3.3

ADVANCES IN TETHERED BALLOON SOUNDING TECHNOLOGY

Ronald A. Shellhorn
Vaisala, Boulder Operations, Boulder, CO

1. LIMITATIONS OF OLD TECHNOLOGY

Tethered meteorological sounding systems have been used in boundary layer research for many years. Due to the scarcity of equipment designed specifically for this type of experimentation, systems have been configured from a wide range of available components. Sensors used in these systems in many cases are not subjected to validation of accuracy, measurement repeatability, or level of performance in the tethered sounding application. Examples of unanticipated problems associated with this type of custom integration include out-gassing effects of various materials on thin film sensors, neglect of sensor ventilation requirements, solar radiation effects and micro-environments created by the mechanical housings and deployment devices. Many of the sensors used in early tethered instrument packages were designed for industrial applications, surface weather measurements or synoptic sounding applications, with questionable suitability for tethered applications.

Another limitation has been long-term sensor usability. Some commercially available tethersondes, with electronically integrated sensors, are calibrated as a complete instrument. Unlike radiosondes that are consumable, one-time use instruments, tethersondes are reusable devices and so, require periodic re-calibration of the sensors. Due to highly proprietary techniques and data formats, this means returning the complete instrument to the factory of origin for re-calibration, a point of frustration for users.

Low power consumption requirements, sensor output formats, lightweight material needs, and data transmission mediums have also been difficult issues to deal with when designing custom configurations. Receiving / data processing systems and methods of deployment for tethered measurements have been no less problematic.

Ronald A. Shellhorn, Vaisala Boulder Operations, 8401 Baseline Rd, Boulder, Colorado 80303.
e-mail: ronald.shellhorn@vaisala.com.

2. BENEFITS FROM NEW TECHNOLOGY

Technical advances in personal computers, data processing, meteorological sensors, and synoptic sounding systems make possible, significant improvements in tethered balloon sounding equipment. In parallel, modern quality processes can insure that systems are designed and tested to meet the specific requirements of boundary layer tethered measurements.

2.1 NEW SENSORS

Vaisala has incorporated many technological advances into a new DigiCORA Tethersonde System. The new design integrates proven Vaisala HUMICAP, THERMOCAP, and BAROCAP sensors into a sensor transducer version validated for tethered sounding applications. These are the same sensors used in Vaisala radiosondes worldwide. Sensors are individually calibrated in Vaisala's CAL4 calibration chamber. Pressure and Temperature references used in CAL4 are calibrated at regular intervals at Vaisala's Measurement Standards Laboratory (MSL). For Pressure and Temperature MSL has traceability to the National Institute of Standards and Technology (NIST), USA. Dew-point references used in CAL4 are calibrated at regular intervals at the Finnish National Measurement Standards Laboratory. The traceability of the relative humidity value is composed of traceability of dew-point temperature and chamber temperature. *[Lentonen, 2002]*

Calibration coefficients are stored in serial EPROM on board the Tethersonde. They are transmitted to a ground based sounding processor along with the meteorological data, eliminating the need for paper tape readers. An even greater benefit to the user is the interchangeability of the sensor transducer/modules. These economical, consumable components are simply unplugged and replaced with fresh modules anytime sensors are contaminated or degrade in accuracy, eliminating expensive re-calibration.

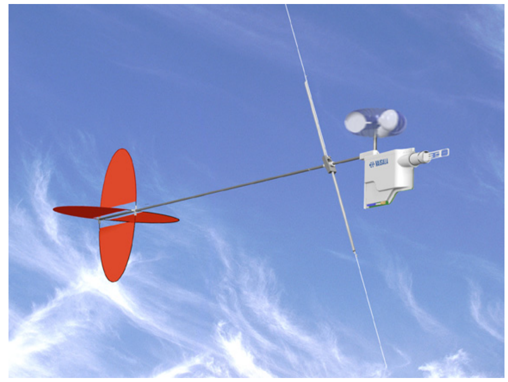
2.2 MORE NEW FEATURES AND IMPROVEMENTS

New transmitters benefit from an ASIC design that provides easier transmission frequency programming, narrower transmission bandwidths, and an obvious advantage, less weight. A new digital, solid state compass introduces a level of accuracy unattainable in earlier versions that used electro-mechanical compasses. The system includes a calibration fixture and leveling tri-pod for simple calibration in the field, prior to flight. The calibration accounts for magnetic inclination with magnetic declination accounted for in the user interface software. Validation testing of the new compass indicates a calibration repeatability differential of less than 3°, a significant improvement over earlier versions, where accuracy errors could exceed $\pm$10°. Actual wind direction accuracy is dependent on a number of factors including balanced Tethersonde attachment to the tetherline, ambient wind conditions, and stability of the Tethersonde in flight. However, type testing in a variety of conditions indicates that users can expect to find a 50% improvement in wind direction accuracy.

Improvement of the stability of the Tethersonde has been accomplished through a re-design of the tail fin shaft, now longer and less susceptible to vertical wind components.

Results of wind tunnel testing at NCAR's ATD facility in Boulder show improved wind speed accuracy from the new Tethersondes as well; the result of improvements in anemometer gear housings and wind speed software calculations.

A new feature in the Vaisala Tethersonde is the addition of six A/D channels. These channels, in addition to an optional Ozone sensor interface, allow adding user supplied sensors with appropriate outputs.



Vaisala's new TTS111 Tethersonde

3. VERSATILITY

The cost of performing tethered soundings has always been a difficult hurdle for researchers with limited project budgets. A powerful new feature of Vaisala's DigiCORA Tethersonde system adds considerable value. By designing the new Tethersonde product around the same sounding processor as used in the DigiCORA radiosonde systems, a variety of modular, synoptic sounding options can be added. Tethersonde system user's can add GPS, LORAN-C, and radiotheodolite synoptic sounding options, and conversely, existing DigiCORA users can add tethered sounding capability to their systems. A wider range of functional capability at significantly less cost than acquiring different systems for each application.

The DigiCORA Tethersonde system is designed for two modes of tethered atmospheric soundings. By raising and lowering a tethersonde at constant ascent and descent rates, a boundary layer profile can be acquired. Or, by attaching up to six Tethersondes to the tetherline, meteorological data can be acquired over time at selected altitudes.

4. POWER SOURCE ALTERNATIVES AND NEW USER INTERFACE

Two other constraints that have limited tethered research projects in the past are the ability to power tethered instruments over extended periods of time, and the ability to handle and archive large flight data files that would be the result of extended flights. Vaisala's new, optional external battery pack can now extend Tethersonde flight time to over twenty hours. And, PC hard disk technology evolution has resolved the later issue with seemingly exponential growth in data storage capacity. The result is the ability to perform a tethered sounding up to five times longer than with previous systems.

Vaisala's earlier generations of tethered sounding systems included PC DOS based application software. This out-dated operating system and software has now been replaced by a new Windows® based user interface with new and useful features. A few of these are new graphical options, low battery voltage warning, and high wind speed warnings.

5. EXTENSIVE VALIDATION

At the time of this writing, several validation tests of the new system have been completed, and others are in process. Some test result summaries related to new design improvements are listed here. Detailed reports and data for the various tests are available upon request from the author.

5.1 FLIGHT DURATION TESTING

Objective was to qualify operational performance of selected power sources for TTS111 Tethersondes. *[Quire (2002)]* Instruments were tested with batteries selected for optimum availability to users. Testing was done in a bench test environment at 25° C on a test lot of ten, prototype TTS111 Tethersondes in operational mode. Power requirements are 100 mA @ 9 volts. Drop out defined as loss of data transmission or degradation of PTU values exceeding sensor specifications.

Battery life test data of three of the power source configurations are shown graphically in figures 1, 2, & 3. Shown are; internal Eveready alkaline 9V; internal Eveready lithium 9V; and internal Eveready lithium with optional external battery pack (6-AA).

Results indicate an expected flight time of 2 hours, forty minutes on single, internal Eveready Alkaline 9V batteries, eight hours on single internal Eveready Lithium batteries, and twenty-eight hours using a combination of internal lithium and the optional external battery pack. The external. battery pack containing six AA Duracell batteries, is deployed on the tetherline beneath the tethersonde, and connected via a flexible power cable. Field experience with earlier versions of Vaisala Tethersondes, where only one power source configuration was available, has shown flight times in the range of 3.5 to 4.5 hours depending on weather conditions.

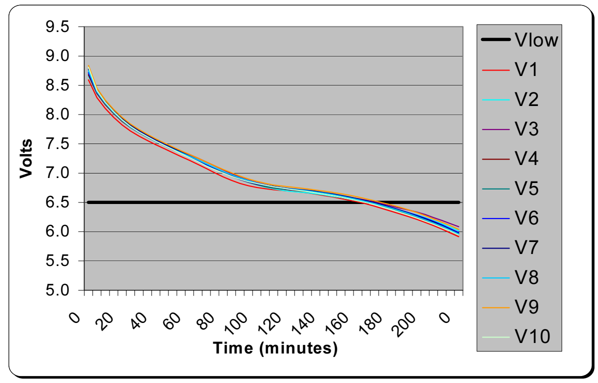


Figure 1 Internal 9V Eveready Alkaline

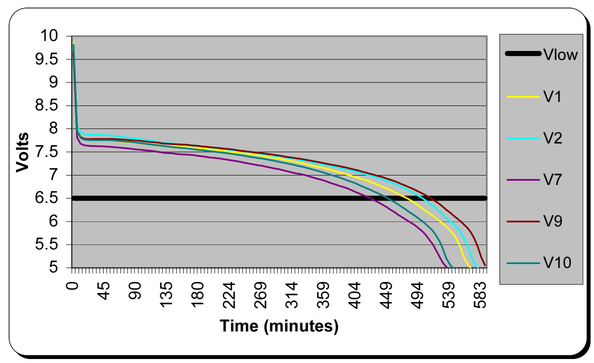


Figure 2 Internal 9V Energizer Lithium

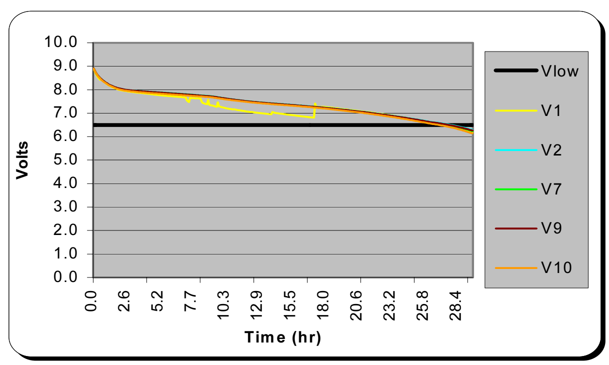


Figure 3Internal 9V Ultralife Lithium w/ External Battery Pack

5.2 TESTING AT THE BOULDER ATMOSPHERIC OBSERVATORY (BAO) – 300 METER TOWER

Managed by NOAA's Environmental Technology Laboratory, the BAO tower is a one-of-a-kind instrumentation platform. With meteorological sensors at 10, 50, 100, 200, & 300 meters, the tower has been used in many atmospheric research experiments since its completion in 1977.

The DigiCORA Tethersonde System was deployed August 14 through August 28, 2002 at the BAO tower for validation of the portable tower application. It was also included in a mixing study in conjunction with LIDAR, SODAR, Wind Profiler and synoptic radiosonde systems. This project was in cooperation with NOAA and the University of Oklahoma.

Data acquired from the Tethersonde portable tower correlated remarkably well to the BAO tower data. Over the test period a total of twenty tethersondes were deployed in 10 flights of two Tethersondes each. The flights were based approximately 285 meters from the tower with tethersonde altitudes approximating the tower sensor levels. Difference means and standard deviation was recorded through the test period. Avg. standard deviation between sets of tethersondes and tower, over the ten flights was 0.26°C for temperature and 1.74% for relative humidity. *[Woller, 2002]* Pressure data was not available from the tower. North/South and East/West wind vector comparisons showed excellent correlation and this data is available from the author by request.

5.3 WIND SPEED TESTING AT NCAR'S ATD WIND TUNNEL

The objective was the empirical characterization of the wind speed algorithms used to produce wind speed data output. A second objective was to determine the repeatability of wind measurements between Tethersondes. *[Holladay 2002]* The one-meter diameter wind tunnel employs a PITO tube with differential sensor to accurately measure wind speeds to 22 m/s. The TTS111 Tethersonde uses a three-cup anemometer and coupled light chopper disk to produce counts that are then converted to wind speed.

Prior versions of Vaisala Tethersondes, used a similar mechanical anemometer and employed a linear fit of count to wind speed ratio to produce wind speed data. At wind speeds exceeding ten meters per second, deviations based on this linear algorithm become greater than 0.5 meters per second, and worsen as speeds increase. Data acquired during the recent testing indicate a better approximation using a logarithmic function over the range of experimentation. Figure 5 plots a representative set of this data.

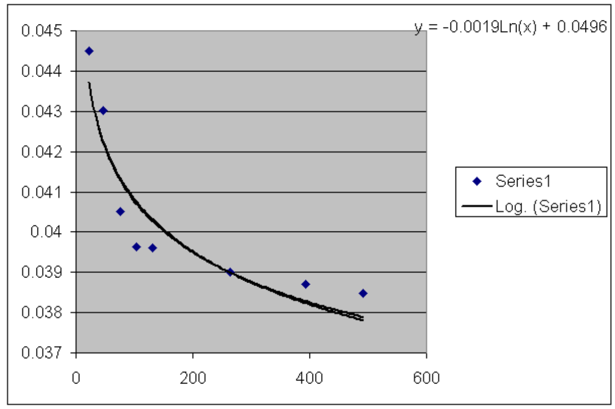


Figure 5 – Logarithmic Wind Ratio Plot for Test 1

A worst case deviation of 0.3 m/s is observed using the logarithmic fit.

Based on the wind tunnel testing, a different approach was implemented for the SW wind speed calculation in the new DigiCORA Tethersonde system. A lookup table is employed from fifty tunnel wind speed points between 1 and 19 m/s, with a RMSE of 0.025098. This is a significant improvement in calculated wind speed data accuracy over the entire range of measurement. Graphical presentation of wind speed deviation is shown in figure 6.

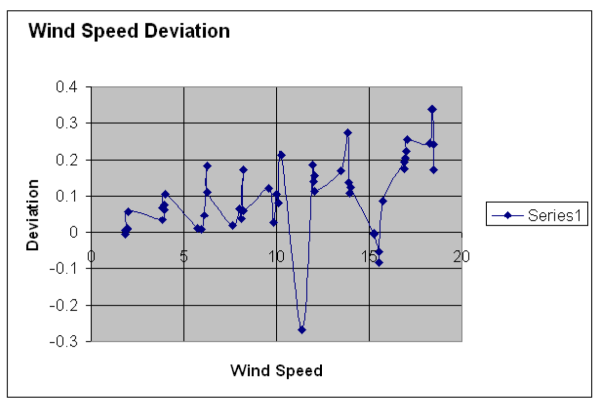


Figure 6 - Wind Deviation Using Look-up Table

Repeatability of count to wind speed was found to be exceptional over a small sample size of six, prototype TTS111 Tethersondes. Count to wind speed ratio (C/mps) was determined to be identical for all Tethersondes at 0.04. This is not a direct indicator of the level of repeatability of wind speed data, but does provide confidence in the mechanical to SW conversion methodology.

5.4 WIND DIRECTION VALIDATION

Objective was to determine error differential and repeatability of the TTS111 new digital, solid state compass. Secondary standard used is a Brunton M2 compass, calibrated against the Brunton master needle in Riverton, Wy. Twelve prototype TTS111 Tethersondes were leveled carefully and calibrated against the compass over the 360 degree range. Test points were selected every 30 degrees. Worst case differentials were recorded over the calibrated range. Worst case differential for the entire sample lot of twelve, over all tested points was 3 degrees. As with wind speed, wind direction accuracy is dependent on the level of the tethersonde in flight, which in turn is related to attachment of the Tethersonde to the tetherline and actual weather conditions. However, type test results indicate at least a 50% improvement in accuracy over previous versions where published specifications were typically +/- 10°.

5.5 COMPARISON FLIGHTS

The objective was to validate repeatability within design specifications on all measured parameters.

Ten dual flights of TTS111 Tethersondes were conducted. Average standard deviation over the ten flights for temperature was 0.3° C, 0.97% for RH, and for pressure, 0.24 mb. One minute averaging of North/South and East/West wind vector data showed average standard deviations of .66 and .77 m/s respectively.

6.0 A WIDE RANGE OF APPLICATIONS

Though Vaisala's DigiCORA Tethersonde system was developed primarily for atmospheric research, the system is suitable for any application requiring accurate boundary layer meteorological data. One example of the system's application diversity is acquisition of PTU and winds data at Sikorsky Aircraft in West Palm Beach, FL, where the data is used in certification testing of new helicopter design. Another example is wind dispersion modeling at Disneyland in California, where dissipation of fireworks exhaust is an environmental concern. In any application, system users will appreciate the many new features, enhanced versatility, and improved reliability and performance. Truly a next generation in tethered sounding technology.

7.0 SUMMARY

Though a sizable amount of validation and qualification testing remains to be completed at the time of this writing, test results to date have been very positive. The use of current technology in the design of the new system has produced a much-improved product. Not, only have all measurement aspects tested to date shown improved performance, operational functionality and versatility have been demonstrably superior to past versions of Tethersonde systems.

Holladay, D.L., 2002: *Wind Computation Evaluation, Vaisala Boulder Test Report*

Lentonen, J., 2002: CAL4 Uncertainty Vaisala Oyj, Quality Documentation

Quire, C.E., 2002: Functional Verification (DR2) Test Plan and Report on TTS111 Tethersonde Version 2.0 Vaisala Boulder

Woller, B., 2002: Sonde Data Analysis Process, Woller Contract Engineering