WIND TURBINE POWER PRODUCTION UNDER CURRENT MARTIAN ATMOPSHERIC CONDITIONS. C. Holstein-Rathlou[1], P.E. Thomas[2], J. Merrison[3], J.J. Iversen[3], [1]Center for Space Physics, Boston University, 725 Commonwealth Ave, Boston, MA 02215 (rathlou@bu.edu), [2]Faculty of Health and Medical Science, University of Copenhagen, Copenhagen, Denmark, [3]Department of Physics and Astronomy, Aarhus University, Aarhus, Denmark

Introduction: Any mission to Mars must always contend with the limitations on power production placed upon it by mission design or location on the planet. For future possible missions to the polar regions of Mars standard power sources will be unfit for the task. Solar cells will have limited or no sunlight for roughly half the year and the heat expunged by MMRTGs (or similar) would be detrimental to any science performed in a polar region.

A different possible power source would be a wind turbine along with a battery for storing produced electricity, potentially in combination with solar cells. The concept of a Martian wind turbine has been explored theoretically in connection with manned missions to Mars [1,2,3,4], and along the same lines, a 100 kW wind turbine was designed and tested in Antarctica, a general Mars analog site, by NASA AMES [5]. However all the above considered large (> 5m radius) and heavy (> 100 kg) wind turbines which would need wind speeds of the order of several 10s m/s. These sizes and masses are unfeasible for the power supply for a science missions to Mars, which are generally much smaller and lightweight. Also, typical wind speeds on Mars are closer to the 2-10 m/s range [6, 7], making these large wind turbines useless most of the time.

This paper introduces the first experimental demonstration of a small, light-weight wind turbine under simulated current Martian atmospheric conditions. The objective of the wind turbine was to see how much power is produced under realistic Martian atmospheric conditions.

Experimental setup and runs: The experiments were conducted in the Aarhus Wind Tunnel Simulator II at Aarhus University, Denmark [8] in the fall of 2010.

To simulate a Martian atmospheric environment in the wind tunnel, one wants to duplicate the atmospheric density from Mars. Using the ideal gas law, assuming equal atmospheric densities, we can write: $P_{Earth} = P_{Mars} \cdot (M_{Mars}/M_{Earth}) \cdot (T_{Earth}/T_{Mars})$, where P is pressure, T is temperature and M is molar mass of the respective atmosphere. For the Martian atmosphere M_{Mars} = 44.01 g/mol and, for Phoenix lander conditions, T_{Mars} = 203 K and P_{Mars} = 7.5 mbar. For Earth M_{Earth} = 28.96 g/mol. The lab (and the wind tunnel) was at room temperature, T_{Earth} = 293 K. This results in a desired atmospheric pressure inside the wind tunnel of 1640 Pa. Although it is possible to lower the temperature in the wind tunnel, input dust and have a CO2 atmosphere, none of these were utilized as it was beyond the scope of this experiment.

***Figure 1: (left)** The wind turbine positioned in the wind tunnel, which is 2 m in diameter. **(right)** Close-up of the wind turbine, with the wind tunnel fan visible in the background.*

***Figure 2:** Close-up of the wind turbine central parts showing wing and motor connections.*

The wind turbine consisted of 6 wings attached to a generator (a 5V DC motor) and suspended on a test stand. Each wing was a 6 by 18 cm piece of parchment paper kept taut by straws on the back and attached to a thin wooden. The wings were angled at 45° and connected to each other using LEGO Technic pins and angle connectors, and to the larger gear via an axle (see Fig. 2). Another axle and smaller gear was used to connect the wings to the generator. The connected wings has a weight of 24.7 g and the generator weighed 80.7 g, putting the entire wind turbine at a total weight of 105 g. The generator wiring was run through the wind tunnel flanges to an outside circuit containing the resistor (either 1 or 10 Ω).

The experiment was run at 6 different wind speeds (as seen in Table 1), which were chosen based on (a) the most common wind speeds at the Phoenix landing site in the northern polar regions of Mars (~ 2 - 6 m/s) [7], (b) the minimum wind speed needed to make the wind turbine rotate and (c) the maximum wind speed the wings could withstand. For each wind speed the output voltage was measured for 30-120 s.

Results: The experiment was run a total of three times with different combinations of resistance (R) and generators (small motors). The initial run used a too small generator for the wind turbine, and highlighted some unevenness in the design which was corrected for later runs. The two other runs used the generator imaged in Fig. 2, and a resistance of 1 or 10 Ω, respectively. Fig. 3 shows the test results for the 10 Ω run, which generated the highest amount of voltage. The 1 Ω run looks similar, but with maximum output voltages of 0.035 V. Each "step" corresponds to a new wind speed.

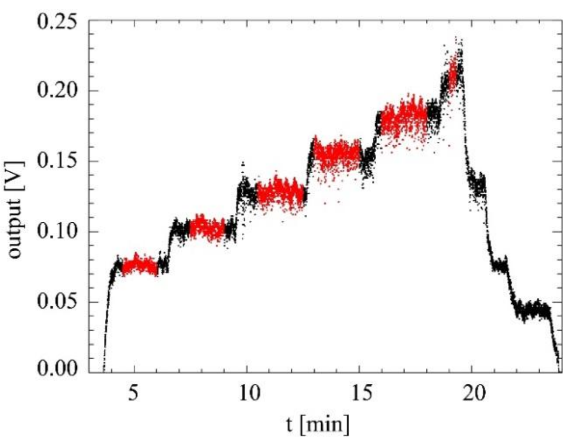

Figure 3: *Output voltage as a function of time from the wind turbine in the case of the 10 Ω experiment. The data in Table 1 for this experiment are calculated from the red data in the plot.*

Power produced for each wind speed was calculated from voltage, where $P = U^2/R$ (combining Ohm's and Joule's laws). The average voltage per time period per wind speed (red data of Fig. 3) was calculated as the integral over time for the indicated time periods (in essence, the area under the curve using trapezoidal sums). The average produced power vs wind speed for both runs is shown in Table 1.

v [m/s]	Average power produced [mW]	
	with 1 Ω	with 10 Ω
4.41	0.086	0.576
5.00	0.215	1.059
5.59	0.382	1.633
6.17	0.547	2.389
6.76	0.793	3.265
7.34	1.077	4.473

Table 1: *Average power produced for the specified wind speeds for the two experimental runs.*

Discussion: This simple experiment has shown that power production by a wind turbine under current Martian atmospheric conditions, more specifically, at wind speeds which are regularly seen at the Martian surface, is indeed possible. The optimal locations for this type of power production are areas where the Sun doesn't always shine, but winds will blow, such as latitudes poleward of the polar circles.

The output is in the few mW range, which can be put in relation to the maximum power output expected [2]: $P = ½\ \eta\ \rho\ A_{sw}\ v^3$, where η is turbine efficiency, ρ is atmospheric density, A_{sw} is swept area of the turbine, and v is wind speed. The maximum efficiency is 16/27 as given by Betz' law. For the wind turbine used in this experiment the produced power is roughly 0.5-1% of the maximal possible produced, highlighting the inefficiency of the design.

There are certainly a suite of studies to be conducted before sending wind turbines to Mars, however most designs (singular or part of a system) will be more efficient than this experiment, and thus should lead to power production in a range that is able to support some or all instrumentation on a small lander (Pathfinder sized or less). For now, we can say for the first time and with certainty, that, YES, you can use wind power on Mars!

References:

[1] Haslach (1989) *J. British Interplan. Soc., 42*, pp. 171-178 **[2]** Litcher and Viterna (1999) *NASA Tech. Rep. 209390* **[3]** Hemmat, Nguyen, Singh, Wylie (U. Houston) (1999) *NASA Tech.Rep. 20000028286*, pp. 131-145 **[4]** Kumar, Paraschivoiu, and Paraschivoiu (2010) *Wind Eng., 34, 4*, pp. 461-476 **[5]** Coleman (ed.) (2013) *NASA Spinoff*, pp.106-107 **[6]** Hess et al. (1977) *JGR, 82, 28* **[7]** Holstein-Rathlou et al. (2010) *JGR, 115*, E00E18 **[8]** Holstein-Rathlou et al. (2014) *J. Atmos. And Oceanic Tech., 31*, pp.447-457