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AEROSPACE ENGINEERING

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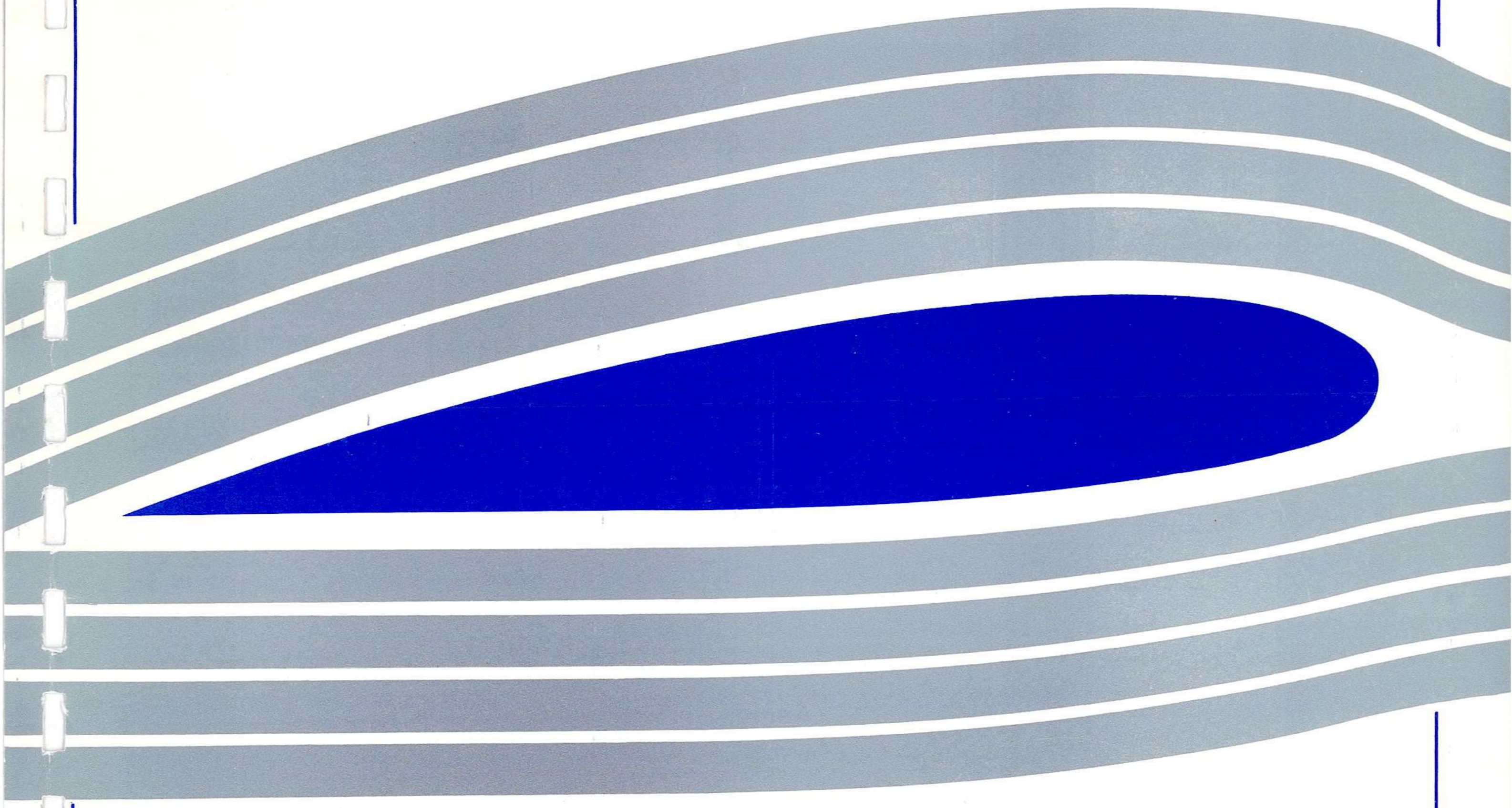

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Introduction

The RAF 2000 GTX-SE is a contemporary light gyroplane of conventional construction. It is powered by a 130 hp Subaru automobile engine driving a 3-bladed fixed pitch propeller. It has dual controls, side-by-side seating, and a fully-enclosed cabin for the occupants. The rotor is a conventional two-bladed teetering system.

The particular aircraft tested, G-BXDD, is operated by Roger Savage Gyroplanes Ltd. of Carlisle. This particular example is new to the UK, and was bought to satisfy the need for a reliable training aircraft, Figure 1.

The author was approached by the owner following expression of concerns regarding the suitability of the type for training. Particular anxiety was raised regarding pitch axis dynamics, and to a lesser but still significant extent, the yaw axis dynamics. The owner is a very experienced gyroplane pilot and instructor, and has been approved by the Civil Aviation Authority as a gyroplane display pilot. However he found himself unable to identify the nature of the deficiencies in handling, and asked if the extensive experience generated as part of CAA Contract 7D/S/1125 "Aerodynamics of Gyroplanes" could be brought to bear on this particular problem.

This offered a unique opportunity for testing and verifying the understanding of gyroplane stability and control generated for the CAA. Given the absence of sophisticated flight test instrumentation, it was also significant because it would required the use of techniques and approaches that would be used by constructors and pilots who were not professional aeronautical engineers. It therefore represented an opportunity for realistic application of knowledge and understanding which was generated for the CAA using a

sophisticated mathematical model and advanced flight test techniques.

Background

Stability and control issues play a dominant role in aircraft handling qualities. Pitching moment characteristics obviously dominate pitch axis dynamics, and the impact of stability derivatives such as M_u , M_w and M_q on stability is well known. For example, M_u and M_w are known to influence the period and damping of the long-period phugoid-type oscillation of helicopters, Ref. 1.

A key issue in the investigation of G-BXDD's pitch axis dynamics was therefore to explore M_u and M_w . Since sophisticated flight test instrumentation was not available, other approaches had to be used. Specifically, flight tests involving measurement of stick position at a variety of airspeeds gives insight into M_u, while ground-based measurement of weight and balance allows interpretation of the nature of M_w .

The rationale for this approach comes from Phase 1 of the CAA Contract 7D/S/1125, Ref. 2. A parametric study of gyroplane stability and control sought to relate the rather abstract and specialist interpretation of derivatives to design features. Accordingly, the impact of a range of design and configuration variations on static and dynamic stability was explored. It was found that the low frequency phugoid-type oscillation was sensitive to the position of the propeller thrust line relative to the aircraft centre of mass, largely because of the impact on M_u and M_w . A detailed study using the Glasgow University individual blade/blade element rotorcraft model RASCAL, Ref. 3, quantified this effect for the VPM M16 Tandem Trainer gyroplane and offered a simple explanation for stabilising (or otherwise) influence of propeller thrust line and centre-of-mass relationship. Flight tests using a fully-instrumented VPM M16, Figure 1, validated the hypothesis, Ref. 4.

The objective of this study is to develop an understanding of RAF 2000 pitch axis dynamics, in the context of the extensive studies conducted previously on behalf of the CAA. The specific aims were:

- conduct flight tests to determine the nature of speed stability ;
- conduct weight and balance measurements to determine the nature of angle of attack stability ;

Flight testing

Two flights of approximately 30 min. duration each were undertaken. The aim was to obtain qualitative and quantitative data that would help in the assessment of pitch axis dynamics.

The quantitative measurements were of longitudinal stick position taken simply with a 12 in. ruler. The gradient of the stick position with speed is an important handling qualities parameter and although derived from steady flight, is a measure of the dynamic stability derivative M_u. This derivative has been shown to have a significant impact on phugoid mode characteristics, Ref. 1. Hence one simple test can reveal much about static as well dynamic stability. Consider a much simplified form of the pitching moment equation of motion:

$$\delta\dot{q} = M_u \delta u + M_{\eta_s} \delta\eta_s$$

where $\delta\dot{q}$ is the perturbation in pitch acceleration, δu is a perturbation in airspeed, $\delta\eta_s$ is a perturbation in longitudinal stick position, and M_q and M_{η_s} are the stability and control derivatives. Perturbations are relative to a steady flight condition.

For quasi-steady flight this can be re-arranged as

$$\frac{\delta\eta_s}{\delta u} = -\frac{M_u}{M_{\eta_s}}$$

Hence the gradient of the stick position with speed $\frac{\delta\eta_s}{\delta u}$ is a direct measure of M_u.

The qualitative assessment required the author and a colleague to fly with the owner, performing the simple task of maintaining steady, level flight. The author is an experienced fixed-wing pilot, the other has no flying experience whatsoever. The author found the stabilisation task demanding, and the determination of pitch trim ambiguous - many turns of the wheel produced little effect. The colleague performed better at the stabilisation task, but this is perhaps unsurprising given that he was not having to "unlearn" any predisposed techniques, unlike the author. The author's judgement is that the aircraft would fail the long-period dynamic stability requirements of BCAR Section T, Ref. 5.

Figure 3 shows the stick position curves against speed. Fully forward stick is 0 in. Simple second order polynomial curve fits were made of these data, giving excellent fits. The polynomials were then differentiated with respect to airspeed, the resulting linear equations representing stick gradient as a function of speed. The two observer results for the RAF 2000 were then averaged, and these data are shown in Figure 4. The dissimilar speed ranges for the two aircraft represent their respective performance abilities. Note that both gradients are negative, which means that $M_u > 0$, i.e. both aircraft are speed-stable. The gradients reduce with increasing speed for both aircraft and the VPM M16 has much better speed stability across its speed range than does the RAF 2000. At 60 knots, both are similar but in terms of dynamic stability, other considerations come into play, so it is not necessarily the case that both types will have similar handling qualities at 60 knots.

Given that both aircraft have similar rotor systems (and therefore are likely to have similar values of M_{η_s}) the RAF 2000 will have M_u somewhat less than that of the VPM M16. As stated previously, reducing M_u tends to reduce the frequency of any phugoid oscillation and can tend to make it less

stable. This is consistent with observed RAF 2000 behaviour, and contributes partly to a coherent explanation of RAF 2000 pitch axis characteristics.

Further vindication of these very simple flight tests, comes from the parameter estimation results from the VPM M16, which has identified actual values of M_u and M_{η_s} . Remember that other parameters feature in the pitching moment equation (angle of attack, pitch rate and rotorspeed terms), and they will tend to distort calculation of stick gradient from $-\frac{M_u}{M_{\eta_s}}$, particularly at higher speeds. Notwithstanding this, at 30 knots theidentified derivatives give a value of $-\frac{M_u}{M_{\eta_s}}$ = -0.149±0.046, and at 55 knots, -0.091±0.016. From Figure 4, the corresponding values are -0.1 and -0.046. These results indicate consistency between the simple steady flight trim data, and the parameter estimation results from dynamic tests.

Ground testing

Weight and balance calculations were obtained from geometric and wheel reaction measurements. The fore/aft centre-of-mass position was determined in the usual manner, as follows:

$$x_{cg} = d\frac{W_{nose}}{W}$$

where x_{cg} is the position of the centre of mass in a direction parallel to the keel, measured relative to the nosewheel, d is the wheelbase, W_{nose} is the nosewheel reaction and W is the weight of the aircraft. The vertical position of the centre of mass can then be determined by suspending the aircraft from the teeter bolt, and measuring the suspension angle. The vertical position is given by

$$z_{cg} = \frac{f - x_{cg}}{\tan\theta}$$

where f is the distance parallel to the keel (the x-direction) from the reference point to a point directly underneath the teeter bolt, and θ is the suspension angle.

The calculation of z_{cg} is sensitive to errors in $f - x_{cg}$ if the suspension angle is small. For example, a suspension angle of 5 deg and an error in $f - x_{cg}$ of 2.5 mm, will produce an uncertainty in z_{cg} of 2.8 cm. This problem is compounded by the fact that f cannot be measured directly due to the configuration of the aircraft, and has itself to be calculated from measurements that are easy to make.

Table 1 lists the measurements required. All geometric measurements were taken to within ± 2.5 mm. A clinometer was used for angular measurements which can to all intents and purposes be regarded as error-free. Reaction forces at the wheels were measured digitally to 0.1 kg resolution.

Table 1 Summary of geometric measurements

Quantity	Measurement
main/tail wheel	3.1425 m
hub bar/ground (drop)	2.47 m
teeter block height	0.065 m
teeter bolt/tail wheel	2.86 m
nose/main wheel	1.33 m
tail wheel radius	0.127 m
ground angle	6.6667 deg

Table 2 shows calculated centre-of-mass position for two configurations: single pilot; and pilot plus passenger. The error band for x_{cg} and z_{cg} is the maximum achievable from appropriate selection of plus or 2.5 mm as measurement error on the parameters in Table 1.

Table 2 Weight and balance results

	Solo	Dual
Mass (kg)	487.4	566.9
x_{cg} (m)	1.2090±0.0023	1.1364±0.0021
z_{cg} (m)	0.7277±0.2659	0.6495±0.1611

Note that the larger error for the solo configuration is because the suspension angle was just over 4 deg, whereas for the dual configuration it was almost 7 deg. The propeller hub is 0.909 m above the datum, hence it is clear that the centre of mass lies substantially below the nominal propeller thrust line.

Previous simulation work, Ref. 2, indicates that this will tend to produce negative angle of attack stability, i.e. $M_w > 0$.

Discussion

An objective assessment of the flight- and ground-based measurements for the RAF 2000, interpreted in the context of previous CAA-funded research, indicates that this aircraft is likely to have poor pitch axis characteristics. The fact that it does serves as an important verification of the previous work, and gives confidence that simple tests can give useful insight into the nature of gyroplane behaviour.

Of concern for the future however, is that extreme care has to be applied to measurements that are subsequently applied to the calculation of vertical centre-of-mass position, given the sensitivity of the result to suspension angle and measurement error.

It is difficult to suggest modifications that would improve the RAF 2000's pitch axis handling qualities. The most obvious solution, would be to incline the engine and propeller downwards. However, to permit the propeller thrust line to pass through the calculated centre-of-mass would require a tilt of 18 deg for dual configurations, or 14 deg for solo configurations (the former therefore allowing the propeller thrust line to pass below the centre-of-mass in solo operation). Ballast is probably the easiest engineering modification. Its impact is limited however. For example, 20 kg placed in front of the engine is estimated to raise the centre of mass by only 1 cm. Fitting a horizontal tailplane will probably help somewhat, given the relatively high cruising speed of the aircraft, but will do little elsewhere in the speed range.

Conclusions

Subjective assessment of G-BXDD in pitch axis suggests that the aircraft is at best marginally stable.

An important correlation exists between this observation, and the extensive knowledge and understanding of light gyroplane stability and control gained in previous CAA-funded research. Specifically, measurement of stick position with speed, as well as weight and balance, in combination indicates that the aircraft is likely to have poor longitudinal stability.

The RAF 2000, if G-BXDD is typical of the fleet, would have improved pitch axis handling qualities if the engine and propeller were inclined downwards. At high speed, a horizontal tailplane may also be of some benefit.

Great care must be taken in measurement and calculation of the vertical position of the centre-of-mass.

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Figure 1 -- RAF 2000 GTX-SE Gyroplane

Figure 2 -- VPM M16 Gyroplane

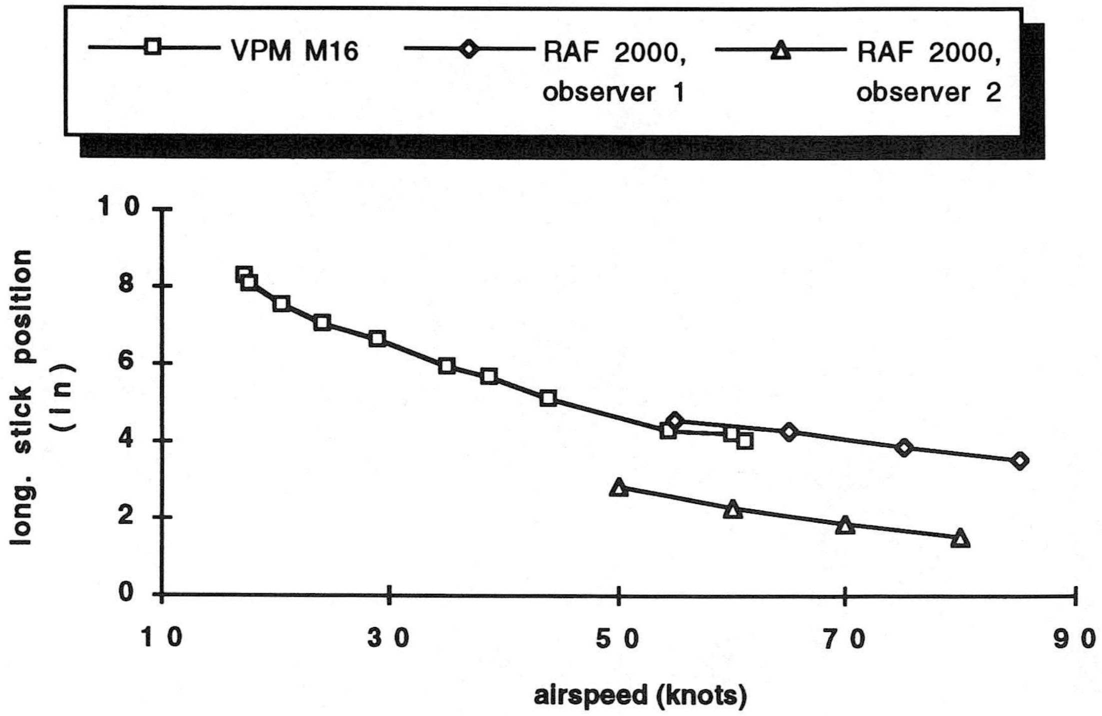

Figure 3 -- Comparison of stick position with speed, RAF 2000 and VPM M16

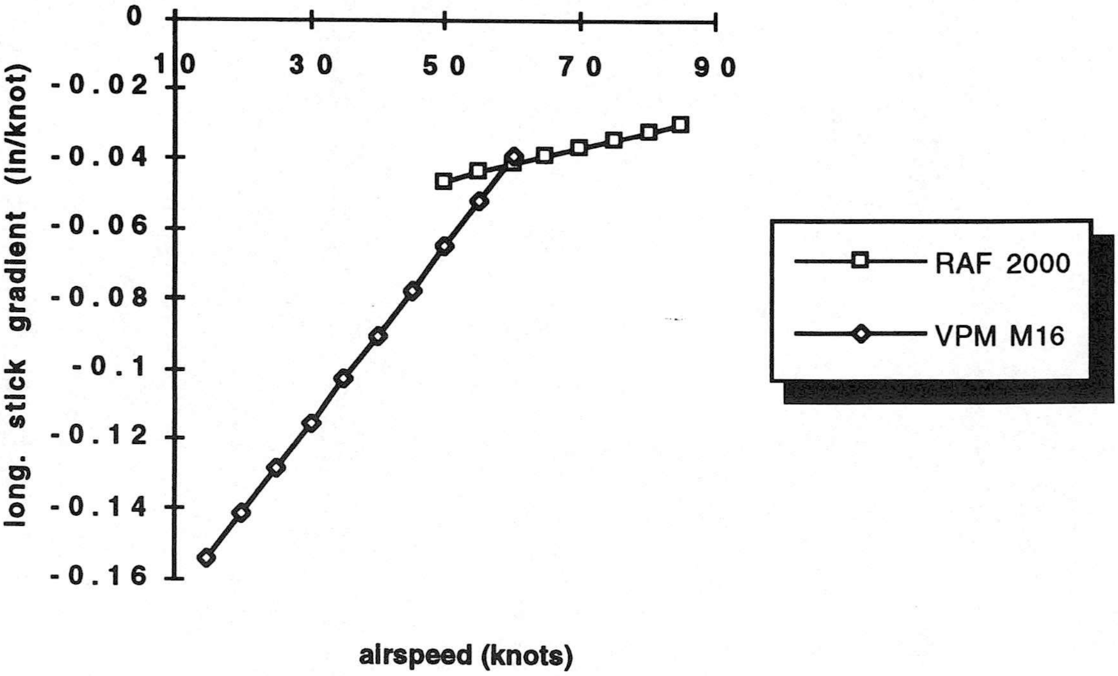

Figure 4 – Comparison of stick position gradient with speed, RAF 2000 and VPM M16