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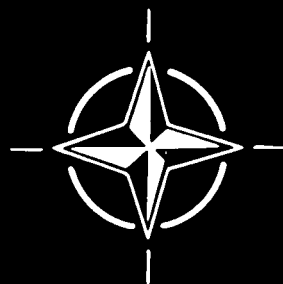
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Bibliography of Documents Containing Numerical Data on Planar Lifting Surfaces

by

R. Dat

NORTH ATLANTIC TREATY ORGANIZATION



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BIBLIOGRAPHY OF DOCUMENTS CONTAINING NUMERICAL
DATA ON PLANAR LIFTING SURFACES

by

R. Dat

Office National d'Etudes et de Recherches Aérospatiales
92 - Châtillon, France

Published August 1970

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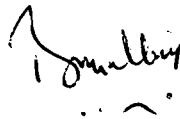


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FOREWORD

This Report was originally planned as part of Volume VI of the AGARD loose leaf Manual on Aeroelasticity. The loose leaf Manual on Aeroelasticity was started in August 1959 and contains some 47 different articles.

This and future Reports will be published as separate AGARD Reports. To ensure that the new reader of each Report is aware of the wide scope of work on this subject covered by the Structures and Materials Panel of AGARD, each Report will contain a full list of all previously printed articles.



B.P. Mullins

Chairman, Editorial Committee,
AGARD Structures and Materials Panel

March 1970

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BIBLIOGRAPHY OF DOCUMENTS CONTAINING NUMERICAL DATA ON PLANAR LIFTING SURFACES

R. Dat

INTRODUCTION

Progress from the strip method to lifting-surface theory, which is a significant step in the field of aeroelasticity, has brought about a complete change in calculation procedures. The number of parameters necessary to define the planform and the harmonic motion of a lifting surface is such that it prevents the setting up of tables covering all cases, like the tables for two-dimensional coefficients. Because of this, the programmes for aeroelasticity calculations must be associated with non-stationary aerodynamics programmes that calculate the aerodynamic influence coefficients, in order to store them as soon as a new planform has been defined.

Under these conditions, it may seem strange to publish numerical results since they do not save the user the trouble of performing the calculations. This may be the reason why there are few publications containing any large number of numerical results presented in relation to parameters that are being systematically varied; most authors generally confine themselves to the publication of partial results, which they compare with other data, whether theoretical or experimental.

Thus, calculations like those that result in the publication of Reference (a) on page 3, which includes results covering a fairly wide range of planforms and of calculated cases, appears to be unique.

These results, however, represent a real contribution, although they cannot be applied directly to flutter calculations, since they are a collection of data which facilitate the choice of methods and the supervision of programmes.

The results published outside this Manual are generally fragmentary and unsuited for systematic control, but their whole nevertheless constitutes a great contribution (which should not be ignored) to the knowledge of non-stationary aerodynamic forces. The number of planforms and calculated cases dealt with in other publications is such that the results could not be included in the Manual, and it has therefore been necessary to restrict mention of them to a bibliographical list.

The publications listed may be of use, in some cases, in the supervision of a programme, under specific conditions, but the main interest of this bibliography is that it will enable the user to establish comparisons and to define general trends. Great emphasis has been placed on experimental results and on comparisons of theory and experiment, since it is important to know which are the cases in practice where the theory provides results that are in agreement with experiment.

Finally, programme descriptions have been presented, since they may be used as models and may prevent errors.

A bibliographical work restricted to experimental results was published in 1959 by H. Hall (Item 37). It covers the period 1940-1956.

The present work covers the period 1951-1968, but in some cases only very brief information is given on the contents of works published before 1959, which are mostly of less interest than recent documents, because the results were obtained with experimental tools or computers that are now out-dated.

Documents containing a larger amount of valuable data than the present ones may be published during the next few years, because research is being done in several countries in order to obtain numerical data, either experimentally (measurement of non-stationary pressures) or from the theory (for control surfaces in particular). For this reason, updating of the present bibliography is of paramount importance. It involves no difficulty, since the items are arranged in chronological sections.

Finally, the problem of the non-planar wing is being considered in various places and some results have already been published; but this research is not mentioned here because, to tie in with Reference (a), it was felt necessary to restrict the subject to the planar lifting surface. Advanced configurations will probably be considered in a subsequent updating.

Limits Assigned to the Subject

The purpose of this chapter is to provide the reader with sources of information included in Reference (a). The bibliography is restricted to the problem of the planar lifting surface and it lists documents containing theoretical or experimental results as well as programme descriptions.

Theoretical results are restricted, as far as possible, to calculations resulting from the general formulation of the problem: the integral equation or "box" method. Some works based on less general theories are mentioned, however, such as the work of H.R. Lawrence and E.H. Gerber (Item 4), of V.J.E. Stark and M.T. Landahl (Item 12), of E.M. de Jager (Item 41), of D.E. Lehrman (Item 43), of J.P. Benthem and J.G. Wouters (Item 67) and of S. Chopin and P. Salaün (Item 40). Calculations based on theories that apply only to the limiting cases of very low or very high aspect ratios have not been included.

As regards experimental results, the selection of documents must take into account the existence of non-linearities which are outside the present field. It has been agreed that only the experiments where thickness and incidence effects may normally be considered as negligible should be included. This means eliminating documents where the authors have voluntarily investigated non-linear effects, in particular the effect of upper surface vortices on a low aspect ratio delta wing with high incidence.

Finally, programme descriptions remain scarce and it is probable that none of them could be used directly by any organisation other than the originator. Nevertheless, their usefulness as models remains indisputable.

Presentation of the Documents

The documents presented give the following information:

- (a) Name of authors, title, publishing organisation, and date.
- (b) A summary generally provided by IAA or STAR cards or by the author himself. It is completed by brief information on the nature of the results and their importance (number of tables or diagrams).
- (c) Finally, in a frame, very brief captions indicate at a glance the speed range (subsonic, transonic, supersonic), whether the results are theoretical or experimental, whether control surfaces are considered and whether pressure distributions are represented.

These documents are arranged in chronological sections, by year of publication. Considering the relatively small number of documents it did not appear appropriate to break down the classification further.

The documents are preceded by a list of authors in alphabetical order.

Comments

The documents, being relatively few, may be referred to individually and the comments on them are very brief: the reader's attention is drawn only to a few details.

(a) Systematic Tables and Graphs

Only a few authors have been tempted to publish systematic results, probably because they knew that the field of application of these results would remain restricted to some special cases, whatever the volume of results. A few examples are to be found, however: supersonic influence coefficients for a rectangular grid (Item 28); functions that make it possible to calculate a rectangular wing with deformation in supersonic flow (Item 41); and coefficients relative to rigid rectangular and delta wings with a subsonic control surface (Item 40).

(b) Methods of Calculation

The calculations are generally based on the integral equation of the normal velocity w in relation to the pressure Δp on the wing:

$$w(x, y) = \iint_{\text{wing}} K(x - \xi, y - \eta) \Delta p(\xi, \eta) d\xi d\eta. \quad (1)$$

The solution is generally obtained by a collocation method, after the pressure has been represented by a superposition of specific functions. But the least-squares method may also be used (Items 35-46).

The integral (1) is not readily calculated and convergence and accuracy studies are given in Items 81, 63, 88.

In supersonic flow, one may use also the formula relating the potential and its normal derivative on the wing:

$$\phi(x, y) = \iint_{\substack{\text{wing} \\ \text{plane}}} G(x - \xi, y - \eta) w(\xi, \eta) d\xi d\eta. \quad (2)$$

This formula is used by placing a rectangular or diamond-shaped grid in the wing plane. The grids at the wing edges are generally treated as special cases, which renders the calculation programmes more complicated while improving their accuracy (Item 75). But it is also possible to disregard these special cases and to rely on the fineness of grid to obtain accuracy (Item 99).

The calculation methods that do not start from Equations (1) and (2) almost always lack generality, at least in application (Items 4, 12, 40, 41, 43). Special emphasis should be placed on the doublet lattice method (Item 103), which in future could contribute to a better knowledge of the subsonic control surface problem.

(c) *Control Surfaces*

As regards numerical calculation, this problem is still not adequately solved in the subsonic field. It is only in recent documents that results are found which take into account the logarithmic singularities (Items 95-104). In general, the results are obtained by representing the control surface deflection by a polynomial surface (Items 78, 94, 96, 107).

(d) *Comparison between Theory and Experiment*

There are many comparisons of theoretical and experimental results, but only a few authors attempt to deduce corrections from them, as H. Bergh and R. J. Zwaan (Item 91), have done.

(e) *Synthesis Documents*

Periodically documents are found that summarise the state of the art in non-stationary aerodynamics. The most recent ones, containing significant results, are of particular interest (Items 79-108). Finally, mention should be made of the work of D. L. Woodcock (Item 101), in which the author presents a synthesis of the results of a broad range of calculations and experiments.

ACKNOWLEDGMENTS

The author wishes to extend his thanks to all those who have assisted him in collecting the documentation required for the present work.

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- (a) Woodcock, D.L. *A Comparison of Methods Used in Lifting-Surface Theory.* To be published in the AGARD Report series.

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1. Nelson, Herbert C. *Lift and Moment on Oscillating Triangular and Related Wings with Supersonic Edges.* NACA TN 2494, 1951.

Supersonic
Theory

2. Watkins, Charles E. *Effect of Aspect Ratio on the Air Forces and Moments of Harmonically Oscillating Thin Rectangular Wings in Supersonic Potential Flow.* NACA Report 1028, 1951.

Supersonic
Theory

1952

3. Woodcock, D.L. *Aerodynamic Derivatives for a Delta Wing Oscillating in Elastic Modes.* RAE Report Structures 132, 1952, ARC Current Paper 170.

Aerodynamic derivatives are given for a delta wing of aspect ratio 3 and 90° apex angle oscillating with symmetric elastic modes in incompressible inviscid flow. They have been determined by the lattice method of W.P. Jones, using the values of the downwash calculated by D.E. Lehrian when obtaining aerodynamic derivatives for the same delta wing oscillating in rigid wing modes.

Incompressible
Theory

The results for several modes of the form $|\eta|^n$ are given both as local derivatives and also as equivalent constant derivatives, that is derivatives invariable with spanwise position, with the virtual inertias included in the aerodynamic stiffness derivatives. Derivatives for other modes can be obtained either from these or from the values of the reciprocal \bar{W}^{-1} of the downwash matrix, which also are tabulated.

12 diagrams, 13 tables.

4. Lawrence, H.R.
Gerber, E.H. *The Aerodynamic Forces on Low Aspect Ratio Wings Oscillating in an Incompressible Flow.* Journal of the Aeronautical Sciences, Vol. 19, November 1952.

A method for calculating the aerodynamic forces acting on a harmonically oscillating low aspect ratio wing in incompressible flow is presented for the class of planforms with straight trailing edges. The aerodynamic lift and moment resulting from oscillatory vertical translation and rotation are computed for rectangular and triangular wings of aspect ratios ranging from 0 to 4 with reduced frequencies from zero to unity. The aerodynamic forces arising from the harmonic rotation of 25, 37, and 50% chord trailing-edge flaps are computed for rectangular wings of aspect ratios 1 and 2 for the zero to unity reduced frequency range. The results are shown to be in accord with the Garrick theory for planforms of very low aspect ratio and with the infinite aspect ratio theory for rectangular wings. In the limiting case of zero frequency, the results reduce to steady-state solutions. A rapid method for solving the integral equation is developed for cases where the steady-state solution has been expressed in matrix form.

Incompressible
Theory

6 diagrams, 8 tables.

5. Lomax, Harvard
Heaslet, Max A.
Fuller, Franklyn B.
Sluder, Loma *Two- and Three-Dimensional Unsteady Lift Problems in High-Speed Flight.* NACA Report 1077, 1952.

Supersonic
Theory

6. Watkins, Charles E.
Berman, Julian H. *Air Forces and Moments on Triangular and Related Wings with Subsonic Leading Edges Oscillating in Supersonic Potential Flow.* NACA Report 1099, 1952.

Supersonic
Theory

1953

7. Scruton, C.
Woodgate, L.
Alexander, A.J.

Measurements of the Aerodynamic Derivatives for a Swept Wing of Low Aspect Ratio Describing Pitching and Plunging Oscillations in Incompressible Flow. ARC R & M 2925, 1953.

The aerodynamic lift and moment derivatives for pitching oscillations in incompressible flow have been measured for two axis positions on (i) a clipped delta wing of aspect ratio 1.2, (ii) a complete delta wing of aspect ratio 1.6, and (iii) an arrowhead wing of aspect ratio 1.32. The results for the arrowhead wing and the clipped delta wing are compared with values predicted by the vortex-lattice and the Multhopp-Garner methods of calculation. The results for the complete delta wing are compared with values calculated by Garner and by Lawrence and Gerber. In each of the comparisons a satisfactory measure of agreement was found between the theoretical and experimental values of the derivatives. Calculated values for the clipped delta wing based on very low aspect ratio theory did not accord with those found by experiment.

Incompressible
Theory
Experiment

36 diagrams, 13 tables.

8. Beals, V.
Targoff, W.P.

Control Surface Oscillatory Coefficients Measured on Low Aspect-Ratio Wings. Wright Air Development Center, WADC Technical Report 53-64, April, 1953.

The ceiling of the test section was used as a reflection plane for rectangular wing models with an effective aspect ratio of 1 and 2. Model chord was 5 ft, the flap hinge line was at 60% of the chord. The airfoil section used was NACA 0010. The tests were conducted in January 1952.

Low Subsonic
Experiment
Control Surfaces

Static and oscillatory tests were carried out and wing moment and lift due to flap deflection and flap hinge moment due to flap deflection were measured. Measured inertia effects of the flap and zero speed airloads were subtracted from the measured loads and theoretically estimated loads due to apparent mass of the air were added.

The Reynolds number of the oscillatory tests varied from 1.4 to 5.4 million because the airspeed was varied to cover a k -range from 2.0 to 0.28, while restricting the frequencies of oscillation to the two values $f = 3$ and 5 c/s. The Reynolds number of the static tests ($k = 0$) was approximately 7 million. The tunnel atmosphere was approximately equal to standard sea level atmosphere. The Mach number of the oscillatory tests varied from $M = 0.04$ to $M = 0.15$. For the static test $M = 0.20$.

9. Watkins, Charles E.
Berman, Julian H.

Velocity Potential and Air Forces Associated with a Triangular Wing in Supersonic Flow, with Subsonic Leading Edges, and Deforming Harmonically According to a General Quadratic Equation. NACA TN 3009, 1953.

Supersonic
Theory

1954

10. Laidlaw, W.R.

Theoretical and Experimental Pressure Distributions on Low Aspect Ratio Wings Oscillating in an Incompressible Flow. Technical Report 51-2 (Contract No. NO a(s) 52-576-c, Bur. Aero.), Aeroelastic and Structures Research Laboratory, Massachusetts Institute of Technology, September, 1954.

Rectangular wings of aspect ratio 1.0 and 2.0 and delta wing of aspect ratio 2.31 oscillating in pitch and in plunge. Reduced frequencies from 0.24 to 0.66 based on root semi-chord.

Incompressible
Experiment
Pressure

11. Nelson, Herbert C.
Rainey, Ruby A.
Watkins, Charles E.

Lift and Moment Coefficients Expanded to the Seventh Power of Frequency for Oscillating Rectangular Wings in Supersonic Flow and Applied to a Specific Flutter Problem. NACA TN 3076, 1954.

Linearized theory for compressible unsteady flow is used to derive the velocity potential and lift and moment coefficients in the form of power series in terms of the frequency of oscillation for a harmonically oscillating rectangular wing moving at a constant supersonic speed. Closed expressions for the velocity potential and lift and moment coefficients associated with pitching and translation are given to the seventh power of the frequency. These expressions extend the range of usefulness of NACA Report 1028 in which similar expressions were derived to the third power of the frequency of oscillation. For example, at a Mach number of 10/9 the expansion of the potential to the third power is an accurate representation of the potential for values of the reduced frequency only up to about 0.08; whereas the expansion of the potential to the seventh power is an accurate representation for values of the reduced frequency up to about 0.2, a value of this parameter large enough to cover most rectangular-wing flutter cases likely to occur at this Mach number.

Supersonic
Theory

The section and total lift and moment coefficients are discussed with the aid of several figures. In addition, flutter speeds obtained in the Mach number range from 10/9 to 10/6 for a rectangular wing of aspect ratio 4.53 by using section coefficients derived on the basis of three-dimensional flow are compared with flutter speeds for this wing obtained by using coefficients derived on the basis of two-dimensional flow.

19 diagrams.

12. Stark, Valter J.E.
Landahl, Marten T.

Determination of Non-Stationary Aerodynamic Forces on a Rectangular Wing with the Aid of an Electrolytic Tank Analogue. KTH Aero Report FL 158, Sweden, 1954.

An electrical potential tank analogy has been developed for the determination of aerodynamic forces on arbitrary finite wings oscillating in arbitrary modes in incompressible flow. The method was applied to a rectangular wing of aspect ratio 3 and potentials were measured for the symmetric wing modes of rigid translation and pitch, flapping, parabolic bending and linear torsion as well as for rigid pitch and linear torsion of a full-span control surface.

Incompressible
Theory

(The results of this investigation are partly reproduced in Item 35 and also in *Aeroelastisches Kolloquium*, Göttingen, 1957, AVA Bericht No. 18, 1958, pp. 124-155).

1955

13. Guyett, P.R.
Poulter, D.E.G.

Measurements of Pitching Moment Derivatives for a Series of Rectangular Wings at Low Wind Speeds. ARC Current Paper 249, 1955.

The direct aerodynamic moments for pitching oscillations have been measured on a series of rectangular wings having aspect ratios between 2 and 8 for axis positions at the wing leading edges and trailing edges. Two of the wings were also tested with single end plates which were aerodynamically effective in doubling the wing geometric aspect ratio. The measurements were made at low speeds in an open-jet wind tunnel and covered the range of frequency parameter (based on wing chord) 0.13 to 0.39. The results are in general agreement with theoretical results due to Lawrence and Gerber.

Low Subsonic
Theory
Experiment

Similar tests were also made on a wing fitted with two end-plates in an attempt to obtain results for two-dimensional flow. The results do not agree with other experimental results and two-dimensional theoretical values and indicate that wind tunnel interference is important for this test configuration.

48 diagrams, 2 tables.

14. Molyneux, W.G.
Ruddlesden, F.

Derivative Measurements and Flutter Tests on a Rectangular Wing with a Full Span Control Surface Oscillating in Modes of Wing Roll and Aileron Rotation. ARC R & M 3010, 1955.

Details are given of tests to measure the aerodynamic coefficients for a rectangular wing with a full-span aileron oscillating in modes of wing roll and aileron rotation. A new technique was used in which aileron rotation was geared to wing roll so that oscillation occurred in both degrees of freedom simultaneously.

Incompressible
Experiment
Control Surfaces

The measured coefficients are compared with those derived from two-dimensional theory, and with coefficients estimated by an empirical method. The agreement with theory is poor but the estimated coefficients agree well with those measured.

Flutter calculations for the system were made, using both measured and theoretical derivatives, and the results are compared with flutter test results. The calculated flutter speed using measured derivatives agrees closely with that measured, whereas the agreement is poor using theoretical derivatives.

33 diagrams.

15. Cunningham, H.J.

Total Lift and Pitching Moment on Thin Arrowhead Wings Oscillating in Supersonic Potential Flow. NACA TN 3433, 1955.

Expressions based on linearized supersonic potential theory are given for the total lift and moment coefficients of thin arrowhead wings oscillating in pitch and vertical translation. The arrowhead planform as treated herein includes all pointed-tip wings; the delta planform with an unswept trailing edge is a special case. A restriction is that the component of flow normal to the trailing edge must be supersonic or sonic. The total coefficients have been obtained by integration of the section coefficients given in NACA Report 1099 for the subsonic-leading-edge wing (to the fifth power of the frequency) and in NACA Technical Note 2494 for the supersonic-leading-edge wing (to the third power of the frequency). The accuracy of these expressions extends to sufficiently high frequencies to make them potentially useful in flutter applications.

Supersonic
Theory

15. (Continued)

A correlation of coefficient notation is given for the present flutter coefficients, for dynamic stability coefficients, and for the exact flutter coefficients developed by Miles for the supersonic-leading-edge delta planform. For the supersonic-leading-edge delta wing, curves are given to show the comparison of these three types of coefficients. The relative importance of higher order frequency terms as compared with the lowest order frequency term in each flutter coefficient decreases rather rapidly with the following parametric changes: increasing Mach number, increasing leading-edge sweep angle (except for the supersonic-leading-edge delta wing), and decreasing trailing-edge sweep angle. These parametric changes have the concurrent result that the accuracy of the approximate coefficients increases for any given reduced frequency.

18 diagrams, 4 tables.

16. Martin, Dennis J.
Thompson, Robert F.
Martz, C. William

Exploratory Investigation of the Moments on Oscillating Control Surfaces at Transonic Speeds. NACA RM L55E31b, 1955.

Control hinge-moment data are presented for oscillating trailing-edge controls on unswept, swept, and delta wings through the use of wind-tunnel and rocket test models. A range of unstable aerodynamic damping was found in the transonic speed range for each of the configurations tested. Examination of the results indicates the importance of several parameters. It appears that the transonic control-surface-instability problem may be alleviated to some extent by structural modifications or by aerodynamic configuration changes.

Transonic
Experiment
Control Surfaces

Reviews experimental hinge-moment data for a 25% chord flap on a slightly tapered low-aspect-ratio wing at Mach numbers from 0.6 to 1.02, for a 25% chord full-span rudder with 35° hinge-line sweep on a tapered wing with 50° leading-edge sweep, and for a constant-chord full-span flap on a 60° delta wing at Mach numbers from 0.3 to 1.8.

9 diagrams.

17. Pines, Samuel
Dugundji, John
Neuringer, Joseph

Aerodynamic Flutter Derivatives for a Flexible Wing with Supersonic and Subsonic Edges. Journal of the Aeronautical Sciences, Vol.22, October, 1955, pp.693-700.

A box method is developed for obtaining the generalized air forces on an oscillating flexible wing in supersonic flow with both supersonic and subsonic edges. Essentially, the method consists of representing the wing by a grid of square boxes and determining the influence of one box on another. These aerodynamic pressure influence coefficients, when tabulated, permit the flutter analysis of an arbitrary wing with arbitrary normal modes to be carried out in a routine way. The coefficients satisfy the linearized unsteady supersonic flow equations and the downwash boundary conditions, and, in addition, are formulated in a manner independent of the modal shapes of the structure.

Supersonic
Theory

The box method is applied to some simplified examples involving rigid body modes, and agreement with other methods is seen to be reasonably good.

The box procedure appears to offer a simple routine manner of analyzing flexible wings for supersonic flutter analyses which is well adapted to programming on computing machinery. However, the square box method as

17. (Continued)

developed here for subsonic edges is inapplicable to Mach numbers below $M = 1.414$ without further modification. Some suggested modifications for extending below the $M = 1.414$ range are discussed in the body of the paper.

Compares spanwise distributions of lift and moment calculated by the "box" method with those calculated by the method of Watkins (NACA TN 2457) for a 63.4° delta wing in pitching and plunging motions at $M = 1.414$, reduced frequency = 0.11 and 0.075.

18. Reese, David E. Jr
Carlson, William C.A.

An Experimental Investigation of the Hinge-Moment Characteristics of a Constant-Chord Control Surface Oscillating at High Frequency. NACA RM A55J24, 1955.

The results of an experimental investigation of the hinge-moment characteristics of a constant-chord control surface oscillating at high frequency are presented. The control surface was mounted on an aspect-ratio-2 triangular wing. The aerodynamic restoring-moment and damping-moment coefficients were obtained at a frequency of 260 c/s for a Mach number range of 0.6 to 0.8 and 1.3 to 1.9, corresponding to reduced frequencies from 0.189 to 0.078. A discussion is given in the Appendix of a drive motor suitable for systems where a high-frequency oscillatory torque is desired.

Subsonic.
Supersonic
Experiment
Control Surfaces

Results are compared with linear-theory calculations based on series expansion of the velocity potential in powers of a frequency parameter; effects of a thickness correction are also examined.

8 diagrams.

19. Zartarian, G.
Hsu, P.T.

Theoretical Studies on the Prediction of Unsteady Supersonic Airloads on Elastic Wings. Part I - Investigations on the Use of Oscillatory Supersonic Aerodynamic Influence Coefficients. Wright Air Development Center, WADC Technical Report 56-97, Part I, December, 1955.

Supersonic
Theory

1956

20. Woodcock, D.L.

Aerodynamic Derivatives for Two Cropped Delta Wings and One Arrowhead Wing Oscillating in Distortion Modes. RAE Report Structures 201-1956, ARC Current Paper 268, 1956.

Aerodynamic derivatives are given for three particular planforms oscillating with symmetric distortion modes in incompressible flow. The planforms are:

Incompressible
Theory

- (i) a cropped delta wing of aspect ratio 3 and taper ratio 1/7;
- (ii) a cropped delta wing of aspect ratio 1.2 and taper ratio 1/7;
- (iii) an arrowhead wing of aspect ratio 1.32, taper ratio 7/18 and angle of sweep of 63.4° at the quarter chord.

The results are for modes of the form $|\eta|^n$ for $n = 0(1)4$, where η is a non-dimensional spanwise co-ordinate. They have been determined from intermediate results which D.E. Lehrian had earlier obtained by the vortex lattice method. The results are compared, for some cases, with the corresponding values given by very-low-aspect-ratio theory.

86 tables.

21. Woodcock, D.L.

Calculated Aerodynamic Forces on a Sweptback Untapered Wing Oscillating in Incompressible Flow. RAE Report Structures 217-1956, ARC Current Paper 411, 1956.

The air forces are given for an untapered wing of aspect ratio 2 and sweepback 40° oscillating with symmetric distortion modes in incompressible flow. The results are for frequency parameters of $0(0.6)1.8$. These are presented both as influence matrices based on the displacement at a particular set of points and also as overall derivatives for modes of the form $|\eta|^n$ for $n = 0(1)4$, where η is a non-dimensional spanwise co-ordinate. The method used was the vortex lattice method. The standard lattice was modified by making the mesh size (in a chordwise direction) adjacent to the leading edge smaller than that over the main part of the wing. Comparison is made with some values obtained by a variant of the Multhopp method and the agreement is good. An Appendix shows how the vortex lattice method is modified to obtain the virtual inertias.

Incompressible
Theory

12 tables.

22. Berman, Julian H.

Lift and Moment Coefficients for an Oscillating Rectangular Wing-Aileron Configuration in Supersonic Flow. NACA TN 3644, 1956.

Supersonic
Theory
Control Surfaces

23. Clevenson, S.A.
Leadbetter, S.A.

Some Measurements of Aerodynamic Forces and Moments at Subsonic Speed on a Wing-Tank Configuration Oscillating in Pitch about the Wing Midchord. NACA TN 3822, 1956.

Subsonic
Experiment

24. Epperson, T.B.
 Pengelley, C.D.
 Ransleben, G.E. Jr
 Wilson, L.E.
 Younger, D.G. Jr
- Non-Stationary Airload Distributions on a Straight Flexible Wing Oscillating in a Subsonic Wind Stream.* Wright Air Development Center, WADC Technical Report 55-323, January, 1956.
- Low speed tests of a rectangular wing of aspect ratio 5 at reduced frequencies = 0.16, 0.25, 0.50, ∞ .
- Subsonic
 Experiment
 Pressure
25. Martz, C. William
- Experimental Hinge Moments on Freely Oscillating Flap-Type Control Surfaces.* NACA RM L56G20, 1956.
- Rocket-model tests of a clipped-tip 60° delta wing-fuselage with constant-chord full-span flap. $0.4 \leq M \leq 1.9$.
- Subsonic
 Transonic
 Supersonic
 Experiment
 Control Surfaces
26. Zartarian, G.
- Theoretical Studies on the Prediction of Unsteady Supersonic Airloads on Elastic Wings. Part II - Rules for Application of Oscillatory Supersonic Aerodynamic Influence Coefficients.* Wright Air Development Center, WADC Technical Report 56-97, Part II, February, 1956.
- Supersonic
 Theory

1957

27. Bratt, J.B.
Miles, C.J.W.
Johnson, R.F.

Measurements of the Direct Hinge-Moment Derivatives at Subsonic and Transonic Speeds for a Cropped Delta with Oscillating Flap. ARC R & M 3163, 1957.

Measurements of the direct hinge-moment derivatives at subsonic and transonic speeds have been made for a cropped delta wing of aspect ratio 1.8 with an oscillating full-span flap. The measurements were obtained with new derivatives apparatus fitted to the National Physical Laboratory 9½ in High Speed Tunnel, and some account is given of the estimation of apparatus errors.

Subsonic
Transonic
Theory
Experiment
Control Surfaces

The effect of amplitude of oscillation ξ_0 and frequency parameter ω on the derivatives has been investigated, a maximum value for ω of 0.25 at $M = 1.0$ being attained.

A comparison of the measured derivatives with theory shows satisfactory agreement for the damping and reasonable agreement for the stiffness at subsonic speeds. At supersonic speeds ($M = 1.1$) large discrepancies occur.

12 diagrams, 2 tables.

28. Voss, H.M. (Editor)
(USAF Aircraft
Laboratory)

A Tabulation of Unsteady Supersonic Aerodynamic Influence Coefficients for the Square-Box Grid. Wright Air Development Center, WADC Technical Report 54-413, ASTIA Document No. AD 118330, May, 1957.

This report presents a tabulation of aerodynamic influence coefficients for use in the determination of unsteady supersonic airloads by the box method, employing a square-box grid. The coefficients are given for a 20×20 grid for Mach numbers between 1.2 and 5, and for values of reduced frequency based on box dimension from zero to 0.40.

Supersonic
Theory (Tables)

1958

29. Guyett, P.R.
Curran, J.K.

Aerodynamic Derivative Measurements on a Rectangular Wing of Aspect Ratio 3.3.
ARC R & M 3171, 1958.

A complete set of oscillatory aerodynamic stiffness and damping derivatives has been determined for a rectangular wing for rigid-wing modes of normal translation, pitch, and roll, in the range of frequency parameter 0.4 to 1.3, at low subsonic wind speeds. Each available comparison shows that the results are in satisfactory agreement with theoretical derivatives calculated by W.P. Jones and by Lawrence and Gerber.

Low Subsonic
Theory
Experiment

30 diagrams, 3 tables.

30. Cunningham, H.J.

Lift and Moment on Thin Arrowhead Wings with Supersonic Edges Oscillating in Symmetric Flapping and Roll and Application to the Flutter of an All-Movable Control Surface. NACA TN 4189, 1958.

A method based on linearized supersonic potential-flow theory, applied previously to vertical translation and pitching oscillations, is applied herein to symmetric flapping and rolling oscillations to obtain section and total unsteady lift and moment coefficients. Spanwise distributions are illustrated and compared with results of a strip-theory method. The aerodynamic coefficients are applied to a coupled-mode flutter analysis of an all-movable control surface for which the flexibilities are concentrated in a supporting shaft.

Supersonic
Theory
Control Surfaces

11 diagrams.

31. Cunningham, Herbert J.
Woolston, Donald S.

Developments in the Flutter Analysis of General Planform Wings Using Unsteady Air Forces from the Kernel Function Procedure. Proceedings of National Specialists' Meeting on Dynamics and Aeroelasticity, Sponsored by the Institute of the Aerospace Sciences, Fort Worth, Texas, November, 1958.

Some developments and results of a procedure for applying lifting-surface theory to aeroelastic problems, both static and dynamic, are reported. The procedure is based on the integral equation that relates the downwash distribution to the lift distribution on a wing. The preparatory work of NACA Reports 1234 and 1257 has made possible the numerical evaluation of the kernel function of the integral equation for finite wings. The use of modern high-speed digital computers makes practicable the application of the kernel function procedure on a systematic and economical basis. Some results of such application are presented. For subsonic and supersonic speeds oscillating air forces from the kernel function procedure are compared with results from other theories, and at subsonic speeds with measured air forces. Comparisons of theoretical flutter solutions with flutter experiments are also presented for both subsonic and supersonic speeds.

Subsonic
Supersonic
Theory

17 diagrams.

32. Hsu, Pao-Tan

Some Recent Developments in the Flutter Analysis of Low-Aspect-Ratio Wings. Proceedings of National Specialists' Meeting on Dynamics and Aeroelasticity, sponsored by the Institute of the Aerospace Sciences, Fort Worth, Texas, November, 1958.

The present paper describes the method of solution developed in Reference 1 together with some numerical examples. This method has many similarities to the investigations mentioned above. The main difference is in the spanwise integration technique. By the

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Subsonic
Theory
Experiment

32. (Continued)

proper choice of a set of interdigitated upwash and spanwise stations, correct integrated results can be obtained by simply ignoring the second-order singularity in the kernel function. In the chordwise direction, the optimum locations of the upwash and integration stations are found. These locations are identical to Richardson's for the subsonic case. The number of the chordwise stations is not limited to two, as in the case of Multhopp, and the use of these stations is definitely a more efficient approach than the method of Falkner used by Runyan and Woolston.

Includes comparison of spanwise distributions of lift and pitching moment from kernel function and from the experiments of Laidlaw (Item 10) for pitching and plunging motion of an untapered wing with 45° sweepback and aspect ratio 2. $k = 0.4$, $M = 0, 0.8$.

12 diagrams, 3 tables.

(Reference 1)
 Hsu, Pao-Tan

Flutter of Low-Aspect-Ratio Wings. Part I - Calculation of Pressure Distributions for Oscillating Wings of Arbitrary Planform in Subsonic Flow by the Kernel-Function Method. Massachusetts Institute of Technology, Aeroelastic and Structures Research Laboratory Report 64-1, (Contract No. NO a(s) 55-771-c), October, 1957.

33. Widmayer, E. Jr
 Clevenson, S.A.
 Leadbetter, S.A.

Some Measurements of Aerodynamic Forces and Moments at Subsonic Speeds on a Rectangular Wing of Aspect Ratio 2 Oscillating about the Midchord. NACA TN 4240, 1958.

Results are presented for a range of Mach number from 0.15 to 0.81, a range of reduced frequency from 0.15 to 1.32, and a range of Reynolds number from 0.60×10^6 to 9.21×10^6 . A comparison of the measured aerodynamic forces and moments is made with some available published data. Comparisons are also made between the measured data and theoretical incompressible-flow coefficients obtained from the aspect-ratio theory of Reissner, the aspect-ratio theory of Lawrence and Gerber, and the two-dimensional-flow theory. Some experimental results pertaining to the influence of wind-tunnel-wall effects on non-steady aerodynamic measurement are included.

Subsonic Theory Experiment

Rectangular wing of aspect ratio 2.

General motion.

Overall forces.

34. Woolston, D.S.
 Clevenson, S.A.
 Leadbetter, S.A.

Analytical and Experimental Investigation of Aerodynamic Forces and Moments of Low-Aspect-Ratio Wings Undergoing Flapping Oscillations. NACA TN 4302, 1958.

Theory Experiment Control Surfaces
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35. Stark, V.J.E.

A Method for Solving the Subsonic Problem of the Oscillating Finite Wing with the Aid of High-Speed Digital Computers. SAAB TN 41, 1958.

An attempt is made to formulate the linearized, subsonic problem of the oscillating finite wing in such a way that its solution can be obtained with the aid of high-speed digital computers. An integral equation for a special function, the integrated acceleration potential, is formulated. The solution is approximated by a linear combination of members in a set of functions, chosen on the basis

Subsonic Theory

35. (Continued)

of two-dimensional theory. For the calculation of the downwash induced by the pressure distributions pertaining to each of these functions, a straight-forward method is developed by dividing the field of integration into a relatively large number of square boxes and expanding the functions in series of orthogonal polynomials in each of these boxes. The numerical results presented, for a rectangular wing of aspect ratio 3 and incompressible flow, were obtained by approximating the given downwash by the least-squares method. With coefficients thus determined a linear combination of the functions is found, which approximates the solution of the integral equation.

21 diagrams, 3 tables.

1959

36. Bratt, J.B.
Raymer, W.G.
Townsend, J.E.G. *Measurements of the Direct Pitching-Moment Derivatives for Two-Dimensional Flow at Subsonic and Supersonic Speeds and for a Wing of Aspect Ratio 4 at Subsonic Speed.* ARC R & M 3257, 1959.
- Apparatus based on a self-excitation technique has been developed for the measurement of direct pitching-moment derivatives at high speeds, and has proved to function satisfactorily.
- Measurements have been made at subsonic speeds on a two-dimensional RAE 104 aerofoil, both with and without spoilers, and a rectangular wing of aspect ratio 4 with the same section; and at supersonic speeds ($M = 1.42$ and 1.61) on two-dimensional biconvex aerofoils of $7\frac{1}{2}\%$ and 5% thickness.
- Comparisons with theory are made and discussed.
- 146 diagrams.
- Subsonic
Theory
Experiment
37. Hall, H. *A Record of Information on Oscillatory Derivative Measurement.* RAE TN Structures 268, 1959. ARC R & M 3232.
- List of references and index cards covering the period 1940-1956.
38. Moseley, William C. Jr
Gainer, Thomas G. *Effect of Wing Thickness and Sweep on the Oscillating Hinge-Moment and Flutter Characteristics of a Flap-Type Control at Transonic Speeds.* NASA TM X-123, 1959.
- Free-oscillation tests with 30% chord full-span flaps on untapered wings of aspect-ratio 3, with leading-edge sweep of 0° , 30° , and 45° . Thickness ratio = 0.04, 0.06, 0.08, 0.10 for the unswept wing and 0.06 for the swept wings. Models tested with and without tip stores. $0.60 \leq M \leq 1.02$. Reduced frequency = 0.34 to 0.16, based on flap chord.
- Data presented: Hinge moments and damping factors.
- 98 diagrams.
- Transonic
Experiment
Control Surfaces
39. Watkins, Charles E.
Woolston, Donald S.
Cunningham, Herbert J. *A Systematic Kernel Function Procedure for Determining Aerodynamic Forces on Oscillating or Steady Finite Wings at Subsonic Speeds.* NASA TR R-48, 1959.
- Details are given of a numerical solution of the integral equation which relates oscillatory or steady lift and downwash distribution in subsonic flow. The procedure has been programmed for the IBM 704 electronic data processing machine and yields the pressure distribution and some of its integrated properties for a given Mach number and frequency and for several modes of oscillation in from 3 to 4 minutes. Results of several applications are presented.
- Theoretical results and comparison of theory and application.
- Subsonic
Theory
Experiment

40. Chopin, S.
 Salaün, P.

Coefficients Aérodynamiques Instationnaires Théoriques en Régime Compressible Subsonique, pour une Voilure de Faible Allongement. Mémo Technique ONERA No.13, 1959. (Ce document, qui n'est pas diffusé actuellement, pourra éventuellement faire l'objet d'une publication).

1ère partie: théorie
 2ème partie: tables

Subsonic
 Theory
 Control Surfaces

Fascicule 1 Aile delta 60°
 2 Aile droite d'allongement 1
 3 Aile droite d'allongement 2
 4 Aile droite d'allongement 3
 5 Aile droite d'allongement 4
 6 Aile delta 45°

La théorie est une extension, au cas du fluide compressible, de la théorie de Lawrence et de Lawrence et Gerber. Les coefficients aérodynamiques de voilure indéformable figurent dans des tableaux et l'évolution des coefficients de gouverne est présentée sur des courbes, en fonction de la position de la charnière, pour des gouvernes occupant toute l'envergure, à Mach 0,5 et 0,7.

Les résultats du fascicule 2 figurent dans les postes No.107 et 90.

41. de Jager, E.M.

Oscillating Rectangular Wings in Supersonic Flow with Arbitrary Bending and Torsion Modes Shapes.

Part I : Development of the Theory. (NLL TR W3).

Part II: Numerical Results. (NLL TR W5). NLL, Amsterdam, 1959.

The pressure distribution at the surface of rectangular harmonically oscillating wings at supersonic speeds is determined by the aid of Gardner's method for the solution of the potential equation. The solution is valid for arbitrary normal velocity distributions prescribed at the surface of the wing.

Supersonic
 Theory

Lift and moments have been calculated for arbitrary bending and torsion mode shapes.

The aerodynamic derivatives are given as the sum of several terms, each of which consists of two factors, one being a function of the reduced frequency and the Mach number only, the other containing the bending or the torsion mode shape in a very simple form.

1960

42. Bratt, J.B. *Wind-Tunnel Techniques for the Measurement of Oscillatory Derivatives.* ARC R & M 3319, 1960.

No numerical results, but references are given.

43. Lehrian, D.E. *Vortex-Lattice Treatment of Rectangular Wings with Oscillating Control Surfaces.* ARC R & M 3182, 1960.

Calculation of the derivatives for rectangular wings with oscillating constant-chord flaps, by application of the vortex-lattice method for simple harmonic motion of general frequency. The discontinuous chordwise boundary conditions associated with full-span flaps, is replaced by a continuous equivalent downwash which is determined on the basis of two-dimensional oscillatory theory. In the particular case when the frequency tends to zero, the equivalent downwash is obtained on a distinct quasi-steady basis; stability derivatives are then evaluated by using an alternative form of the vortex-lattice method for low frequency. To allow for the spanwise discontinuity due to outboard flaps, a further adjustment is made to the boundary condition by the use of partial-span downwash factors. Comparison of the stability derivatives with values obtained by the Multhopp-Garner method, indicates that the present treatment for low frequency is satisfactory for full-span and outboard flaps on planforms of aspect ratio 2 and 4. For general frequencies, results for aspect ratio 2 with full-span flaps compare well with the values for lift and pitching-moment derivatives obtained by Lawrence and Gerber.

Incompressible
Theory
Control Surfaces

9 diagrams, 8 tables.

44. Lehrian, Doris E. *Calculation of Stability Derivatives for Tapered Wings of Hexagonal Planform Oscillating in a Supersonic Stream.* ARC R & M 3298, 1960.

The lift and pitching-moment derivatives due to slow pitching oscillations are evaluated for eleven symmetrically tapered wings. The planforms have supersonic leading and trailing edges of constant sweep, but varying side-edge rake and aspect ratio. Derivatives for Mach numbers $\sqrt{2} \leq M \leq 2.4$ are calculated to first-order in frequency by linearized thin-wing theory. Thickness corrections for a 5% double-wedge section are also estimated by use of two-dimensional aerofoil theory; although these corrections are not large, comparison with measured pitching-moment derivatives is thereby improved.

Supersonic
Theory
Experiment

24 diagrams, 9 tables.

45. Lessing, Henry C. Troutman, John L. Menees, Gene P. *Experimental Determination of the Pressure Distribution on a Rectangular Wing Oscillating in the First Bending Mode for Mach Numbers from 0.24 to 1.30.* NASA TN D-344, 1960.

The results of an experimental investigation in a wind tunnel to obtain the aerodynamic pressure distribution on an unswept rectangular wing oscillating in its first symmetrical bending mode are presented. The wing was of aspect ratio 3 with 5% thick bi-convex airfoil sections. Data were obtained at 0° and 5° angle of attack in the Mach number range from 0.24 to 1.30. The experimental data are compared with oscillatory pressure distributions computed by means of the most complete linearized theories available.

Subsonic
Transonic
Supersonic
Theory
Experiment
Pressure

46. Stark, V.J.E.

Aerodynamic Forces on Rectangular Wings Oscillating in Subsonic Flow. SAAB TN 44, 1960.

Extension of a previously developed method (Item 35) to include a linear approximation for the integrated acceleration potential of the reversed flow, the tangency condition being satisfied in the least square sense. Numerical applications are presented for four rectangular wings at Mach number $M = 0$ and for one rectangular aspect ratio 2 wing at Mach number 0.9. Tabulated results are given for high-order modes and several reduced frequencies in both cases. Lift distributions are shown for $A.R. = 2$ and $M = 0.9$. The forces computed for rigid modes are compared to those calculated by other theories as well as to those measured in a number of low speed tests.

Subsonic
Theory

15 diagrams, 13 tables.

1961

47. Scruton, C.
Woodgate, L.
Lapworth, K.C.
Maybrey, J.F.M.

Measurements of the Pitching-Moment Derivatives for Rigid Wings of Rectangular Planform Oscillating About the Mid-Chord Axis in Supersonic Flow. ARC Current Paper 594, 1961.

Results are given of the measurements of pitching moment derivatives for wings of rectangular planform of aspect ratio from 1 to 5 oscillating in supersonic flow. The influence of a body with various nose shapes was also investigated. It was found that the general trend of the variation of the derivatives with aspect ratio was predicted by theory.

Supersonic
Experiment

13 diagrams, 5 tables.

48. Woodgate, L.
Maybrey, J.F.M.
Scruton, C.

Measurement of the Pitching-Moment Derivatives for Rigid Tapered Wings of Hexagonal Planform Oscillating in Supersonic Flow. ARC R & M 3294, 1961.

Pitching-moment derivatives have been measured, using a free-oscillation technique, for a series of thin tapered wings with both streamwise and raked tips. Wings of three aspect ratios (2.74, 2.00 and 1.25) were tested with three positions of the pitching axis ($h = 0.4, 0.5$ and 0.6). The Mach number ranged from 1.38 to 2.47 and the Reynolds number and frequency parameter were less than 1.6×10^6 and 0.03 respectively. Tunnel boundary-layer effects were avoided by the use of reflection plates. A smaller test programme was also carried out on the effects of a body (non-oscillating) in close proximity to the wing with two alternative nose shapes.

Supersonic
Experiment

The theory predicted the trends of the derivative variation with Mach number. The numerical agreement was much improved when allowances were made in the theory for finite thickness of the wings. The effect of the body on the derivatives was very small; the only significant difference found was in the stiffness derivative at $h = 0.4$.

22 diagrams.

49. Garrick, I.E.

On the Measurement of Oscillatory Aerodynamic Derivatives, Including a Summary of Recent Results. Presented to AGARD Structures and Materials Panel, Paris, May 22-26, 1961.

General discussion of state of the art. Compares some roll-due-to-sideslip results of Clevenson and Leadbetter, NACA TN 4402, with results of Maugler, NACA TM 856, and with results from NACA TN 3245.

Subsonic
Supersonic
Experiment

Mach Number: 0.4 to 1.8

32 diagrams.

1962

50. Müller, A.

Zur Programmierung des Laschka'schen Tragflächenverfahrens für instationäre Unterschallströmung für die IBM 650. Bericht Nr.3/62 des Entwicklungsring Süd, München, 1962.

Subsonic
Programme

51. Acum, W.E.A.

The Comparison of Theory and Experiment for Oscillating Wings. ARC Current Paper 681, 1962. AGARD Manual on Aeroelasticity, Part II, Chapter 10.

The comparison between experimental and theoretical values of the aerodynamic derivatives for wings and controls in oscillating motion for subsonic, transonic and supersonic flight in two or three dimensions is discussed. The success or failure of theory in predicting derivatives is summarized for the two most common experimental situations, namely, pitching of rigid wing and rotation of a rigid trailing-edge control.

Subsonic
Transonic
Supersonic
Theory
Experiment
Control Surfaces

37 diagrams.

52. Davies, D.E.

The Air Forces on the Low Aspect Ratio Rectangular Wing Oscillating in Sonic Flow. RAE TN Structures 311, also ARC R & M 3339, 1962.

Approximate expressions for the generalised air forces acting on a rectangular wing of low aspect ratio oscillating harmonically in sonic flow at low frequencies are derived in this paper. The modes of oscillation considered are rigid modes and a small selection of flexible modes. Results are presented as the first few terms of infinite expansions.

Transonic
Theory

A brief description of the modes of oscillation and of the generalised air forces is given towards the end of the paper so that the results may be used without the main text of the paper having to be read.

24 diagrams.

53. Miles, C.J.W.
Bridgman, K.B.

Measurements of the Direct Pitching Oscillation Derivatives for Three Cropped Delta and Three Arrowhead Planforms at Subsonic and Transonic Speeds. ARC R & M 3397, 1962, also ARC 23,990.

Measurements of the direct pitching oscillation derivative coefficients on three cropped delta and three arrowhead planforms have been made at subsonic and transonic speeds in the NPL 9½ in High-Speed Tunnel. The cropped delta wings had aspect ratios of 3.0, 2.0 and 1.5, whilst the arrowheads, of constant aspect ratio 2.575, possessed varying degrees of leading- and trailing-edge sweepback. The measurements were made about two model axes for each planform and the effects of changing amplitude of oscillation from 2° to 10° have been investigated in the transonic region. Comparison with subsonic theory is reasonably good for the damping and stiffness derivative coefficients measured about the forward axis, but agreement for the latter coefficients is poorer for all the rearward axis positions.

Subsonic
Transonic
Theory
Experiment

32 diagrams, 18 tables.

54. Bond, Reuben
 Packard, Barbara B.
 Warner, Robert W.
 Summers, Audrey L.

A Method for Calculating the Generalized Aerodynamic Forces on Rectangular Wings Deforming Symmetrically in Supersonic Flight with Indicial or Sinusoidal Time-Dependence. NASA TN D-1206, 1962.

Generalized forces are derived for prescribed upwash in linearized potential flow. Both the mode shapes forced and the upwash distributions are polynomials in chordwise and spanwise coordinates. Indicial and sinusoidal force coefficients are reported in terms of analytical solutions and tabular output samples of digital computer programs for a wing aspect ratio 4 at a Mach number of 1.2.

Supersonic
Theory

Rectangular wing.

Reduced frequency: 0.02 to 2.

24 tables.

55. Leadbetter, S. A.
 Clevenson, S. A.
 Igoe, W. B.

Experimental Investigation of Oscillating Aerodynamic Forces, Moments, and Pressures Acting on a Tapered Wing Oscillating in Pitch at Mach Numbers from 0.40 to 1.07. NASA TN D-1236, 1962.

Data were obtained for an aspect-ratio-3, taper-ratio-0.5 wing oscillating $\pm 1.5^\circ$ about mean angles of attack of 0° , 5° , and 10° . Results of the experimental investigation are compared, in the subsonic Mach number range, with those obtained by use of a theoretical analysis based on a numerical solution of the integral equation of subsonic lifting-surface theory. Comparisons with theory of the measured force, moment, and pressure coefficients and their respective phase angles, when the wing was at a mean angle of attack of 0° , showed generally good agreement.

Subsonic
Transonic
Experiment

37 diagrams.

56. Destuynder, Roger
 Chopin, Suzanne

Détermination Expérimentale de Coefficients Instationnaires Transsoniques aux Fréquences Réduites Elevées et Comparaison avec la Théorie (Experimental Determination of the Transonic Unsteady Coefficients at the Higher Range of Reduced Frequencies and Comparison with Theoretical Results). La Recherche Aéronautique, September-October, 1962, pp.53-58.

Discussion of the tests that have been carried out in the transonic test-section of the S-2 Modane wind-tunnel, on a rectangular wing of aspect-ratio 4. A new device is described by which the higher range of reduced frequencies can be obtained by using the natural modes of the structure as degrees of freedom. The test results are compared with predictions from Landahl's theory.

Transonic
Theory
Experiment

For the theory, see
 Landahl, Marten T.

Theoretical Studies of Unsteady Transonic Flow - IV, The Oscillating Rectangular Wing with Control Surface. Aeronautical Research Institute of Sweden, FFA Report 80, 1958.

57. Stark, Valter J.E.

Applications at $M = 1$ of a Method for Solving the Subsonic Problem of the Oscillating Finite Wing with the Aid of High-Speed Digital Computers. Proceedings of the International Union of Theoretical and Applied Mechanics, Symposium Transsonicum, Aachen, West Germany, September 3-7, 1962, Symposium sponsored by the Union of Theoretical and Applied Mechanics, Federal Ministry of the Interior, and Deutsche Versuchsanstalt für Luft- und Raumfahrt. Edited by Klaus Oswatitsch. Springer, Berlin, 1964, pp.440-455; Discussion, pp.455-459.

Description of a method developed earlier for solving the linear subsonic problem of the oscillating surface, and specialized for the solution of the nonsteady linear sonic problem. The modifications required are described. The method also uses a linear approximation to the lift distribution. The weight coefficients are determined by satisfying the tangency condition in the least-square sense. Some applications for rectangular and cropped delta wings are presented. It is stated that comparisons with exact results for a rectangular wing indicated that the method of integration is accurate and that the set of functions originally employed for approximation is applicable for rectangular planform. Preliminary applications are said to have shown that a proposed new set may be more expedient for cropped delta wings.

Transonic
Theory

12 diagrams.

1963

58. Laschka, Boris

The Potential and the Velocity Field of a Harmonically Oscillating Airfoil in a Subsonic Flow. (Das Potential und das Geschwindigkeitsfeld der harmonisch schwingenden tragenden Fläche bei Unterschallströmung. Zeitschrift für Angewandte Mathematik und Mechanik, Vol.43, July-August, 1963, pp.325-333. In German, with summaries in English and Russian.

Formulation of the potential and the velocity field for a wing executing harmonic oscillations normal to the wing plane in subsonic flow. The corresponding influence functions are investigated, and are discussed for some special cases.

Subsonic
Theory

59. Laschka, B.

Zur Theorie der harmonisch schwingenden tragenden Fläche bei Unterschallanströmung. Zeitschrift für Flugwissenschaft, Vol.11, 1963, Heft 7.

A lifting-surface method is derived applicable to harmonically oscillating wings in three-dimensional subsonic flow. The solution of the integral equation is obtained by a collocation method. The method yields unsteady lifting pressure distributions.

Subsonic
Theory

Planforms: trapezoidal

Modes: $f(x,y) = 1; x - x_k; y^2; (x - x_k) y^2; y_k + |y|$.

Reduced frequencies: $k = \omega s/v = 0, 0,5, 1, 2$.

Mach numbers: 0, 0,6, 0,8, (0.9).

Basic concept: The method is based on the integral equation derived by H.G.Küssner¹ by means of the acceleration potential and for which C.E.Watkins, H.L.Runyan and D.S.Woolston² developed the kernel function.

References

1. Küssner, H.G. *Allgemeine Tragflächentheorie. Luftfahrtforschung, Vol.17, 1940, pp.370-378.*
2. Watkins, C.E. *On the Kernel Function of the Integral Equation Relating the Lift and Downwash Distributions of Oscillating Finite Wings in Subsonic Flow. NACA Report 1234, 1955.*
Runyan, H.L.
Woolston, D.S.

60. Allen, D.J.
Sadler, D.S.

Oscillatory Aerodynamic Forces in Linearized Supersonic Flow for Arbitrary Frequencies, Planforms and Mach Number. ARC R & M 3415, January, 1963.

A method is described of performing a numerical integration to solve the integral equation connecting downwash and velocity potential in linearised unsteady supersonic flow. Supersonic and subsonic leading edges and wakes are dealt with, and some practical results are given. By using this approach, a sufficiently general computer programme could deal accurately with kinked and curved edges.

Supersonic
Theory

30 diagrams, 4 tables.

61. Lehrian, Doris E.
Smart, Gillian

Theoretical Stability Derivatives for a Symmetrically Tapered Wing at Low Supersonic Speeds. ARC Current Paper 736, 1963.

Pitching and heaving derivatives are calculated to first order in frequency for a symmetrically tapered wing of aspect ratio 4 with streamwise tips. These stability derivatives are evaluated for eight Mach numbers from 1.017 to 2.462, on the basis of linearized oscillatory theory. Comparisons are made with oscillatory strip theory and steady sonic theory.

Low Supersonic
Theory

7 diagrams, 1 table.

62. Wight, K.C.
Nixon, Miss J.A.

Measurements of the Direct Oscillatory Derivatives for a Linear Bending Mode on Four Rigid Half-Span Models at Subsonic and Transonic Speeds, in Closed and Slotted Tunnels. ARC R & M 3376, 1963.

Measurements have been made of the direct damping and stiffness derivatives for four rigid half-span models oscillating in a linear bending mode about an axis near the root in high-speed wind tunnels. A Mach number range of 0.6 to 1.1 was covered and the frequency parameter varied between 0.12 to 0.04. The effect of converting the slotted tunnel to a closed tunnel gave large changes in the stiffness derivatives, whilst the damping derivatives showed only small to moderate changes. Comparison with theory for the damping derivatives showed reasonable agreement, especially under closed-tunnel conditions.

Subsonic
Transonic
Theory
Experiment

20 diagrams.

63. Woodcock, D.L.

On the Accuracy of Collocation Solutions of the Integral Equation of Linearized Subsonic Flow Past an Oscillating Aerofoil. Proceedings of the International Symposium on Analogue and Digital Techniques Applied to Aeronautics, Liège, 1963, pp.173-202.

Examination of the accuracy of a particular approximation collocation solution of the Multhopp type of integral equation relating the aerodynamic loading and upwash on a thin wing oscillating about a position of zero incidence in a subsonic stream. The objective was to provide information which would permit the prediction of the number and arrangements of collocation points necessary for some desired accuracy of the calculated loading, the wing planform, Mach number, frequency, and mode of oscillation being taken as arbitrary parameters. The five ways in which accuracy varies with the number and arrangement of the collocation points are assessed. The investigations are confined mainly to three planforms: (1) the circular wing, (2) a rectangular wing of aspect ratio 2, and (3) a tapered swept-back wing of aspect ratio 2. Modes of oscillation involving deformation of the wing are considered, in addition to the rigid body modes. All the calculations were made using digital computer programs in Mercury Auto-code, a basic program which determines generalized force coefficients and modified versions to give the loading distribution, the upwash distribution due to the calculated loading, and the two integrals considered.

Subsonic
Theory

6 diagrams, 23 tables.

64. Woodgate, L.
 Pugh, P.G. *Measurements of the Pitching-Moment Derivatives on a Sharp-Edged Delta Wing in Incompressible Flow.* ARC R & M 3379, 1963.
- Oscillatory pitching-moment derivatives $m_{\dot{\theta}}$ and $m_{\ddot{\theta}}$ were measured by an inexorable forcing method on a sharp-edged delta wing of aspect ratio 1.484. Mean incidence was varied from 0° to 15° , frequency parameter from 0.2 to 1.01 and Reynolds number from 1.28×10^6 to 2.56×10^6 . Steady-force measurements were also made to determine C_m , C_L and C_D . The pitching-moment derivatives showed large variations with incidence. Reynolds number effects were found at zero incidence and at 15° incidence, but these were reduced by boundary-layer trip wires to give more representative values for high Reynolds number conditions. The results are compared with the nonlinear theory of Garner and Lehrman for variations due to incidence and with the theory of Lawrence and Gerber for variations due to frequency parameter. In general the results were in better agreement with theory at low angles of incidence and, except for one condition ($-m_{\dot{\theta}}$ at $h = 1.0\bar{c}$), they confirmed the trend of the variation with frequency parameter predicted by Lawrence and Gerber, but the values were numerically smaller.
- 26 diagrams, 12 tables.
- Incompressible
Theory
Experiment
65. Murrow, Harold N.
 Pratt, Kermit G.
 Drischler, Joseph A. *An Application of a Numerical Technique to Lifting-Surface Theory for Calculation of Unsteady Aerodynamic Forces Due to Continuous Sinusoidal Gusts on Several Wing Planforms at Subsonic Speeds.* NASA TN D-1601, 1963.
- The technique provides for the calculation of gust forces and forces due to motion and deformation on a consistent basis. Results presented include the following complex quantities: (a) spanwise distribution of section lift coefficient, (b) total lift coefficient, and (c) total pitching-moment coefficient. Calculations were made for two subsonic Mach numbers and a reduced-frequency range of 0 to 1.0.
- Subsonic
Theory
66. Ransleben, Guido E. Jr
 Abramson, H. Norman *Experimental Determination of Oscillatory Lift and Moment Distribution on Fully Submerged Flexible Hydrofoils.* Journal of Ship Research, Vol.7, No.2, October, 1963, pp.24-41; also Southwest Research Institute Report No.2, Contract No. Nonr-3335(00).
- Tests in water of rectangular wing of aspect ratio 5 at reduced frequencies of 0, 0.6, 0.8, 1.2, 2.0.
- Incompressible
Experiment
67. Benthem, J.P.
 Wouters, J.G. *The Calculation of Aerodynamic Forces on the Circular Wing in Unsteady Incompressible Flow.* Nationaal Lucht- en Ruimtevaartlaboratorium (NLR) (National Aero- and Astronautical Research Institute) Amsterdam, the Netherlands, NLR-TN W.25, 1963.
- The circular wing is in the xy-plane. Four symmetrical modes of vertical vibration are considered $H = c(1, x, x^2, y^2) \exp i\omega t$. The range of investigated reduced frequencies is from 0 to 1. Forces, pressures and lift distribution are given in tables or diagrams. The calculations are based on the exact theory of van Spiegel.
- 20 diagrams, 4 tables.
- Incompressible
Theory

1964

68. Laschka, Boris

Pressure, Lift, and Moment Distributions on a Harmonically Oscillating Low-Aspect Swept Wing in the Lower Subsonic Range (Die Druck- Auftriebs- und Momentenverteilungen an einem harmonisch schwingenden Pfeilflügel kleiner Streckung im niedrigen Unterschallbereich - Vergleich zwischen Theorie und Messung). Proceedings of the 4th International Congress of the Aeronautical Sciences, AIAA Paper 64-572, 1964. Spartan Books, Washington, and Macmillan, London.

Wind-tunnel investigation, at low subsonic Mach numbers, of the pressure distributions on a harmonically oscillating swept wing (VJ 101-C aircraft), with and without external nacelles. The pressure, lift, and moment distributions, obtained at relatively high reduced frequencies, are compared with the theory.

Low Subsonic
Theory
Experiment
Pressure

Experimental results and comparison with numerical values. Additional results are collected in two company reports of the Entwicklungsring Süd, München, namely EWR-Bericht Nr.116/63 (1963) and EWR-Bericht Nr.56/64 (1964).

69. Harris, G.Z.

Mercury Programmes for Lifting Surface Theory Calculations on Wings Oscillating in Supersonic Flow. RAE TR 64064, 1964, ARC 26,839, ARC Current Paper 851.

Programmes for lifting-surface theory calculations on wings oscillating in supersonic flow are described. The computation falls into two parts: one finding the complex influence matrices connecting lift and downwash, and the other finding the generalized forces when the influence matrices are given as data. The numerical method is described, and values of constants used in the calculations are given.

Supersonic
Programme

(Describes programmes but does not give coding details).

70. Lehrian, Doris E.

The Theoretical Stability Derivatives for a Symmetrically Tapered Wing of Aspect-Ratio 3 at Supersonic Speeds. ARC Current Paper 855, 1964. (Supersedes NPL Aero 1026).

Heaving and pitching derivatives are calculated to first order in frequency on the basis of linearized oscillatory theory. Derivatives are tabulated for six Mach numbers in the range $1.031 \leq M \leq 1.875$. Some comparisons are made with transonic and supersonic experimental results and with other theoretical values.

Low Supersonic
and Supersonic
Theory
Experiment

4 diagrams, 1 table.

71. Baines, D.J.
Rockliff, R.J.

Results of a Programme of Unsteady Aerodynamic Wing Force Derivative Measurement Using Ground Launched Rocket Boosted Test Vehicles. Weapons Research Establishment, Australia, Report HSA 15, April, 1964.

Unsteady aerodynamic force and moment derivatives for eight wing planforms have been measured at frequency parameters near 0.1 in the Mach number range 0.9 to 2.1, using a free oscillation technique with ground-launched, rocket-boosted, test vehicles. Brief descriptions of the vehicle and technique are given with an assessment of accuracy. The experimental results are presented and compared with some theoretical results.

Transonic
Supersonic
Theory
Experiment

These results are referred to in Item 101.

78 diagrams.

72. Loiseau, Henri

Measurements of Coefficients of Small Aspect-Ratio Ailerons at Transonic Speeds (Mesure de Coefficients d'Ailerons de Faible Allongement en Transsonique). ONERA TN-75, May, 1964.

Experimental results in this field already published concerned transonic measurements on two- and three-dimensional ailerons extending all along the span. More recent measurements have provided experimental results in the case of very small aspect-ratio ailerons (same order of magnitude as in the case of real aeroplanes) working close to each other and mounted on the same axis of rotation. The direct and the coupling terms between the two ailerons have been obtained. They are compared with those given by a simple method applicable to supersonic speeds.

Transonic
Experiment
Control Surfaces

Rectangular wings

18 diagrams.

73. van Gennip, M. J. M. G.
Wouters, J. G.

An Algol Programme for the Calculation of Aerodynamic Forces on Wings Oscillating Harmonically in Subsonic, Compressible Flow, Using Laschka's Method. Nationaal Lucht- en Ruimtevaartlaboratorium (NLR) (National Aero- and Astronautical Research Institute), Amsterdam, Netherlands, NLR TN W.28, 1964.

It was decided to develop a universal programme for the calculation of aerodynamic forces using Laschka's theory. Because of the storage capacity of the computer in use at the NLR the programme has been split up into three parts. The first and third part are presented in this report in the form of an Algol programme; the second part, determining the solution of a set of linear equations, is not presented because an autocode programme was used. The results of some calculations carried out with these programmes have been published in Item 74.

Subsonic
Programme

The method is limited to subsonic flow, but has no restrictions as to planform configuration, reduced frequency or vibration mode.

74. Zwaan, R. J.

Some Comparative Calculations with the Lifting-Surface Theory of Laschka for Circular and Elliptic Wings Oscillating in Subsonic Flow. Nationaal Lucht- en Ruimtevaartlaboratorium (NLR) (National Aero- and Astronautical Research Institute), Amsterdam, Netherlands, NLR TN F.281, 1964.

In order to check Laschka's method to determine unsteady pressure distributions on wings oscillating in subsonic flow, pressure distributions have been calculated for circular and elliptic wings oscillating in translating and pitching modes up to $M = 0.9$ and $k = 0.9$ (related to half-span). In some cases comparisons with results of more analytical theories have been made. Also the influence of the location of collocation points in the chordwise direction has been investigated. It appeared that the pressure distributions depended highly on the location of the collocation points when values of both M and k were large.

Subsonic
Theory

91 diagrams, 2 tables.

75. Stark, Valter J.E.

Calculation of Aerodynamic Forces on Two Oscillating Finite Wings at Low Supersonic Mach Numbers. SAAB TN 53, February, 1964.

A box method employing a characteristic grid and based upon the source superposition method of the linear theory is used to calculate non-steady aerodynamic forces on one rectangular and one cropped delta wing. Allowance is made for the downwash singularity at the subsonic leading edge of the cropped delta wing. Results are shown for the reduced frequency 0.9 (based on the semi-span) and for Mach numbers in the range $1.05 \leq M \leq 1.42$.

Low Supersonic
Theory

14 diagrams, 3 tables.

1965

76. Bratt, J.B.
Raymer, W.G.
Townsend, J.E.G.

Measurements of the Direct Pitching-Moment Derivatives for Three Wing Planforms at High Subsonic Speeds. ARC R & M 3419, ARC 16,267, 1965.

Measurements of the direct pitching damping and stiffness derivatives for a delta and two swept wing planforms made in the NPL 9½ in High Speed Tunnel are discussed, and results for the delta are compared with theory. Experiments to investigate the cause of loss of damping at low frequencies obtained in earlier tests are also described, and the effect on derivative measurements of random oscillatory flow disturbances is examined.

High Subsonic
Experiment

Planforms: Cropped delta and swept wings.

82 diagrams.

77. Harris, G.Z.

The Calculation of Generalized Forces on Oscillating Wings in Supersonic Flow by Lifting-Surface Theory. ARC R&M 3453, 1965. (Supersedes RAE TR 65078).

A numerical method of solving the integral equation connecting the lift and downwash on a wing oscillating harmonically in a supersonic flow of any Mach number is described. The integral equation is replaced by a matrix equation connecting the values of the lift and downwash at sets of points on the wing, and the generalised aerodynamic forces acting on the wing are found simply as a matrix product. Comparisons are made between aerodynamic derivatives calculated by this method, and theoretical and experimental derivatives from other sources.

Supersonic
Theory

78. Lehrian, Doris E.
Garner, H.C.

Comparative Numerical Applications of the Reverse-Flow Theorem to Oscillating Wings and Control Surfaces. ARC R & M 3488, 1965.

The reverse-flow theorem gives alternative expressions for generalised forces on oscillating wings. Relations for plunging and pitching derivatives are deduced for general and low frequencies. By a reverse-flow approach, wings with oscillating control surfaces are represented by smooth equivalent upwash functions. Illustrative examples indicate the reliability of solutions by numerical lifting-surface methods for various Mach numbers, frequencies, and wing-control-surface configurations.

Incompressible
Subsonic
Transonic
Theory
Control Surfaces

Wings examined: Rectangular, tapered, swept and delta.

For general frequency, the treatment of oscillating control surfaces by smooth equivalent upwash functions is considered by means of reverse flow, with particular reference to rectangular wings with full-span controls.

Comparison of numerical results obtained by different methods.

Mach number: 0 and 0 to 1.2.

19 diagrams, 4 tables.

79. Ashley, Holt
Widnall, Sheila
Landahl, Marten T.

New Directions in Lifting-Surface Theory. AIAA Journal, Vol.3, No.1, January, 1965, pp.3-16.

Includes comparison of spanwise lift distributions from kernel functions and from the experiments of Ransleben and Abramson (Item 66) for a cantilevered rectangular wing of aspect ratio 5 in bending oscillation in water. Reduced frequency = 0.6, 0.8, 1.2, 2.0.

Incompressible
Theory
Experiment

80. Rodemich, E.R.
Andrew, L.V.

Unsteady Aerodynamics for Advanced Configurations, Part II, A Transonic Box Method for Planar Lifting Surfaces. USAF Flight Dynamics Laboratory, FDL TDR 64-152, Part II, 1965.

A sonic box procedure is developed for square box patches of velocity potential doublets. The set of downwashes at each successive downstream station are matched by solving a set of simultaneous equations. The potentials for the entire surface are fitted in the least-square sense by a surface with the proper edge conditions. Generalised forces are computed from these fitted potentials.

Transonic
Theory
Programme

Contains a complete summary of the development of the equations and a resulting FORTRAN IV computer programme.

81. Rowe, William S.

Collocation Method for Calculating the Aerodynamic Pressure Distributions on a Lifting-Surface Oscillating in Subsonic Compressible Flow. AIAA Symposium on Structural Dynamics and Aeroelasticity, Boston, August 30 - September 1, 1965.

Development of a method for identification and evaluation of the major parameters affecting the solution accuracy of the integral equation that relates pressure and downwash distributions in subsonic flow. Results of several planform analyses are presented to identify the critical parameters and to show their effects on solution accuracy. Comparisons of theoretical and experimental results for both the steady-state and oscillatory conditions are presented to demonstrate the validity of the analysis method.

Subsonic
Theory
Experiment

Planforms examined: Swept and delta wings

Data presented: Overall coefficients and pressure distributions

20 diagrams, 1 table.

82. Darovsky, L.
Dat, R.

Détermination des Forces Aérodynamiques Instationnaires Tridimensionnelles. AGARD Report 512, Juin, 1965.

Ce document indique les méthodes utilisées par le Constructeur Sud-Aviation pour résoudre les trois problèmes suivants:

1. Aile sans gouvernes en écoulement subsonique.
2. Aile sans gouvernes en écoulement supersonique, avec bord d'attaque subsonique et bord de fuite supersonique.
3. Gouvernes en écoulement supersonique.

Subsonic
Supersonic
Theory
Experiment
Control Surfaces

La validité de ces méthodes est justifiée par des comparaisons théorie-expérience portant sur des ailes rectangulaires, une aile delta de 60° et une gouverne trapézoïdale n'occupant qu'une fraction de l'envergure.

Grandeurs figurées: Pressions et coefficients globaux.

31 graphiques.

1966

83. Böhm, G.
Ebeling, P.
Wolf, R.
- Ein FORTRAN-Programm zur Berechnung der instationären Luftkräfte für den in Überschallströmung schwingenden Tragflügel nach dem Verfahren von V.J.E.Stark.*
Bericht der Vereinigten Flugtechnischen Werke (VFW), München, Nr.M-74/66, 1966.
- Supersonic
Programme
84. Laschka, B.
Böhm, G.
Schmid, H.
- Generalised Aerodynamic Forces for Some Wing Planforms According to the Unsteady Three-Dimensional Lifting-Surface Theory in Subsonic and Supersonic Flow.* (AGARD Project SGVA 227), Vereinigte Flugtechnischen Werke, Report N-75/66, 1966.
- Generalised aerodynamic forces on oscillating flat-plate wings in three-dimensional flow are calculated. The flow may be subsonic, sonic or supersonic.
- Planforms: Elliptic, trapezoidal
- Modes: $f(x,y) = 1, x, x^2, y^2, y, xy, (x^2 y^2)$
and flap rotations for the sonic and supersonic cases
- Reduced frequencies: $k = \omega s/v = 0, 0.1, 0.3, 0.5, 0.6, 1.2, 1.4, 2, 4$
- Mach numbers: $0 \leq M \leq 2$
- Basic concept: For the subsonic case see Item 59.
For the sonic or supersonic case see Item 75.
- Subsonic
Transonic
Supersonic
Theory
Control Surfaces
85. Schmid, H.
- Ein FORTRAN-Programm zur Berechnung der instationären Luftkräfte schwingender Tragflächen bei Unterschallanströmung nach dem Verfahren von B.Laschka.* Bericht der Vereinigten Flugtechnischen Werke (VFW), München, Nr.M-73/66, 1966.
- Subsonic
Programme
86. Garner, H.C.
Fox, D.A.
- ALGOL 60 Programme for Multhopp's Low-Frequency Subsonic Lifting-Surface Theory.*
ARC R & M 3517, April, 1966.
- An improved programme for the KDF9 digital computer is described and illustrated. The mathematical equations, general flow diagrams and the ALGOL text are presented. The improvements incorporate a new procedure for evaluating the influence functions and a scheme for more accurate spanwise integration without increase in the number of collocation sections. Up to four chordwise terms are included, but the extension to five or more terms should be straightforward in principle.
- No numerical results.
- Subsonic
Programme

87. Harris, G.Z.

Supersonic Flutter Derivatives for a Series of Swept and Cropped Delta Wings. ARC Current Paper 920, 1966.

A programme for the experimental and theoretical determination of flutter derivatives for a series of swept and cropped delta wings was initiated. This report gives values of the pitching and heaving derivatives for a number of these planforms in the intermediate supersonic speed range. The derivatives have been found using supersonic lifting-surface theory.

Supersonic Theory Experiment

Results reproduced in Item 101.

88. Cunningham, Herbert J.

Improved Numerical Procedure for Harmonically Deforming Lifting Surfaces from the Supersonic Kernel Function Method. AIAA Journal, Vol.4, No.11, November, 1966.

The planform treated has subsonic leading and supersonic trailing edges. In the integral equation from linear theory that relates static or oscillatory distributions of known downwash to unknown lifting pressure, the lift is approximated by a series of terms, and a collocation procedure is employed. Lift series used earlier proved inadequate for general wing deformations such as those representative of natural vibration modes of root-cantilevered wings. A lift series now has been developed for which generally good agreement has been obtained between the approximate and the prescribed distributions of downwash for several representative cases. Comparisons are presented for modes 1 to 3 of the 45°-delta model and with modes 1 and 2 of the 70°-delta model 1A. Each term of the lift series provides a continuous distribution of downwash on the wing. This characteristic is important for low-aspect-ratio wings, especially where collocation points are desired in the plane of symmetry because of motion or flexibility there. The results obtained were with 16 terms in the lift series, and from 35 to 46 collocation points on the half-span. Solutions for the weighting factors in the lift series were made by a least-square-error process.

Supersonic Theory

Mach numbers: 1.4 and 2.

Reduced frequency: 0.5.

Data presented: Distribution of angle of incidence.

10 diagrams.

89. Olsen, James J.

Demonstration of a Transonic Box Method for Unsteady Aerodynamics of Planar Wings. USAF Flight Dynamics Laboratory, AFFDL TR 66-121, October, 1966.

The report presents and interprets the predictions of an unsteady aerodynamic prediction method known as the Sonic Box method. Illustrations are given on how the program interprets input model data, the programs techniques for smoothing certain input and output data, convergence of the numerical results, and comparisons of predicted results with experiments. It is shown how the present program requires the user to devote some care to defining input mode shapes; however, this problem can be removed by a simple modification. Generally speaking, the programs' current limit of fifty boxes in any one direction is sufficient to obtain satisfactory convergence, with the exception of pitching moments on cropped deltas. In this respect

Transonic Theory Experiment

89. (Continued)

other modifications are apparent which could improve convergence at the cost of increased complexity. Agreement with experiment was generally qualitatively good, but illustrated the need for further optimization of the method as well as the lack of experimental data of the type and quality desired for correlation.

The purpose is to demonstrate the application and usefulness of the computer program of Item 80.

64 diagrams, 12 tables.

90. Dat, R.
Leclerc, J.
Akamatsu, Y.

Optimisation de l'Emploi de la Théorie de la Surface Portante en Aéroélasticité Subsonique. Recherche Aérospatiale, No.113, Juillet Aout, 1966, pp.37-52.

Cet article comporte une discussion et des résultats théoriques. On présente des coefficients d'aile rectangulaire d'allongement 1, munie d'une gouverne occupant toute l'envergure. Les calculs ont été effectués avec un programme du Constructeur Sud-Aviation, en écoulement direct et en écoulement inverse, en représentant la répartition d'angle d'attaque correspondant aux oscillations de gouvernes par des polynômes "équivalents". Les résultats numériques sont présentés sur des courbes, en fonction de la position de la charnière, et comparés aux valeurs figurant dans le poste No.40.

Subsonic
Theory
Control Surfaces

Nombre de Mach: 0,5

Les coefficients figurant dans cet article ont été calculés avec un programme amélioré à Mach 0,7 - Voir poste No.107.

91. Bergh, H.
Zwaan, R. J.

A Method for Estimating Unsteady Pressure Distributions for Arbitrary Vibration Modes from Theory and from Measured Distributions for One Single Mode. Nationaal Lucht- en Ruimtevaartlaboratorium (NLR) (National Aero- and Astronautical Research Institute), Amsterdam, Netherlands, NLR TR F.250, 1966.

A method is proposed for estimating the pressure distributions for a lifting surface required for arbitrary vibration modes, by the aid of theory and measured distributions for one single mode. Its usefulness is demonstrated by the case of two swept wings of small aspect ratio oscillating in flapping and pitching mode in incompressible flow. Due to insensitivity to reduced frequency variations of this method it appears to be possible to predict experimental pressure distributions for reduced frequencies, somewhat different from the values used in the measurements.

Incompressible
Theory
Experiment

60 diagrams.

1967

92. Hertrich, H.

Zur experimentellen Prüfung instationärer dreidimensionaler Tragflächentheorien bei inkompressibler Strömung. AVA-Bericht 67 J 02, 1967. Dissertation, Technische Hochschule Braunschweig, 1967.

Pressure distributions on harmonically oscillating rigid wings in incompressible flow have been measured. The local unsteady airloads at the model surface are transmitted by pressure leads to a central pressure transducer outside the model. The dynamic response of all leads is identical. The process of measurement and the recording data are automatically controlled by a special electronic measuring system. These experimental results are compared with corresponding results of several different lifting surface theories.

Incompressible
Theory
Experiment
Control Surfaces
Pressure

Profile: NACA 0012.

Theoretical reference: Item 59.

Planforms: Trapezoidal. Aspect ratios 3.1 and 2.5.

Modes: $f(x,y) = x - x_k$ and flap rotation

Reduced frequencies: $\omega^* = 0$ and $0.13 \leq \omega^* \leq 0.76$.

Mach numbers: Incompressible

93. Garner, H.C.
 Lehrian, Doris E.

Comparative Theoretical Calculations of Forces on Oscillating Wings Through the Transonic Speed Range. NPL Aero Report 1246, ARC 29,367, 1967.

Numerous linearised theories are applied to plunging and pitching rectangular, delta and symmetrical tapered wings in subsonic, sonic and supersonic flow. Pitching moments are presented as continuous curves against Mach number for fixed frequency parameter. General theories are appraised beside exact theories for particular wings. Comparisons with experiment are satisfactory, except in transonic flow where uncertain wall interference masks the true discrepancies.

Transonic
Theory

Planforms: Rectangular with aspect ratio 2, delta with aspect ratio 1.5, symmetrical tapered with aspect ratio 4.33.

General motion and overall coefficients.

Mach Number: 0.9 to 1.15.

Reduced frequency: 0 to 0.63.

37 diagrams, 22 tables.

94. Lehrian, Doris E.

Calculation of Subsonic Flutter Derivatives for an Arrowhead Wing with Control Surfaces. NPL Aero Report 1230, ARC 29,047, 1967.

Subsonic lifting-surface theory is applied with direct and reverse-flow methods to calculate flutter derivatives for an arrowhead wing with trailing-edge controls. By a reverse-flow treatment, equivalent upwash functions are constructed for control oscillations. Except for the direct control derivatives, comparison with other theories for general and low frequencies is satisfactory. Pitching derivatives show good agreement with low frequency measurements.

Subsonic
Theory
Control Surfaces

24 diagrams, 8 tables.

95. Curtis, A.R.
 Gikas, X.A.
 Hassig, H.J.

Oscillatory Flap Aerodynamics - Comparison between Theory and Experiment. Presented at Aerospace Flutter and Dynamics Council Meeting, Cocoa Beach, Florida, November 1-3, 1967.

Wing lift, pitching-moment and flap-hinge moment due to oscillatory flap deflection were computed and compared with experimental data for two rectangular wings, of aspect ratios 1 and 2, with full span 40% chord flaps.

Subsonic Theory Experiment Control Surfaces
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Lockheed's Subsonic Kernel Function program with eight chordwise and eight spanwise collocation points was used for the computations. Two versions of the program were used and compared: the regular program, which does not account for the singularity of the hinge, and a program that includes a chordwise pressure distribution with an infinite pressure at the hinge.

The experimental data were obtained from tests performed in the Cornell Variable Density Tunnel in 1952 (Item 8).

Computed magnitude and phase of the lift due to flap deflection are in good agreement with experiment. For the total moment due to flap deflection the agreement is fair to good. The computed phase of the hinge moment shows good agreement with the experimental results. At steady state the computed magnitude of the hinge moment is considerably larger than the experimental value. For the oscillatory case the agreement is fair to good.

The two versions of the program give very similar results and no conclusion regarding their relative merit has been reached.

Mach number: 0.2

Reduced frequency: 0 to 1.5

15 diagrams.

96. Hassig, H. J.

Symmetric Airloads on a Wing with Ailerons Obtained with the Subsonic Kernel Function Program using Differing Numbers of Collocation Points. Paper presented at the Aerospace Flutter and Dynamics Council Meeting, Cocoa Beach, Florida, November, 1967.

Lockheed's subsonic kernel function program was used to determine the effect of varying the number of collocation points. A planform studied in connection with the L-1011 (airbus) program was used for this investigation. The spanwise x chordwise arrays of collocation points used are: 9 x 9, 8 x 8, 7 x 7, 6 x 6, 9 x 4. The following symmetric angle of attack distributions were considered: Uniform α , linear α , inboard aileron deflection, outboard aileron deflection, both ailerons.

Subsonic Theory Control Surfaces
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Cases examined: Swept wing with control surfaces, overall forces.

75 diagrams.

97. Olsen, James J.

Recent AFFDL Research in Unsteady Aerodynamics. Presented by W.J. Mykytow to AGARD Structures and Materials Panel, Ottawa, 25-29 September, 1967.

This paper summarizes and gives reference to some US Air Force sponsored research.

98. Stenton, T.E.
Andrew, L.V.

Transonic Unsteady Aerodynamics for Wings with Control Surfaces. A Transonic Box Method for Planar Lifting Surfaces with Trailing Edge Flaps. North American Report NA-67-1054, November, 1967, also US Air Force Flight Dynamics Laboratory, AFFDL TR 67-180.

The transonic box method has been extended to include the effects of a swept trailing edge and a trailing-edge flap. The method is based on the representation of the velocity potentials by a doublet distribution. Thickness effects are not included, and the free-stream Mach number is assumed to be 1.0.

Transonic
Theory
Programme
Control Surfaces

A digital computer program written in FORTRAN IV is presented. The program provides for a swept trailing edge with two sections, and as many as three sweep angles on the leading edge. Provision is made for treating a trailing-edge aileron. For a maximum of ten modes of oscillation, the program computes the oscillatory potentials and pressures and a generalized aerodynamic force matrix.

The procedure is similar to that used in Item 106. It will handle a subsonic trailing edge.

99. Fenain, M.
Guiraud Vallée, D.

Calcul Numérique des Ailes en Régime Supersonique Stationnaire et Instationnaire. 2ème partie: Ecoulement Instationnaire. Recherche Aérospatiale No.116, Janvier-Février, 1967, pp. 23-33.

Les calculs sont fondés sur une méthode des "bôîtes", avec un maillage suivant des lignes caractéristiques.

Les résultats numériques concernent des ailes rectangulaires et une aile delta en battement et rotation, à Mach 2. Les tableaux et courbes donnent la comparaison avec la solution exacte de de Jager (poste No.41), pour l'aile rectangulaire, et avec des résultats fournis par le programme du poste No.82, pour l'aile delta.

Supersonic
Theory

100. van de Vooren, A. I.

Some Modifications to Lifting-Surface Theory. Journal of Engineering Mathematics, Vol.1, April, 1967, pp.87-101.

Calculation of the pressure distributions in a subsonic flow for a vertical stabiliser by using the theory of orthogonal functions. In addition, the procedure offers advantages when calculating the pressure distribution due to a symmetrical loading for a swept wing near its central section. In this case the assumption of a zero derivative of the pressure in the relevant direction does not need to be introduced and a potential-theoretical solution, which is more accurate near the mid-section, can be obtained. It is pointed out that an ALGOL 60 program for symmetrical loading of a swept wing in incompressible flow is available.

Subsonic
Theory
Programme

1968

101. Woodcock, D.L.

Coordinated Experimental and Theoretical Research on the Oscillatory Air Forces for Selected Planforms at Subsonic and Supersonic Speeds. RAE Technical Report 68033, February, 1968.

Oscillatory heave and pitch derivatives have been determined experimentally and theoretically for a set of eight planforms - three cropped delta wings, three arrowhead wings, and two unswept tapered wings. Three experimental procedures of widely different type were used. These were a free oscillation technique for wall-mounted half-span wind-tunnel models, a similar technique for models mounted on rocket-boosted test vehicles and an inexorable forcing technique of the internal rigid drive type applied to half-span wind-tunnel model wings. The theoretical values were obtained by various form of lifting-surface theory. All these results are tabulated and compared. They cover a Mach number range of approximately 0.8 to 2.5. Some theoretical values of control surface derivatives are included in the tables, and a few other miscellaneous experimental or theoretical results are also described.

Subsonic
 Supersonic
 Theory
 Experiment

67 diagrams, 64 tables.

102. Woodgate, L.

Measurements of the Oscillatory Pitching-Moment Derivatives on a Slender Sharp-Edged Delta in Incompressible Flow. NPL Aero Report 1274, ARC 30,357, 1968.

The derivatives, m_{θ} and $m_{\dot{\theta}}$, were measured on a wing of aspect ratio 0.654. Mean incidence was varied from 0° to 15° , frequency parameter from 0.2 to 1.0 and Reynolds number (based on \bar{c}) from 1.28×10^6 to 2.56×10^6 . Comparisons are made with similar measurements on a delta wing of aspect ratio 1.484. The effects on the derivatives of incidence, frequency and Reynolds number was smaller for the more slender wing.

Incompressible
 Experiment

16 diagrams, 6 tables.

103. Albano, E.
 Rodden, W.P.

A Doublet Lattice Method for Calculating Lift Distributions on Oscillating Surfaces in Subsonic Flows. AIAA Paper No.68-73, 1968.

Approximate solutions from the linearized formulation are obtained by simulating the surface by a set of lifting elements which are short line-segments of acceleration potential doublets. The normal velocity induced by an element of unit strength is given by an integral of the subsonic kernel function. The load on each element is determined by satisfying normal velocity boundary conditions at a set of points on the surface. It is seen *a posteriori* that the lifting elements and collocation stations can be located such that the Kutta condition is satisfied approximately. The method obviates the prescription of singularities in lift distribution along lines where normal velocity is discontinuous and is readily adapted for problems of complex geometries. Results compare closely with those from methods which prescribe lift-mode series and from pressure measurements

Subsonic
 Theory
 Control Surfaces

The method is a generalization of the work of S.G.Hedman, Swedish FFA Report 105 (1965), for steady flow. Some results are compared with other

103. (Continued)

theories and experiments for several wings, including a swept tapered wing with partial-span flaps.

Cases examined: Incidence and control surface effects for steady flow.

Mach number: 0.6 to 0.8.

Overall forces and pressure distribution.

8 diagrams.

104. Berman, J.H.
Shyprykevich, P.
Smedfjeld, J.B.

Unsteady Aerodynamic Forces for General Wing/Control-Surface Configurations in Subsonic Flow. I - Theoretical Development. II - Digital Computer Programs.
US Air Force Flight Dynamics Laboratory, AFFDL TR 67-117, May, 1968.

This report presents a FORTRAN IV computer program which is based on the subsonic-kernel-function procedure for finite-aspect-ratio wings with partial-span control surfaces. The basic wing pressure-series functions used in previous kernel-function applications have been augmented in this report to include the logarithmic singularity at the control-surface leading edge, and to account for gap effects at the control surface side edges. The procedure employs either a conventional planar kernel function, or, on an optional basis, a non-planar kernel function which considers the effect of an initially deflected control surface. The solution for the unknown coefficients of the pressure-series functions is performed in a least-squares sense, based on downwash values at locations chosen by the program user. The final results obtained are in the form of pressure distributions and generalized forces. A limited correlation of program calculations with available experimental data is presented.

Subsonic
Theory
Experiment
Programme
Control Surfaces
Pressure

Part I shows calculated pressure distributions associated with control-rotation mode for a low-aspect-ratio swept wing with outboard flap, $M = 0.8$, $k = 0.404$, for a rectangular wing of aspect ratio 1 with full-span flap, $M = 0.0394$ with $k = 1.0$, $M = 0.151$ with $k = 1/3.5$, for a rectangular wing of aspect ratio 4 with partial-span flap, $M = 0.5$, $k = 0.5$, and compared with experiment for an unswept, tapered, high-aspect-ratio wing with outboard flap, $M = 0.6$, $k = 0$.

Part II gives instructions, a sample problem, and complete listing of the Fortran IV computer program.

105. Curtis, Alan R.
Lingard, Robert W. Jr

Unsteady Aerodynamic Distributions for Harmonically Deforming Wings in Supersonic Flow. AIAA Paper No.68-74, 1968.

A collocation method is used to solve the integral equation relating the downwash to the pressure distribution over thin planar wings with arbitrary planforms in supersonic flow. In particular, this method is applied to wings with subsonic leading and supersonic trailing edges. For planforms with other edge conditions, such as streamwise side edges, a technique is presented where a set of partially coupled integral equations is used.

Subsonic
Theory

Results compared with theories of Watkins and Berman (Item 6) and of Zartarian and Hsu (Item 19).

105. (Continued)

Cases examined: Cropped delta wing, angle of sweep 60° .

Mach number: 1.5.

Reduced frequency: 0.2.

Delta wing with aspect ratio 3.

Mach number: 1.054 - steady.

Data presented: Overall forces and spanwise distribution.

18 diagrams.

106. Donato, Vincent W.
Huhn, Charles R. Jr

Supersonic Unsteady Aerodynamics for Wings with Trailing Edge Control Surfaces and Folded Tips. North American Report NA-68-92, January, 1968. US Air Force Flight Dynamics Laboratory, AFFDL TR-68-30.

A Mach box digital computer program has been developed and written in FORTRAN IV for surfaces with trailing edge control surfaces. It is a method for obtaining steady and unsteady supersonic aerodynamic coefficients, and at the option of the user, lifting pressure distributions. Wing configurations can include those with folded tips, cranked leading and trailing edges, and supersonic or subsonic leading and trailing edges.

Supersonic
Theory
Programme
Control Surfaces

The program is based on the supersonic Mach box procedure which employs Evvard's diaphragm concept to establish a set of source patches (Mach boxes), with strengths that match the tangential flow condition or, if on the diaphragm, the zero pressure condition at the box center. Velocity potential influence coefficients are used here rather than pressure influence coefficients because the variations of the potentials are usually less severe in the region of integration.

All boxes are the same size and source strengths on boxes that lie partially on the primary surface partially on the flap and partially in the wake are linear interpolations based on the percentage of the box area in those regions.

107. Dat, R.
Darovsky, L.
Darras, B.

Considérations sur la Solution Matricielle du Problème Portant Instationnaire en Subsonique et Application aux Gouvernes. Note technique ONERA NT No.135, 1968.

Cet article reprend, en les précisant, les considérations développées dans un article précédent sur "l'Optimisation de l'Emploi de la Théorie de la Surface Portante en Aéro-élasticité". La discussion porte sur la mise en oeuvre pratique de l'équation intégrale qui lie la perturbation et la pression sur l'aile, et sur la formulation matricielle obtenue en représentant la pression dans une base de fonctions. On montre le sens de l'approximation effectuée.

Subsonic
Theory
Control Surfaces

L'application aux gouvernes limitées en envergure est examinée. Il apparaît que les singularités logarithmiques, qui sont maintenant connues, peuvent être introduites sans trop de complication.

107. (Continued)

Les coefficients aérodynamiques de l'aile carrée avec gouverne ont été calculés par la méthode des perturbations équivalentes et sont comparés aux résultats du poste No.40.

Nombre de Mach: 0,7

24 graphiques.

Les mêmes coefficients sont présentés pour Mach 0,5 dans le poste No.90.

108. Landahl, M.T.
Stark, V.J.E.

Numerical Lifting-Surface Theory - Problems and Progress. American Institute of Aeronautics and Astronautics, Aerospace Sciences Meeting, 6th, New York, N.Y., January 22-24, 1968, paper 68-72.

Progress report on the status of solutions to the unsteady lifting-surface problem, for planar or non-planar configurations. Only the linearized thin-wing problem is considered in detail, and a major portion of the study is concerned with the subsonic case. Several different ways of formulating the unsteady lifting-surface problem are described, the nature of the formulation being dependent upon the function upon which the formulation is based - i.e., the velocity potential, pressure, or any other related function.

Subsonic Transonic Supersonic Theory Experiment Pressure

Several procedures for the evaluation of the surface integral occurring for each loading function are described.

Some theoretical results and comparison of theory and experiment.

Rectangular wing at Mach numbers of 1 and 0.8.

Delta wing (45°) at Mach numbers of 1.054 and 2

Data presented: Pressure, potential, overall forces.

15 diagrams.

MANUAL ON AEROELASTICITY

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