Richmond Road Turbine Spatters

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Rondeau Watershed, March 11th 2008

<u>FINAL REPORT</u>

On Saturday, March 1st 2008, after finishing recording the 1500kW GE turbines on Richmond road, south of Nova Scotia Line, East Elgin, constructed by Aim Power Gen,
(42.66694deg.N, 80.85908deg.W);

I noticed, on the top 3rd of the north turbine column, a number of spatters that appeared to radiate from the southwest.

I took a digital 3888x2592 jpeg photo with a canon 400D with a 70-300IS lens, F5.6, 1/640sec, ISO100 at 5:01 PM, from the road, facing east, approximately 60m from the tower.

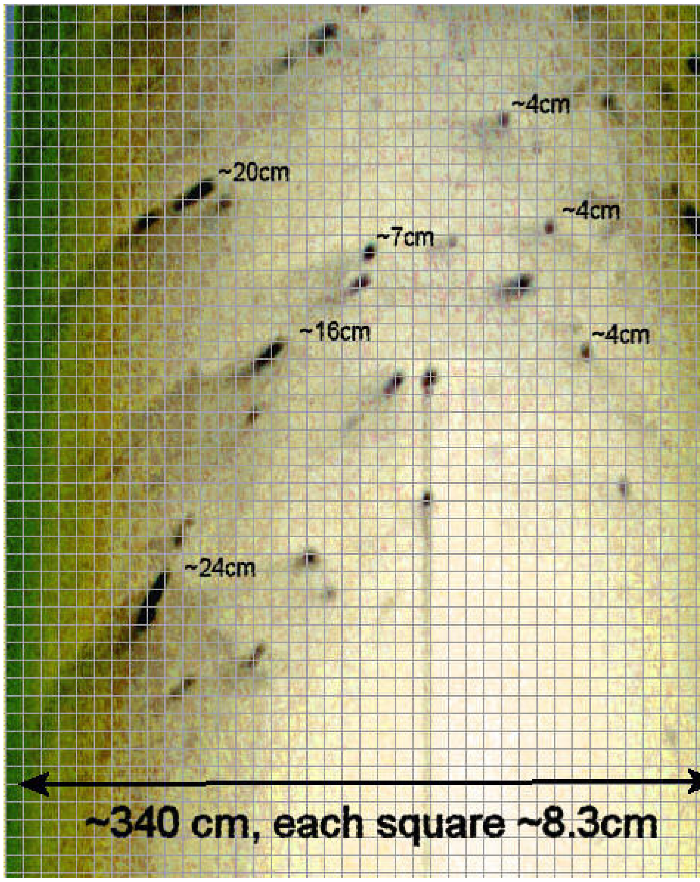
Below is a copy of the original and on the right, a digitally enhanced version that clarifies the spatters. All image functions were applied evenly to the column

Richmond Road turbine, post construction 2006

Richmond Road turbine, March 1st 2008
Image enhancement used to clarify the spatters

From the direction and distribution of the spatters it appears that individual tracks were moving a high velocity, from the South-southwest. Parabolic spatter patterns indicate a direction of impact. Notice on the lower spatter vectors, the angle of impact is quite high indicating something falling. The lower density of spatters further down the column is probably correlated and would indicate bodies either losing forward momentum or being thrown at a descending angle.

Below, in this photo smaller spatters are 16% the size of larger ones.



Methods:

There is no way to tell using this photograph, whether spatters resulted from a single event or a series of occurrences. The likelihood however, of spatters being concentrated solely along the column would be low. It is reasonable to assume that the column is providing a “window” of observation which can be used to extrapolate. Calculations are based on the assumption that spatters would be evenly distributed throughout the circumference of each concentric ring. I will demonstrate a method for determining an upper level estimation of spatters, throughout the entire swept area of the turbine blades, given the available data.

With this overlay one can see that the spatter width is just over 1/3rd of the 38.5m blade width.

I selected areas where the spatters began at the bottom.

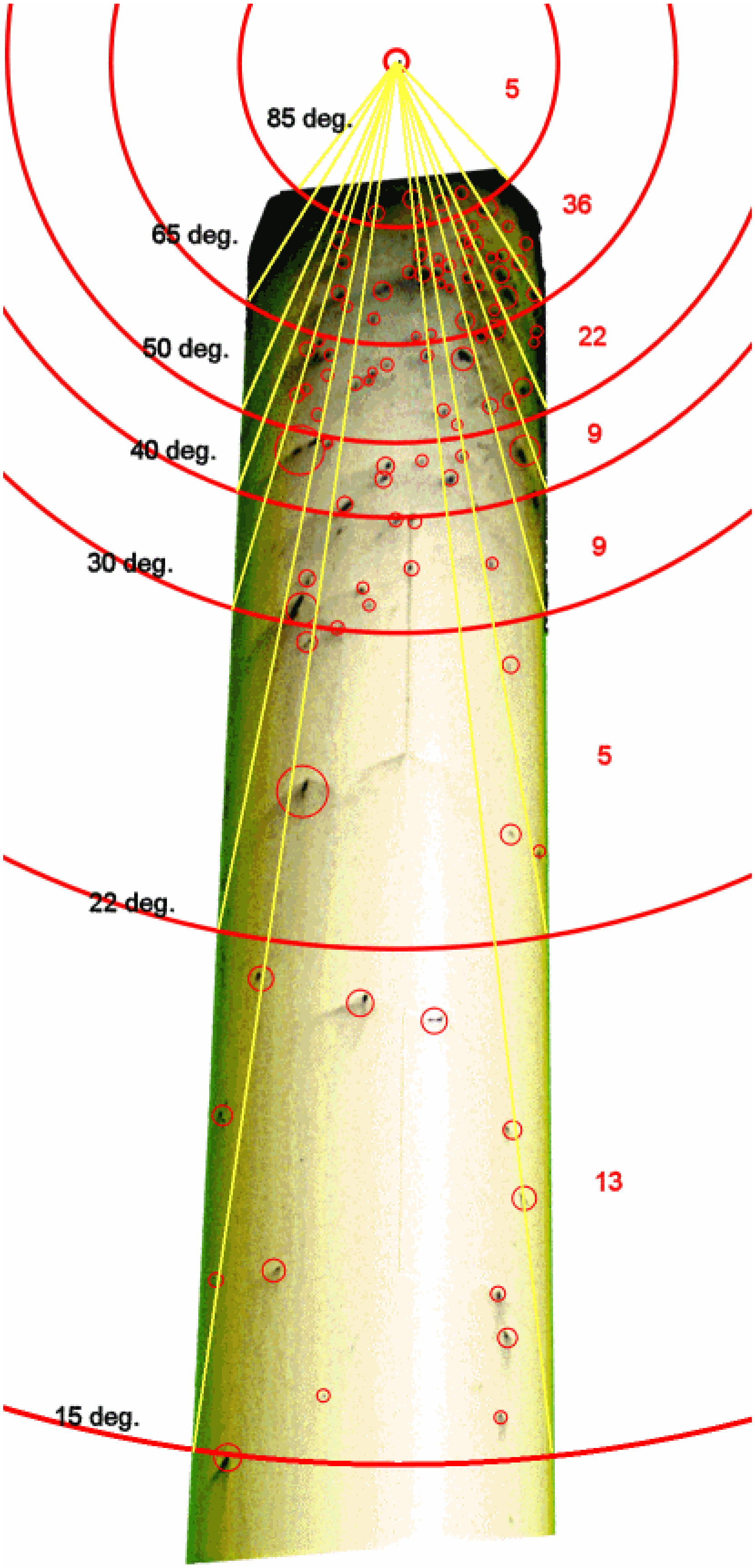
Using concentric rings I defined areas, (*transects*) to isolate groups of spatters.

Within each transect individual spatters were circled and counted.

The degree width of each transect was measured with a protractor.

Two methods were used to count the 99 spatters circled. The high density of spatters at the top of the column made it virtually impossible to get an accurate count from Transect 1. I decided to circle only definable features and use a low, rather than a high estimate. In future counts, on other towers lighting and density may provide more clarity.

Below is an image enhanced cutout of the column of the North Richmond Road turbine. The red arcs define an area within which a transect count is made. Counts are numbered along the right of the column. The yellow radiating lines from the top center define the transect angles that are used to determine the proportion of the swept ring that each transect occupies. Counts are projected throughout the transect ring in proportion to the sector area.

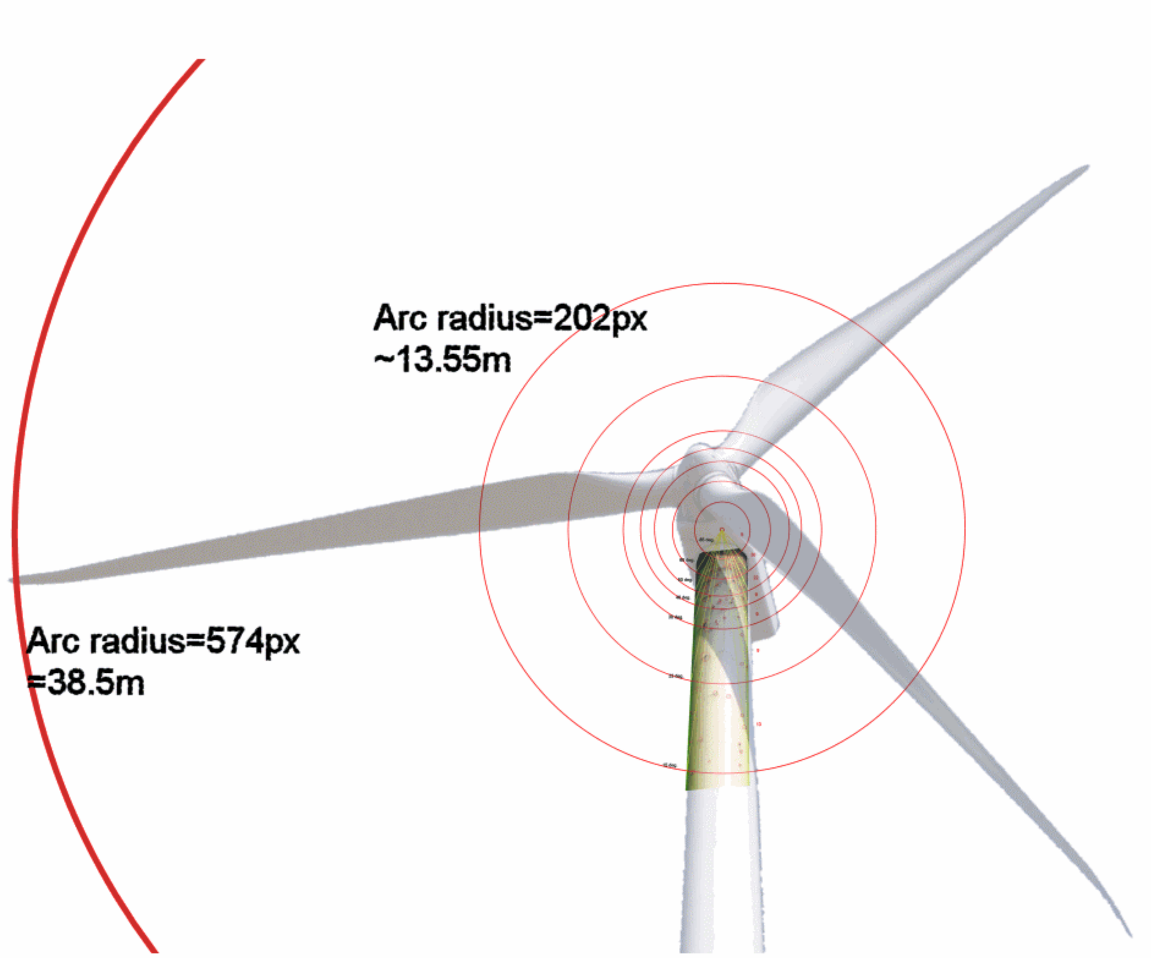

85 deg.
5
65 deg.
36
50 deg.
22
40 deg.
9
30 deg.
9
5
22 deg.
13
15 deg.

From top to bottom: Rounded off to the nearest whole number
Ring widths are averaged for sake of simplicity.

Transect 1	**360**	**/85**	**x5**	**=**	**21**
Transect 2	**360**	**/((85+65)/2)**	**x36**	**=**	**173**
Transect 3	**360**	**/((65+50)/2)**	**x22**	**=**	**138**
Transect 4	**360**	**/((50+40)/2)**	**x9**	**=**	**72**
Transect 5	**360**	**/((40+30)/2)**	**x9**	**=**	**93**
Transect 6	**360**	**/((30+22)/2)**	**x5**	**=**	**69**
Transect 7	**360**	**/((22+15)/2)**	**x13**	**=**	**253**

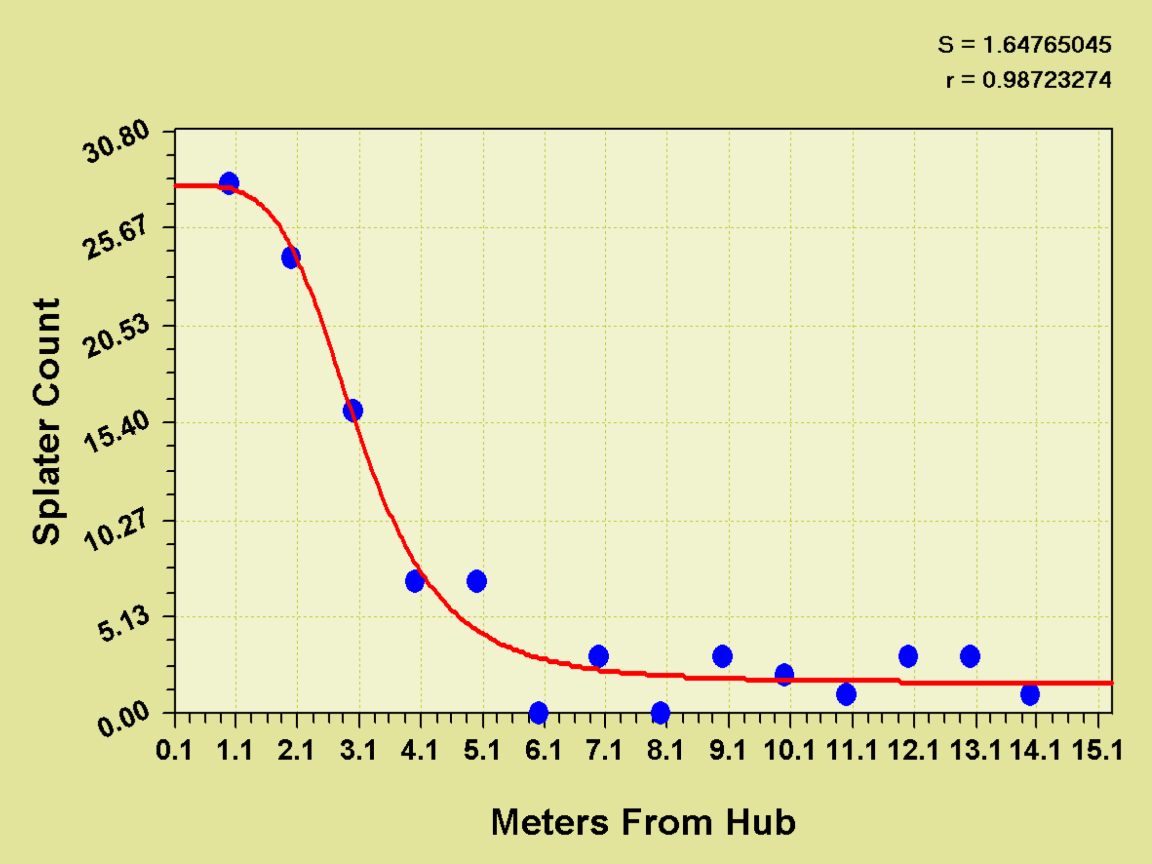
TOTAL calculated over swept area 819

The total swept area *A* of the GE 1.5 kW Turbine is 4657 sq.m, blade length, 38.5m
The approximate swept area *A1* of this spatter count is about 577 sq.m
Using the 13.55m arc radius estimation, spatters were recounted at 1m intervals and plotted to derive a density function. This will be used to extrapolate a spatter count over the remaining 4080 sq. m ring *(A-A1)*. A1 was estimated using the ratio of pixel radii of the Arcs. The left, (orthogonal) blade was referenced to minimize perspective distortion.



Modelling:

Multiple Multiplicative Factor
MMF Model: y=(a*b+c*x^d)/(b+x^d)
Coefficient Data:
a = 1.6645635
b = 0.0069037368
c = 27.895276
d = -4.426174



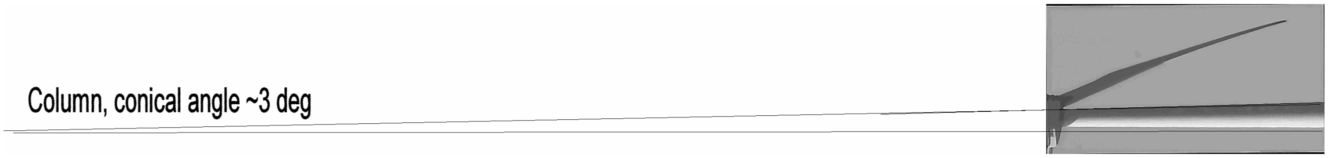
At 38.5m this model integrates to 149.06 spatters. Subtracting the initial 99 spatters, the model estimates 50 spatters over the remaining 24.95 meters.

Since the change in density appears linear over that area, we can interpolate a potential spatter count for the entire swept area, 4657 sq.m., based on a linear regression. This is not to exclude to potential for clusters outside of the study area, there is just simply no data at this site.

We'll first determine the transect angle, (Transect 8) and find a multiplier for that radial section.

To estimate the column width at 13.55m, we bisect the transect angle at 13.55m
to make 2 right triangles, then determine the width of the conical column at that point:

W1= tan(15/2) * 13.55 * 2 = 3.568m



Using the same method to estimate the column width at 38.5m

3.568 + (tan(3/2) * 38.5 * 2)   =5.58m

…then calculating the angle,

transect @ 38.5m = 2*atan(5.58/(2*38.5))   =8.29deg.

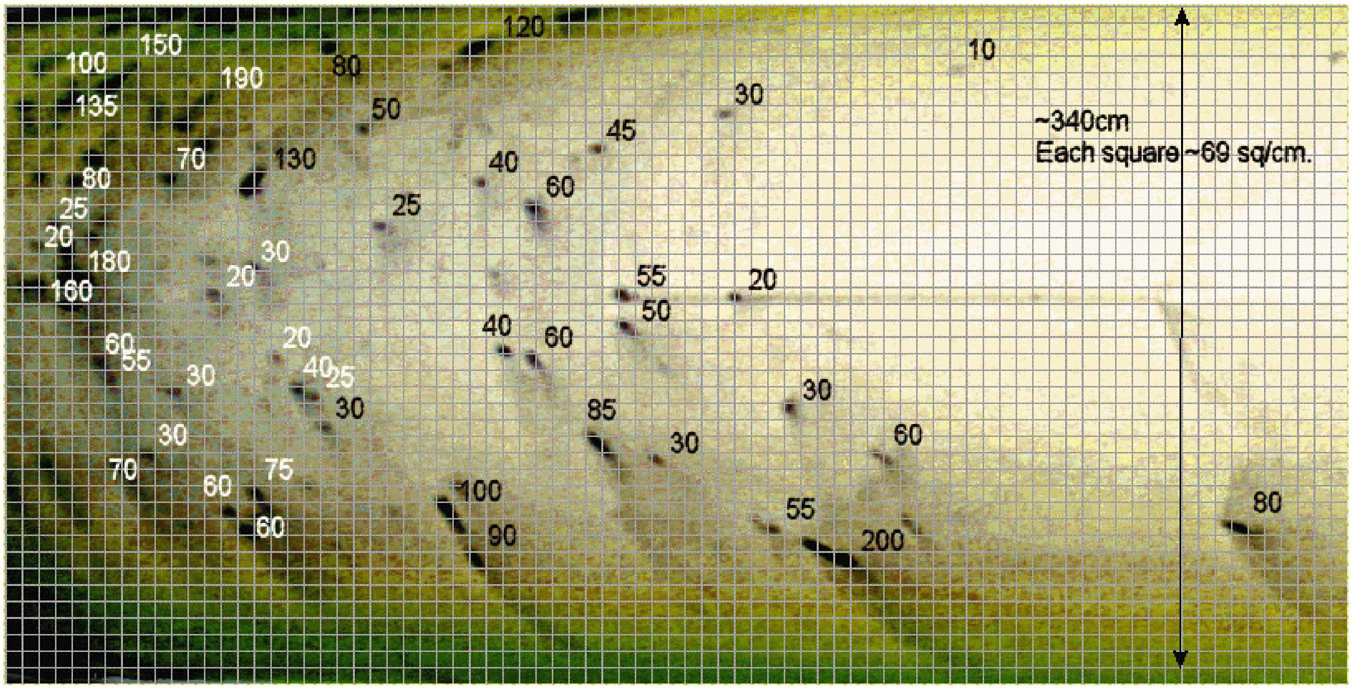
…and interpolating over the remaining swept area, A-A1.

Transect 8   360   /((15+8.29)/2)   x50   =1545

TOTAL calculated over swept area	**819**
TOTAL interpolated over swept area	**1545**
Calculated + interpolated	**2364**

Areas:

When spatter areas are averaged over the photograph the average ***As*** is **68 sq/cm**



If the spatters were the result of a fluid leak then the drop size can be calculated in relation to spatter size. Assuming that drops are roughly spherical, we will calculate the drop volume:

Calculating drop volume:

For simplicity sake, spatters can be modeled as circular.
the average splatter width:

ws = 2*(As/pi)^(1/2)
=2*(68/3.14)^(1/2) = 9.3cm

The maximum spread radius, made dimensionless with the drop radius, is correlated as

$$R_{max}^{*} = 0.61(Re^{2}Oh)^{0.166} \quad (1)$$

where Re and Oh are the Reynolds and Ohnesorge numbers. respectively.
The width of a drop

$$wd = ws/\ R_{max}^{*}$$

The **Ohnesorge number**, Oh , relates the viscous and surface tension force.

$$Oh = \frac{\mu}{\sqrt{\rho\sigma L}}$$

where

- **μ is the liquid viscosity**
- **ρ is the liquid density**
- **σ is the surface tension**
- **L is the characteristic length scale (typically- drop diameter)**

Reynolds Number, is a dimensionless number related to flow behavior (inertia vs. viscosity)

$$Re = \frac{\rho v_s^2/L}{\mu v_s/L^2} = \frac{\rho v_s L}{\mu} = \frac{v_s L}{\nu} = \frac{\text{Inertial forces}}{\text{Viscous forces}}$$

where:

- **v_s is the mean fluid velocity in m s^{-1}**
- ***L* is the characteristic length in m.**
- **μ is the (absolute) dynamic fluid viscosity in Nsm^{-2} or Pa s**
- **v is the kinematic fluid viscosity, defined as v = μ/ρ, in m^2s^{-1}**
- **ρ is the density of the fluid in kgm^{-3}**

The GE 1.5MW turbines use an air cooled oil lubricating system. The main types of lubricants used in large turbines are:

- **PAOs (Poly Alpha Olefin)** provide excellent viscosity index and low pour point. These properties make them a fluid of choice for applications characterized by wide ranges of operating temperatures.
- **PAO/ester Blend.** There have been hydrolysis issues (breakdown in the presence of water), making selection of hydrolytically stable products a critical issue.
- **PAGs (Polyalkalene Glycol)** offer improved resistance to micropitting but have compatibility problems with coatings and seal material.

Since the physical properties of these were unavailable, I substituted properties from a mixture of 40% deionized water and 60% glycerol which would have spatter properties similar to light oil. These normalized to 20deg. C are:

	cgs	mks
surface tension	**67.4 dyn/cm,**	**.687289kg/m2**
density	**1.16 g/cm3**	**1160 kg/m3**
viscosity	**14.4 cP**	**0.0144 Pa s**

The GE 1.5Kw turbine rotor speed varies from **10** to **20.4** rpm and has a circumference of 242m so that the tip velocity varies between 40 an 82 m/s or up to 290 km/h

Most of the recorded spatters occurred between 1 and 7 meters from the hub. Velocity can be estimated using **15 rpm at 3.5m radius.**

v_s =7*pi*(15/60)= 5.495m/s

Re=8639.58

Oh=0.003652

$$R_{max}^* = 0.61(Re*Oh)^{0.166}$$

$$R_{max}^* = 4.871$$

The drop width:

wd at 5.5m/s -> ~2cm

With this ratio, a fluid volume can easily be calculated using the formula for the volume of the sphere:

*4/3*pi*r^3*

and substituting

*4/3*pi*wd^3* so that the average drop volume is ~3.7cc

Total Estimated Volume:

Using the model illustrated above, average volumes can be interpolated:

At **5.5m/s** from **9L** ,and up to **17L** (*one standard deviation from the average*)
At **10m/s**, (36km/h) between **5.5L** and up to **11L**
At **20m/s**, (72km/h) between **3L** and up to **6L**

Conclusion:

The height of the spatters, most over 90m from the base along with their size virtually eliminate the possibility of casual vandalism. It occurred to me that there may have been some sort of machine failure that caused something to leak from the nacelle pivot and splash, in globs on the support column. Upon examination of the direction and distribution of the spatters, It seemed more likely that fluid came from the blades themselves or maybe the nose cone. It has been suggested that spatters may have resulted from a single or multiple collision with large avians or was the result of a maintaince spill of grease. Reviewing the direction and distribution of the spatters suggests that if they resulted from maintaince then it would have to have been done during high wind conditions, with the rotor turning. Without actually getting sample of from the tower, or interviewing someone who witnessed an event, there is no way to know for sure whether spatters resulted from leakage or collision.

Recommendations:

Unless a realistic alternative explanation that takes into account the available data is forwarded, I would recommend, further observations of all turbine surfaces. If the spatters represent a mechanical failure then the possibility of environmental pollution exists. With more data such as the physical properties of the lubricant, this method will be refined. If on the other hand, spatters result from an avian collision then questions surrounding the subject of flight avoidance must be asked.

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References

1) Brian L. Scheller, Douglas W. Bousfield, Newtonian drop impact with a solid surface
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PN: 0001-1541Dept. of Chemical Engineering, University of Maine, Orono, ME 04469