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AERO-ELASTIC EFFECTS ON THE STABILITY AND CONTROL OF AIRCRAFT DESIGNED TO OPERATE AT MACH NUMBERS UP TO 2.5

by

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Aero-elastic effects on the stability and control of aircraft designed to operate at Mach numbers up to 2.5

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SUMMARY

Aero-elastic effects on longitudinal stability and control and on lateral control are discussed. An assessment is made of the types of deformation and associated aero-elastic phenomena that are likely to be of most importance. The results of calculations of the effects of fuselage bending on longitudinal stability and control are given for some typical designs and attention drawn to the need to review the present AP.970 fuselage stiffness requirements. In dealing with the choice of lateral control, consideration is given to devices for reducing distortion effects and control hinge moments and to the associated problem of powered controls.

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ILLUSTRATION

1 Introduction

Apart from the problem of flutter which will not be discussed in this paper, the aero-elastic phenomena which have received most attention from designers are:-

(a) wing divergence

(b) aileron reversal and the associated problem of rolling effectiveness throughout the speed range

(c) the variations in longitudinal stability and control due to the effects of structural deformation.

Reference 1 gives a brief review of the development of the subject up to the advent of swept wings and the achievement of high subsonic speeds. Present day designs, for supersonic aircraft, differ radically in geometric layout from the earlier aircraft and it is therefore desirable to consider what types of distortion are likely to be important for these new designs, to assess the adequacy of existing methods of estimation and, if necessary, to devise new methods.

2 Aircraft configurations and flight plans

The designers of large (bomber or long-range reconnaissance) aircraft appear to agree that the wings should have low aspect ratios of the order 1.5-2.0, but there are differences of opinion as to whether the planform should be triangular, or substantially unswept and moderately tapered, or something in between. Similarly, fighter designers agree, for the most part, on a wing of aspect ratio of about 2.5-3.0, but once again there is a diversity of views regarding planform.

A very long fuselage (2-3 times the wing span) of fineness ratio about 20, is usual in projected long range aircraft and many designers locate the horizontal control surface ahead of the wing in a canard arrangement.

Fighter fuselage lengths are likely to be from 1.5 to 2 times the wing span with a fineness ratio of 12-15; tail aft, canard and tailless (delta) designs all appear to be under consideration.

In general, tailplanes and foreplanes may be expected to have aspect ratios of the same order as those of the respective wings.

In a long range M = 2.5 aircraft with unswept wing, the engines will probably be concentrated in nacelles at the wing-tips, while in a delta design they may be (partially) buried in the wings over the inboard parts of the span. In the fighters, the engines are likely to be located in the fuselage although some designers might favour (inboard) wing engines.

The magnitude of a particular aero-elastic effect in a given flight condition depends on the combination of equivalent air speed and Mach number. If the maximum permissible E.A.S. can be attained at the Mach number for which the relevant (rigid) aerodynamic derivatives attain their peak values, this combination will probably produce the maximum effect although it will not necessarily be critical for the behaviour of the (deformable) aircraft itself, since the behaviour of the corresponding rigid aircraft is a function of Mach number*. If the maximum permissible E.A.S. at ground level corresponds to $M > 1$, however, the maximum aero-elastic effect may occur at a lower E.A.S. corresponding to a transonic Mach number at, or near, the value for which the aerodynamic derivatives peak.

Speed-height envelopes corresponding to typical flight plans for the aircraft are shown in Fig.1. Plans 1 and 2 represent alternative speeds of climb for reconnaissance or bomber aircraft. Plan 3 is typical for a fighter aircraft. It seems improbable that the large aircraft will exceed the flight plan speeds in normal practice, except inadvertently by a small amount - say 5%. Thus for these aircraft, the design speed height envelopes can probably be obtained from the flight plan envelopes by increasing speeds everywhere by 5%. On the other hand, the fighters may well be required to operate to the right of the normal flight-plan boundary ((3) in Figure 1) below 36,000 feet. Thus for practical design purposes, the design speed-height envelope would probably be derived from the hypothetical flight-plan envelope (3') of Figure 1, consisting of a constant E.A.S. line ($V_E \approx 710$ knots) below 36,000 feet and a constant Mach number line ($M \approx 2.3$) above that height.

3 Assessment and estimation of aero-elastic effects

All the aircraft under consideration have wings of low aspect ratio (less than 3). Because of this the wing cannot, strictly speaking, be treated, either structurally or aerodynamically as if isolated from the fuselage. Simple structural conceptions such as the flexural axis and associated distributions of bending and torsional stiffness are quite inadequate for specifying the deformation characteristics of the wing and recourse must be made to some form of influence coefficients. Preferably the structural properties of the complete aircraft rather than of the wing alone should be specified in this manner. An approach to the problem along these lines has recently been suggested by Williams[2,3]. He has demonstrated[2] in principle how, with the aid of an automatic digital computer, a set of structural influence coefficients can be calculated for a network of spanwise and chordwise points. For this method to be fully effective[3], a set of corresponding aerodynamic influence coefficients is required which would specify not only the characteristics of the individual components, but also their mutual interference effects. This information is not available, but the method is so comprehensive that it must be a powerful incentive for aerodynamicists to set about devising an adequate theory. The information will be needed for three regimes of flow - subsonic, transonic and supersonic. The need to include shock wave and boundary layer effects presents a serious obstacle to the development of a theory valid in the transonic range, so that at present we must rely mainly on slender wing-body theory backed up by such experimental information as is available. Existing theories[4,5,6] give only a limited amount of data on the loading of wings at subsonic and supersonic speeds; they require experimental verification and also need to be extended and modified[7,8] to be more generally applicable. The use of a digital computer will probably be necessary in this connection.

*For example, in manoeuvre point considerations, the maximum forward shift due to (say) wing deformability might occur at maximum E.A.S., associated with a transonic Mach number, for which a rearward movement of rigid wing aerodynamic centre would have occurred. The resulting manoeuvre point position would not necessarily be the most forward that could occur.

Particular developments of the linear theories envisaged are the provision of more detailed chordwise variations of aerodynamic loading, which will be necessary for thin wings of low aspect ratio, especially if some form of camber is envisaged for these wings. It is probable that the work of Multhopp[9] could be suitably modified to account for the chordwise variations in more detail, while the theory put forward by Wieghardt[10] might also be developed to deal with the low aspect ratio wings of various planforms.

Until a method is developed which enables the integrated aero-elastic effects on the whole aircraft to be calculated, the problem must be dealt with piecemeal, deriving the affect of each component in turn.

3.1 Effect of wing deformability

3.11 Longitudinal stability and control

Because of the low aspect ratio of the wings it may be inferred, on the basis of past experience, that the effect of wing "elastic washout" on longitudinal stability and control will be quite small, particularly for the larger aircraft. However, the effects of "elastic camber", which in the past have often been ignored*, are now likely to be at least as important as those of elastic washout and the overall effects of wing deformability should therefore not be dismissed as negligible until sample calculations have been made.

For the purpose of estimating such effects, information is required about the deformation of the wing under a distributed load. This may be supplied in several ways, one of the simplest being to express it in terms of the deformations of a series of chordwise strips forming the wing. A more comprehensive method, which has to be used when chordwise deformations have to be taken into account, is to use a set of influence coefficients, as mentioned earlier. In the latter form, the data are directly applicable to calculations as outlined in Ref.3 but they are also capable of being presented in forms which may be more suitable to the other methods of calculating aero-elastic effects. The information may, for instance, be converted to the form used by Broadbent in Ref.12 and then the wing loading problem may be solved, allowing only for elastic washout, by any method applicable to the planform and Mach number under consideration. To the references already given we may add 13, 14 and 15 (subsonic), 16 (supersonic flow with wing leading edges subsonic) and 17 (applicable in principle to subsonic and supersonic flow).

The loading of the wing with elastic washout may now be used, in conjunction with the original set of structural influence coefficients, to obtain a first approximation to the distribution of elastic camber, whose effect on the wing loading can then be found, using a suitable method (e.g. Multhopp two chordwise point solution for subsonic conditions[9]). An iterative process could be employed to refine the estimate.

It should be remembered, when investigating the effect of wing deformability on (say) the manoeuvre point, to include not only the direct effect on the wing aerodynamic centre, but also the changes in fuselage and tailplane contributions to manoeuvring stability, resulting from the wing elastic washout and camber. (See for instance Ref.11 Part II).

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* But see Ref.11 where Fingado and Taylor have derived approximate formulae for calculating elastic camber and its effect on manoeuvre point.

Account should also be taken of inertial loads due to distributed or concentrated weights in the wing. In this connection wing-tip engines might produce important effects.

3.12 Lateral control

The importance of wing deformation in relation to lateral control probably does not diminish with decreasing aspect ratio as rapidly as it does for longitudinal stability, and a reasonably accurate assessment of the effect of wing deformation on rolling performance must certainly be made. In general, considerations of wing flutter or aileron reversal determine the wing weight[18] (wing divergence is usually less important) and therefore the problem of aileron reversal must be considered at an early stage of the design.

In passing, it should be mentioned that the requirements in rolling performance of the new fighters and bombers do not appear to be well defined. Some clarification of these requirements would be most useful, and would provide guidance in the selection of the type of lateral control i.e. trailing edge flap aileron, all-moving tip, spoiler or some combination of these.

There are several methods[12,19,20,21,22,23] available for calculating aileron reversal speeds, and one attempt has been made to put the results in chart form[23] thus giving a rapid method of estimating the reversal speed for a given configuration. All these methods have serious limitations resulting from the simplifications introduced in order to obtain the structural deformations and the aerodynamic loading.

A marked advance has recently been made by Broadbent*, applying the aerodynamic information available from Multhopp[9] to the problem of aileron reversal, using semi-rigid theory. The first four modes of distortion were taken into account; the number can of course be increased, but at a greatly increased cost in computing time. This method allows for the effects of distortion on the spanwise loading of the wing, but no chordwise distortions were considered. It is probable that an extension of Multhopp's theory, allowing for chordwise loading changes, could be fitted into the existing method provided the structural data were available for the wing, but the computational labour might increase prohibitively.

For supersonic flow, some work has recently been done at the NACA[24] on a rectangular planform using linearised lifting surface theory. This has been simplified in a later paper[25] and extended nominally to cover swept-back wings. Chordwise deformations are neglected.

These methods are logical extensions of existing techniques, using more sophisticated aerodynamic data, and allowing for the effects of distortions on these data, but they are a long step from the approach of reference 3 which has been discussed in Para. 3.11 and which is equally applicable to the problem of aileron reversal.

3.2 Effect of tail-plane or fore-plane deformability

Because, like the wings, the tailplanes or fore-planes of the new aircraft are going to be of small aspect ratio, their deformability is not

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* This work has not yet been published (September 1955). Our thanks are due to Mr. Broadbent for letting us see his calculations at such an early stage.

likely to be of great significance in considerations of stability and control. We should not, perhaps, dismiss the effect as completely negligible, without making some representative calculations. The essential aero-elastic problem here is exactly the same as for the wings and must be tackled by similar methods.

3.3 Effect of fuselage deformability

The distortion of the long slender fuselage, which is a prominent feature of many of the aircraft to be considered, is likely to give rise to the most serious effects on longitudinal stability and control.

Bending of the various portions of the fuselage will, of course, influence the lift and pitching moment contributions of the fuselage itself and also the various contributions due to the interference with wing and tailplane/foreplane. In view of the difficulty and uncertainty of estimating these contributions, even for the rigid aircraft, it is doubtful whether any worth-while attempt can be made to estimate the relevant deformability effects. It is, however, as well to remember the existence of such effects when attempting to account for any apparent discrepancies that may be found to exist between calculations and experimental results when an aircraft flies.

A more serious effect, but one which is more amenable to approximate calculation, arises from the change in effective tail-plane or fore-plane setting, (relative to the wing) due to bending of that part of the fuselage lying between the wing and tail-plane/fore-plane root attachments.

A qualitative survey of this effect applicable to the conventional tail-aft lay-out is given by Lyon and Ripley in section 3.30 of Ref.26 and Campion also discusses it in Ref.27. For such a lay-out, the effect of fuselage bending is to reduce the tail-plane setting by an amount proportional to the upload on the tail and thus to reduce the effectiveness of the tail unit when functioning either as a fixed stabilizing surface or as a movable control surface, (i.e. A_1, A_2* are both reduced progressively as speed increases, although A_1/A_2 remains unchanged).

The manoeuvre margin H_m is reduced progressively as speed increases, while the control angle per 'g' is reduced by an amount which is independent of speed for a given c.g. position.

The static margin K_n is given approximately by

$$K_n = -\bar{V} A_2 \cdot \frac{d\eta_o}{dC_L} \qquad (1)$$

where the slope of the trim curve $\left(\frac{d\eta_o}{dC_L}\right)$ is unaffected by fuselage bending if $C_{m_o} = 0$. In that case (assuming $\frac{d\eta_o}{dC_L} < 0$ for the rigid aircraft) K_n will decrease due to fuselage bending (because A_2 decreases) but

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* A_2 will here be used to denote tailplane/foreplane lift slope with respect to control deflection whether the control is an elevator or an all-moving tailplane. (Note that in general, in the latter case, $A_2 \neq A_1$).

cannot become negative. If, however, $C_{m_o} < 0$, bending of the fuselage will have an increasingly destabilizing effect on trim curve slope as the speed increases so that $\frac{d\eta_o}{dC_L}$ may even become positive. Thus the static margin K_n will decrease more rapidly with increasing speed than in the $C_{m_o} = 0$ case and may become negative.

In a canard arrangement, the effect of fuselage bending is to increase the foreplane setting by an amount proportional to the up load on the foreplane, and thus to increase A_1 and A_2. Since, in the expression for manoeuvre margin, the main contribution (excluding rotary damping) due to the foreplane is of negative sign (destabilizing) and since this contribution is proportional to A_1, it follows that the manoeuvre margin is reduced by fuselage bending, as in the case of the conventional (tail-aft) lay out. Control angle per 'g' is again reduced by an amount which is independent of speed for a given c.g. position.

The static margin K_n will still be given by equation (1) if $\overline{V}$ is taken to be negative for a fore-plane. The slope of the trim curve $(d\eta_o/dC_L)$, which will now be positive for stability, will again be unaffected by fuselage bending if $C_{m_o} = 0$, so that since A_2 has increased, K_n will have increased as the result of fuselage bending. If, however, $C_{m_o} < 0$ there will be required on the foreplane an upload which increases with speed. Since, in the presence of a flexible fuselage, this would lead to an increment in effective foreplane setting which also increased with speed, it follows that the control angle to trim with a flexible fuselage must be less than that required with a rigid fuselage, by an amount which increases as the speed increases, i.e. as C_L decreases. Thus the positive (stabilizing) slope of the trim curve against C_L will be increased by fuselage bending. With A_2 also increasing, K_n will increase more rapidly with increasing speed than in the $C_{m_o} = 0$ case.

In following the analysis of Ref.26 it should be noted that compressibility effects, which in practice will always be present as well as structural deformability effects, have not been explicitly considered, although as Campion[27] points out, the formulae deduced for A_1/a_1, A_2/a_2 etc. allowing for fuselage bending, may be applied quite generally if a_1, a_2 etc. are interpreted as the values of A_1, A_2 etc. when compressibility and any distortion effects other than fuselage bending are included.

In studying the behaviour of the static margin in the presence of both compressibility and structural deformability it may help to use the generalized expression for K_n:-

$$K_n = -\left[\frac{\partial C_m}{\partial \alpha} \Big/ \frac{\partial C_R}{\partial \alpha}\right]\left\{1 + \frac{1}{2C_R}\left(M\frac{\partial C_R}{\partial M} + \delta\frac{\partial C_R}{\partial \delta}\right)\right\}$$

$$+ \frac{1}{2C_R}\left(M\frac{\partial C_m}{\partial M} + \delta\frac{\partial C_m}{\partial \delta}\right) \qquad (2)$$

introduced in Ref.28*. Here the dependence of C_m, C_R on speed in virtue of both compressibility and deformability effects, is explicitly recognised by the inclusion of the terms in M and δ respectively, where M is the Mach number and δ is a proposed "Aero-elastic number" which, like M, is directly proportional to speed and which involves some elastic characteristic of the airframe. Provided C_m and C_R (or C_L, in cases where $C_R \approx C_L$) can be expressed analytically or graphically as functions of α, M and δ over the significant ranges of these parameters, it is a straightforward matter to evaluate K_n, although if some of the derivatives have to be obtained graphically, the estimate may be somewhat inaccurate.

Rough estimates of the effects of fuselage bending on longitudinal stability have been made for some typical designs of large supersonic aircraft employing the canard layout. The fuselage fineness ratios varied between 15 and 21 while the wing planforms were representative of the widely differing types that might be advocated for such aircraft. The values of the fuselage flexibility factor k_f (Rotation of tailplane/foreplane chord relative to wing chord due to unit load applied at the tailplane/foreplane) required to apply the methods of Ref.26 to the computation of A_1/a_1 etc. were supplied by Structures Department, R.A.E. This factor k_f is related to the fuselage vertical stiffness F_{f_1} involved in the AP.970[29] Stiffness Criterion, by the equation

$$F_{f_1} = \frac{2\ell}{k_f}$$

where ℓ, the tail arm, is defined[29] as the distance between the wing root quarter chord point and the elevator hinge line. This definition is unrealistic when applied to supersonic design, especially so for highly swept delta wings, and alternative definitions had to be adopted to suit the individual geometries.

The values of the AP.970 criterion as estimated lay between 0.06 and 0.09, whereas the minimum required value is 0.12. The maximum values of A_1/a_1 ($= A_2/a_2$) lay between 1.4 and 1.8 and the corresponding losses in manoeuvre margin, ΔH_m, were between 0.09 and 0.14, the upper of which values is somewhat excessive while the lower is perhaps marginal.

It must be stressed that these are typical designs. Since the criterion is proportional to the square root of the stiffness, the weight increases required to make the designs satisfy the present requirements would be prohibitively large. Nevertheless it would seem desirable to aim at a value of 0.09 for the criterion to keep the fuselage bending within reasonable bounds.

It is clear that the AP.970 requirement needs revision, as regards both the definition of the criterion, in relation to supersonic designs, and the minimum value which is to be achieved.

Estimates were also made of the effect of fuselage deformation on static margin. In one of the worst cases, at M = 1.25 and V_E = 600 knots EAS, (Plan 1 Fig.1) K_n increased due to deformation from 0.15 to about 0.35. It was calculated that due to fuselage bending the incremental

* Terms in Reynolds number R are omitted as being of no significance in the present context.

control plane deflection required to produce a 10% change of speed (from 600 knots) would be increased from 0.38° to 0.66°.

4 Effects on dynamic longitudinal stability

Consideration should be given to the question of including deformability effects in dynamic stability investigations. To include such effects directly means, that in setting up the equations of disturbed longitudinal motion, one or more freedoms, corresponding to the more important structural flexibility modes, must be admitted in addition to the rigid aircraft freedoms usually considered. In Ref.30 the freedom associated with a flexible wing mode was introduced, as was also the case in Ref.31, which deals with the gust response problem. For aircraft of the type that we have been considering, it seems possible that the fuselage bending mode might be more important than the wing mode. A formulation of the dynamical equations for an aircraft with flexible fuselage (represented by a single semi-rigid bending mode) is given by Duncan in Ref.32, where it is shown that the determinantal equation for the free motion is a sextic. Duncan also shows that if the rigid aircraft frequencies are sufficiently small compared with the lowest natural frequency of the structure involving distortion of the type considered, the characteristics of the aircraft stability modes may be obtained with reasonable accuracy from the standard equations, provided that the aerodynamic derivatives are modified to allow for deformability (and compressibility) on a quasi-steady basis. McLaughlin, in Ref.30, makes a comparison between results obtained by this and other simplified methods on the one hand and by the direct method on the other. Although the quasi-static approach appeared to yield a good approximation in some cases, agreement between results obtained by this method and by the direct method in other cases was poor.

Further exploratory investigations of this type are needed to establish the circumstances in which such simplified methods can be satisfactorily applied to the estimation of the short period longitudinal stability characteristics of the coming generation of supersonic aircraft.

5 Longitudinal stability and control - General Discussion

The most important aero-elastic effect on longitudinal stability and control of the type of aircraft under consideration will probably be that due to fuselage bending. The effects of wing and tailplane/foreplane distortions should be small; however some sample calculations are desirable to confirm this.

The results of some calculations on typical configurations of large supersonic aircraft suggest that the effect of fuselage bending is quite considerable and that allowance should be made for it in all stability and control estimates. Only comprehensive calculations, incorporating both compressibility and deformability effects, and covering the entire range of operating conditions, can provide a satisfactory basis for deciding, in a particular case, whether the effects of fuselage bending can be tolerated or whether the fuselage stiffness should be modified.

In this connection, consideration might be given to the possibility of counteracting an undesirably large fuselage bending effect by an approximately equal, but opposite, effect due to elastic washout of the foreplane. This would necessitate using a foreplane of fairly high aspect ratio and sweepback. Such a procedure could make possible a considerable weight saving, but would depend for its success on the designer's ability to calculate accurately the large separate effects of fuselage bending and foreplane elastic washout.

6 Lateral control - general

No discussion of aero-elastic effects on lateral control is complete without some consideration being given to means of alleviating the distortions due to the trailing edge flap type control and also of alternatives to this control.

The suitability of any proposed form of lateral control must be assessed from several points of view: the purely aerodynamic (effectiveness and control forces when associated with a rigid wing), the aero-elastic, and the engineering. Although the concern of the paper is primarily with aero-elastic problems it is not advisable when attempting to decide on the optimum form of control to divorce the aero-elastic considerations from the remainder. In particular, some thought must be given to the question of aerodynamic balancing of controls and to the related problems of powered controls.

6.1 Types of lateral control

There are three main types of lateral control: trailing edge flap aileron, all-moving tip aileron and spoiler, between which there are considerable variations in aerodynamic properties. Although the moving tip control looks the most attractive from the aerodynamic and aero-elastic points of view, the engineering difficulties associated with taking loads through a single bearing may tell against it. The spoiler, to be effective at incidence, usually requires the wing to be vented, which means cutting slots in the surface of the wing, a measure to be avoided unless the slots can be cut in a position where they will not affect the structural properties of the wing. These difficulties may force the use of the more conventional trailing edge flap ailerons with their adverse aero-elastic effects.

Another solution may be to go to a trailing edge flap control with a large horn balance; this is a compromise which might enable a reduction to be made in hinge moments while at the same time making it possible to take the aileron loads into the wing in a conventional manner.

6.2 Aerodynamic balancing of controls

At subsonic speeds several devices are available for the reduction of control hinge moments. They include inset tabs, horn balances and set-back hinge lines. At transonic speeds most of these devices detract more from the control effectiveness available than at subsonic speeds and are of questionable value..

It is difficult to calculate theoretically the effects of these devices at supersonic speeds because they are either placed at the trailing edge in the thickest part of the boundary layer or depend upon interference effects between the tab and the main control, or are influenced by shock waves or sudden expansions. They may also present an engineering problem, and their effect upon control flutter would have to be investigated.

Some experimental work has been done by the NACA[33,34,35,36] on various tab devices and also set-back hinges at transonic and supersonic speeds. So far, the results have not been very encouraging. Some tests on paddle balances[35] are very interesting, but the drag penalty would appear to be high. The effectiveness of these devices appears to be limited to fairly small ranges of control deflection and incidence.

6.3 Powered controls

There are two problems here (i) the strength and thus the weight of the jacks required to deflect the controls and (ii) the power requirements.

If the controls were designed in the first place to minimize both requirements the all moving tip would appear to be the best solution. But if the control is given, anything that can be done to reduce the hinge moments should be beneficial to the first, but may not be to the second, because to obtain the same rolling effectiveness for reduced hinge moment usually requires a larger deflection of the control. The deflection work given by

$$b_f.\bar{c}_f^{\,2}\left[\int_0^{\xi} C_h\, d\left(\frac{\xi}{57.3}\right)+\int_0^{-\xi} C_h\, d\left(\frac{\xi}{57.3}\right)\right]$$

is a useful criterion for the amount of energy required to be supplied to the power control system. How quickly the deflection of the control is effected will govern the power requirements of the control system.

It is possible that for some aircraft, the power requirements will be fixed by the response at low speed, i.e. by the landing and take-off case. Here we may require a quick response, and it will necessitate the maximum deflection of the controls in a short time. The problem of power requirements is discussed in more detail in a paper by Hadekel[37]. The high E.A.S. requirement on control effectiveness may well fix the jack sizes and also the wing weight. The criterion at all speeds should preferably be based on the response of the aircraft to control deflection, which will call for high rates of deflection of the controls.

7 Conclusions and Recommendations

For the type of supersonic aircraft considered in this note,bending of the fuselage seems likely to prove the most important type of structural deformation affecting longitudinal stability and control. The AP.970 requirements for fuselage stiffness should be reviewed since, in their present form, they are not strictly applicable to supersonic aircraft, and the minimum value demanded for the vertical stiffness criterion is likely to prove unattainable. It should be noted that whereas with a tail-aft layout, fuselage bending reduces A_2,the reverse is the case for a canard arrangement. The designer of a canard'aircraft must therefore reckon with increased control effectiveness at high E.A.S. near $M = 1$, where the controllability of the rigid aircraft would already be at its most sensitive.

Because of the low aspect ratios to be used, deformability of the wings and tailplane/foreplane is not likely to produce very serious effects on longitudinal stability and control. However, some sample calculations should be made, investigating in particular the effects of elastic camber and elastic washout. The deformability of the wing will still have important effects on lateral control.

A general method of solution for calculating these aero-elastic effects has been suggested by Williams, who has also given a suitable method for obtaining the structural information, but as yet no general method is available whereby the aerodynamic information applicable to current aircraft designs at subsonic and supersonic speeds can be obtained. Pressure plotting would be essential to obtain the necessary aerodynamic information at transonic speeds. An effort should be made to develop the necessary aerodynamic theory.

Until the comprehensive method is fully developed use has to be made of some of the existing methods, which are adequate for the present, provided the basic structural and aerodynamic information can be obtained to the requisite degree of accuracy.

Further exploratory investigations are necessary to establish whether approximate methods (e.g. the quasi-steady approach using derivatives modified for deformability effects) will suffice for determining the short period dynamic stability characteristics of the new aircraft or whether when setting up the equations of motion, degrees of freedom corresponding to the more important flexibility modes should be introduced as well as the usual rigid aircraft freedoms.

Despite their aeroelastic disadvantages, trailing edge flap ailerons may have to be employed for lateral control. Devices for reducing the hinge moments of such controls may be suggested on the basis of subsonic experience, but they are not very amenable to theoretical treatment transonically or supersonically, and experimental evidence would be necessary for their evaluation.

LIST OF SYMBOLS

A_1, A_2	$\frac{\partial C_{L_T}}{\partial \alpha_{T_o}}$, $\frac{\partial C_{L_T}}{\partial \eta_o}$ respectively
C_h	control hinge moment coefficient
C_L	aircraft lift coefficient
C_{L_T}	tailplane lift coefficient
C_m	aircraft pitching moment coefficient
C_{m_o}	value of C_m at $C_L = 0$
C_R	aircraft resultant force coefficient
F_{f_1}	fuselage vertical stiffness defined in Ref. 29
H_m	stick-fixed manoeuvre margin
ΔH_m	increment in H_m due to deformability
K_n	stick-fixed static margin
M	Mach number
S, S_T	wing area, tail- or fore-plane area
$\bar{V}$	tail- or fore-plane volume ratio, $= \frac{S_T \ell}{S\bar{c}}$
V_E	equivalent airspeed corresponding to flight condition under consideration
δ	aero-elastic number (Ref. 28)
a_1, a_2	values of A_1, A_2 when they are independent of δ (but not necessarily of M)
b_f	control surface span
$\bar{c}$	wing mean chord
$\bar{c}_f$	mean aerodynamic chord of portion of control behind hinge line
k_f	fuselage flexibility factor (Ref. 26)
ℓ	tail- (fore-) plane arm; positive for tailplane, negative for foreplane
α_{T_o}	tail- (fore-) plane root incidence
η_o	longitudinal control deflection
ξ	lateral control deflection (degrees)

REFERENCES

No.	Author	Title, etc.
1	A.S. Taylor	Methods of Investigating the Effects of Aero-elasticity on the Stability and Control of Aircraft: A Review of the Present Situation. RAE Technical Note No. Aero.2289, February 1954. ARC 16670.
2	D. Williams	(a) Recent Developments in the Structural Approach to Aeroelastic Problems. Journal Royal Aero. Society. June 1954. (b) A General Method (Depending on the Aid of a Digital Computer) for Deriving the Structural Influence Coefficients of Aeroplane Wings. RAE Report No. Structures 168, November 1954. ARC 17438.
3	D. Williams	Solution of Aero-elastic Problems by Means of Influence Coefficients. RAE Report No. Structures 169, November 1954. ARC 17439.
4	F.W. Diederich	Calculation of the Aerodynamic Loading of Swept and Unswept Flexible Wings of Arbitrary Stiffness. NACA Report 1000, 1950. Formerly NACA TN.1876, NACA/TIB/1889.
5	F.W. Diederich	Approximate Aerodynamic Influence Coefficients for Wings of Arbitrary Planform in Subsonic Flow. NACA TN.2092, July 1950.
6	F.W. Diederich K.A. Foss	Charts and Approximate Formulas for the Estimation of Aero-elastic Effects on the Loading of Swept and Unswept Wings. NACA Report 1140, 1953. Formerly NACA TN.2608.
7	H. Voepel	Tests on Wings of Small Aspect Ratio. RAE Library Translation No.276, October 1948. ARC 12450.
8	D. Küchemann	A Non-Linear Lifting Surface Theory for Wings of Small Aspect Ratio with Edge Separations. RAE Report No. Aero.2540, April 1955. ARC 17769.
9	H. Multhopp	Methods for Calculating the Lift Distribution of Wings (Subsonic Lifting Surface Theory). RAE Report No. Aero.2353, January 1950. R & M No.2884. ARC 13439.
10	K. Wieghardt	Chordwise Load Distribution of a Simple Rectangular Wing. NACA Technical Memo. No.963, December 1940.
11	H. Fingado A.S. Taylor	An Approximate Method of Estimating the Effect of Elastic Deformability of the Aircraft Structure on the Manoeuvre Point: General Introduction and Part I: The Effect of Wing Deformability. RAE Report No. Aero.2320, April 1949. ARC 12501.

REFERENCES (Contd.)

No.	Author	Title, etc.
11 (Contd.)		Part II: The effect of the deformability of the fuselage and of an unswept tailplane. RAE Report No. Aero.2362.
12	E.G. Broadbent	The Rolling Power of an Elastic Swept Wing. RAE Report No. Structures 85, July 1950. ARC 13639, R & M 2857, 1954.
13	B.A. Hunn	A Method of Estimating the Loading on an Elastic Airframe. Journal Royal Aeronautical Society, April 1952.
14	F.W. Diederich, M. Zlotnick	Calculated Spanwise Lift Distributions and Aerodynamic Influence Coefficients for Unswept Wings in Subsonic Flow. NACA TN.3014, September 1953.
15	J.J. Foody, L. Reid	The Solution of Aero-elastic Problems on Wings of Arbitrary Planform by Matrix Methods. Short Bros. & Harland Ltd. Aero Report No.66, January 1954. ARC 16671.
16	B.A. Hunn, G.N. Lance	An Aspect of the Deformation of Swept Wings in Steady Supersonic Flight. Journal Royal Aeronautical Society, November 1954.
17	R.B. Brown, K.F. Holtby, H.C. Martin	A Superposition Method for Calculating the Aero-elastic Behaviour of Swept Wings. Journal Aeronautical Sciences, Vol.18, No.8, August 1951. ARC 15011.
18	E.G. Broadbent	The Elementary Theory of Aero-elasticity. Bunhill Publications Ltd. 1954.
19	A.R. Collar, E.G. Broadbent	The Rolling Power of an Elastic Wing. R & M 2186. October 1945.
20	E.G. Broadbent, O. Mansfield	Aileron Reversal and Wing Divergence of Swept Wings. RAE Report No. Structures 9, September 1947.
21	J.R.M. Radok	Aileron Reversal and Divergence of Swept Wings with Special Consideration of the Relevant Aerodynamic and Elastic Characteristics. College of Aeronautics Report No.55, March 1952.
22	F.W. Diederich	Calculation of the Lateral Control of Swept and Unswept Flexible Wings of Arbitrary Stiffness. NACA Report 1024, 1951. Formerly NACA/TIB/1882.
23	F.W. Diederich, K.A. Foss	Charts and Approximate Formulas for the Estimation of Aero-elastic Effects on the Lateral Control of Swept and Unswept Wings. NACA Report 1139, 1953. Formerly NACA TN.2747.

REFERENCES (Contd.)

No.	Author	Title, etc.
24	J.M. Hedgepeth, R.J. Kell	Rolling Effectiveness and Aileron Reversal of Rectangular Wings at Supersonic Speeds. NACA Technical Note 3067, April 1954.
25	J.M. Hedgepeth, P.G. Waner, Jr. R.J. Kell	A Simplified Method for Calculating Aero-elastic Effects on the Roll of Aircraft. NACA Technical Note 3370, March 1955.
26	H.M. Lyon, J. Ripley	A General Survey of the Effects of Flexibility of the Fuselage, Tail Unit, and Control Systems on Longitudinal Stability and Control. RAE Report No. Aero.2065, July 1945. ARC 9015, (R & M 2415).
27	B.S. Campion	Estimation of the Effects of Distortion on Longitudinal Stability of Swept Wing Aircraft at High Speeds (Sub-Critical Mach Numbers). College of Aeronautics Report No.77, January 1954. ARC 16,683.
28	S. Neumark, A.S. Taylor, H.H.B.M. Thomas	Aero-elastic Number. RAE Technical Note No. Aero.2389, August 1955.
29	-	A.P.970, Vol.2, Leaflet 500/4.
30	M.D. McLaughlin	A Theoretical Investigation of the Short-Period Dynamic Longitudinal Stability of Airplane Configurations having Elastic Wings of 0° to 60° Sweepback. NACA Technical Note 3251, December 1954.
31	John C.Houbolt, Eldon E.Kordes	Gust-Response Analysis of an Airplane including Wing Bending Flexibility. NACA Technical Note 2763, August 1952.
32	W.J. Duncan	The Principles of the Control and Stability of Aircraft. (Chapter 12). Cambridge University Press, 1952.
33	D.R. Lord, C. Driver	Investigation of the Effect of Balancing Tabs on the Hinge Moment Characteristics of a Trailing Edge Flap Type Control on a Trapezoidal Wing at a Mach number of 1.61. NACA/TIB 4326. August 1954. NACA RM L54F22.
34	K.R. Czarnecki, D.R. Lord	Preliminary Investigation of the Effect of Fences and Balancing Tabs on the Hinge Moment Characteristics of a Tip Control on a 60° Delta Wing at a Mach number of 1.61. NACA/TIB 3745, May 1953. NACA RM L53 D14.
35	J.W. Boyd, F.A. Pfyl	Experimental Investigation of Aerodynamically Balanced Trailing Edge Control Surfaces on an Aspect Ratio 2 Triangular Wing at Subsonic and Supersonic Speeds. NACA/TIB 3610, February 1953. NACA RM A52L04.

REFERENCES (Contd.)

No.	Author	Title, etc.
36	V.E. Lockwood, J.E. Fikes	Preliminary Investigation at Transonic Speeds of the Effect of Balancing Tabs on the Hinge Moments and other Aerodynamic Characteristics of a Full-Span Flap on a Tapered 45° Sweptback Wing of Aspect Ratio 3. NACA/TIB 3078. April 1952. NACA RM L52A23.
37	R. Hadekel	Some Problems of Powered Flying Controls. ARC 16,925. March 1954.

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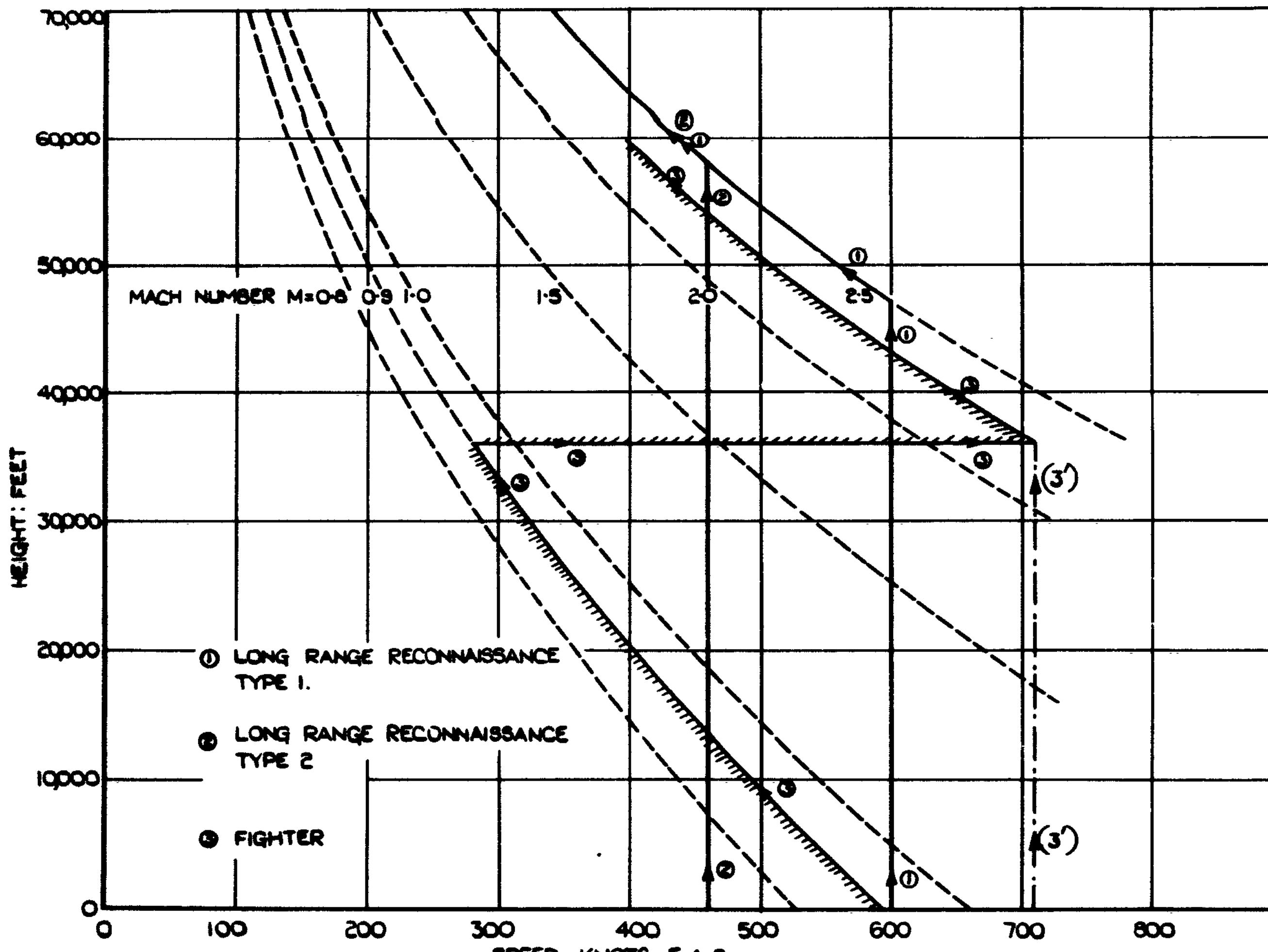

FIG. 1. SPEED - HEIGHT ENVELOPES CORRESPONDING TO TYPICAL FLIGHT PLANS FOR SUPERSONIC AIRCRAFT

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