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The Calibration and Testing of the G-BWTP Montgomerie Gyroplane Instrumentation

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Abstract

In the following report a quantitative description will be given of the calibration and testing for the instrumentation of the **G-BWTP Montgomerie** gyroplane. This light aircraft together with the instrumentation package has been acquired by the department in order to enhance the research in the field of rotorcraft flight dynamics. The gyroplane is due to be flight tested within the next months providing the opportunity to acquire data unique in the rotorcraft field.

The intention of this report is to illustrate the way in which parameters relating to the sensor characteristics, such as the calibration constants, were derived and how the sensors themselves were tested using a well established software package. A presentation will also be given of the design of the full software program to be used for the data acquisition and analysis.

The key objective of the report is to provide a reference on the way in which instrumentation is set up for the flight testing of a light gyroplane.

1. Introduction

The two seat **G-BWTP 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 structural data.

The instrumentation obtained for the experiments is aimed to fully determine the translational and angular positions and velocities of the aircraft, the linear accelerations, together with the pilot inputs that produce the aircraft motion. The data acquisition is performed by a Kontorn Elektronik industrial PC recording 64 channels at a sample rate of 100Hz using a National Instruments DAQ card and Labview software, telemetry being possible via a radio modem link. Initial trails will focus on recording standard flight dynamics data and hence the sensor package consists of:

i) one British Aerospace Systems and Equipment three axis accelerometer to measure the component inertial accelerations,
ii) three British Aerospace Systems and Equipment rate gyros to measure the attitude rates,
iii) three British Aerospace Systems and Equipment angle indicators to measure attitude angles,
iv) one Space Age Technology mini air data boom to measure airspeed, angle of attack and angle of sideslip,
v) four Space Age Technology displacement transducers to measure the pilot's control inputs (fore and aft stick, pedals and throttle).

The aim of this report is to provide a detailed description of the purpose and functionality of each instrument, together with the procedure that was used for calibrating and testing. Parameters such as calibration constants and offsets will be obtained both from the manufacturer's data sheets and from testing. Wherever possible, the theoretical and obtained values will be compared, though in many cases regarding the calibration constants, the manufacturer's results were the only ones available.

For the purpose of testing and calibrating, an interface board consisting of some basic signal conditioning was produced, which in conjunction with an **SCB-100** board was used to feed the sensor signals into the PC. Most sensors operate by producing an output voltage in the region of 0 to 5 Volts. A detailed description of how the well established Labview software package was used to analyse the test data will be given, together with the full program to be used for the data acquisition in the flight testing. The above procedures are described in detail in the following sections.

2. Instrument Calibration and Testing

Each sensor was connected (via the interface boards), to a different channel of the DAQ card. Each channel was configured using the Labview channel wizard. This allows the user to select a channel name, the range of the physical quantity to be measured, the range of the sensor output voltage and most importantly the scaling formula to be used for transforming the voltage into engineering units. A linear variation of voltage with the measured quantity was assumed for each sensor. In order to determine the scaling equation, the sensor calibration constant and zero point offset had to be determined. A list of the channel allocations for each instrument is presented in **Table 1**.

For most of the sensors the scaling factor was assumed constant and was obtained from the manufacturer's data sheets. In some cases (such as the air-data probe vanes), the constant was obtained from measurement. In the case of the zero point offset, it was observed that although in theory for most sensors it has a value of 2.5 V, in practice it varies slightly from day to day. In this report, an average value obtained from different measurements will be given but it is suggested that this is checked and taken into account before each flight experiment, with the aircraft in a still position.

Sensor	**Channel number**
Longitudinal stick transducer	0
Lateral stick transducer	1
Rudder position transducer	2
Throttle position transducer	3
Roll attitude indicator	4
Pitch attitude indicator	5
Yaw attitude indicator	6
Roll rate gyro	8
Pitch rate gyro	9
Yaw rate gyro	10
1-Axis accelerometer	11
3-Axis accelerometer (x-axis)	12
3-Axis accelerometer (y-axis)	13
3-Axis accelerometer (z-axis)	14
Temperature probe	15
Angle of attack vane	16
Angle of sideslip vane	17
Velocity	18
Ambient atmospheric temperature	19
Static atmospheric pressure	20

Table 1: Channel allocations

The instruments are presented in different categories each of which is used to measure a different property of the aircraft dynamics. These consist of angle detectors, rate gyros, 3-axis accelerometer, 1-axis accelerometer, temperature probe, position transducers and the air-data probe. A list of the instruments together with the measured quantities is given in **Table 2**.

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	deg/s	Rate Gyro
Q	Pitch Rate	deg/s	Rate Gyro
R	Yaw Rate	deg/s	Rate Gyro
Φ	Roll Attitude	deg	Angle Indicator
Θ	Pitch Attitude	deg	Angle Indicator
Ψ	Yaw Attitude	deg	Angle Indicator
V_f	Indicated Airspeed	knots	Air Data Probe
P	Static Pressure	mbar	Air Data Probe
T	Ambient temperature	deg Celsius	Air Data Probe
α	Angle of Attack	deg	Air Data Probe
β	Angle of Sideslip	deg	Air Data Probe
η_T	Throttle Position	cm	Displacement Transducer
η_s	Longitudinal Stick Position	cm	Displacement Transducer
η_c	Lateral Stick Position	cm	Displacement Transducer
η_p	Pedal Position	cm	Displacement Transducer

Table 2: Sensors and measured properties

A. Angle detectors

This group of three sensors is used to measure the roll, pitch and yaw attitudes of the aircraft. The physical unit of the measured quantity is *degrees*.

Roll and pitch angle detectors

- Purpose: To measure the aircraft roll and pitch angle attitudes.
- Manufacturer: British Aerospace Systems and Equipment

- Serial Numbers : 7053204, 7053155

- Theoretical characteristics:

Parameter	Roll Sensor	Pitch sensor
Range	± 45 deg	± 45 deg
Scale factor	44.2 mV/°	44.2 mV/°
Zero point offset	2.5 V	2.5 V

- Practical characteristics :

Parameter	Roll Sensor	Pitch sensor
Range	± 45 deg	± 45 deg
Scale factor	44.2 mV/°	44.2 mV/°
Zero point offset	2.520 V	2.559 V

Comments on the calibration: The scale factor was obtained from the manufacturer's data sheet. A rough check was performed using a conventional protractor. The zero offset value was obtained by measurement.

- Scaling equations:

The following equations relating degrees of attitude to voltage were produced from the calibration:

$$\Phi = 22.62 \cdot V_{\Phi} - 57.90$$

(for roll attitude)

$$\Theta = 22.62 \cdot V_{\Theta} - 57.01$$

(for pitch attitude)

Yaw angle detector

- Purpose: To measure the aircraft yaw angle attitude.
- Manufacturer: British Aerospace Systems and Equipment
- Serial Number : 6062350
- Theoretical characteristics:

Range	± 180 deg
Scale factor	11.1 mV/°
Zero offset	2.5 V

- Practical characteristics :

Range	± 180 deg
Scale factor	11.1 mV/°
Zero offset	2.553 V

Comments on the calibration: The scale factor was obtained from the manufacturer's data sheet. A rough check was performed using a conventional protractor. The zero offset value was obtained by measurement.

- Scaling equation:

The following equation relating degrees of attitude to voltage was produced from the calibration:

$$\Psi = 90.90 \cdot V_{\psi} - 232.09$$

B. Rate gyros

This group of three sensors (of British Aerospace VSG2000 type), is used to measure the roll, pitch and yaw rates of the aircraft. The physical unit of the measured quantity is *degrees/second.*

- Purpose: To measure the aircraft roll, pitch and yaw rate.

- Manufacturer: British Aerospace Systems and Equipment

- Serial Numbers : 30201, 30202, 30206

- Theoretical characteristics:

Parameter	Roll rate sensor	Pitch rate sensor	Yaw rate sensor
Range	± 100 deg/s	± 100 deg/s	± 100 deg/s
Scale factor	20 mV/°/s	20 mV/°/s	20 mV/°/s
Zero point offset	2.5 V	2.5 V	2.5 V

- Practical characteristics :

Parameter	Roll rate sensor	Pitch rate sensor	Yaw rate sensor
Range	± 100 deg/s	± 100 deg/s	± 100 deg/s
Scale factor	20 mV/°/s	20 mV/°/s	20 mV/°/s
Zero point offset	2.513 V	2.521 V	2.524 V

Comments on calibration: The scale factor was obtained from the manufacturer's data sheet. The zero offset value was obtained by measurement.

- Scaling equations:

The following equations relating deg/s of rate to voltage were produced from the calibration:

$P = 50 \cdot V_P - 125.65$
(for roll rate)

$Q = 50 \cdot V_Q - 126.05$
(for pitch rate)

$R = 50 \cdot V_R - 126.20$
(for yaw rate)

C. 3-Axis accelerometer

This 3-axis sensor, is used to measure the three linear accelerations from three separate channels. The physical unit of the measured quantity is *g*.

- Purpose: To measure the aircraft linear accelerations.

- Manufacturer: British Aerospace Systems and Equipment

- Serial Number : 702111

- Theoretical characteristics:

Parameter	x-axis sensor	y-axis sensor	z-axis sensor
Range	± 2 g	± 2 g	± 2 g
Scale factor	N/A	N/A	N/A
Zero point offset	N/A	N/A	N/A

- Practical characteristics :

Parameter	x-axis sensor	y-axis sensor	z-axis sensor
Range	± 2 g	± 2 g	± 2 g
Scale factor	1 V/g	1 V/g	1 V/g
Zero point offset	2.477	2.480	2.490

Comments on the calibration: No theoretical value was available for the scaling parameters. This was determined from measurement by sitting each axis in turn vertically thus forcing it to measure 1 g. It was observed that the sign of the output voltage was opposite to that of the measured acceleration. Also for the z-axis it was observed that there was a 1 g offset in the measurements. These facts were taken into consideration when designing the analysis software.

- Scaling equations:

The following equations relating g of acceleration to voltage were produced from the calibration:

$$a_x = V_{a_x} - 2.48$$
(for the x-axis)

$$a_y = V_{a_y} - 2.48$$
(for the y-axis)

$$a_z = V_{a_z} - 2.48$$
(for the z-axis)

D. 1-Axis accelerometer

This 1-axis sensor, is used to measure the vertical linear acceleration. This sensor is used in the case of the range of the 3-axis accelerometer not being sufficient for the experiments. The physical unit of the measured quantity is *g*.

- Purpose: To measure the aircraft z-axis acceleration.
- Manufacturer: Seika, Scientific Electro Systems Limited
- Serial Number : 7659
- Theoretical characteristics:

Range	± 3 g
Scale factor	120.8 mV/g
Zero offset	2.5 V

- Practical characteristics :

Range	± 3 g
Scale factor	120.8 mV/g
Zero offset	2.517 V

Comments on the calibration: The scale factor was obtained from the manufacturer's data sheet. The zero offset value was obtained by measurement.

- Scaling equation:

The following equation relating g of acceleration to voltage was produced from the calibration:

$$a_z = V_{a_z} - 2.48$$

E. Temperature probe

The purpose of this sensor was to measure the room temperature, thus providing a check that the connections and software were set up correctly. It is intended in the future to replace this sensor with the one to be used for measuring the aircraft rotorspeed. The physical unit of the measured quantity was *deg Celsius*.

- Purpose: To measure the room temperature thus testing the software design.
- Manufacturer: RS components.
- Serial Number : N/A
- Theoretical characteristics:

Range	0-100 °C
Scale factor	0.1 V/°C
Zero offset	0 V

- Practical characteristics :

Range	0-100 °C
Scale factor	0.1 V/°C
Zero offset	0 V

Comments on the calibration: The scale factor and zero point offset were obtained from the manufacturer's data sheet.

- Scaling equation:

The following equation relating degrees of temperature to voltage was produced from the calibration:

$$T = 10 \cdot V_T$$

F. Position transducers

The four position transducers are used to measure the pilot's inputs to longitudinal stick, lateral stick, rudder and throttle. The physical unit of the quantities measured is *cm*.

Longitudinal and lateral stick transducers

- Purpose: To measure longitudinal and lateral stick inputs.
- Manufacturer: Space Age Control, Inc.
- Serial Number : 4851, 4852.
- Theoretical characteristics:

Range	N/A
Scale factor	N/A
Zero offset	N/A

- Practical characteristics :

Range	10.5 cm
Zero point offset	0 V
Maximum deflection offset	5 V
Scale factor	0.476 V/cm

Comments on calibration: No theoretical values were available for the scaling and offset factors of this sensor. Those were determined by measurement by extending the cables over their range and measuring the output voltages.

- Scaling equation:

The following equation relating cm of position to voltage was produced from the calibration:

$\eta_S = 2.1 \cdot V_{\eta_S} - 5.25$

Rudder position transducer

- Purpose: To measure the rudder deflection input.
- Manufacturer: Space Age Control, Inc.
- Serial Number : 4854
- Theoretical characteristics:

Range	N/A
Scale factor	N/A
Zero offset	N/A

- Practical characteristics :

Range	21 cm
Zero point offset	0 V
Maximum deflection offset	5 V
Scale factor	0.238 V/cm

Comments on calibration: No theoretical values were available for the scaling and offset factors of this sensor. Those were determined by measurement by extending the cables over their range and measuring the output voltages.

- Scaling equation:

The following equation relating cm of position to voltage was produced from the calibration:

$$\eta_p = 4.2 \cdot V_{\eta_p} - 10.5$$

Throttle position transducer

- Purpose: To measure the throttle input.
- Manufacturer: Space Age Control, Inc.
- Serial Number : 4853
- Theoretical characteristics:

Range	N/A
Scale factor	N/A
Zero offset	N/A

- Practical characteristics :

Range	5.7 cm
Zero point offset	0 V
Maximum deflection offset	5 V
Scale factor	0.877 V/cm

Comments in calibration: No theoretical values were available for the scaling and offset factors of this sensor. Those were determined by measurement by extending the cables over their range and measuring the output voltages.

- Scaling equation:

The following equation relating cm of deflection to voltage was produced from the calibration:

$$\eta_T = 1.14 \cdot V_{\eta_T} - 2.85$$

G. Air-data probe

The air-data probe is the most complex of the sensors. It reads aerodynamic data from 5 different channels including angle of attack, angle of sideslip, static pressure, dynamic pressure and ambient temperature. At the time this report was written, only the angle vanes had been calibrated. The pressure and temperature transducers were in the process of calibration.

Angle of attack vane

- Purpose: To measure aerodynamic angle of attack.

- Manufacturer: Space Age Control, Inc.

- Serial Number : 4029.

- Theoretical characteristics:

Range	N/A
Scale factor	N/A
Zero offset	N/A

- Practical characteristics :

Range	± 30 deg
-20 deg point voltage	0.898 V
0 deg point offset	2.465 V
20 deg point voltage	4.118 V
Scale factor	80.5 mV/deg

Comments on calibration: No theoretical values were available for the scaling and offset factors of this sensor. Those were determined by measurement. A calibration kit was obtained from the manufacturer and the output voltage over a certain angular range was obtained in order to perform calibration.

- Scaling equation:

The following equation relating deg of angle of attack to voltage was produced from the calibration:

$$\alpha = 12.4239 \cdot V_{\alpha} - 30.6249$$

Angle of sideslip vane

- Purpose: To measure aerodynamic angle of sideslip.

- Manufacturer: Space Age Control, Inc.

- Serial Number : 4029.

- Theoretical characteristics:

Range	N/A
Scale factor	N/A
Zero offset	N/A

- Practical characteristics :

Range	$\pm$ 30 deg
-20 deg point voltage	0.6885 V
0 deg point offset	2.2069 V
20 deg point voltage	4.7545 V
Scale factor	76.65 mV/deg

Comments on calibration: No theoretical values were available for the scaling and offset factors of this sensor. Those were determined by measurement. A calibration kit was obtained from the manufacturer and the output voltage over a certain angular range was obtained in order to perform calibration.

- Scaling equation:

The following equation relating deg of angle of attack to voltage was produced from the calibration:

$$\beta = 13.0463 \cdot V_{\beta} - 28.7919$$

3. Software design

The design of the software which will analyse the acquired data, forms an integral part of the overall data acquisition system. The transducer signals are fed into the PC card, which is of **National Instruments AT-MIO-64E-3** type, and processed in order to be analysed. The software package that was used for the task was the well established Labview software. As mentioned earlier in the report, the individual channels from which the data is to be read, were configured using the channel wizard. This configuration tool was then used to test and calibrate the instruments.

In order to perform the full data acquisition, a program had to be developed within Labview in the form of a **'virtual instrument (VI)'**. The purpose of this program would be to acquire the desired data over a specific amount of time at a specific sampling rate. Once the acquisition is completed, the data is to be written to a text file and plotted using the Labview plotting utilities. The sampling time and rate are taken as inputs to the program and the created data file can then be used for analysis either in Labview itself or other data analysis packages such as Excel, Matlab etc.. The text file format of the file facilitates such a function.

The core of the program is based on what is described in the *DAQ Labview User Manual* as the **Acquired Multiple Waveforms.VI**. This is the equivalent of a built in subroutine which is used to sample specified channels. Since Labview is programmed using block diagram form (i.e. it is a graphical language), each VI is represented by a separate box. For more details on the function of this VI please refer to the User Manual.

Within Labview the data is stored in the form of a two dimensional array each column representing the data from one channel. The **VI 'write to spreadsheet.VI'** is then used to write the data to a user-specified data file. The **VI 'index array.VI'** together with some additional processing is used to separate the channel data and display it in the Labview front panel as separate graphs. The Labview graph tools can then be utilised to look at specific portions of the data by zooming into it. This is an important feature, since it is intended to set the software running just before each flight and to stop it just after. For most experiments this could be as long as 1 hour's worth of data from which only a few minutes may be of real interest. It is thus necessary to be able to study independently the portion of the data that is useful.

It should also be noted that for the case of the 3-axis accelerometer corrections to the raw data are applied in order to get it into the correct measuring unit. A full block diagram of the designed program (called **fullsyscom.vi**) together with a view of the front panel , are presented in the **Appendix**.

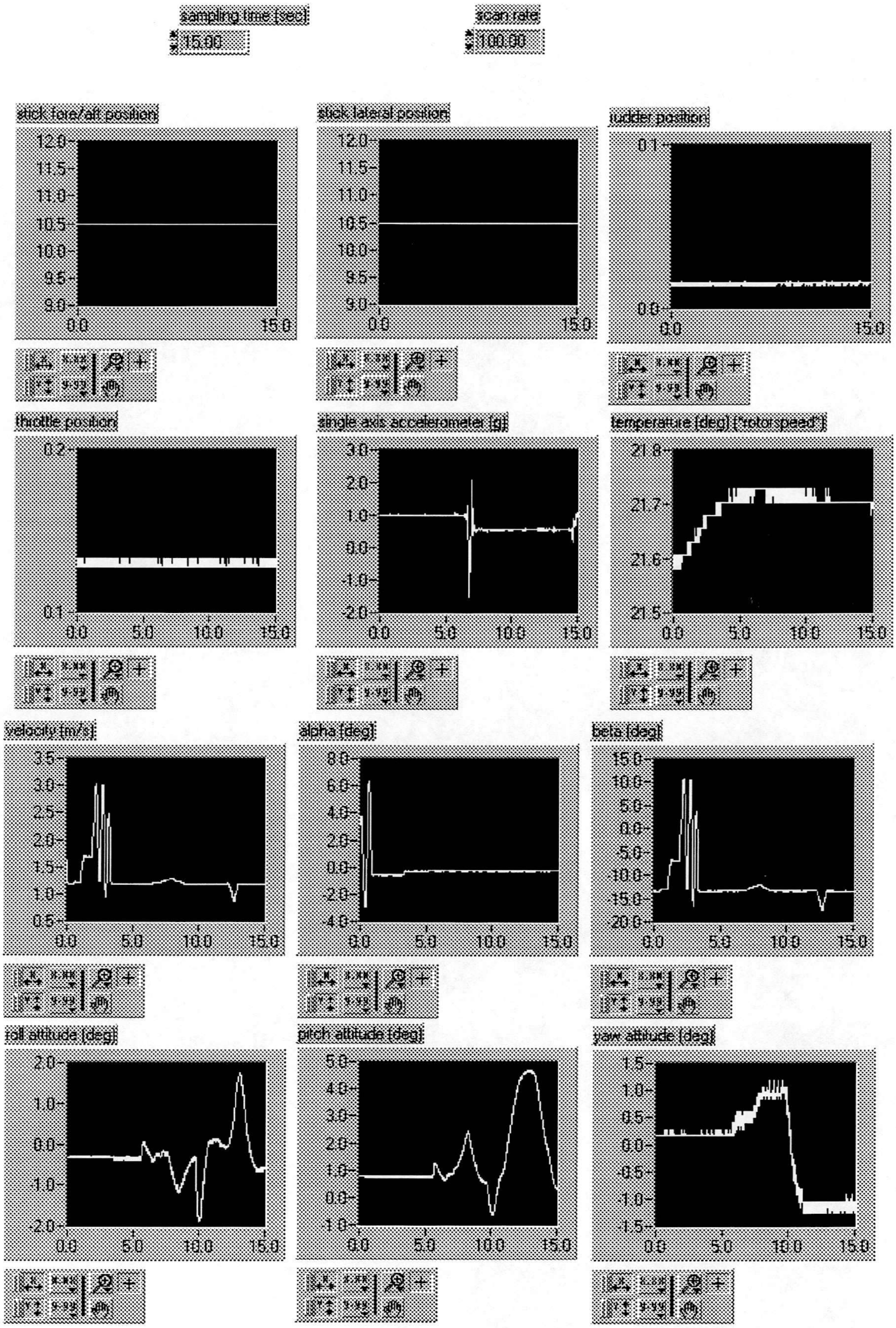
4. Conclusions

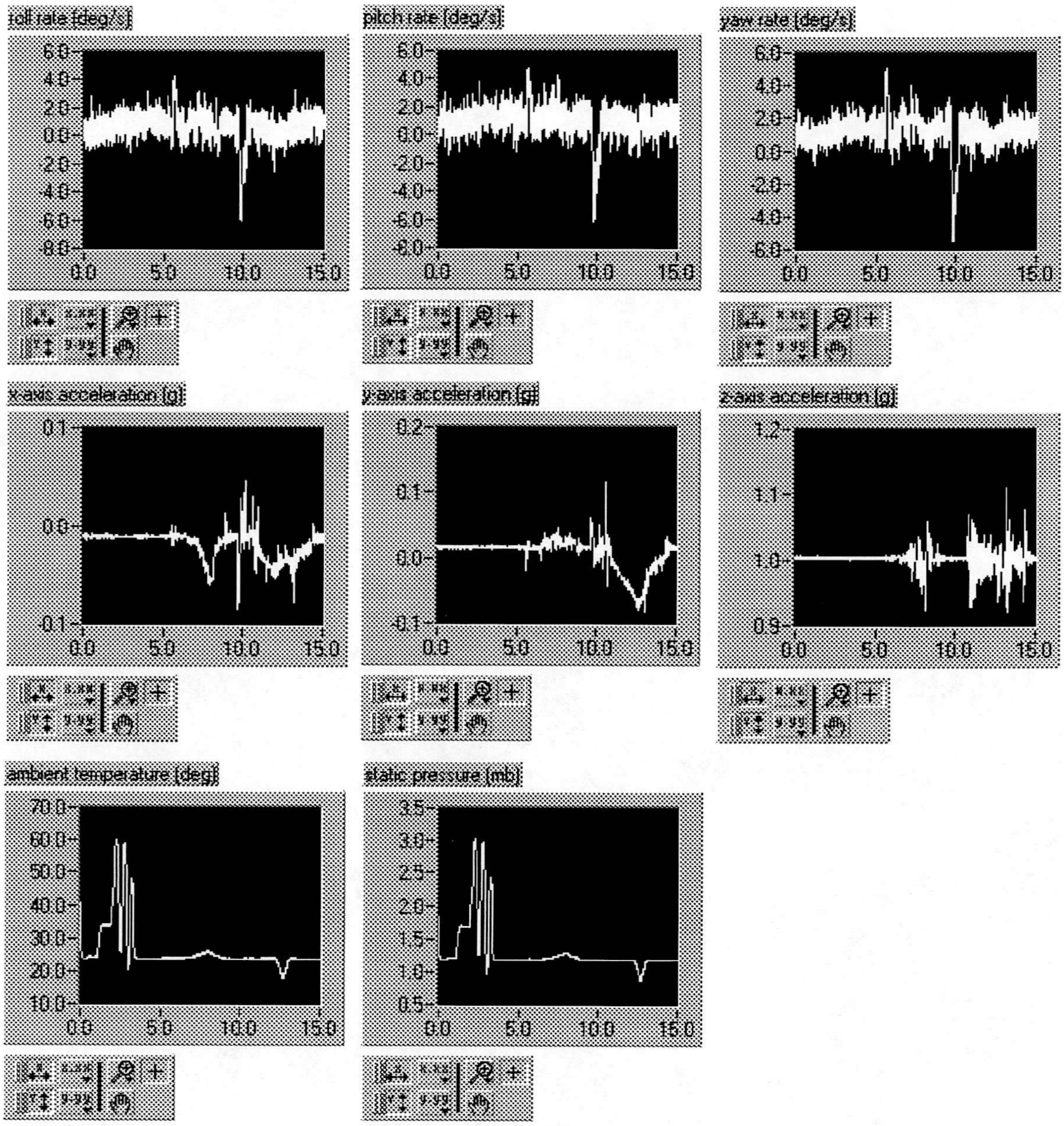
Throughout this report it has been demonstrated how the instrumentation to be used for the flight testing of the two seat **G-BWTP Montgomerie** light gyroplane, was tested and calibrated successfully using the Labview software package. The full instrumentation is properly functioning and the basic software to be used for storing and analysing the data has been developed although it may need to be refined when the experiments actually take place. The next obvious stage in the project will be the design of the positioning of the hardware on the aircraft itself. This should hopefully lead to a successful and unique series of flight tests.

Acknowledgment

Special acknowledgment should be given to Mr. Robert Gilmour whose technical assistance made the completion of this work possible.

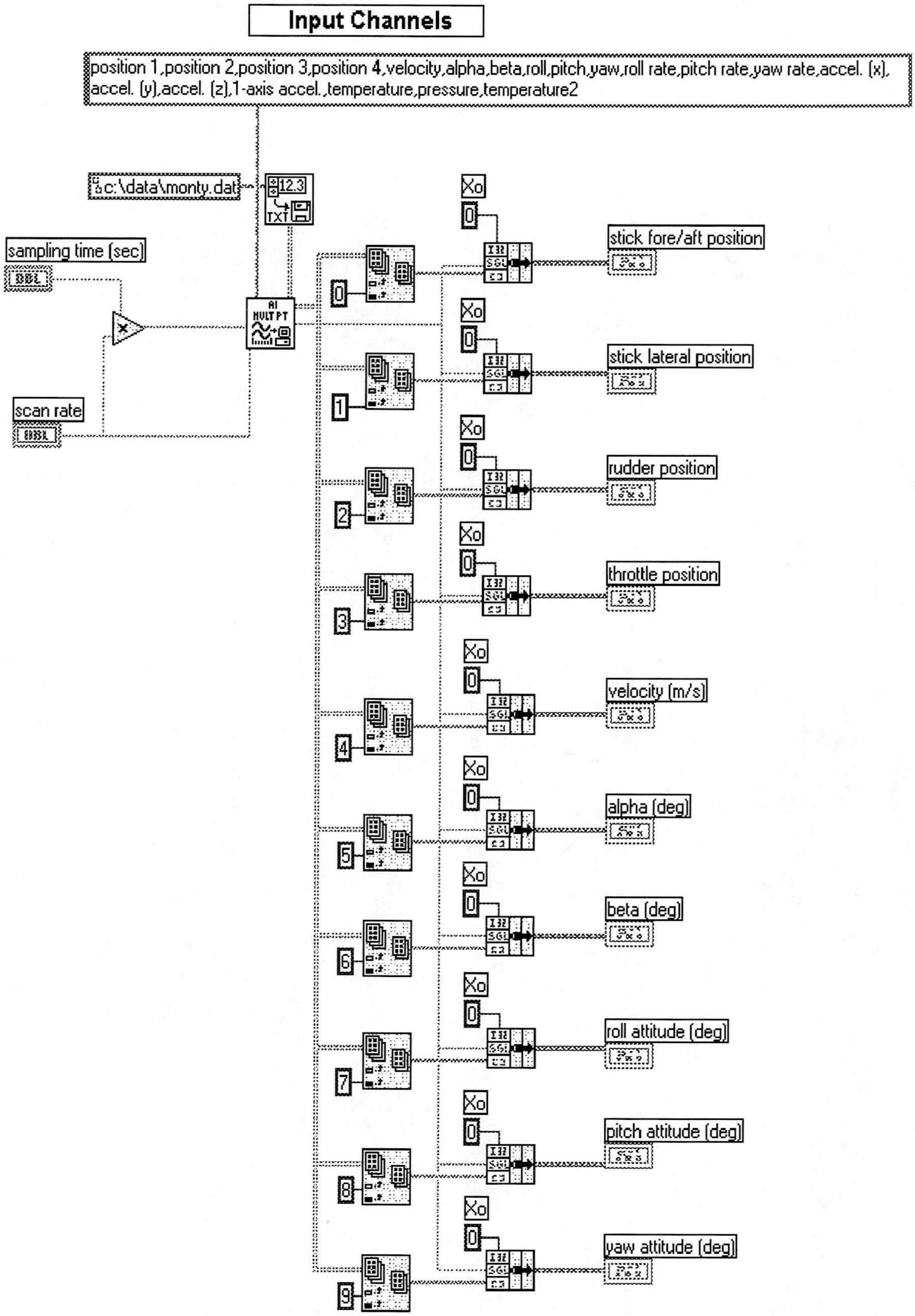
Appendix A: Labview front panel

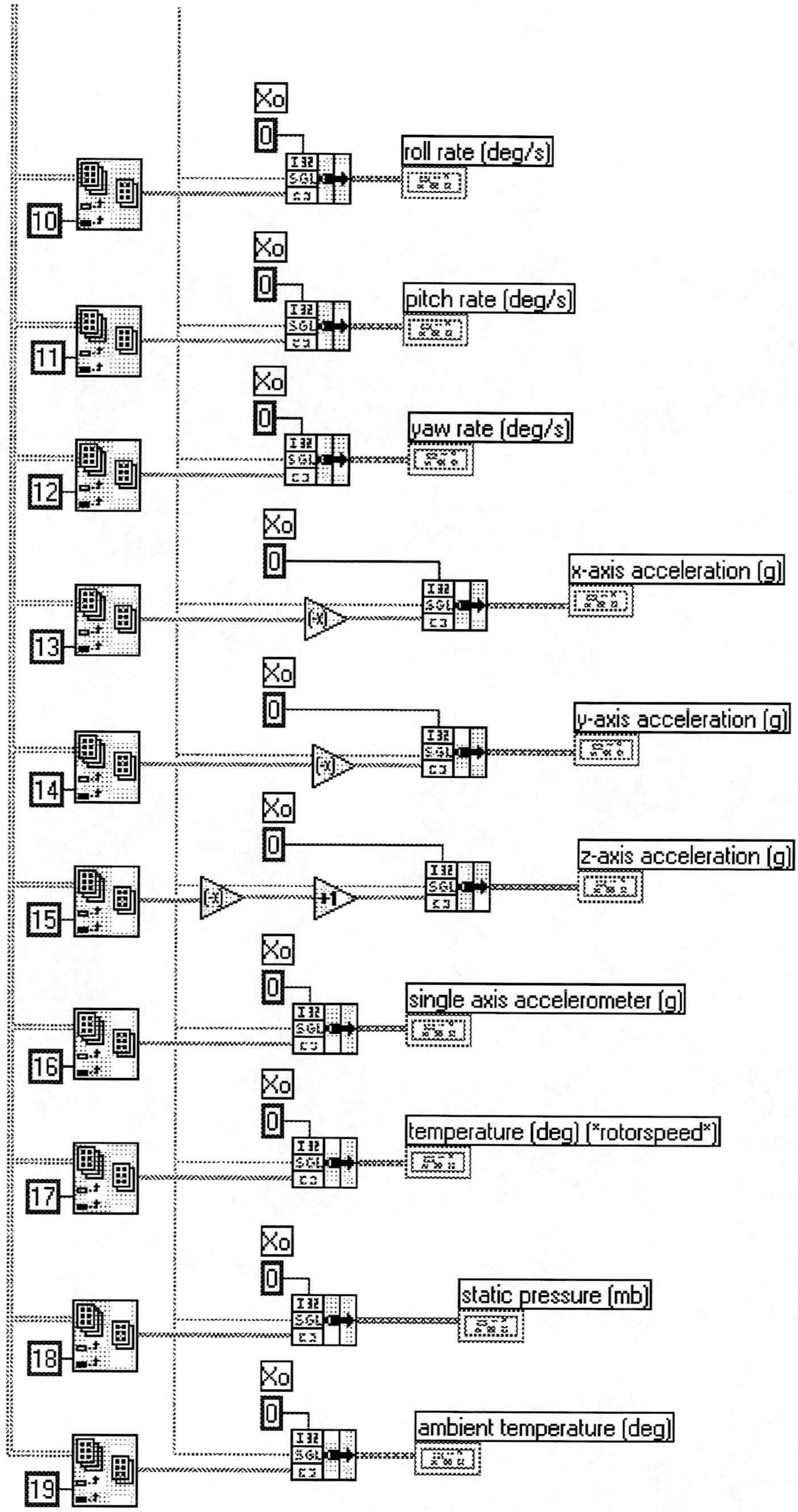

sampling time (sec)
15.00
scan rate
100.00
stick fore/aft position
stick lateral position
rudder position
throttle position
single axis accelerometer (g)
temperature (deg) ("rotorspeed")
velocity (m/s)
alpha (deg)
beta (deg)
roll attitude (deg)
pitch attitude (deg)
yaw attitude (deg)



roll rate [deg/s]
6.0 4.0 2.0 0.0 -2.0 -4.0 -6.0 -8.0
0.0 5.0 10.0 15.0
pitch rate [deg/s]
6.0 4.0 2.0 0.0 -2.0 -4.0 -6.0 -8.0
0.0 5.0 10.0 15.0
yaw rate [deg/s]
6.0 4.0 2.0 0.0 -2.0 -4.0 -6.0
0.0 5.0 10.0 15.0
x-axis acceleration [g]
0.1 0.0 -0.1
0.0 5.0 10.0 15.0
y-axis acceleration [g]
0.2 0.1 0.0 -0.1
0.0 5.0 10.0 15.0
z-axis acceleration [g]
1.2 1.1 1.0 0.9
0.0 5.0 10.0 15.0
ambient temperature [deg]
70.0 60.0 50.0 40.0 30.0 20.0 10.0
0.0 5.0 10.0 15.0
static pressure [mb]
3.5 3.0 2.5 2.0 1.5 1.0 0.5
0.0 5.0 10.0 15.0

Appendix B: Block diagram representation


Input Channels
position 1,position 2,position 3,position 4,velocity,alpha,beta,roll,pitch,yaw,roll rate,pitch rate,yaw rate,accel. (x),
accel. (y),accel. (z),1-axis accel.,temperature,pressure,temperature2
c:\data\monty.dat
12.3
TXT
sampling time (sec)
DBL
scan rate
DBL
AI
MULT PT
0
1
2
3
4
5
6
7
8
9
Xo
stick fore/aft position
stick lateral position
rudder position
throttle position
velocity (m/s)
alpha (deg)
beta (deg)
roll attitude (deg)
pitch attitude (deg)
yaw attitude (deg)



10
11
12
13
14
15
16
17
18
19
Xo
0
roll rate (deg/s)
pitch rate (deg/s)
yaw rate (deg/s)
x-axis acceleration (g)
y-axis acceleration (g)
z-axis acceleration (g)
single axis accelerometer (g)
temperature (deg) (*rotorspeed*)
static pressure (mb)
ambient temperature (deg)