Closeout Summary Report on

1. DOE Award Number: 07ER41493 to Carnegie Mellon University

2. Title: Prototype Power and Communication System for EeV Cosmic Ray Studies, James Russ, PI

3. Award Period: 9/01/2007-8/31/2008
Extension 1: 9/01/2008-8/31/2009
Extension 2; 9/01/2009-6/30/2010

4: Project Goals and Accomplishments:

A. Wind Power Studies

For many remotely-sited experiments or sensing stations at high latitudes, solar power is limited in the winter months. Renewable energy in such cases must come from wind power. Because wind speeds are frequently low except along mountain ridge lines, it was important to see if there might be a cost effective way to increase the average wind speed available to a small wind turbine in the range of 20-40 watts. Such turbines are suitable for charging batteries for low-power electronics typically used in remote sensing applications.

The problem with such turbines is that full power is developed only for wind speeds above 25 mph. Because the available power delivered to the turbine goes up as the cube of the wind speed, there is a clear advantage to augmenting the turbine with a cheap, light-weight housing to funnel the wind onto the turbine blades and by the Venturi effect, to increase the average speed. The goal of this project was to determine the wind characteristics for an average site and make a realistic housing design appropriate for this range of wind speeds that would double the average velocity over the blades.

(a) Development of portable Data Acquisition System based on Netbook Computer

To collect data from the power monitoring digital voltmeter (DVM) and the Oregon Scientific weather station providing wind speed and temperature measurements we developed a compact system based on USB communication to a local netbook computer. Undergraduate students wrote data base software to log the readings at preset time intervals. The data were transmitted to a host machine over the Carnegie Mellon wireless network and saved in a mySQL data base built on the host machine.

(b) Installation and Operation of Commercial Wind Turbine

To generate power at low wind speeds without any Venturi housing, we purchased an Air-X 400W turbine from Southwest Windpower. This machine came with a predicted power versus wind-speed chart that matched the expected airspeeds of winds at our test site atop the Physics building at Carnegie Mellon. We designed and built a mount with support fixtures that satisfied Carnegie Mellon engineering requirements. Wind energy was saved in a battery supplied by Carnegie Mellon.

(c) Venturi Design

In parallel with this effort, we used Carnegie Mellon's access to the FLUENT fluid mechanics design package to explore housing designs. A student with a joint Physics/Mechanical Engineering major did his undergraduate research project on this design. The program allowed us to include the compressibility of air as well as temperature effects into the flow studies. The input was the air speed at the entrance to the housing. For program simplicity, the design geometry was rectangular. In a real application using molded plastic housings, one would switch to cylindrical geometry, but that will not make a fundamental modification in the findings of this project. The change in wind speed through the system is shown in Fig. 1. The constant velocity region of the plot corresponds to the region holding the turbine. To the right in the figure is the exhaust region, with indeterminant velocity depending on how much momentum was transferred to the blades by that element. Including efficiency factors, this would correspond to more than a factor of 5 improvement in the power generated by the turbine.

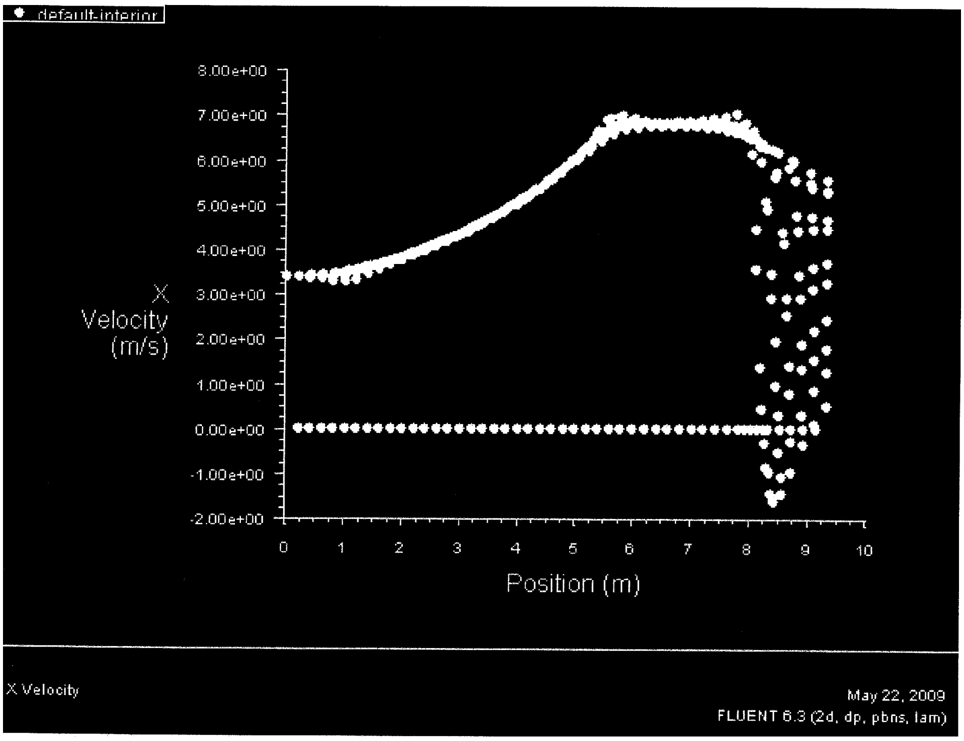

Figure 1: Air speed versus distance from Venturi entrance

(d) Venturi Fabrication Study

In conjunction with Unique Machine and Tool, McKees Rocks, PA, we made a prototype fabrication study for a single Venturi housing to shroud the Air-X turbine. This involved the housing, a rotary bearing and commutator to allow unimpeded rotation to follow wind direction changes, and a support tower to handle wind loading even in severe thunderstorms.

(e) Final Engineering Study

To make a more sophisticated test of the projected efficiency improvement, we collaborated with the Mechanical Engineering group at Fermilab to expand the study region using their ANSYS software. That group had extensive experience with expansive fluid flows in, e.g., cooling system design for LHC silicon detectors. They pointed out that it was important to consider a larger entrance volume to include possible back -pressure effects on the effective wind speed at the entrance to the Venturi housing. The Fermilab computation, shown in Fig. 2, confirms the factor of 2 increase in wind speed through the Venturi but also shows that the back pressure effects reduce the free air wind speed by a signficant factor. This makes the overall Venturi improvement closer to a factor of 2.5 in power, rather than a factor of 5.

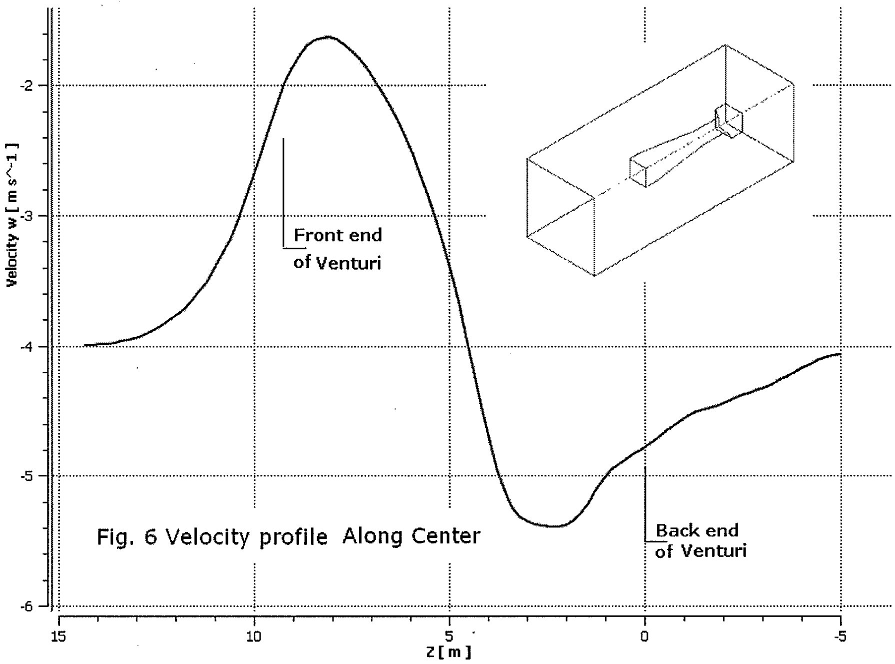

Figure 2: Wind Speed through Venturi On Large Distance Scale

The next step in the project is to build a scale model prototype and test it in a wind tunnel. However, the engineering students involved with the project had all graduated. Because the physics has been validated and the design issues identified, this seemed an appropriate time to terminate the project under the Advanced Detector Projects auspices. The next step would be an engineering evaluation of Venturi housing optimization and manufacturing study, to determine real costs and benefits.

(B) Communication Studies

Cosmic ray experiments for EeV studies cover very large areas. Each detector station is an independent data generating center. The overall trigger decision may not be made until individual stations have reported their measurements and a global decision, based on time windowing the results, can be made at a later time. This means that a low-power data collection, compression and transmission system has to be supplied at each station. The on-going development of distributed intelligence networks based on low-power computing nodes with wireless capability provides an excellent match to the needs of these experiments.

(a) We have designed and tested a preliminary data acquisition system designed to be fault-tolerant and robust, using commercial motes (iMote, FireFly) purchased with project funds as well as by Carnegie Mellon grants. This work was done by undergraduate students along with Dr. John Detwiler, a retired CMU Ph.D. and computing expert who volunteers on the project. The system is based on clustering a base grid of four nodes. All nodes have wireless communication capability. Any one of the nodes in the base grid can serve as its master under external wireless control, for fault recovery. The nodes collect data from each detector station, compress it, and send it to the local master. Four grids comprise a sixteen-fold data segment (DS). The DS master has an RF modem to send the entire DS data set back to the base station. A failure of the DS master requires active intervention. We have confirmed reliable data transmission among nodes over a distance of 200 m, suitable for the experimental needs. We also confirmed reliable operation from a DS master to a base station over a 3 km distance, typical for a cosmic ray experimental setup.

(b) We have designed a GPS time stamp system to tag each detector station's data by a 10-ns resolution stamp for offline processing and association.

(c) We have evaluated the computing power needed for the data compression and station readout and confirmed that the resources in the iMote or FireFly systems have adequate reserve power to accomodate substantial growth in the load without redesign.

5. Paper: no publication has resulted from this work.

6. Personnel involved:
(a) Alex Yuschuk, undergraduate (2007-2008 partial summer support)
(b) Jonathan Lind, graduate student (2007-2008 summer support)
(c) Zhen Tang, graduate student (2010 partial summer support)
(d) Christopher Lee, undergraduate (no support)
(e) Dr. John Detwiler, Visiting Researcher (no support)

7. Cost Status

Grant Total	Amount Expended	Amount Deobligated
$26,000.00	$21377.14	$4622.86