R. & M. No. 2809
(13,906)
A.R.C. Technical Report

MINISTRY OF SUPPLY

AERONAUTICAL RESEARCH COUNCIL
REPORTS AND MEMORANDA

Control Effectiveness Tests at Transonic Speeds on an EC.1250 Section with 0·25 chord Concave Control

By

T. LAWRENCE, B.Sc., B.E.

LONDON: HER MAJESTY'S STATIONERY OFFICE
1955
PRICE 2*s* 6*d* NET

Control Effectiveness Tests at Transonic Speeds on an EC.1250 Section with 0·25 chord Concave Control

By

T. LAWRENCE, B.Sc., B.E.

COMMUNICATED BY THE PRINCIPAL DIRECTOR OF SCIENTIFIC RESEARCH (AIR),
MINISTRY OF SUPPLY

*Reports and Memoranda No. 2809**
January, 1951

Summary.—Control effectiveness tests, using the ground-launched rocket-boosted model technique, have been made on rectangular wings of aspect ratio 4, EC.1250 section, and fitted with a 25 per cent chord concave control flap. Tests were done from $M = 0 \cdot 73$ to $M = 1 \cdot 5$, and at $R = 3 \cdot 5 \times 10^6$ and 7×10^6 at $M = 1$. There is a sudden and large reversal in control effectiveness at $M = 0 \cdot 9$, but the measured effectiveness below $M = 0 \cdot 8$ and above $M = 1 \cdot 1$ is in good agreement with theory. These tests confirm and extend to higher Reynolds numbers and Mach numbers previous tunnel tests on the same section, which are reported in R. & M. 2436.

1. *Introduction.*—On a number of aircraft the pursuit of high Mach numbers has been halted by more or less sudden and uncontrollable wing dropping. Wind-tunnel tests by Shaw on an EC.1250 section with 25 per cent concave control (R. & M. 2436[1]) have suggested a possible explanation in sudden changes in the flow pattern and associated pressure distributions in the neighbourhood of a deflected control. The tests were done at a Reynolds number of about 2×10^6, and the highest Mach number reached was $0 \cdot 88$. Qualitatively similar results have also been obtained by Göthert (Ref. 2) at $R = 7 \times 10^6$, to a maximum also of about $M = 0 \cdot 88$.

The development of the Royal Aircraft Establishment ground-launched rocket-boosted model technique[3] offers a convenient method of confirming Shaw's results and also of extending them to both higher Reynolds numbers and higher Mach numbers. This note describes tests on the same aerofoil and control as used by Shaw, at Reynolds numbers at $M = 1$, of $3 \cdot 5 \times 10^6$ and 7×10^6, over the Mach number range from $0 \cdot 73$ to $1 \cdot 50$.

No attempt is made in this note to discuss the phenomena encountered in terms of Shaw's arguments, *i.e.*, in terms of the flow changes. For a detailed understanding of the reasons for the phenomena reference should be made to Shaw's report (R. & M. 2436[1]).

2. *Technique.*—The methods of test and analysis are described in detail in Ref. 3. Photographs of the models are given in Fig. 1 and particulars are given in Fig. 2 and Table 1. Each model carried three half-wings, the wings being of EC.1250 section and fitted with a full-span 25 per cent chord concave control, at a nominal fixed deflection of 5 deg. The wings were made of compressed wood to the ordinates given in Table I of Ref. 1. The net aspect ratio of the test wings was $4 \cdot 0$, this being a compromise between the need to use low aspect-ratio to reduce the loss due to wing flexibility, and the desire to use high aspect-ratio to get a more justifiable comparison with the two-dimensional tests of Ref. 1. Simple measurements of torsional stiffness about a spanwise axis and of flexural stiffness were made on typical wings assembled into the body, and the results are given in Table 1. From these measurements an estimate was made of the rolling power of the wing using R. & M. 2186[4] (Fig. 3).

* R.A.E. Tech. Note Aero 2089, received 9th April, 1951.

Two tests were first made using wings of 6-in. chord; these are referred to as 'small-scale' models. Since the results of these two tests were in such close agreement (Fig. 4) only one test was made using wings of 12-in. chord, referred to as the 'large-scale' model.

3. *Results.*—The results of the tests on the two small-scale models are plotted in Fig 4a as curves of $pb/2V\xi$ (wing tip helix angle in degrees per degree aileron angle) against Mach number. These results have been corrected for the headwind component observed during the test period, and for the effects of the rolling inertia of the model. The test Reynolds number, which varied linearly with Mach number, is shown on the abscissa scale.

In Fig. 4b is shown the test result for the large-scale model corrected as above. These two models were decelerating at different rates, due to their different size and drag. For example the small models were decelerating at about $5g$ at $M = 1 \cdot 2$ and about $2g$ at $M = 0 \cdot 9$, while appropriate figures for the large models are respectively about $12\frac{1}{2}g$ and $5\frac{1}{2}g$.

4. *Discussion.*—4.1 *Comparison with Theory.*—In Fig. 5 the mean curve from Fig. 4a, and the curve from Fig. 4b are shown. The agreement is as good as can be expected; the difference is of the opposite sign to that expected from the different stiffnesses of the wings (Fig. 3), but is not considered significant in this experiment, *i.e.*, it is concluded that the reversal effect is independent of Reynolds number between 3·5 and 7 millions.

The theoretical values for the small-scale model with both rigid and flexible wings are indicated in Fig. 5. Within the accuracy of the estimation process, these curves apply also to the large-scale model, the effect of the different span/body diameter ratio being negligibly small. The agreement between theory and experiment is considered satisfactory, except of course for the transonic effects.

4.2. *Comparison with Wind-Tunnel Result.*—In Fig. 6 the curve from Fig. 4a is plotted as wing-tip helix angle for an assumed aileron angle of 5 deg. This is the tip-chord incidence for a model rolling so that the distribution of incidence and lift along the span gives zero rolling moment. Shown also are figures obtained from a further analysis of unpublished results obtained during Shaw's tunnel measurements (R. & M. 2436[1]). The Reynolds number of the tunnel tests is 2×10^6. In this case are plotted, on the same scale, the incidence for zero lift on a two-dimensional wing with the aileron deflected to 2 deg, $3\frac{1}{2}$ deg and 5 deg. It is claimed that all these curves are in good agreement with one another in that they reveal the sudden decrease in control effectiveness and the eventual control reversal at substantially the same Mach number. The ratio between the incidence of the two-dimensional wing and the tip incidence of the rolling wing is of the expected order.

4.3. *General.*—These tests confirm the previous tunnel experience (R. & M. 2436[1]) and extend it to higher Mach numbers and Reynolds numbers. Due to the limitations of the present technique (Ref. 3) this extension is strictly valid only at a control angle of 5 deg. Experience with other control layouts has confirmed that when reversal is indicated at a given deflection, it is also present at all smaller deflections, but that at a sufficiently large deflection the reversal does not occur. Thus one may expect the reversal at 2 deg and $3\frac{1}{2}$ deg, found in the tunnel tests and shown in Fig. 6, would also be confirmed, but that at about 10 deg and above the control would behave normally; in this latter case the effectiveness at $M = 0 \cdot 9$ would be appreciably less than at either say $M = 0 \cdot 8$ or $M = 1 \cdot 0$.

Assuming linearity in the middle range, we may write, in the usual manner

$$C_L = a_1(\alpha - \alpha_0) + a_2\xi$$

where α_0 = angle of zero lift. Putting $C_L = 0$ we have

$$\alpha = \alpha_0 - \left(\frac{a_2}{a_1}\right)\xi$$

so that the tunnel result of Fig. 6 is related to a_2/a_1, α_0 being zero in the present symmetrical section, as confirmed by the tunnel tests. The rocket model result is

$$l_\xi/l_p$$

where $l_\xi = \left\{\frac{\partial C_l}{\partial \xi}\right\} \propto a_2$ and $l_p = \left\{\frac{\partial C_l}{\partial \frac{pb}{2V}}\right\} \propto a_1$

and is thus also related to a_2/a_1.

Available evidence suggests that a_1 increases according to the Glauert law up to the critical Mach number, and then collapses; the tunnel tests show that on the present section the collapse occurs at about $M = 0 \cdot 8$, which is as expected. a_2, however, does not show such an increase with Mach number; the subsonic value is retained until a collapse occurs. Now the present tests show that the collapse in a_2 is more drastic than that in a_1, since the ratio a_2/a_1 decreases. Furthermore, a_2 must become negative, for a_1, on a symmetrical section of this type, is certainly positive.

Some further light would be shed on this problem of collapse by a knowledge of the changes in l_p, and an attempt should be made to measure l_p through the transonic region.

An explanation for these changes cannot be obtained by the present transient technique, which reveals only the overall effects; the explanation must be sought in tunnel tests, when a study of shock-waves and boundary layers may be made at leisure. But the rocket model test is a powerful technique for extending the tunnel test to high Reynolds numbers, and for studying overall effects through the transonic region.

REFERENCES

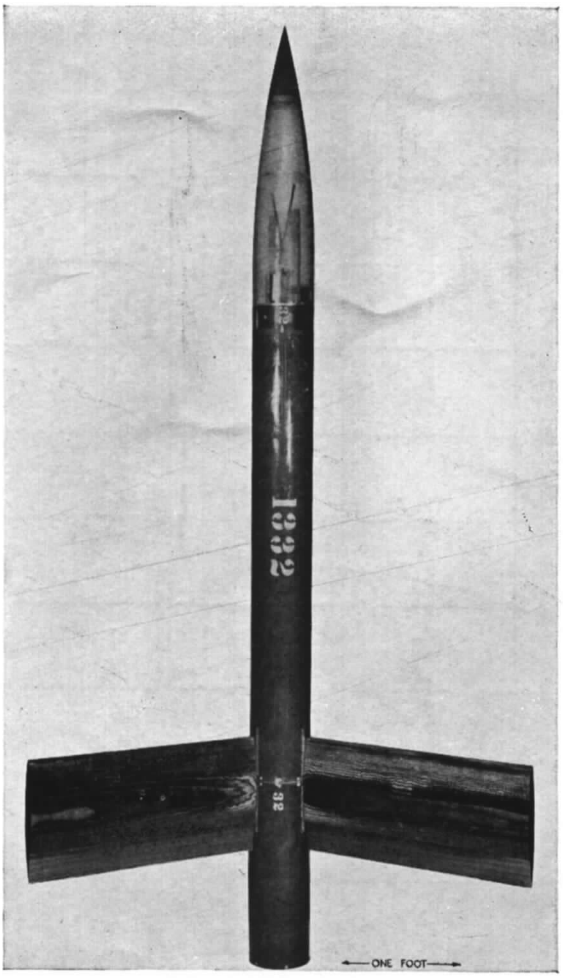
No.	*Author*	*Title, etc.*
1	R. A. Shaw	Changes in control characteristics with changes in flow pattern at high subsonic speeds. Tests on an EC.1250 aerofoil with 25 per cent concave control flap. R. & M. 2436. November, 1948.
2	B. Göthert	Control effectiveness at high subsonic speeds. Lilienthal Gesellschaft für Luftfahrtforschung, No. 156, pp. 51–63 (M.O.S. Volkenrode R. and T. No. 72 . TIB/GDC 10/1147 T(F).) A.R.C. 11,879. February, 1947.
3	T. Lawrence and J. Swan ...	Development of a transonic research technique using ground-launched rocket-boosted models. Part I. Control effectiveness tests. A.R.C. 13,740. July, 1950.
4	A. R. Collar and E. G. Broadbent	The rolling power of an elastic wing. R. & M. 2186. October, 1945.

TABLE I

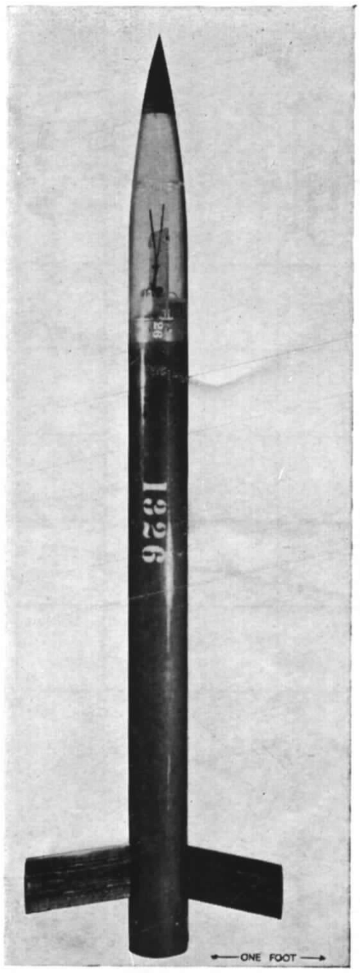
Details of Models

Scale	Large	Small	
Model No.	1332	1326	1327
Wing chord ... ... ft.	1·0	0·5	
Exposed half-span ... ... ft.	2·0	1·0	
Net aspect ratio	4·0		
Aileron angle ... ... mean deg	4·91	4·85	4·57
,, ,, ... range deg	4·8 – 5·2	4·5 – 5·4	4·1 – 5·0
Trailing-edge angle* ... ... deg	9·7	12·1	11·6
Test weight ... ... lb	106·5	95·9	98·1
Moment of inertia ... ... slug ft^2	2·61	0·223	0·227
Wing tip torsional stiffness ... lb ft/radn $\times 10^{-3}$	8·45	1·04	
Wing tip flexural stiffness ... lb ft/radn $\times 10^{-3}$	6·15	1·98	
Torsion axis aft of L.E. ... per cent chord	46	50	

* Trailing-edge angle defined as angle between lines drawn through measured profile ordinates at 0·95 and 0·99 of local chord.



(*a*) Large-scale model, No. 1332.



(*b*) Small-scale model, No. 1326. (No. 1327 model, similar.)

Fig. 1. Scale models.

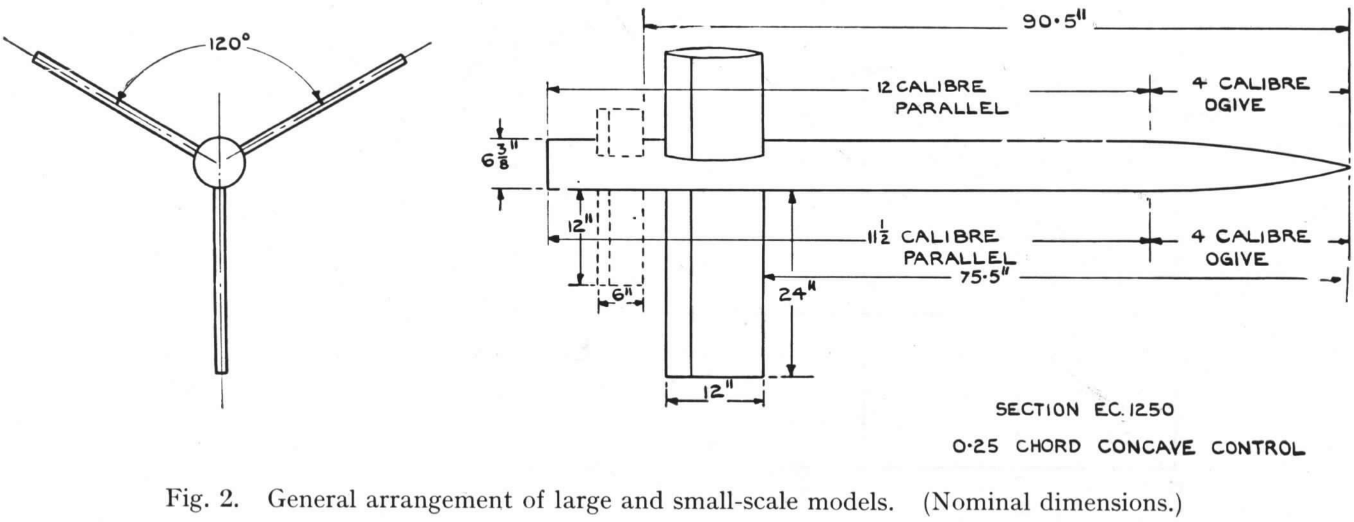


Fig. 2. General arrangement of large and small-scale models. (Nominal dimensions.)

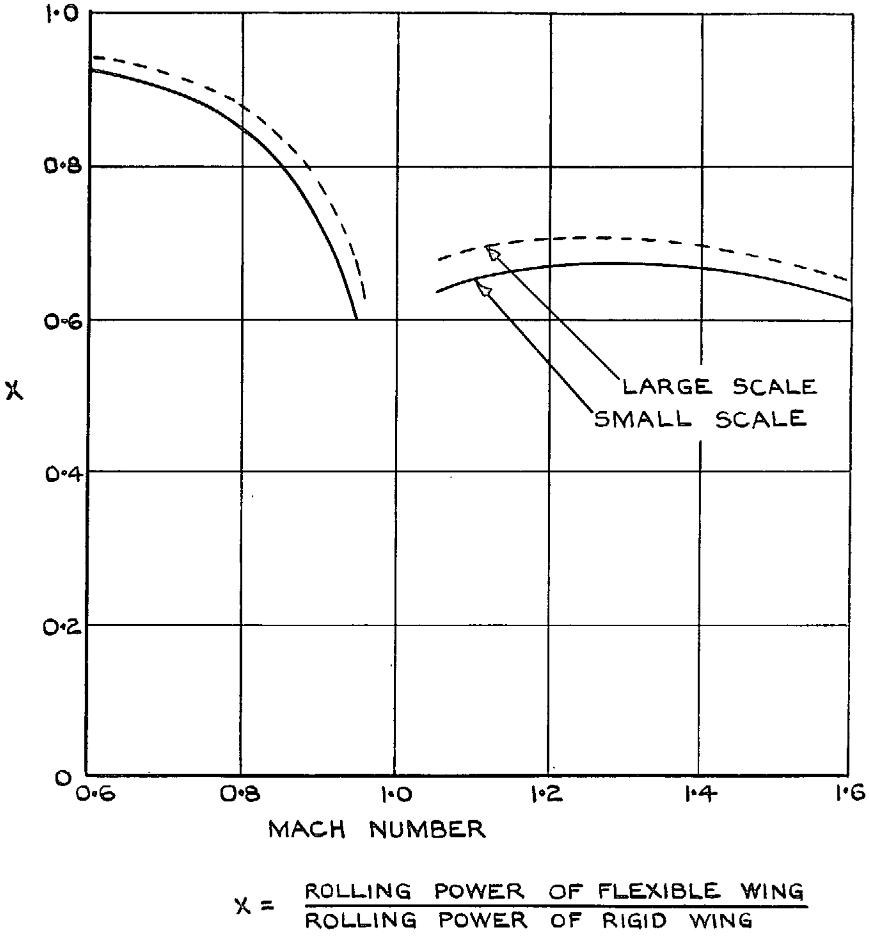


FIG. 3. Variation of rolling power with Mach number.

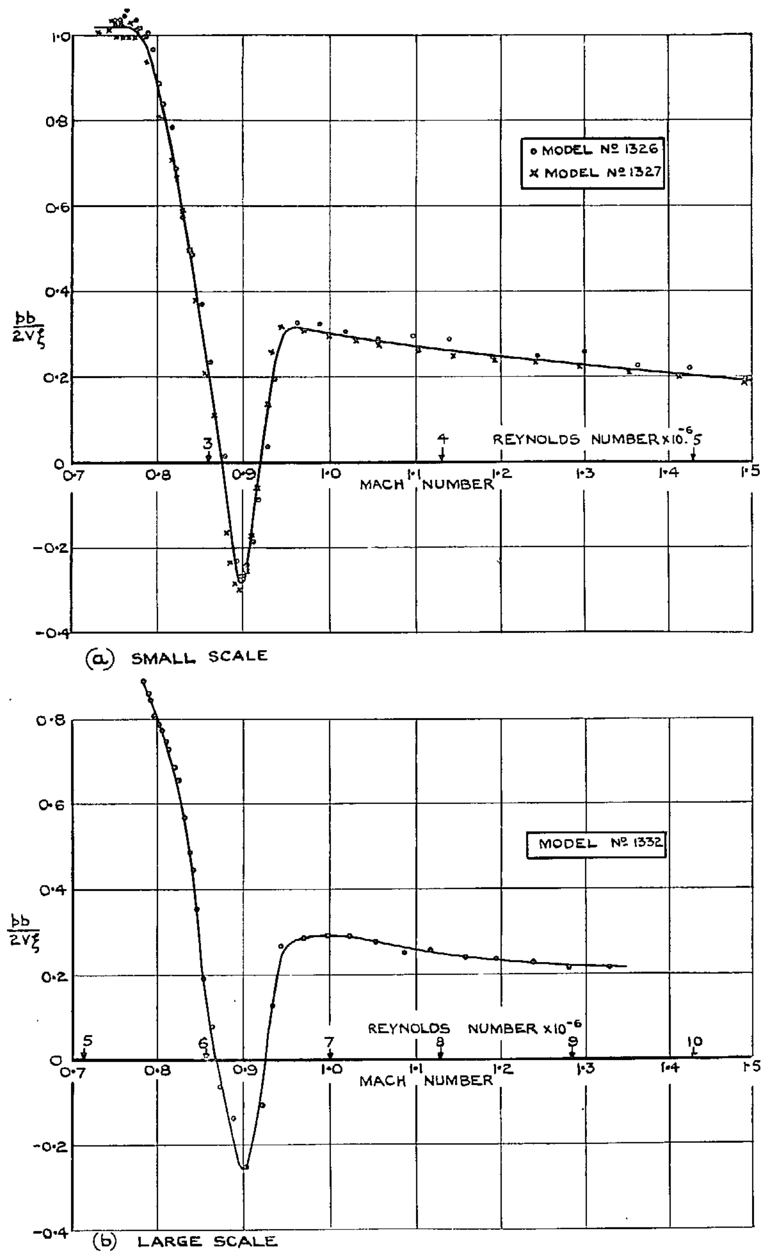


Fig. 4. Variation of rolling effectiveness with Mach number. 0·25 chord full-span concave control on EC.1250 section.

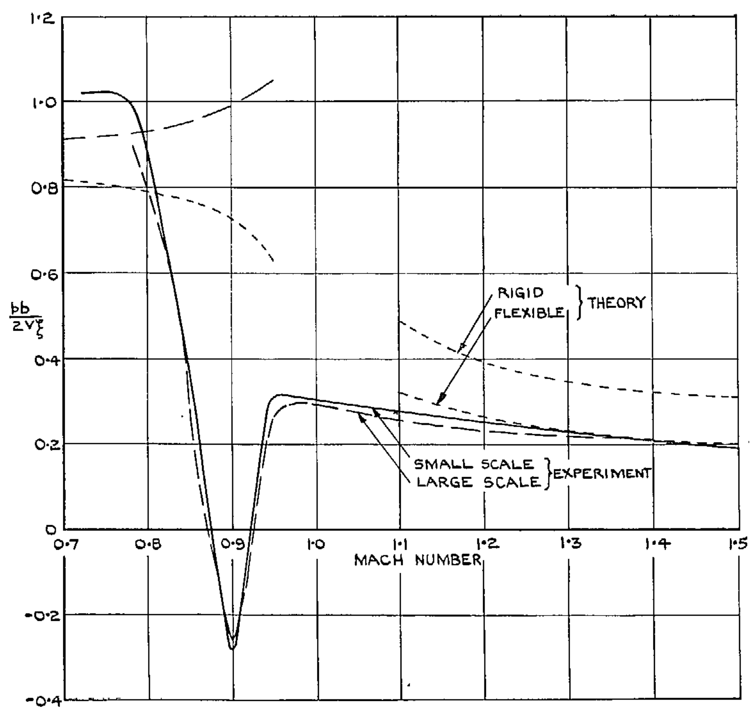


Fig. 5. Comparison with theory.

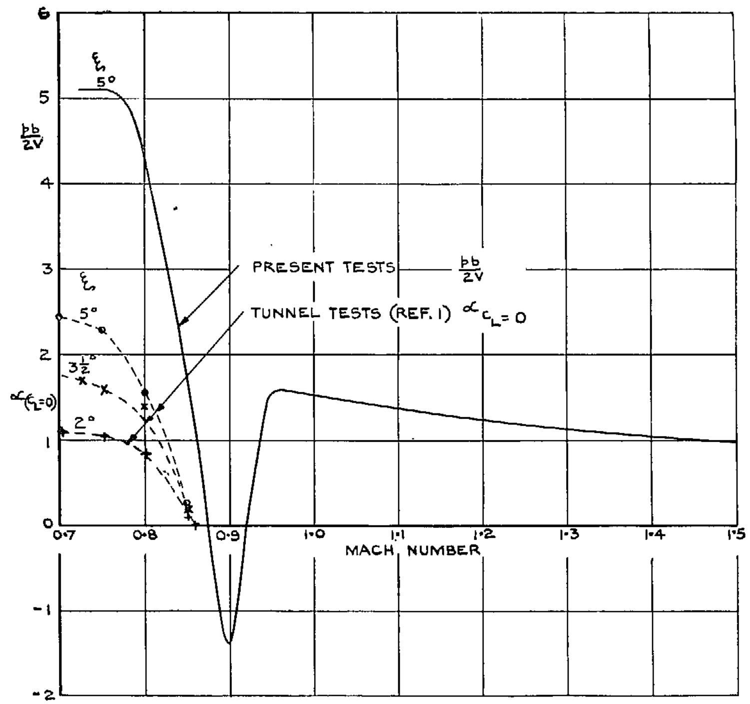


Fig. 6. Comparison with tunnel result.

Wt. 17/680 K.9 5/55 G.G. 34-262

PRINTED IN GREAT BRITAIN

Publications of the Aeronautical Research Council

ANNUAL TECHNICAL REPORTS OF THE AERONAUTICAL RESEARCH COUNCIL (BOUND VOLUMES)

1936 Vol. I. Aerodynamics General, Performance, Airscrews, Flutter and Spinning. 40*s.* (41*s.* 1*d.*)
Vol. II. Stability and Control, Structures, Seaplanes, Engines, etc. 50*s.* (51*s.* 1*d.*)

1937 Vol. I. Aerodynamics General, Performance, Airscrews, Flutter and Spinning. 40*s.* (41*s.* 1*d.*)
Vol. II. Stability and Control, Structures, Seaplanes, Engines, etc. 60*s.* (61*s.* 1*d.*)

1938 Vol. I. Aerodynamics General, Performance, Airscrews. 50*s.* (51*s.* 1*d.*)
Vol. II. Stability and Control, Flutter, Structures, Seaplanes, Wind Tunnels, Materials. 30*s.* (31*s.* 1*d.*)

1939 Vol. I. Aerodynamics General, Performance, Airscrews, Engines. 50*s.* (51*s.* 1*d.*)
Vol. II. Stability and Control, Flutter and Vibration, Instruments, Structures, Seaplanes, etc. 63*s.* (64*s.* 2*d.*)

1940 Aero and Hydrodynamics, Aerofoils, Airscrews, Engines, Flutter, Icing, Stability and Control, Structures, and a miscellaneous section. 50*s.* (51*s.* 1*d.*)

1941 Aero and Hydrodynamics, Aerofoils, Airscrews, Engines, Flutter, Stability and Control, Structures. 63*s.* (64*s.* 2*d.*)

1942 Vol. I. Aero and Hydrodynamics, Aerofoils, Airscrews, Engines. 75*s.* (76*s.* 3*d.*)
Vol. II. Noise, Parachutes, Stability and Control, Structures, Vibration, Wind Tunnels. 47*s.* 6*d.* (48*s.* 7*d.*)

1943 Vol. I. Aerodynamics, Aerofoils, Airscrews. 80*s.* (81*s.* 4*d.*)
Vol. II. Engines, Flutter, Materials, Parachutes, Performance, Stability and Control, Structures. 90*s.* (91*s.* 6*d.*)

1944 Vol. I. Aero and Hydrodynamics, Aerofoils, Aircraft, Airscrews, Controls. 84*s.* (85*s.* 8*d.*)
Vol. II. Flutter and Vibration, Materials, Miscellaneous, Navigation, Parachutes, Performance, Plates and Panels, Stability, Structures, Test Equipment, Wind Tunnels. 84*s.* (85*s.* 8*d.*)

Annual Reports of the Aeronautical Research Council—

1933–34	1*s.* 6*d.* (1*s.* 8*d.*)	1937	2*s.* (2*s.* 2*d.*)
1934–35	1*s.* 6*d.* (1*s.* 8*d.*)	1938	1*s.* 6*d.* (1*s.* 8*d.*)
April 1, 1935 to Dec. 31, 1936	4*s.* (4*s.* 4*d.*)	1939–48	3*s.* (3*s.* 2*d.*)

Index to all Reports and Memoranda published in the Annual Technical Reports, and separately—

April, 1950 R. & M. No. 2600. 2*s.* 6*d.* (2*s.* $7\frac{1}{2}$*d.*)

Author Index to all Reports and Memoranda of the Aeronautical Research Council—

1909–1954. R. & M. No. 2570. 15*s.* (15*s.* 4*d.*)

Indexes to the Technical Reports of the Aeronautical Research Council—

December 1, 1936 — June 30, 1939.	R. & M. No. 1850.	1*s.* 3*d.* (1*s.* $4\frac{1}{2}$*d.*)
July 1, 1939 — June 30, 1945.	R. & M. No. 1950.	1*s.* (1*s.* $1\frac{1}{2}$*d.*)
July 1, 1945 — June 30, 1946.	R. & M. No. 2050.	1*s.* (1*s.* $1\frac{1}{2}$*d.*)
July 1, 1946 — December 31, 1946.	R. & M. No. 2150.	1*s.* 3*d.* (1*s.* $4\frac{1}{2}$*d.*)
January 1, 1947 — June 30, 1947.	R. & M. No. 2250.	1*s.* 3*d.* (1*s.* $4\frac{1}{2}$*d.*)
July, 1951.	R. & M. No. 2350.	1*s.* 9*d.* (1*s.* $10\frac{1}{2}$*d.*)
January, 1954.	R. & M. No. 2450.	2*s.* (2*s.* $1\frac{1}{2}$*d.*)
July, 1954.	R. & M. No. 2550.	2*s.* 6*d.* (2*s.* $7\frac{1}{2}$*d.*)

Prices in brackets include postage

Obtainable from

HER MAJESTY'S STATIONERY OFFICE

York House, Kingsway, London, W.C.2; 423 Oxford Street, London, W.1 (Post Orders: P.O. Box 569, London, S.E.1); 13a Castle Street, Edinburgh 2; 39 King Street, Manchester 2; 2 Edmund Street, Birmingham 3; 109 St. Mary Street, Cardiff; Tower Lane, Bristol 1; 80 Chichester Street, Belfast, or through any bookseller

S.O. Code No. 23-2809