Balloon Measurements of Winds in Planetary Atmospheres

Stephen S. Wayne[(1)], Kamal Oudrhiri[(2)], Sami Asmar[(2)], David H. Atkinson[(1,2)], A. Kitchen[(1)], R. Perry[(1)], P. Petersen[(1)], J. Slater[(1)]

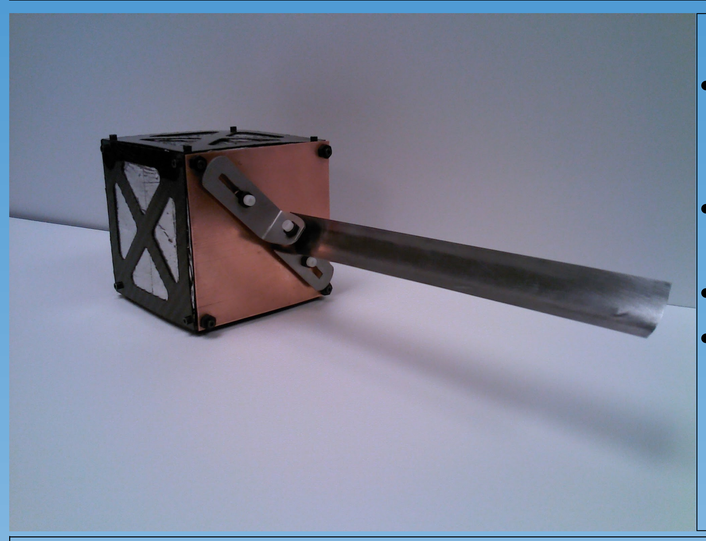
(1)University of Idaho, Moscow, ID 83844 USA (wayn0327@vandals.uidaho.edu)

(2) Jet Propulsion Laboratory, California Institute of Technology, Pasadena CA 91109-8099 USA

Abstract: Characterizing the dynamics of atmospheres is an important element in studying planetary atmospheres. Measurements of planetary winds have been made by Doppler tracking of entry and descent probes to determine the kinematics of the capsule as it is moved by the winds. Planetary atmospheric dynamics can be better characterized if data is recorded simultaneously from multiple spatially separated capsules. One method under study to measure planetary winds is to use a planetary lander that would release multiple balloon-bourne transceivers that can be Doppler tracked by the lander. From precise measurements of the Doppler profile from each of the balloon-borne capsules, the balloon dynamics and associated wind profiles can be determined. A Capstone Senior Design team at the University of Idaho has developed a proof of concept design to demonstrate the radio science techniques and feasibility of this method to measure planetary wind fields.

To demonstrate the concept of wind profiling by Doppler tracking of multiple small probes, an engineering senior design team at the University of Idaho designed a a CubeSat to be carried by balloon to an altitude of nearly 100,000 feet. The CubeSat will include a transceiver to transmit a 433 MHz carrier frequency to a ground-based receiving station, where the received frequency and associated Doppler shift will be recorded as a function of probe location (from independent GPS tracking) and time during ascent and descent. Since GPS data is also being recorded, the Doppler shift wind speed data can be matched with wind speeds recorded by the National Weather Service to check the accuracy of the measurements.

The CubeSat system has been tested in a cold chamber to ensure the CubeSat provides protection for the electronic subsystems onboard at the expected external temperatures. The transceiver subsystem is designed to maintain a strong connection up to a maximum line-of-site distance of approximately 23 km.



Limitations of Doppler Tracking Entry-and-Descent Probes

- To maximize recorded data and increase recorded wind dynamics resolution, multiple probes could be released from a surface lander and used to collect data simultaneously. See Atkinson, et al., "**FUTURE PLANETARY PROBE DOPPLER WIND EXPERIMENT TEQUNIQUES UTILIZING ADVANCED TRACKING & RANGING SUBSYSTEMS**", abstract #8084.
- Deploying multiple atmospheric probes from an orbiter or flyby spacecraft requires that each probe have heat shielding, landing gear, and reliable data transmission systems to link back to the orbiter or flyby. This added complexity results in additional mass and volume which are not always available to low cost missions.
- Greater complexity introduces more variables and increases cost and potential for errors in data collection.
- Entry-and-Descent probes travel through planetary atmospheres very quickly, meaning that they cannot quickly respond to an instantaneous gust of wind, and therefore it is more difficult to accurately characterize planetary wind dynamics. The time it takes to respond to an instantaneous gust is V_d/g, where V_d is the descent speed, and g is the acceleration due to gravity. If, for example, a probe is descending at 100 m/s and the acceleration due to gravity is 10 m/s^2, the response time to an instantaneous gust of wind is about 10 seconds. At this speed the probe will have already descended approximately 1 km before it can respond. This makes it very difficult to measure wind spends that change significantly over a layer thinner than $(V_d)^2/g$ meters.

Design Parameters

The balloon-borne transceiver must be able to properly communicate at up to 22.36 km, transmit for a full two hour flight time, and maintain proper internal temperatures during the flight time and a one hour recovery time.

- Radiometrix BHX2-433-5-SMA 500mW Transceiver; sensitivity of -118 dBm operating at 433 MHz to use on balloon capsule and ground station.
- Yagi-Uda Array of at least 7 dBi gain for the receiving transceiver.
- "1U CubeSat" (10cm*10cm*10cm) with six external panels made of carbon fiber (one is overlaid with copper for the antenna ground plane) with insulating foam and electronic systems inside.
- Four 9-volt batteries: three each in series with a 240 Ω resistor, and one in series with a 100 Ω resistor.
- Two 9-volt batteries in parallel to power the transceiver.

Testing and Results

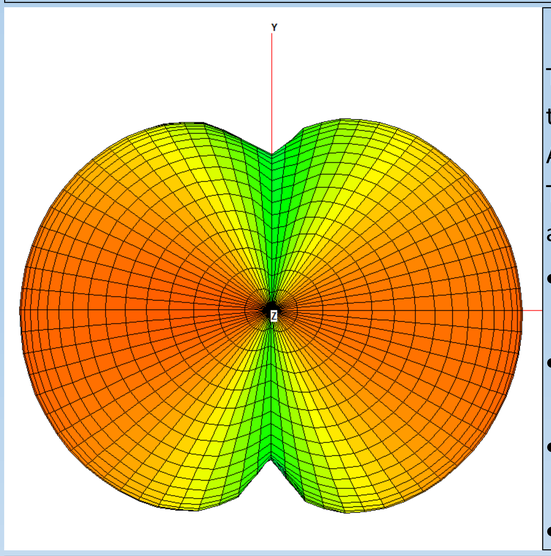
The transceiver is able to transmit for more than the required two hours using two off-the-shelf 9-volt batteries in parallel as the power supply. Additionally, the electronics will be able to operate properly at the required altitude and external temperature for the duration of the test.

- The system will be able to maintain a communication link at 433 MHz with the receiver at the desired distance for the desired period of operation.
- Doppler shift and radio science analysis requires highly accurate frequency measurements, which could not be reliably recorded at 433 MHz using inexpensive, off-the-shelf hardware. The balloon-borne probe is, however, theoretically capable of performing radio science experiments for wind speed measurements in our atmosphere.

Future Work

Future goals include optimizing the power, antenna, thermal, and structural systems, as well as researching inexpensive methods of recording frequency.

- Connect a slightly longer antenna to a network analyzer to trim it for resonance and optimal VSWR for maximum power transfer.
- Include an Arduino microprocessor with a thermocouple to scale back or disable the heating system if the electronics begin to overheat.
- Use a strong 3D printed material, such as metal polymer fused powders, to reduce machining time and increase control over CubeSat dimensions.
- Replace the 9-volt batteries with a rechargeable system to power the transceiver and maintain adequate internal temperatures.
- Build one face of the cube out of copper for the antenna ground plane to reduce mass and cost while increasing durability.



Antenna Analysis

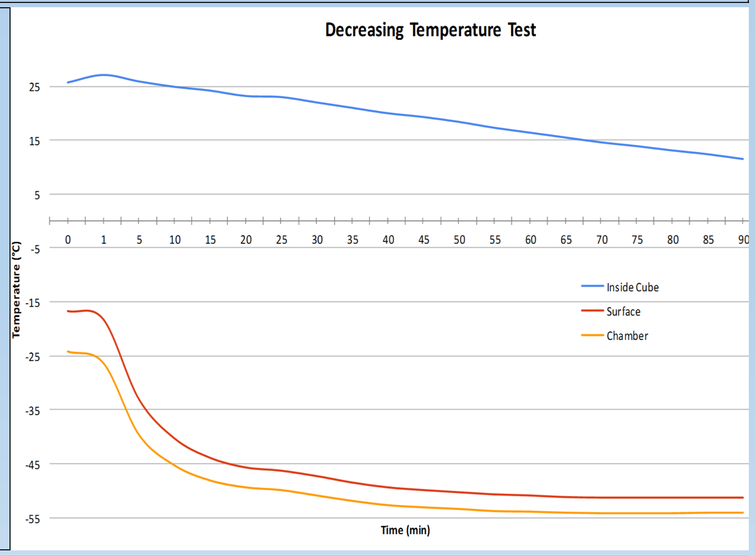
The capsule antenna was designed as a quarter-wave tape-measure monopole, and was tested in the Smart Antenna and Radio Lab (SARL) at Gonzaga University. The beam pattern and VSWR were measured for antennas of length 17.3, 17.6, and 18 cm.

- The balloon-borne transmit system was tested in increments of 10° in θ and ϕ.
- The tape-measure antenna radiation properties are as expected for a quarter-wave monopole.
- Antenna pattern results are estimates due to chamber limitations.
- The image to the left is the pattern in θ.

Thermal Analysis

The temperature inside the capsule must be kept between –20° and +60° C for the electronics to operate properly. The internal temperature goal was set to be between –10° and +30° C, which was met.

- Thermal testing was conducted in the University of Idaho Near Space Engineering Cold Chamber, which can reach and sustain a temperature of –55° C.
- Using a smartphone battery with different resistors can result in similar temperature-time curves.
- The external atmospheric temperature typically reaches approximately –50° C at the altitude that capsules are cut down from the balloon system.



References: [1] Atkinson, D.H., A. Seiff, and A.P. Ingersoll. "Deep Winds on Jupiter as Measured by the Galileo Probe," Nature, 388, 649-650, 1997. [2] Bird, M.K., M. Allison, S.W. Asmar, D.H. Atkinson, I.M. Avruch, R. Dutta-Roy, Y. Dzierma, P. Edenhofer, W.M. Folkner, L.I. Gurvits, D.V. Johnson, D. Plettermeier, S.V. Pogrebenko, R.A. Preston, and G.L. Tyler "The vertical profile of winds on Titan," Nature 438, 800-802, 8 December 2005. [3] Atkinson, D.H., S. W. Asmar, and T. R. Spilker, "Outer Planet Doppler Wind Measurements," 8th International Planetary Probe Workshop, Portsmouth, VA 6-10 June 2011.

IPPW-11 / #8095