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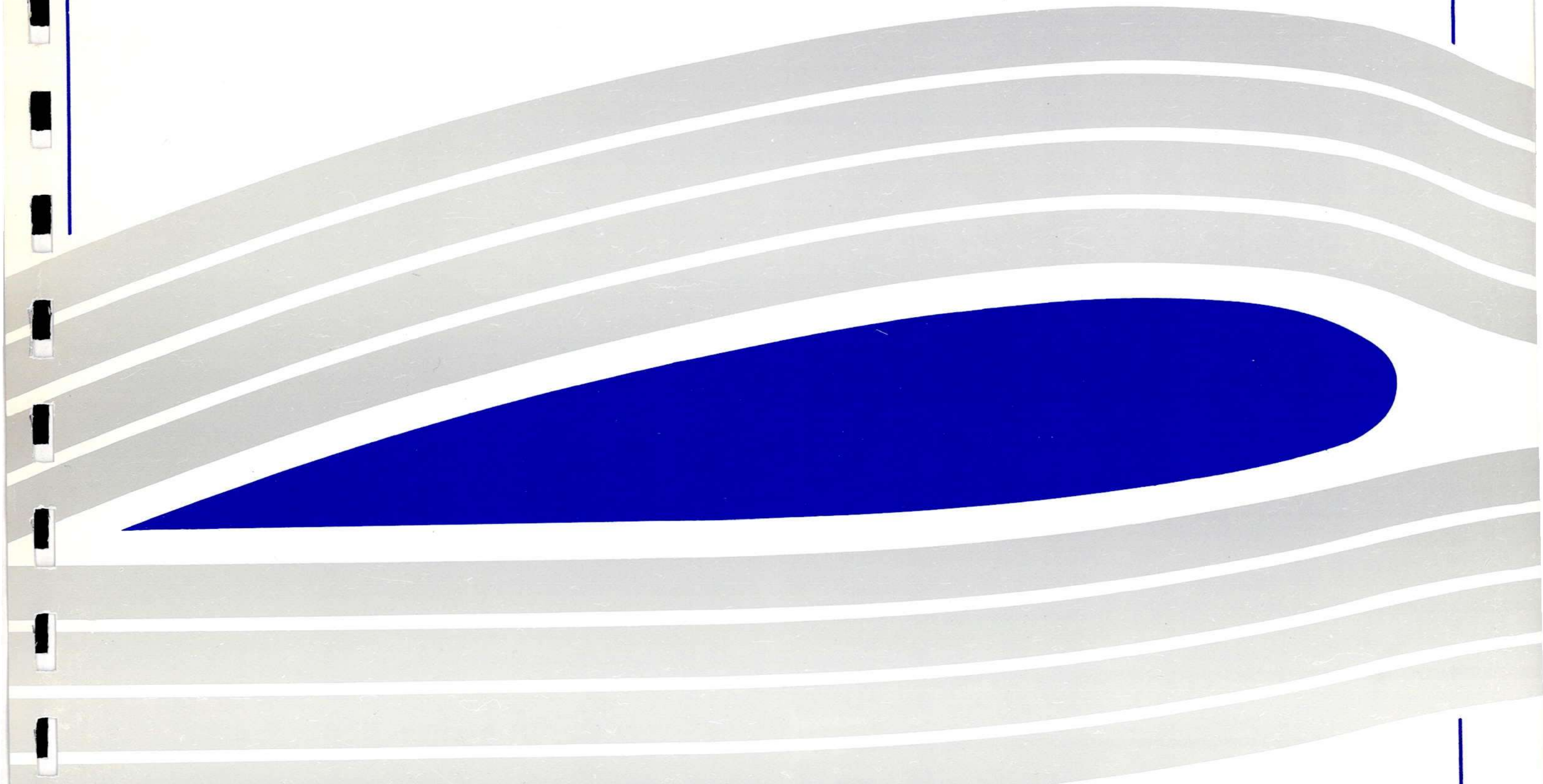

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Summary

Weight and balance measurements have been conducted on G-BUZL, a VPM M16 Tandem Trainer gyroplane. The purpose of these tests was to determine longitudinal and vertical c.g. position in two configurations: the standard, approved configuration for which an AAN exists; and a modified configuration. In the latter case, the Arrow engine was replaced with a turbocharged Rotax unit. The standard aircraft weight and balance is very similar to that determined previously for a similar machine, G-BWGI, which was used to support the CAA investigation "Aerodynamics of Gyroplanes". The only substantial difference for the modified aircraft weight and balance is the longitudinal c.g. position, which is some 3 in further aft. Recommendations are made in respect of operating limitations, and additions to the flight test schedule that has been proposed to demonstrate the airworthiness of the modified aircraft.

Introduction

The VPM M16 Tandem Trainer is a contemporary light gyroplane of conventional construction. It is powered by a 120 hp Arrow engine driving a 3-bladed fixed pitch propeller. It has dual controls, tandem seating, and an open pod for the occupants. The rotor is a conventional two-bladed teetering system.

The particular aircraft tested, G-BUZL, is operated by Roger Savage Gyroplanes Ltd. of Carlisle. The author was approached by the owner for comment regarding a proposed modification to the aircraft which was to involve replacing the Arrow engine with a turbocharged Rotax unit. It was suggested that a weight and balance exercise would offer the best opportunity for assessing the impact of the new installation on stability and control characteristics. There is no requirement for gyroplanes to have a weight and balance schedule, although it is one of the recommendations made to CAA by this author in a review of BCAR Section T, Ref. 1.

This aircraft modification therefore offered an opportunity for putting into practise elements of these recommendations, for the first time. Their usefulness can therefore be addressed.

Background

Unlike fixed wing aircraft and helicopters, gyroplanes are not required to have a weight and balance schedule. They are however required to demostrate compliance with a "hang check", which involves demonstrating that the aircraft, when suspended from the teeter bolt location on the rotor hub, will adopt a pitch attitude that is within pre-determined limits. This test, although indirectly associated with weight and balance, is conducted to confirm that control margins will not be compromised in limiting parts of the flight envelope.

However, the extensive research programme conducted under CAA Contract No. 7D/S/1125 "Aerodynamics of Gyroplanes", highlighted the importance to longitudinal stability of the vertical position of the c.g. in relation to the propeller thrust line. In addition, the extensive simulation, wind tunnel and flight testing has enabled a deep insight into the flight mechanics of these aircraft, and as a result the assessment of weight and balance allows this insight to be applied to give an informed assessment of new, untested configurations, such as the major modification carried out on G-BUZL to install the Rotax engine.

Determination of the longitudinal c.g. position is conventional, straightforward and relatively error-free. The vertical c.g. position however, is not, Ref. 2. In the weight and balance exercise conducted on G-BWGI for the CAA contract flight trials, the vertical c.g. was determined by measurements obtained from a hang test. This method was also used on RAF 2000 G-BXDD, Ref. 2, where the error bounds on the calculation of vertical c.g. by this method were shown to be substantial indeed. The present exercise allowed the opportunity of exploring an alternative method, and the results will compare the error bounds using this method with those from a hang test.

Results

Weight and conventional hang test results

Tests to determine weight and to conduct the hang check were conducted with rotor off. The aircraft had approximately 11 kg of fuel on board. Table 1 compares results for G-BUZL in both configurations.

Table 1 Weight and hang check results

	Mass (kg)	Hang angle (deg)
Standard (Arrow)	229.1	3.83
Modified (Rotax)	234.6	4.33

The Rotax installation incurs a mass penalty of 5 kg. Note that the manufacturer's limits for hang angle are 3.5 - 4.5 deg. While the standard aircraft lies close to the middle of this range, in modified configuration the hang angle is very close to the upper limit, indicating that the centre of mass is further aft.

Longitudinal centre of mass (c.g.) position

These tests were conducted with 11 kg of fuel on board. Results are for the complete aircraft, i.e. rotor on. The datum position is a line normal to the keel, passing through the main wheel hub. This c.g. position is calculated simply from a moment balance that gives

$$x_{cg} = d\frac{m_1}{m}$$

where d is the distance between main wheels and the third reaction point (which may be either nose or tail wheel), m is the mass of the aircraft and m_1 is the third reaction. Note that the result is obtained with respect to Earth axes, and needs to be transformed into aircraft axes if the keel (aircraft reference line) is not parallel to the Earth. This transformation, where appropriate is applied to all results. Figures in brackets are measurement errors.

Table 2 Longitudinal c.g. results

	x_{cg} (m)
Standard (Arrow)	-0.0396 (0.0010)
Modified (Rotax)	-0.1306 (0.0004)
G-BWGI	-0.0149 (n/a)

G-BWGI is the aircraft used for the CAA Contract, and the result is taken from an unpublished FRA document, Ref. 3. The negative result indicates a position aft of the main wheels. Note that G-BUZL is very similiar to G-BWGI, the slight difference probably relating to different equipment fit (they have dissimilar prerotator installations). G-BUZL in modified form has a c.g. position some 0.09 m, or 3.6 in, further aft than in standard form. This is consistent with the hang check results.

Vertical centre of mass (c.g.) position

These tests were conducted with 11 kg of fuel on board. Results are for the complete aircraft, i.e. rotor on. The datum position is the keel. This c.g. position is calculated from a geometrical consideration that gives

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

where f is the distance between the normal projection of the suspension point on the keel and the longitudinal reference point, and θ is the suspension angle. Note that the result is obtained with respect to Earth axes, and needs to be transformed into aircraft axes if the keel (aircraft reference line) is not parallel to the Earth. This transformation, where appropriate is applied to all results. Figures in brackets are measurement errors.

Table 3 Vertical c.g. results

	z_{cg} (m)
Standard (Arrow)	-0.8121 (0.0595)
Modified (Rotax)	-0.8652 (0.0017)
G-BWGI	-0.909 (n/a)

The negative result indicates a position above the keel. Modified with the Rotax, G-BUZL's c.g. is some 0.05 m (2 in) above that of the unmodified aircraft. Both these results are lower on the aircraft than G-BWGI, but the latter calculation is based on zero fuel. The 11 kg in G-BUZL's tank is low down, and will tend to lower the c.g. somewhat.

It is important to appreciate that calculation of vertical c.g is sensitive to the accuracy in $f - x_{cg}$. This is because for the small suspension angles achievable (with or without ballast), $\tan\theta$ will have a value of between 0.1 and 0.2. Hence a 1 cm error in $f - x_{cg}$ will give rise to a 5 - 10 cm error in z_{cg}. It is therefore of vital importance that f in particular is measured accurately. This is difficult to do directly, and several measurements (each with its own error bound) are usually required to calculate f from airframe geometry. If the aircraft is suspended from its teeter bolt, perhaps 5 or six measurements are required, and the almost 6 cm error bound for G-BUZL in standard configuration reflects this. However, a much more accurate estimate was obtained for the aircraft in modified trim, as the suspension method was not used. Instead, the aircraft was mounted on an incline: this transfers some load from the main wheels to the reaction m_1, from which the vertical c.g. location can be inferred. The governing equation is of the same form as that given above, but requires only one measurement.

Summary

With the Rotax engine, G-BUZL is 5 kg heavier than with the Arrow. The hang test shows that it complies with the kit manufacturer's limits, although closer to the upper bound. Relative to the Arrow engine, the aircraft c.g. position is further aft and above with the Rotax engine.

Discussion

With the Rotax engine fitted, G-BUZL complies with the hang check requirements specified by the kit manufacturer, at a marginal weight penalty. On this basis it could be argued that the modified aircraft complies with the pertinent limitations, and no further investigation is necessary. This may be the logic adopted by PFA or CAA as appropriate, and such an approach is entirely consistent with these measurements.

However, a greater insight into gyroplane stability and control has been obtained as a result of the studies conducted for the CAA Contract 7D/S/1125 "Aerodynamics of Gyroplanes". The resulting data can be used to make informed judgement regarding the impact of the modification made to G-BUZL.

For example, the vertical c.g. position has been found to be important for dynamic stability, but only in relation to the propeller thrust line. If it is assumed that the propeller thrust line acts through the centre of the propeller hub, then comparing the distance between z_{cg} and z_{prop} (the distance of the hub above the reference line, in this case the top of the keel) allows some interpretation to be made of the impact of the new configuration on dynamic stability, Table 4.

Table 4 Vertical c.g. in relation to propeller hub distance above keel

	z_{cg} (m)	z_{prop} (m)
Standard (Arrow)	-0.8121 (0.0595)	-0.8700 (0.0025)
Modified (Rotax)	-0.8652 (0.0017)	-0.8950 (0.0025)
G-BWGI	-0.909 (n/a)	-0.885 (n/a)

The modified configuration has propeller thrust line and vertical c.g. much closer together, which will *tend* to improve longitudinal dynamic stability.

The longitudinal c.g. position is not as significant for dynamic stability, but it will influence control margins. A more aft c.g. will cause the aircraft to fly more nose-up at a given speed, and since the rotor disc will require approximately the same angle of attack relative to the air, the stick will be

displaced further forward for a given airspeed. The trim springs may therefore require some adjustment to function across the speed range. The mathematical model used for the CAA Contract provides a very accurate prediction of VPM M16 stick position across the speed range, Ref. 5, and was reconfigured with a c.g. further aft to simulate G-BUZL modified with the Rotax engine. Results are shown in Table 5 for 70 mph, the nominal level flight maximum speed.

Table 5 Simulated longitudinal stick position, 70 mph

	stick position (%)
Standard (Arrow)	38.5
Modified (Rotax)	22.8

Full forward stick is 0%, fully aft 100%, so it is clear that the stick is closer to the forward stop for the modified aircraft, than for the original. In terms of displacement, the standard aircraft will have about 4 in of stick travel to the forward stop, whereas the modified aircraft will have about 2.75 in.

It would be appropriate to investigate control margins following engine failure in high speed, level flight. Other flight conditions with forward stick positions, such as high speed climbs, are perhaps more limiting following engine failure, and should also be investigated.

Finally, the VPM M16 is placarded for a minimum front seat pilot mass of 70 kg. Calculations based on the new weight and balance presented here would indicate that this limit would have to be increased to 90 kg, if the modified aircraft were to have its c.g. and hence stick margins, the same as for the unmodified aircraft. This appears unnecessarily restrictive, but a conservative and prudent limitation might be 80 kg, until sufficient service experience is achieved.

Recommendations

As a consequence of the weight and balance results described in this report, it is recommended that G-BUZL fitter with the Rotax engine should

1 be placarded for a minimum front seat pilot mass of 80kg, until service experience or flight tests indicate that this limit be reduced;

2 be flight tested to examine longitudinal control margins following engine failure:

(i) at maximum level flight speed;
(ii) in 60 mph climb;
(iii) in 40 mph climb,

all three conditions with the aircraft flown dual as the "worst case".

Summary

G-BUZL fitted with the Rotax engine is some 5 kg heavier, and with a c.g. 3 in further aft and 2 in higher, than the standard aircraft. Longitudinal dynamic stability will *tend* to be improved, but only slightly. Longitudinal stick margins may be reduced by about 1 in, and trim springs may require readjustment to ensure that stick forces can be trimmed out.

References

1 Houston, S., "Review of BCAR Section T (issue2)", July 1997

2 Houston, S., "Investigation of the Longitudinal Stability Characteristics of RAF 2000 GTX-SE Gyroplane G-BXDD", University of Glasgow Dept. of Aerospace Engineering Report No.9718, October 1997.

3 Handley, C., "FRA Post Flight Report ref. M16-99-01", May 1996.

4 Houston. S., Thomson, D., "Phase 3 Progress Report (issue3)", CAA Contract 7D/S/1125, July 1997.