 gas in the Langley Transonic Dynamics Tunnel (refs. 8 and 9). This was a cantilever-mounted research model that had essentially the same planform as the wing of the F-16 airplane except the strake was not reproduced in the model. The model was aeroelastically tailored to washin under aerodynamic load in contrast to the usual washout deformation exhibited by wings of conventional construction. The model had no twist nor camber, however, and was flutter tested at essentially zero angle of attack so that static aeroelastic deformation - conventional or unconventional - did not occur. The only influence of the aeroelastic tailoring on flutter, therefore, should be through its effect on the vibration modes, five of which were measured. Structural-influence-coefficient matrices were also calculated and measured, and mass distribution was carefully evaluated. These structural and mass properties are contained in U. S. Air Force reports that are subject to distribution restrictions. However, the Air Force representative who supervised this project has indicated that the model properties could be removed from the restriction if this configuration is selected as one of the AGARD standards.

The tests were conducted at moderately high Reynolds numbers, so boundary-layer transition strips were not used. Although only one hard flutter point was obtained (at Mach number 0.82), a considerable amount of subcritical-response data was obtained at five Mach numbers between 0.65 and 1.15. One of the objectives of these tests was to evaluate several methods for extrapolating flutter points from subcritical-response data. As shown in figure 11, the range of extrapolated dynamic pressures at flutter increased as the bottom of the transonic dip was approached. This large scatter and the small number of Mach numbers covered in the experiments make the available data set unacceptable as an AGARD standard. However, the model still exists and could be used for further tests. It is therefore, regarded as a category 2 configuration and is suggested for consideration virtually by default since no other suitable low-aspect-ratio configuration emerged in the survey.

Rigid Rectangular Wing.- Two "rigid" rectangular wings have been flutter tested in Freon-12 gas in the Langley Transonic Dynamics Tunnel as a proof-of-concept demonstration of a flexible mount system (fig. 12). This mount (ref. 10) was designed to provide rigid-body pitch and plunge degrees of freedom for flutter models. In this system the model is rigidly attached to an end plate which is connected to the turntable in the tunnel wall by four rods and a cantilevered flat spring that serves as a drag strut. The arrangement of these elements shown in figure 13 effectively constrains rolling and yawing motion of the model.

The two wing models had no twist nor camber and were essentially identical except for airfoil shape. One had a "conventional" NACA 64A010 section; the other had a 10%-thick supercritical thickness distribution. The tips of both wings were squared off. Both had boundary-layer transition strips at 10% chord. The models still exist and could be used for further testing.

Flutter data obtained at essentially zero angle of attack (measured on the end plate) are shown in figure 14. Although only a limited number of flutter points are shown on each boundary, a number of "no-flutter" points were also recorded which help to substantiate the shape of the boundaries. The points on each boundary near Mach number 0.8 are indicated to be near the bottom of the transonic dip. The now-familiar detrimental effect on flutter of the supercritical airfoil in the transonic range is again evident - but with a difference. The separation of the two flutter boundaries in figure 14 is caused solely by the difference in thickness distribution; whereas, other comparisons of conventional and supercritical wings (e.g., TF-8A) have been complicated by differences in static aeroelastic deformation.

The absence of static aeroelastic deformation and the simplicity of geometry and modes of motion of the two rectangular wings make these worthy of consideration as a potential category 1 configuration. Note also that this system permits flutter testing at nonzero angles of attack. Indeed, the conventional wing has been tested up to 11° angle of attack at low Mach numbers (ref. 10), and there is no constraint against such testing at higher Mach numbers. Some degree of uncertainty remains, however, with regard to the effect of flow over and around the moving end plate as well as the aerodynamic forces on the exposed rods of the mount system. These effects are probably not large because the end plate remains always parallel to the airstream and moves only edgewise in the cross-stream direction, and the motion of the rods decreases to zero at the tunnel wall. Nevertheless, for further testing of this sort, a stationary splitter plate has been built in which the moving end plate will be flush-mounted. Transonic tests at angle of attack with this arrangement are awaiting tunnel time.

Rectangular Wing in Cryogenic Tunnel.- The "paddle" model shown in figures 15 and 16 consisted of a relatively rigid rectangular wing with NACA 64A010 airfoil mounted on an integral beam flexure which provided freedom in flapping and pitching. The flutter tests were conducted in the NASA Langley 0.3 m Transonic Cryogenic Tunnel to explore techniques and problems involved with flutter testing in a cryogenic environment (ref. 11). The effects of temperature variation on material properties and hence on vibration modes, frequencies, and modal damping were examined by calculation and experiment. Five modes were calculated. Frequencies and node lines of four modes were measured and agreed well with calculated values. The flutter tests were run at zero angle of attack, both with and without boundary-layer transition strips. Subcritical-response data were recorded as flutter was approached, but relatively few flutter points were obtained (fig. 17). Although the model still exists, no specific follow-on tests are planned at this time. However, because of the high Reynolds numbers involved, the limited existing data for this model may be useful as a category 2 configuration.

Two-Dimensional Flutter Tests.- The survey did not reveal the existence of any two-dimensional transonic flutter tests. However, preparations are being made for two very similar tests in the immediate future - one at DFVLR Göttingen and one at NASA Langley. Both tests will employ the supercritical MBB-A3 airfoil, provide pitch and plunge degrees of freedom as well as a means of reacting static load so that tests may be run at lifting conditions, and include plans to measure subcritical response and aerodynamic forces on the model. Tests at Göttingen will be in the 1m x 1m Transonic Wind Tunnel. At Langley shakedown tests of the mount system are under way in the 6- by 19-Inch Transonic Tunnel, to be followed immediately by flutter tests in the 6- by 28-Inch Transonic Tunnel. Two models will be used in the Langley tests - the basic MBB-A3 airfoil and an uncambered model with the same thickness distribution. The results of both series of tests should be very useful for comparison with calculations made by two-dimensional theories, and hopefully both will produce category 1 configuration/data sets.

Configurations Not Recommended

A number of other configurations were considered in the course of this survey and assessment but are not recommended as AGARD standards. Because they might normally be regarded as logical candidates, eleven of these are mentioned here along with a brief indication of the reasons that they are not suitable. Five of these are generic research models; three are supercritical wings; and three are military aircraft configurations. An interacting-lifting-surface configuration is also mentioned for possible later consideration.

A series of models with systematic variation of sweep and aspect ratio was tested in the Langley 26-Inch Blowdown Tunnel (e.g., ref. 12). Usually only one or two flutter points were obtained per model, so it was necessary to construct a number of models of each configuration. These models were relatively small so that it was difficult to make a set of supposedly identical models with the same properties. It was also difficult to measure accurately the properties of small models. Moreover, the tunnel flow was quite rough, and large amplitudes of motion were frequently observed before flutter was indicated. Scatter in the resulting data is unacceptable for AGARD standard.

A 45° swept wing was extensively tested by Cornell Aeronautical Laboratory for the U.S. Air Force (ref. 13). A number of parameters were varied in these tests. The model, however, had a "rigid" root stub extending into the airstream with the flexible wing panel attached. The associated sharp discontinuity in stiffness resulted in vibration models with "kinks" which are considered unsuitable for standards.

Flutter tests were performed by the Lockheed-California Company with tapered wing models of two planforms - one swept 20° with aspect ratio 5.72 and the other swept 60° with aspect ratio 2.73. All models were bevel-edge flat plates. The Mach numbers were 0.80, 1.43, 2.46. The sparsity of data and the bevel-edge models do not recommend these configurations.

A two-dimensional model with NACA 0012 airfoil was used at Middle East Technical University to measure unsteady pressures at low Mach number (ref. 14). No transonic flutter data were obtained.

A clipped-tip delta wing was flutter tested at NASA Langley, primarily to investigate control laws for active flutter suppression (ref. 15). The model had a 3%-thick sharp-edge airfoil. Therefore, even though it was tested at zero angle of attack, the flutter motion generated a leading-edge separation bubble or vortex. It is not known whether the bubble became large enough or strong enough to affect the flutter characteristics. The detrimental effect on flutter of leading-edge flow separation is well known. The model had two "pencil" nacelles under the wing to simulate engine/nacelle inertia. These created aerodynamic interference on the wing and complicated the vibration modes. Two of the four open-loop flutter points were obtained after the model had been damaged. The ensuing repair altered modal frequencies.

Calculated flutter characteristics for the supercritical Japanese transport wing have been found to be quite sensitive to small variations in wing-section centers of gravity since the centers of gravity are close to the elastic axis. Such sensitivity is unacceptable for a standard configuration.

The supercritical wing of a proposed executive-jet-transport was flutter tested at NASA Langley, both with and without winglets (ref. 16). There were five fairly large simulated flap track fairings on the aft portion of the wing. Although the wing was tested near zero angle of attack, the large nose-down pitching moment caused enough twist to create concern about the existence of significant flow separation on the outboard portion of the wing. Only two hard flutter points were obtained for the wing without winglet.

The high-aspect-ratio supercritical ARW-2 (Aeroelastic Research Wing) wing, which was intended for flight testing on the DAST (Drone for Aerodynamic and Structural Testing) vehicle, has been flutter tested in the Langley Transonic Dynamics tunnel (ref. 17). The resulting flutter boundary occurred virtually at a constant Mach number of 0.9 over a very wide range of dynamic pressure. This unexpected behavior is not fully understood at the present time. It is not known, for example, whether significant amounts of static aeroelastic deformation and/or flow separation were involved. Investigation is continuing.

Experimental flutter data exist for the T-38 trainer and F-5 fighter wings, much of it for the F-5 with stores. However, the nature, quantity, and quality of data for clean-wing configuration are not known at this time nor is it known whether the flutter models still exist. The F-5 wing has a small amount of camber over the forward portion and hence is subject to some degree of static aeroelastic deformation even at angles of attack near zero. If suitable data can be made available or if the flutter model(s) can be made available for further testing, this configuration could be an interesting cambered, low-aspect-ratio counterpart to the uncambered, low-aspect-ratio modified F-16 wing.

A limited amount of transonic flutter data over a restricted range of Mach number exists for the AV-8B Harrier VSTOL fighter configuration. The semispan model and support system provided pitch and plunge rigid-body degrees of freedom as well as structural flexibility. The configuration is complicated, however, by large inlets at the wing roots and a curved tip shape that is difficult to model accurately in a computational grid. If data-release constraints can be avoided, this might be classified as a category 3 configuration for further consideration at a later time.

Aeroelastic instabilities encountered during flight tests of the B-1 bomber are well known (e.g., ref. 18). To study these problems a semispan wing-body model was flutter tested at the NASA Ames Research Center. Subcritical response and about 80 flutter points were recorded over a range of Mach number, angle of attack and sweep angle. The flow phenomena that drive the instabilities are complex, however, and involve complicated effects and interactions of leading-edge-separation vortices and shock waves. Moreover, the vortex formation and flow pattern are probably influenced by the leading-edge bump at the juncture of the fixed and variable-sweep portions of the wing.

Finally, a proposed category 3 interacting-lifting-surface configuration/data set should be mentioned for later consideration. A series of untapered 45° and 60° swept-wing models was tested for the U.S. Air Force in the Cornell Aeronautical Laboratory 8x8-Foot Variable Density Transonic Wing Tunnel (ref. 19). All models had a modified NACA 63-006 airfoil perpendicular to the leading edge and were tested at zero angle of attack both individually and as wing-tail combinations. In each combination the wing and tail had the same planform but different stiffness levels and were elastically coupled at the root by an interconnecting torsion bar. The tests covered a range of Mach number, mass ratio, and frequency ratio as well as a series of longitudinal and vertical separation distances between the surfaces.

Status Assessment

The assessment of available and needed data and information given here is based on a perception of requirements for the establishment of AGARD standard configurations, not on research needs. The two are, of course, closely related, however. For example, wind-tunnel-wall effect has not been addressed in this assessment, although it is an important research topic which can have a significant impact on subsequent choices of standard configuration/data sets and their interpretation.

This assessment is given below in three parts addressing moderate-to-high-aspect-ratio wings, low-aspect-ratio swept wings,and two-dimensional wings. Three rather obvious general comments, however, pertain to all three parts. First, high-Reynolds-number data are obviously needed for all three types of configurations for closer simulation of aircraft flight conditions. These data are also needed for standard configuration/data sets to provide a basis for closer, more valid comparisons with calculations made with inviscid-flow theories, with viscous/inviscid interaction methods, and with Navier-Stokes solutions. Second, data are needed for configurations which incorporate some degree of control-surface deflection in their modes of motion. These data are needed to assess the accuracy of calculated control-surface behavior and influence on flutter and are especially needed in connection with active-control studies. In the absence of suitable control-surface data of this type, control-surface effects must be evaluated by comparisons of calculations with measured aerodynamic data such as those of reference 20. Third, in any subsequent tests of the recommended configurations or other prospective candidates subcritical-response data should be recorded as flutter is approached. These data are needed to assess the accuracy and validity of calculated subcritical response (which may be amplitude-sensitive) as well as to provide information for the continuing assessment of methods for extrapolating to flutter points. Static aeroelastic deformation should also be measured if at all possible.

Moderate-to-High-Aspect-Ratio Wings.- The first three configurations listed in Table 2(a), along with the rigid rectangular wing in Table 2(b), provide reasonably adequate representation of moderate-to-high-aspect-ratio wings at moderate Reynolds numbers, including supercritical and conventional wings, both with and without twist and camber and the accompanying complications of static aeroelastic deformations. Some pecularities in the effect of angle of attack on the transonic dip for supercritical wings have been delineated; subcritical-response data are available; and the models still exist for further testing as needed. As indicated previously, further transonic tests of rigid rectangular conventional and supercritical wings on the two-degree-of-freedom mount system (first configuration in Table 2(b)) are awaiting tunnel time. These tests will include variations in angle of attack at transonic speeds and should provide an additional data set for this kind of configuration. Note also that use of this mount system is not limited to rectangular wings nor even to rigid wings, although rigid wings are, of course, relatively easy, quick, and cheap to build and test.

It is recognized that the highly efficient subsonic/transonic transport or long-range bomber with moderate-to-high-aspect-ratio wing is probably the type of aircraft mostly likely to be flutter critical and hence is the type of aircraft for which computational methods require the most stringent validation. The configurations recommended here, however, appear to be adequate for initial AGARD standard configurations. Subsequent tests of other configurations may produce data sets suitable for use as AGARD standards. Such tests, however, should be undertaken for research purposes rather than for the purpose of creating an AGARD standard.

Low-Aspect-Ratio Swept Wings.- The greatest current deficiency appears to exist for low-aspect-ratio (fighter-type) swept wings. As stated previously, the modified F-16 wing is recommended virtually by default and only because the model is still available. Existing data for this model are inadequate. Therefore, additional tests with this model, preferably at both zero and nonzero angles of attack, would be required for it to be considered suitable as a standard configuration. For nonzero angles of attack the static aeroelastic deformation of this model will be washin rather then the washout of more conventional wing structures. This behavior, however, should not compromise the usefulness of the results for validation of analytical methods. Moreover, future fighter aircraft may be designed this way to improve maneuverability.

A further effort should be made to determine the nature and amount of data that can be made available for the T-38/F-5 clean-wing configuration. Such data could provide a valuable complement to the modified-F-16 data.

For research purposes as well as to establish a subsequently needed AGARD standard, flutter tests are needed for low-aspect-ratio highly-swept wings (e.g., delta or clipped-delta wings) at zero to moderately high angle of attack. The free-vortex-dominated flow over such wings is known to increase structural loads and decrease flutter speeds relative to those for attached flows. Methods for calculating such flows at transonic speeds, steady and unsteady, are emerging, and experimental data are needed for validation. It is suggested that models initially have sharp edges so that the separation line location will remain fixed and known. Tests are also need for wings with strakes at zero and nonzero angles of attack. Tests of this type might readily be performed on the two-degree-of-freedom mount system previously described.

Two-Dimensional Wings.- The survey did not reveal the existence of any transonic flutter data for two-dimensional wings. However, imminent tests of the MBB-A3 supercritical airfoil at DFVLR Gottingen and at NASA Langley should provide the needed data sets. It is suggested that any follow-on tests include also a conventional airfoil and perhaps a control-surface degree of freedom.

RECOMMENDATIONS FOR ACTION BY THE AEROELASTICITY SUBCOMMITTEE

1. It is recommended that the Aeroelasticity Subcommittee in its entirety or through a designated working group thereof review the results of the survey and assessment presented here, along with other available information, for the purpose of selecting "standards" from existing configurations and data sets as well as to define configurations and data needed to fill gaps in available information.

2. It is recommended that the Subcommittee (a) undertake to acquire the additional information indicated to be needed for the existing recommended configurations, (b) establish procedures and format for presenting model information and experimental data for the standard configurations, and (c) publish the complete sets of information and data for the standard configurations as a counterpart to AGARD-R-702, which contains aerodynamic information on the configurations established in AGARD-AR-156 and -167.

3. It is recommended that the Subcommittee promote and coordinate the filling of gaps and deficiencies in configurations and data sets (but only where specific needs are identified) by (a) further measurement and testing of existing models of recommended configurations and (b) testing additional configurations.

4. It is recommended that the Subcommittee regard the standard configurations/data sets as open-ended and consider from time to time the inclusion of additional configurations involving more complex geometry, flow phenomena, and dynamic behavior. Selections should be judiciously made and unnecessary proliferation avoided.

REFERENCES

1. Bland, S. R.: AGARD Two-Dimensional Aeroelastic Configurations. AGARD-AR-156, 1979.

2. Bland, S. R.: AGARD Three-Dimensional Aeroelastic Configurations. AGARD-AR-167, 1982.

3. Yates, E. Carson, Jr.; Land, Norman S.; and Foughner, Jerome T., Jr.: Measured and Calculated Subsonic and Transonic Flutter Characteristics of a 45° Sweptback Wing Planform in Air and in Freon-12 in the Langley Transonic Dynamics Tunnel. NASA TN D-1616, 1963.

4. Farmer, Moses G.; Hanson, Perry W.; and Wynne, Eleanor C.: Comparison of Supercritical and Conventional Wing Flutter Characteristics. NASA TM 72837, 1976.

5. Yates, E. Carson, Jr.; Wynne, Eleanor C.; and Farmer, Moses G.: Measured and Calculated Effects of Angle of Attack on the Transonic Flutter of a Supercritical Wing. AIAA Paper 82-0647, 1982.

6. Houwink, R.; Kraan, A. N.; and Zwaan, R. J.: Wind-Tunnel Study of the Flutter Characteristics of a Supercritical Wing. Journal of Aircraft, Vol. 19, No. 5, May 1982, pp. 400-405.

7. Persoon, A. J.; Horsten, J. J.; and Meijer, J. J.: Measurement of Transonic Dips in the Flutter Boundaries of a Supercritical Wing in a Wind Tunnel. Journal of Aircraft, Vol. 21, No. 11, Nov. 1984, pp. 906-912.

8. Ruhlin, C. L.; Watson, J. J.; Ricketts, R. H.; and Doggett, R. V., Jr.: Evaluation of Four Subcritical Response Methods for On-Line Prediction of Flutter Onset in Wind Tunnel Tests. Journal of Aircraft, Vol. 20, No. 10, Oct. 1983, pp. 835-840.

9. Murphy, A. C.; Rogers, W. A.; Shirk, M. H.; and Ruhlin, C. L.: The Design Testing and Analysis of Aeroelatically Tailored Transonic Flutter Model Wings. AIAA Paper 83-1027, 1983.

10. Farmer, Moses G.: A Two-Degree-of-Freedom Flutter Mount System with Low Damping for Testing Rigid Wings at Different Angles of Attack. NASA Technical Memorandum 83302, 1982.

11. Cole, Stanley R.: Exploratory Flutter Test in a Cryogenic Wind Tunnel. AIAA Paper 85-0736, 1985.

12. Unangst, John R.; and Jones, George W., Jr.: Some Effects of Sweep and Aspect Ratio on the Transonic Flutter Characteristics of a Series of Thin Cantilever Wings Having a Taper Ratio of 0.6. NASA TN D-1594, 1963.

13. Maier, H. G.; and King, S. R.: Transonic Flutter Model Tests. Part I - 45 Degree Swept Wings. WADC TR 56-214. Wright Air Development Center, 1957.

14. Ciray, Cahit: Turbulent Flow Around an Oscillating NACA 0012 Airfoil. Part Two - Experimental Investigation. Hydromechanics Laboratory, Middle East Technical University, Ankara, 1979.

15. Sandford, Maynard C.; Abel, Irving; and Gray, David L.: Development and Demonstration of a Flutter-Suppression System Using Active Controls. NASA TR R-450, 1975.

16. Ruhlin, Charles L.; Rauch, Frank J., Jr.; and Waters, Catherine: Transonic Flutter Study of a Wind-Tunnel Model of a Supercritical Wing With/Without Winglet. AIAA Paper 82-0721, 1982.

17. Seidel, David A.; Sandford, Maynard C.; and Eckstrom, Clinton V.: Measured Unsteady Transonic Aerodynamic Characteristics of an Elastic Supercritical Wing with an Oscillating Control Surface. AIAA Paper 85-0598, 1985.

18. Dobbs, S. K.; and Miller, G. K.: Shock Induced Oscillation Wind Tunnel Test of a Variable Sweep Wing. AIAA Paper 85-0739, 1985.

19. Balcerak, John C.: Flutter Tests of Variable Sweep Configurations. AFFDL-TR-68-101, 1968.

20. Anon: Compendium of Unsteady Aerodynamic Measurements. AGARD Report No. 702, 1982.

APPENDIX

LETTER OF INQUIRY

National Aeronautics and
Space Administration

Langley Research Center
Hampton, Virginia
23665

NASA

Reply to Attn of: 243

Dear ______________:

The desirability of establishing a set of standard configurations for comparisons of calculated and measured dynamic aeroelastic behavior was discussed at the last meeting of the Aeroelasticity Subcommittee of the AGARD Structures and Materials Panel. You may recall that several years ago the SMP selected two-dimensional and three-dimensional standard lifting-surface configurations (AGARD Advisory Report Nos. 156 and 167) to provide a common basis for comparison of pressures and forces calculated by the emerging transonic unsteady aerodynamic codes in order to assess how well these methods model the essential flow physics. It is appropriate now to designate a similar set of configurations as "standard" for the comparison of flutter characteristics and dynamic response (either forced or turbulence-excited) in order to assess how well these codes do the job for which they were intended, namely, predict aeroelastic behavior. At the request of the subcommittee I have agreed to survey the member countries for recommended candidate configurations and experimental data sets. Your assistance in providing input from your organization and country is respectfully requested.

The standard-configuration set should be regarded from the start as open-ended to provide for the inclusion of additional configurations as computational capabilities expand to treat more complicated shapes and flow phenomena, as additional useful data sets become available, and as additional aeroelastic peculiarities are observed. For initial purposes, however, the following guidelines seem appropriate.

Although emphasis is on the transonic range, it is desirable to include data sets which extend also into the upper subsonic and lower supersonic speed ranges.

Since most current aerodynamic theories are based on the assumption of attached flow, candidate data sets should be for test conditions that are not likely to involve any significant amount of flow separation, including that which may be introduced by model deformation. An exception to this guideline might be configurations and conditions for which vortex-type separation from lifting surface edges is present. Conditions involving pressure-gradient-induced or shock-induced flow separation from surfaces, on the other hand, may be more appropriate for inclusion at a later time.

Emphasis is on well-defined sets of flutter data for accurately known geometrical, structural, and flow conditions. It is highly desirable, however, to include also subcritical response data to facilitate an assessment of our ability to predict forced-response characteristics as well as the nature of the onset of flutter.

Both two-dimensional and three-dimensional configurations having conventional or supercritical airfoils, either with or without control-surface deflections, should be considered. Although emphasis is on isolated lifting surfaces, the candidate configurations may include interacting lifting surfaces such as wing-tail, wing-canard, or wing-winglet combinations. For initial purposes, however, configurations which involve interferring bodies, such as stores or nacelles, are not being considered.

The geometrical, mass, and stiffness properties of candidate models should be well defined and validated. Moreover, it should be remembered that mode shapes, frequencies, damping values, and generalized masses are not sufficient for structural description where dynamic behavior is nonlinear. Stiffness properties must also be known to permit the calculation of the statically deformed shape about which the flutter motion or dynamic response occcurs.

Within these guidelines your input, recommendations, and comments are earnestly solicited. Please furnish as much information as possible relative to each proposed configuration, the associated test conditions, and the resulting data sets. For example, was angle of attack varied? Was static or mean deformation measured under airload? If so, at how many points on the model? If not, was mean pressure distribution measured at enough points so that static deformation can be calculated from the stiffness data? If all pertinent information is not available to you at this time, please indicate the nature and extent of information that may be supplied later and approximately when it can be submitted. It would be helpful to know the extent to which model properties and other information have been validated or, conversely, the nature of any relevant inconsistencies or uncertainties. Please indicate whether the model still exists and could be available for further measurements and tests if needed.

In order to allow time for me to organize the material and prepare a preliminary report for presentation at the SMP meeting in September, please let me have your input by July 8, 1985. I thank you in advance for your contribution to this effort.

Sincerely,

E. Carson Yates, Jr.
Chief Scientist
Loads and Aeroelasticity Division

TABLE 1.- ORGANIZATIONS CONTACTED.

BELGIUM

1. Laboratoire de Techniques
   Aéronautiques et Spatiales
   Université de Liège
   Liège

CANADA

*2. Directorate of Science & Technology (O&V)
   Department of National Defence
   Ottawa

3. National Aeronautical Establishment
   National Research Council of Canada
   Ottawa

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4. Prospective Aerospatiale
   37 Bld De Montmorency
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*9. Institut A Für Mechanic
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   7000 Stuttgaart 80

**10. Institut Für Aeroelastik
   DFVLR-AVA Göttingen
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   3400 Göttingen

GREECE

11. Technology Research Center (KETA)
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   Athens

12. University of Patras
   Polytechnic School
   Patras

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13. Istituto Di Technologia Aerospaziale
   Universita Degli Studi Roma
   Via Eudossiana 16-19-00
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14. Aeritalia
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15. Politecnico di Milano
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16. Universita di Pisa
   Pisa

17. Instituto Progetto Velivoli
   Universita di Napoli
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*Responded without proposing candidate configurations
**Proposed configurations

NETHERLANDS

**18. National Aerospace Laboratory NLR
Anthony Fokkerweg 2
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19. CEMUL
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**20. Middle East Technical University
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21. British Aerospace Aircraft Group
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Warton, Preston, Lanes PR4 1AX

22. BAC Ltd.
Commercial Aircraft Division
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23. Hawker-Siddeley Aviation Ltd.
Woodford Aerodome
Stockport, Cheshire SK7 1QR

24. Aerodynamics Department
R141 - Royal Aircraft Establishment
Farnborough, Hants GUA 6TD

25. British Aerospace Dynamics Dept.
182 Building, Warton Aerodrome
Lancashire PR144X

26. Structures Department
Royal Aircraft Establishment
Farnborough, Hants GU14 6TD

27. British Aerospace, Weybridge, Div.
Weybridge, Surrey

UNITED STATES

**28. AFWAL/FIB
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*29. The Boeing Company
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Seattle, WA 98124

*30. Northrop Corporation
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Hawthorne, CA 90250

**31. Rockwell International Corporation
Los Angeles, CA 90009

*32. McDonnell Douglas Corporation
3855 Lakewood Boulevard
Long Beach, CA 90846

**33. McDonnell Douglas Corporation
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*34. Grumman Aerospace Corporation
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**35. General Dynamics Corporation
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**36. Lockheed California Company
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Durham, NC 27706

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Massachusetts Institute of Technology
Cambridge, MA 02139

---

*Responded without proposing candidate configurations
**Proposed configurations

UNITED STATES (Continued)

**40. Department of Aeronautics and Astronautics
Stanford University
Stanford, CA 94305

**41. NASA Langley Research Center
Hampton, VA 23665-5225

*Responded without proposing candidate configurations
**Proposed configurations

TABLE 2.- CONFIGURATIONS RECOMMENDED

(A) SWEPT WINGS

CONFIGURATION		WING 445.6	TF-8A WING	SUPERCRITICAL TRANSPORT WING	MODIFIED F-16 WING
GEOMETRY	ASPECT RATIO	4	6.78	11	3.28
	SWEEP ANGLE	45° (C/4)	44.5° (LE)	16° (C/4)	40° (LE)
	TAPER RATIO	0.6	0.364		0.214
	CAMBER/TWIST	NO/NO	YES/YES	YES/YES	NO/NO
	AIRFOIL	65A004	SUPERCRIT, CONVENTIONAL	16% - 11.5%	(64A003.5 64A004)
	FUSELAGE	NO	YES	YES	YES
MODEL PROPERTIES	VIBRATION MODES	4 NODES	6M,12C	2M,2C	5M
	STIFFNESS	EI,GJ	EI,GJ		MEAS,CALC.
	GENERALIZED MASSES OR DISTRIBUTION	TOTAL MASS	6M,12C	2M,2C	CALC.
TEST CONDITIONS	ANGLE OF ATTACK	0	0 - 3°	-0.35 - 2.05°	0
	MACH NUMBER	0.34 - 1.14	0.60 - 1.06	0.60 - 0.79	0.65 - 1.15
	REYNOLDS NO. x 10^{-6}	0.5 - 6.7	3. - 9.		6. - 10.
MODEL EXISTS		NO	YES		YES
PUBLISHED REFERENCES		3	4,5	6,7	8,9

M = MEASURED C = CALCULATED

TABLE 2.- CONFIGURATIONS RECOMMENDED (CONCLUDED)

(B) UNSWEPT WINGS

CONFIGURATION		RIGID RECTANGULAR WING	RECTANGULAR WING -CRYOGENIC	2D
GEOMETRY	ASPECT RATIO	6	3	∞
	SWEEP ANGLE	0	0	0
	TAPER RATIO	1.0	1.0	1.0
	CAMBER/TWIST	NO/NO	NO/NO	YES/NO
	AIRFOIL	SUPERCRIT. 64A010	64A010	MBB-A3
	FUSELAGE	NO	NO	NO
MODEL PROPERTIES	VIBRATION MODES	2M,2C	4M,5C	2
	STIFFNESS	MEAS,CALC	CALC	
	GENERALIZED MASSES OR DISTRIBUTION	MEAS	MEAS,CALC	
TEST CONDITIONS	ANGLE OF ATTACK	0	0	0 - 4°
	MACH NUMBER	0.52 - 0.95	0.50 - 0.90	0.6 - 0.88
	REYNOLDS NO. x 10^{-6}	4. - 5.	5. - 20.	6. - 10.
MODEL EXISTS		YES	YES	YES
PUBLISHED REFERENCES		10	11	

M = MEASURED C = CALCULATED

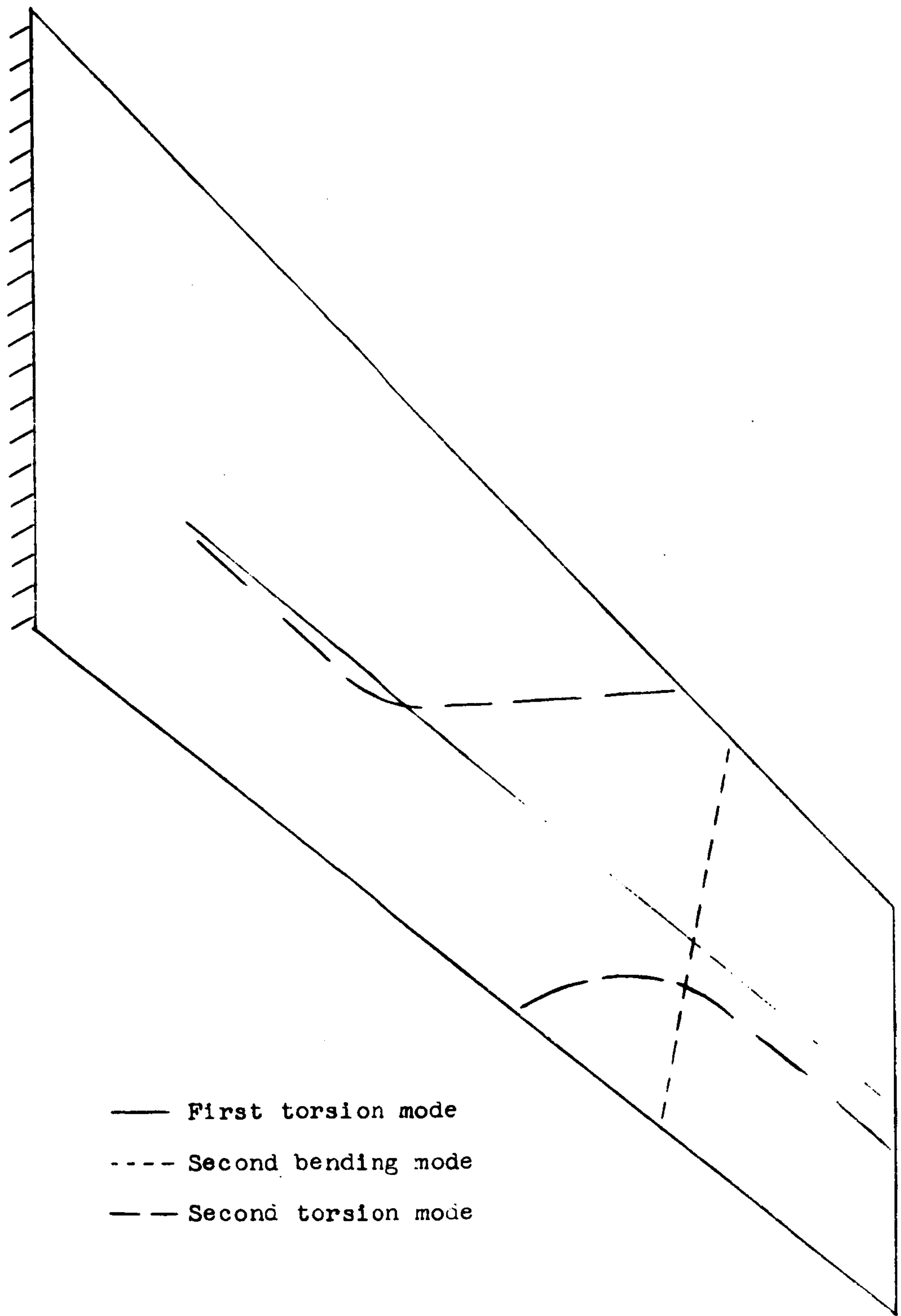

FIGURE 1.- PLANFORM AND MEASURED NODE LINES OF WING 445.6.

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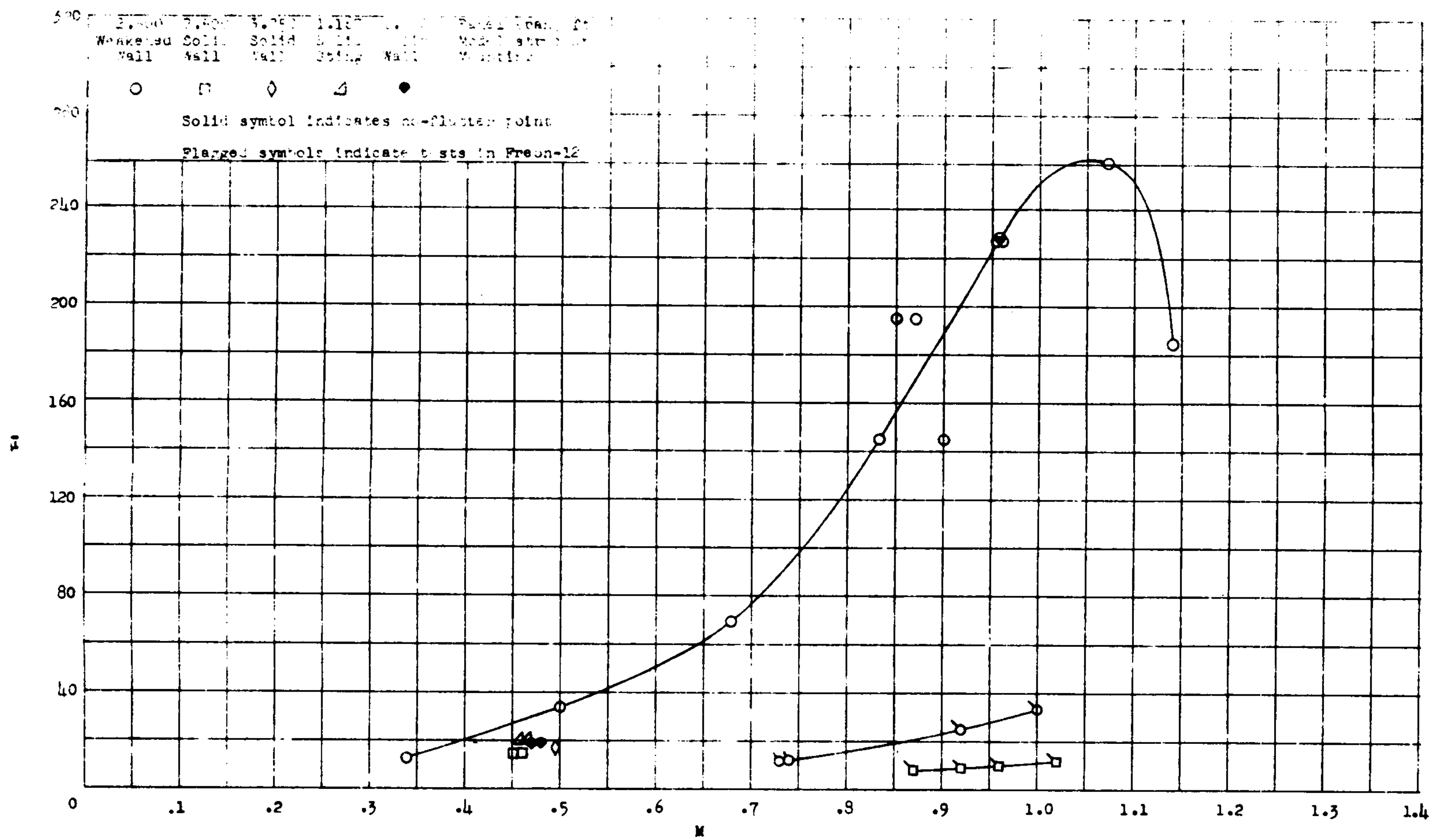
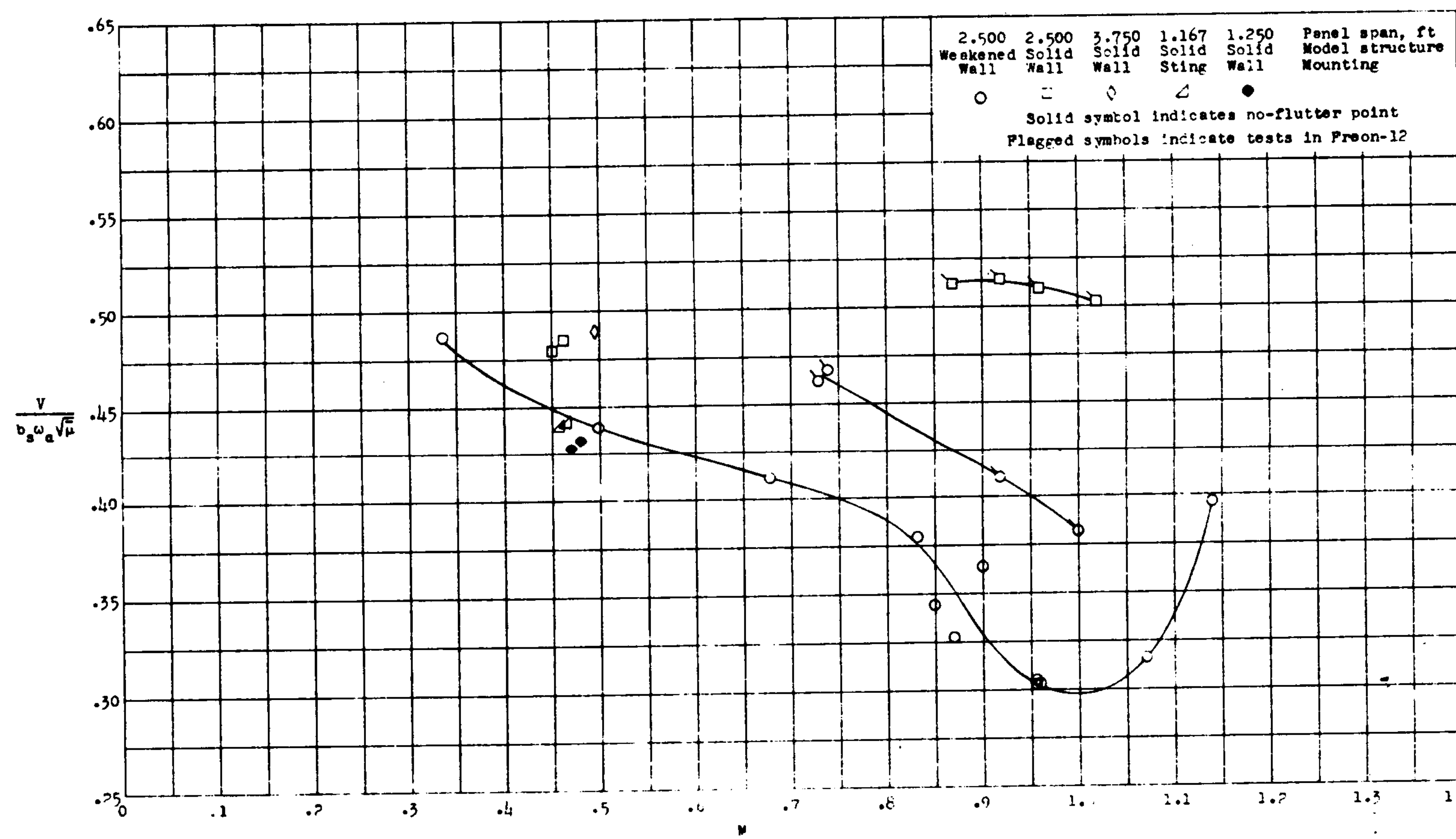


Mass ratios and Mach numbers covered in the present tests in air and Freon-12 in the transonic dynamics tunnel.

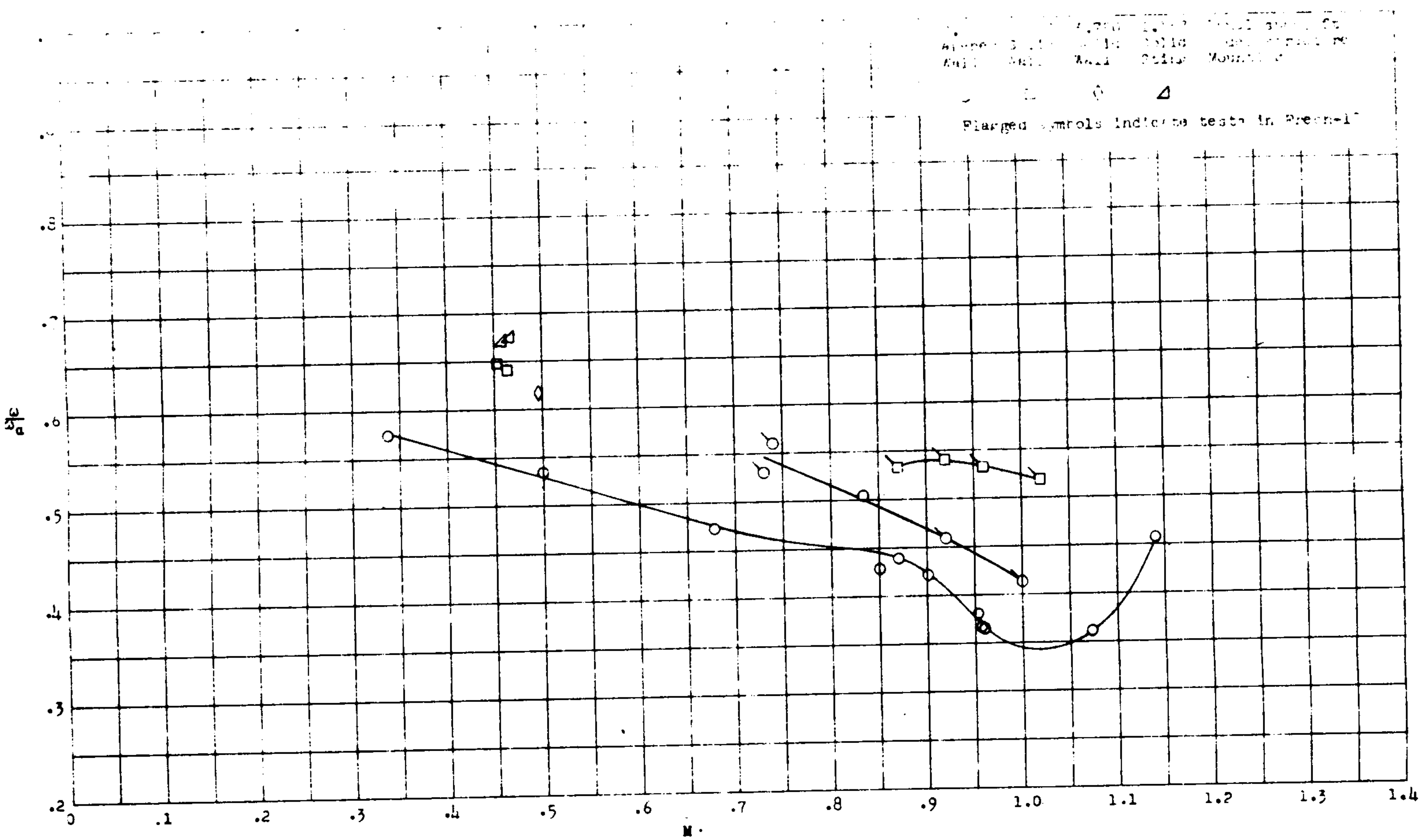
FIGURE 2.- MASS RATIOS FOR WING 445.6.



(a) Flutter-speed coefficient.

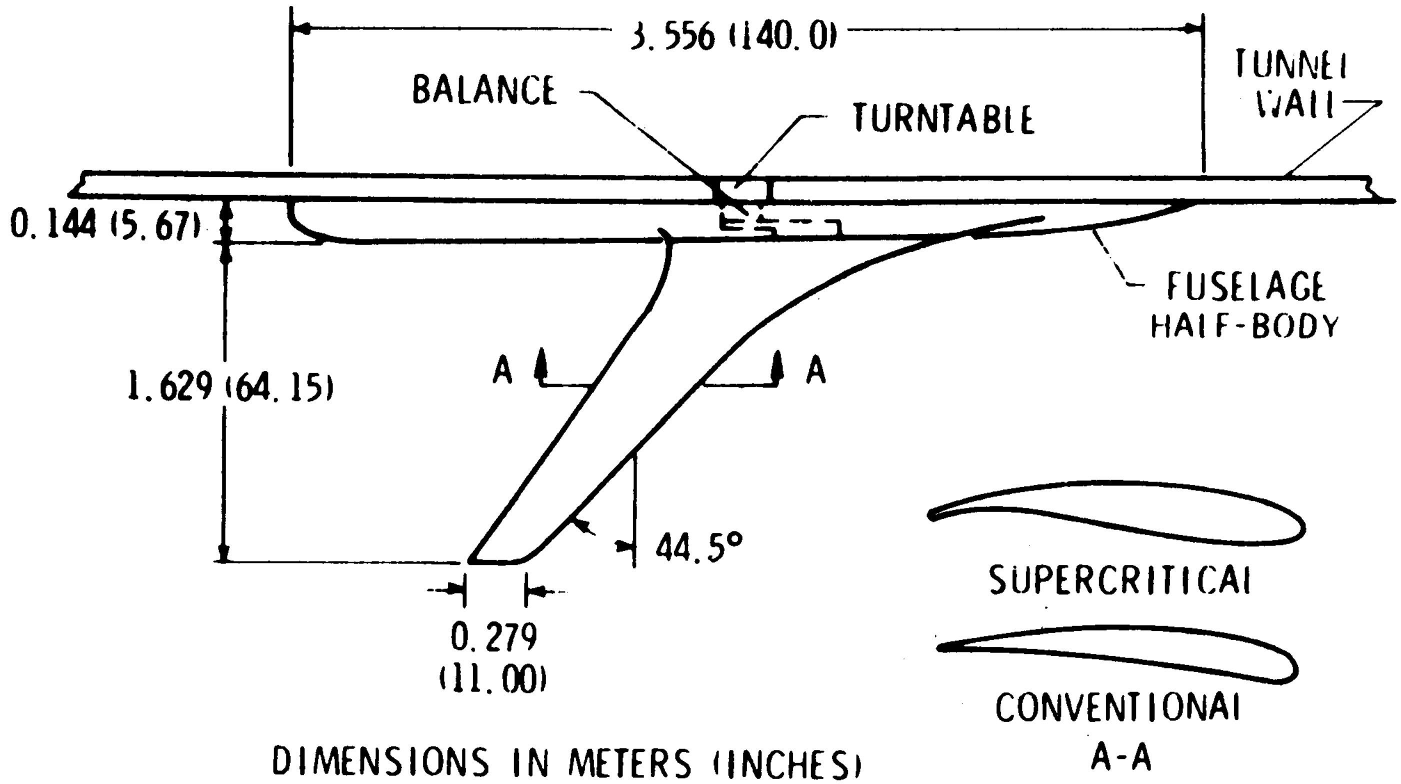
Flutter characteristics measured in air and in Freon-12 in the transonic dynamics tunnel.

FIGURE 3.- FLUTTER CHARACTERISTICS OF WING 445.6.



(b) Flutter-frequency ratio.

FIGURE 3.- CONCLUDED.



Model geometry.

FIGURE 4.- TF-8A WING.

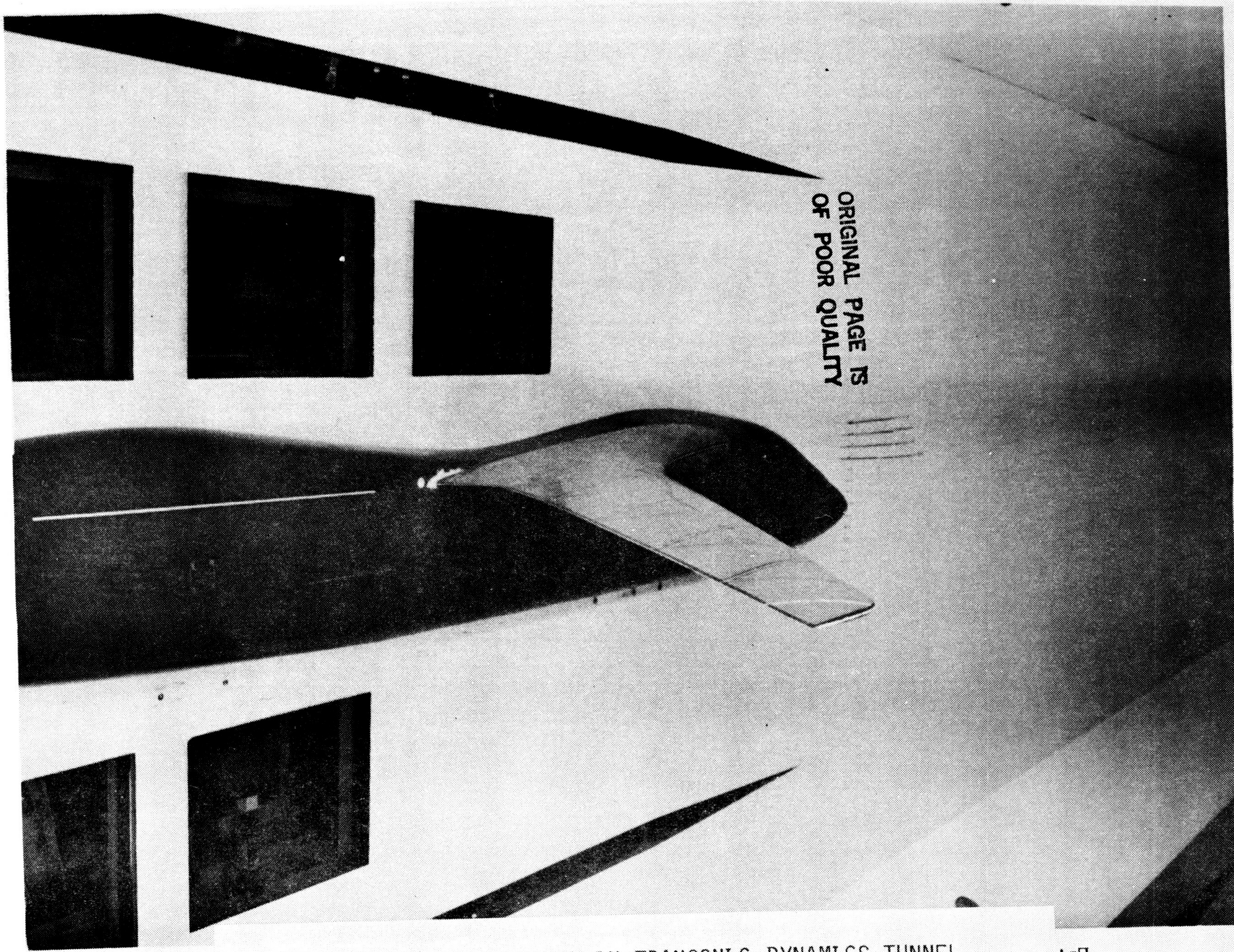
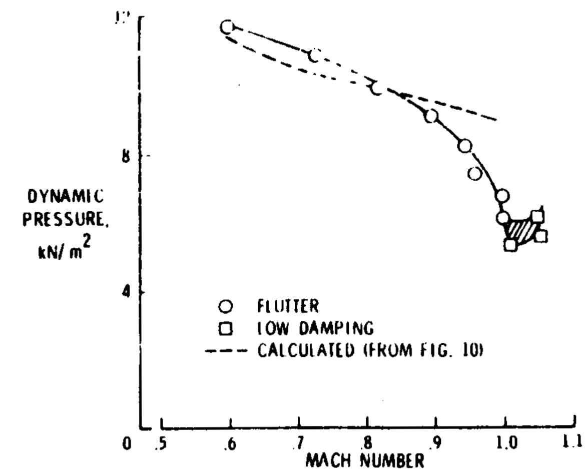
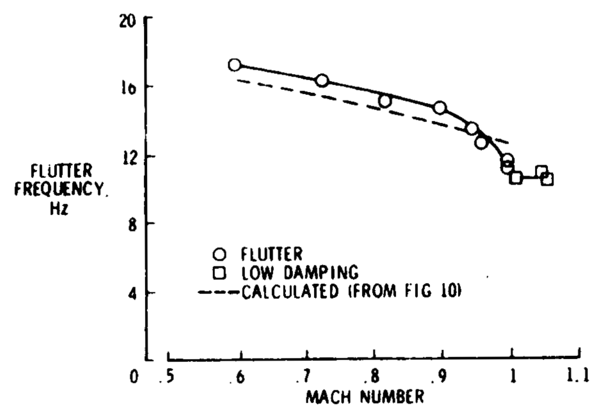


FIGURE 5.- TF-8A MODEL IN TRANSONIC DYNAMICS TUNNEL.

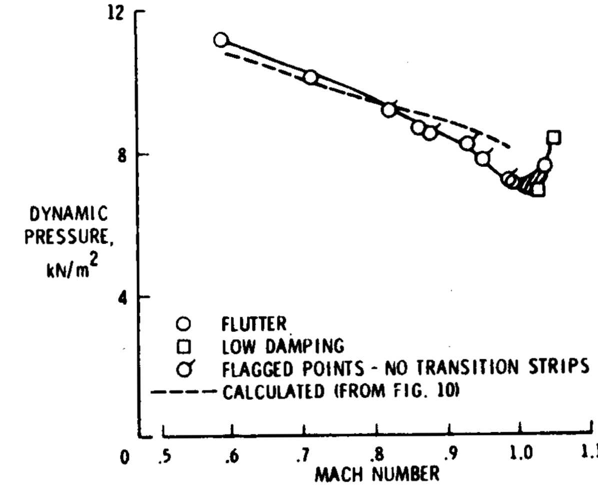


(a) Flutter boundary.

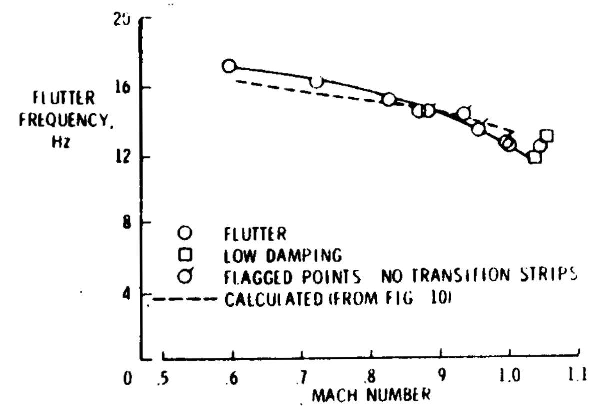


(b) Flutter frequency.

Comparison of measured and calculated flutter characteristics of supercritical wing.



(a) Flutter boundary.



(b) Flutter frequency.

Comparison of measured and calculated flutter characteristics of conventional wing.

FIGURE 6.- FLUTTER CHARACTERISTICS OF TF-8A WING NEAR ZERO ANGLE OF ATTACK.

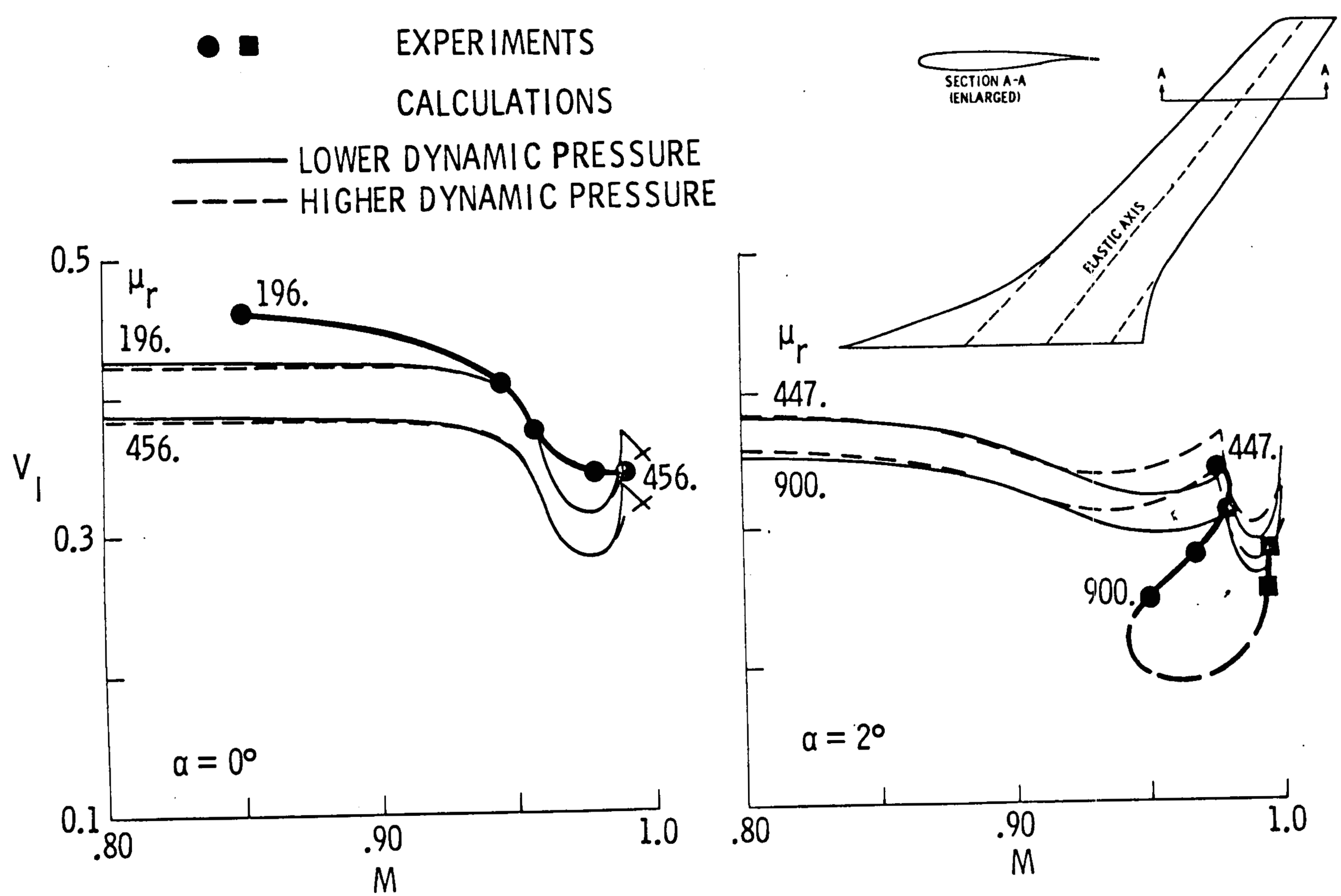
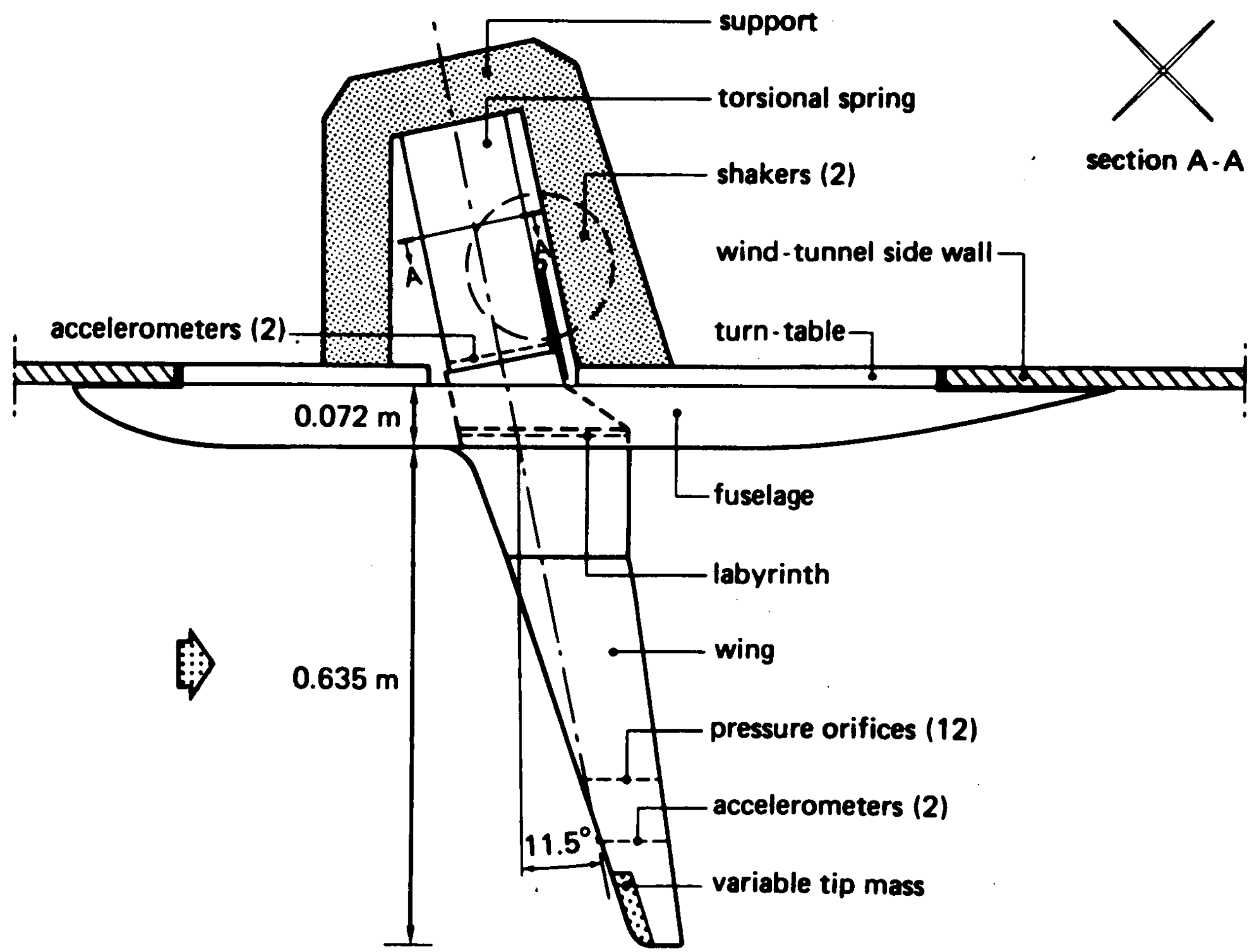
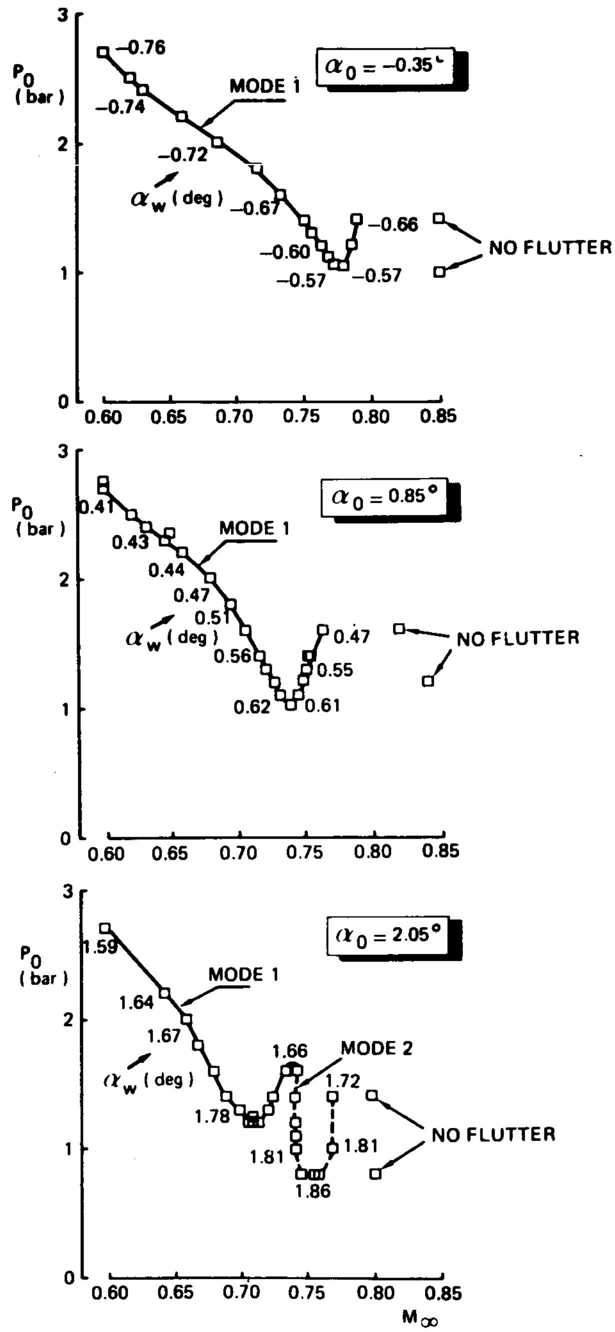


FIGURE 7.- EFFECT OF ANGLE OF ATTACK ON FLUTTER CHARACTERISTICS OF TF-8A WING.



Global view of flutter model and support.

FIGURE 8.- SUPERCRITICAL TRANSPORT WING.



Measured flutter boundaries at $\alpha_0 = -0.35$, 0.85, and 2.05 deg (fixed transition).

FIGURE 9.- FLUTTER CHARACTERISTICS OF SUPERCRITICAL TRANSPORT WING.

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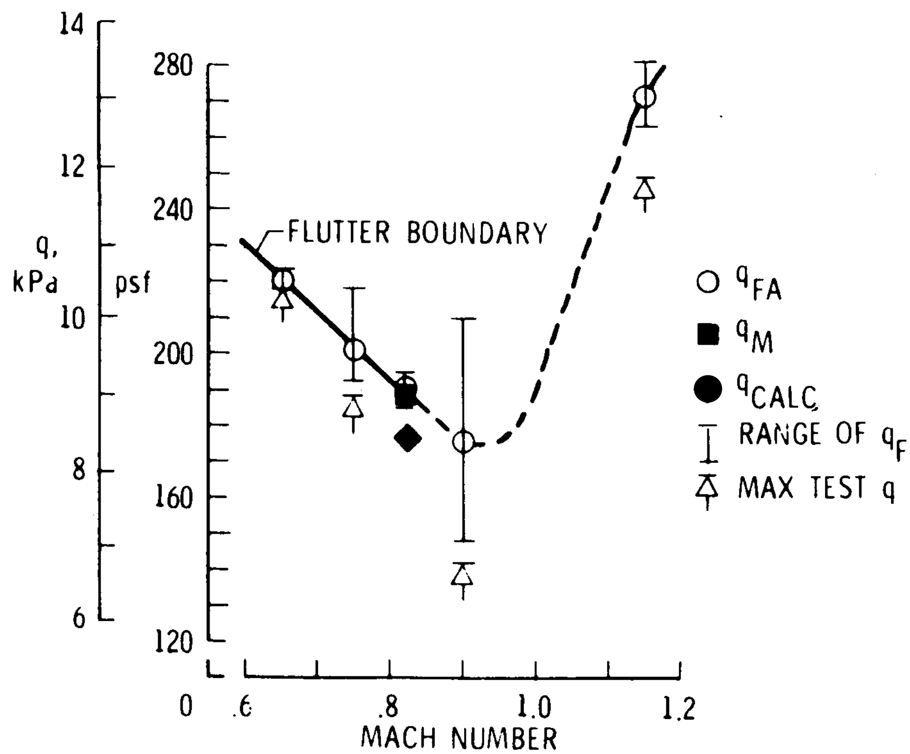
FIGURE 10.- MODIFIED F-16 WING MODEL.



Flutter boundary predicted by SR methods.

FIGURE 11.- FLUTTER CHARACTERISTICS OF MODIFIED F-16 WING.

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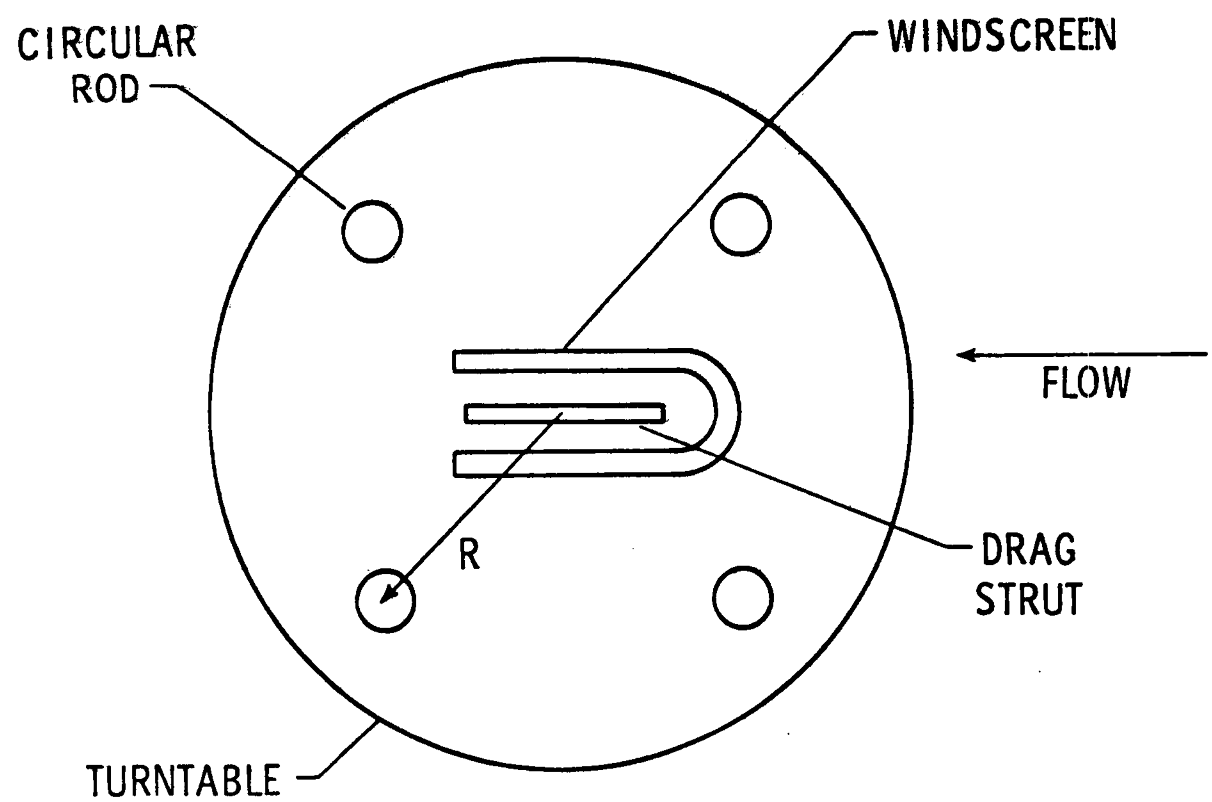
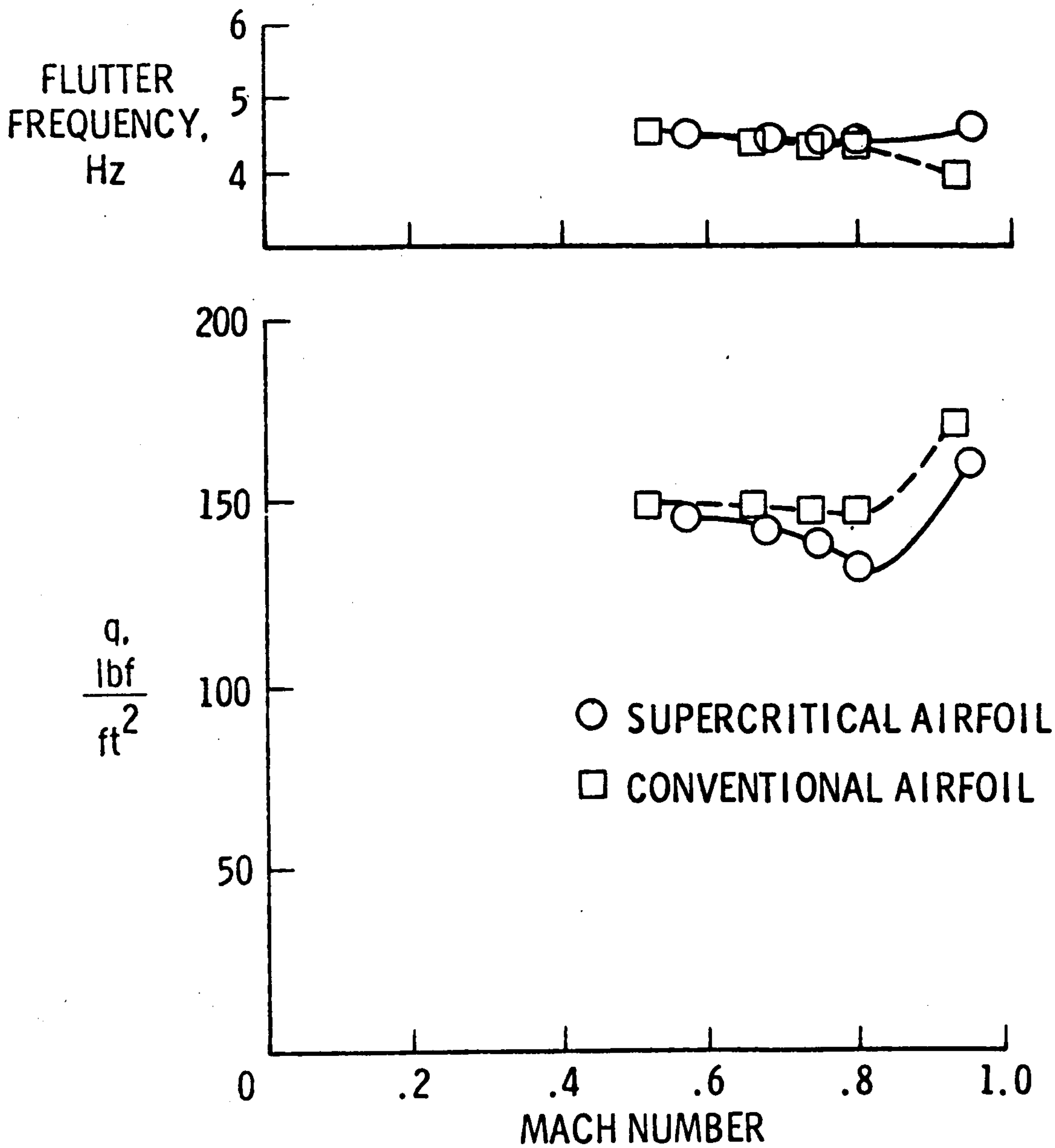
FIGURE 12.- RIGID RECTANGULAR WING ON FLEXIBLE MOUNT.



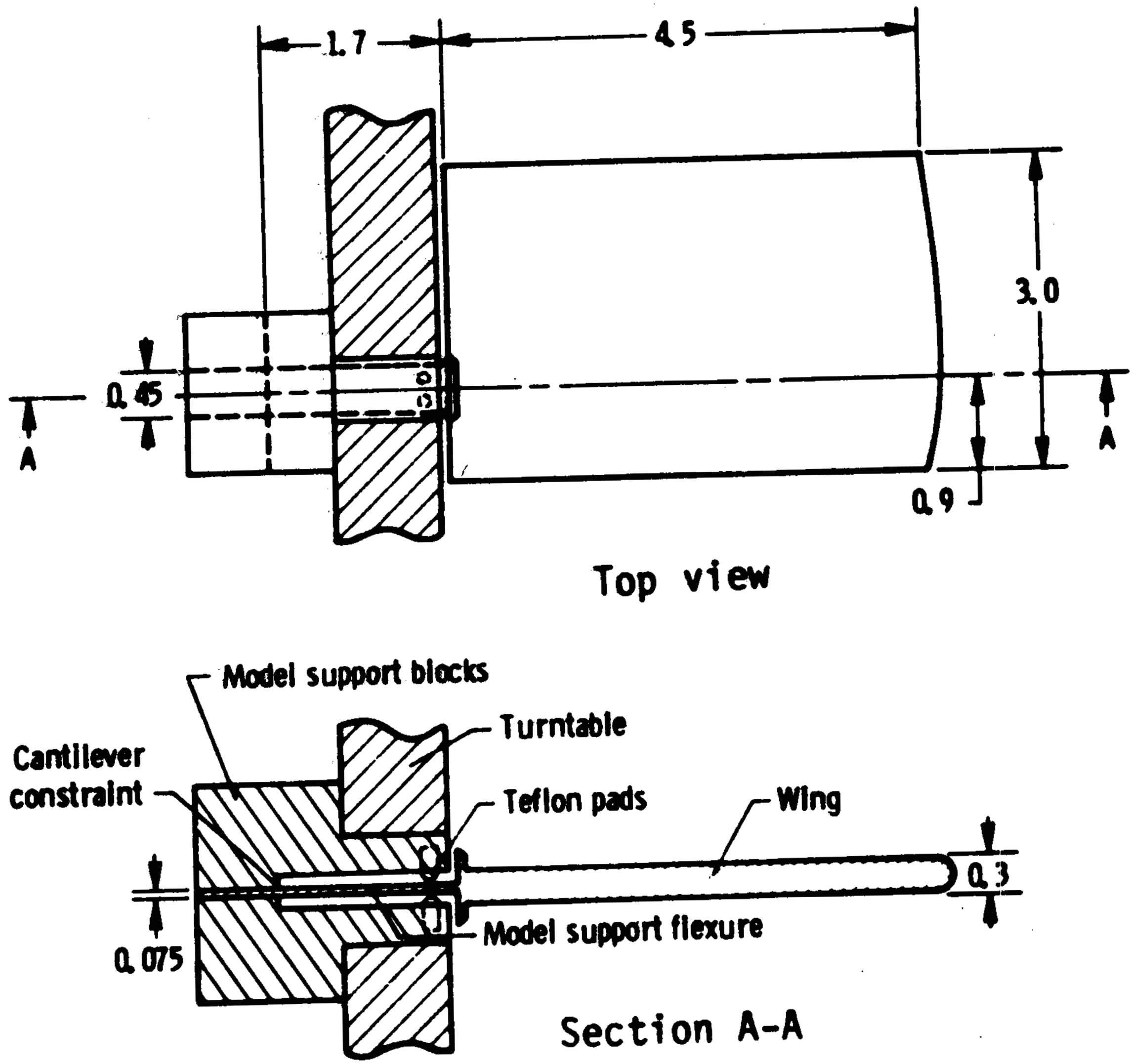
Horizontal view looking perpendicular to the face of the turntable

FIGURE 13.- ARRANGEMENT OF FLEXIBLE MOUNT COMPONENTS.



Comparison of the measured low angle of attack flutter boundaries for two wings in freon.

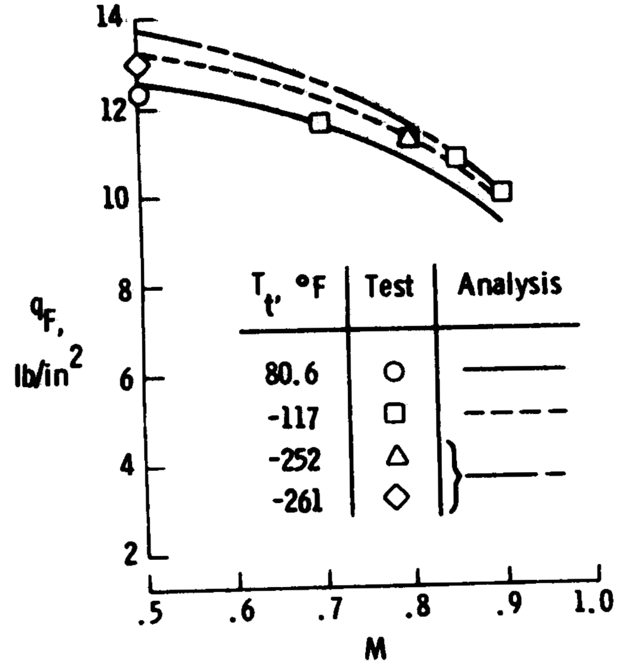
FIGURE 14.- FLUTTER CHARACTERISTICS OF RIGID RECTANGULAR WING ON FLEXIBLE MOUNT.



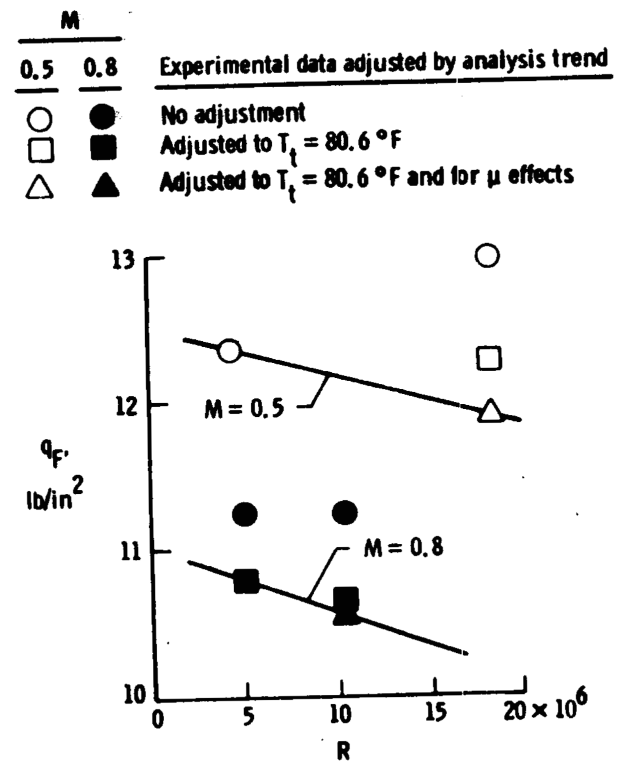
Sketches of model and support arrangement. (Dimensions are inches.)

FIGURE 15.- RECTANGULAR WING MODEL AND SUPPORT.

FIGURE 16.- RECTANGULAR WING IN CRYOGENIC TUNNEL.



Experimental and calculated flutter results.



Experimental effects of Reynolds number on q_F.

FIGURE 17.- FLUTTER CHARACTERISTICS OF RECTANGULAR WING IN CRYOGENIC TUNNEL.

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15. Supplementary Notes

Presented at 61st Meeting of the AGARD Structures and Materials Panel in Oberammergau, Federal Republic of Germany, September 9-13, 1985.

16. Abstract

At the request of the Aeroelasticity Subcommittee of the AGARD Structures and Materials Panel, a survey of member countries has been conducted to seek candidates for a prospective set of standard configurations to be used for comparison of calculated and measured dynamic aeroelastic behavior with emphasis on the transonic speed range. This set is a sequel to that established several years ago for comparisons of calculated and measured aerodynamic pressures and forces. Approximately two dozen people in the United States, and more than three dozen people in the other member countries, were contacted. This preliminary report presents the results of the survey and an analysis of those results along with recommendations for the initial set of standard configurations and for additional experimental work needed to fill significant gaps in the available information.

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