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# AGARD STANDARD AEROELASTIC CONFIGURATIONS FOR DYNAMIC RESPONSE

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## GUIDELINES FOR PRELIMINARY ASSESSMENT

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.

- Emphasis on transonic speed range
- Configurations with clean, smooth surfaces
  - Isolated surfaces now
    - Two- and three-dimensional
    - With or without control-surface deflections
    - Conventional or supercritical airfoils
- Well-defined configurations/data sets
  - Geometrical properties
  - Structural properties
  - Flow properties
- Subcritical-response data as well as flutter data
- Exclude:
  - Complicated shapes and flow
  - Configurations/tests likely to involve
    - Flow separation
    - Uncertain model properties
    - Uncertain behavior
    - Sensitivity to variations in model properties

## RESPONSE TO SURVEY

Several years ago, the AGARD Structures and Materials Panel 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. The results of that survey were given in reference 3 and are summarized here along with the initial selection of a standard configuration.

The survey produced no particular surprises in terms of the unexpected abundance or deficiency of specific kinds of data and information. It was no surprise, for example, that suitable data do not appear to be available from the industry. The high-aspect-ratio transport-type wings that have been flutter tested generally had pylon-mounted nacelles attached and hence are not considered suitable 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.

- No particular surprises
- Suitable data not available from industry
  - High-aspect-ratio wings have nacelles
  - Low-aspect-ratio wings have stores

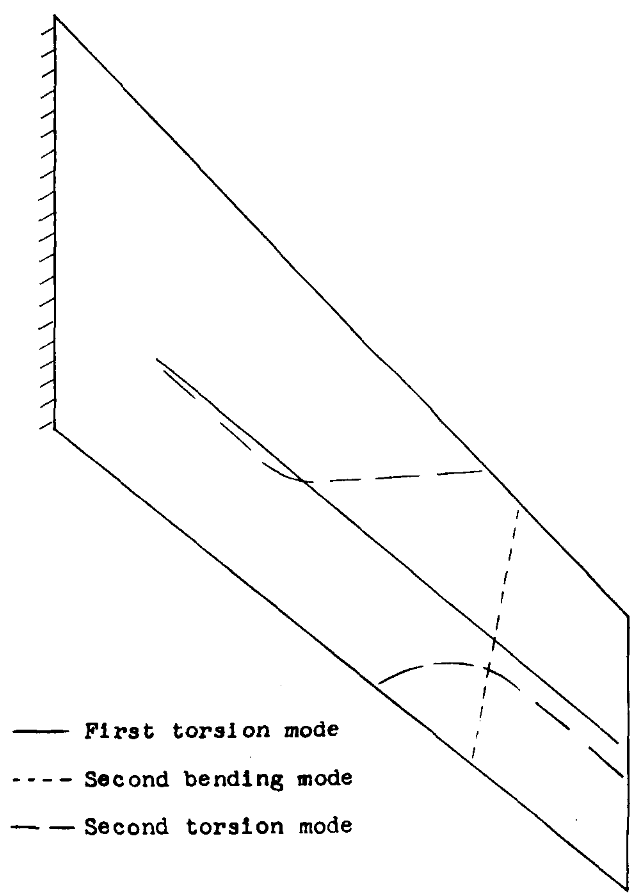
## RESULTS

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. 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. However, adequate experimental data sets presently exist for only three of these configurations.

- Seven configurations appear suitable for AGARD standards
  - Four swept wings
  - Two unswept wings
  - One two-dimensional wing
- All were
  - Isolated, clean wings
  - Wall-mounted semispan models (except 2D)
  - Tested in slotted-throat tunnels
- Adequated experimental data sets exist for only three of these configurations

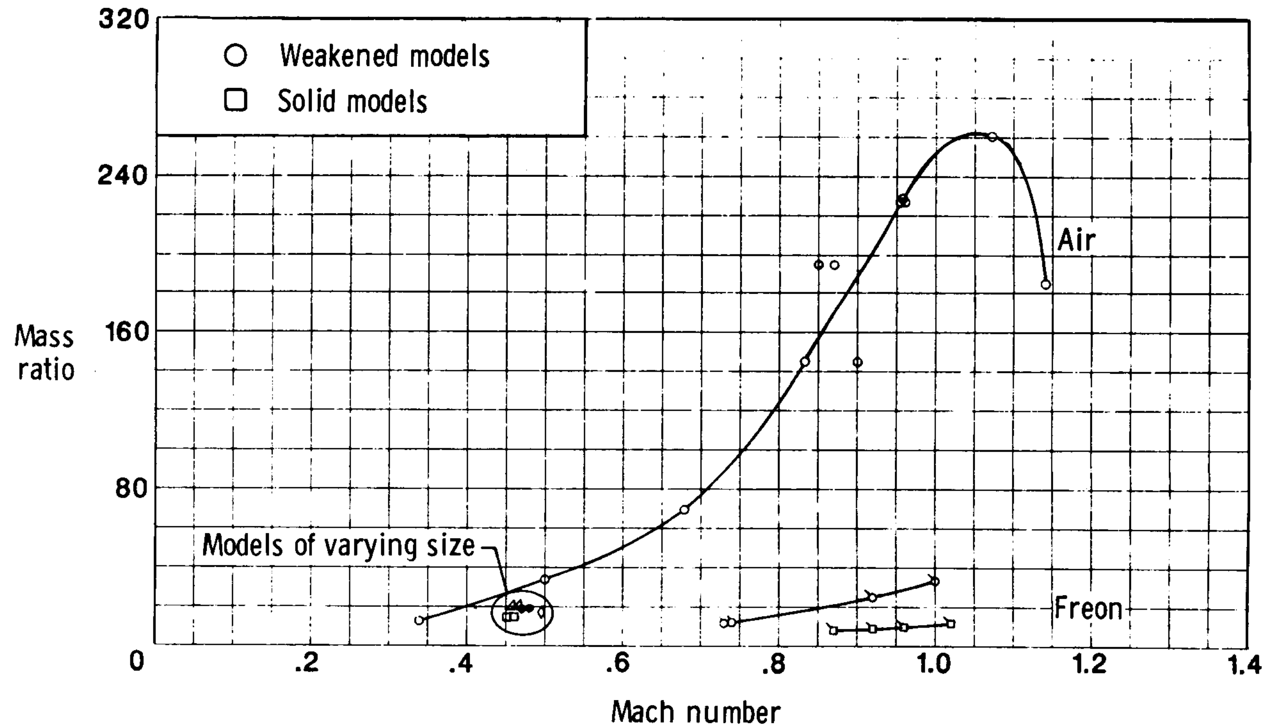
PLANFORM AND MEASURED NODE LINES OF WING 445.6

The first configuration to be tentatively accepted as an AGARD standard is designated "Wing 445.6". Wing 445.6 identifies the shape of a set of sweptback, 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. 4). 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 NACA 65A004 airfoil sections with 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. 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.



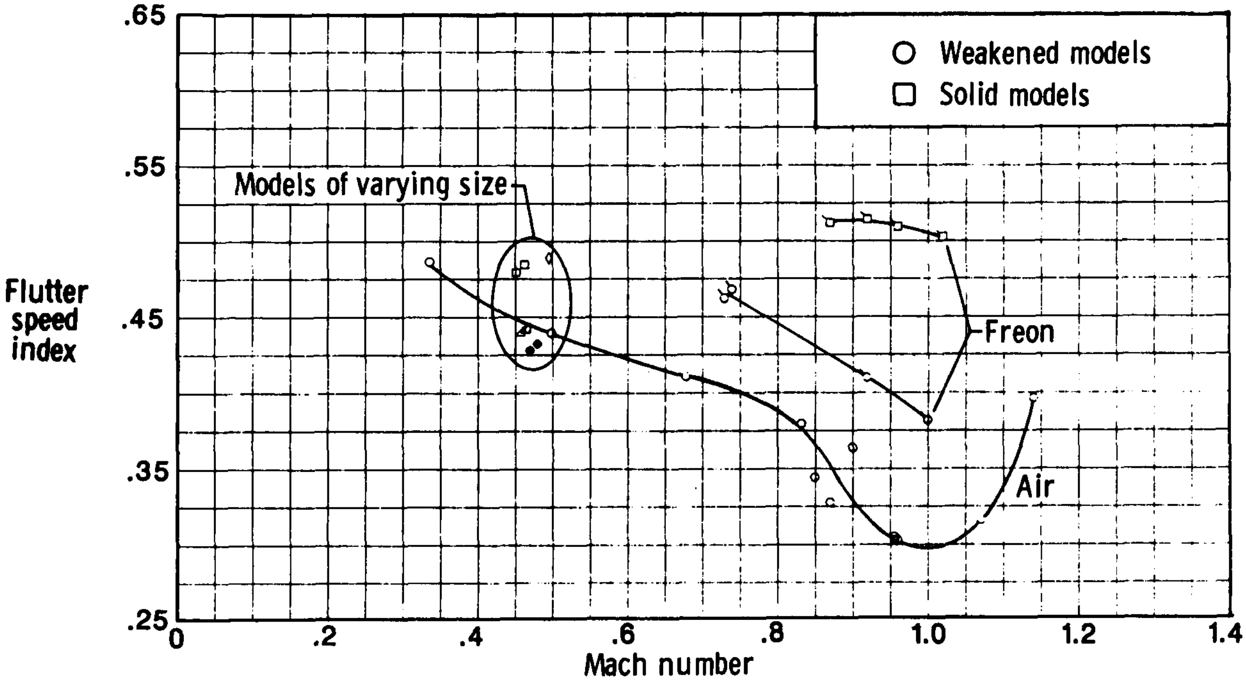
## MASS RATIOS FOR WING 445.6

This configuration and associated data are recommended for several reasons. The tests in air and freon covered a very wide range of mass ratio (8.5 to 260 overall as shown here). 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.



FLUTTER-SPEED INDEX FOR WING 445.6

The transonic dip is defined, including the supersonic side, and data extend also well into the subsonic range. Very good repeatability of data was shown. 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.



## WING 445.6

The features that make wing 445.6 attractive as a standard configuration are summarized in this figure.

Reasons recommended:

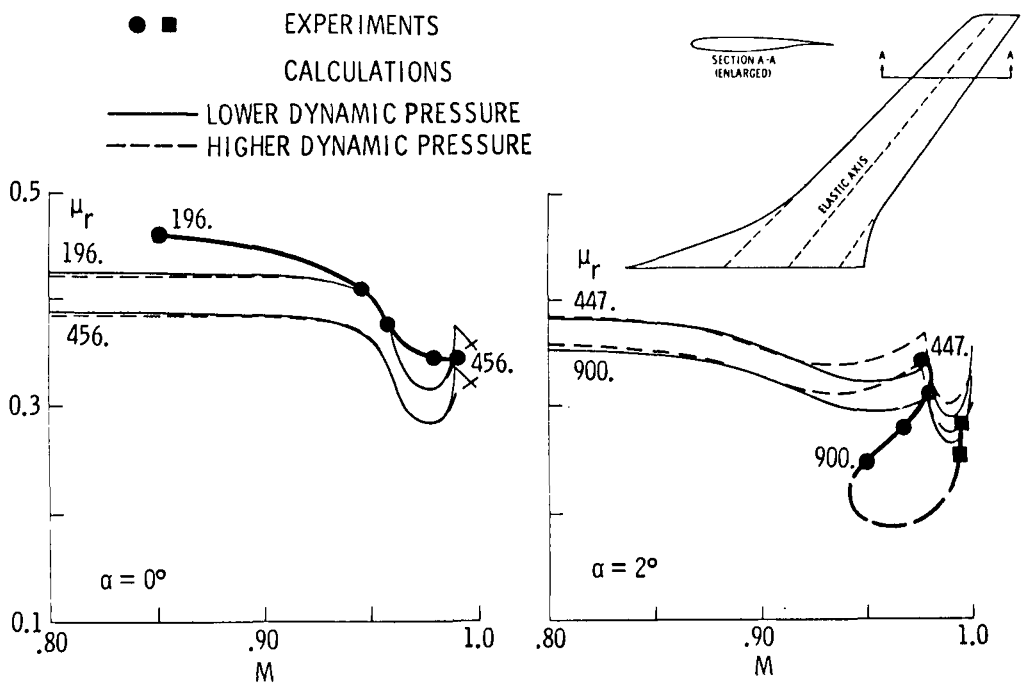
- No twist, camber, angle of attack - therefore, no static aeroelastic deformation
- Cantilever-mounted with no fuselage - therefore, no interference flow
- Tests covered large range of mass ratio
- Transonic dip fully defined
- Good repeatability of flutter data

Information not available:

- Mode shapes not measured, but have been calculated

FLUTTER-SPEED INDEX FOR TF-8A WING

The TF-8A wing and associated data sets constitute the most complex of the candidate configurations considered in reference 3. Two models of this wing were tested in air and in Freon-12 (refs. 5 and 6). The models were mounted on a half fuselage for testing and were as nearly identical as possible except one had a supercritical airfoil, and the other had a conventional airfoil. The data obtained in Freon for both wings for angles of attack near zero (ref. 5) show little scatter, extend well into the subsonic range, and include a well-defined transonic dip. Moreover, the flutter boundary for the wing with supercritical airfoil has been closely predicted by modified strip analysis (ref. 6). A limited amount of flutter data obained in air for the supercritical wing at angles of attack between 0° and 3° (ref. 7) shows a drastically detrimental effect of angle of attack, even at only one or two degrees. The unconventional shape of the flutter boundary for nonzero angle of attack has been shown by modified-strip-analysis calculations to be generated by large variations in mass ratio (refs. 7 and 8), although static aeroelastic deformation apparently has an influence as well.



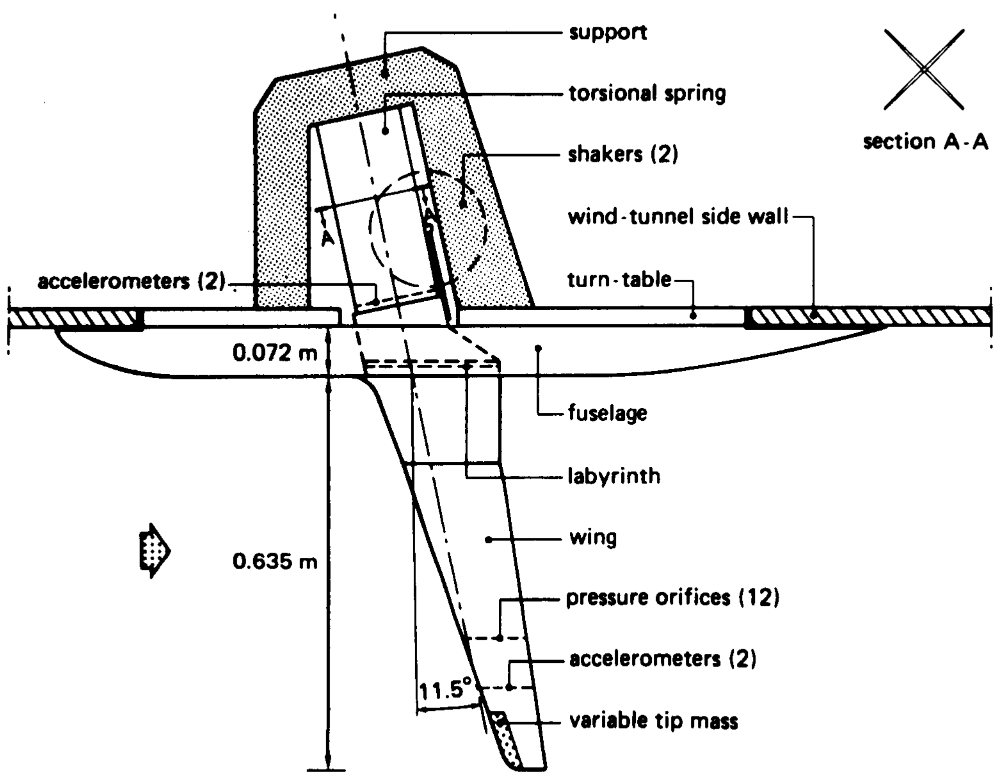
## TF-8A WING

The features that make the TF-8A wing models attractive as standard configurations are summarized here. Note that calculation of flutter characteristics for these models should include also calculation of the aeroelastically deformed shape and associated static loading about which the flutter oscillation occurs (refs. 7 and 8).

Reasons recommended:

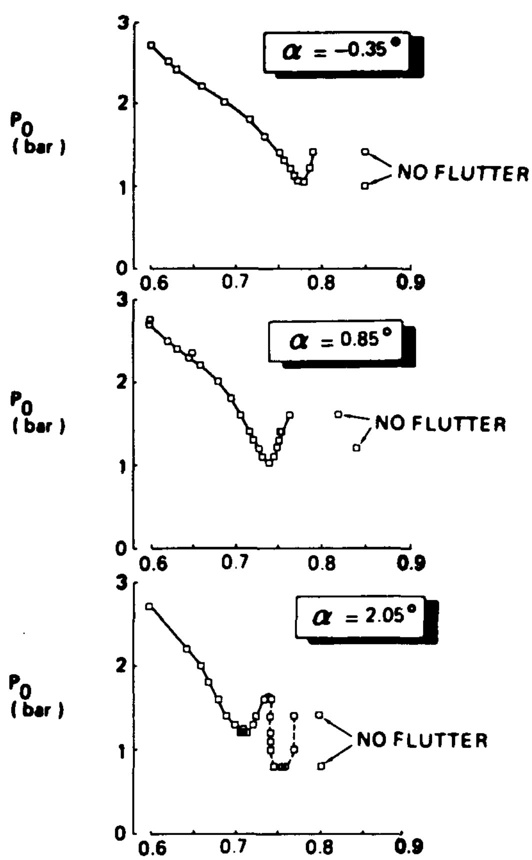
- Data for wings with conventional and supercritical airfoils
- Flutter boundary well defined, including transonic dip
- Tests covered large range of mass ratio
- Data include effects of nonzero angles of attack
- Shapes, frequencies, and generalized masses for six modes measured

The high-aspect-ratio supercritical transport-type wing shown here has been studied extensively at NLR Amsterdam (refs. 9 and 10). 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.




**Global view of flutter model and support.**

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°. 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. 7). The flutter boundaries for the supercritical transport wing, however, do not show the backward turn which was found experimentally for the TF-8A wing at positive angles of attack.



# SUPERCRITICAL TRANSPORT WING

The features that make the supercritical transport wing attractive as a standard configuration are summarized here.

Reasons recommended:

- Flutter boundary very well defined, especially transonic dip
  - Many flutter points, little scatter
- Subcritical-response data taken
- Data include effects of nonzero angles of attack

## STATUS ASSESSMENT - GENERAL

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. Three rather obvious general comments are pertinent: First, high-Reynolds-number data are obviously needed for all types of configurations for closer simulation of aircraft flight conditions. These data are also needed for standard configuration/data sets. Second, data are needed for configurations which incorporate some degree of control-surface deflection in their modes of motion. 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 (e.g., refs. 2 and 11). 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.

Based on a perception of requirements for AGARD standard configurations, not on research needs

- High-Reynolds-number data are needed for all types of configurations
  - For closer simulation of aircraft flight conditions
  - For closer, more valid comparisons with calculations by
    - Inviscid-flow theories
    - Viscous/inviscid interaction methods
    - Navier-Stokes solutions
- Data are needed for configurations with control-surface deflections
  - For assessment of calculated contol-surface behavior and influence on flutter
  - For active-control studies
- In future tests subcritical-response data and static aeroelastic deformations should be recorded as flutter is approached

## STATUS ASSESSMENT - CONFIGURATIONS

Moderate-to-High-Aspect-Ratio Wings.- The three configurations listed provide reasonably adequate representation of moderate-to-high-aspect-ratio wings at moderate Reynolds numbers. Some pecularities in the effect of angle of attack on the transonic dip for supercritical wings have been delineated; models still exist for further testing as needed.

Low-Aspect-Ratio Swept Wings.- The greatest current deficiency appears to exist for low-aspect-ratio (fighter-type) swept wings. As indicated previously, design-related testing of such models in clean-wing configuration has usually not been taken to hard flutter points. Flutter tests are needed for low-aspect-ratio highly-swept wings at zero to moderately high angles 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.

Two-Dimensional Wings.- The survey did not reveal the existence of any transonic flutter data for two-dimensional wings. However, planned tests of the MBB-A3 supercritical airfoil at DFVLR Göttingen and at NASA Langley may provide the needed data sets.

- Moderate-to-high-aspect-ratio wings:
  - Wing 445.6, TF-8A wing, supercritical transport wing provide reasonably adequate standards for
    - Moderate Reynolds numbers
    - Conventional and supercritical wings with and without twist and camber
    - Effects of zero and nonzero angles of attack
    - Subcritical response data exist
- Low-aspect-ratio swept wings:
  - Greatest deficiency in configurations and data indicated by survey
  - Flutter tests are needed for low-aspect-ratio highly swept wings at zero to moderately high angle of attack (free-vortex-dominated flow)
- Two-dimensional wings:
  - No transonic flutter data appear to exist
  - Imminent tests at DFVLR and NASA should fill need

## SYMBOLS

$M$ freestream Mach number

$P_o$ freestream stagnation pressure

$V_I$ flutter-speed index

$\alpha$ steady-state (or mean) angle of attack at wing root

$\mu_r$ mass ratio

## 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.: Preliminary Report on Candidates for AGARD Standard Aeroelastic Configurations for Dynamic Response. Presented at the 61st Meeting of the AGARD Structures and Materials Panel, Oberammergau, Federal Republic of Germany, September 9-13, 1985. Available as NASA TM-89142, 1987.

4. 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 Freon-12 in the Langley Transonic Dynamics Tunnel. NASA TN D-1616, 1963.

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

6. Yates, E. Carson, Jr,; Wynne, Eleanor C.; Farmer, Moses G.; and Desmarais, Robert N.: Prediction of Transonic Flutter of a Supercritical Wing by Modified Strip Analysis. Journal of Aircraft, Vol. 19, No. 11, November 1982, pp. 999-1004.

7. Yates, E. Carson, Jr.; Wynne, Eleanor C.; and Farmer, Moses G.: Effects of Angle of Attack on Transonic Flutter of a Supercritical Wing. Journal of Aircraft, Vol. 20, No. 10, Oct. 1983, pp. 841-847.

8. Yates, E. Carson, Jr.; and Chu, Li-Chuan: Static Aeroelastic Effects on the Flutter of a Supercritical Wing. In "Static Aeroelastic Effects on High Performance Aircraft." AGARD CP-403, 1986. Available also as NASA TM-89132, 1987.

9. 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.

10. 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, November 1984, pp. 906-912.

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