Experimental and Theoretical Studies of Autogyro Flight Dynamics

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Keywords: autogyro, stability, simulation, flight testing

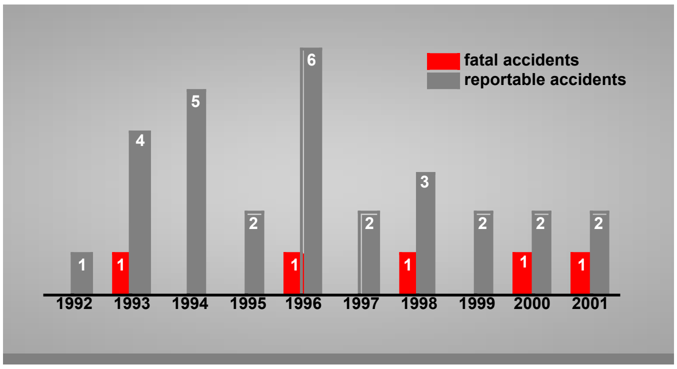
Abstract

A comprehensive flight dynamics study of the autogyro is presented in this paper. A state of the art generic simulation of the vehicle type was developed and validated against flight data. This validation is presented in the paper and it is shown that the model can be applied to the autogyro with some confidence within well defined limitations bounds. It is also shown that the general stability characteristics of the autogyro can be considered as a mix of helicopter and fixed wing aircraft modes of flight. Most significantly the autogyro has a lightly damped, high frequency phugoid mode. Further, it is demonstrated that the only significant configurational effect is related to the relative vertical position of the centre of gravity with respect to the propeller thrustline, a centre of gravity which lies above the thrustline being more desirable. Finally, results from preliminary handling qualities trials using an autogyro are presented.

1. Introduction

The emergence of the autogyro aircraft in the 1920's and '30's paved the way for the development of the helicopter in the 1940's [1]. Many of the technical problems associated with rotary wing flight had been discovered and rectified by the early autogyro pioneers most notably Juan de la Cierva's solution of installing flap hinges to accommodate non-symmetric lift from the rotor blades. The development of the autogyro receded as the helicopter became more popular and successful. In recent years however there has been a resurgence of interest in this type of aircraft both as a recreational aircraft and as a low cost alternative to the helicopter with companies such as Groen and Cartercopter both seeking to market autogyro configurations to commercial and military operators. The autogyro has become a very popular vehicle for hobby flying, possibly due to its flying characteristics but also as they are often purchased in kit form giving the owner the opportunity to build and fly his own aircraft.

This resurgence in interest by private flyers has also led to closer scrutiny by regulatory authorities. In particular, in the UK in the early 1990's the Civil Aviation Authority's attention was drawn to autogyro's after a series of accidents between 1989 and 1991 which gave statistics of 6 fatalities per 1000 hours of flying time. Given that there were less than 100 aircraft of this type registered in the UK this was constituted a serious problem. The latest statistics show some improvement, Figure 1, [2], however it is clear that there is still a problem with this aircraft type.



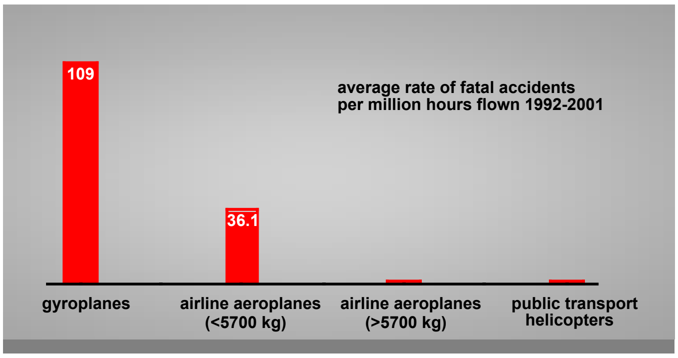


Figure 1: UK Autogyro Safety Statistics in Comparison with other Aircraft Types

Investigation of these accidents was hindered by a lack of contemporary published research into this vehicle, particularly in its aerodynamic characteristics and its flight dynamics and flying qualities. This led the UK Civil Aviation Authority (CAA) to fund research in these areas to support a major review of the British Civil Airworthiness Requirements for autogyros (BCAR Section T) [3]. The aim is to improve the design standard of autogyros in the UK and so improve their safety. The University of Glasgow has been supporting the CAA in this activity in a number of ways including wind tunnel testing of an autogyro model, flight testing of 2 aircraft types and development of comprehensive simulation models. The aim of this paper is to review the research carried out on autogyros in the area of flight dynamics by Glasgow researchers.

One of the most notable outcomes of the research was the first comprehensive study of the aerodynamics of an autogyro configuration [4], and this research is summarised in section 2 of this paper. More significantly much more is now understood about the flight dynamic characteristics of this configuration [5-8], and section 3 of the paper is devoted to this work. Finally, and most recently, work is now underway to develop handling qualities measures for this aircraft type, and the most recent results are discussed in section 4.

2. The Aerodynamic Properties of Autogyros

There were two main aims in undertaking wind tunnel tests of an autogyro configuration. Firstly there was no known data for this type of vehicle and it was essential to have appropriate information to ensure that the flight mechanics simulations were as accurate as possible. Secondly, there was evidence that some of the accidents which had occurred were related to owners modifying their aircraft by changing aerodynamic surfaces, pod or tailplane, for example. The question was just how much were the forces and moments on the aircraft influenced by such adjustments. The wind tunnel testing therefore included cases with the pod removed, tailplane removed etc to allow comparisons to be made. The effect of propeller wash was also established by conducting tests with power on and power off.

The model used in this study was a powered, one-third scale model of a VPM-M14 gyroplane minus rotor, Figure 2. It is normal, in rotorcraft testing, to carry out wind tunnel tests without the rotor since scaling considerations of a combined rotor-fuselage configuration would require the use of a very large test facility and would be prohibitively expensive. Note that a representation of the pilot is included as it is likely to be significant for a vehicle of this size. The tests were conducted in the 3m Low Speed Wind Tunnel of the Aeronautical Research and Test Institute (VZLU) of Prague in the Czech Republic. The particular wind tunnel used in this study is an atmospheric open-section, closed return, Gottigen style tunnel with a maximum velocity of around 60m/s. Forces and moments were measured on a six component fully-automatic overhead gravitational balance which is accurate to between 0.01% and 0.05% full scale. The tests were conducted at representative advance ratio and propeller thrust coefficients however the Reynolds number (2.5×10^6) is 40% of the full vehicle value at cruise. It is unlikely that the reduced Reynolds number of the tests would produce any significant differences between the measured force and moment coefficients and those experienced by the full-scale aircraft. This is primarily because the basic gyroplane structure is non-streamlined and, consequently, insensitive to Reynolds number changes.

Figure 2: Wind Tunnel Model (Rotor for display purposes only)

A full analysis of the test results is given by Coton et al in reference 4, here only some of the more pertinent conclusions are discussed. The aerodynamic characteristics of the gyroplane configurations considered in this study are generally benign. It is, however, pertinent to note that there are several effects associated with the cowling which are detrimental to stability. Although the cowling on the VPM-M14 is particularly large, it is likely that any 'open' cowling design will be subject to similar effects in the longitudinal mode. Additionally, the length of the VPM cowling is substantial; extending from well in front of the pilot up to the rotor support column. The increased wetted area which this presents to the onset flow in sideslip acts to oppose the stabilising effect of the tail. The tail of this aircraft benefits from the additional sideforce produced by the endplates on the horizontal surfaces.

With this data now available it was possible to construct a simulation model of the aircraft with which to determine its dynamic characteristics. Further, as most autogyros have the same basic shape it is proposed that this set of aerodynamics data (with appropriate scaling) will give a useful estimate for a range of aircraft.

3. Flight Dynamics of Autogyros

3.1 The *RASCAL* Mathematical Model

One of the main aims of the research was to modify an existing generic rotorcraft mathematical model, *RASCAL* [9] to simulate an autogyro, which could then be used to predict the stability of new or modified configurations. It is appropriate here to present brief details of the rotorcraft flight mechanics model *RASCAL* it is described more fully by Houston [8, 9]. It is a generic rotorcraft simulation code, the nonlinear equations of motion taking the form:

$$\dot{x} = f(x, u) \qquad (1)$$

where the state vector, *x*, contains the airframe translational and angular velocity, blade flap, lag and feather angles and rates for each blade on each rotor, the induced velocity states for each rotor wake as well as the angular velocity of each rotor, and the engine torque. Elements of the control vector, *u*, are the four controls, which vary with aircraft type, e.g., single main and tail rotor configurations will have three main rotor controls and one tail rotor control, and the autogyro will have for/aft shaft tilt, lateral shaft tilt, rudder and throttle. Blade attachment is modeled as offset hinges and springs, with a linear lag damper. The aerodynamic and inertial loads are represented by up to 20 elements per blade. Rotor blade element lift and drag forces are functions of section angle of attack and Mach number, derived from 2-D lookup tables. Airframe aerodynamic loads are functions of angle of attack and sideslip, also derived from 2-D lookup tables which were constructed from the wind tunnel data collected in the tests described above. Depending on the number of blades on each rotor, there can be up to 100 nonlinear, periodic ordinary differential equations describing the coupled rotor/airframe behavior. A simple model of the International Standard Atmosphere is used, with provision for variation in sea level temperature and pressure.

The model is therefore a very conventional individual blade/blade element representation of a generic two-rotor aircraft. The rotor module is called twice in the simulation code, each rotor being discriminated by data that specifies its location and orientation on the airframe, and its characteristics in terms of blade mass distribution, hinge offset and restraint, etc. In addition, a simple blockage factor, similar to that used for tail rotor applications, [9] can be specified when the rotor module is used to simulate the propeller of an autogyro.

The nonlinear representation given by (1) can be linearized numerically to give the state-space form, i.e.

$$\dot{x} = \mathbf{A}x + \mathbf{B}u \qquad (2)$$

where for the longitudinal dynamics:

$$\mathbf{A} = \begin{bmatrix} X_u & X_w & X_q & X_\theta & X_\Omega \\ Z_u & Z_w & Z_q & Z_\theta & Z_\Omega \\ M_u & M_w & M_q & M_\theta & M_\Omega \\ 0 & 0 & 1 & 0 & 0 \\ Q_u & Q_w & Q_q & Q_\theta & Q_\Omega \end{bmatrix}, \mathbf{B} = \begin{bmatrix} X_{\eta_s} \\ Z_{\eta_s} \\ M_{\eta_s} \\ 0 \\ Q_{\eta_s} \end{bmatrix}$$

$$x = [u \ w \ q \ \theta \ \Omega]^T \quad \text{and} \quad u = [\eta_s]$$

This constitutes the longitudinal subset of the conventional 6 degree-of-freedom rigid-body flight mechanics model, with the important (and unique) addition of the rotorspeed degree of freedom. This is required due to the aircraft operating in autorotation, the coupling of rotorspeed, Ω, to the body modes being captured by the derivatives X_Ω, Z_Ω and M_Ω. The rigid body states are taken to be with respect to a mutually orthogonal, right-handed frame of reference whose origin is at the c.g.. The longitudinal and vertical axes are respectively parallel and normal to the keel of the aircraft. Trim and linearization are performed using the procedure described in [9]. Reduction of the nonlinear model to the form given by (2) limits the bandwidth of applicability, since rotor blade dynamics are treated in a quasi-steady manner by the linearization process.

3.2 Validation of Mathematical Model

The mathematical model has been validated against two different autogyro configurations, VPM M16, Figure 3 and Montgomerie, Figure 4. The start point is to collect all of the necessary data for the aircraft. Dimensions are relatively easy to obtain as the aircraft are small and easily accessible however care has to be taken in measuring the location of the centre of gravity. The longitudinal and vertical location with respect to a datum are required (as will become apparent later). The validation process was then simply to compare results from the simulation with those from flight trials of the actual aircraft. It was assumed that as both aircraft are similar in configuration to the VPM M14 used in the wind tunnel tests, the data obtained for the M14 could be applied, after appropriate scaling.

Figure 3: VPM M16 Autogyro

Figure 4: Montgomerie Flight Research Autogyro

Both aircraft used were two seat aircraft with one seat removed and replaced by appropriate instrumentation. In both cases the instrumentation allowed full sets of data to be recorded in flight, that is all aircraft states, angles of attack and sideslip, flight velocity, pilot control inputs and in the case of the Montgomerie, aircraft position from a GPS receiver. Full details of these flight trials are provided by Houston [5 – 9] and Bagiev et al [10].

Two techniques of validation were applied. Firstly the nonlinear representation (1) was assessed by direct comparison between states measured in steady and unsteady flight with trim values and response time histories from the simulation. Secondly, the linear model (2) was validated using parameter estimation to make a comparison of stability derivatives estimated from the flight data with those from the model. In both cases the flight data was collected from trials with the Montgomerie aircraft, and the simulation was of course configured to represent this aircraft. The results of comparisons with the VPM aircraft are broadly similar in quality.

3.2.1 Validation of Non-linear Representation

A comparison of trim results from flight with those computed by the *RASCAL* model are presented in Figure 5. The simulation results are presented at two aircraft masses, (325kg and 355kg) which represent the aircraft with empty and full fuel tank. Given the relatively small mass of fuel expended in the short flights it is difficult to be more precise than to say that the flight data is recorded somewhere between the two values. The pitch attitude results show an over prediction at low speed and under prediction at high speed whilst stick position magnitude and trend with airspeed are well-predicted.

The rotorspeed prediction for the Montgomerie is consistently in error by about 10 - 30rpm. Accurate rotorspeed prediction is difficult to achieve without good knowledge of blade aerodynamic or elastic properties, so this result may still be regarded as a good given the multiplicity of factors that affect this parameter in autorotation. This is of course only one element of a complex picture of the validity of the model. The next stage is to examine the predictions of response to controls from the model with those from the flight. Figure 6 shows a doublet input of longitudinal hub tilt (i.e. fore-aft stick). This input was measured in flight, as was the aircraft's response. The same input was applied to the simulation model and the response compared with the flight data. There is a good match for most of the response both in trend and amplitude although there does seem to be a phase problem with the simulation leading the flight data. The comparison is encouraging as it is maintained for much of the test period, only diverging slightly towards the end. This quality of result can be obtained on other control axes and for other aircraft. In conclusion the full non-linear version of the *RASCAL* model appears to simulate accurately the response of autogyro aircraft to control inputs.

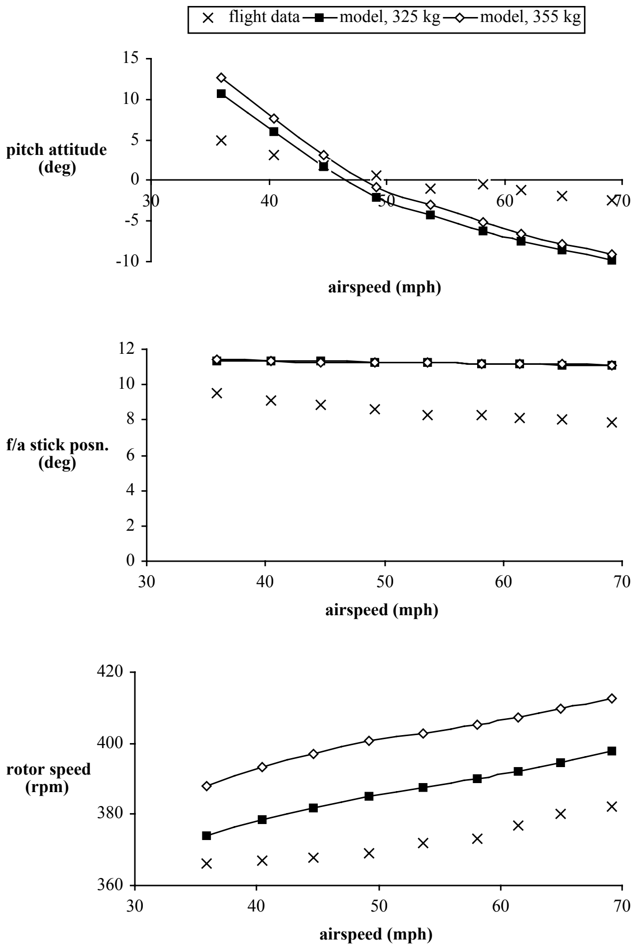


Figure 5: Comparison of Trim Results for Montgomerie Aircraft

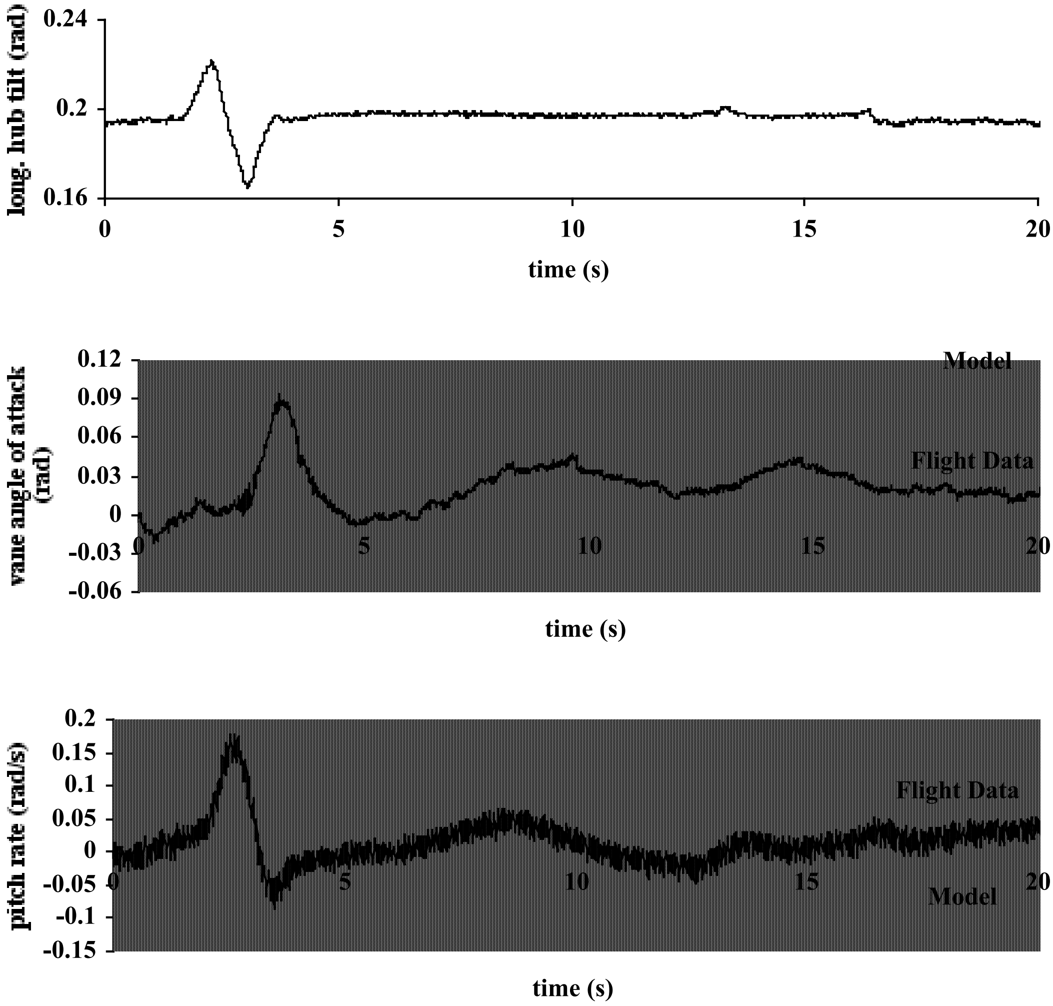


Figure 6: Comparison of Aircraft (Montgomerie) and Simulation Response to Doublet in Longitudinal Stick Input

3.2.2 Validation of Linearised Representation

Establishing the validity of the non-linear model was an important and significant achievement. It is equally important that the linearised model represents the actual vehicle. This will give confidence in any stability assessment made of the Montgomerie or (as the model is generic) any other aircraft investigated. The flight test technique used was to apply inputs to each control axis in turn in the form either of a frequency sweep or a multi-step input. Parameter estimation using a simple frequency-domain, equation-error approach was then used to estimate the values of the stability derivatives from the recorded flight data, [5, 6]. Figure 7 shows plots of aerodynamic derivatives calculated from the linearisation of the *RASCAL* model for the flight speeds of 40 and 60 mph. Also on the plot is the 95% confidence boundaries from the parameter estimation from flight data. The drag damping derivative X_u is poorly predicted for the Mongomerie - a result is consistent with the VPM study indicating a deficiency in the model. The flight test results indicate very low values of X_u which would imply almost no damping in the phugoid, however the model predicts a value of around -0.225 for X_u implying that there is damping present. This result can be viewed in a more positive light by noting that there is consistency between the two aircraft types and therefore use of *RASCAL* on other aircraft can be made provided this fact is taken into account. This contrasts with the heave damping derivative, Z_w, which is well predicted for the Montgomerie. The rotorspeed force derivatives, X_Ω and Z_Ω are well predicted largely falling within the 95% confidence boundaries. The trends for these derivatives are not so good, the likely cause being poor rotorspeed sensor resolution. The rotorspeed error bounds are significantly large, which is associated with rotorspeed measurement resolution.

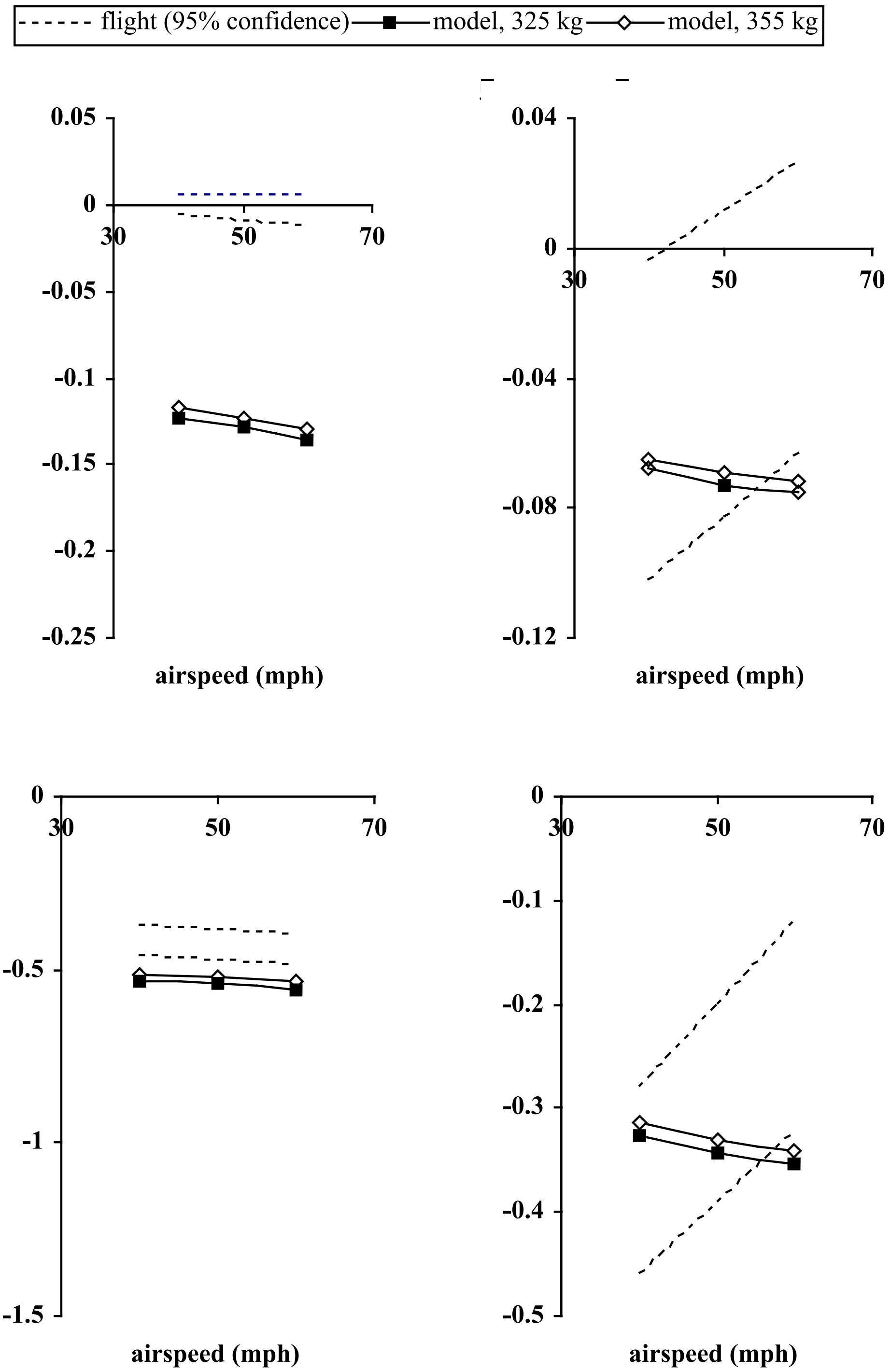


Figure 7: Comparison of Stability Derivatives Estimated from Flight Test Data and Calculated from Mathematical Model (Montgomerie)

This type of analysis can be repeated for all of the stability derivatives [5 – 9] and a reasonably consistent picture emerges. The comparisons are generally good, and consistent results between VPM and Montgomerie are observed. This is not unexpected as both aircraft are similar in general configuration. The model does have deficiencies, particularly in its estimation of speed damping, X_u. The most likely cause of this is the difficulty in modelling the complex interactions between rotor and propeller wakes and their effect on airframe loads. This can only be resolved by the addition of a more complex model of the wake dynamics. This understanding of the limitations of the mathematical model allows use to be made of it in analysing the stability of specific configurations as well as the generic type.

3.3 Autogyro Dynamic Stability Characteristics

At the outset of this research little information on the dynamic stability of autogyros is available in open literature. It was known that they exhibited some of the characteristics of the aircraft and some of the helicopter. This had never been confirmed by scientific experiment (i.e. flight trial) or analysis and there was little evidence of any parametric studies to see which configurational aspects of the vehicle influenced its stability. The aim of this research was firstly to establish the general stability characteristics of an autogyro, and then to determine which aspects of its design were most influential on its dynamics properties.

3.3.1 The Stability Characteristics of the VPM M16

Typical light autogyro rigid-body modes of motion exhibit characteristics that are similar to a mix of typical fixed-wing and helicopter modes. Typically, simulation predicts helicopter-like aperiodic pitch and heave modes (as opposed to the short-period pitch oscillation found with fixed-wing aircraft). Conversely, the autogyro can have a fixed-wing-like lightly-damped phugoid oscillation (albeit somewhat “faster” in frequency), unlike some helicopters where the phugoid oscillation can be unstable. Examination of the character of these modes indicates that in one regard at least, the autogyro is similar to helicopters in that a degree of cross-coupling exists between longitudinal and lateral/directional degrees of freedom. The autogyro is however unique in that the rotorspeed degree of freedom results in an additional mode of motion that only helicopters in autorotation will possess. Rotorspeed couples quite strongly into the airframe modes of motion. Of course, exceptions exist and the following discussion will highlight these, and their significance.

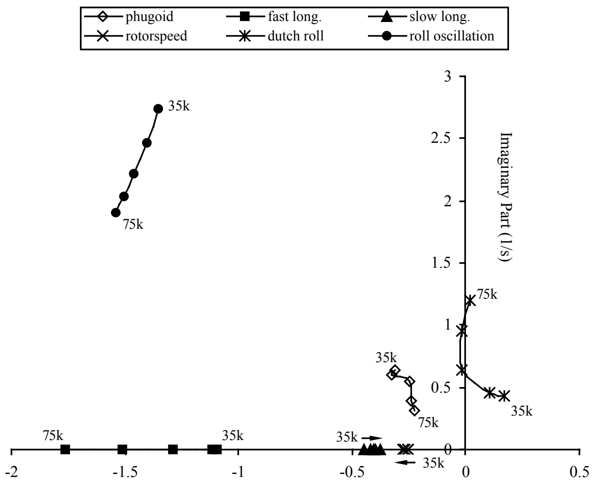


Figure 8: Modes of Motion foor VPM M16

Figure 8 shows modes of motion predicted by simulation for a VPM M16 trimmed in steady level flight between 35 and 75 knots. In this case, the helicopter-like aperiodic fast and slow pitch and heave modes define the short-term longitudinal behaviour. The slow pitch mode changes very little with speed. The rotorspeed mode has a fairly slow time constant, and it too changes little with speed. The phugoid oscillation is stable but of relatively high frequency when compared with typical helicopters or fixed-wing aircraft, and the dutch roll is very lightly damped with frequency increasing with airspeed (typical of helicopters and fixed-wing). Similar characteristics are predicted for the Montgomerie aircraft.

3.3.2 Parametric Studies

Having examined the stability characteristics of a particular aircraft, and as the purpose of the research was to support a new design standard for autogyros, the next stage was to identify which aspects of the vehicle configuration influences its stability characteristics. All evidence available was that the lateral directional dynamics of the vehicle were benign and insensitive to configuration, whilst instability (often suspected as pilot induced) was often observed in the pitch axis. The focus of the study was therefore on the longitudinal characteristics of the vehicle. The process was simply to vary key parameter values in the model of the VPM M16 autogyro and examine their effect on the eigenvalues of the linearised representation of the aircraft. Rotor parameters (rotor radius, chord, airfoil section for example) will have little effect on the body dynamics as the rotor characteristic frequencies are much higher than those of the body modes. The wind tunnel tests gave an ideal opportunity to investigate the often suggested notion that changes to pod or tailplane design caused major changes in stability characteristics. Wind tunnel data was available for pod on/pod off and tailplane on/tailplane off, and as the data was in coefficient form it was possible also to vary tailplane or pod surface area. The result of this investigation was that pod or tailplane aerodynamics have a very limited effect on longitudinal dynamics. This can be understood considering the relatively small size of these surfaces and the low speed at which the aircraft operates, it is only at the higher speed end of the range that these surfaces have any significant effect. Other parameters such as mast height (i.e. the height of the rotor head above the c.g.) were also considered but theses tended to have more influence on static stability (i.e. trim) than dynamics stability. The only significant configurational effect observed was that of vertical location of centre of gravity with respect to propeller thrust line.

3.3.3 Effect on Longitudinal Stability of Vertical C.G. Position

Measurement of the actual VPM M16 aircraft indicates that the centre of gravity lies 0.03m below the propeller hub. For the purposes of this study vertical c.g. positions of ±10cm from this point were examined. Table 1 shows the variation in the longitudinal and rotorspeed modes for these three configurations of the VPM M16 autogyro. It can be seen that the phugoid oscillation is the most sensitive to the variation in vertical position of the centre-of-mass relative to the propeller thrust line. In fact if the c.g. is sufficiently far below the propeller thrustline then the phugoid motion becomes unstable.

c.g. relative to propeller thrustline			
0.13m below	-1.22±2.76i	0.06±0.93i	-0.38
0.03m below	-1.31±2.83i	-0.06±0.78i	-0.34
0.07m above	-1.37±2.94i	-0.15±0.56i	-0.28

Table 1 Longitudinal mode eigenvalues - VPM M16 Tandem Trainer, 35 mph

For an aircraft of this size this variation of vertical c.g. position is unfeasible, however there are autogyros where vertical c.g. offsets of this magnitude are observed. Table 2 shows the eigenvectors for the short-period and phugoid modes for the configuration with the c.g. 0.055 m above the propeller thrust line (the estimated maximum amount possible in this aircraft). These results indicate that the rotorspeed degree of freedom is strongly coupled with these rigid-body modes, the phugoid in particular. It is clear that consideration of rotorspeed behaviour cannot be separated from the study of rigid-body behaviour. This is significant as it indicates the importance of a stable phugoid mode with light gyroplanes. Any handling problems with a lightly damped or unstable phugoid might be compounded with lightly damped or unstable rotorspeed oscillations as well. Normally, phugoid oscillations are relatively easy for aeroplane and helicopter pilots to control, but the light gyroplane phugoid seems to be of a significantly higher frequency than that found on these aircraft. PIO tendency, a subject of much discussion among gyroplane pilots, is most probably caused by this relatively high frequency, lightly damped or even unstable phugoid.

	$\lvert e_{sp} \rvert$	$\lvert e_{ph} \rvert$
u	0.16	0.75
w	0.76	0.12
q	0.12	0.02
θ	0.04	0.04
	0.26	0.59

Table 2 Longitudinal mode eigenvectors - VPM M16 Tandem Trainer, 35 mph

The influence of relative position of centre of gravity can be explained by consideration of Figure 9. The nose-up moment produced by a configuration with propeller thrust line below the centre-of-mass will require to be trimmed in equilibrium flight by having the main rotor thrust line passing behind the centre of mass as shown. In disturbed flight then, the possibility exists of the reduction in nose-down moment caused by the rotor flapping back, being overcome by the contribution from the increase in thrust, resulting in $M_w < 0$. This derivative has a major impact on the stability of the phugoid mode. A configuration with propeller thrust line below the centre-of-mass could exhibit $M_w < 0$ even at low airspeeds where any tailplane (the aircraft component normally considered to endow $M_w < 0$) contribution would be negligible. Note that although the VPM M16 c.g. position will *tend* to be destabilising (0.03m below thrustline), the very large horizontal tailplane and relatively small pilot pod may go some way to mitigate this. The vertical location of the c.g. of the Montgomerie aircraft is 0.075m above the propeller thrustline – a destabilising position. Flight tests have shown [11], that the aircraft has an oscillation in pitch of period around 7 seconds which has almost no associated damping.

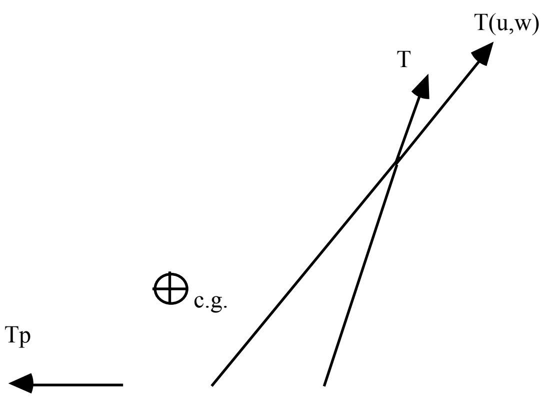


Figure 9: Stabilising Effect of Centre of gravity above thrustline

4. <u>Autogyro Handling Qualites Assessment</u>

The overall aim of this research is improved autogyro airworthiness and by inference, handling qualities. The initial stages have been to raise the level of understanding of the stability characteristics of this vehicle, and then to apply this knowledge to improve safety. As no handling qualities standards exist for autogyros the objective of this part of the research was to suggest a possible route to developing such a standard. The philosophy was that the handling qualities requirements for U.S. military rotorcraft, ADS-33E [12] (which are now widely applied across the world) should be applicable in some way to autogyros. The main feature of ADS-33E is that rotorcraft handling qualities should be assessed using the Cooper-Harper rating system [13] whilst flying standard manoeuvres referred to as Mission Task Elements (MTEs). These have been developed and tested such that the dimensions and performance requirements are suitable for military helicopters. To use this technique for autogyros the first stage was to devise suitable MTEs by adapting those in ADS-33E. To achieve this a technique known as inverse simulation was applied [10, 14]. Inverse simulation takes a mathematical model of the manoeuvre of interest and computes the pilot inputs required for the simulated vehicle to fly it. For this study an inverse simulation of the autogyro was developed, [15] and various MTEs tested. For example, the slalom MTE from ADS 33E, Figure 10, was modified to a "minimum" slalom as shown in Figure 11 to make it suitable for autogyro testing, and the possible range of dimensions established, Table 3.

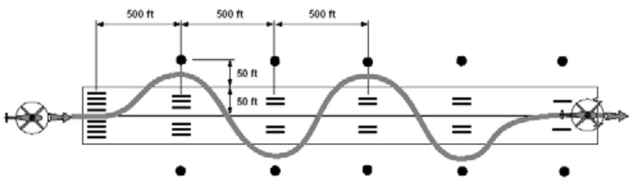


Figure 10: Suggested course for slalom maneuver (reproduced from the ADS-33E-PRF, Ref 12)

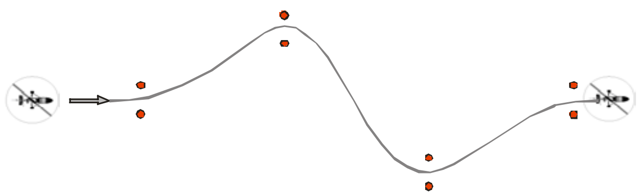


Figure 11: "Minimum" Slalom Adopted for Autogyro Tests

course	length, m	width, m	AR
1	450	30	0.067
2	300	30	0.1
3	225	30	0.13
4	300	60	0.2
5	150	30	0.2

Table 3: Slalom Test Cases

Having designed the various test cases, then next stage was to have a test pilot fly the modified MTEs in the Montgomerie aircraft, and award handling qualities ratings (HQRs) to the aircraft. Five different courses indicated in Table 3 were prepared and marked on the ground using traffic cones, and the pilot instructed to fly through each of the 15m gates. Each slalom course was conducted for three different flight speeds of 35 mph, 50 mph and 70 mph. For each of these courses, the test pilot completed two evaluation runs to increase accuracy of subjective HQRs. In total, thirty slalom runs were performed. After each flight the test pilot assigned HQRs using the Cooper-Harper rating scale. Results for fifteen different configurations are summarised in Figure 12. It can be observed that by the increase in the airspeed and AR, the pilot's subjective HQRs are degrading. For the most aggressive conditions (AR 0.2, length 150 m, airspeed 70 mph) pilot could not complete the slalom course and hence the very high HQR values returned.

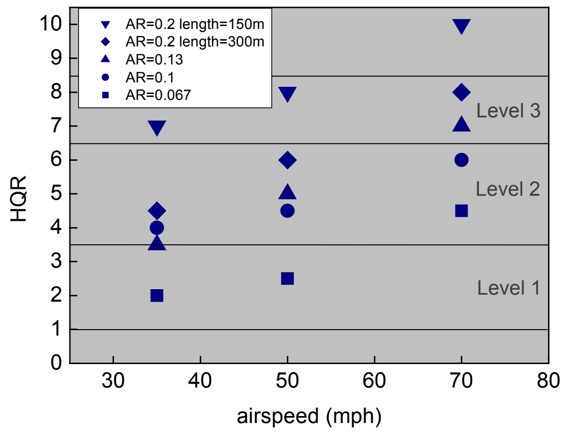


Figure 12: HQRs for different slalom courses

This is a very simple demonstration that ADS-33E can be modified to suit autogyro flight, and that meaningful results can be obtained.

5. Conclusions

Increasing commercial and private interest in the autogyro demands that more knowledge on its aerodynamic and stability characteristics must be obtained to ensure safety. Research at the University of Glasgow has focussed on supporting the UK Civil Aviation Authority's updating of the British Civil Airworthiness Requirements Section T which defines the design requirements for light autogyros. The following observations and conclusions can be drawn from the research to date.

i) Wind tunnel tests have shown that autogyro aerodynamic properties are relatively insensitive to configurational changes. Even at the high speed end of the range the aerodynamic properties of the vehicle pod and tailplane have little influence.

ii) The RASCAL mathematical model both in its linear and nonlinear formulation was validated using flight test data. Consistent results were obtained allowing the models applicability and limitations to be defined.

iii) In general autogyros exhibit a mix of stability characteristics typical of those from fixed wing aircraft and helicopters. Notably, they possess a lightly damped phugoid mode.

iv) Autogyro stability is insensitive to changes in most configurational parameters with the exception of vertical location of centre of gravity. It has been shown that a centre of gravity location above the propeller thrustline has a stabilising effect on the phugoid mode.

v) It has been demonstrated that the techniques outlined in ADS 33-E for assessing helicopter handling qualities can be modified to suit autogyros.

Acknowledgements

The authors wish to acknowledge the support of the UK Civil Aviation Authority in funding much of the research documented in this paper. The authors also acknowledge the efforts of Prof. Frank Coton for his analysis of the wind tunnel results and Marat Bagiev who conducted the handling qualities trials.

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