6.B6 FURTHER DEVELOPMENT OF THE TETHERSONDE INSTRUMENT

M.J. Hobby*, S. D. Mobbs, A.M. Blyth

National Centre for Atmospheric Science (NCAS) University of Leeds, Leeds, UK

1. INTRODUCTION

A balloon borne instrument for recording turbulent wind data sufficient for calculating fluxes has been designed by NCAS at the University of Leeds in collaboration with Gill Technology Ltd.

Following initial prototype testing in 2006, an improved robust second prototype has been developed. In conjunction with the UK Met Office, the instrument is being subjected to a variety of different flight conditions, comparing results to a nearby sonic anemometer mounted at a height of 50m.

This work presents the engineering considerations behind the design of the instrument, and initial results taken from a recent flight in Bedfordshire, UK.

2. SCIENTIFIC BACKGROUND

Profiling instruments (sondes) for attachment to tethered balloons have been in existence for about 30 years. One of their limitations has been that the principal method for obtaining turbulence data from fixed platforms, namely sonic anemometers, have not been used on tethered sondes. Without the use of sonic anemometers, wind data are generally limited to low frequency measurements and usually limited to the horizontal components. This gives an incomplete representation of the turbulence. Deployment of sonic anemometers on tethered platforms is challenging because

1. the need for high-frequency data transmission,
2. the lack of physical robustness of the instruments
3. the need to correct for the motion of the instrument.

For these reasons, the development of a tethered sonde using a sonic anemometer for wind measurement at sufficiently high frequency to explicitly determine fluxes is at the forefront of technology.

Furthermore, a lightweight platform for monitoring three dimensional wind speeds would provide data for street canyon experiments not currently available. By utilizing a set of tensioned lines and pulleys, an instrument could be positioned at any vertical point along a horizontal traverse. The instrument would similarly be subject to motion, as in the tethered balloon case.

*Corresponding author address: Matt Hobby, School of Earth and Environment, University of Leeds, Leeds, LS2 9JT, UK; e-mail: m.hobby@see.leeds.ac.uk

3. INSTRUMENT OVERVIEW

As part of a NERC funded infrastructure project, collaboration has been developed between Gill Technology Ltd and NCAS. Under this collaboration, Gill have taken the sensing head and electronics from one of their commercial sonic anemometers and built it into a prototype Tethersonde (essentially replacing the sonic anemometer casing with a streamlined, fin-like structure which can be attached to the tether of a balloon

Needless to say a balloon is subject to translational motion in addition to rotation about all three axes. The instrument therefore takes advantage of recent MEMS[1] sensor development and utilizes a three axis accelerometer with coupled rate gyros to record all motion. This data is complemented by a 3 axis magnetometer and a GPS, which is also used to synchronize the data to UTC.

The instrument is capable of transmitting 1Hz data to ground using a radio link operating in the ISM 868MHz band. This is useful for making scientific mission decisions

The system is designed to be low weight to enable the system to be flown on relatively small balloons. Since, the largest weight in a remote electronic system is the battery; the system is also designed to be low power. Hence, a bespoke logging system has been designed to maximize battery life for long flight times. The system records all data in real time to an on board SD card and can operate for up to 10 hours.

Figure 1 shows the instrument with all inspection panels attached.

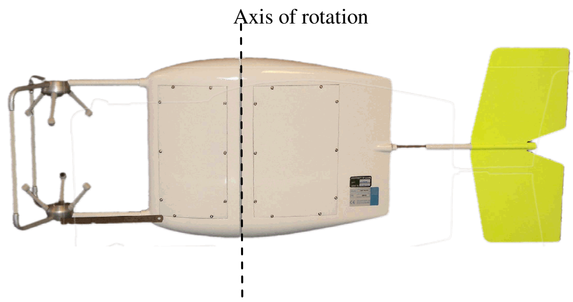

Figure 1. The Tethersonde Instrument

[1] MEMS – Micro Electro Mechanical System

4. INSTRUMENT DETAILS

4.1. SENSOR MOUNTING

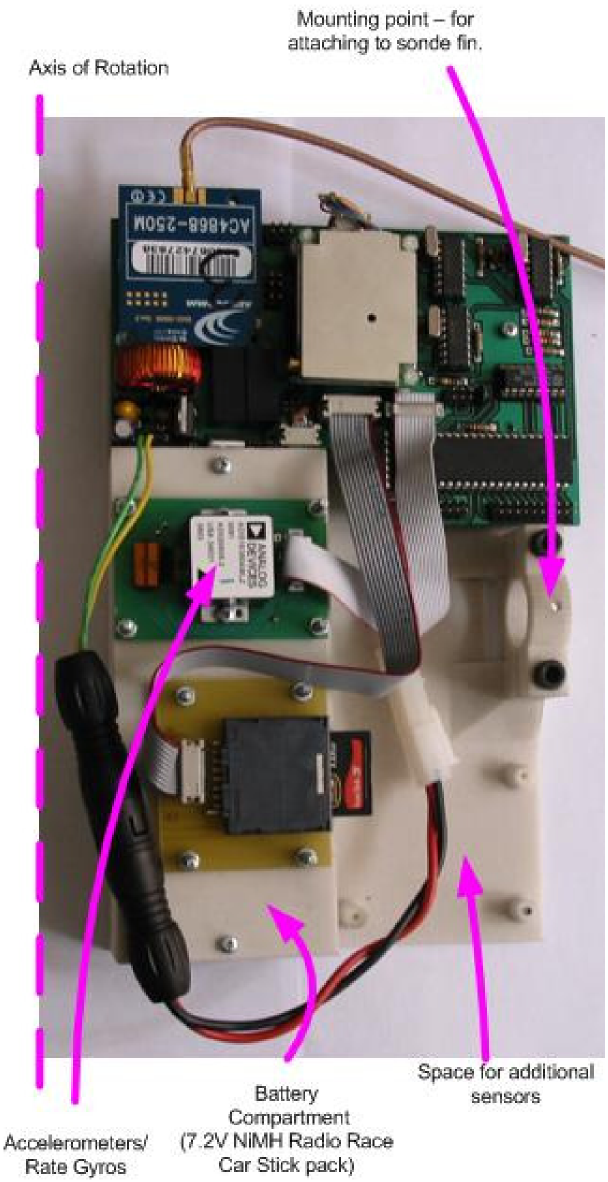

Figure 2. Internal instrument electronics and mountings. System extracted from body for clarity.

A mounting plate has been designed using rapid prototyping tools. The plate is designed to fix into the sonde shell such that the rate gyros and accelerometers align along the sonde axis, thus ensuring the motion data occurs in the same plane as the wind data. The mounting plate with the system electronics is shown in Figure 2.

The accelerometers/rate gyros are mounted on the axis of rotation for the sonde, so as to limit cross contamination of rotational and translational motion.

4.2. DATA SYNCHRONISATION

Each sensor provides asynchronous data across a serial link, using RS232, RS485 or SPI protocols. This has the advantage that all data is converted to a digital format at source and is therefore less susceptible to noise. Sensors are either streamed at a predefined rate or polled, with an associated time lag between poll and response.

The asynchronous nature and subsequent unpredictability of each sensor requires a robust timing system so as to interpolate data points to a integer sample point value in time. Without such a system, it would be difficult to be sure motion was being removed from wind data recorded at the same instance in time. The stipulation that the Tethersonde instrument should be low weight and low power led to a design decision to use an 8 bit microprocessor for the data logging. Since 8 bit microprocessors are resource limited it has been necessary to develop a real time operating system. The real time system buffers data and provides a 'scheduler' to ensure that the system deals with data from each sensor in a timely manner. Additionally, semaphore control is utilized to ensure there is no microprocessor resource conflict.

4.3. FILE SYSTEM

Writing to SD card takes approximately 20ms per sector (512 bytes) and data can only be written in integral sector quantities. Common file systems such as the FAT system require 4 sectors of file handling data writing for every 1 sector of data, creating an unnecessary file system overhead. A file system has therefore been developed for the sonde with file handling information being stored on an EEPROM locally, which can be written to in single byte quantities. The EEPROM is synchronized with the SD card at startup and shutdown. This system decreases the overhead by 75% when compared with a FAT file system.

5. MOTION CORRECTION

Data recorded from the accelerometers, rate gyros, magnetometer and GPS is processed to provide pitch, roll, yaw, and velocity in x, y and z directions. A block diagram of the algorithm used to process this data is shown in Figure 3.

A 'Right Hand Coordinate' system is used throughout, with rotations acting clockwise around the axis looking from negative to positive.

The system is considered to be subjected to (in order) yaw, pitch and roll motion. Hence, to rotate back in to an earth reference frame the following matrix transformation is applied to both the velocity and wind vectors; where α is pitch, β is roll and γ is yaw.

$$A = \begin{pmatrix} \cos\gamma\cos\alpha & -\cos\beta\sin\gamma - \sin\beta\cos\gamma\sin\alpha & \sin\gamma\sin\beta + \cos\beta\cos\gamma\sin\alpha \\ \cos\alpha\sin\gamma & \cos\beta\cos\gamma - \sin\beta\sin\alpha\sin\gamma & -\sin\beta\cos\gamma - \cos\beta\sin\alpha\sin\gamma \\ -\sin\alpha & \sin\beta\cos\alpha & \cos\beta\cos\alpha \end{pmatrix}$$

The translational motion is subsequently removed from the rotated wind vector, to provide a corrected measurement.

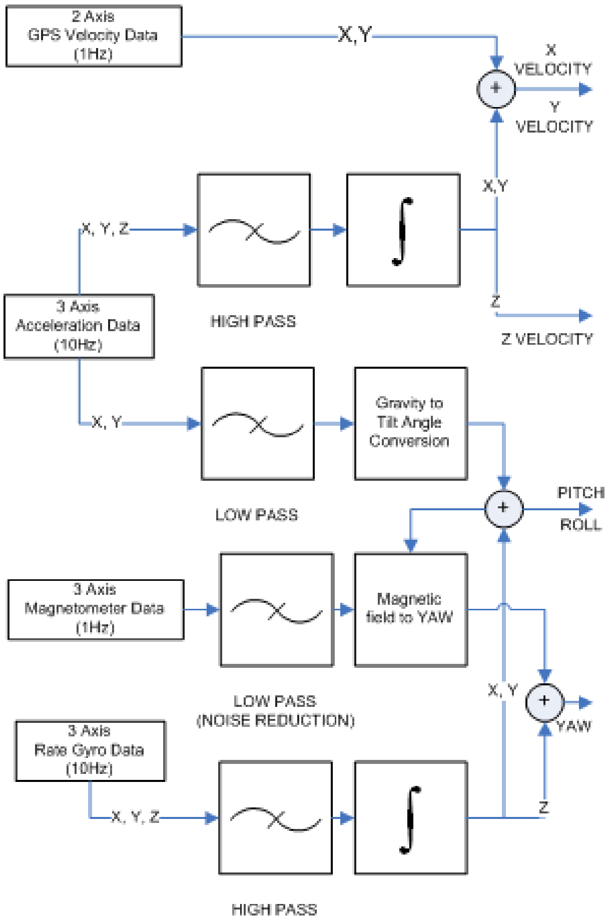

Figure 3. Block diagram of the motion correction algorithm

6. DATA

The process of testing, validation and instrument refinement involves laboratory (wind tunnel) and field trials. Here we describe preliminary results from the field trials.

Data was recorded over an hour long period during light winds. The instrument was suspended at 50m above ground. Measurements that have been corrected for motion show a roughly similar time series shape and spectrum to that recorded from a sonic mounted on a nearby mast at 50m.

Figure 4 shows a time series comparison of wind in the u direction between sonde (with and without motion correction) and the mast. It can be seen that both the raw data and the data corrected for motion follow the same pattern as the mast data, however the corrected data decreases the fluctuations around this pattern. Other axes compare similarly.

Figure 5 shows the power spectra for wind in the u direction recorded from the mast and the sonde with and without correction for motion. A feature at approximately 0.2Hz is observed in the uncorrected data. This feature is replicated in the power spectrum of the yaw data shown in Figure 6. The feature is significantly decreased by the motion correction algorithm. By tuning the individual filters a more accurate correction could be obtained.

The mean and variance of wind data across all axes demonstrate that the sonde is recording data at the right order of magnitude. This data is summarized in Table 1.

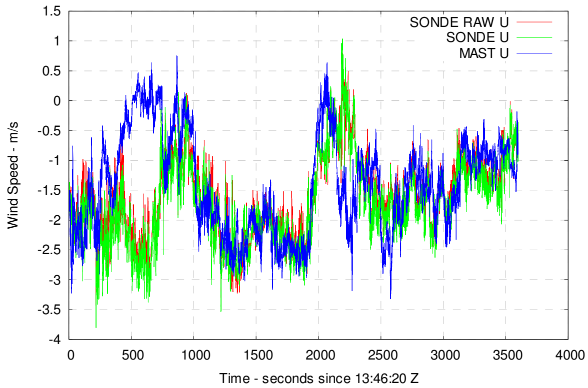

Figure 4. Time series of wind speed (u) collected from the sonde without motion correction(red), with motion correction (green) and data collected from a nearby mast at the same height (blue)

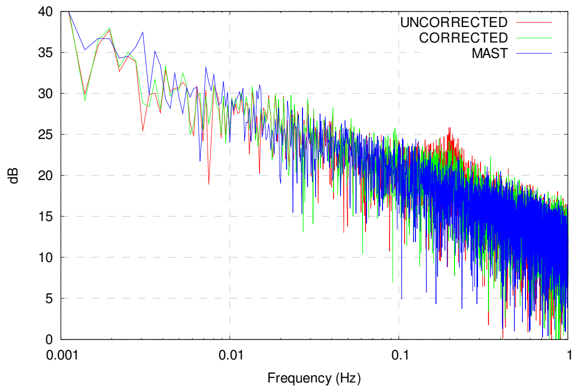

Figure 5. Power spectrum of sonde uncorrected (red), corrected (green) and mast wind speeds

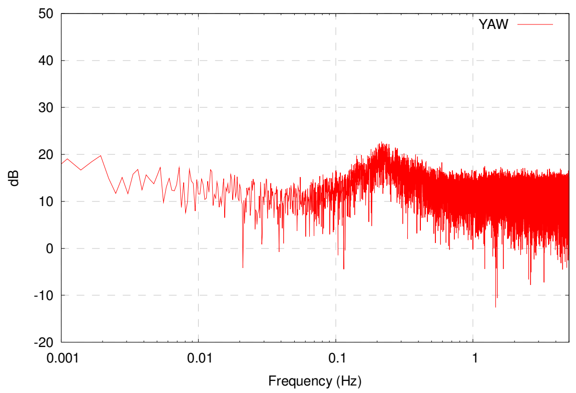

Figure 6. Power spectrum of sonde Yaw motion.

	SONDE (m/s)	*MAST (m/s)*
<u>	-1.70	*-1.41*
<v>	0.71	*0.23*
<w>	-0.04	*0.17*
var u	0.48	*0.67*
var v	0.66	*0.64*
var w	*0.13*	*0.13*

Table 1. Summary of mean and variances comparison between sonde and mast.

These results show that the motion correction algorithms achieve values in the region of magnitude expected under light wind conditions, however further developments are required to improve the correction. More testing is required to provide confidence in the wind data provided.

7. SUMMARY

The Tethersonde instrument has now reached a point where the electronic and mechanical design is performing well, providing reliable data for subsequent motion correction and analysis.

Initial flight tests have returned useful data and demonstrated that the motion correction algorithms are providing reasonable results.

Further testing and development of the motion correction algorithm is required to ensure that the instrument can be used to collect reliable turbulent wind data for a real application. This work is planned to occur over the next 12 months.

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