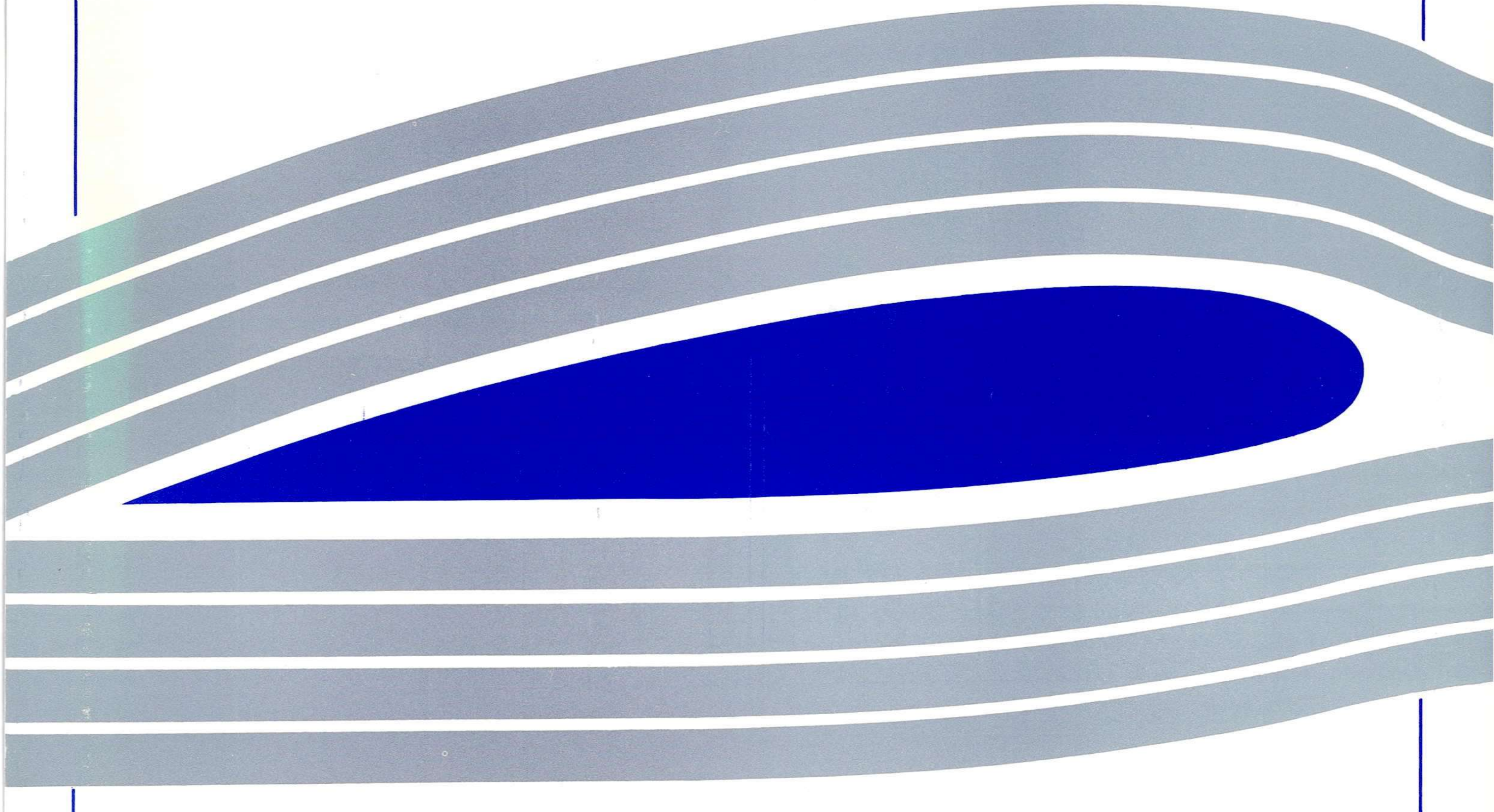
University of Glasgow
DEPARTMENT OF
AEROSPACE ENGINEERING

Studies on the Sensitivity of Gyroplane Dynamic Stability[1]

Department of Aerospace Engineering

Internal Report No. 9405

5 May 1994



UNIVERSITY
of
GLASGOW

Studies on the Sensitivity of Gyroplane Dynamic Stability[1]

Department of Aerospace Engineering

Internal Report No. 9405

5 May 1994

Dr Stewart Houston

---

[1] Prepared as Phase 2 Interim Report for CAA Contract 7D/S/1125 "Aerodynamics of Gyroplanes"

Summary

This Interim Report describes work conducted to address specifically two items of concern highlighted at the Phase 1 Progress Meeting: the overestimate of rotorspeed obtained with the engineering models; and the degree of instability predicted by the RASCAL model. Both characteristics are not reflected in the existing limited flight test experience. Although this additional work is limited in scope, it is felt that the results are significant enough to justify an Interim Report.

1. Introduction

This Interim Report contains results that follow on from Phase 1 of CAA contract No. 7D/S/1125 "Aerodynamics of Gyroplanes". These results address issues raised in the Phase 1 Outline Report (Ref. 1) and at the 1st. Progress Meeting. The results are felt to be significant enough to justify an Interim Report.

2. **Background**

The Phase 1 Progress Report (Ref. 1) contained results that were judged to be valid in relative terms, but two aspects of the prediction of VPM M16 characteristics were inconsistent with flight test experience, Ref. 2. These were first: that the rotorspeed was over-predicted by the model by around 30%; second, that in reality this aircraft was stable throughout the level flight speed range, unlike the model where the phugoid-type longitudinal motion was predicted to be strongly unstable.

The use of NACA 0012 aerodynamic data for the blade section was thought to have been a possible reason for the over-estimate in rotorspeed. The blade section used on the VPM M16 is the NACA 8-H-12. Tests have been conducted on this section, Ref. 3. The data has now been obtained and incorporated into the aircraft dataset.

The importance of accurately predicting absolute characteristics (rotorspeed, stability or any other quantity) is that it will enhance the credibility of the results obtained from the parametric studies, and that it also gives confidence in using the model to support the design of flight test experiments.

3. Analysis

The Phase 1 Progress Report, Ref. 1, showed that the gyroplane stability was insensitive to a wide variation in a range of parameters. The only outstanding issue was the vertical position of centre-of-mass. Simple inspection of a VPM M16 general arrangement drawing, suggested initially that the centre-of-mass could be about 40 cm below the engine thrust line. Now, this would give a substantial nose-down moment in equilibrium flight, that would have to be trimmed out by the main rotor thrust line passing well ahead of the centre-of-mass. As is pointed out in Ref. 1 this is a destabilising configuration from the point of view of angle of attack stability, and indeed the derivative M_w was shown to be positive (destabilising) over most of the speed range.

The flight test data available, Ref. 2, indicates however that the aircraft tends to pitch up when power is applied. This suggests that the thrust line of the propeller is close to, if not slightly below the centre-of-mass. The aircraft dataset was modified by raising the vertical position of the centre-of-mass to the same level in the airframe as the propeller hub. Since the propeller thrust line is inclined downwards by 2 deg., this would give the required nose-up moment.

4. Results

4.1 Effect of vertical position of centre-of-mass

Trim and stability analyses were conducted at 60 knots (approximately 70 mph), since this was the airspeed at which the real aircraft stability characteristics were investigated. The configuration with the centre-of-mass raised to the level of the propeller hub was considered to be the default, and the centre-of-mass position was then varied by ±3 in. vertically. Note that the NACA 0012 blade section data was retained, to provide a direct comparison with the previous results.

It was found that raising the centre-of-mass to the level of the propeller hub by the amount required (40 cm), had a dramatic effect on stability. The short-period mode becomes "classical" in nature i.e. oscillatory rather than aperiodic. The phugoid mode becomes stable, and is in fact well damped, unlike the previous simulations reported in Ref. 1. The lateral/directional modes are largely unaffected by the change in vertical centre-of-mass. The phugoid results are summarised in Table 4.1-1.

Table 4.1-1 Phugoid mode characteristics

c.g. relative to propeller	time to half (double) amplitude (s)	period (s)
3in. above	5.61	29.84
default	5.07	23.92
3in. below	(2.04)	12.53

Note that the phugoid characteristics for the unstable configuration are very similar to those obtained in Ref.1, i.e. whether the propeller thrust line is 3 or 12 in. above the centre-of-mass is largely immaterial to the degree of phugoid instability. Likewise, the degree of phugoid stability is relatively insensitive to the distance of the thrust line below the centre-of-mass.

The flight test results given in Ref. 2 indicate that the period of the phugoid at 70 mph is about 13 s, and the time to half amplitude can be inferred to be about 3 to 6 s. Although the period predicted by the model is about twice that measured in flight, the overall correlation, particularly in damping, is very good.

The short-period results are summarised in Table 4.1-2. These characteristics appear relatively insensitive to the ±3 in. variation in propeller thrust line above or below the centre-of-mass. The flight test results quote a short-period mode frequency of 2.5 Hz, which equates to a period of 0.4 s, i.e. 10 times faster than predicted. The model prediction is more appropriate, and it is felt that the test method is questionable, having returned a mode that is fast enough to be due to the rotor system, rather than the rigid-body airframe mode that is required. The flight test report does point out that the short-period mode was difficult to identify.

Table 4.1-2 Short-period mode characteristics

c.g. relative to propeller	time to half amplitude (s)	period (s)
3in. above	1.19	4.46
default	0.97	4.66
3in. below	0.47	2.88

The dutch roll results are summarised in Table 4.1-3. While the period is insensitive to the variation in the vertical position of the centre-of-mass, the damping varies from positive to negative. This is attributed to the differing height of the main rotor from the centre-of-mass. The flight test results quote a short-period mode frequency of 0.7 Hz, which equates to a period of 1.4 s, i.e. 3-4 times faster than predicted. The model prediction is more appropriate, and once again it is felt that the test method is questionable, having returned a mode that is fast enough to be due to the rotor system, rather than the rigid-body airframe mode that is required.

Table 4.1-3 Dutch roll mode characteristics

c.g. relative to propeller	time to half (double) amplitude (s)	period (s)
3in. above	(35.91)	4.99
default	(6.32)	4.63
3in. below	24.93	4.95

At this stage the lack of dutch roll damping in the model is not thought to be significant, since very pessimistic estimates of the effectiveness of the endplates and fin/rudder were used. Results from the wind tunnel test programme will quantify the extent to which this is the case.

4.2 Discussion of stability derivatives

Consideration of the stability derivatives is important, since it helps to quantify the degree to which qualitative judgements about the relative positions of lines of actions of forces actually impact on the dynamic stability of the aircraft.

The pitching moment derivatives have a dominant (but not exclusive) impact on longitudinal dynamic stability. M_u, M_w and M_q are those normally considered in analysing aeroplane and helicopter longitudinal stability. The values of these derivatives for the three configurations are given in Table 4.2-1, together with the derivative M_Ω.

Table 4.2-1 Comparison of pitching moment stability derivatives

c.g. relative to propeller	phugoid stability	M_u	M_w	M_q	M_Ω
3in. above	**stable**	-0.007	-0.071	-0.182	-0.021
default	**stable**	-0.001	-0.060	-0.190	-0.021
3in. below	**unstable**	0.005	-0.050	-0.197	0.077

It should be remembered that the derivatives on their own simply indicate a tendency, with regard to stability. Whether or not the aircraft is stable or unstable depends on the complex interaction of all derivatives. With regard to the three classical aircraft derivatives, M_w and M_q should be negative for positive stability, which they are in all three cases. M_u should be positive, yet where it is negative (i.e. tending to be destabilising) the phugoid is actually stable, and where it is positive (i.e. tending to be stabilising) the phugoid is unstable. M_u would in fact appear to be too small to influence the dynamic stability, irrespective of its sign.

It is the derivative M_Ω that would appear to determine whether or not the phugoid is stable. Intuitively, M_Ω should be negative if it is to be stabilising. This is because an increase in rotorspeed will increase the thrust - if this produces a nose-down moment, it will tend to return the perturbation in rotorspeed to trim. Indeed, Table 4.2-1 illustrates this correlation, with the unstable configuration being the one for which M_Ω is destabilising. Simple parametric studies have shown that this is in fact the case - even with stabilising M_u, M_w and M_q , changing the sign of M_Ω can either stabilise or destabilise the phugoid.

Since the derivative M_Ω arises solely from the offset of the main rotor thrust line from the centre-of-mass, the only way in which it can be stabilising is for the centre-of-mass to be placed ahead of the main rotor thrust. It would appear that placing the propeller thrust line below the centre-of-mass is the most powerful means of ensuring that this is the case.

4.3 Effect of NACA 8-H-12 aerodynamic data

Table 4.3-1 compares the rotorspeed predicted by the model when using NACA 8-H-12 and 0012 data. A flight speed of 70 mph has been used, with the propeller thrust line 3 in. below the centre-of-mass. This should then tend to give the most stable configuration longitudinally. Note that with the 8-H-12 data, the rotorspeed is substantially reduced, but not to the level measured in flight, of about 370 rpm. Nonetheless the original over-prediction with 0012 data of about 100 rpm has been reduced to 60 rpm.

Table 4.3-1 Comparison of rotorspeed with NACA 8-H-12 and 0012 data

blade section	rotorspeed (rpm)
NACA 8-H-12	434
NACA 0012	471

The source of 8-H-12 data is very limited for the gyroplane application for two reasons. First, the results are only valid for low Mach numbers since compressibility effects are absent in the data. Second, it would appear that the section used by the gyroplane community is not the same as the 8-H-12 tested. Figure 4.3-1 shows the section, taken from Ref. 3. A portion of blade obtained from Montgomerie, together with inspection of the blades on the VPM, indicates that the lower surface is completely flat. It would appear that the portion of the section below the chord line in figure 4.3-1 is absent in these two gyroplane applications.

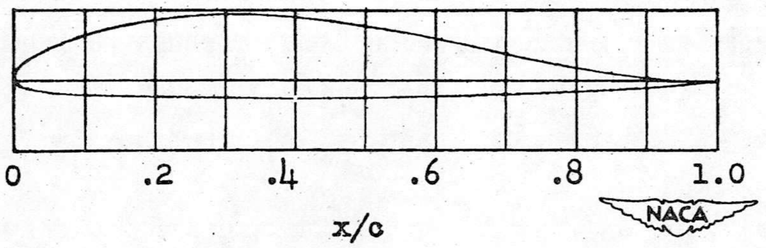


Figure 4.3-1 NACA 8-H-12 profile

Tables 4.3-2, 4.3-3 and 4.3-4 compare phugoid, short-period and dutch roll mode stability respectively for NACA 8-H-12 and 0012 data.

Table 4.3-2 Phugoid mode characteristics

blade section	time to half (double) amplitude (s)	period (s)
NACA 8-H-12	9.61	40.49
NACA 0012	5.61	29.84

Table 4.3-3 Short-period mode characteristics

blade section	time to half (double) amplitude (s)	period (s)
NACA 8-H-12	0.64	3.39
NACA 0012	1.19	4.46

Table 4.3-4 Dutch roll mode characteristics

blade section	time to half (double) amplitude (s)	period (s)
NACA 8-H-12	(3.13)	4.81
NACA 0012	(35.91)	4.99

There are differences in the stability of the two configurations, but the essential character of each mode is the same whether the 8-H-12 or 0012 data has been used.

5. Discussion

Placing the engine thrust line below the centre-of-mass, tends to result in the main rotor thrust line being placed aft of the centre-of-mass in equilibrium flight. This is in general a stable configuration, which is reflected in the results.

Other airframe components e.g. that tailplane or cowling should also tend to influence the position of the main rotor thrust line relative to the centre-of-mass. However, they have previously been shown to have little impact on trim, Ref. 1. It should not be surprising then, that the relative positions of the vertical centre-of-mass and propeller thrust line have a significant effect, since only small moment arms will be required to produce large pitching moments. This is because, relative to other airframe components, the propeller thrust is a large force having as it does, to overcome rotor and airframe drag.

At low airspeeds, the propeller thrust line will have to be substantially below the centre-of-mass to provide a stabilising configuration, since the rotor thrust will be tilted substantially further aft than at high speeds, to provide the required lift. It is therefore more likely to be close to, if not in front of the centre-of-mass. Low speed then becomes that critical part of the flight envelope with regard to placing the engine thrust line for stability.

A further point concerns the importance of the stability derivative M_{Ω}. It is a derivative unique to rotorcraft where rotorspeed is a degree of freedom, and that makes it essentially unique to gyroplanes or helicopters in autorotation. It has been shown to have a dominant effect on phugoid stability. It will in practice be stabilising if the main rotor thrust line is placed aft of the centre-of-mass, and it has been shown that appropriately placing the propeller thrust line is the dominant means of doing so.

Finally, the correlation between the limited amount of flight test data available (Ref. 2) and the RASCAL model is now very good in terms of overall aircraft stability and rotorspeed predictions. The phugoid mode in particular, traditionally difficult to predict theoretically, is very well estimated by the RASCAL model. However, more flight test work is required to determine the correct natural frequency for both short-period and dutch roll modes, where it is believed that the RASCAL model is more appropriate than the results quoted in Ref. 2. The standard flight-test method used is thought to be of questionable value.

6. Conclusions

1 Improved correlation between actual measured rotorspeed in flight tests, and that predicted by the RASCAL model, is obtained with the NACA 8-H-12 data. The data is however of limited applicability in view of the fact that compressibility (Mach number) effects are absent.

2 Improved correlation between actual phugoid damping measured in flight tests, and that predicted by the RASCAL model, is obtained with the centre-of-mass above the propeller thrust line.

3 The importance of the relative vertical positions of propeller thrust line and the centre-of-mass is emphasised. A centre-of-mass that lies above the propeller thrust line is a strongly stabilising feature.

4 The importance of the derivative M_Ω to gyroplane flight mechanics is such that it needs to be considered alongside conventional interpretations of aircraft stability and control embodied by other derivatives such as M_u or M_w.

5 Preparation for any flight tests should involve the determination of the vertical as well as fore-and-aft centre-of-mass positions.

References

1. Houston, S., Thomson, D.G., Coton, F.; "The Aerodynamics of Gyroplanes CAA Contract No. 7D/S/1125 Phase 1 Progress Report". 28 February 1994.

2. Anon, "Flight Test Report No. 2/93 on the VPM M16 Gyroplane G-BUPM Against the Requirements of BCAR Section T". Arrow Engines UK Flight Test Report No. 2/93. June 1993.

3. Schaefer, R.F., Smith, H.A.; "Aerodynamic Characteristics of the NACA 8-H-12 Airfoil Section at Six Reynolds Numbers". NACA Technical Note 1998. December 1949.