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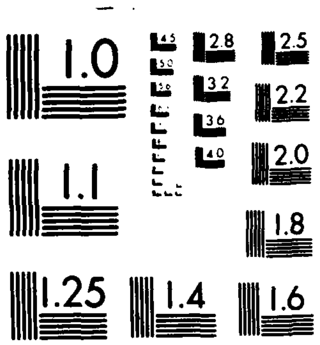

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AERODYNAMICS NOTE 413

PROPELLER POWER EFFECTS WITH WING FLAPS DEFLECTED

by

C. A. MARTIN

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PROPELLER POWER EFFECTS WITH WING FLAPS DEFLECTED

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C. A. MARTIN

SUMMARY

In this Note a model of the dynamic motion of a single-engine propeller-driven aircraft has been used to illustrate a longitudinal stability problem caused by the effects of power. In a recent general study on the effects of power the problem was shown to be due to changes in propeller slipstream dynamic head acting on a tailplane carrying a download. The problem is here studied in closer detail using the methods developed in the general study. A notable feature of the destabilising effect is that it increases as c.g. moves forward and so opposes the conventional stabilising effects associated with forward c.g. movement.

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CONTENTS

REFERENCES

NOMENCLATURE

FIGURES

DISTRIBUTION

DOCUMENT CONTROL DATA

1. INTRODUCTION

Because the propeller proved to be a key element in achieving the first power-driven flight in 1903 and is still used as the main method of producing thrust on low-speed aircraft, the effects of propellers on aircraft stability and control have been the topic of much research throughout the history of flight. During the 1930s and 1940s this topic was a major area of research in the national research agencies of Germany, Britain and the USA. With the advent of jet engines and swept-wing aircraft the research emphasis rapidly moved away from propeller-driven aircraft and has only recently been revived with the development of V/STOL aircraft and with developments in numerical analysis.

Throughout this period a large number of propeller-driven aircraft types have been flown and tested, and their power effects have been measured. Nothwithstanding this large amount of research and design experience, accurate theoretical methods for the estimation of propeller power effects do not exist. Furthermore, while the net effects of power are known, little published information exists on the way individual power effects accumulate to alter aircraft flying qualities. The deficiency in reliable design techniques for the estimation of the effects of power, is in fact evidence that the characteristics are very sensitive to small changes in aircraft layout.

A good discussion of the effects of propeller operation and power on Aircraft Flying Qualities was given by Phillips in 1948 (Ref. 1). In Reference 2 a digital computer has been used to calculate the flying quality parameters of a single-engine aircraft to illustrate these effects and to show how they are altered by changes in aircraft layout.

One effect described in Reference 1 and illustrated in Reference 2 results in a marked reduction in longitudinal stability. The effect occurs at low speeds with high power and with flaps deflected. Since this flight condition is frequently associated with poor longitudinal stability it has been studied in closer detail using the methods of Reference 2 and is the subject of the present Note.

2. LONGITUDINAL STABILITY

The effect to be illustrated involves aerodynamic coefficients which are functions of both incidence and speed and whose variation is nonlinear. However, the analysis is presented using conventional methods such as "trim curves" and "static stability" theory which can be related to general linear system stability theory. This approach can be justified since it gives a framework for identifying the main elements of the problem and also is still used widely for flight test analysis. The assumptions involved in this approach are outlined below.

The variation of pitching moment with incidence C_{m_α} termed the "pitch stiffness" is extremely important in determining longitudinal stability. When Mach number, aeroelastic and power effects are negligible on an aircraft, the equations describing aircraft motion can be simplified to a linear set such that positive "pitch stiffness" (C_{m_α} negative) becomes a condition for stability. This is the simple theory of "static stability" in which speed dependent terms are zero. In this theory a c.g. position termed the netural point and denoted h_n is defined such that:

$$C_{m_\alpha} = C_{L_\alpha}(h - h_n) \qquad (1)$$

where C_{L_α} is the aircraft lift curve slope, and

h is the longitudinal c.g. position.

For $h > h_n$, C_{m_α} is positive and the longitudinal motion of the aircraft will be unstable.

When power effects are present, the pitching moment becomes a function of speed as well as incidence. Providing these effects can be represented by linear equations, the condition for longitudinal stability is, as given in Reference 3:

$$(C_{L_\alpha} + C_{D_e})C_{m_V} - C_{m_\alpha}(C_{L_V} + 2C_{W_e}) > 0. \qquad (2)$$

As with the simple theory, a c.g. position can be determined which defines a boundary between stable and unstable longitudinal motion. This is termed in Reference 3 the longitudinal "static stability limit", h_s, and is given by:

$$h_s = h_n + C_{m_V}/(C_{L_V} + 2C_{w_e}). \tag{3}$$

In general the effects of power are non-linear but, if the study is confined to small disturbances about an equilibrium condition, then a linear model employing aerodynamic derivatives can be used and the parameters h_n and h_s are still applicable. The values of h_n and h_s will, however, change with changes in equilibrium condition.

In the flight measurement of longitudinal stability, the use of elevator "trim curves" has traditionally been used as a simple and informative method of analysis. It is shown in Reference 3 that the variation of elevator angle for trim with speed is a true criterion for stability and that the c.g. position for which this variation becomes zero is the "static stability limit" h_s. It is conventional practice in the analysis of flight measurements to interpret trim and stability changes from plots of elevator angle versus lift coefficient rather than speed, since in the absence of velocity-dependent and non-linear terms the plots against lift coefficient are linear while those against speed are parabolic. When these restricted assumptions do not hold, it is still more convenient to use lift coefficient for the abscissa, since the non-linear effects can be observed as non-linearities in the trim curves, and the curves are still good, if not absolute, indicators of stability.

3. ESTIMATION OF POWER EFFECTS

The main changes to the longitudinal forces and moments due to applying power on propeller-driven aircraft are listed in Reference 1 as:

(1) moment of propeller axial force about centre of gravity;
(2) moment of propeller normal force about centre of gravity;
(3) increased angle of downwash;
(4) increased dynamic pressure at the tail;
(5) changes in pitching moment of wing due to action of slipstream.

In Reference 2 these effects have been calculated using the estimation method of Reference 4 for the single-engine propeller-driven aircraft layout shown in Figure 1. This layout is termed in Reference 2 the "typical aircraft layout" since it possesses features similar to many modern single-engine aircraft, viz. the wing is located below the propeller thrust line and the tailplane above, with the thrust line located along the fuselage horizontal centre-line. The estimation methods are mainly based on techniques developed during the 1940s which combine a relatively elementary theoretical analysis of the important elements of the problem with empirical data obtained from experiment. At the current time numerical solutions for the aerodynamic forces on wings immersed in jets and propeller slipstream are under development. However, these techniques have not reached the level of routine design application and do not cover the full range of effects listed above. Consequently they have not been used in the present analysis.

Flying quality parameters have been determined using numerical solutions of the non-linear equations of motion for steady level and steady turning flight. Longitudinal derivatives are calculated by local numerical linearisation about the equilibrium conditions and permit the power effects listed above to be considered separately or in any combination.

4. EFFECT OF PROPELLER SLIPSTREAM ACTING ON A TAILPLANE CARRYING A DOWNLOAD

In Reference 2 it is shown that the aircraft layout in Figure 1 experiences a large decrease in stability at large lift coefficients when the flaps are deflected. Figure 2 shows the "trim curves" that would result from flight test measurement of this layout for forward c.g., maximum power and with flap angles of zero and 20°. With flaps deflected to 20° increased negative elevator angle is required to trim the increased nose-down pitching moment at the wing and body. This increased pitching moment results from an increase in negative C_{m_0} when flaps are deflected which is magnified by the presence of the propeller slipstream. However, because wing downwash is increased with flaps deflected, the increase in elevator angle required for trim is not as large as it would otherwise be. Flight measurement would also show that the tailplane load with zero flap would be negative only at high speeds (low lift coefficient) as shown in Figure 3 while with flaps deflected 20° the tailplane would carry a download at all speeds.

The slope of the trim curves (Fig. 2) reveals a reduction in stability with increasing lift coefficient both with flaps zero and 20°. However, for 20° flap there is a dramatic decrease above $C_L = 0{\cdot}94$; in fact the aircraft is almost neutrally stable at the forward c.g. This loss in stability is clearly shown in Figure 4 by the reduction in static stability limit h_s at high lift coefficient.

Normally it would be extremely difficult to infer from the trim curves and plots of h_s which of the listed power effects were responsible for the loss in stability. However, in the computer model developed in Reference 2 the power effects can be introduced separately or accumulated separately as shown in Figure 5. From this figure it can be seen that the main cause of the instability above $C_L = 0{\cdot}94$ is the effect of slipstream at the taliplane.

The plot of h_n in Figure 6 enables the loss in stability to be identified primarily as an incidence effect rather than a speed effect. Comparison of h_n with h_s (Fig. 4) shows that the speed derivatives, which account for the difference between h_s and h_n, are stabilising with flaps deflected, but are slightly destabilizing in the zero flap case. The stabilising effect with flaps deflected is caused by the effective increase in negative C_{m_0} due to increased dynamic pressure ratio at the wing when speed is reduced. This gives a positive C_{m_V} derivative which as shown in equation (2) is stabilising. This increase is reduced slightly at high C_L by the effect of the slipstream acting on the tailplane when it carries a download as discussed by Phillips in Reference 1. As speed reduces, the increased dynamic head ratio at the tail increases the tailplane download and so contributes a negative C_{m_V}.

For the aircraft layout considered, the major destabilising effect occurs as a result of incidence changes and is caused, as shown in Figure 7 by the tailplane entering a region of increasing dynamic pressure as incidence increases. Normally an increase in tailplane incidence produces increased upload but this effect is more than offset by the large increase in dynamic pressure above $C_L = 0{\cdot}94$ shown in Figure 8 which produces increased download. Since the tailplane download required for trim is greatest for forward c.g.'s the destabilising effect increases as c.g. moves forward. This effect differs strikingly from the classical result of simple static stability theory, in which "pitch stiffness" and stability increase as c.g. moves forward. The instability demonstrated in the example depends upon the vertical position of the tailplane and on the variation of dynamic head within the slipstream. For this study, the location of the slipstream is calculated according to the methods of Reference 4. The slipstream is assumed to be cylindrical with diameter equal to the propeller diameter as shown in Figure 7, and the dynamic head in the slipstream, which is assumed to be uniform, is estimated from the method of Reference 4. This representation is a significant simplification of the true situation as shown by the dynamic head distribution on Figure 9 taken from Reference 6. As such, it is likely that the power effects illustrated by the computer model exaggerate the loss in stability that would be expected in practice. A comparison of the effective dynamic head ratio for the model and for the distribution of Figure 9 is shown in Figure 10 for the case in which the tailplane is assumed to be entering the slipstream from above. While the increases of effective dynamic head ratio for the two cases shown are very similar it would be incorrect to infer from this one comparison that the estimation method is in general as accurate as indicated.

5. FLIGHT TEST RESULTS

The author is aware of two cases of aircraft with longitudinal problems similar to those described in this paper. In the first example reported in Reference 5 the aircraft was found to be unstable during the climb even at forward c.g. Relocation of the tailplane by using tailplane dihedral solved the problem. In the second example the aircraft exhibited longitudinal divergence at low speeds with power-on, flaps-deflected and forward c.g. The divergence did not occur at aft c.g. A complete analysis of these stability problems has not been carried out and would be difficult, because as previously discussed the effects of power are complex and theoretical methods of prediction having the necessary degree of accuracy do not yet exist. However, because of the strong similarity in the above flight conditions with those studied in this paper, it appears likely that the effect of propeller slipstream in combination with a download on the tailplane was a major factor in both cases.

6. CONCLUSION

In this Note a mathematical model of the longitudinal characteristics of a single-engine propeller aircraft is used to illustrate a stability problem associated with flight conditions of low speed, high power and flaps-deflected. The problem is caused by changes in propeller slipstream dynamic head acting on a tailplane carrying a download. In the example the tailplane download is needed to trim the wing/body moments due to flap deflection. The increase in dynamic head at the tail is caused firstly by an increase in thrust coefficient as speed reduces and secondly by the tailplane entering the propeller slipstream as incidence increases. In the example considered, the latter effect, which is critically dependent on vertical tail location, is dominant and results in the aircraft becoming almost neutrally stable at forward c.g. The example illustrates the difficulty of analysing power effect stability problems from flight test measurements and demonstrates the need for more accurate theoretical prediction methods.

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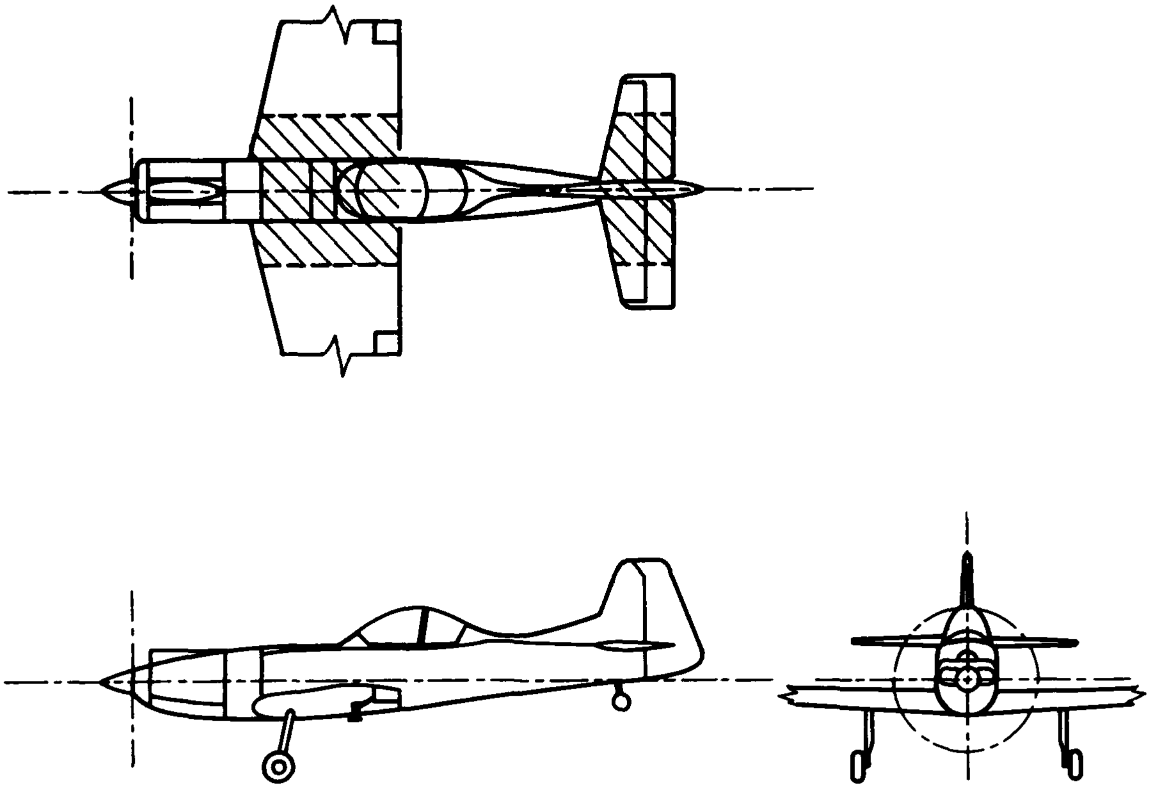
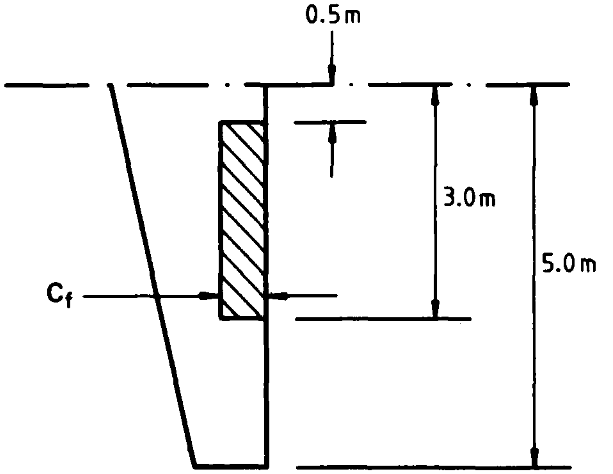
NOMENCLATURE

α	Aircraft incidence
c.g.	Centre of gravity
C_L	Lift coefficient
C_m	Pitching moment coefficient
C_{m0}	Zero lift pitching moment coefficient
C_w	Weight coefficient
h	Longitudinal c.g. position as fraction of MAC
h_n	Neutral point as fraction of MAC
h_s	Static stability limit as fraction of MAC
MAC	Mean aerodynamic chord
V	Forward speed

Subscripts

e	Equilibrium value





C_f/M.A.C. = 0.2

Details of single-slotted Flap

FIG. 1 AIRCRAFT LAYOUT USED IN THE STUDY

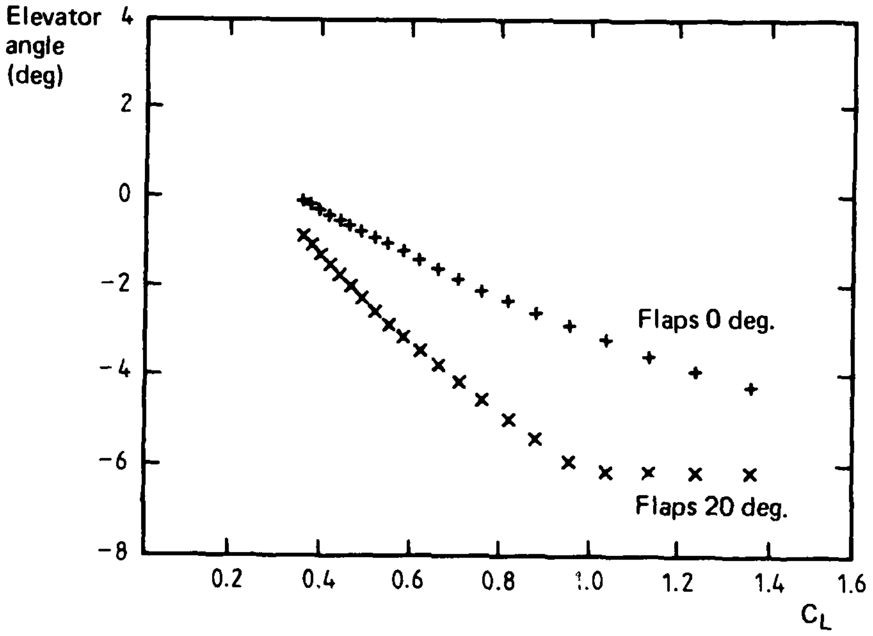


FIG. 2 TRIM CURVES POWER-ON FWD.C.G.

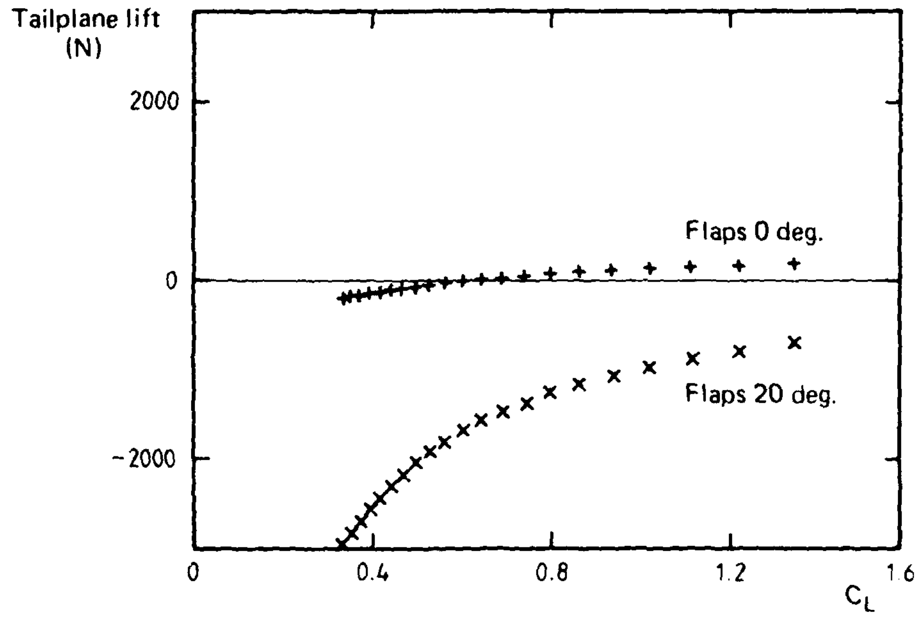


FIG. 3 VARIATION OF TAILPLANE LIFT POWER ON FWD. C G.

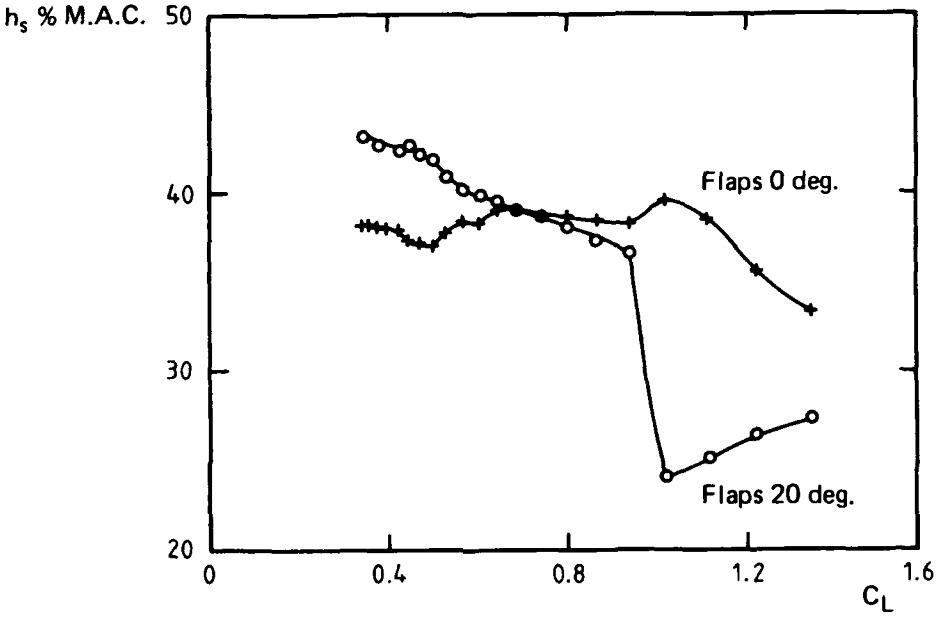


FIG. 4 VARIATION OF h_s WITH C_L POWER–ON

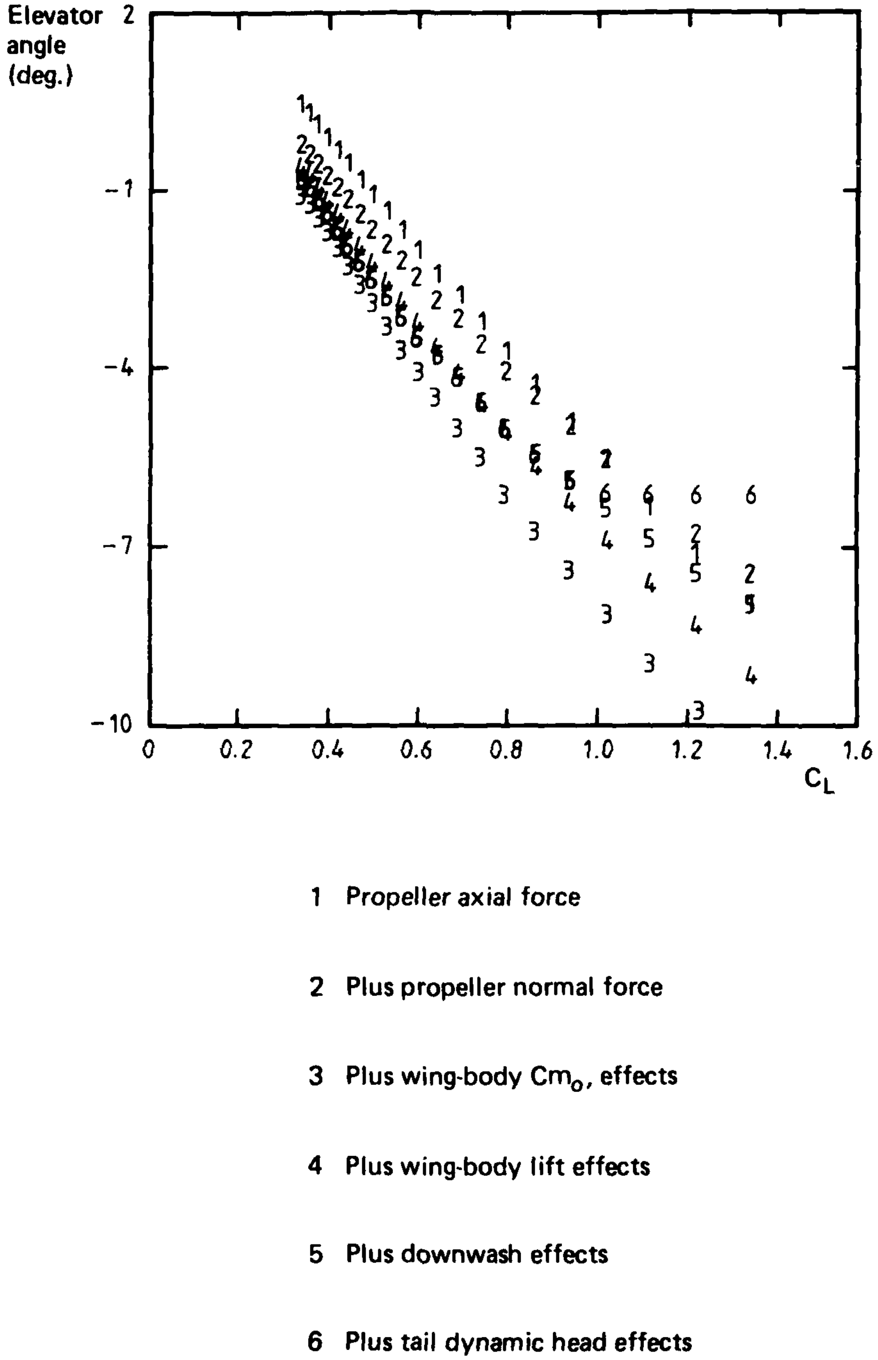


FIG. 5 ACCUMULATION OF POWER EFFECTS FLAPS 20 DEG. FWD. CG.

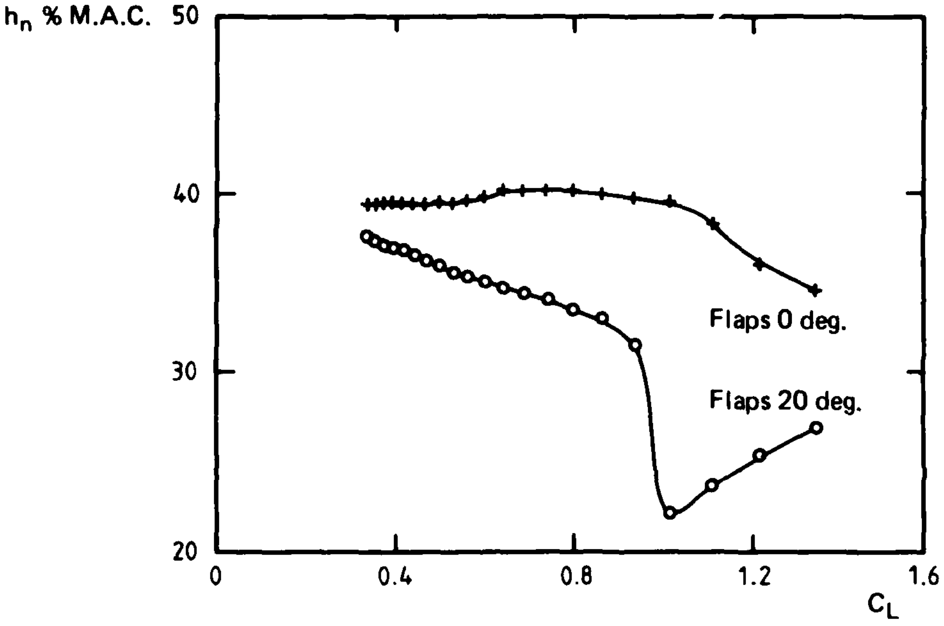


FIG. 6 VARIATION OF h_n WITH C_L POWER–ON

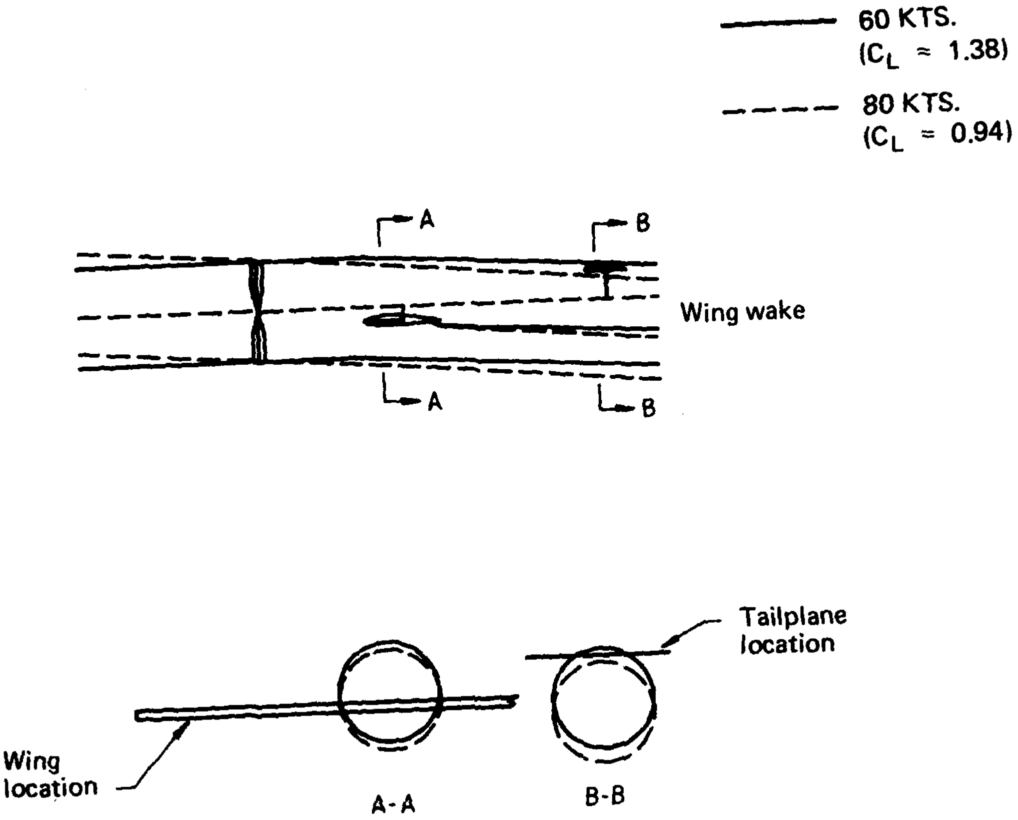


FIG. 7 SLIPSTREAM LOCATION FLAPS 20 DEG. POWER ON

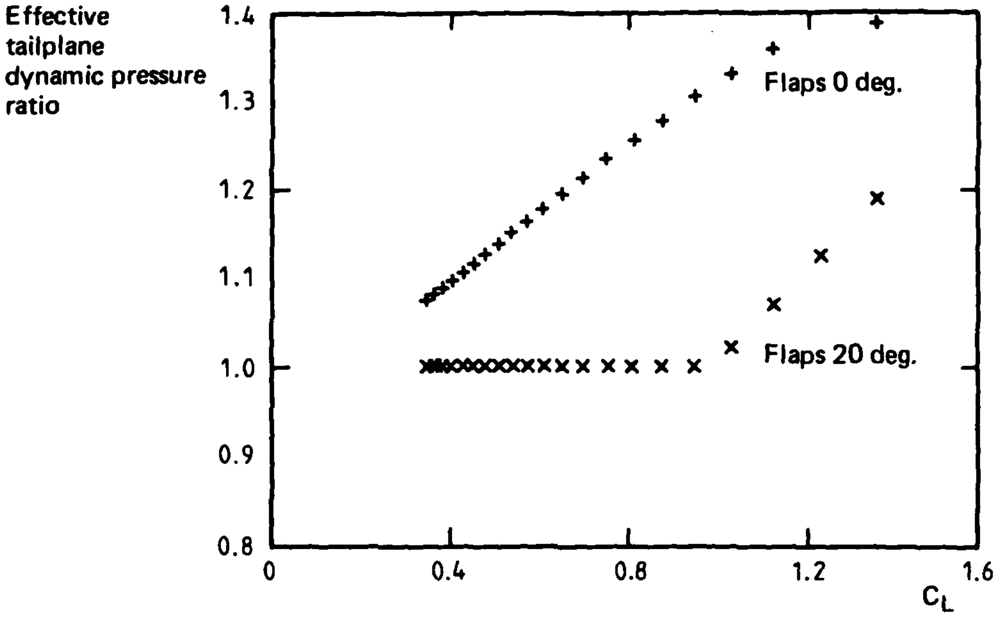


FIG. 8 TAILPLANE DYNAMIC PRESSURE RATIO POWER ON

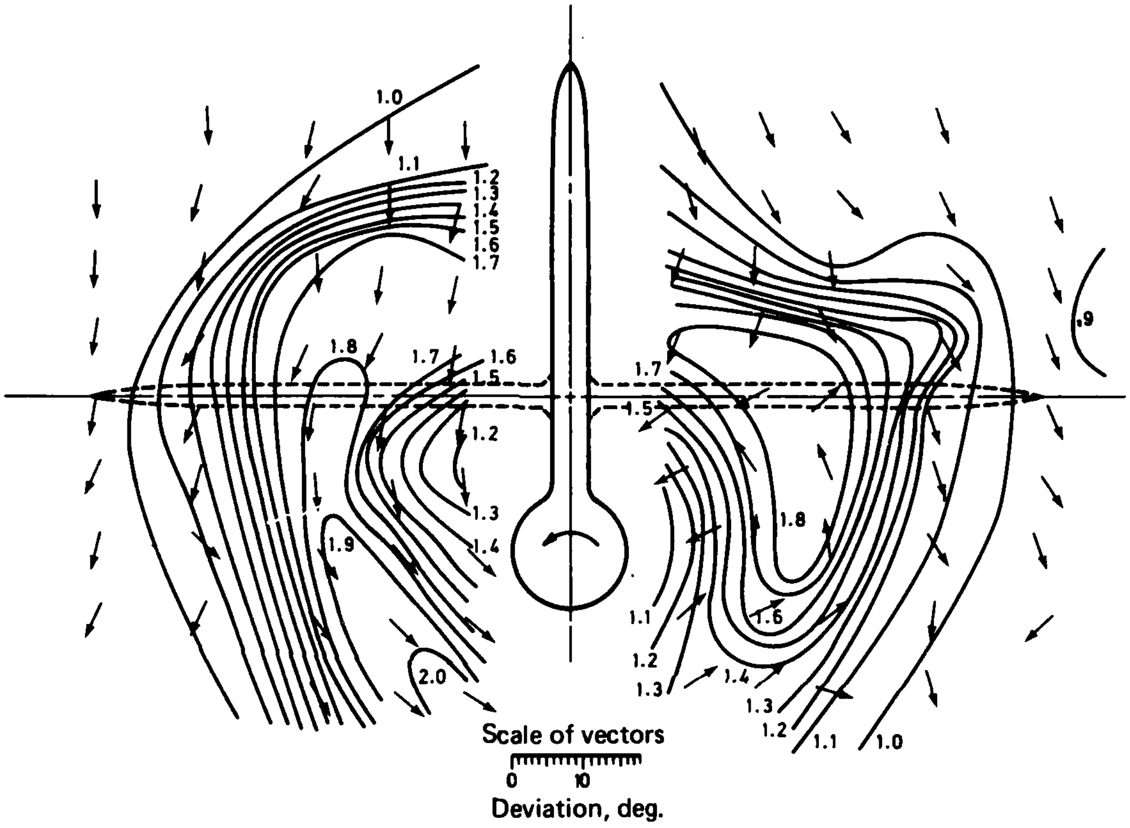


FIG. 9 TOTAL HEAD DISTRIBUTION AT THE TAIL (FROM REF. 6)

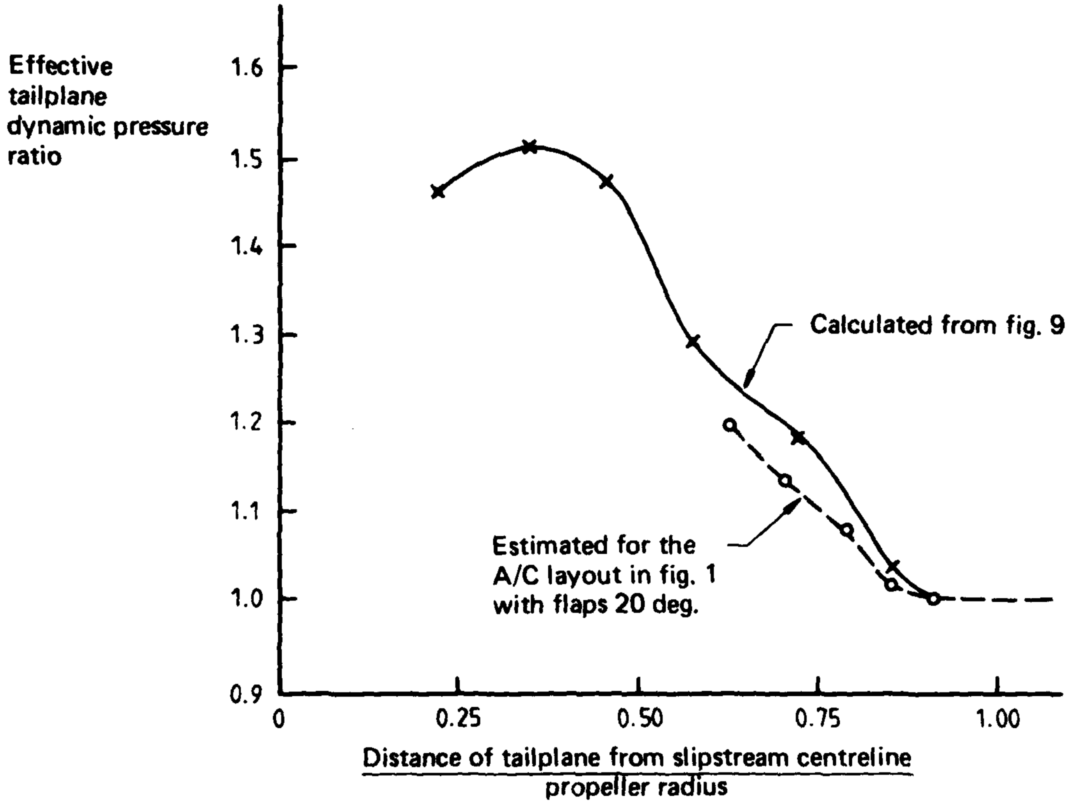


FIG. 10 COMPARISON OF EFFECTIVE TAILPLANE DYNAMIC HEAD RATIO

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16. Abstract

In this Note a model of the dynamic motion of a single-engine propeller-driven aircraft has been used to illustrate a longitudinal stability problem caused by the effects of power. In a recent general study on the effects of power the problem was shown to be due to changes in propeller slipstream dynamic head acting on a tailplane carrying a download. The problem is here studied in closer detail using the methods developed in the general study. A notable feature of the destabilising effect is that it increases as c.g. moves forward and so opposes the conventional stabilising effects associated with forward c.g. movement.

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17. Imprint Aeronautical Research Laboratories, Melbourne		
18. Document Series and Number Aerodynamics Note 413	19. Cost Code 52 7730	20. Type of Report and Period Covered ——
21. Computer Programs Used ——		
22. Establishment File Ref(s) ——		