R. & M. No. 3232

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A Record of Information on Oscillatory Aerodynamic Derivative Measurements

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A Record of Information on Oscillatory Aerodynamic Derivative Measurements

By H. Hall

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Summary. This Note contains the results of a survey on aerodynamic derivative measurements since 1940 made in both this country and abroad. References are given to 53 papers on the subject and it is believed that most of the published work on derivative measurements is recorded.

1. *Introduction.* In December 1955 a paper was issued by the Royal Aircraft Establishment[1] which recorded information on British wing flutter experiments. It was thought that a similar paper on derivative measurements from both British and foreign sources would be useful. In the present paper information is presented from 24 British sources and 29 foreign (mainly American); the work is divided into two parts according to whether the measurements were made in this country or abroad. A similar form of presentation of the reports listed is adopted as in the compilation on wing flutter[1] and in addition measured derivative values are quoted.

The survey is arbitrarily confined to papers issued during the years 1940 to 1956 inclusive.

This R. and M. should prove useful as a reference work providing within a single paper information from many sources on experimental derivative measurements. It is suggested that the record should be kept up to date by the periodic issue of supplements.

2. *Survey of Experimental Work on Derivative Measurements.* The survey shows that in this country most effort has been directed to measuring the main surface pitching moment derivatives. Considerable work has also been done on main surface lifting derivatives due to motion in pitch and vertical translation and to measurements of control surface hinge moments. The majority of measurements have been made at the National Physical Laboratory, the first R.A.E. paper being published in 1950. Apart from one set of free flight tests by R.A.E., all work at high Mach numbers has been done at N.P.L.

Much of the American work has also been directed to the investigation of pitching moment derivatives. Particularly valuable results are given by them for hinge moment derivatives in the transonic and supersonic regions, a field of some importance at present. Relatively, much more of the American work has been done at universities and colleges than at similar institutions in this country.

* Previously issued as R.A.E. Tech. Note No. Structures 268—A.R.C. 21,595.

Much more work was done in this country during the war years than in America. Since 1949, however, they have published a great volume of work on the subject. The general picture revealed by the survey is that British work at low subsonic speeds is more comprehensive than the American whereas the converse is true at transonic and supersonic speeds.

3. *Presentation of Information.* The reports analysed are listed in the two Appendices to this R. and M. Each Appendix is divided up in the following way:

(1) A list giving the title, author, reference number and date of publication of each report together with a reference number appropriate to this R. and M.

(2) A précis of each report. Each précis consists of five parts:

  (*a*) A summary

  (*b*) A record of the parameter variations

  (*c*) The model details

  (*d*) The results obtained (in most cases so many results are given in the original paper that it has only been possible to give a selection)

  (*e*) The site of the tests.

(3) A series of tables indicating which reports deal with the measurement of particular derivatives. Each table covers the corresponding damping and stiffness derivative, though in some cases the latter includes the virtual inertia derivative.

The sections on parameter variations give, where appropriate, details of Mach number, frequency parameter, Reynolds number, mean incidence, amplitudes of oscillation, axis of oscillation, etc. The axis of oscillation is in general given as a distance aft of the leading edge for an unswept rectangular wing and a distance aft of the apex for a swept or delta wing.

The sections on model details give the following data:

(i) Sweepback of the leading edge unless some other axis is specified.

(ii) Aspect ratio $= 2s/c_m$ where s is the semi-span and c_m the mean chord*.

(iii) Taper ratio $=$ Tip-chord/root-chord.

(iv) Span: The full or semi-span is quoted depending on the model

(v) Chord: The mean chord is quoted unless otherwise stated.

(vi) Thickness/chord ratio.

(vii) Aerofoil section.

(viii) Construction.

Control and tab details where appropriate are given after these.

The results are presented as overall derivatives unless otherwise stated; overall derivatives being related to the forces on the complete wing. The equivalent constant strip derivatives given in several instances do not give the correct force on each strip of the wing, but are defined in such a way that

* In cases where the aspect ratio is referred to as being infinite, the tests were either performed on a model which spanned the tunnel or on a wing placed between two parallel end plates in the section. In the latter case the extended vortex trail of finite width beyond the edge of the end plates is likely to reduce the effective aspect ratio.

they are constant over the span and after appropriate integration over the span give the correct generalised forces on the wing. In one instance results are presented as local derivatives for five spanwise stations. All results are presented in the British manner following the definitions of the derivatives given in the notation section of this report. No effort has been made to correct for still air damping where this is not done in the original paper. The effect is likely to be small in any case.

4. *Notation and Definitions.* For the conventional wing-control-tab configuration oscillating in rigid modes the air forces on the system are given by the following expressions which provide definitions of the overall derivatives.

L = Aerodynamic lift on complete wing, positive upwards

$$= \rho V^2 S \left\{ L_Z \frac{Z_A}{c_m} + L_\alpha \alpha + L_\beta \beta + L_\gamma \gamma + L_\phi \phi \right\}$$

M = Aerodynamic moment about reference axis A, positive nose up

$$= \rho V^2 S c_m \left\{ M_Z \frac{Z_A}{c_m} + M_\alpha \alpha + M_\beta \beta + M_\gamma \gamma + M_\phi \phi \right\}$$

H = Aerodynamic moment about control surface hinge line, positive tail heavy

$$= \rho V^2 S c_m \left\{ H_Z \frac{Z_A}{c_m} + H_\alpha \alpha + H_\beta \beta + H_\gamma \gamma + H_\phi \phi \right\}$$

T = Aerodynamic moment about tab hinge line, positive tail heavy

$$= \rho V^2 S c_m \left\{ T_Z \frac{Z_A}{c_m} + T_\alpha \alpha + T_\beta \beta + T_\gamma \gamma + T_\phi \phi \right\}$$

N = Aerodynamic rolling moment about an axis coincident with the wing root, positive in the restoring sense

$$= \tfrac{1}{2} \rho V^2 S s \left\{ N_Z \frac{Z_A}{c_m} + N_\alpha \alpha + N_\beta \beta + N_\gamma \gamma + N_\phi \phi \right\}$$

where Z_A Downward displacement of reference axis of aerofoil

α Rotation of aerofoil about this axis, positive nose up

β Rotation of control surface about hinge line, positive tail down

γ Rotation of tab about hinge line, positive tail down

ϕ Angle of rotation in roll, positive tip downwards

L_Z Component of lift due to vertical translation

$$= l_z + i\nu l_{\dot z} - \nu^2 l_{\ddot z}$$

and similarly for the other components of L, M, H, and N. l_z, $l_{\dot z}$ and $l_{\ddot z}$ are respectively the stiffness, damping and virtual inertia derivatives.

ρ	Fluid density
V	Velocity of the undisturbed flow
S	Wing area
s	Span
c_m	Mean chord of wing or other main surface (including control surface and tab)
ν	Frequency parameter
	$= \omega c_m/V$ (If defined in terms of some other length this is indicated)
ω	Circular frequency of oscillation.

For a canard control system the lift on the main surface due to oscillation of the control is given by:

$$L = \rho V^2 S \{(l_\delta - \nu^2 l_{\ddot{\delta}}) + i\nu l_{\dot{\delta}}\}$$

where δ is the angle of rotation of the control surface, positive nose up.

Acknowledgement. The author is greatly indebted to G. C. Cook and Miss Judy A. Poulter for their help in the compilation of this R. and M.

REFERENCE

No.	*Author*	*Title, etc.*
1	D. R. Gaukroger	A record of information on British wing flutter experiments. A.R.C. 18,697. December, 1955.

APPENDIX I

List of Reports—British

No.	*Author*	*Title*	*Reference*
1	J. B. Bratt K. C. Wight A. Chinneck	Free oscillations of a symmetrical aerofoil about the half-chord axis at high incidences, and pitching moment derivatives for decaying oscillations.	R. & M. 2214 September, 1940
2	W. P. Jones N. C. Lambourne	Derivative measurements and flutter tests on a model tapered wing.	R. & M. 1945 August, 1941
3	J. B. Bratt K. C. Wight V. J. Tilly	The application of a wattmeter harmonic analyser to the measurement of aerodynamic damping for pitching oscillations.	R. & M. 2063 May, 1942
4	J. B. Bratt W. G. Raymer C. J. W. Miles	Interim note on the measurement of torsional derivatives in the Compressed Air Tunnel.	A.R.C. 6339 December, 1942
5	J. B. Bratt W. G. Raymer C. J. W. Miles	Interim report on further measurements of torsional damping in the Compressed Air Tunnel.	A.R.C. 6716 May, 1943
6	C. Scruton W. G. Raymer	Measurements of the direct elevator and fuselage bending derivatives for decaying oscillations.	R. & M. 2323 October, 1943
7	J. B. Bratt C. J. Davis	The influence of aspect ratio and taper on the fundamental damping derivative coefficient for flexural motion.	R. & M. 2032 February, 1945
8	C. Scruton W. G. Raymer D. V. Dunsdon	Experimental determination of the aerodynamic derivatives for flexural aileron flutter of B.A.C. wing type 167.	R. & M. 2373 May, 1945
9	J. B. Bratt K. C. Wight	The effect of mean incidence, amplitude of oscillation, profile, and aspect ratio on pitching moment derivatives.	R. & M. 2064 June, 1945
10	J. B. Bratt A. Chinneck	Measurements of the mid-chord pitching moment derivatives at high speeds.	R. & M. 2680 June, 1947
11	N. C. Lambourne A. Chinneck D. R. Betts	Measurements of the aerodynamic derivatives for a horn balanced elevator.	R. & M. 2653 January, 1949
12	A. L. Buchan K. D. Harris P. M. Somervail	The measurements of the derivative z_w for an oscillating aerofoil.	Coll. of Aero. Report No. 40 June, 1950
13	J. B. Bratt K. C. Wight	The effect of sweepback on the fundamental derivative coefficient for flexural motion.	R. & M. 2774 October, 1950
14	K. C. Wight	Measurements of the two-dimensional derivatives of a wing-aileron-tab system with a 1541 section aerofoil. Part I.	R. & M. 2934 October, 1952
15	G. F. Moss	Low speed wind tunnel measurements of longitudinal oscillating derivatives on three wing planforms.	R. & M. 3009 November, 1952

No.	*Author*	*Title*	*Reference*
16	C. Scruton L. Woodgate A. J. Alexander	Measurements of the aerodynamic derivatives for clipped delta wing at low aspect ratio describing pitching and plunging oscillations in incompressible flow.	R. & M. 2925 December, 1952
17	C. Scruton L. Woodgate A. J. Alexander	Measurements of the aerodynamic derivatives for an arrowhead and a delta wing of low aspect ratio describing pitching and plunging oscillations in incompressible flow.	R. & M. 2925 October, 1953
18	R. I. Taylor	Experimental determination of the aileron aerodynamic damping derivative.	A.R.C. 16,920 July, 1954
19	W. G. Molyneux F. Ruddlesden	Derivative measurements and flutter tests on a rectangular wing with a full span control surface oscillating in modes of wing roll and aileron rotation.	R. & M. 3010 February, 1955
20	K. C. Wight	Measurements of two-dimensional derivatives on a wing-aileron-tab system with a 1541 section aerofoil. Part II.	R. & M. 3029 March, 1955
21	W. G. Molyneux	The determination of aerodynamic coefficients from flutter test data.	C.P. 347 April, 1955
22	W. G. Molyneux F. Ruddlesden	A technique for the measurements of pressure distribution on oscillating aerofoils with results for a rectangular wing of aspect ratio 3·3.	C.P. 233 June, 1955
23	P. R. Guyett D. E. G. Poulter	Measurements of pitching moment derivatives for a series of rectangular wings at low wind speeds.	C.P. 249 June, 1955
24	G. E. Whitmarsh	Measurements of the derivative z_w for oscillating sweptback wings.	Coll. of Aero. Report No. 92 July, 1955

R. & M. Aeronautical Research Council publication. Reports and Memoranda.
C.P. Aeronautical Research Council publication. Current Papers.
A.R.C. Aeronautical Research Council publication. Unpublished report.

'Free oscillations of a symmetrical aerofoil about the half-chord axis at high incidences, and pitching moment derivatives for decaying oscillations', by J. B. Bratt, K. C. Wight and A. Chinneck.

Summary. Tests carried out to investigate the damping characteristics of an aerofoil oscillating sinusoidally about the half-chord axis, measurements of the pitching moment derivative being made for a range of frequency parameter. Tests also made for case of decaying oscillations.

Parameter Variations

Mach number	0·0273, 0·0546
Frequency parameter	0·09 to 1·23
Reynolds number	$1 \cdot 42 \times 10^5$ and $2 \cdot 83 \times 10^5$
Mean incidence	0 deg
Amplitude of oscillation	5 deg
Axis of oscillation	mid-chord axis

Model Details

Sweepback	0 deg
Aspect ratio	4·44
Taper ratio	1:1
Semi-span	18·48 in.
Chord	9·00 in.
Thickness/chord ratio	0·15
Aerofoil section	Joukowski
Construction	—

Results

Pitching moment stiffness derivatives due to pitching motion A
Pitching moment damping derivatives due to pitching motion B

where

$$\left.\begin{aligned} \tfrac{1}{2}A &= m_\alpha - \nu^2 m_{\ddot{\alpha}} \\ \tfrac{1}{2}B &= \nu m_{\dot{\alpha}} \end{aligned}\right\}$$

For $R = 1 \cdot 42 \times 10^5$ the results are

ν	A	B
1·16	0·862	−0·332
1·23	0·944	−0·352

and for $R = 2 \cdot 83 \times 10^5$

ν	A	B
0·260	1·125	−0·191
0·595	1·018	−0·298

Site: N.P.L.

Report No. 2 R. & M. 1945 August, 1941
(*See* also A.R.C. 5258)

'Derivative measurements and flutter tests on a model tapered wing', by W. P. Jones and N. C. Lambourne.

Summary. Measurements made of the aerodynamic torsional stiffness and damping derivatives over a range of frequency parameter. Flexural damping derivative also measured. A forced oscillation technique was used.

Parameter Variations

Mach number	0·027 to 0·047
Frequency parameter	0 to 2·5 (based on root chord)
Reynolds number	$0 \cdot 3 \times 10^6$ to $0 \cdot 525 \times 10^6$
Amplitude of oscillation	2·5 deg to 5·0 deg

Model Details

Sweepback	of line at $0 \cdot 3c$ aft of L.E. = 0 deg
Aspect ratio	4·43
Taper ratio	0·52:1
Semi-span	54 in.
Chord (root)	24·3 in.
Thickness/chord ratio	0·12
Aerofoil section	NACA 23012
Construction	Light rib construction with spars of cruciform cross-section

Results

Pitching moment derivatives are referred to an axis at $0 \cdot 3c$ aft of L.E.

ν	1·0	1·5	2·0	2·5
$n_{\dot{\phi}}$	1·52	1·46	1·45	1·43
$\nu m_{\dot{\alpha}}$	−0·08	−0·121	−0·161	−0·201

$m_\alpha = -0 \cdot 0453$ and is independent of ν

Site: N.P.L.

Report No. 3 R. & M. 2063 May, 1942

'The application of a wattmeter harmonic analyser to the measurement of aerodynamic damping for pitching oscillations', by J. B. Bratt, K. C. Wight and V. J. Tilly.

Summary. The paper summarises results obtained by applying the wattmeter harmonic analyser method of measurement to tests on a Joukowski aerofoil over a range of frequency parameter.

Parameter Variations

Mach number	0·027 to 0·054
Frequency parameter	0·314 to 1·517
Reynolds number	$0{\cdot}142 \times 10^6$ to $0{\cdot}283 \times 10^6$
Mean incidence	8 deg to 24 deg, a few measurements also made at $-0{\cdot}2$ deg
Amplitude of oscillation	2 deg, 4 deg, 6 deg
Axis of oscillation	half-chord axis

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Semi-span	40 in.
Chord	9 in.
Thickness/chord ratio	0·15
Aerofoil section	Joukowski
Construction	—

Results

Pitching moment damping derivatives due to pitching motion: b_1
where $\frac{1}{2}b_1 = \nu m_{\dot{\alpha}}$

The results presented are for a Reynolds number of $0{\cdot}142 \times 10^6$, an amplitude of oscillation of 5·1 deg and a small mean incidence = ($-0{\cdot}2$ deg).

ν	0·314	0·628	0·924	1·257	1·571
b_1	−0·388	−0·434	−0·440	−0·453	−0·458

Site: N.P.L.

Report No. 4 | A.R.C. 6339 (*See* also A.R.C. 6716) | December, 1942

'Interim note on the measurement of torsional derivatives in the Compressed Air Tunnel', by J. B. Bratt, W. G. Raymer and C. J. W. Miles.

Summary. Measurements made to determine the effects of change of Reynolds number on torsional damping over a range of mean incidences and frequency parameter. A few measurements of the stiffness derivative were made at a mean incidence 0 deg.

Parameter Variations

Mach number	— —
Frequency parameter	$1 \cdot 00$ to $3 \cdot 00$
Reynolds number	$0 \cdot 15 \times 10^6$ to $4 \cdot 0 \times 10^6$
Mean incidence	0 deg to 21 deg
Amplitude of oscillation	2 deg and 4 deg
Axis of oscillation	mid-chord axis

Model Details

Sweepback	0 deg
Aspect ratio	$6 \cdot 0$
Taper ratio	1:1
Semi-span	$24 \cdot 0$ in.
Chord	$8 \cdot 0$ in.
Thickness/chord ratio	$0 \cdot 15$
Aerofoil section	NACA 0015
Construction	Steel, with a hollow Duralumin nose

Results

Pitching moment damping derivatives due to pitching motion: b_1
Pitching moment stiffness derivatives due to pitching motion: a_1

where
$$\tfrac{1}{2}a_1 = m_\alpha - \nu^2 m_{\ddot{\alpha}}$$
$$\tfrac{1}{2}b_1 = \nu m_{\dot{\alpha}}$$

The results are for $R = 2 \times 10^6$, mean incidence of 0 deg and amplitude of oscillation of 4 deg.

ν	$1 \cdot 0$	$1 \cdot 5$	$2 \cdot 0$	$2 \cdot 5$	$3 \cdot 0$
b_1	$-0 \cdot 302$	$-0 \cdot 375$	$-0 \cdot 437$	$-0 \cdot 504$	$-0 \cdot 577$
a_1	$1 \cdot 090$	$1 \cdot 170$	$1 \cdot 355$	$1 \cdot 600$	$1 \cdot 895$

The values of a_1 are uncorrected for structural interference. The structural interference arises because in some of the tests it was necessary to restrict the flexure of the wing. This was done by attaching the wing through a centre bearing to a streamlined earthed structure, the latter causing the interference.

Site: Compressed Air Tunnel, N.P.L.

Report No. 5 | A.R.C. 6716 (*See* also A.R.C. 6339) | May, 1943

'Interim report on further measurements of torsional damping in the Compressed Air Tunnel', by J. B. Bratt, W. G. Raymer and C. J. W. Miles.

Summary. Further tests to measure effect of varying Reynolds number, mean incidence, frequency parameter and amplitude of oscillation on torsional damping.

Parameter Variations

Mach number	— —
Frequency parameter	$1 \cdot 0$ to $3 \cdot 5$
Reynolds number	$0 \cdot 3 \times 10^6$ to $4 \cdot 0 \times 10^6$
Mean incidence	0 deg to 27 deg
Amplitude of oscillation	2 deg and 4 deg
Axis of oscillation	mid-chord axis; one-third chord axis

Model Details

Sweepback	0 deg
Aspect ratio	$4 \cdot 8$
Taper ratio	1:1
Semi-span	$24 \cdot 0$ in.
Chord	$10 \cdot 0$ in.
Thickness/chord ratio	$0 \cdot 15$
Aerofoil section	NACA 0015
Construction	As in Report No. 4, steel with hollow Duralumin nose, but with addition of a profiled jacket to increase the chord

Results

Pitching moment damping derivatives due to pitching motion: b_1

where $\frac{1}{2}b_1 = \nu m_{\dot{\alpha}}$

Results for $R = 2 \times 10^6$, mean incidence of 0 deg and an amplitude of oscillation of 4 deg.

ν	$1 \cdot 0$	$1 \cdot 5$	$2 \cdot 0$	$2 \cdot 5$	$3 \cdot 0$
$b_{1(c/2)}$	$-0 \cdot 23$	$-0 \cdot 29$	$-0 \cdot 34$	$-0 \cdot 40$	$-0 \cdot 48$
$b_{1(c/3)}$	$-0 \cdot 34$	$-0 \cdot 56$	$-0 \cdot 74$	$-0 \cdot 89$	$-1 \cdot 08$

Site: Compressed Air Tunnel, N.P.L.

'Measurements of the direct elevator and fuselage vertical bending derivatives for decaying oscillations', by C. Scruton and W. G. Raymer.

Summary. Measurements made on a complete wing-fuselage-tail unit model. Decaying oscillation tests on twin-fin and single-fin type rudders and for two different elevator:tailplane chord ratios.

Parameter Variations

Mach number	0·0182 to 0·0636
Frequency parameter	0·25 to 1·4 (based on elevator mean chord)
Reynolds number	$0 \cdot 11 \times 10^6$ to $0 \cdot 40 \times 10^6$ (based on tailplane mean chord)
Mean chord of elevators behind hinge line	0·352, 0·320 ft

Model Details

Aspect ratio of each elevator	2·3 (= elevator span ÷ elevator mean total chord)
Tailplane span	2·417 ft
Tailplane mean chord	0·883 ft
Total elevator span	1·872 ft
Elevator mean total chord	0·405 ft
Construction	Front fuselage and wings rigid. Rear fuselage attached by cross spring hinges. Elevators fitted to hinge brackets.

Results

Results below are for $E_\beta = 0 \cdot 4$ and twin-fin rudder tailplane.

ν	0·92	0·90	0·78	0·60	0·57	0·45	0·35	0·29	0·27
$-h_\beta$	0·38	0·33	0·64	0·54	0·59	0·55	0·47	0·40	0·41
$-\nu h_{\dot\beta}$	0·89	0·97	0·91	0·75	0·59	0·51	0·42	0·36	0·32

Results below are for $E_\beta = 0 \cdot 4$ and single-fin rudder tailplane.

ν	0·87	0·77	0·72	0·59	0·43
$-h_\beta$	0·61	0·34	0·45	0·38	0·42
$-\nu h_{\dot\beta}$	0·86	0·76	0·79	0·64	0·51

Fuselage vertical bending stiffness derivative: l_ψ
Fuselage vertical bending damping derivative: $l_{\dot\psi}$

Frequency parameters quoted below are based on distance between fuselage bending axis and elevator leading edge (l). The ratio of this distance to the tailplane mean chord = 2·12.

ν	1·86	1·41	1·17	1·00	0·88	0·72	0·61
l_ψ	4·72	3·54	3·90	3·64	4·36	3·60	3·37
$\nu l_{\dot\psi}$	5·85	4·47	3·75	3·21	2·96	2·44	2·19

The aerodynamic moment on the rear fuselage is given by

$$L = L_\psi \psi + L_{\dot\psi} \dot\psi + L_{\ddot\psi} \ddot\psi$$

the non-dimensional derivatives l_ψ and $l_{\dot\psi}$ are defined in terms of these quantities by the relations

$$l_\psi = \frac{L_\psi}{\rho V^2 l c_t s_t} \text{ and } \nu l_{\dot\psi} = \frac{L_{\dot\psi}}{\rho V^2 l c_t s_t}$$

where c_t = tailplane mean chord

s_t = tailplane span

Site: 7-ft Square Tunnel, N.P.L.

'The influence of aspect ratio and taper on the fundamental damping derivative coefficient for flexural motion', by J. B. Bratt and C. J. Davis.

Summary. Tests were made on five aerofoils, three rectangular and two linearly tapered, to show effect of varying aspect ratio and taper, employing a method of free decaying oscillations.

Parameter Variations

	Rectangular	Tapered
Mach number	0·034 to 0·105	
Frequency parameter (based on root chord)	0·023 to 1·516	0·072 to 2·095
Reynolds number	$0{\cdot}25 \times 10^6$ to $1{\cdot}3 \times 10^6$	$0{\cdot}25 \times 10^6$ to $1{\cdot}3 \times 10^6$
Aspect ratio	6, 8, 10	6, 8

Model Details

	Rectangular	Tapered
Sweepback	0 deg	of line $0{\cdot}3c$ from L.E. = 0 deg
Taper ratio	1:1	0·524
Semi-span	60 in.	60 in.
Chord	20 in., 15 in., 12 in.	20 in., 15 in.
Thickness/chord ratio	0·15	0·15
Aerofoil section	NACA 0015	
Construction	Hollow structure of ribs and wood covering	

Results

Damping derivative coefficient for rolling motion: $\lambda_{\dot\phi} = l_{\dot z}$

Results presented below are for the wings of aspect ratio = 6.

The Reynolds number in both cases is $1{\cdot}26 \times 10^6$

Rectangular wing		Tapered wing	
ν	$\lambda_{\dot\phi}$	ν	$\lambda_{\dot\phi}$
0·074	1·625	0·098	1·825
0·157	1·490	0·208	1·655
0·296	1·445	0·301	1·650
0·376	1·445	0·529	1·600
0·507	1·355	0·704	1·535

Site: 9-ft × 7-ft Tunnel, N.P.L.

Report No. 8 R. & M. 2373 May, 1945

'Experimental determination of the aerodynamic derivatives for flexural-aileron flutter of Bristol Aircraft Company wing type 167', by C. Scruton, W. G. Raymer and Miss D. V. Dunsdon.

Summary. Measurements made over range of frequency parameter, on a 1/20th scale model at low speeds.

Parameter Variations

Mach number	0·018 to 0·054
Frequency parameter	0·473 to 3·82 (based on root chord)
Reynolds number	$0{\cdot}2 \times 10^6$ to $0{\cdot}6 \times 10^6$

Model Details

Model wing of light but rigid construction with planform and section similar to that proposed for the B.A.C. wing type 167, but without camber. The wing root was attached to a mock fuselage. The aileron was of light rib and spar construction with paper covering.

Aileron chord aft of hinge line = 0·2 wing chord.

Results

At $R = 0{\cdot}4 \times 10^6$, $(-h_\beta) = 0{\cdot}00124$ for $\nu = 0{\cdot}473$ to $1{\cdot}863$

$= 0{\cdot}6 \times 10^6$, $(-h_\beta) = 0{\cdot}00143$ for $\nu = 0{\cdot}317$ to $1{\cdot}264$

$(-h_{\dot\beta}) = 0{\cdot}00035$ over the range $\nu = 0$ to 2

$(-h_\phi)$ no reliable result obtained

$(-h_{\dot\phi})$ overall mean of rather scattered results gives value of $0{\cdot}00062$ for the frequency parameter range $0{\cdot}5$ to $2{\cdot}0$

$l_z = 0$

$l_{\dot z}$ over the range $\nu = 0$ to 4 a representative value is $1{\cdot}538$

$R = 0{\cdot}3 \times 10^6$

ν	1·081	1·602	1·943	2·63
l_ξ	+0·1626	0·1512	0·1432	0·1405
$\nu l_{\dot\xi}$	−0·0221	−0·0153	−0·0103	+0·0019

$R = 0{\cdot}6 \times 10^6$

ν	0	0·344	0·534	0·777	1·072	1·284
l_ξ	0·2289	0·2218	0·2089	0·1949	0·1957	0·1890
$\nu l_{\dot\xi}$	0	0·0240	0·0285	0·0268	0·0198	0·0163

In this paper there is insufficient data given to transfer all the results to the notation of Section 4. Thus the restoring rolling moment due to aileron rotation is defined as

$$L_\xi = \rho V^2 l^3 (l_\xi - \nu^2 l_{\ddot\xi} + i\nu l_{\dot\xi})$$

where ξ is the aileron angle, $l = 0{\cdot}75\, s$ and c_0 is the root chord.

Site: N.P.L.

'The effect of mean incidence, amplitude of oscillation, profile, and aspect ratio on pitching moment derivatives', by J. B. Bratt and K. C. Wight.

Summary. Measurements made to investigate effect of varying frequency parameter, mean incidence, axis of oscillation, Reynolds number, amplitude of oscillation and aspect ratio. The effect of turbulence wires was noted.

Parameter Variations

Mach number	$0 \cdot 007$ to $0 \cdot 054$
Frequency parameter	0 to $1 \cdot 571$
Reynolds number	$0 \cdot 142 \times 10^6$ to $0 \cdot 283 \times 10^6$
Mean incidence	0 deg to 18 deg
Amplitude of oscillation	2 deg to 6 deg
Axis of oscillation	$0 \cdot 333c$, $0 \cdot 5c$
Aspect ratio	$1 \cdot 0$ to ∞

Model Details

Sweepback	0 deg
Taper ratio	1:1
Semi-span	up to 40 in.
Chord	$9 \cdot 0$ in.
Thickness/chord ratio	$0 \cdot 15$
Aerofoil section	Joukowski, EC.1550, Elliptic, hollow ground
Construction	—

Results

Pitching moment damping derivatives due to pitching motion: b_1

Pitching moment stiffness derivatives due to pitching motion: a_1

$\frac{1}{2}a_1 = m_\alpha - \nu^2 m_{\ddot{\alpha}}$

$\frac{1}{2}b_1 = \nu m_{\dot{\alpha}}$

The results presented below are nominally two dimensional derivatives for a Joukowski aerofoil oscillating about the axis at $0 \cdot 333c$. The amplitude of oscillation is 6 deg and the mean incidence zero.

ν		a_1		b_1	
$R = 0 \cdot 142 \times 10^6$	$R = 0 \cdot 283 \times 10^6$	$R = 0 \cdot 142 \times 10^6$	$R = 0 \cdot 283 \times 10^6$	$R = 0 \cdot 142 \times 10^6$	$R = 0 \cdot 283 \times 10^6$
0	0	$0 \cdot 533$	$0 \cdot 550$		
$0 \cdot 314$	$0 \cdot 157$	$0 \cdot 466$	$0 \cdot 523$	$-0 \cdot 218$	$-0 \cdot 126$
$0 \cdot 628$	$0 \cdot 314$	$0 \cdot 408$	$0 \cdot 467$	$-0 \cdot 348$	$-0 \cdot 214$
$0 \cdot 924$	$0 \cdot 462$	$0 \cdot 358$	$0 \cdot 446$	$-0 \cdot 447$	$-0 \cdot 282$
$1 \cdot 257$	$0 \cdot 628$	$0 \cdot 293$	$0 \cdot 418$	$-0 \cdot 543$	$-0 \cdot 349$
$1 \cdot 571$	$0 \cdot 785$	$0 \cdot 225$	$0 \cdot 396$	$-0 \cdot 641$	$-0 \cdot 429$

Site: 4-ft Tunnel, N.P.L.

'Measurements of mid-chord pitching moment derivatives at high speeds', by J. B. Bratt and A. Chinneck.

Summary. Measurements made by the method of decaying oscillations over a range of subsonic and supersonic speeds. Variation of frequency parameter was investigated, and conditions giving rise to growing oscillations at subsonic speeds were examined.

Parameter Variations

Mach number	0·4 to 0·9 (1·275, 1·455, 1·515)
Frequency parameter	0 to 0·0334
Reynolds number	$0\cdot444 \times 10^6$ to $0\cdot822 \times 10^6$
Mean incidence	0 deg
Amplitude of oscillation	0·1 deg to 5·0 deg

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	12·0 in. (tunnel width)
Chord	2·0 in.
Thickness/chord ratio	0·075
Aerofoil section	Bi-convex
Construction	solid steel

Results

Results presented below for supersonic flow are mean values of equivalent constant strip derivatives and are independent of frequency parameter in the range 0 to 0·025.

M	m_α	$-m_{\dot{\alpha}}$
1·275	0·34	0·635
1·455	0·272	0·330
1·515	0·250	0·275

The results below for the subsonic flow are measured values of equivalent constant strip derivatives. Derivatives are dependent on Mach number only for $M < 0\cdot6$ but for M larger than this they depend on both frequency parameter and Mach number.

M	ν	$-m_{\dot{\alpha}}$	m_α
0·4	0·0186	1·06	0·79
0·5	0·0148	1·04	0·828
0·6	0·0112	1·14	0·90
0·7	0·008	1·96	1·04
0·8	0·0062	11·20	1·14
0·85	0·0064	9·9	1·02
0·875	0·0084	1·14	0·30
0·898	0·00825	0·765	0·38

Site: 1-ft diameter Tunnel, N.P.L.

'Measurements of the aerodynamic derivatives for a horn balanced elevator', by N. C. Lambourne, A. Chinneck and D. B. Betts.

Summary. Measurements made by a forced oscillation method on a complete wing-fuselage-tail unit at low speeds. The effect of mean elevator angle, frequency parameter, trailing edge chords, and transition wires, were investigated.

Parameter Variations

Mach number	0·018 to 0·054
Frequency parameter	0 to 1·53
Reynolds number	$0 \cdot 85 \times 10^5$ to $2 \cdot 54 \times 10^5$
Mean incidence	0 deg, 10 deg
Amplitude of oscillation	1 deg to 4 deg
Elevator angle,	
at incidence 0 deg	0 deg
at incidence 10 deg	−8 deg to +11·9 deg

Model Details

Wings and forward fuselage	1/6th scale Blenheim
Tail and rear fuselage	1/6th scale Mosquito

Elevator construction was light wooden framework covered with stretched paper.

Aspect ratio of tailplane	4·41

Results

The results presented are for zero incidence and mean elevator angle of zero and are mean values of those actually obtained.

$$h_\beta = 0 \cdot 07866 \bar{h}_\eta \qquad \nu h_{\dot\beta} = 0 \cdot 07866 \, \omega_\eta h_{\dot\eta}$$

ω_η	ν	$-\omega_\eta h_{\dot\eta}$	$-\bar{h}_\eta$
0·1	0·24	0·19	0·56
0·2	0·48	0·32	0·57
0·3	0·72	0·48	0·57
0·4	0·95	0·63	0·58
0·5	1·19	0·77	0·58

Site: 7·ft No. 3 Tunnel, N.P.L.

'The measurement of the derivative z_w for an oscillating aerofoil', by A. L. Buchan, K. D. Harris and P. M. Somervail.

Summary. Measurements made of the damping derivative z_w ($\equiv l_{\dot{z}}$) for constant chord rigid wings of various aspect ratios having sweepback angles of zero and 45 deg.

Parameter Variations

Mach number	0·048 to 0·157
Frequency parameter	0·1 to 0·5
Reynolds number	$0 \cdot 10 \times 10^6$ to $0 \cdot 35 \times 10^6$
Aspect ratios	3, 4, 5, 6

Model Details

Sweepback	0 deg, 45 deg
Taper ratio	1:1
Span	11·25, 15·0, 18·75, 22·5 in.
Chord	3·75 in.
Thickness/chord ratio	0·20
Aerofoil section	NACA 0020
Construction	—

Results

The derivative $l_{\dot{z}}$

ν	Unswept wing			45 deg Swept wing	
	$AR = 3$	$AR = 4$	$AR = 5$	$AR = 3$	$AR = 5$
0	1·44	1·67	1·90	1·33	1·60
0·5	1·25	1·46	1·66	1·09	1·30

Measured values of the derivative for intermediate values between $\nu = 0$ and $0 \cdot 5$ lie on straight lines joining the values at these points.

Site: College of Aeronautics, Cranfield.

'The effect of sweepback on the fundamental derivative coefficient for flexural motion', by J. B. Bratt and K. C. Wight.

Summary. Measurements were made on a rectangular wing with and without sweepback, for a range of frequency parameter.

Parameter Variations

Mach number	0·0364 to 0·191
Frequency parameter	0 to 1·6
Reynolds number	$0{\cdot}42 \times 10^6$ to $2{\cdot}2 \times 10^6$
Mean incidence	0 deg
Amplitude of oscillation	0·5 deg

Model Details

Sweepback	0 deg	41·3 deg
Aspect ratio	6·0	6·0
Taper ratio	1:1	1:1
Semi-span	60 in.	60 in.
Chord	20 in.	20 in.
Thickness/chord ratio	0·15	0·15
Aerofoil section	NACA 0015	
Construction	Hollow wooden structure built up from two spars and set of ribs with thin wooden cover.	

Results

Lift damping derivative for rolling motion: $\lambda_{\dot\phi} = l_{\dot z}$
Lift stiffness derivative for rolling motion: $\lambda_{\phi} = l_{z}$
Lift damping derivative for pitching motion: $\lambda_{\dot\theta}$ (corresponding to $l_{\dot\alpha}$)
Lift stiffness derivative for pitching motion: λ_{θ} (corresponding to l_{α})

Unswept wing

ν	$\lambda_{\dot\phi}$	λ_{ϕ}
0·268	1·401	0·036
0·803	1·256	0·238
1·399	1·193	0·374
1·871	1·160	0·559
2·406	1·097	0·824

Swept wing

ν	λ_{ϕ}	$\lambda_{\dot\phi}$	λ_{θ}	$\lambda_{\dot\theta}$
0·1	0·005	1·245	1·720	0·826
0·4	0·056	1·170	1·667	1·049
0·7	0·150	1·123	1·575	1·258
1·0	0·223	1·051	1·514	1·393
1·3	0·290	1·009	1·555	1·558
1·6	0·402	0·990	1·767	1·552

Site: 9-ft × 7-ft Tunnel, N.P.L.

'Measurements of two-dimensional derivatives on a wing-aileron-tab system with a 1541 section aerofoil', by K. C. Wight.

Part I. Direct aileron derivatives.

Summary. Measurements made to show variation with frequency parameter, amplitude of oscillation, Reynolds number, aileron angle and transition point on the wing.

Parameter Variations

Mach number	0·056 to 0·166
Frequency parameter	0 to 3·0
Reynolds number	$1 \cdot 0 \times 10^6$ to $3 \cdot 0 \times 10^6$
Amplitude of oscillation	2·5 deg, 5·0 deg
Aileron angle	0 deg, ± 4 deg, -8 deg
Transition point	Natural, $0 \cdot 4c$, $0 \cdot 1c$

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Semi-span	72 in.
Wing chord	30 in.
Aileron chord	6 in.
Tab chord	1·25 in.
Thickness/chord ratio	0·15
Aerofoil section	1541 (N.P.L. 282)
Construction	Box construction of pine and mahogany, with solid tab.

Results

Results presented are for natural transition, $R = 0 \cdot 94 \times 10^6$, mean aileron angle of zero and amplitude 5 deg.

ν	$\{(-h_\beta) - \nu^2(-h_{\ddot\beta})\} \times 10^2$	ν	$-h_{\dot\beta} \times 10^2$
0	1·259	—	—
0·6	1·135	0·733	0·442
1·2	1·098	1·215	0·488
1·6	1·096	1·718	0·507
2·0	1·111	2·208	0·524
2·5	1·138	2·672	0·537
3·0	1·169	3·158	0·540

Site: 9-ft × 7-ft Tunnel, N.P.L.

'Low speed wind tunnel measurements of longitudinal oscillatory derivatives on three wing planforms', by G. F. Moss.

Summary. Two methods of measurement were used, forced oscillations in pitch and free oscillations in pitch and vertical translation. The tests covered a range of frequency parameter, and amplitude of oscillation. Wings tested were 90 deg apex delta, 40 deg sweptback, and 60 deg sweptback. In first two cases tests were also made with body attached.

Parameter Variations

Mach number	$0{\cdot}091$ to $0{\cdot}274$
Frequency parameter	0 to $0{\cdot}3$
Reynolds number	$0{\cdot}74 \times 10^6$ to $3{\cdot}42 \times 10^6$
Mean incidence	0 deg [0 deg to 15 deg. Delta]
Amplitude of oscillation	0 deg to 2 deg

Model Details

	Delta	60 deg Swept	40 deg Swept
Sweepback ($\frac{1}{4}$-chord line)	$36{\cdot}9$ deg	60 deg	40 deg
Aspect ratio	$3{\cdot}00$, $2{\cdot}97$	$3{\cdot}0$	$4{\cdot}4$
Taper ratio	$0{\cdot}143$	—	$0{\cdot}311$
Span	$5{\cdot}485$, $3{\cdot}350$ ft	$5{\cdot}33$ ft	$7{\cdot}60$, $8{\cdot}124$ ft
Chord	$1{\cdot}828$, $1{\cdot}129$ ft	$1{\cdot}780$ ft	$1{\cdot}722$, $1{\cdot}84$ ft
Thickness/chord ratio	$0{\cdot}10$	$0{\cdot}06$ inboard, $0{\cdot}120$ tips	$0{\cdot}10$
Aerofoil section	RAE 102	RAE 101	EQ 1040
Axis of oscillation	$0{\cdot}38c_r$, $0{\cdot}536c_r$	$0{\cdot}884c_r$, $1{\cdot}111c_r$	$0{\cdot}553c_r$, $0{\cdot}962c_r$

Where c_r is the root chord at the centre-line.

Results

Results presented below were obtained by the method of inexorable forcing.

Delta wing (*with body*) $5{\cdot}845$ ft span.

The pitching axis is at $0{\cdot}380c_r$ and the amplitude is $1{\cdot}65$ deg

$$l_\alpha = 1{\cdot}45 \text{ for } \nu = 0 \text{ to } 0{\cdot}175$$
$$l_{\dot\alpha} = 1{\cdot}14 \text{ for } \nu = 0{\cdot}025 \text{ to } 0{\cdot}175$$
$$m_\alpha = -0{\cdot}38 \text{ for } \nu = 0 \text{ to } 0{\cdot}175$$

$m_{\dot\alpha}$	$-0{\cdot}464$	$-0{\cdot}56$	$-0{\cdot}576$	$-0{\cdot}58$	$-0{\cdot}58$
ν	$0{\cdot}022$	$0{\cdot}05$	$0{\cdot}10$	$0{\cdot}15$	$0{\cdot}17$

60 deg *Sweptback wing*

The pitching axis is at $0{\cdot}884c_r$ and the amplitude is $1{\cdot}70$ deg

$$l_\alpha = 1{\cdot}18 \text{ for } \nu = 0 \text{ to } 0{\cdot}175$$
$$l_{\dot\alpha} = 1{\cdot}09 \text{ for } \nu = 0{\cdot}03 \text{ to } 0{\cdot}175$$

m_α	$-0{\cdot}377$	$-0{\cdot}377$	$-0{\cdot}395$	$-0{\cdot}44$
ν	0	$0{\cdot}05$	$0{\cdot}10$	$0{\cdot}15$

$m_{\dot\alpha}$	$-0{\cdot}66$	$-0{\cdot}58$	$-0{\cdot}61$	$-0{\cdot}64$
ν	$0{\cdot}030$	$0{\cdot}05$	$0{\cdot}10$	$0{\cdot}15$

Site: $11\frac{1}{2}$-ft $\times$ $8\frac{1}{2}$-ft Tunnel, R.A.E.

'Measurements of the aerodynamic derivatives for a clipped delta wing of low aspect ratio describing pitching and plunging oscillations in incompressible flow', by C. Scruton, L. Woodgate and A. J. Alexander.

Summary. Measurements taken over a range of incidence, frequency parameter and amplitude of oscillation for two axis positions.

Parameter Variations

Mach number	0·054 to 0·109
Frequency parameter	0·06 to 0·60
Reynolds number	$0{\cdot}75 \times 10^6$ to $1{\cdot}5 \times 10^6$
Mean incidence	0 deg to 15 deg
Amplitude of oscillation	1 deg to 4 deg
Axis of oscillation	$0{\cdot}754\bar{c}$, $0{\cdot}973\bar{c}$ from apex

where $\bar{c}$ is the mean chord.

Model details

Sweepback	68·2 deg
Aspect ratio	1·2
Taper ratio	1:7
Span	28·8 in.
Chord (root)	42 in.
Thickness/chord ratio	0·06
Aerofoil section	RAE 102
Construction	Solid balsa wood with pine framework.

Results

The results quoted are for mean values over the frequency parameter range tested. They can be considered to correspond to $\nu = 0{\cdot}3$.

Distance of pitch axis from apex	l_z	$l_{\dot{z}}$	l_α	$l_{\dot{\alpha}}$	m_z	$m_{\dot{z}}$	m_α	$m_{\dot{\alpha}}$
0	0	0·552	0·856	1·404	0	−0·574	−0·831	−1·667
$0{\cdot}754\bar{c}$	0	0·552	0·856	0·988	0	−0·157	−0·195	−0·489
$0{\cdot}973\bar{c}$	0	0·552	0·850	0·867	0	−0·036	−0·008	−0·265

Site: Low Turbulence Tunnel, N.P.L.

Report No. 17 R. & M. 2925 October, 1953

'Measurements of the aerodynamic derivatives for an arrowhead and a delta wing of low aspect ratio describing pitching and plunging oscillations in incompressible flow', by C. Scruton, L. Woodgate and A. J. Alexander.

Summary. The aerodynamic lift and moment derivatives for pitching oscillations were measured at two axis positions for each wing over a range of frequency parameter, incidence, and amplitude of oscillation.

Parameter Variations

Mach number	0·0989, 0·108	
Frequency parameter	0·027 to 0·735	
Reynolds number	$1 \cdot 5 \times 10^6$ and $1 \cdot 7 \times 10^6$ arrowhead	
	$1 \cdot 1 \times 10^6$ and $1 \cdot 2 \times 10^6$ delta	
Mean incidence	0 deg to 15 deg	
Amplitude of oscillation	1·3 deg to 3·8 deg	
	Arrowhead	Delta
Axis position (dist. from apex)	$0 \cdot 883\bar{c}$	$0 \cdot 862\bar{c}$
	$1 \cdot 063\bar{c}$	$1 \cdot 112\bar{c}$

where $\bar{c}$ is the wing mean chord.

Model Details

	Arrowhead	Delta
Sweepback	65·4 deg	68·2 deg
Aspect ratio	1·32	1·60
Taper ratio	1:2·6	0
Span	38·5 in.	33·6 in.
Chord (root)	42·0 in.	42·0 in.
Thickness/chord ratio	0·10	0·06
Aerofoil section	RAE Section	RAE Section
Construction	Pine framework, with solid balsa wood.	

Results

Arrowhead wing

The derivatives given are for $\nu = 0 \cdot 3$ and the wing pitching about an axis $0 \cdot 883\bar{c}$ from the apex where $\bar{c}$ is the mean chord.

$$l_z = -0 \cdot 195, \quad l_{\dot{z}} = 1 \cdot 223 \qquad m_z = 0 \cdot 008, \quad m_{\dot{z}} = -0 \cdot 189$$
$$l_\alpha = 0 \cdot 950, \quad l_{\dot{\alpha}} = 0 \cdot 770 \qquad m_\alpha = -0 \cdot 128, \quad m_{\dot{\alpha}} = -0 \cdot 268$$

Delta wing

The derivatives are for the wing pitching about an axis $0 \cdot 862\bar{c}$ from the apex.

ν	$-m_\alpha$	$-m_{\dot{\alpha}}$	l_α	$l_{\dot{\alpha}}$
0	0·36	0·68	—	—
0·25	0·36	0·68	0·975	1·19
0·5	0·31	0·68	0·962	1·19

Site: Low Turbulence Tunnel, N.P.L.

Report No. 18 | A.R.C. 16,920 | July, 1954

Valiant Mk. II (Pathfinder)

'Experimental determination of the aileron aerodynamic damping derivatives', by R. I. Taylor.

Summary. Tests made on scale model of wing and aileron of *Valiant Mk. II* to determine the aileron damping characteristics.

Parameter Variations

Mach number	0·09
Frequency parameter	0·3 to 1·2
Reynolds number	$0 \cdot 95 \times 10^6$

Model Details

An existing 1/10th scale half model of the Valiant wing was used. The aileron was sealed with a beak and rubber seal which were shrouded. For this aileron $E_\beta = 0 \cdot 25$.

Results

The derivative $(-h_\beta)$

ν	0·34	0·69	1·04	0·35	0·65	1·14
$(-h_{\dot\beta})$ gap sealed	—	—	—	0·0044	0·0063	0·0094
$(-h_{\dot\beta})$ gap unsealed	0·0041	0·0060	0·0066	—	—	—

Site: Vickers Armstrong Limited, Weybridge.

'Derivative measurements and flutter tests on a rectangular wing with a full span control surface oscillating in modes of wing roll and aileron rotation', by W. G. Molyneux and F. Ruddlesden.

Summary. Measurements of the aerodynamic coefficients were made using a technique in which aileron rotation is geared to wing roll so that oscillation occurs in both degrees of freedom simultaneously. Comparison between measured and calculated derivatives is made.

Parameter Variations

Mach number	0·036 to 0·218
Frequency parameter	0·21 to 1·29
Reynolds number	$0 \cdot 39 \times 10^6$ to $2 \cdot 32 \times 10^6$
Gear ratio, Aileron angle/roll angle	$\pm 2 \cdot 3$, $\pm 4 \cdot 6$, $\pm 9 \cdot 2$

Model Details

Sweepback	0 deg
Aspect ratio	4·05
Taper ratio	1:1
Semi-span	3·04 ft
Chord	1·50 ft
Thickness/chord ratio	0·10
Aerofoil section	RAE 101
Construction	Solid spruce with single steel spar.

Results

These are given as equivalent constant strip derivatives.

$$(-h_{\dot\beta}) = 0 \cdot 00464 \qquad l_{\dot\beta} = 0 \cdot 0533$$
$$(-h_{\beta}) = 0 \cdot 00861 \qquad l_{\beta} = 0 \cdot 602$$
$$h_{\dot z} = 0 \qquad l_{\dot z} = 1 \cdot 06$$
$$h_{z} = 0 \qquad l_{z} = 0$$

Site: 5-ft diameter Tunnel, R.A.E. Farnborough.

'Measurements of two-dimensional derivatives on a wing-aileron-tab system with a 1541 section aerofoil', by K. C. Wight.

Part II. Direct tab and cross aileron-tab derivatives.

Summary. Measurements made to illustrate the effect of frequency parameter, Reynolds number, transition point, mean tab angle, and sealing of the control hinge.

Parameter Variations

Mach number	0·056 to 0·166
Frequency parameter	0 to 2·9
Reynolds number	$1 \cdot 0 \times 10^6$ to $3 \cdot 0 \times 10^6$
Mean aileron angle	0 deg, −8 deg
Mean tab angle	0 deg, 4 deg, 8 deg, 12·4 deg
Amplitude of oscillation	5 deg
Transition point	Natural, $0 \cdot 1c$, $0 \cdot 4c$

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Semi-span	72 in.
Wing chord	30 in.
Thickness/chord ratio	0·15
Aerofoil section	1541 (N.P.L. 282)
Construction	Box construction of pine and mahogany, solid magnesium alloy tab.
Aileron chord	6·0 in.
Tab chord	1·25 in.

Results

The derivatives given are for $R = 10^6$ and natural transition and for mean tab and aileron angles = 0 deg.

ν	$-t_\gamma \times 10^4$	$-t_{\dot\gamma} \times 10^5$	$-h_\gamma \times 10^2$	$-h_{\dot\gamma} \times 10^3$	$-h_\beta \times 10^2$	$-h_{\dot\beta} \times 10^2$	$-t_\beta \times 10^4$	$-t_{\dot\beta} \times 10^4$
0	4·16	—	1·07	—	1·08	—	1·40	—
0·73	4·01	—	1·04	0·530	0·99	0·405	1·49	1·03
1·21	3·97	3·89	1·04	0·585	1·03	0·470	1·37	1·00
1·69	3·99	3·93	1·04	0·640	0·99	0·480	1·37	0·99
2·17	4·05	4·15	1·05	0·685	1·01	0·510	1·50	1·01
2·66	4·10	4·46	1·06	0·725	1·04	0·525	1·52	1·00
2·90	4·30	4·67	1·07	0·745	1·04	0·540	1·56	1·04

Values are also given for the derivatives for $R = 2 \times 10^6$ and 3×10^6, for transition at $0 \cdot 1c$ and $0 \cdot 4c$ and for two other values of mean tab and aileron angles.

Site: 9-ft × 7-ft Tunnel, N.P.L.

'The determination of aerodynamic coefficients from flutter test data', by W. G. Molyneux.

Summary. A method is applied enabling the oscillatory aerodynamic coefficients for an aerofoil to be derived from data measured in flutter tests. Measurements on two rectangular wings at two axis positions are used to illustrate the technique.

Parameter Variations

Mach number	0·076 to 0·104	
Frequency parameter	0·21 to 0·25 and 0·16 to 0·20	
Axis of oscillation	L.E. 1·196 ft upstream of L.E.	

Model Details

Sweepback	0 deg	0 deg
Aspect ratio	3·70	2·47
Taper ratio	1:1	1:1
Semi-span	0·925 ft	0·617 ft
Chord	0·5 ft	0·5 ft
Thickness/chord ratio	0·1	0·1
Aerofoil section	RAE 101	RAE 101
Construction	Solid spruce with balsa leading edge.	

Results

Equivalent constant strip derivatives referred to the wing leading edge.

	l_z	$l_{\dot{z}}$	$(-m_z)$	$(-m_{\dot{z}})$	l_α	$l_{\dot{\alpha}}$	$(-m_\alpha)$	$(-m_{\dot{\alpha}})$
$AR = 3·7$, $\nu = 0·21$ to $0·25$	0·16	2·23	0·19	0·30	1·47	0·98	0·47	1·24
$AR = 2·47$, $\nu = 0·16$ to $0·20$	−0·067	2·60	0·29	0·28	1·21	1·16	0·38	1·14

Site: 5-ft diameter Tunnel, R.A.E. Farnborough.

'A technique for the measurement of pressure distribution on oscillating aerofoils, with results for a rectangular wing of aspect ratio 3·3', by W. G. Molyneux and F. Ruddlesden.

Summary. Pressure measurements were made and values for the aerodynamic derivatives were obtained from the integrated pressure distributions. The values are compared with those derived from overall force measurements and theoretical values. The comparison reveals discrepancies with theory and these are thought to be due to a wind tunnel interference effect.

Parameter Variations

Mach number	0·182 to 0·218
Frequency parameter	0·275, 0·33
Reynolds number	$2\cdot15 \times 10^6$ and $2\cdot58 \times 10^6$
Mean incidence	$\pm 2\cdot2$ deg
Roll angle	$\pm 1\cdot02$ deg

Model Details

Sweepback	0 deg
Aspect ratio	3·28
Taper ratio	1:1
Semi-span	32·8 in.
Chord	20 in.
Thickness/chord ratio	0·10
Aerofoil section	RAE 101
Construction	Solid spruce.

Results

The following derivatives are for a frequency parameter of 0·33 and are referred to the wing leading edge.

l_z	$l_{\dot{z}}$	l_α	$l_{\dot{\alpha}}$	$(-m_z)$	$(-m_{\dot{z}})$	$(-m_\alpha)$	$(-m_{\dot{\alpha}})$	n_z	$n_{\dot{z}}$	n_α	$n_{\dot{\alpha}}$
−0·20	1·50	1·35	2·05	−0·05	0·36	0·25	0·86	−0·13	1·34	1·20	1·86

The following derivatives are for a frequency parameter of 0·275.

$$l_{\dot{\phi}} = 1\cdot15, \qquad (-m_{\dot{\phi}}) = 0\cdot21, \qquad n_{\dot{\phi}} = 1\cdot30$$

Site: 5-ft diameter Open Jet Tunnel, R.A.E.

'Measurements of pitching moment derivatives for a series of rectangular wings at low wind speeds', by P. R. Guyett and D. E. G. Poulter.

Summary. Measurements taken on a series of wings of varying aspect ratio over a range of frequency parameter. Tests with end plates fitted to the wings were also made.

Parameter Variations

Mach number	0·036 to 0·109
Frequency parameter	0·131 to 0·393
Reynolds number	$0 \cdot 13 \times 10^6$ to $0 \cdot 38 \times 10^6$
Mean incidence	0 deg
Amplitude of oscillation	5·0 deg nominal
Axis of oscillation	L.E., T.E.
Aspect ratio	2, 3·25, 4·0, 5·0, 6·5, 8·0, ∞

Model Details

Sweepback	0 deg
Taper ratio	1:1
Semi-span	48, 30, 19·5, 12 in.
Chord	6·0 in.
Thickness/chord ratio	0·10
Aerofoil section	RAE 101
Construction	Sandwich construction, mild steel and spruce.

Results

Equivalent constant strip derivatives for pitch about the leading edge.

	$AR = 2$			$AR = 5$			$AR = 8$		
ν	0·131	0·197	0·393	0·131	0·197	0·393	0·131	0·197	0·393
$-m_\alpha$	0·280	0·308	0·282	0·430	0·447	0·438	0·496	0·498	0·548
$-\nu m_{\dot{\alpha}}$	0·080	0·119	0·213	0·083	0·090	0·158	0·066	0·099	0·162

Site: 5-ft diameter Tunnel, R.A.E. Farnborough.

'Measurements of the derivative z_w for oscillating sweptback wings', by G. E. Whitmarsh.

Summary. Measurements were made of the damping derivatives $z_w\,(\equiv l_{\dot{z}})$ for oscillating wings of varying aspect ratio, taper ratio, and sweepback over a range of frequency parameter.

Parameter Variations

Mach number	0·0546 to 0·182
Frequency parameter	0·09 to 0·41
Reynolds number	$1 \cdot 2 \times 10^5$ to $4 \cdot 1 \times 10^5$
Aspect ratio	2·63, 3·0, 4·74, 5·0
Taper ratio	1:1, 1:2, 2:3
Sweepback ($\frac{1}{4}$-chord)	30 deg, 45 deg, 60 deg

Model details

Chord (root)	3·80 in., 3·75 in.
Aerofoil section	NACA 0018
	NACA 0020

Results

The derivative $l_{\dot{z}}$

ν	Sweepback 30 deg		Sweepback 60 deg		Sweepback 45 deg		Unswept
	$AR = 2 \cdot 63$	$AR = 4 \cdot 71$	$AR = 2 \cdot 63$	$AR = 4 \cdot 71$	$AR = 3$	$AR = 5$	$AR = 3$
0·1	1·83	2·33	1·49	1·49	1·53	2·03	1·64
0·2	1·81	2·11	1·30	1·17	1·50	1·78	1·58
0·3	1·75	2·00	1·27	1·06	1·40	1·65	1·52
0·4	1·70	1·91	1·26	1·04	1·21	1·56	1·44

Site: College of Aeronautics, Cranfield.

TABLE 1

The Derivatives $m_{\dot{\alpha}}$ and m_{α}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
1	4·44	0	Rectangular, Joukowski section	0·0273, 0·054
2†	4·43	$0_{(0\cdot 3c)}$	Tapered wing, NACA 23012 section	0·027 to 0·047
3*	∞	0	Rectangular, Joukowski section	0·027 to 0·054
4	6·0	0	Rectangular, NACA 0015 section	—
5*	4·8	0	Rectangular, NACA 0015 section	—
9	1·0 to ∞	0	Rectangular, Joukowski, EC 1550, Elliptic and Hollow Ground sections	0·027 to 0·054
10	∞	0	Rectangular, Bi-convex section	0·4 to 0·9 1·275, 1·455 1·515
15	2·97 3·0 4·4	36·9 60 40	Delta, RAE 102 section and two sweptback wings, RAE 101 and EQ 1040 sections	0·09 to 0·27
16	1·2	68·2	Clipped delta wing, RAE 102 section	0·054 to 0·109
17	1·32 1·6	65·4 68·2	Arrowhead and delta wings	0·0989, 0·108
21	3·7 2·47	0	Two rectangular wings, RAE 101 section	0·076 to 0·104
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218
23	2·0 3·25 4·0 5·0 6·5 8·0 ∞	0	Rectangular, RAE 101 section	0·036 to 0·109

* Damping derivatives only.

† Derivatives appropriate to torsional oscillations.

TABLE 2

The Derivatives $m_{\dot{z}}$ and m_z

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
16*	1·2	68·2	Clipped delta wing, RAE 102 section	0·05 to 0·1
17	1·32	65·4	Arrowhead and delta wings	0·0989, 0·108
	1·6	68·2		
21	3·7	0	Two rectangular wings, RAE 101 section	0·076 to 0·104
	2·47			
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218

* Derived from results for pitching about two axes.

TABLE 3

The Derivatives $l_{\dot{\alpha}}$ and l_α

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
13	6·0	0, 41·3	Rectangular and swept untapered, NACA 0015 section	0·036 to 0·19
15	2·97	36·9	Delta, RAE 102 section and two sweptback wings,	0·09 to 0·27
	3·0	60	RAE 101 and EQ 1040 sections	
	4·4	40		
16	1·2	68·2	Clipped delta wing, RAE 102 section	0·054 to 0·109
17	1·32	65·4	Arrowhead and delta wings	0·099, 0·108
	1·60	68·2		
21	3·7	0	Rectangular wings, RAE 101 section	0·076 to 0·104
	2·47			
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218

TABLE 4

The Derivatives $l_{\dot{z}}$ and l_z

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
7*	6, 8, 10	0	Rectangular and tapered, NACA 0015 section	0·034 to 0·105
8	—	—	B.A.C. wing, type 167	0·018 to 0·054
12*	3·0, 4·0, 5·0, 6·0	0 45	Rectangular and sweptback wings, NACA 0020 section	0·048 to 0·157
13	6	0 41·3	Rectangular, NACA 0015 section	0·036 to 0·191
15*	2·97 3·0 4·4	36·9 60 40	Delta, RAE 102 section and two sweptback wings, RAE 101 and EQ 1040 sections	0·09 to 0·27
16†	1·2	68·2	Clipped delta wing, RAE 102 section	0·054 to 0·109
17	1·32 1·6	65·4 68·2	Arrowhead and delta wings	0·0989, 0·108
19	4·05	0	Rectangular, RAE 101 section	0·036 to 0·218
21	3·70 2·47	0	Rectangular wings, RAE 101 section	0·076 to 0·104
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218
24*	2·63, 3·0, 4·74, 5·0	30 45 60	Rectangular and tapered wings with NACA 0018 and 0020 sections	0·055 to 0·182

* Damping derivatives only.

† Derived from results for pitching about two axes.

TABLE 5

The Derivatives $l_{\dot{\beta}}$ and l_β

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
19	4·05	0	Rectangular, RAE 101 section. Full span control.	0·036 to 0·218

TABLE 6

The Derivatives $h_{\dot{\beta}}$ and h_{β}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
6	2·3	—	Wing-fuselage-tail unit	0·018 to 0·064
8	—	—	B.A.C. wing, type 167	0·018 to 0·054
11	—	—	Wing-fuselage-tail unit, horn balanced elevator	0·018 to 0·054
14	∞	0	Wing-aileron-tab system, 1541 section	0·056 to 0·166
18*	—	—	Scale model of *Valiant* wing	0·09
19	4·05	0	Rectangular, RAE 101 section	0·036 to 0·218
20	∞	0	Wing-aileron-tab system	0·056 to 0·166

* Damping derivatives only.

TABLE 7

The Derivatives $h_{\dot{\gamma}}$ and h_{γ}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
20	∞	0	Wing-aileron-tab system	0·056 to 0·166

TABLE 8

The Derivatives $h_{\dot{z}}$ and h_{z}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
8	—	—	B.A.C. wing, type 167	0·018 to 0·054

TABLE 9

The Derivatives $t_{\dot{\gamma}}$ and t_{γ}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
20	∞	0	Wing-aileron-tab system	0·056 to 0·166

TABLE 10

The Derivatives $t_{\dot{\beta}}$ and t_{β}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
20	∞	0	Wing-aileron-tab system	0·056 to 0·166

TABLE 11

The Derivatives $l_{\dot{\phi}}$ and l_{ϕ}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218

TABLE 12

The Derivatives $m_{\dot{\phi}}$ and m_{ϕ}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218

TABLE 13

The Derivatives $n_{\dot{\alpha}}$ and n_{α}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218

TABLE 14

The Derivatives $n_{\dot{\phi}}$ and n_{ϕ}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
2*	4·43	$0_{(0\cdot 3c)}$	Tapered, NACA 23012 section	0·027 to 0·047
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218

*Damping derivative only.

TABLE 15

The Derivatives $n_{\dot{z}}$ and n_{z}

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
22	3·28	0	Rectangular, RAE 101 section	0·182 to 0·218

TABLE 16

The Derivatives l_{ψ} and $l_{\dot{\psi}}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
6	2·3	—	Wing-fuselage-tail unit	0·018 to 0·064

APPENDIX II

List of Reports—Foreign

No.	Author	Title	Reference
25	E. G. Reid	Experiments on the lift of airfoils in non-uniform motion.	Stanford University Report TIB P 8282 July, 1942
26	H. Drescher	Results of experiments executed in the wind tunnel of N.L.L. for the determination of the aerodynamic moments upon an oscillating wing.	A.R.C. 9675 January, 1946
27	H. Drescher	An experimental determination of the aerodynamic reactions on an aerofoil with an oscillating rudder.	English Electric Co. Translation 1950
28	G. L. Mitcham J. E. Stevens H. P. Norris	Aerodynamic characteristics and flying qualities of a tail-less triangular-wing airplane configuration as obtained from flights of rocket-propelled models at transonic and low supersonic speeds.	N.A.C.A. TIB 2644 February, 1950
29	M. Tobak D. E. Reese, Jr. B. H. Beam	Experimental damping in pitch of 45 deg triangular wings.	N.A.C.A. TIB 2725 December, 1950
30	R. L. Halfman	Experimental aerodynamic derivatives of a sinusoidally oscillating airfoil in two-dimensional flow.	N.A.C.A. Tech. Note 2465 November, 1951
31	R. L. Halfman H. C. Johnson S. M. Haley	Evaluation of high angle of attack aerodynamic derivative data and stall flutter prediction techniques.	N.A.C.A. Tech. Note 2533 November, 1951
32	J. A. Wyss R. M. Sorensen	An investigation of the control surface flutter derivatives of an NACA 65_1–213 airfoil in the Ames 16-ft High Speed Wind Tunnel.	N.A.C.A. TIB 2952 December, 1951
33	J. H. Greidanus A. I. van de Vooren H. Bergh	Experimental determination of the aerodynamic coefficients of an oscillating wing in incompressible two-dimensional flow.	N.L.L. Amsterdam F 101–104 A.R.C. 15,770 August, 1952
34	B. H. Beam	The effects of oscillation amplitude and frequency on the experimental damping-in-pitch of a triangular wing having an aspect ratio of 4.	N.A.C.A. TIB 3347 September, 1952
35	M. Tobak	Damping in pitch of low aspect ratio wings at subsonic and supersonic speeds.	N.A.C.A. TIB 3686 April, 1953
36	D. E. Reese, Jr.	An experimental investigation at subsonic and supersonic speeds of the torsional damping characteristics of a constant chord control surface of an aspect ratio 2 triangular wing.	N.A.C.A. TIB 3782 July, 1953
37	E. Widmayer, Jr. S. A. Clevenson S. A. Leadbetter	Some measurements of aerodynamic forces and moments at subsonic speeds on a rectangular wing of aspect ratio 2 oscillating about the midchord.	N.A.C.A. TIB 3860 August, 1953

No.	*Author*	*Title*	*Reference*
38	A. Henderson, Jr.	Investigation at Mach numbers of 1·62, 1·93 and 2·41 of the effect of oscillation amplitude on the damping in pitch of delta-wing-body combinations.	N.A.C.A. TIB 3940 October, 1953
39	S. A. Leadbetter S. A. Clevenson	Some measurements at subsonic speeds of the aerodynamic forces and moments on two delta wings of aspect ratios 2 and 4 oscillating about the midchord.	N.A.C.A. TIB 4039 December, 1953
40	S. A. Clevenson J. E. Tomassoni	Experimental investigation of the oscillating forces and moments on a two-dimensional wing equipped with an oscillating circular arc spoiler.	N.A.C.A. TIB 4068 January, 1954
41	J. A. Wyss R. Herrera	Effects of angle of attack and airfoil profile on the two-dimensional flutter derivatives for airfoils oscillating in pitch at high subsonic speeds.	N.A.C.A. TIB 4458 October, 1954
42	J. A. Wyss J. C. Monfort	Effects of airfoil profile on the two-dimensional flutter derivatives for wings oscillating in pitch at high subsonic speeds.	N.A.C.A. TIB 4232 November, 1954
43	J. C. Monfort J. A. Wyss	Effects of rigid spoilers on the two-dimensional flutter derivatives of airfoils oscillating in pitch at high subsonic speeds.	N.A.C.A. TIB 4515 December, 1954
44	W. R. Laidlaw R. L. Halfman	Experimental pressure distributions on oscillating low aspect ratio wings.	I.A.S. Preprint No. 499 January, 1955
45	D. A. Reese W. C. A. Carlson	An experimental investigation of the hinge moment characteristics of a constant chord control surface oscillating at high frequency.	N.A.C.A. TIB 4908 December, 1955
46	L. R. Fisher J. H. Lichtenstein K. D. Williams	A preliminary investigation of the effects of frequency and amplitude on the rolling derivatives of an unswept wing model oscillating in roll.	N.A.C.A. Tech. Note 3554 January, 1956
47	R. F. Thompson W. C. Moseley, Jr.	Oscillating hinge moments and flutter characteristics of a flap type control surface on a 4 per cent thick unswept wing with low aspect ratio at transonic speeds.	N.A.C.A. TIB 4995 February, 1956
48	A. G. Rainey	Preliminary study of some factors which affect the stall flutter characteristics of thin wings.	N.A.C.A. Tech. Note 3622 March, 1956
49	W. J. Tuovila R. W. Hess	Aerodynamic damping at Mach numbers of 1·3 and 1·6 of a control surface on a two-dimensional wing by the free oscillation method.	N.A.C.A. TIB 5099 May, 1956
50	A. G. Rainey	Measurement of aerodynamic forces for various mean angles of attack on an airfoil oscillating in pitch and on two finite span wings oscillating in bending with emphasis on damping in the stall.	N.A.C.A. Tech. Note 3643 May, 1956
51	D. E. Reese, Jr.	An experimental investigation of the unsteady lift induced on a wing in the downwash field of an oscillating canard control surface.	N.A.C.A. TIB 4773 June, 1956

No.	*Author*	*Title*	*Reference*
52	S. A. Clevenson E. Widmayer, Jr.	Experimental measurements of forces and moments on a two-dimensional oscillating wing at subsonic speeds.	N.A.C.A. Tech. Note 3686 June, 1956
53	S. A. Clevenson S. A. Leadbetter	Some measurements of aerodynamic forces and moments at subsonic speeds on a wing tank configuration oscillating in pitch about the wing midchord.	N.A.C.A. Tech. Note 3822 December, 1956

N.A.C.A.	National Advisory Committee for Aeronautics.
N.A.C.A. TIB	Ministry of Supply numbering of N.A.C.A. Research Memoranda.
N.L.L.	National Luchtvaartlaboratorium.
I.A.S.	Institution of Aeronautical Sciences.

Report No. 25 | Stanford University Report TIB P 8282 | 23rd July, 1942

'Experiments on the lift of airfoils in non-uniform motion', by E. G. Reid.

Summary. Experiments were carried out to determine the effect of frequency parameter, Reynolds number, model size, amplitude of oscillation and mean incidence on the lift on wings due to pitching motion. A forced oscillation technique was used.

Parameter Variations

Mach number	0·021 to 0·109
Frequency parameter	0·431 to 4·91
Reynolds number	$0\cdot125 \times 10^6$ to $0\cdot969 \times 10^6$
Mean incidence	0 deg to 30 deg
Amplitude of oscillation	1 deg to 5 deg

Model Details

	A	*B*	*C*	*D*
Sweepback	0 deg	0 deg	0 deg	0 deg
Aspect ratio	∞	∞	∞	∞
Taper ratio	1:1	1:1	1:1	1:1
Span	36 in.	36 in.	36 in.	36 in.
Chord	15 in.	15 in.	10 in.	10 in.
Thickness/chord ratio	0·15	0·15	0·15	0·15
Aerofoil section	NACA 0015	NACA 0015	NACA 0015	NACA 0015
Axis of oscillation	0·4*c*	0·3*c*	0·4*c*	0·3*c*
Construction	Solid spruce	Solid spruce nose, hollow birch tail section	Solid spruce	Solid spruce nose, hollow birch tail section

All wings are mass-balanced about their axes of oscillation by fitting balancing weights in the preformed leading edge recesses of all models.

Results

The results presented are for Model *A* oscillating with an amplitude of 2·5 deg about a mean incidence of zero.

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$
0·442	2·1715	0·0530
0·656	1·9309	0·3638
0·986	1·9309	0·6933
1·772	1·7590	1·6100
2·186	1·7790	1·9653

Site: 7·5-ft diameter free jet, open return type tunnel at the Guggenheim Aeronautical Laboratory, Stanford University. The tunnel was modified by two symmetrically disposed vertical partitions so that the test section was 3 ft wide.

'Results of experiments executed in the wind tunnel of N.L.L. for the determination of the aerodynamic moments upon an oscillating wing', by H. Drescher.

Summary. A forced oscillation technique is used to determine the two dimensional aerodynamic derivatives for a wing oscillating in pitch about a fixed axis.

Parameter Variations

Mach number	0·0117 to 0·117
Frequency parameter	0·2 to 2·0
Reynolds number	$0 \cdot 8 \times 10^5$ to 8×10^5
Mean incidence	0 deg
Axes of oscillation	$0 \cdot 774c$, $0 \cdot 40c$, $0 \cdot 0255c$, $-0 \cdot 349c$, $-0 \cdot 723c$ forward of the $\frac{1}{4}$-chord point.

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	2·62 ft
Chord	0·98 ft
Thickness/chord ratio	0·06
Aerofoil section	—
Construction	Wood

Results

These are presented for oscillation about an axis $0 \cdot 0255c$ forward of the quarter-chord, to which axis the derivatives are referred.

ν	0·6	0·8	1·0	1·2	1·4	1·6	1·8	2·0
$(-m_\alpha)$	0·0511	0·0123	−0·0262	−0·0656	−0·107	−0·155	−0·196	−0·230
$(-\nu m_{\dot\alpha})$	0·203	0·270	0·342	0·409	0·484	0·573	0·658	0·730

Site: N.L.L. Amsterdam.

Osterreichisches Ingenieuer Archiv.
Vol. 4—Parts 3 and 4
English Electric Company Translation

1950

'An experimental determination of the aerodynamic reactions on an aerofoil with an oscillating rudder', by H. Drescher.

Summary. Pressure measurements were made on a wing fitted with a control surface. The tests were made in a water tunnel, the rudder being excited sinusoidally whilst the main wing was kept fixed.

Parameter Variations

Mach number	—
Frequency parameter	0 to 10
Reynolds number	$0 \cdot 3 \times 10^6$ to $0 \cdot 9 \times 10^6$
Mean incidence	Wing fixed at 0 deg
	Rudder 0 deg
Amplitude of oscillation	5·8 deg

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	2·46 ft
Chord	0·98 ft
Thickness/chord ratio	—
Aerofoil section	Symmetrical *Gö* 409
Construction	Model made of bronze
Rudder data	Chord = $0 \cdot 3c$, full span

Results

The pitching moment derivatives are referred to the wing leading edge.

ν	0·5	1·0	1·5	2·0	2·5	3·0	3·5	4·0
$l_\beta - \nu^2 l_{\ddot\beta}$	0·138	0·116	0·105	0·0994	0·0982	0·0936	0·0828	0·0821
$l_{\dot\beta} \times 10^2$	−6·30	−0·724	−0·0186	2·06	2·66	2·98	3·28	3·5
$(-m_\beta) - \nu^2(-m_{\ddot\beta})$	0·0655	0·0572	0·0524	0·05	0·05	0·0476	0·0429	0·0357
$(-m_{\dot\beta}) \times 10^2$	−0·357	0·953	2·26	3·57	4·88	6·43	7·98	9·64
$\{(-h_\beta) - \nu^2(-h_{\ddot\beta})\} \times 10^2$	0·345	0·316	0·287	0·259	0·201	0·144	0·0574	0
$(-h_{\dot\beta}) \times 10^2$	0·172	0·259	0·287	0·287	0·276	0·278	0·287	0·288

Site: Aerodynamic Research Station, Göttingen.

'Aerodynamic characteristics and flying qualities of a tail-less triangular-wing airplane configuration as obtained from flights of rocket-propelled models at transonic and low supersonic speeds', by G. L. Mitcham, J. E. Stevens and H. P. Norris.

Summary. Results are given amongst much aerodynamic information of the pitching moment damping derivative due to pitch.

Parameter Variations

Mach number	0·75 to 1·28
Reynolds number	$7 \cdot 64 \times 10^6$ to $14 \cdot 57 \times 10^6$
Mean incidence	0 to 15 deg

Model Details

Sweepback	60 deg
Aspect ratio	2·31
Taper ratio	0
Span	45·59 in.
Chord	19·74 in.
Thickness/chord ratio	—
Aerofoil section	NACA $65_{(06)}$ $-006 \cdot 5$
Construction	The model fuselage and components were of Duralumin, magnesium castings and magnesium skin. The fuselage was of the monocoque type divided into three sections.

Results

The results presented below are for two centre of gravity positions at 0·2 and 0·25 of the mean aerodynamic chord $\bar{c}$. The derivatives are referred to axes at these chordwise points.

Values of $(-m_{\dot{\alpha}})$

M	0·80	0·85	0·90	1·00	1·05	1·10	1·15	1·20
$0 \cdot 2\bar{c}$	1·370	1·507	1·495	1·350	1·339	1·336	1·269	1·169
$0 \cdot 25\bar{c}$	—	—	—	0·725	0·837	1·014	1·065	0·938

Site: Langley Pilotless Aircraft Research Station.

'Experimental damping in pitch of 45 deg triangular wings', by M. Tobak, D. E. Reese, Jr. and B. H. Beam.

Summary. The results of an experimental wind-tunnel investigation of the damping in pitch of two triangular wings having leading edges swept back 45 deg are presented. The investigation consisted of tests made of the isolated wings and of the wings in combination with a slender body. Results were obtained by a single degree of freedom oscillation technique at supersonic and subsonic speeds.

Parameter Variations

Mach number	1·15 to 1·70 0·23 to 0·94
Frequency parameter	Insufficient data given to calculate this.
Reynolds number	$0{\cdot}922 \times 10^6$ to $1{\cdot}01 \times 10^6$ (supersonic) $0{\cdot}922 \times 10^6$ and $0{\cdot}412 \times 10^6$ (subsonic)
Mean incidence	0 deg and 5 deg (supersonic) 0 deg (subsonic)
Axes of oscillation	$0{\cdot}35\bar{c}$ to $0{\cdot}475\bar{c}$ (supersonic) $0{\cdot}35\bar{c}$ (subsonic)

$\bar{c}$ is the mean aerodynamic chord defined as $\dfrac{2}{S}\displaystyle\int_0^s c^2\,dy$

where S = wing area, including portion enclosed by body

s = semi-span

c = local chord

Model Details

Sweepback	45 deg	45 deg
Aspect ratio	4	4
Taper ratio	0	0
Span	30 in.	30 in.
Chord (root)	15 in.	15 in.
Thickness/chord ratio	0·06	0·06
Aerofoil section	NACA 0006—63	Sharp leading-edge biconvex section.

Construction: Wood over a thin steel spar.

The body of thin laminated wood construction extended 15 in. ahead of the wing apex and terminated at the wing trailing edge. Its maximum diameter was 4 in., giving a ratio of wing span to body diameter of 7·5.

Results

Experimental pitching moment damping derivatives at subsonic and supersonic speeds for an NACA 0006—63 section triangular wing-body combination at $\alpha = 0$ deg and axis of rotation at $0{\cdot}35\bar{c}$ aft of the leading-edge.

M	$-(m_{\dot{\alpha}})$
0·25	0·356
0·40	0·373
0·60	0·471
0·80	0·720
0·90	1·138
0·93	0·444
1·40	0·044
1·60	0·178
1·70	0·222

Experimental pitching moment damping derivative for the biconvex section triangular wing-body combination at $\alpha = 0$ deg and axis of rotation at $0{\cdot}35\bar{c}$.

M	$-(m_{\dot{\alpha}})$
1·35	−0·018
1·40	0·444
1·45	0·098
1·50	0·124
1·55	0·151
1·60	0·169
1·70	0·178

Site: Ames 6-ft × 6-ft Supersonic Tunnel.
Ames 12-ft Pressure Tunnel.

'Experimental aerodynamic derivatives of a sinusoidally oscillating airfoil in two-dimensional flow', by R. L. Halfman.

Summary. Experimental measurements of the aerodynamic reactions on a symmetrical airfoil oscillating harmonically in a two dimensional flow are presented and analysed. Harmonic motions include pure pitch and pure translation for several amplitudes and superimposed on an initial angle of attack, as well as combined pitch and translation,

Parameter Variations

Mach number	0·104 to 0·137
Frequency parameter	0·106 to 0·92
Reynolds number	$0{\cdot}715 \times 10^6$ to $0{\cdot}930 \times 10^6$
Amplitude of oscillation in pitch	0 to 13·48 deg
Amplitude of oscillation in vertical translation	0 to 2 in.
Mean angle of attack	0 deg to 6·1 deg
Elastic axis at 37 per cent chord	

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	2 ft
Chord	1 ft
Thickness/chord ratio	0·12
Aerofoil section	NACA 0012
Construction	Twin spars of light magnesium and stressed skin covering.

Results

All results referred to an axis at $0{\cdot}37c$ aft of leading edge and are averages of all the measured values.

Experimental Values of Derivatives for Pure Pitch, Pitch Amplitude 6·74 *deg*

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·20	2·2117	−0·0773	0·2835	−0·0895
0·30	2·1269	0	0·2812	−0·1169
0·40	2·0703	0·1087	0·2780	−0·1412
0·50	2·0295	0·2136	0·2749	−0·1618
0·60	1·9949	0·3519	0·2780	−0·1877

Experimental Values of Derivatives for Pure Translation; Translation Amplitudes, 1·00 *inch*

ν	$l_z - \nu^2 l_{\ddot{z}}$	$\nu l_{\dot{z}}$	$m_z - \nu^2 m_{\ddot{z}}$	$\nu m_{\dot{z}}$
0·2	0·0496	0·4335	0·0223	0·0682
0·3	0·0936	0·6660	0·0405	0·0955
0·4	0·1665	0·8985	0·0565	0·1210
0·5	0·2589	1·1184	0·0716	0·1439
0·6	0·3581	1·3320	0·1034	0·1718

Site: M.I.T. 5-ft × 7½-ft Flutter Tunnel.

'Evaluation of high-angle-of-attack aerodynamic-derivative data and stall flutter prediction techniques', by R. L. Halfman, H. C. Johnson and S. M. Haley.

Summary. The problem of stall flutter is approached in two ways. First, using the M.I.T.–N.A.C.A. airfoil oscillator, the aerodynamic reactions on wings oscillating harmonically in pitch and translation in the stall range have been measured. Second, the results of numerous experimental observations of stall flutter have been reviewed and the various known attempts at its prediction have been examined, compared and extended.

Parameter Variations

Mach number	0·086 to 0·132
Frequency parameter	0·1 to 1·1
Reynolds number	$\doteqdot 1 \times 10^6$
Mean incidence	0 deg to 22 deg
Elastic axis	0·37*c*
Pitch amplitude	6·08 deg
Translation amplitude	0·9 in.

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	—
Chord	11·6 in.
Thickness/chord ratio	0·12
Aerofoil section	Max. thickness at 30 per cent chord. The three wings have respectively a blunt, intermediate and sharp nose.
Construction	The three aerofoils used were constructed of sycamore wood and 0·007 magnesium alloy sheet.

Results

All results presented are for a mean incidence of zero.

Experimental values of derivatives for blunt wing in pure pitch and pure translation.

Pure Pitch

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·186	2·0619	−0·0716	0·2535	−0·0726
0·336	1·9498	0·0679	0·2384	−0·1008
0·484	1·6887	0·2978	0·2017	−0·1470
0·668	1·4682	0·9904	0·2921	−0·0726

Pure Translation

ν	$l_z - \nu^2 l_{\ddot{z}}$	$\nu l_{\dot{z}}$	$m_z - \nu^2 m_{\ddot{z}}$	$\nu m_{\dot{z}}$
0·184	−0·1510	0·4659	0·0155	0·0426
0·338	−0·0542	0·7847	0·0361	0·0529
0·498	−0·1045	1·1952	0·0632	0·0813
0·672	−0·3382	1·5901	0·0916	0·1175

Experimental values of derivatives for intermediate wing in pure pitch and pure translation.

Pure Pitch

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·188	2·5519	−0·0886	0·2902	−0·1357
0·336	2·2532	0·1970	0·2950	−0·1131
0·492	2·1929	0·3082	0·2629	−0·1706
0·678	2·0525	0·6672	0·2412	−0·2026

Pure Translation

ν	$l_z - \nu^2 l_{\ddot{z}}$	$\nu l_{\dot{z}}$	$m_z - \nu^2 m_{\ddot{z}}$	$\nu m_{\dot{z}}$
0·18	−0·0955	0·4917	0·0090	0·0542
0·332	−0·0891	0·7279	0·0284	0·0813
0·544	0·6518	0·8338	0·0813	0·1523
0·654	0·4414	1·2132	0·0568	0·1342

Experimental values of derivatives for sharp wing in pure pitch and pure translation.

Pure Pitch

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·190	2·3446	0·0820	0·2507	−0·0396
0·339	2·1835	0·3072	0·2526	−0·1640
0·528	2·1882	0·2686	0·2460	−0·1480
0·674	2·0393	0·5456	0·3119	−0·1951

Pure Translation

ν	$l_z - \nu^2 l_{\ddot{z}}$	$\nu l_{\dot{z}}$	$m_z - \nu^2 m_{\ddot{z}}$	$\nu m_{\dot{z}}$
0·178	0·4337	0·1239	0·0052	0·0490
0·330	0·1123	0·7137	0·0271	0·0710
0·492	0·2039	1·0519	0·0658	0·0852
0·688	−0·0258	1·5230	0·0723	0·1213

Site: M.I.T.

'An investigation of the control-surface flutter derivatives of an NACA 65_1-213 airfoil in the Ames 16-foot High-Speed-Wind Tunnel', by J. A. Wyss and R. M. Sorenson.

Summary. Control surface flutter derivatives were determined for a sinusoidally oscillating control surface mounted on a two-dimensional fixed aerofoil. For Mach numbers less than the critical the magnitudes of the resultant hinge-moment coefficients were in reasonable agreement with the values predicted by the theory of Theodersen.

Parameter Variations

Mach number	0·2 to 0·8
Frequency parameter	0·10 to 4·00
Reynolds number	5×10^6 to 11×10^6
Mean incidence	0 deg and 4 deg
Amplitude of oscillation	3 deg

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	18 $\frac{1}{8}$-in.
Chord	4 ft
Thickness/chord ratio	—
Aerofoil section	NACA 65_1-213 ($a = 0 \cdot 5$)
Construction	Wood and aluminium.
	The control surface chord was 25 per cent of that of the wing. The surface was of the round nosed, unsealed type with a 1/64 in. nose gap and no aerodynamic balance.

Results

Data for 0 deg angle of attack.

M	ν	$h_\beta - \nu^2 h_{\ddot{\beta}}$	$\nu h_{\dot{\beta}}$
0·2	0·610	−0·0328	−0·0069
	2·386	−0·0346	−0·0238
	4·314	−0·0414	−0·0376
0·6	0·200	−0·0256	−0·0021
	0·774	−0·0247	−0·0007
	1·324	−0·0221	−0·0031
0·75	0·158	−0·0246	−0·0012
	0·600	−0·0266	0·0020
	1·042	−0·0256	−0·0001
0·80	0·146	−0·0347	0·0067
	0·564	−0·0311	0·0212
	0·980	−0·0286	0·0089

Site: Ames 16-ft High Speed Tunnel.

Report No. 33 N.L.L. Amsterdam August, 1952

F.101—F.104 A.R.C. 15,770

'Experimental determination of the aerodynamic coefficients of an oscillating wing in incompressible two-dimensional flow'.

- Part I. Wing with fixed axis of rotation—by J. H. Greidanus, A. I. van de Vooren and H. Bergh.
- Part II. Wing with oscillating axis of rotation—by A. I. van de Vooren and H. Bergh.
- Part III. Experiments at zero airspeed—by H. Bergh.
- Part IV. Calculation of the coefficients—by H. Bergh and A. I. van de Vooren.

Summary. In this report results are presented for the aerodynamic moment about a fixed axis of rotation of the (plain) wing for five different chordwise locations of this axis.

Parameter Variations

Mach number	0 to 0·159
Frequency parameter	0·16 to 2·0
Reynolds number	$0{\cdot}08 \times 10^6$ to $1{\cdot}1 \times 10^6$
Axes of oscillation	−0·5328, −0·1527, 0·2273, 0·6075, 0·9876 (in terms of fractions of chord behind leading edge).

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	31·5 in.
Chord	11·65 in.
Thickness/chord ratio	0·073
Aerofoil section	Maximum thickness was at 30 per cent of the chord from L.E.
Construction	Symmetrical hollow wooden aerofoil. Mahogany covering was 0·16 in. thick.

Results

ν	$l_z - \nu^2 l_{\ddot{z}}$	$\nu l_{\dot{z}}$	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$(-m_z) - \nu^2(-m_{\ddot{z}})$	$\nu(-m_{\dot{z}})$	$(-m_\alpha) - \nu^2(-m_{\ddot{\alpha}})$	$\nu(-m_{\dot{\alpha}})$
0·20	−0·1885	0·6504	2·4818	−0·1461	0·0345	0	−0·0055	0·0573
0·40	−0·0628	1·0526	2·3044	0·1602	0·0314	0	0	0·1272
0·80	−0·0251	1·6967	2·1049	0·8325	−0·0628	0	−0·0236	0·2639
1·20	−0·2828	2·2559	1·9792	1·4247	−0·2309	0·0283	−0·0919	0·3974
1·60	−0·8546	2·7964	1·7718	1·8849	−0·4084	0·1461	−0·1744	0·5262
2·00	−1·6590	3·3364	1·3509	2·0577	−0·3769	0·5498	−0·2733	0·6574

The lift and pitching moment derivatives are referred to the quarter-chord point

Site: A.4 Tunnel National Aeronautical Research Institute.

'The effects of oscillation amplitude and frequency on the experimental damping-in-pitch of a triangular wing having an aspect ratio of 4', by B. H. Beam.

Summary. The results are presented of a wind tunnel investigation of the damping in pitch of a model triangular wing having an aspect ratio of 4 combined with a slender pointed body. A feed-back controlled, forced oscillation technique was used.

Parameter Variations

Mach number	0·10 to 0·95
Frequency parameter	0·046 to 0·104 at high Mach numbers
(based on mean chord)	0·165 to 0·42 at low Mach numbers
Reynolds number	$0{\cdot}413 \times 10^6$ and $0{\cdot}938 \times 10^6$
Additional data obtained at	
Reynolds numbers	$2{\cdot}25 \times 10^6$ and $4{\cdot}5 \times 10^6$ and a
Mach number of	0·23
Mean incidence	0 deg to 19 deg
Amplitude of oscillation	1 deg to 4 deg
Axes of oscillation	$0{\cdot}5\dot{6}c_r$ to $0{\cdot}6\dot{3}c_r$ aft of wing apex where c_r is the root chord.

Model Details

Sweepback	45 deg
Aspect ratio	4
Taper ratio	0:15
Span	30 in.
Chord (mean)	7·5 in.
Thickness/chord ratio	0·06
Aerofoil section	NACA 0006–63
Construction	Wood over a steel spar, with brass stiffeners in the wing tips and at the base of the body.

continued overleaf

Results

The results presented are for pitch about an axis at $0{\cdot}56c_r$ and a mean incidence of zero at a Reynolds number of $0{\cdot}938 \times 10^6$.

	M	Amplitude of oscillation (deg)	ν	$(-m_{\dot{\alpha}})$
	0·3		0·13	0·48
$\omega = 11$ c.p.s.	0·7	2	0·058	0·649
	0·9		0·046	1·307
	0·3		0·18	0·404
$\omega = 15$ c.p.s.	0·7	2	0·079	0·6
	0·9		0·063	1·022
	0·3		0·22	0·258
$\omega = 19$ c.p.s.	0·7	2	0·10	0·396
	0·9		0·080	0·880
	0·3		0·27	0·280
$\omega = 23$ c.p.s.	0·7	2	0·12	0·520
	0·9		0·097	0·807
	0·3		0·32	0·24
$\omega = 27$ c.p.s.	0·7	1·5	0·14	0·462
	0·9		0·11	1·022

Site: Ames 12-ft Pressure Tunnel.

'Damping in pitch of low-aspect-ratio wings at subsonic and supersonic speeds', by M. Tobak

Summary. Results are given of an experimental investigation, using a single degree of freedom free oscillation technique, on the effects of changes in Mach number, aspect ratio and planform on the pitching moment damping derivative due to pitch.

Parameter Variations

Mach number ranges	0·6 to 0·9 and 1·2 to 1·9
Frequency parameter	0·0105 to 0·075
Reynolds number ranges	$1 \cdot 2 \times 10^6$ per foot for major portion of tests. Additional data obtained at $0 \cdot 75 \times 10^6$ per foot and $2 \cdot 4 \times 10^6$ per foot.
Axes of oscillation	$0 \cdot 20\bar{c}_m$ to $0 \cdot 45\bar{c}_m$ aft of leading edge at $\bar{c}_m$ where $\bar{c}_m$ is the mean aerodynamic chord defined as $\bar{c}_m = \dfrac{2}{S}\displaystyle\int_0^s c^2\,dy$ S = wing area, including portion enclosed by body s = wing semi-span c = local chord
Mean incidence	0 deg
Amplitude of oscillation	5 deg

Model Details

Sweepback of leading edge	63·4 deg	53·1 deg	45 deg	45 deg	19·1 deg
Aspect ratio	2	3	4	3	3
Taper ratio	0	0	0	1:2·48	1:2·46
Span	21·2 in.	26 in.	30 in.	26 in.	25·8 in.
Chord (mean aerodynamic)	14·1 in.	11·6 in.	10 in.	9·2 in.	9·2 in.
Thickness/chord ratio	0·03	0·03	0·03	0·03	0·03
Aerofoil section	NACA 0003–63	NACA 0003–63	Bi-convex circular-arc	Bi-convex circular-arc	Bi-convex circular-arc

Construction: The delta wings of aspect ratios 2 and 3 were built of aluminium and the remainder were of steel. The models were fitted with bodies such that the distance from the body apex to the wing-body intersection was the same for each model. Ratio of wing area to body maximum cross-sectional area was 17·9 for each model. Forward of the point of maximum radius, the bodies were of thin laminated wood construction. The aluminium after-bodies were cylindrical in shape and terminated at the trailing edges of the wings.

M	$(-m_{\dot{\alpha}})$		
	$A = 2$	$A = 3$	$A = 4$
1·2	0·373	0·204	0·033
1·3	0·347	0·222	0·053
1·4	0·324	0·218	0·111
1·5	0·300	0·213	0·156
1·6	0·280	0·211	0·187
1·7	0·258	0·218	0·209
1·8	0·244	0·227	0·227
1·9	0·220	0·231	0·244

Comparison of experimental pitching moment damping derivatives for three wing-body combinations having triangular wings of aspect ratios, 2, 3 and 4.
Axes at $0{\cdot}35\bar{c}_m$.

($\bar{c}_m$ = wing mean aerodynamic chord)

M	$(-m_{\dot{\alpha}})$		
	Delta	Swept and Tapered	Unswept and Tapered
1·2	0·244	0·160	0·146
1·3	0·236	0·144	0·033
1·4	0·218	0·156	0·032
1·5	0·200	0·162	0·081
1·6	0·191	0·162	0·101
1·7	0·200	0·160	0·112
1·8	0·211	0·156	0·123
1·9	0·218	0·151	0·131

Comparison of experimental pitching moment damping derivatives for three wing-body combinations having triangular, swept, and unswept wings of aspect ratio 3.
Pitching axes

Delta $0{\cdot}418\bar{c}_m$
Swept $0{\cdot}383\bar{c}_m$
Unswept $0{\cdot}333\bar{c}_m$

Site: Ames 6-ft × 6-ft Supersonic Wind Tunnel.

'An experimental investigation at subsonic and supersonic speeds of the torsional damping characteristics of a constant-chord control surface of an aspect ratio 2 triangular wing', by D. E. Reese, Jr.

Summary. The effects of variation in the control surface oscillation amplitude, angle of attack and frequency on the hinge moment damping derivative were investigated. A forced oscillation technique was used.

Parameter Variations

Mach number	0·6 to 0·9 and 1·3 to 1·9
Frequency parameter	0·086 to 0·545
Reynolds number	$1\cdot86 \times 10^6$
Mean incidence	0, 5 and 10 deg
Amplitude of oscillation	up to 5 deg

Model Details

Sweepback	63 deg 26 min
Aspect ratio	2
Taper ratio	0
Span	27·9 in.
Chord	11·27 in. (exposed panel)
Thickness/chord ratio	0·05
Aerofoil section	NACA 0005
Construction	The model was of steel with the exception of the control surface which was fabricated from aluminium.
Aileron data	One wing panel was fitted with a constant chord control surface with an area equal to 23·7 per cent of the exposed area of the wing panel. The chord was 2·9 in.

Results

The values for $(-h_{\dot\beta})$ are the arithmetic mean of three measured values at each Mach number subsonically and of two values at supersonic M. The mean incidence is 0 deg and the aileron amplitude 1 deg.

M	0·6	0·8	0·9	1·3	1·6	1·9
$h_{\dot\beta} \times 10^3$	−6·237	−7·348	−10·263	2·987	0·945	1·153

The values of $(h_\beta - \nu^2 h_{\ddot\beta})$ are for a mean incidence of 0 deg and an aileron amplitude of 5 deg.

M	0·6	0·8	0·9	1·3	1·4	1·6	1·8	1·9
$-(h_\beta - \nu^2 h_{\ddot\beta}) \times 10^3$	2·620	3·010	4·091	5·049	4·261	3·557	3·133	2·928

Site: Ames 6-ft × 6-ft Supersonic Tunnel.

'Some measurements of aerodynamic forces and moments at subsonic speeds on a rectangular wing of aspect ratio 2 oscillating about the mid-chord', by E. Widmayer, Jr., S. A. Clevenson and S. A. Leadbetter.

Summary. Measurements were made of the aerodynamic forces and moments acting on a rectangular wing of aspect ratio 2 which was oscillated about the mid-chord. These measurements were made at four frequencies (31, 43, 54 and 62 c.p.s.) using a resonant oscillation technique.

Parameter Variations

Mach number	0·15 to 0·81
Frequency parameter	0·3 to 2·64
Reynolds number range	$0{\cdot}60 \times 10^6$ to $9{\cdot}21 \times 10^6$
Axis of oscillation	0·5 chord

Model Details

Sweepback	0 deg
Aspect ratio	2
Taper ratio	1:1
Semi-span	12 in.
Chord	12 in.
Thickness/chord ratio	0·10
Aerofoil section	NACA 65A010
Construction	A steel box spar carried four evenly spaced ribs to which plywood skin was attached.

Results

ν	M	R	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·902	0·261	$1{\cdot}872 \times 10^6$	2·576	1·376	0·955	−0·207
0·632	0·360	$2{\cdot}306 \times 10^6$	2·821	0·848	0·520	−0·148
0·496	0·459	$2{\cdot}958 \times 10^6$	2·840	0·820	0·602	−0·146
0·383	0·563	$3{\cdot}346 \times 10^6$	3·010	0·327	0·738	−0·155
0·347	0·653	$1{\cdot}874 \times 10^6$	2·856	0·635	0·660	−0·149
0·293	0·754	$2{\cdot}051 \times 10^6$	3·271	0·355	0·714	−0·149
0·289	0·784	$1{\cdot}131 \times 10^6$	3·123	0·185	0·768	−0·157

Pitching moment derivatives are referred to the mid-chord axis.

Site: Langley 2-ft × 4-ft Flutter Research Tunnel.

'Investigations at Mach numbers of 1·62, 1·93 and 2·41 of the effect of oscillation amplitude on the damping in pitch of delta-wing-body combinations', by A. Henderson, Jr.

Summary. In order to assess the validity of the linear theory, which accounts for neither viscous nor amplitude effects, tests were made of four delta wing and body combinations, to determine the effect of oscillation amplitude on the pitching moment damping.

Parameter Variations

Mach number	1·62, 1·93, 2·41
Frequency parameter	0·0063 to 0·0267
Reynolds number	$0\cdot 33 \times 10^6$ to $1\cdot 27 \times 10^6$
Mean incidence	0 deg
Amplitude of oscillation	0 deg to ± 4 deg

Model Details

Wing number	1	2	3	4
Sweepback	65 deg	60 deg	55 deg	45 deg
Aspect ratio (part of wing submerged in body included)	1·87	2·31	2·82	3·45
Taper ratio	0	0	0	0
Span (tip to tip)	5·10 in.	5·68 in.	6·25 in.	7·5 in.
Mean chord	2·74 in.	2·46 in.	2·23 in.	1·88 in.
Thickness/chord ratio	—	—	—	—
Aerofoil section	—	—	—	—
Construction	Four delta wing and slender body combinations. The bodies were the same and consisted of parabolic nose sections, a circular cylindrical section along the wing body juncture and a boat tailed afterbody.			
Body diameter/wing span	0·147	0·132	0·120	0·100
Axis of oscillation (distance aft of apex)	$0\cdot 51c_r$	$0\cdot 53c_r$	$0\cdot 57c_r$	$0\cdot 63c_r$
	where c_r is the root chord.			

Results

The experimental results are too complex to be presented. They do approximate satisfactorily though with theoretical results. The ones given below are for the 60 deg swept wing and are independent of amplitude of oscillation over the range tested.

M	1·62	1·93	2·41
$-m_{\dot{\alpha}}$	0·303	0·258	0·214

Site: Langley 9-inch Supersonic Tunnel.

'Some measurements at subsonic speeds of the aerodynamic forces and moments on two delta wings of aspect ratios 2 and 4 oscillating about the mid-chord', by S. A. Leadbetter and S. A. Clevenson.

Summary. Air forces and moments acting on delta wings oscillating about the root mid-chord position have been measured. Measurements were made using a resonant oscillation technique. The measured values for the delta wing with aspect ratio of 2 were also compared with the results of 'vanishing-aspect-ratio' theory and good agreement was shown for the lift coefficients.

Parameter Variations

Mach number	0·19 to 0·81
Frequency parameter	0·08 to 0·81
Reynolds number	$0{\cdot}45 \times 10^6$ to $2{\cdot}20 \times 10^6$
Axis of oscillation	0·5 chord at root
Amplitude of oscillation	2 deg

Model Details

Sweepback	63 deg 26 min	45 deg
Aspect ratio	2	4
Taper ratio	0:1	0:1
Span	12 in. semi-span	12 in. semi-span
Chord (root)	24 in.	12 in.
Thickness/chord ratio	0·10	
Aerofoil section	NACA 65A010	
Construction	Thick-skin balsa covered with glass cloth.	

Results

For AR = 2 wing

ν	M	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$\{(-m_\alpha) - \nu^2(-m_{\ddot{\alpha}})\}$	$\nu(-m_{\dot{\alpha}})$
0·32	0·78	1·3903	0·1461	0·128	0·050
0·40	0·57	1·5359	0·2432	0·125	0·036
0·48	0·46	1·5049	0·2383	0·097	0·056
0·56	0·39	1·5517	0·3298	0·094	0·056
0·62	0·36	1·5546	0·3876	0·067	0·078
0·82	0·25	1·3603	0·7854	0·028	0·090

For AR = 4 wing

ν	M	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$\{(-m_\alpha) - \nu^2(-m_{\ddot{\alpha}})\}$	$\nu(-m_{\dot{\alpha}})$
0·16	0·76	2·1358	−0·0372	0·228	0·037
0·22	0·54	1·8374	−0·0319	0·133	0·016
0·28	0·42	1·8532	0·0322	0·157	0·043
0·34	0·34	1·9744	0·1379	0·196	0·048
0·38	0·31	1·7882	0·0936	0·196	0·054

Site: Langley 2-ft × 4-ft Flutter Research Tunnel.

'Experimental investigation of the oscillating forces and moments on a two-dimensional wing equipped with an oscillating circular-arc spoiler', by S. A. Clevenson and J. E. Tomassoni.

Summary. Results are presented of an experimental investigation on the oscillating forces and moments on a two-dimensional wing equipped with an oscillating circular-arc spoiler. The forces and moments and their phase angles with respect to spoiler motion were determined from measurements of the instantaneous pressure distribution and the nature of the flow over the wing was studied with Schlieren photographs.

Parameter Variations

Mach number	$0\cdot20$ to $0\cdot82$
Frequency parameter	0 to $1\cdot84$
Reynolds number	$1\cdot3 \times 10^6$ to $6\cdot3 \times 10^6$
Incidence	0 deg
Spoiler frequency	0 to 35 c.p.s.

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	—
Chord	2 ft
Thickness/chord ratio	$0\cdot10$
Aerofoil section	NACA 65-010
Construction	The model was constructed with an H-type main spar attached rigidly to the tunnel walls to prevent motion of the aerofoil. A thick skin of aluminium alloy was fabricated to give the aerofoil shape and was attached to the spar in spanwise sections to allow access to the pressure gauges and spoiler mechanism.
Spoiler	This was located at $0\cdot7$ chord aft of the leading edge and extended over the whole span. The maximum amplitude of the spoiler was $0\cdot50$ in. ($\equiv 2\cdot1$ per cent chord).

Results

The results presented are for $M = 0\cdot6$ and $R = 2 \times 10^6$.

ν	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$
0	0·0045	0	—	—
0·10	0·0043	−0·0025	−0·07387	0·01305
0·20	0·0038	−0·0043	−0·06815	0·02479
0·30	0·0032	−0·0056	−0·05845	0·03375
0·40	0·0026	−0·0070	−0·05119	0·03587
0·50	0·0022	−0·0082	−0·04065	0·04065
0·60	0·0016	−0·0088	−0·03215	0·03830

The pitching moment coefficients are referred to the quarter-chord and the l's are normal force coefficients.

Site: Langley 2-ft × 4-ft Flutter Tunnel.

'Effects of angle of attack and airfoil profile on the two-dimensional flutter derivatives for airfoils oscillating in pitch at high subsonic speeds', by J. A. Wyss and R. Herrera.

Summary. Two-dimensional aerodynamic lift and moment flutter derivatives are presented for moderate and high angles of attack for several airfoil profiles varying in thickness and thickness distribution.

Parameter Variations

Mach number range	0·2 to 0·87
Frequency parameter	0·24 to 2·4 at $M = 0{\cdot}2$
	0·06 to 0·60 at $M = 0{\cdot}86$
Reynolds number range	3×10^6 to 8×10^6
Amplitude of oscillation	1 deg
Mean angle of attack	0 to 10 deg
Axis of oscillation	0·25 chord

Model Details

Sweepback	0 deg	0 deg	0 deg	0 deg	0 deg
Aspect ratio	∞	∞	∞	∞	∞
Taper ratio	1:1	1:1	1:1	1:1	1:1
Span	—	—	—	—	—
Chord	2 ft	2 ft	2 ft	2 ft	2 ft
Thickness/chord ratio	0·12	0·08	0·04	—	0·08
Aerofoil section	NACA 65A012	NACA 65A008	NACA 65A004	NACA 2–008	NACA 877A008
Construction	—	—	—	—	—

Results

For NACA 65A008 section when mean angle of attack is zero and $M = 0{\cdot}59$.

ν	$\nu l_{\dot{\alpha}}$	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$
0·2	−0·675	2·922	−0·177	0·177
0·3	−0·745	2·777	−0·219	0·205
0·4	−0·598	2·812	−0·303	0·175
0·5	−0·582	2·738	−0·376	0·137
0·6	−0·572	2·689	−0·429	0·135
0·7	0·294	2·808	−0·525	0·165

Site: Ames 16-ft High Speed Tunnel.

'Effects of airfoil profile on the two-dimensional flutter derivatives for wings oscillating in pitch at high subsonic speeds', by J. A. Wyss and J. C. Monfort.

Summary. Aerodynamic lift and moment flutter derivatives were determined at high subsonic speeds for a series of two-dimensional airfoils varying in thickness and thickness distribution. The wings were oscillated sinusoidally in pitch.

Parameter Variations

Mach number	0·491 to 0·942
Frequency parameter	0·09 to 0·9 at $M = 0{\cdot}5$ 0·05 to 0·5 at $M = 0{\cdot}9$
Reynolds number	5×10^6 to 8×10^6
Axis of oscillation	0·25 chord
Mean incidence	0 deg and 2 deg

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	18·25 in.
Chord	24·0 in.
Thickness/chord ratios	0·12, 0·08 and 0·04
Aerofoil sections	NACA 65A012, 65A008, 2-008, 877A008, 65A004.
Construction	Wood-rib and wood-stressed-skin built around steel spars at the quarter-chord, which was axis of rotation. Several wood spars at other chordwise locations were used to minimise spanwise twisting.

Results

For NACA 65A012 with $\alpha_m = 0$ deg at $M = 0{\cdot}885$.

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·06	0·3291	0·3528	1·3303	−0·2803
0·098	−0·0151	0·3201	1·5244	−0·3240
0·194	0·6376	0·6934	0·8055	−0·9136
0·298	1·0086	0·8830	0·6783	−0·6927
0·402	0·6083	0·3980	0·3419	−0·5069
0·492	1·3393	0·0562	0·4667	−0·8084

For NACA 65A004 with $\alpha_m = 0$ deg at $M = 0{\cdot}900$.

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·050	3·5679	−0·8039	0·3159	−0·1694
0·100	4·2965	−1·1832	0·2411	−0·2793
0·294	2·2436	−0·7334	0·0024	−0·2259
0·390	4·0481	0·0425	0·1235	−0·5912
0·440	3·7359	−1·5324	0·5611	−0·7954

Site: Ames 16-ft High Speed Wind Tunnel.

'Effects of rigid spoilers on the two-dimensional flutter derivatives of airfoils oscillating in pitch at high subsonic speeds', by J. C. Monfort and J. A. Wyss.

Summary. A study was made of the effects of spoilers having fixed heights equal to $2\frac{1}{2}$ and 4 per cent of the aerofoil chord, on the aerodynamic lift and moment flutter derivatives of two dimensional airfoils oscillated in pitch.

Parameter Variations

Frequency parameter	0·09 to 0·9 at $M = 0{\cdot}5$ 0·05 to 0·5 at $M = 0{\cdot}9$
Reynolds number	5×10^6 to 8×10^6
Amplitude of oscillation	1 deg
Axis of oscillation	0·25 chord
Mean angle of attack	2 deg

Model Details

These are identical with those given in N.A.C.A. TIB 4232 (Report No. 42 of this R. & M.) apart from the spoilers which were fixed at the 70 per cent chord station on the upper surface of the aerofoils and extended over the whole span.

Results

For NACA 65A008 at $M = 0{\cdot}787$ with spoiler height 4 per cent and mean angle of attack 2 deg.

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·076	4·0291	−0·2677	0·1371	−0·0689
0·116	4·0095	−0·6636	0·0886	−0·1391
0·226	3·0463	−1·5056	0·0090	−0·2063
0·460	2·6970	−0·4030	−0·0297	−0·2980
0·568	4·2189	−0·4583	−0·2488	−0·6948

For NACA 65A012 at $M = 0{\cdot}790$ with spoiler height 4 per cent and mean angle of attack 2 deg.

ν	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$	$m_\alpha - \nu^2 m_{\ddot{\alpha}}$	$\nu m_{\dot{\alpha}}$
0·054	4·7650	0	−0·4905	0·0214
0·108	4·0766	−1·0391	−0·4174	0·1189
0·224	2·9888	−1·7050	−0·1977	0·1642
0·442	2·4533	−0·6989	+0·0705	0·0145
0·550	4·2695	−0·8529	−0·2077	−0·0344

Site: Ames 16-ft High Speed Tunnel.

'Experimental pressure distributions on oscillating low aspect ratio wings', by W. R. Laidlaw and R. L. Halfman.

Summary. The distribution of pressure over the surface of low aspect ratio wings oscillating in an incompressible flow has been measured using a small lightweight barium titanite pressure transducer. These pressures were integrated numerically to yield total lift and pitching moment coefficients. Results are presented for rectangular, sweptback and delta planforms.

Parameter Variations

Mach number	$0 \cdot 118$
Frequency parameter	$0 \cdot 40$ to $0 \cdot 90$ (Rectangular and sweptback wings) $0 \cdot 60$ to $1 \cdot 20$ (Delta wings)
Reynolds number	$1 \cdot 4 \times 10^6$ for rectangular and swept wings $2 \cdot 1 \times 10^6$ for delta wings (based on root chord)
Mean incidence	0 deg
Pitching axis of oscillation	$0 \cdot 5c_r$ for rectangular and delta wings $0 \cdot 7c_r$ for the sweptback wing where c_r is the root chord.

Model Details

The available details are given below:

Wing 1. Rectangular wing, aspect ratio 1.
Wing 2. Rectangular wing, aspect ratio 2.
Wing 3. 45 deg sweptback constant chord wing, aspect ratio 2.
Wing 4. 60 deg leading edge sweep delta wing, aspect ratio $2 \cdot 31$.
Wing 5. 75 deg leading edge sweep delta wing, aspect ratio $1 \cdot 07$.
Wing 6. Rectangular wing, aspect ratio 2 fitted with wing tip tanks of circular cross section, fineness ratio $11 \cdot 1$ and a length to wing chord ratio of 2.

Results

The results presented are for oscillation in the mode of vertical translation. Values for the delta wings are not tabulated as insufficient data is given to transform to the British notation.

Rectangular wing, $AR = 2$

ν	$0 \cdot 474$	$0 \cdot 636$	$0 \cdot 796$	$0 \cdot 870$
$l_z - \nu^2 l_{\ddot{z}}$	$-0 \cdot 0627$	$-0 \cdot 184$	$-0 \cdot 337$	$-0 \cdot 446$
$\nu l_{\dot{z}}$	$0 \cdot 617$	$0 \cdot 737$	$0 \cdot 926$	$1 \cdot 011$
$m_z - \nu^2 m_{\ddot{z}}$	$0 \cdot 0154$	$0 \cdot 0157$	$0 \cdot 0209$	$0 \cdot 00872$
$\nu m_{\dot{z}}$	$0 \cdot 139$	$0 \cdot 179$	$0 \cdot 239$	$0 \cdot 250$

Swept wing, $AR = 2$

ν	$0 \cdot 474$	$0 \cdot 634$	$0 \cdot 706$	$0 \cdot 796$
$l_z - \nu^2 l_{\ddot{z}}$	$0 \cdot 0287$	$-0 \cdot 0660$	$-0 \cdot 130$	$-0 \cdot 225$
$\nu l_{\dot{z}}$	$0 \cdot 529$	$0 \cdot 754$	$0 \cdot 820$	$0 \cdot 974$
$m_z - \nu^2 m_{\ddot{z}}$	$0 \cdot 0107$	$0 \cdot 0408$	$0 \cdot 0483$	$0 \cdot 101$
$\nu(-m_{\dot{z}})$	$0 \cdot 153$	$0 \cdot 231$	$0 \cdot 248$	$0 \cdot 305$

The pitching moment derivatives are referred to the half chord. Results for the lift and moment derivatives due to pitching of the wing can be found in the Sc.D. Thesis, M.I.T. by W. R. Laidlaw in May, 1954.

Site: M.I.T. 5-ft $\times$ $7\frac{1}{2}$-ft Low Speed Flutter Wind Tunnel.

(82877) E

'An experimental investigation of the hinge moment characteristics of a constant chord control surface oscillating at high frequency', by D. A. Reese and W. C. A. Carlson.

Summary. A free oscillation technique was used to determine the hinge moment characteristics of a constant chord control. Frequency is shown to have little effect on the stiffness derivative but at amplitudes of 2·5 deg and more the damping derivative becomes less stabilising with increase of frequency.

Parameter Variations

Mach number	0·6 to 0·8 and 1·3 to 1·9
Frequency parameter	1·20 to 1·46 (supersonic)
Reynolds number	$2 \cdot 33 \times 10^6$
Mean incidence (α)	5 and 10 deg
Amplitude of oscillation	up to 2·5 deg

Model Details

Sweepback	63 deg 26 min
Aspect ratio	2
Taper ratio	0
Span	27·9 in.
Chord	11·27 in. (exposed panel)
Thickness/chord ratio	0·05
Aerofoil section	NACA 0005
Construction	The model was of steel with the exception of the control surface which was fabricated from magnesium.
Aileron data	One wing panel was fitted with a constant chord control surface with an area equal to 15·2 per cent of the exposed area of the wing panel. The chord was 1·81 in.

Results

(1) For $\alpha = 5$ deg

$$h_\beta - \nu^2 h_{\ddot\beta} = -1 \cdot 24 \times 10^{-2} \text{ for } M = 0 \cdot 6 \text{ to } 0 \cdot 8$$
$$= -1 \cdot 86 \times 10^{-2} \text{ at } M = 1 \cdot 3 \text{ and increases linearly to } -1 \cdot 24 \times 10^{-2} \text{ at } M = 1 \cdot 93$$

(2) For $\alpha = 10$ deg and maximum aileron amplitude 1 deg

$$h_{\dot\beta} = -2 \cdot 34 \times 10^{-3} \text{ at } M = 0 \cdot 6 \text{ and decreases linearly to } -2 \cdot 90 \times 10^{-3} \text{ at } M = 0 \cdot 8$$
$$= 0 \cdot 554 \times 10^{-3} \text{ at } M = 1 \cdot 3 \text{ and decreases linearly to } -0 \cdot 598 \times 10^{-3} \text{ at } M = 1 \cdot 9$$

Site: Ames 6-ft × 6-ft Supersonic Tunnel.

'A preliminary investigation of the effects of frequency and amplitude on the rolling derivatives of an unswept wing model oscillating in roll', by L. R. Fisher, J. H. Lichtenstein and K. D. Williams.

Summary. A model with separable wing and tail assembly was oscillated in roll through a range of frequencies and amplitudes of oscillation for an angle of attack of 0 deg and at one frequency and amplitude for two higher angles of attack. The rolling moment damping derivative due to roll was found from these tests.

Parameter Variations

Mach number	0·13
Frequency parameter	0 to 0·081
Reynolds number	$0 \cdot 431 \times 10^6$
Mean incidence	0, 4 deg, 8 deg
Amplitude of oscillation	5 deg to 20 deg

Model Details

Sweepback	2 deg ($\frac{1}{4}$-chord line)
Aspect ratio	6
Taper ratio	0·5:1
Span	33·6 in.
Chord	5·6 in.
Thickness/chord ratio	—
Aerofoil section	NACA 65-110 (a = 1·0)
Construction	Spruce reinforced balsa wood. The model components were separable to allow testing of four configurations—fuselage alone, fuselage and wing, fuselage and tail assembly and complete model.
Tailplane data	AR = 2, area = 0·33 ft², span 13·68 in., height above fuselage centre-line = 3·51 in.
Fuselage data	Length 37·20 in., maximum diameter 5·50 in.
Fin data	Height, tip to fuselage centre-line, 9·63 in.

Results

The results presented are for the wing-fuselage combination, mean incidence 0 deg and amplitude of oscillation 5 deg.

ν	0·010	0·020	0·030	0·040	0·061	0·081
$n_{\dot\phi}$	1·37	1·30	1·30	1·16	1·31	1·33

Results are also given of yawing moment damping derivative due to roll.

Site: Langley Stability Tunnel, 6-ft diameter circular test section.

'Oscillating hinge moments and flutter characteristics of a flap type control surface on a 4 per cent thick unswept wing with low aspect ratio at transonic speeds', by R. F. Thompson and W. C. Moseley, Jr.

Summary. Free oscillation tests were made to determine the dynamic hinge moment characteristics of a trailing edge flap type control surface on an unswept wing of low aspect ratio.

Parameter Variations

Mach number	0·60 to 1·02
Frequency parameter	Varied from about $0\cdot\dot{3}$ to $1\cdot0\dot{6}$ at low test speeds and from $0\cdot5\dot{3}$ to $0\cdot8\dot{6}$ at high test speeds.
Reynolds number	$1\cdot79 \times 10^6$ to $2\cdot08 \times 10^6$
Ratio of trailing-edge thickness to hinge line thickness	0·17 and 1·00
Mean incidence	0 deg and 6 deg
Amplitude of oscillation	Up to 10 deg

Model Details

Sweepback	Leading edge 7 deg 38 min, mid-chord 1 deg 54 min
Aspect ratio	1·80
Taper ratio	0·74:1
Span	5·982 in.
Chord (mean aerodynamic)	0·564 ft.
Thickness/chord ratio	0·04
Aerofoil section	NACA 64A004 (modified)
Construction	Steel core and plastic surface.
Aileron data	The 25 per cent chord control extends from 0·086 span to 0·943 span with aerodynamic balance 0·20 of control chord.

Results

The results presented below are for a frequency parameter of 0·8 and mean incidence of zero. The ratio of the control surface thickness at the trailing edge to the thickness at the hinge line is 0·17.

M	$h_\beta - \nu^2 h_{\ddot{\beta}}$	$h_{\dot{\beta}}$
0·6	−0·022	−0·024
0·7	−0·023	−0·026
0·8	−0·027	−0·029
0·85	−0·031	−0·020
0·9	−0·047	0·013
0·95	−0·056	0·037
1·0	−0·058	0·035

Site: Langley High Speed 7-ft × 10-ft Tunnel.

'Preliminary study of some factors which affect the stall-flutter characteristics of thin wings', by A. G. Rainey.

Summary. The results are given of an investigation on the stall flutter of thin wings in which the effects of Mach number, Reynolds number, density, aspect ratio, sweepback, structural damping, position of nodal line in torsion and concentrated tip weights were studied. The pitching moment damping derivative was measured by the decaying oscillation technique.

Parameter Variations

Mach number	Maximum value reached 0·2
Frequency parameter	0·25 to 2·0
Reynolds number	Maximum value reached $0 \cdot 8 \times 10^6$
Mean incidence	0 to 20 deg
Amplitude of oscillation (initial)	3 deg
Axes of oscillation	0·25, 0·325, 0·5 and 0·75*c* aft of leading edge.

Model Details

Sweepback	0 deg
Aspect ratio	6
Taper ratio	1:1
Span	24 in. (semi)
Chord	8 in.
Thickness/chord ratio	Varies from 0·02 at tip to 0·04 at root.
Aerofoil section	NACA 65A002 at tip and NACA 65A004 at root.
Construction	Solid aluminium alloy.

Results

The results presented are for $\nu(-m_{\dot{\alpha}})$ at a mean angle of attack of 0 deg and various axes of oscillation.

ν	0·267	0·308	0·364	0·444	0·571	0·8
0·25*c*	0·0615	0·0677	0·0779	0·0942	0·123	0·180
0·325*c*	0·0401	0·0435	0·0514	0·0719	0·0950	0·123
0·5*c*	0·0459	0·0430	0·0489	0·0626	0·0567	0·0545
0·75*c*	0·0503	0·0500	0·0500	0·0490	0·0498	0·0492

Site: Langley 4·5-ft Flutter Research Tunnel.

'Aerodynamic damping at Mach numbers of 1·3 and 1·6 of a control surface on a two-dimensional wing by the free oscillation method', by W. J. Tuovila and R. W. Hess.

Summary. Tests have been made at two supersonic speeds, using a free oscillation technique, to obtain experimentally the aerodynamic damping characteristics of a control surface on a two dimensional wing.

Parameter Variations

Mach number	1·3 and 1·6
Frequency parameter	0·178 to 0·444
Amplitude of oscillation	1 deg to $2\frac{1}{2}$ deg approximately

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	9 in.
Chord	5 in.
Thickness/chord ratio	0·04 and 0·05
Aerofoil sections	NACA 65A004 and a 5 per cent thick hexagonal section.
Construction	Both wings were of steel.
Aileron data	Span 7·25 in. chord 1·67 in. Gap between control and wing of 0·02 in. Three controls were tested which were made of steel, aluminium and magnesium.

Results

The results presented are the maximum and minimum of the six results at each Mach number for derivative h_β and $\nu = 0{\cdot}27$.

$$M = 1{\cdot}3, \quad -h_\beta \text{ varies between } 0{\cdot}00050 \text{ and } 0{\cdot}00244$$

$$M = 1{\cdot}6, \quad -h_\beta \text{ varies between } 0{\cdot}00526 \text{ and } 0{\cdot}00717$$

Site: Langley 9-in. × 18-in. supersonic flutter apparatus.

'Measurement of aerodynamic forces for various mean angles of attack on an airfoil oscillating in pitch and on two finite-span wings oscillating in bending with emphasis on damping in the stall', by A. G. Rainey.

Summary. Experimental values are given of pitching moment and normal force derivatives for a wing oscillating in pitch. Damping derivatives for bending oscillations are also given. A forced oscillation technique was used to obtain these results.

Parameter Variations	*Pitching Oscillations*	*Bending Oscillations*	
Mach number	0·35 and 0·7	0·08 to 0·20	0·1 to 0·49
Frequency parameter	0 to 1·3	0·5 to 1·33	0·28 to 1·54
Reynolds number	$5 \cdot 3 \times 10^6$	$0 \cdot 4 \times 10^6$ to $0 \cdot 92 \times 10^6$	$0 \cdot 33 \times 10^6$ to $1 \cdot 47 \times 10^6$
Axis of oscillation	$0 \cdot 5c$		
Mean incidence	0 to 16 deg	0 to 20 deg	0 to 20 deg
Amplitude of oscillation	1·2 deg		
Model Details			
Sweepback	0 deg	0 deg	0 deg (mid chord)
Aspect ratio	∞	5	4·27
Taper ratio	1:1	1:1	0·5:1
Span	2 ft	20 in. (semi)	16 in. (semi)
Chord	1 ft	8 in.	7·5 in. (mean)
Thickness/chord ratio	0·10	0·10	0·03
Aerofoil section	NACA 65A010	NACA 65A010	NACA 16-003
Construction	Two half shells of aluminium alloy with a solid centre section.	Aluminium alloy core with balsa covering.	Solid aluminium alloy.

Results

The results presented below are of $\nu(-m_{\dot{\alpha}})$ for the 10 per cent thick wing of $AR = \infty$ oscillating about the mid-chord with a mean incidence of 0 deg.

ν	0·2	0·4	0·6	0·8	1·0	1·2
$M = 0 \cdot 35$	0·298	0·391	0·447	0·502	0·545	0·574
$M = 0 \cdot 7$	0·591	1·150	1·350	—	—	—

Results are also given for $m_{\alpha} - \nu^2 m_{\ddot{\alpha}}$, $l_{\alpha} - \nu^2 l_{\ddot{\alpha}}$ and $l_{\dot{\alpha}}$

Site: Langley 2-ft × 4-ft Flutter Research Tunnel.

'An experimental investigation of the unsteady lift induced on a wing in the downwash field of an oscillating canard control surface', by D. E. Reese, Jr.

Summary. The in-phase and in quadrature components of the lift and their respective centres of pressure were measured for a range of frequency, incidence and Mach number. The results indicate that existing theories provide a reliable guide for the estimation of lift derivatives and centres of pressure at low frequency parameters and small incidence.

Parameter Variations

Mach number	0·6 to 0·8 and 1·4 to 1·9
Frequency parameter	0·031 to 0·359 at $M = 1{\cdot}9$ 0·077 to 0·923 at $M = 0{\cdot}6$
Reynolds number	$1{\cdot}67 \times 10^6$
Mean incidence	0 deg, 5 deg and 10 deg
Control amplitude	5 deg
Control frequency	10 to 110 c.p.s.

Model Details

	Wing	*Control*
Sweepback	0 deg	0 deg
Aspect ratio	2·1	6·5
Taper ratio	1:1	1:1
Span	21 in.	13 in.
Chord	10 in.	4 in.
Distance between control and wing leading edges	36 in.	
Thickness/chord ratio	0·05	0·05
Aerofoil section	Bi-convex circular arc.	
Construction	The wing and control were mounted in canard arrangement on a 5 in. diameter, hollow, circular cylindrical body of fineness ratio 14. The cylinder was fitted with an ogival nose. The model was fabricated from steel with the exception of the nose and wing. The nose section was made of fibreglass-reinforced plastic while the wing was made from magnesium.	

Results

The results presented are for zero incidence of the wing.

The derivative $(l_\delta - \nu^2 l_{\ddot{\delta}})$

$M \backslash \nu$	0·0513	0·103	0·154	0·205	0·256	0·308	0·359
0·7	−0·151	−0·140	−0·125	−0·110	−0·0845	−0·056	−0·0188
0·8	−0·161	−0·151	−0·136	−0·112	−0·0845	−0·056	−0·0188
1·7	−0·128	−0·122	−0·110	−0·094	−0·0655	−0·0453	−0·0156
1·9	−0·110	−0·100	−0·0905	−0·078	−0·0595	−0·0375	−0·0156

The derivative l_{δ}

$M \backslash \nu$	0·0513	0·103	0·154	0·205	0·256	0·308	0·359
0·7	0·615	0·600	0·575	0·54	0·508	0·470	0·432
0·8	0·658	0·645	0·622	0·585	0·552	0·500	0·462
1·7	0·53	0·512	0·49	0·47	0·438	0·405	0·38
1·9	0·435	0·425	0·41	0·388	0·368	0·330	0·302

Site: Ames 6-ft × 6-ft Supersonic Tunnel.

'Experimental measurements of forces and moments on a two-dimensional oscillating wing at subsonic speeds', by S. A. Clevenson and E. Widmayer, Jr.

Summary. Experimental results for lift and moment about the quarter chord of a two dimensional wing at subsonic Mach numbers are given. A forced oscillation technique was used in the experiment.

Parameter Variations

Mach number	0·348 to 0·786
Frequency parameter	0·30 to 0·70
Reynolds number	1×10^6 to $5 \cdot 5 \times 10^6$
Mean incidence	0 deg
Amplitude of oscillation	2·30 deg (maximum)
Axis of oscillation	0·25 chord

Model Details

Sweepback	0 deg
Aspect ratio	∞
Taper ratio	1:1
Span	2 ft
Chord	8 in.
Thickness/chord ratio	0·10
Aerofoil section	NACA 65A-010
Construction	The wing was of fabricated construction, having a steel spar with Duralumin skin. It was mass-balanced about the quarter-chord axis.

Results

The results presented are the maximum and minimum values measured at the two frequency parameters $\nu = 0 \cdot 377$ and $\nu = 0 \cdot 628$.

ν	M	l_α	$\nu l_{\dot{\alpha}}$	$-m_\alpha$	$\nu(-m_{\dot{\alpha}})$
0·377	0·6755	2·761	−0·2033	constant at 0·03965	0·1458
		2·359	0·0966		0·1670
0·628	0·407	1·847	0·3164	constant at 0·1237	0·0799
		2·286	0·7764		0·5584

Site: Langley $4\frac{1}{2}$-ft Flutter Research Tunnel modified by auxiliary walls so that test section 2-ft wide.

'Some measurements of aerodynamic forces and moments at subsonic speeds on a wing-tank configuration oscillating in pitch about the wing mid-chord', by S. A. Clevenson and S. A. Leadbetter.

Summary. Measurements are presented of the aerodynamic forces and moments acting on a wing-tank configuration, with and without fins, oscillating in pitch about the wing-root mid-chord.

Parameter Variations

Mach number	0·18 to 0·75
Frequency parameter	0·10 to 1·314
Reynolds number	$0{\cdot}9 \times 10^6$ to $9{\cdot}5 \times 10^6$
Axis of oscillation	0·5 chord

Model Details

	Wing	*Tank*
Sweepback	0 deg	Length 24 in.
Aspect ratio	2	Diameter over centre section 5·2 in.
Taper ratio	1:1	
Span	12 in.	
Chord	12 in.	
Thickness/chord ratio	0·10	
Aerofoil section	NACA 65A010	
Construction	The wing consisted of a steel box spar carrying four evenly spaced ribs to which plywood skin was attached. The tank had a thin balsa nose and tail sections attached to a thin magnesium centre section.	

Results

The results presented are for the wing tank combination with trapezoidal fin on the tank.

ν	M	$l_\alpha - \nu^2 l_{\ddot{\alpha}}$	$\nu l_{\dot{\alpha}}$
0·132	0·65	1·6627	−0·0871
0·148	0·62	1·6784	−0·0879
0·168	0·56	1·7882	−0·0936
0·192	0·51	1·7118	−0·0298
0·244	0·42	1·6019	−0·0279

Site: Langley 2-ft × 4-ft Flutter Research Tunnel.

TABLE 17

The Derivatives m_{α} and $m_{\dot{\alpha}}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
26	∞	0	6 per cent thick unswept	0·0117 to 0·117
28*	2·31	60	Delta of NACA $65_{(06)}$–006·5 section	0·75 to 1·28
29*	4	45	Two deltas, one of NACA 0006–63 section and the other a biconvex section	0·23 to 0·94 1·15 to 1·70
30	∞	0	Rectangular of NACA 0012 section	0·104 to 0·137
31	∞	0	Rectangular, maximum thickness of 12 per cent at 30 per cent chord	0·086 to 0·132
33	∞	0	Rectangular, maximum thickness of 7·3 per cent at 30 per cent chord	0 to 0·159
34*	4	45	Delta of NACA 0006–63 section	0·10 to 0·95
35*	2, 3, 4	19·1 to 63·4	Three deltas, one tapered swept and one tapered unswept wing	0·6 to 0·9 1·2 to 1·9
37	2	0	Rectangular, NACA 65A010 section	0·15 to 0·81
38*	1·87 to 3·45	45 to 65	Four delta-wing-body combinations	1·62, 1·93 and 2·41
39	2 and 4	63·4 and 45	Both deltas were of NACA 65A010 section	0·19 to 0·81
40	∞	0	Rectangular of NACA 65–010 section	0·20 to 0·82
41	∞	0	Five rectangular wings of varying sections (NACA 65A012, 65A008, 65A004, 2–008, 877A008)	0·20 to 0·87
42	∞	0	Five rectangular wings, same sections as preceding report	0·491 to 0·942
43	∞	0	Same as in two preceding reports	0·5 to 0·9
48*	6	0	Rectangular, NACA 65A002 section at tip and NACA 65A004 at root	$\leqslant$ 0·2
50	4·27, 5 and ∞	0	Two rectangular, sections NACA 65A010 and one tapered unswept (mid-chord) NACA 16–003 section	0·08 to 0·70
52	∞	0	Rectangular, NACA 65A–010 section	0·348 to 0·786

* Damping derivative only.

TABLE 18

The Derivatives l_α and $l_{\dot{\alpha}}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
25	∞	0	Rectangular, NACA 0015 section	0·021 to 0·109
30	∞	0	Rectangular, NACA 0012 section	0·104 to 0·137
31	∞	0	Rectangular, 12 per cent maximum thickness at 30 per cent chord	0·086 to 0·132
33	∞	0	Rectangular, 7·3 per cent maximum thickness at 30 per cent chord	0 to 0·159
37	2	0	Rectangular, NACA 65A010 section	0·15 to 0·81
39	2, 4	63·4 and 45	Two deltas of NACA 65A010 section	0·19 to 0·81
40	∞	0	Rectangular, NACA 65–010 section	0·20 to 0·82
41	∞	0	Five rectangular wings of varying sections NACA 65A012, 65A008, 65A004, 2–008, 877A008	0·20 to 0·87
42	∞	0	Five rectangular wings, same sections as preceding report	0·491 to 0·942
43	∞	0	Same as in two preceding reports	0·5 to 0·9
50	4·27, 5 and ∞	0	Two rectangular, sections NACA 65A010 and one tapered unswept (mid-chord) NACA 16–003 section	0·08 to 0·70
52	∞	0	Rectangular, NACA 65A–010 section	0·348 to 0·786
53	2	0	Rectangular, NACA 65A010 section fitted with tank	0·18 to 0·75

TABLE 19

The Derivatives h_β and $h_{\dot{\beta}}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
27	∞	0	Rectangular, *Gö* 409 section	—
32	∞	0	Rectangular, NACA 65_1–213 ($a = 0\cdot5$) section	0·20 to 0·80
36	2	63·4	Delta, NACA 0005 section	0·6 to 0·9 1·3 to 1·9
45	2	63·4	Delta, NACA 0005 section	0·6 to 0·8 1·3 to 1·9
47	1·8	7·6	Tapered, NACA 64A004 (modified) section	0·60 to 1·02
49*	∞	0	Two rectangular wings, one of NACA 65A004 section and the other a 5 per cent thick hexagonal section	1·3 and 1·6

* Damping derivative only.

TABLE 20

The Derivatives m_z and $m_{\dot{z}}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
30	∞	0	Rectangular, NACA 0012 section	$0 \cdot 104$ to $0 \cdot 137$
31	∞	0	Rectangular, maximum thickness 12 per cent at 30 per cent chord	$0 \cdot 086$ to $0 \cdot 132$
33	∞	0	Rectangular, maximum thickness $7 \cdot 3$ per cent at 30 per cent chord	0 to $0 \cdot 159$
44	—	—	Rectangular $AR = 1$ and 2, 45 deg swept $AR = 2$, deltas of 60 deg and 75 deg leading-edge sweepback	$0 \cdot 118$

TABLE 21

The Derivatives l_z and $l_{\dot{z}}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
30	∞	0	Rectangular, NACA 0012 section	$0 \cdot 104$ to $0 \cdot 137$
31	∞	0	Rectangular, maximum thickness 12 per cent at 30 per cent chord	$0 \cdot 086$ to $0 \cdot 132$
33	∞	0	Rectangular, maximum thickness $7 \cdot 3$ per cent at 30 per cent chord	0 to $0 \cdot 159$
44	—	—	Rectangular $AR = 1$ and 2, 45 deg swept $AR = 2$, deltas of 60 deg and 75 deg leading-edge sweepback	$0 \cdot 118$

TABLE 22

The Derivatives l_β and $l_{\dot{\beta}}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
27	∞	0	Rectangular, *Gö* 409 section	—

TABLE 23

The Derivatives m_β and $m_{\dot\beta}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
27	∞	0	Rectangular, *Gö* 409 section	—

TABLE 24

The Derivative $n_{\dot\phi}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
46	6	2 ($\frac{1}{4}c$)	Tapered wing, NACA 65–110 ($a = 1\cdot0$) section	0·13

TABLE 25

The Derivatives l_δ and $l_{\dot\delta}$

Report No.	Aspect Ratio	Sweepback Angle (deg)	Details of wing	Mach number
51	2·1	0	Rectangular wing, bi-convex circular section	0·6 to 0·8 1·4 to 1·9

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