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Configurational and Instrumentation Aspects of the Flight Test Gyroplane G-ABCD

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Abstract

In the following report a quantitative description of the **Montgomerie G-ABCD** gyroplane configuration and instrumentation will be presented. This light gyroplane has been acquired by the department in order to enhance the research in the field of rotorcraft flight dynamics. The aircraft configuration is based on a conventional two seater design, with the second seat modified so as to accommodate the instrumentation to be used for the data acquisition.

The intention of this report is to document the configuration properties of the airframe such as its dimensions, its weight and balance and aerodynamic properties in order to later on use them as an input to a rotorcraft simulation program.

It is also intended to provide an overview of the elements comprising the data acquisition system to be used for the research together with information regarding the manufacturers of the components.

The report does not intend to form a detailed document but to serve as a general reference and guide to the aircraft and its instrumentation.

Nomenclature

m	rotor blade mass
$\overline{m}$	rotor blade mass distribution
k	rotor blade mass constant
r	rotor blade radial distance
R	rotor blade radius
I	rotor blade flapping inertia
θ	aircraft suspension inclination angle
c.g.	centre of gravity position
W_b	ballast weight
W_T	aircraft weight
x_b	ballast weight distance from reference point
x_{CG}	centre of gravity longitudinal position
z_{CG}	centre of gravity vertical position
Ixx	roll moment of inertia
Iyy	pitch moment of inertia
Izz	yaw moment of inertia
Ixz	x-z cross product of inertia
ADC	analogue to digital converter

1. Introduction

The two seat **G-ABCD Montgomerie** light gyroplane together with an on-board digital instrumentation has been acquired by the university in order to operate as a unique facility for rotorcraft simulation and flight test research. This type of aircraft allows rotary-wing flight without the enormous purchase or direct operating costs of even a light helicopter. Funding has been made available for conducting a series of flight tests to collect fundamental flight dynamics, aerodynamic and structual data. Those should commence within the next few months.

The purpose of this report, is to document the initial work performed on the **Montgomerie** gyroplane, regarding both the airframe configuration and the components of instrumentation to be used for data acquisition. The tasks undertaken regarding the configuration aspects, include measurements of the basic aircraft dimensions, determination of the areas and centre of pressures of the aerodynamic surfaces (fuselage, tailplane, fin, endplate and rudder), determination of thrust generating surfaces (main rotor, propeller) and estimation of aircraft weight and balance properties (centre of gravity, moments of inertia).

It should be noted that all the measurement estimations and locations of specific points, were made relative to a reference point selected on the keel of the aircraft. A geometric reference point is chosen to allow movement of the centre of gravity. The x-axis was chosen along the keel and in the direction of the aircraft nose, the z-axis positive vertically down and the y-axis to complete the orthogonal system, positive in the starboard direction.

The report also intends to provide a short description of each individual piece of hardware to be used for flight test purposes, including the performance aspects, and also provide an overall view of how the instruments are combined in order to form the core part of the data acquisition system. It should be noted, that the hardware was obtained not only in order to satisfy the existing requirements of the project, but also to be able to cope with future needs that may arise from tasks to be undertaken (for example rotor blade research). The following sections, provide a detailed description of the each of the above tasks.

2. Aircraft Configurational Aspects

In this section, the way in which the configurational data for the gyroplane was collected, will be demonstrated. The various parameters were obtained to the best accuracy possible. It is considered that for the modelling purposes of this project, the level of the results is more than adequate.

2.1 Basic Aircraft Dimensions

The results are illustrated in **Figures 1, 2, 3** which correspond to a side, plan and frontal view of the aircraft. The dimensions of most aerodynamic surfaces, are also included. It should be noted that the figures are only rough sketches and are not intended to be used as detailed engineering drawings. Most results were obtained to the nearest millimetre of accuracy.

2.2 Rotor Blade Parameters

The rotor blade parameters were obtained from the manufacturer of the gyroplane and comprise of the following :

- Radius : The radius of the rotor blades was given to be **3.81 m**.

- Chord : The chord of the rotor blades was measured from a drawing provided, to be **0.197 m**.

- Mass : The mass of each individual blade was given to be **13.15 Kg**.

- Flapping inertia : The flapping inertia of each rotor blade was derived using an analytical method. It was assumed that the mass was uniformly distributed. The mass distribution was calculated as ,

$$\overline{m} = \frac{13.15}{3.81} = 3.451\frac{kg}{m}$$

Thus the mass distribution of the blade is given by $m = 3.451 \cdot r$.

The flapping inertia is given by $I = \int_0^R r^2 dm$

Using the relationship $dm = \overline{m} \cdot dr$ we obtain :

$$I = \int_0^{3.81} 3.451 r^2 dr = \frac{3.451}{3} 3.81^3 = 63.62\, kgm^2$$

i.e. the flapping inertia of the blade is found to be **63.62 kgm^2**

- Shaft Length : The shaft length was measured to be **0.135 m**.

- Lift curve slope, Profile Drag Coefficient : The aerodynamic properties of the main rotor blades were assumed to the identical to those for the VPM gyroplane[1], which has been used for previous research activity. The lift curve slope was therefore assumed to be **5.7 /rad** and the profile drag coefficient , **0.015**.

2.3 Propeller Data

The propeller data was measured using a conventional measuring tape. The estimated parameters included :

- Propeller blade radius : The blade radius was measured to be **0.787 m**.

- Propeller blade chord : The value of the chord was measured over a range of spanwise locations. The average value was found to be **0.09 m**.

[1] The research was conducted under the CAA contract no. 7D/S/1125 by Dr. Stewart Houston and Dr. Douglas Thomson of Glasgow university aerospace department.

- Propeller blade twist : For the purposes of the modelling of the aircraft this was taken to be **zero.**

- Orientation of thrust line : The thrust line was found to be oriented at **1^{o} upwards,** relative to the keel. This was measured by clamping a piece of metal to the centre of the propeller rotor and measuring its inclination using an inclinometer.

- Propeller blade mass : The propeller blade mass is to be obtained in the next series of measurements.

2.4 Weight and Balance

This area of measurements covers the calculation of the aircraft weight and position of its centre of gravity and an estimation of the moments of inertia of the system. Its should be noted that the calculations were performed for the aircraft with zero fuel and no pilot. The calculations were performed both with and without the main rotor blades.

Weight and c.g position without rotor blades

The aircraft was hung from a crane and weighed **195 Kg**. The angle at which it hung was measured using an inclinometer, as $\theta = 2^{o}20^{/}$ nose up. In order to calculate the c.g. position, a weight ballast W_b = 18.5 kg was added at a known position on the

Propeller blade twist. For the purposes of the calculations the amount of twist was taken to be zero.

Orientation of thrust line. The thrust line was found to be inclined at 1° upwards relative to the keel. This was measured by clamping a piece of metal to the centre of the propeller rotor and measuring its inclination using an inclinometer.

Propeller blade mass. The propeller blade mass is to be obtained in the next series of measurements.

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Weight and c.g. position without rotor blades

The aircraft was hung from [illegible] and weighed [illegible] kg. The angle at which it hung was measured using an inclinometer as [illegible]. In order to calculate the c.g. position, a weight of [illegible] kg was added at a known position on the keel (X_b = 1390 mm) and the aircraft brought to a level position. This fact was verified with an inclinometer which was placed at the reference point so as to only produce a negligible moment.

Thus by balancing the moments produced by the aircraft weight W_T and the ballast weight, the following equation is produced :

$$W_T.x_{CG} = W_b.x_b \Rightarrow x_{CG} = \frac{W_b.x_b}{W_T} \Rightarrow \mathbf{x_{cg} = 0.061\ m\ aft}.$$

From simple geometry, the vertical distance of the cg is given by :

$$z_{CG} = 2.13 - \frac{x_{CG}}{\tan\theta} \Rightarrow \mathbf{z_{cg} = 0.643\ m\ up}.$$

A simple diagram illustrating the method of calculation, is presented in **Appendix A**.

Weight and c.g position with rotor blades

It is known that each rotor blade weighs 13.15 kg. The hub bar section was given to weigh 5.89 kg. In adding the weights of the two rotor blades and the hub bar, the whole system has a weight of 32.19 kg, which is located at a distance of 2.13 m from the reference point.

Thus the total aircraft weight, including the main blades, amounts to **227.2 kg**.

Keel (X) = 1500mm) and the aircraft brought to a level position. This test was verified with an inclinometer, which was placed at the reference point to ensure only produce a measurable moment.

Thus by balancing the moments produced by the aircraft weight W_T and the ballast weight, the following equation is produced

$$W \; [illegible] \; x = [illegible] \frac{W}{W} [illegible] \; x_{cg} = 0.001 \text{ m aft}$$

From simple geometry the vertical distance of the cg is given by

$$[illegible] \; 2.15 \; [illegible] \frac{[illegible]}{\tan\theta} [illegible] \; z_{cg} = 0.633 \text{ m up}$$

A simple diagram illustrating the method of calculation is presented in Appendix A.

Weight and c.g position with rotor blades

It is known that each rotor blade weighs 16.10 kg. The hub bar section was given to weigh 5.95 kg. Including the weights of the two rotor blades and the hub bar, the whole system has a weight of 38.19 kg, which is located at a distance of 2.15 m from the reference point.

Thus the total aircraft weight, including the main blades, amounts to 221.2 kg.

By re-calculating the overall moment equations, the c.g. co-ordinates were found to be :

x_{cg} = 0.052 m aft, z_{cg} = 0.854 m up.

It is worth noting that the vertical position of the c.g. has moved up by 21.1 cm.

It should be noted that it is intended in the future to estimate the c.g. position of the aircraft including the fuel, the instrumentation and a pilot. Those elements added to the configuration will be treated as point masses and the new position of the c.g. will be calculated by adding the extra moments which they create.

Moments of Inertia

At this stage of the project, the moments of inertia have not been directly calculated. This is intended to be performed at a later stage. Instead, data was used from the VPM gyroplane and the M.I. were scaled to the correct mass, appropriately. The Ixz inertia was assumed to be zero due to the symmetry of the aircraft. The following results were obtained :

Ixx = 82 kgm^2

Iyy = 362 kgm^2

Izz = 456 kgm^2

Ixz = 0 kgm^2

It should be noted that the moments of inertia have been scaled to the configuration of the aircraft, including the main rotor blades.

2.5 Aerodynamic Surfaces

Finally, the areas and the centre of pressure position of each of the aerodynamic surfaces were calculated. The estimations were made by direct measurement and by use of rough sketches and drawings. It should be noted that for the CP positions the quarter chord point was assumed to be a valid estimate.

- Tailplane data : The tailplane area was measured to be **0.33 m^2.**

The tailpane CP co-ordinates were found to be **(-1.02,0,0)**

- Fin data : The fin area was measured to be **0.28 m^2**.

The fin CP co-ordinates were found to be **(-1.00,0,-0.325)**

- Endplate data : The endplate area was measured to be **0.12 m^2.**

The endplate CP co-ordinates were found to be **(-1.09, $\pm$0.45 ,-0.12)**

- Rudder data : The rudder area was estimated from a drawing to be **0.50 m^2.**

The rudder CP co-ordinates will be estimated in the next stage of measurements.

- Fuselage data **:** The fuselage data will also be obtained in the next stage.

A table summarising the results obtained on the configurational aspects of the aircraft, can be found in **Appendix B**.

3. Gyroplane Instrumentation

In this section of the report, a description of each of the individual instrumentation components used in the data acquisition system, is provided. The description includes the purpose of each component, details of the manufacturer and the main technical characteristics.

The instrumentation provided can be split up and is to be connected, as shown in **Figure 4**.

The acquisition of the data is performed in the following way :

The 'raw' data is obtained via the sensors which include the air-data probe, the rate and attitude gyros, the 3-axis accelerometer and the position transducers. In this way, information is produced regarding the nine states of the aircraft in conjunction with the aerodynamic data, such as angle of attack and sideslip.

The sensors all output an analogue voltage which is then fed into the signal conditioning box. At the time this report was written, the signal conditioning mechanisms had not been set up yet, but the tasks they will perform, include the amplifications and the filtering necessary for the signals to be input to the PC card. The PC card itself is a standard 64 channel card manufactured by National Instruments (AT-MIO-64E-3), whose main element comprises of a 12 bit ADC.

The PC card is plugged into the ruggedised PC with a Pentium 120 MHz processor, that records the digital information and stores it in flight. Finally, the software used for analysing the data, is the well established software package, Lab-View. In the following sections, a more detailed description of each of the instrumentation elements will be provided.

3.1 Sensors

In order to measure all the quantities associated with the flight of the aircraft, a number of different sensors are to be used as pick-up instruments. A list of those elements can be found in **Table 1**. Those instruments comprise the initial stage of the data acquisition system. In this section it is intended to give a brief description of the purpose and the functionality of each component.

Parameter	Description	Units	Sensor
a_x	Longitudinal Acceleration	m/s2	Accelerometer
a_y	Lateral Acceleration	m/s2	Accelerometer
a_z	Normal Acceleration	m/s2	Accelerometer
p	Roll Rate	rad/s	Rate Gyro
q	Pitch Rate	rad/s	Rate Gyro
r	Yaw Rate	rad/s	Rate Gyro
ϕ	Roll Attitude	rad	Angle Indicator
θ	Pitch Attitude	rad	Angle Indicator
ψ	Yaw Attitude	rad	Angle Indicator
Vf	Indicated Airspeed	knots	Air Data Probe
α	Angle of Attack	rad	Air Data Probe
β	Angle of Sideslip	rad	Air Data Probe
T	Throttle Position	%	Displacement Transducer
η_s	Longitudinal Stick Position	%	Displacement Transducer
η_c	Lateral Stick Position	%	Displacement Transducer
η_p	Pedal Position	%	Displacement Transducer

Table 1 : Listing of sensors

Air Data Probe

This sensor is used to estimate the aerodynamic quantities associated with the motion of the aircraft. The relative pressures are transformed into voltages via a pressure transducer. The parameters α and β are acquired from potentiometers attached to the vanes of the probe.

- Manufacturer

The manufacturer of the product is the company **Space Age Control**. The representatives of the company in the UK are **Endevco UK LTD.**

The full address and telephone number is :

Endevco UK LTD

Melbourn Royston, Herts.

SG8 6AQ

Tel. 01763-261311

Facsimile 01763-261120

- Measured Parameters

This sensor is used to measure the following parameters :

- Angle of Attack
- Angle of Sideslip
- Static Pressure
- Total Pressure

- Main Technical Characteristics

The sensor possesses the following main characteristics :

- Miniature size for light aircraft use
- 2024-T351 aluminium body
- Stainless steel nose
- Angle of attack and sideslip vanes
- Static and total head pressure pickups
- Weight : 6 oz

Position Transducers

The four transducers are used to measure the control inputs of the pilot.

- Manufacturer

The manufacturer of the product is the company **Space Age Control**. The representatives of the company in the UK are **Endevco UK LTD.**

The full address and telephone number is :

Endevco UK LTD

Melbourn Royston, Herts.

SG8 6AQ

Tel. 01763-261311

Facsimile 01763-261120

- Measured Parameters

This sensor is used to measure the following parameters :

- Longitudinal stick deflection
- Lateral stick deflection
- Pedal position
- Throttle position

- *Main Technical Characteristics*

The exact characteristics of the sensor vary with respect to the application considered. **Figure 5** illustrates the basic configuration of such a device.

<u>Rate Gyros</u>

The three rate gyros are used to measure the three angular rates of the aircraft.

- *Manufacturer*

The manufacturer of the product is the company **British Aerospace**.

The full address and telephone number is :

British Aerospace (Systems & equipment) Ltd

Clittaford Road, Southway

Plymouth PL6 6DE. UK

Tel. 01752-695695

Fax 1752- 695500

- *Measured Parameters*

This sensor is used to measure the following parameters :

- Roll rate
- Pitch rate
- Yaw rate

- Main Technical Characteristics

The sensor (VSG2000) possesses the following main characteristics :

- Number of axes : 1
- Rate range : 100 deg/s
- Scale factor variation (over temperature) : 2 %
- Linearity : 0.2 % FS
- Bias over temperature : 1.5 deg/s
- In-run bias : 0.01 deg/s
- Quiescent noise : 0.5 deg/s (rms)
- Vibration survival : 10g rms
- Ready time : 0.5 s

Angle Detectors

The three angle detectors are used to measure the three angular attitudes of the aircraft.

- Manufacturer

The manufacturer of the product is the company **British Aerospace**.

The full address and telephone number is :

British Aerospace (Systems & equipment) Ltd

Clittaford Road, Southway

Plymouth PL6 6DE. UK

Tel. 01752-695695

Fax 1752- 695500

- Measured Parameters

This sensor is used to measure the following parameters :

- Roll attitude
- Pitch attitude
- Yaw attitude

- *Main Technical Characteristics*

The sensor (AD01) possesses the following main characteristics :

- Number of axes : 1
- Rate range : 0.2 to 100 deg/s
- Yaw unit angle range ± 180 deg
- Roll/Pitch angle range ± 45 deg
- Scale factor variation (over temperature) : 1 %
- Bias stability : 2 deg/hour

3-Axis Accelerometer

The 3-axis accelerometer is used to measure the translational accelerations of the aircraft.

- *Manufacturer*

The manufacturer of the product is the company **British Aerospace**.

The full address and telephone number is :

British Aerospace (Systems & equipment) Ltd

Clittaford Road, Southway

Plymouth PL6 6DE. UK

Tel. 01752-695695

Fax 1752- 695500

- Measured Parameters

This sensor is used to measure the following parameters :

- Longitudinal acceleration
- Lateral acceleration
- Vertical acceleration

- Main Technical Characteristics

The sensor (C3A-02) possesses the following main characteristics :

- Number of axes : 3
- Acceleration range : $\pm 2g$
- Scale factor variation : 0.05 % deg C
- Bias over temperature : 2 mg/deg C
- In-run bias : 0.2 mg
- Quiescent noise : 1mg rms

- Ready time : 0.3 s

2.2 The PC Card

The PC card is used as the interface between the conditioned sensor output and the ruggedised PC. The software used to drive the card is the *National Instruments NI-DAQ* software, which is provided with the card itself.

- *Manufacturer*

The manufacturer of the product is the company **National Instruments**.

The full address and telephone number is :

National Instruments Corp. Ltd.

21 Kingfisher Court

Hambridge Rd.

Newbury, Berkshire RG14 5SJ

Tel. 01635-523545

Fax 01635-523154

info.uk@natinst.com

www.natinst.com

- *Measured Parameters*

The PC card is used to convert the analogue signals coming from the sensors, into discrete digital form, it therefore consists mainly of a 12 bit ADC.

- *Main Technical Characteristics*

The product (AT-MIO-64E-3) possesses the following main characteristics :

- Input channels : 64 SE, 32 DI
- Input resolution : 12-bit
- Sample rate : 500kS/s
- Output channels : 2
- Output resolution : 12-bit
- Digital I/O : 8
- Triggering : Analogue & Digital

2.3 Ruggedised PC

The ruggedised PC is used to acquire and store the digital information sent from the ADC of the PC card.

- Manufacturer

The manufacturer of the product is the company **Kontron Elektronik**.

The full address and telephone number is :

Walter Gray, sales director

Imex Systems Ltd.

Coatbridge Business Centre

Main Str. Coatbridge ML5 3RB

Tel. 01236-440840

Fax 01236-449392

wdgray@imex.win-uk.net

- Measured Parameters

The ruggedised PC will be used to store and analyse the data picked up from the sensors in its digital form.

- Main Technical Characteristics

The PC possesses the following main characteristics :

Processor : Intel Pentium

Clock frequency : 120 MHz

Cache : 256 kB pipeline burst

RAM : 64 MB

Fast SCSI interface : Optional

Kontron Elektronik BIOS : Flash

2.4 The Software

The software used for the data acquisition system, is the well established Lab-View package. This software is to be used both for acquiring and analysing the obtained data.

- Manufacturer

The manufacturer of the product is the company **National Instruments**.

The full address and telephone number is :

National Instruments Corp. Ltd.

21 Kingfisher Court

Hambridge Rd.

Newbury, Berkshire RG14 5SJ

Tel. 01635-523545

Fax 01635-523154

info.uk@natinst.com

www.natinst.com

- *Measured Parameters*

The software is used to store and analyse the acquired data.

- *Main Technical Characteristics*

The software package possesses the characteristics of the latest (4.1) version of LabView. For further details please refer to the Lab-View user manual.

4. Conclusions

The purpose of this report was to present the information that was produced relevant to the **Montgomerie** gyroplane's basic dimensions and weights and the instrumentation used for the data acquisition system. The configurational data obtained can be used to create an initial data file for the aircraft. In the following stages of the project, it is the intention to refine and enhance this data file.

This report is also intended to be used as a general reference on the instrumentation used on the **Montgomerie** gyroplane. A general outline of the data acquisition system was presented together with a more detailed description of the individual elements that

Fax: 01435-82[illegible]

info@[illegible].com

www.[illegible].com

Microcal Software

The software is used to store and analyse the acquired data.

[illegible] Technical Services

The software package possesses the characteristics of the latest [illegible] version of [illegible] [illegible]. For further details please refer to the [illegible] user manual.

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comprise a. For more detailed references, the relevant company handbooks should be referred to.

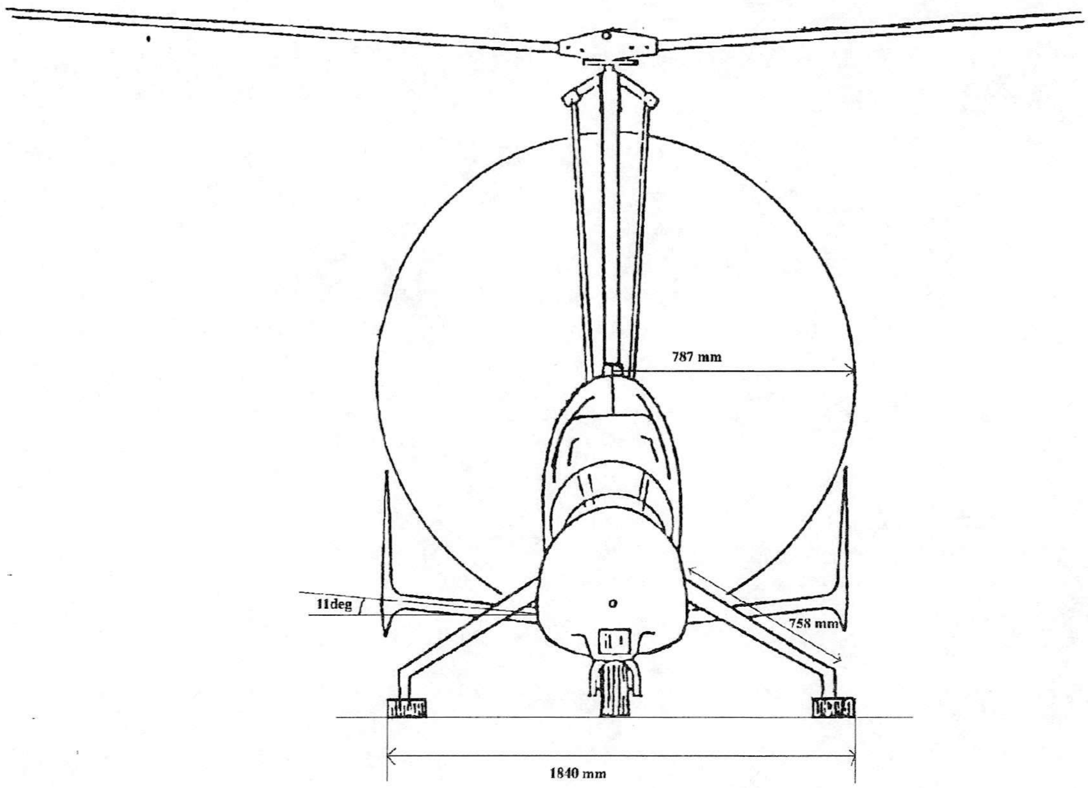


Figure 1 Frontal view of gyroplane

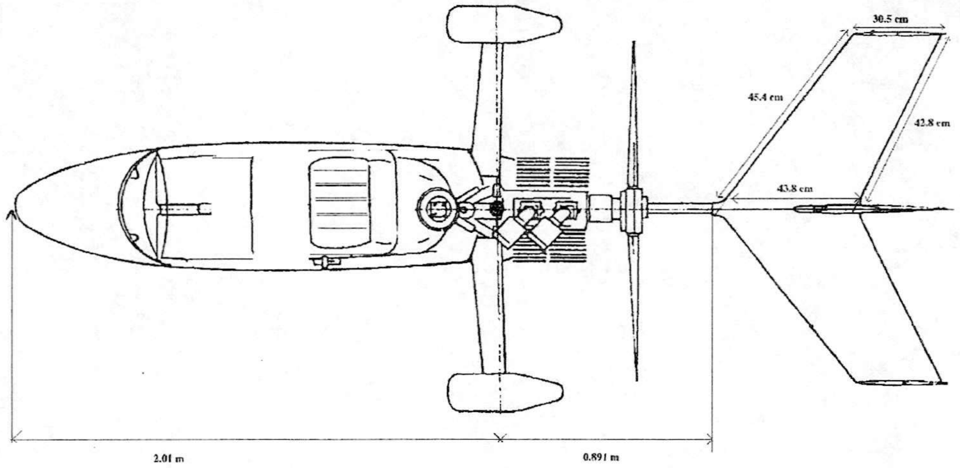


Figure 2 Planar view of gyroplane

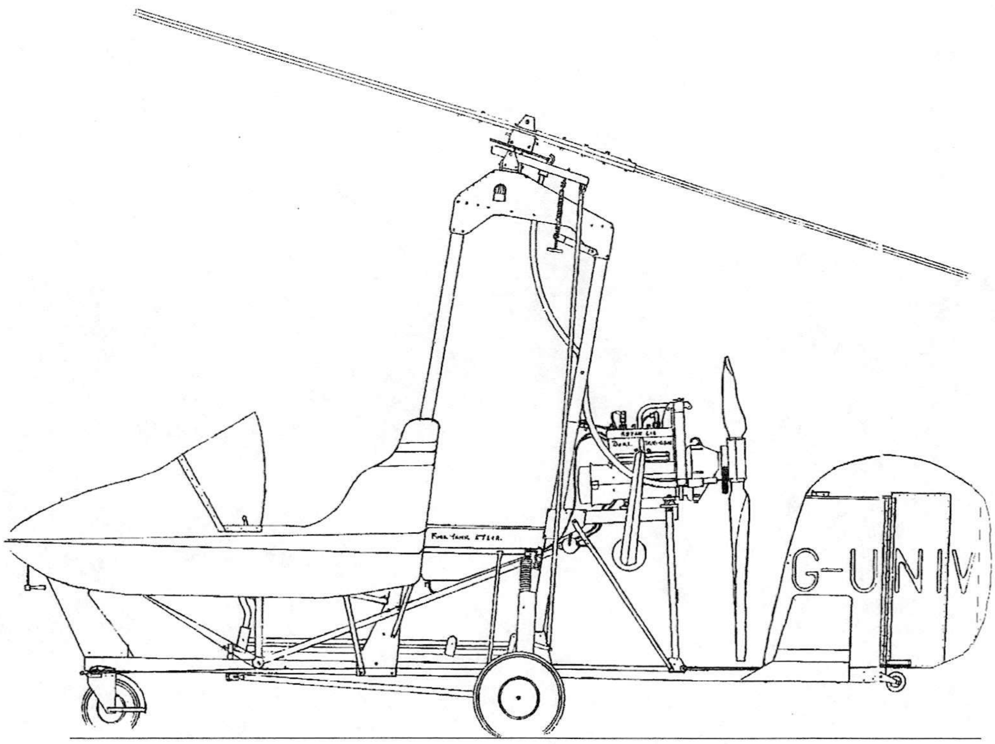


Figure 3 Side view of gyroplane

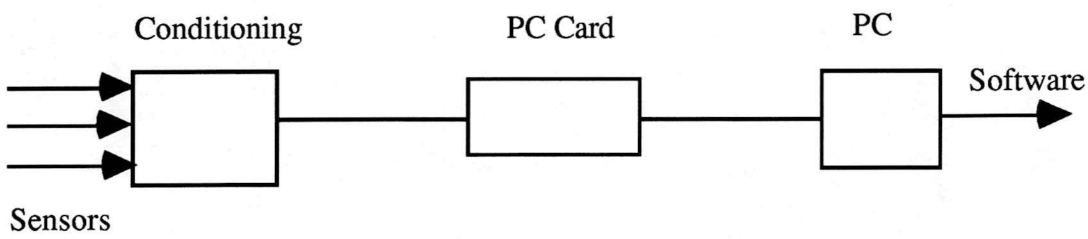
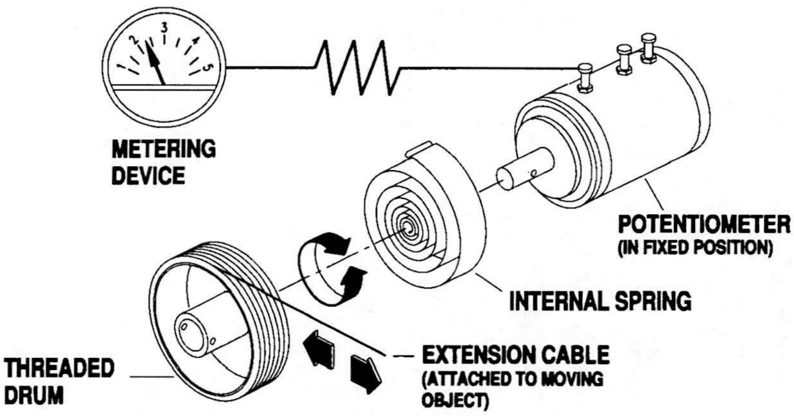


Figure 4 **Basic block diagram of instrumentation**

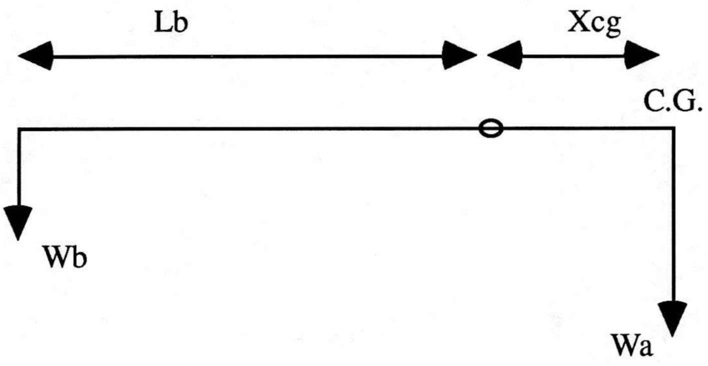


TYPICAL SERIES 160 CONFIGURATION

Figure 5 **Typical position transducer configuration**

Appendix A

Calculation of centre of gravity position



The aircraft is brought to a level position by adding a weight ballast W_b at a length L_b from the reference point. The point at which the aircraft weight W_a is applied (i.e. the c.g. position), is denoted by X_{cg} and is calculated by taking the moment equation about the reference point :

$$X_{cg} \cdot W_a = W_b \cdot L_b \Rightarrow X_{cg} = \frac{W_b \cdot L_b}{W_a}$$

The vertical position (Z_{cg}) of the c.g. is calculated from simple geometry using the formula :

$$Z_{cg} = l - \frac{X_{cg}}{\tan\theta}$$

where,

l denotes the distance of the reference point from the aircraft suspension point.

Appendix B

Summary of aircraft configuration parameters

Configurational Data for Montgomerie Gyroplane (zero-fuel, no-pilot condition)

Gross Mass	227.2 Kg	*Fuselage Data :*	
		Side Area	**********
Moments of Inertia		Plan Area	**********
Ixx	82 Kg m2 *	Frontal Area	**********
Iyy	362 Kg m2 *		
Izz	456 Kg m2 *	*Tailplane Data :*	
Ixz	0 Kg m2 *	Area	0.333 m2
		Setting Angle	0 deg
Co-ordinates (in metres) for :			
Centre of Gravity	(-0.052,0,-0.854)	*Fin Data :*	
Hub Plate Pivot Point	(0,0,-2.13)	Area	0.2808 m2
Propellor Hub	(-0.966,0,-0.848)	Setting Angle	0 deg
Fuselage C.P.	**********		
Tailplane C.P.	(-1.02,0,0)	*Endplate Data :*	
Fin C.P.	(-1.00,0,-0.325)	Area	0.1165 m2
End Plate C.P.	(-1.09,0.45,-0.12)	Setting Angle	0 deg
Rudder C.P.	**********		
		Rudder Data :	
Rotor Blade Parameters :		Area	0.5 m2
Radius	3.81 m		
Chord	0.197 m	*Propellor Data :*	
Mass	13.15 Kg	Blade Radius	0.787 m
Flapping Inertia	63.62 Kg.m2	Blade Chord	0.09 m
Lift Curve Slope	5.7 /rad	Blade Twist	0 deg
Profile Drag Coefficient	0.015	Blade Mass	**********
Shaft Lenght	0.135	Orientation of Thrust Line	1deg

*	scaled
**********	to be estimated