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Note on Semi-Experimental Methods for the Determination of Aerodynamic Derivatives for an Oscillating Wing-Aileron System

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Summary.—A brief survey is given of existing semi-experimental methods for the determination of two-dimensional aerodynamic derivatives for unsteady motion of a wing-aileron system (and, in particular, for aerodynamically balanced controls); a comparison with (partly unpublished) esperimental data is made. The result is encouraging for further investigations.

1. *Introduction.*—In the determination of aerodynamic derivatives for flutter by the two-dimensional unsteady aerofoil theory the wing-aileron system is replaced by a skeleton line[1]. This theory is also used in conjunction with certain experimental aerodynamic data to obtain the derivatives and such methods are called semi-experimental.

There are two kinds of such methods:—firstly methods of correlating the skeleton line with pressure distributions measured in steady flow; secondly, the application, to the theoretical unsteady pressure distribution formula for a given skeleton-line, of corrections derived from experiments in unsteady flow. Methods of the first kind are most important for ailerons with aerodynamic balance, where the choice of the replacing skeleton line is arbitrary if made without such a correlation to experimental results[1, 2]. Simple methods have been suggested by Kuessner and Schwarz[1] and by several German firms[2] and a more complete method has been presented by Schwarz.[3]

This note discusses two instances where a comparison has been made between results calculated by the first method and experimental data, and puts forward suggestions for further investigations. The author's experiments concern ailerons with aerodynamic balance. Drescher[5] investigated a hinged flap—a case where there is no major uncertainty in the choice of the skeleton line. He suggested a semi-experimental method of the second kind which is also of interest for the problem of the aerodynamically balanced aileron.

2. *Theoretical Investigations.*—Kuessner and Schwarz[1] present a theoretical method for the determination of the two-dimensional unsteady derivatives for wings with aerodynamically balanced ailerons and tabs in which the wing profile is replaced by a skeleton line $z(x)$ with steps at the leading edges of the ailerons and tabs. The steps can be ' open '—in which case there is free flow through the gap between main and control surface—or ' closed '—in which case there is no flow. The pressure distribution formula for the ' closed ' step contains a free parameter

* R.A.E. Tech. Note Structures 28—received 12th January, 1949.

which is used for correlating it to the aerodynamic balance,* measured in steady flow, of the aileron in question—a semi-experimental method of the first kind. These and alternative skeleton lines have been used in flutter calculations by German firms; sometimes free parameters have been introduced artificially, *see* Fig. 1, where (b) and (c) are different applications of the closed step. Fig. 1(d) is the open step. Jordan[2] showed that four of the shapes shown in Fig. 1 lead to the same flutter speed and to the same flutter-free region for controls with large aerodynamic balance, the exceptions being those in which the leading edge of the aileron skeleton line does not correspond to the leading edge of the aileron itself (Figs. 1(c), (e)). This rule, however, applies only for free ailerons, not for constrained ailerons with a natural frequency of the same order as that of the wing in pitch (Fig. 4).

Schwarz[3] developed a method for eliminating the skeleton line $z(x)$ by introducing an experimental pressure distribution. In his method, the unsteady pressure distribution $p(x, \omega)$ corresponding to a certain frequency parameter ($\omega = \Omega\, c/V$) is found by extrapolation from an experimental pressure distribution $p_E(x, \omega_E)$ measured at a different frequency parameter ω_E. Schwarz discusses the case where $\omega_E = 0$, since these experimental results are relatively easy to obtain and may be already available from steady aerodynamic model tests. This method still contains the basic assumption that the wing-aileron-tab profile of finite thickness can be replaced by one and the same skeleton line at different frequency parameters ω† but this skeleton line does not appear explicitly in the formula. There remains one arbitrariness: the question whether the skeleton line contains an open step, or not, cannot be answered from the experimental pressure distribution $p_E(x, 0)$, but must be decided by the user considering the actual profile. Data for the application of Schwarz's method were produced by Jordan[4].

Comparison of Schwarz's method with experimental data by Jordan, *see* section 3.1, and by Drescher, *see* section 3.2, showed that the extrapolation[3] from $\omega_E = 0$ is not satisfactory if it is extended to frequency parameters $\omega = 2$ and higher. Drescher[5] derived from his experiments corrections which establish a semi-experimental method of the second kind for wings with hinged flaps, (here, the obvious choice of skeleton line is the simple hinged combination of two straight lines). He introduces, like Schwarz, the steady pressure distribution $p_E(x, 0)$; his other corrections to the theoretical pressure distribution formula are:—

(i) The general circulation function $A - iB$ ($= (1 + T)/2$ in notation of Ref. 1) is replaced by an experimental function $A_E - iB_E$ which is shown in Fig. 2.

(ii) Several *ad hoc* corrections are applied to the remaining terms in order to get agreement with the experimental results.

The function $A_E - iB_E$ is claimed by Drescher to be generally valid and could thus be used in any of the methods in question. Corrections corresponding to (ii) for the aerodynamically balanced aileron can be derived when suitable measurements are available.

3. *Experimental Investigations*.—3.1. The author's experiments, made early in the war but so far unpublished, were made in a small water tunnel on a two-dimensional solid metal wing which was allowed to pitch about an axis 0·24 chord aft of the leading edge. Two interchangeable ailerons were used with different profiles giving different aerodynamic balance (Fig. 3). The high density of the water gave a low 'reduced mass' of the model ($\mu \simeq 1$ against a usual value of $\mu \simeq 20$) which led to high frequency parameter values ($\omega > 2$).

The constraint of the aileron was varied in order to vary the aileron natural frequency, and thus to vary the critical flutter speed. These flutter speeds were similar for the two ailerons and the results shown in Fig. 4 refer to the round nose aileron I (Fig. 3) where $\tau_p \simeq 0$ (*see* Fig. 1) was found to give the correct balance.

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* 'Aerodynamic balance' is defined as that percentage of the hinge moment of the corresponding aileron without aerodynamic balance—'hinged flap'—which is cancelled by forces acting on the balancing part of the aileron. Correlation to this dimensionless quantity is preferred to correlation to the actual hinge moment.

† There are two objections to this assumption:—

(i) *Two* features of the actual profile, finite thickness and amplitude, are to be expressed by *one* feature of the skeleton line:—its amplitude.

(ii) The boundary-layer effects are contained in the skeleton line but not as such involved in the theory used for the extrapolation; these boundary effects depend upon the frequency parameter.

The internal damping referred to in Fig. 4 is that due to friction in the bearings; it was measured by the decaying oscillations method in air. The damping by the air and the damping in the gap between model and water tunnel walls was assumed to be negligible. The value of damping was found to be equivalent to a phase difference of about $0 \cdot 03$ radians; this value, which is incidentally the usual minimum value of structural damping, was inserted in the theoretical calculations for both wing and aileron, Figs. 4 and 5. The Reynolds number of these experiments was $R = 0 \cdot 6 \times 10^6$ for $V = 3$ m/sec.

3.2. Later experiments by Drescher[5] were made in a larger water tunnel. The model consisted of a fixed wing with a hinged flap (Fig. 6); the latter was subject to forced oscillations. The unsteady pressure distribution over wing and flap was measured by means of holes in the surface through which the pressure was led to an oscillograph. The Reynolds number of these experiments lay between $R = 0 \cdot 3 \times 10^6$ and $R = 0 \cdot 9 \times 10^6$.

4. *Comparison of Theory and Experiments.*—The theoretical and experimental results are given in Figs. 4, 5 and 6, Figs. 4 and 5 referring to the flutter experiments (section 3.1), Fig. 6 to the pressure measurements (section 3.2). In Fig. 4, the purely theoretical results (Kuessner-Schwarz[1]) as well as the semi-experimental results (Schwarz[3]) are given both for the ' closed ' and the ' open ' step and with and without internal damping, the ' closed step ' corresponding to Fig. 1(b). Samples of the different ' air ' reaction derivatives which distinguish the calculations leading to Fig. 4 are compared in Table 1. While Fig. 4 shows two non-dimensional parameters, viz. the reciprocal frequency parameter $1/\omega$ against the frequency ratio, Fig. 5 repeats the most important results of Fig. 4, showing the directly measured quantities velocity V and circular frequency Ω against the aileron circuit stiffness.—The theoretical results of Fig. 6 concern of course the simple skeleton line consisting of two straight lines, without any step.

Fig. 6 shows that a discrepancy exists between semi-experimental and experimental results at $\omega = 1 \cdot 9$ and implies that Schwarz's extrapolation cannot be extended up to frequency parameters $\simeq 2$. (Unfortunately, measurements in the most interesting region $\omega = 1$ are not available). This evidence explains the failure of Schwarz's method to predict the correct flutter speed at frequency parameter values of order 2 (Fig. 5). Nevertheless the semi-experimental method indicates flutter over a large range of the aileron circuit stiffness where flutter actually occurred, though the pure theory indicated no possibility of flutter in this region.

The last observation is a strong argument in favour of further investigation of semi-experimental methods, even for high values of the frequency parameter ω. As regards low values of ω Borkmann[6] has given an example of a wing with a simple flap where the purely theoretical results for flutter speed agree satisfactorily with the experiments at frequency parameters $\omega < 2$. As far as can be judged by this evidence, the more powerful Schwarz method should yield good results also in the more difficult case of the aerodynamically balanced aileron up to values of well over 1. Improvements of the second kind can easily be developed as soon as further experimental evidence becomes available.

Lastly, it should be mentioned why the ' open step ' results from Fig. 4 have not been repeated in Fig. 5: no open step seems to appear in the arrangement, Fig. 3, as long as the aileron angle remains small. A slight flow through the gap between wing and aileron was in fact observed in steady condition at aileron angles of more than 4 deg, this flow, however, was opposite to that supposed by the theory, Fig. 7.

5. *Conclusions.*—Semi-experimental methods are useful for the determination of unsteady aerodynamic derivatives, in particular for surfaces with aerodynamically balanced controls; one instance has been found where flutter which actually occurred was predicted by semi-experimental theory but not by the usual pure theory. More experimental evidence is required to check the range of frequency parameter for which existing semi-experimental methods are valid.

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TABLE

External force derivatives obtained by different theories

Moment acting on axis of:—	Wing		Aileron	
Due to pitch of:—	wing	aileron	wing	aileron
Mass inertias	0·594	0·050	0·050	0·050
	Air reactions for $\omega = 1$			
Case A	0·287—2·065i	—1·732—0·570i	—0·008—0·084i	—0·033—0·051i
Case B	,, ,,	—1·677—0·703i	,, ,,	—0·033—0·053i
Case C	0·126—1·760i	—1·169—0·225i	0·014—0·067i	—0·043—0·026i
Case D	,, ,,	—1·177—0·154i	,, ,,	—0·042—0·027i
	Air reactions for $\omega = 2$			
Case A	0·370—1·038i	—0·416—0·289i	0·015—0·044i	—0·006—0·027i
Case B	,, ,,	—0·402—0·356i	,, ,,	—0·006—0·028i
Case C	0·222—0·884i	—0·267—0·134i	0·015—0·035i	—0·009—0·013i
Case D	,, ,,	—0·275—0·079i	,, ,,	—0·009—0·014i

Cases	Closed	Open	Step
	A	B	Pure theory[1]
	C	D	Semi-experimental theory

Note: The mass inertias, given in the first line, are reduced by the mass of the water cylinder, surrounding the wing, and the square of half the wing chord. The remaining numerical values represent the total 'air'-reactions; these air-reactions are reduced in such a way as to show effective aerodynamic inertias comparable with the mass inertias in the first line.

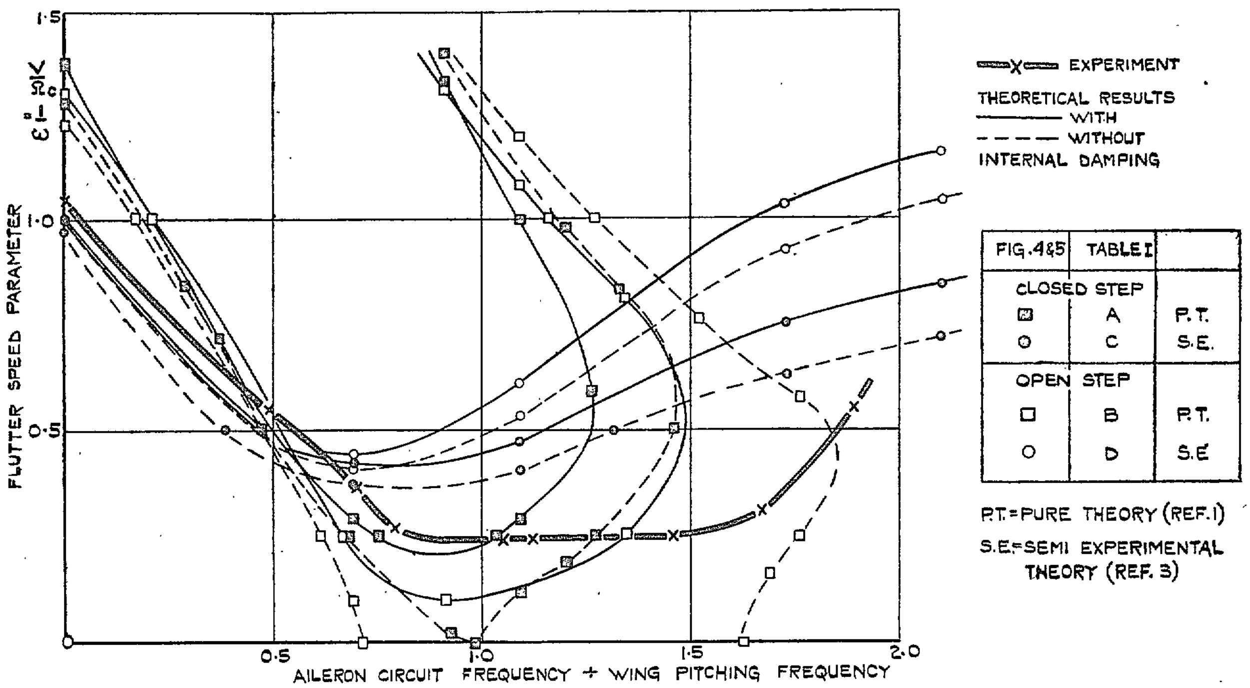

FIG. 4. Variation of flutter speed parameter with aileron circuit frequency.

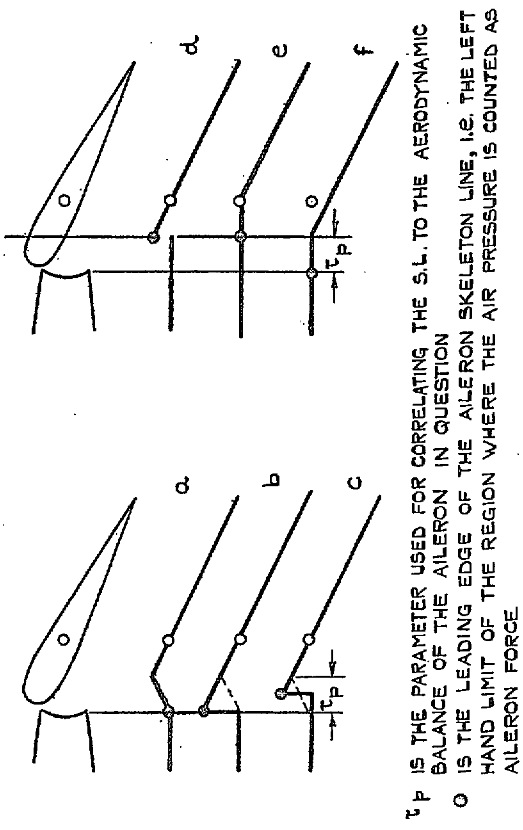

FIG. 1. Wing—aileron skeleton lines.

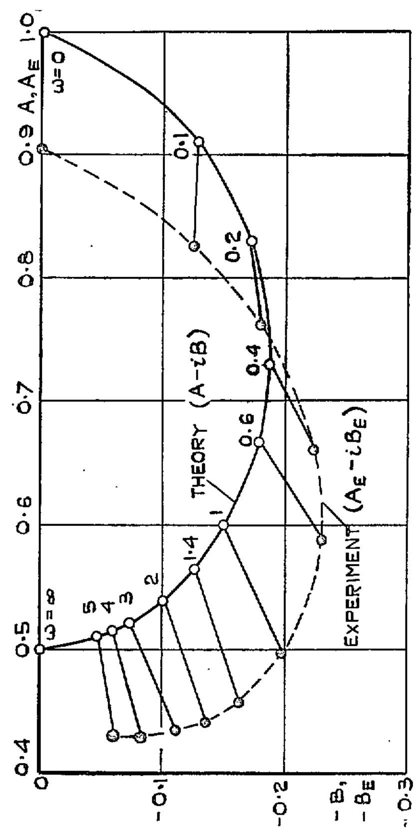

FIG. 2. Theoretical and experimental circulation functions (Drescher).

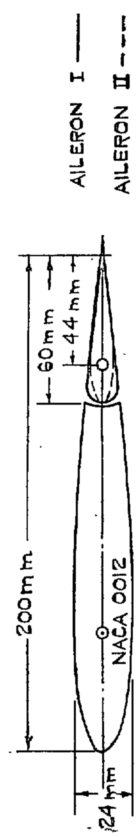

FIG. 3. Model for flutter experiments.

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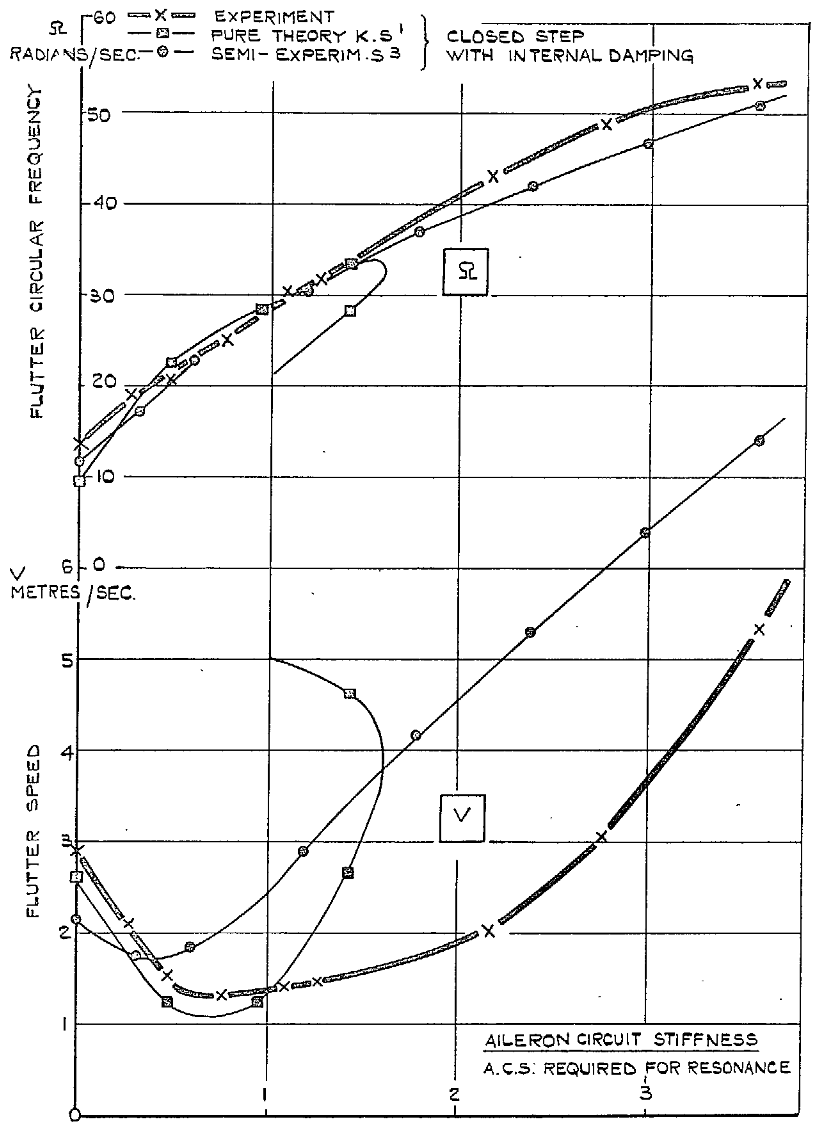

FIG. 5. Variation of flutter speed and frequency with aileron circuit stiffness.

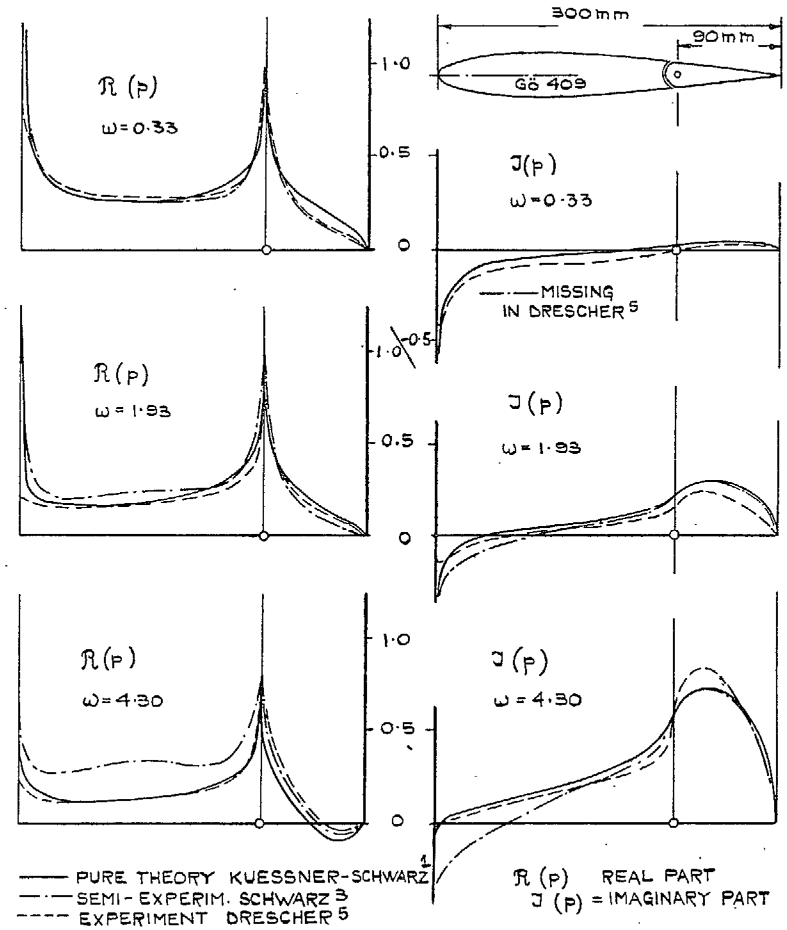

FIG. 6. Theoretical and experimental pressure distributions $p(x, t)$ (Drescher).

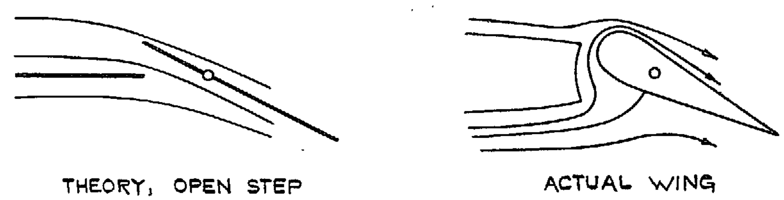

FIG. 7. Flow through wing aileron gap (diagrammatic).

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