Wind Report

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As Stanley Freese once said "often enough when the wind blew in autumn, the miller would work from Sunday midnight to Tuesday evening, Wednesday morning to Thursday night, and Friday morning to Saturday midnight". I now have evidence that this is unlikely.

1. Introduction

SPAB has bought an anemometer with which to measure wind speeds at a windmil. Below, I report on why we wanted to do this, and what results we are obtaining. This will be an ongoing project which has important consequences for all wind millers, and, we hope, will become a major influence on planning decisions.

A surprise result of measurements taken with the anemometer is to find that the wind only blows at night with less than 40% of the daytime speed – and 40% speed equates to much less, about 10%, of the time for milling, because the mill has a threshold wind speed below which there isn't enough power to grind. So, Freese's comment might represent a once in 10 year event, but hardly one that occurred often.

Background

Wind loss at Windmills

When a house is built or a tree planted near to a windmill, the wind available to the mill is reduced by the "wake" behind the obstacle whenever the wind blows from it towards the mill. Most mills (apart from the very tall town mills) were built in open fields some distance from their local village, typically more than 400 m, and enjoying unobstructed wind flows. In many places, modern developments have now encroached on the mills and caused a substantial reduction in the wind availability. At my mill, I now only receive enough wind to operate about 23 days per year, compared to 166 days during its working life before 1930 when the surrounding housing estate was built.

Planning Issues

In such circumstances, additional building causes a disproportionately higher loss of the remaining available milling time and there is an urgent need both to define the current state and to predict reliably what further loss would arise from building the planned development so that the harm that would be done by granting permission can be quantified. Planning law, governed by the NPPF, states that "the benefit of the proposed development must outweigh the harm done to a listed building" in order for permission to be granted.

However, until very recently, the assessment of wind loss was always carried out by the developers themselves, and, not surprisingly, underestimated the harm. In particular, the loss due to the new development has always been judged without taking into account the current state. At Stanton Mill, a planning inspector upheld an appeal, rejecting our wind loss arguments out of hand and basing his decision on the developer's estimates instead.

Following this decision, I have been writing wind reports for planners based upon Dutch methods of assessing wind loss. The Dutch have used a calculation called the Molenbiotoop since the late 1940s, and in most districts this prescribes the maximum acceptable loss at any mill, restricting the height of developments within a 400 m radius of the mill.

This year, at High Salvington Mill, following SPAB representations based on the Molenbiotoop, another inspector rejected an appeal by the would-be developer, giving his decision that "substantial harm would be caused to the mill by wind loss". This is a milestone because it seems to be the first time that wind loss calculations carried out on behalf of the mill have achieved any recognition.

What we now want to do is set formal guidelines for calculating wind loss and, if possible, get these accepted by planning authorities across the country. This process has to begin by determining the current situation at any mill. It would then go on to estimate the additional loss that would be caused by any new building and hence provide a measure of the harm that would be done to the mill.

The SPAB Anemometer

The primary data for determining how much wind is available at any site is the windrose, usually presented as a radar plot.

This shows the time and wind speed available (the radial axis) versus compass direction (circumferential axis). Such windroses are available from meteorological stations averaging the results over long periods. The one opposite (Fig. 1) is from RAF Mildenhall for the period from 1993 up to the present. This is the nearest published station to my mill at Impington – and it's 30 km away. Generally the meteorological stations are sited at airports as far away from local obstacles as

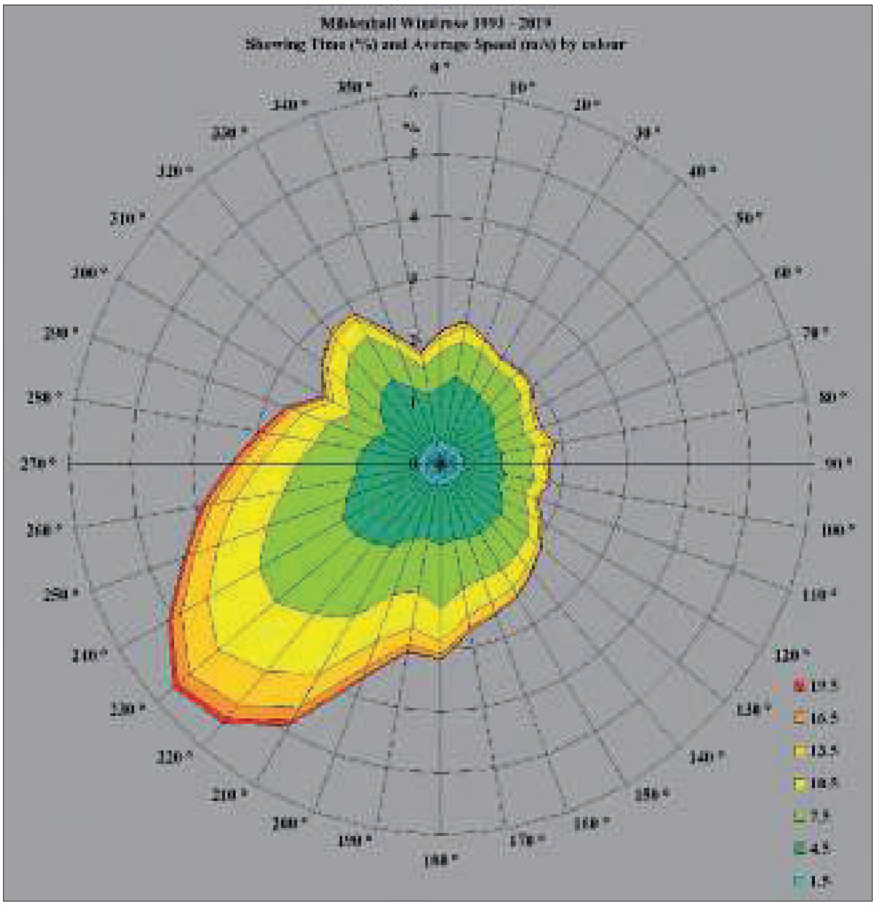

Fig. 1. Mildenhall windrose - the coloured area shows the distribution of wind speed by direction.

possible, so that this rose represents the open field condition, as enjoyed by most mills during their heyday.

To work out what is happening at Impington, we need to transpose this rose and take into account the wind loss due to local obstacles. Following a suggestion by Dave Pearce, SPAB has bought an anemometer and datalogger, built a magnetometer to go with it, and mounted it on my windmill.

The anemometer collects the windspeed and direction at frequent intervals and the datalogger records these. In addition, we need to determine which way the mill is pointing and add that to the anemometer's built-in wind vane – hence the magnetometer, which is an electronic compass built around the same chip as is used in mobile phones.

The anemometer is mounted high up, above the cap, and as clear as possible of the sails. The magnetometer and datalogger are inside the cap and turn with it. This confuses the wind vane, which does not know which way is north, so the magnetometer provides this information.

With these tools, we can measure how the wind speed differs at the mill from simultaneous readings taken at Mildenhall, and can deduce the relationship between them.

Objectives

The overall objectives of the wind analysis are:

- to provide methods for transposing a local meteorological station windrose to the actual windmill, taking into account the local obstacles;
- to verify the whole calculation process for assessing the current state of the wind at a mill by testing it at a number of mills;
- to check and update the Molenbiotoop calculation used to predict future losses. As it stands, the Molenbiotoop does not allow for trees, and there is no available verification evidence from its original inception;
- to provide well substantiated statements to planners about the potential harm done by any new planning proposal in the vicinity of a windmill.

To meet these objectives, we need to break down the process into a number of steps.

Fig. 2. The anemometer (arrowed) mounted on the fantail frame at Impington Mill.

Proof of Linearity

We need to show that the whole system is linear. In mathematical terms, that means that we can add or multiply two effects together to find their combined effect. This is one of the basic assumptions made by the Molenbiotoop. If the system is non-linear (and most fluid dynamics is) then we cannot justify the use of a simplified approach.

It is obvious that we cannot afford to spend 10 years or more collecting data in relation to any one windmill. However, if the system is linear, then we can use data collected in the much shorter term to define a simple relationship between wind at the mill and at the nearest meteorological station, from whence we can get published long-term data. Basically, we assume that for any one direction, there is a simple factor that gives the wind speed at the mill as a fraction of the simultaneous windspeed at the meteorological station. This is pretty fundamental – if there were no such constant factor, then we could not use the long-term data from the station.

At Impington, the anemometer was installed for three months (May to July this year) during which time the wind turned a full 360° three times. A sample of raw data is shown in Fig. 3 below. The data has been cleaned up a bit, with averages taken over two hours to smooth out the gusts and missing data removed. Even so, it's not obvious how to make sense of it.

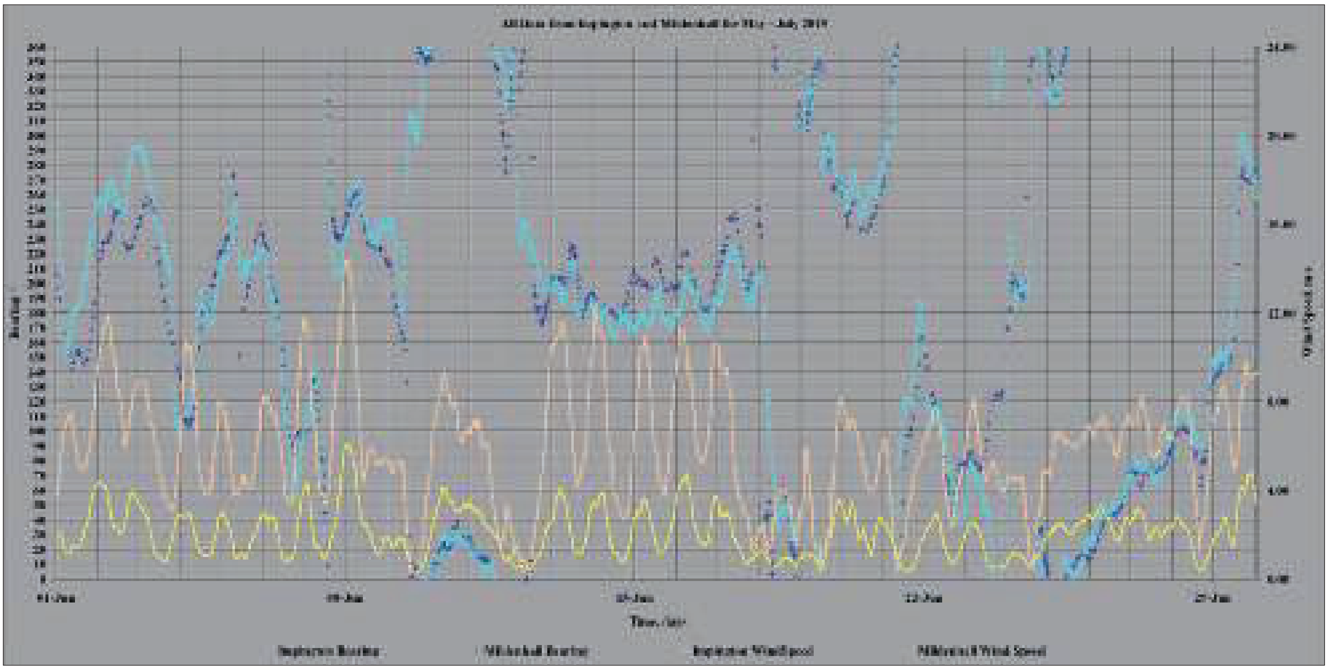

Fig. 3. Comparison of anemometer data from Impington and Mildenhall, May to June 2019.

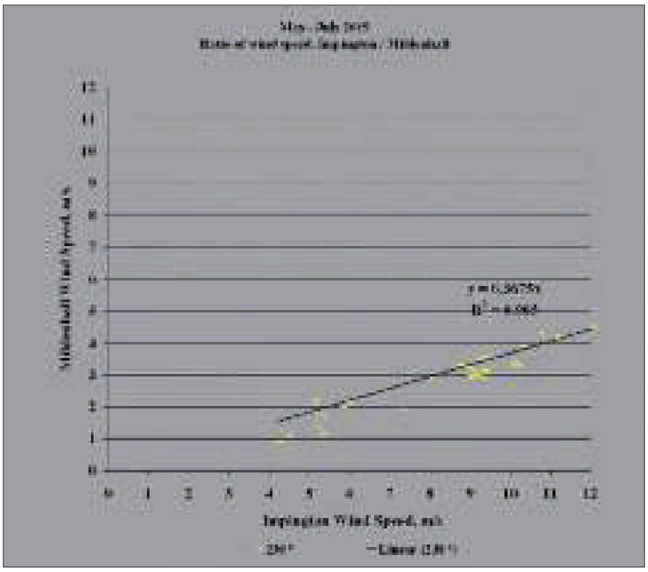

Fig. 4. Relationship between windspeeds at Impington and Mildenhall.

Something that jumps out, however, is that the wind speeds have a maximum and a minimum each day, a diurnal variation, with the peaks always occurring at around midday, and the troughs about midnight. I have not been able to find an explanation of this, except on the coast where differential heating of the land and the sea produce sea and land breezes diurnally. Since we are nowhere near the sea, this phenomenon was a great surprise and explains my comment in the introduction. It's a quite big effect with generally less than 40% of the wind available at night, and over the entire three months of measurement there were only a few nights when the speed barely got above the minimum speed for milling – certainly not enough to justify the intense night-time milling that Freese quotes.

The other obvious conclusion is that the speed at Impington tracks the speed at Mildenhall – this is what we hoped for.

There is enough data to draw a scatter plot for each 10° wind direction and show that the relationship between the two speeds is indeed linear. One of those plotsis shown in Fig. 4 above.

It is fairly obvious that the solid line fits the data well, and means that we can accept the single factor, in this case, 0.37 with a 90% confidence, as relating the two sites for this direction, approximately SW. The factor means that the windspeed at the windshaft of the mill is 37% of that at Mildenhall. All the 36 sectors gave a similar linear relationship, all with a high statistical confidence, and with factors ranging from 26% to 53%.

Transposition of Windroses

We can now take all the data from the long-term windrose at Mildenhall, multiply the availability of the wind in each direction by the equivalent measured factor and re-plot the windrose, effectively transposing it to Impington, taking into account all the current obstacles surrounding the mill. This is plotted in Fig. 5, with Mildenhall shown in orange and Impington in yellow. One way of interpreting the two lines is that the Mildenhall line represents what wind my grandfather would have received at Impington with open fields surrounding the mill and the second line represents what I get today, and makes rather depressing reading.

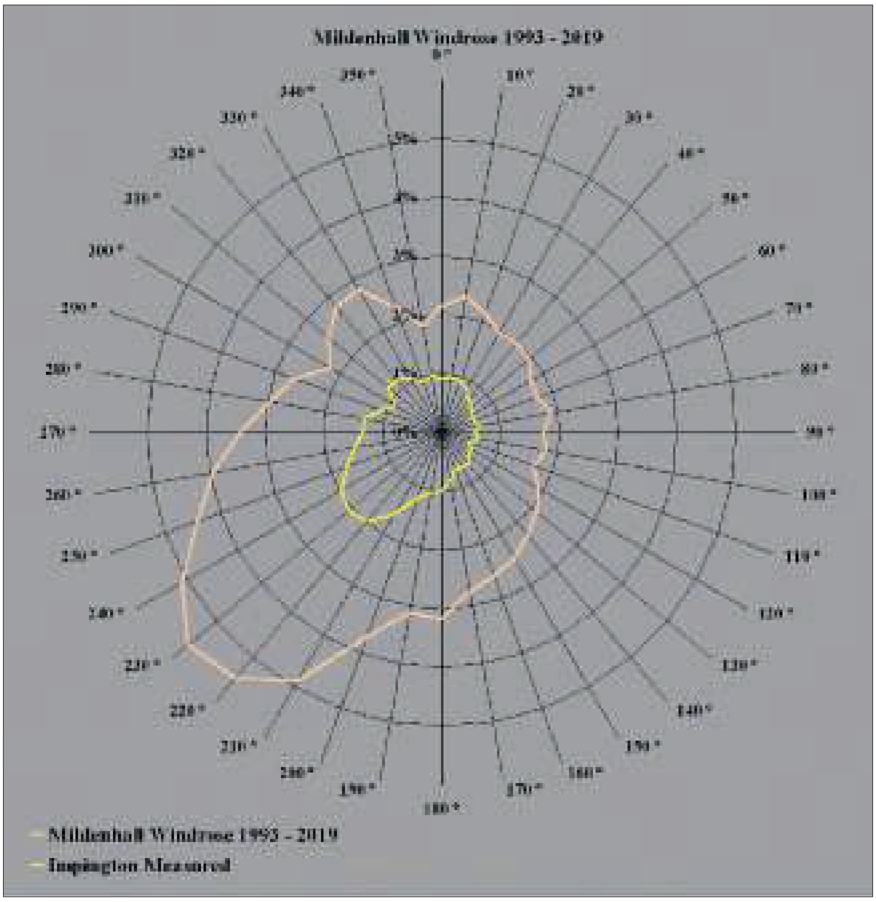

Fig. 5. Mildenhall long-term windrose transposed to Impington Mill.

Milling Time

We can go further and predict the actual time available for milling in each direction. The mill will only operate when the wind blows faster than 5 m/s at the windshaft, and by using a mathematical formula called the Rayleigh Distribution, we can calculate how much time the wind blows above any particular speed.

We need to know if this method fits with the data. As with the speed factors, this is crucial to being able to use the data effectively and to make future predictions. It is common practice to use the Rayleigh Distribution, but I have not found strong evidence to support its use. Here it is: for each direction, we plot the wind speed distribution data from Mildenhall (blue line) and from the Rayleigh formula for the same average speed (yellow line). They are extremely similar, as they are for all directions – so we can justify using the Rayleigh formula. This means that the windrose can be summarised by just two figures for each direction: the % time and the average for all wind speeds from this direction. The transposition is summarised by multiplying the average speed by the speed ratio for each direction.

Using the Rayleigh formula, we can then calculate how often the wind speed lies between the minimum and

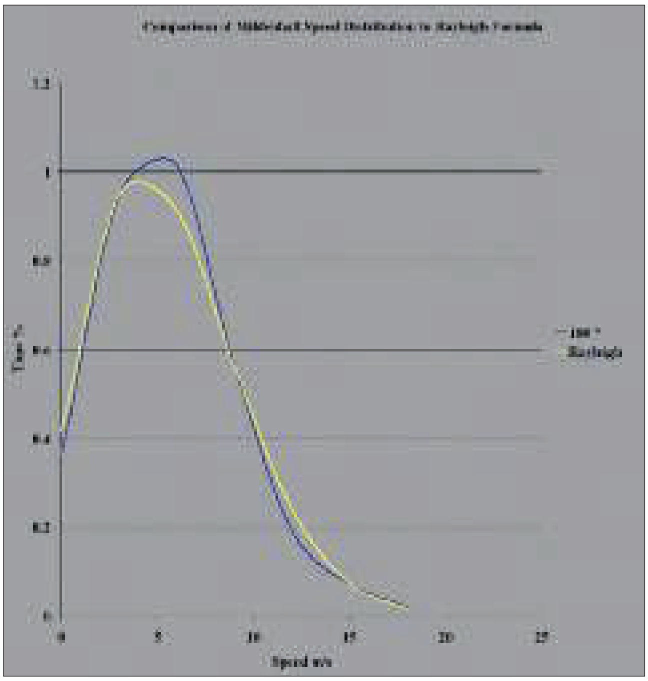

Fig. 6. Comparison of Mildenhall to Rayleigh Distribution.

maximum speed for milling, both for the original rose and for the transposed one. Fig. 7 shows these versions of the rose, but now the lines only show time available for milling, and we call it a "milling rose".

Adding together all the times from the sectors, we find that my grandfather could have milled on 166 days each year, while I am restricted to just 23 days. This is even more depressing than the speed plot, because of the threshold milling speed. It fits with what I have known for many years – the sails will not turn if the wind has an easterly component.

This is the key plot from the point of view of presenting evidence to planners. Anything the developers produce must accord with this result – and past experience shows that this is not what happens, as, for example, at the Stanton inquiry.

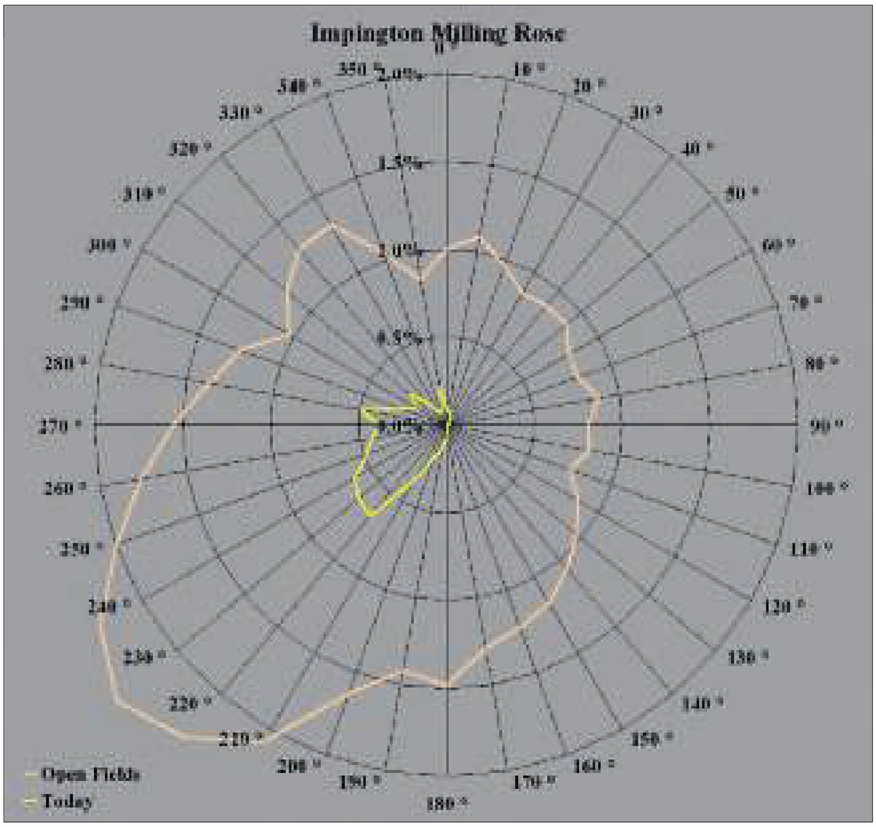

Fig. 7. Milling rose for Impington Mill.

On it must be superimposed any further loss due to the proposed development – which we look at next.

Molenbiotoop

The Molenbiotoop calculation has been in use in Holland for many years, and is incorporated into planning regulations in many districts. Unfortunately, the original theory and measurements to support it have been lost, so we effectively need to redo them. We also need to extend it to model the effect of trees, using similar simplifications to those applied (very successfully) to houses. There are two objectives for doing this:

- we need to be able to predict the effect of a new development, putting its additional wind loss into the context of the existing situation;
- we may not always be able to collect sufficient data from anemometry to reproduce the milling time wind rose above – for example, when, as often happens, we don't get enough notice of a planning application to set up the anemometer and measure enough all-round wind speeds to replicate the above data. Instead, we can do a "desk top" study and predict the transposition of the rose using the Molenbiotoop alone.

The Molenbiotoop makes more assumptions of linearity and we need to check that these are justifiable. The anemometer results can be used to do this: if we apply the Molenbiotoop to a known situation and it gives similar results to those measured, then its simplifications and assumptions are verified. Preferably, we need to do this several times for different situations (e.g. different mills and different seasons to allow for leaf fall).

The Molenbiotoop addresses the wind speed at the windshaft height (i.e. at the centre of the sails). It predicts the same factor that we have derived from the anemometry and which gives the ratio of the speed at the mill to the open field speed (upwind of obstacles), as given by the meteorological station.

It assumes that the effect of an obstacle is to lift the "boundary Layer" (the atmospheric layer in which the wind speeds are reduced by the drag of the ground) up to the height of the roof. This uplift then gradually reduces downwind of the obstacle until it meets the ground again and the free stream is restored. It is assumed that the distance in which this takes place is 50 times the height of the obstacle. The wake region can be thought of as a "wind shadow" in which the wind speed is zero. In the wake length, the speed at the windshaft height simply reduces linearly based on the height of the wind shadow at the windmill compared to the height of the windshaft. This is what gives the speed ratio for this obstacle. If there are multiple houses in line, then only the one that casts the highest wind shadow at the mill is relevant. This is an example of a non-linear effect.

Wind Report – continued

The effect of a tree is somewhat different because it is porous, so the boundary layer does not come to a complete stop – instead it simply slows down to the porosity value. In summer, this may be 50% or so, while in winter it may be 80% – these are figures which need to come out of the measurements.

Because of linearity, the effect of a house and a tree or multiple trees in line is simply to multiply the wake profiles together.

Height Measurement

It is fundamental to the Molenbiotoop that an "obstacle rose" can be prepared – measuring all the heights and distances for every dominant house and tree round the mill. Data for any new development comes from the architect's drawings, but this has to be put into the context of all the existing obstacles in order to determine the additive effect of a new development. Obtaining the heights of the existing obstacles can be non-trivial.

Google Earth

Google Earth (GE) can be used to measure horizontal distances to a high resolution, less than 1 m. However, where they are available, heights are only resolved to 1 m, and this is quite a large error compared to the height of typical houses. The values for heights given at Impington accord well with a few measured ones. Fig. 8 shows the obstacle rose taken from GE at Impington in glorious 3D. Green lines show the dominant trees, red ones, the dominant houses.

Unfortunately, GE's coverage of buildings in 3D is limited, and so at other mills it may not be so straightforward to plot the obstacle rose.

Summary of Results

Impington Mill

The wind speed ratios as calculated by the obstacle rose for Impington mill and applying the Molenbiotoop calculations are shown in Fig. 9 overleaf, blue line, with the measured values from the anemometer in yellow. Also shown are error bars on the measured values giving an idea of the uncertainty arising from anemometry, and addressed by fitting a single common line to them as described above for the scatter plot.

The correlation between the Molenbiotoop and the measurement is good – everywhere the Molenbiotoop value falls within the range represented by a height error of ±0.5 m and ±1 standard deviations of the scatter in wind measurement. Most importantly, it shows that the Molenbiotoop method is giving results that are far closer to reality than any fluid dynamics calculation that have yet

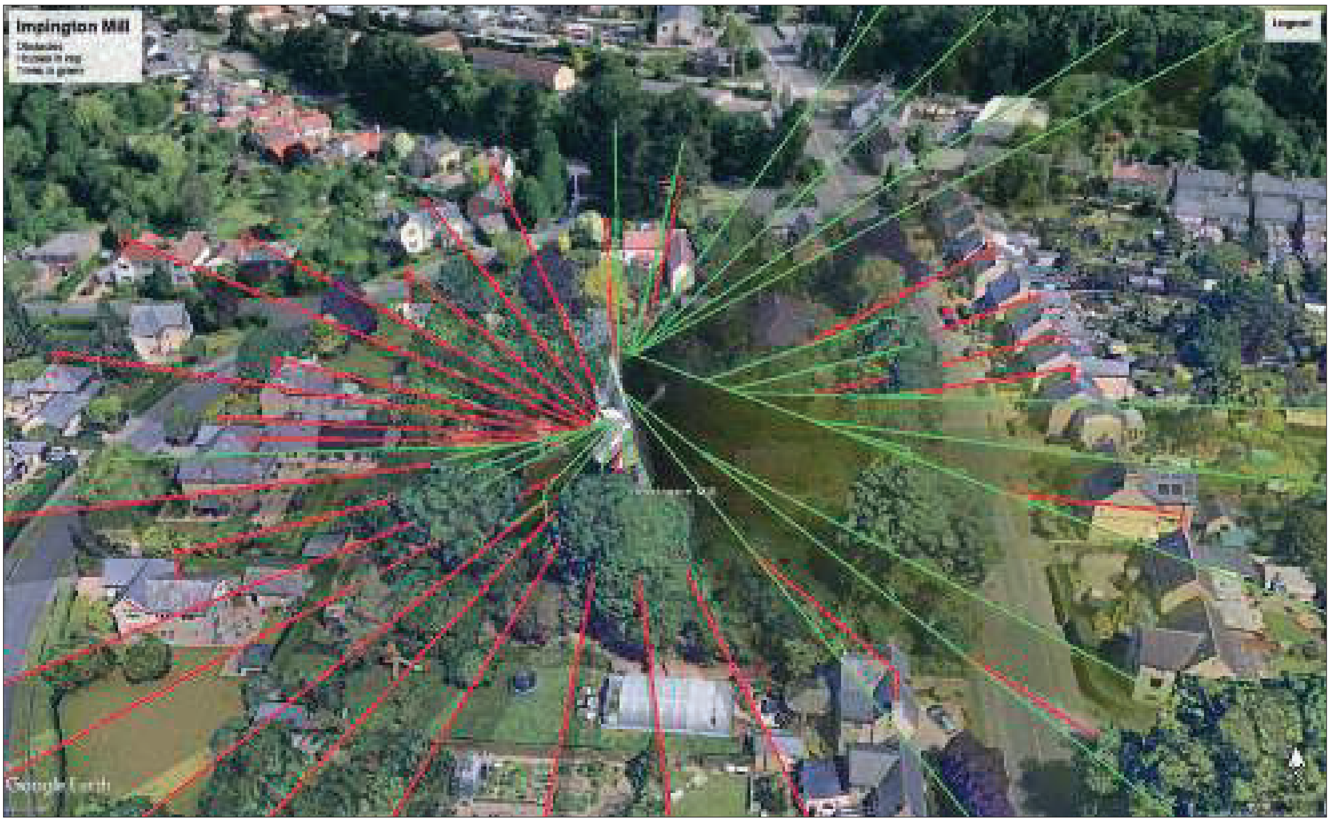

Fig. 8. Obstacle rose for Impington Mill derived from Google Earth.

been seen for this type of prediction. It is reasonable to assume, therefore, that it is much more reliable than the techniques typically used by would be developers. Its basic assumptions appear to work well.

We conclude that:

The Molenbiotoop can be used to transpose a wind rose from a nearby meteorological station to a windmill, taking into account the obstacles round the mill. It can be used to predict the additional loss that would be caused by a new development, expressing that loss as a percentage of the currently available milling time.

Foster's Mill and beyond

I have also gathered data from Foster's Mill at Swaffham Prior. At the time of writing, the results are similar but not so conclusive. At Impington, I was able to measure heights of obstacles directly from Google Earth, but this data is not available at Swaffham. Instead, I measured from photographs and this is neither straightforward nor is it giving consistent answers, so that developing tools to do this is a work in progress.

I also plan to take measurements at both Impington and Foster's during the winter months to see how much difference this makes and to provide a winter calibration for trees. This should give a firm basis for setting the Molenbiotoop parameters to account for a variety of situations and thereby give authoritative values for prediction of harm to a listed building.

I plan to place articles such as this one in architects and planners/conservationists magazines.

Acknowledgements

- This venture was made possible by the SPAB's acquisition of an anemometer system.
- The magnetometer was developed by John Lewis.
- The wind roses were provided by Iowa State University.
- The Molenbiotoop calculation is supplied by De Hollandsche Molen.

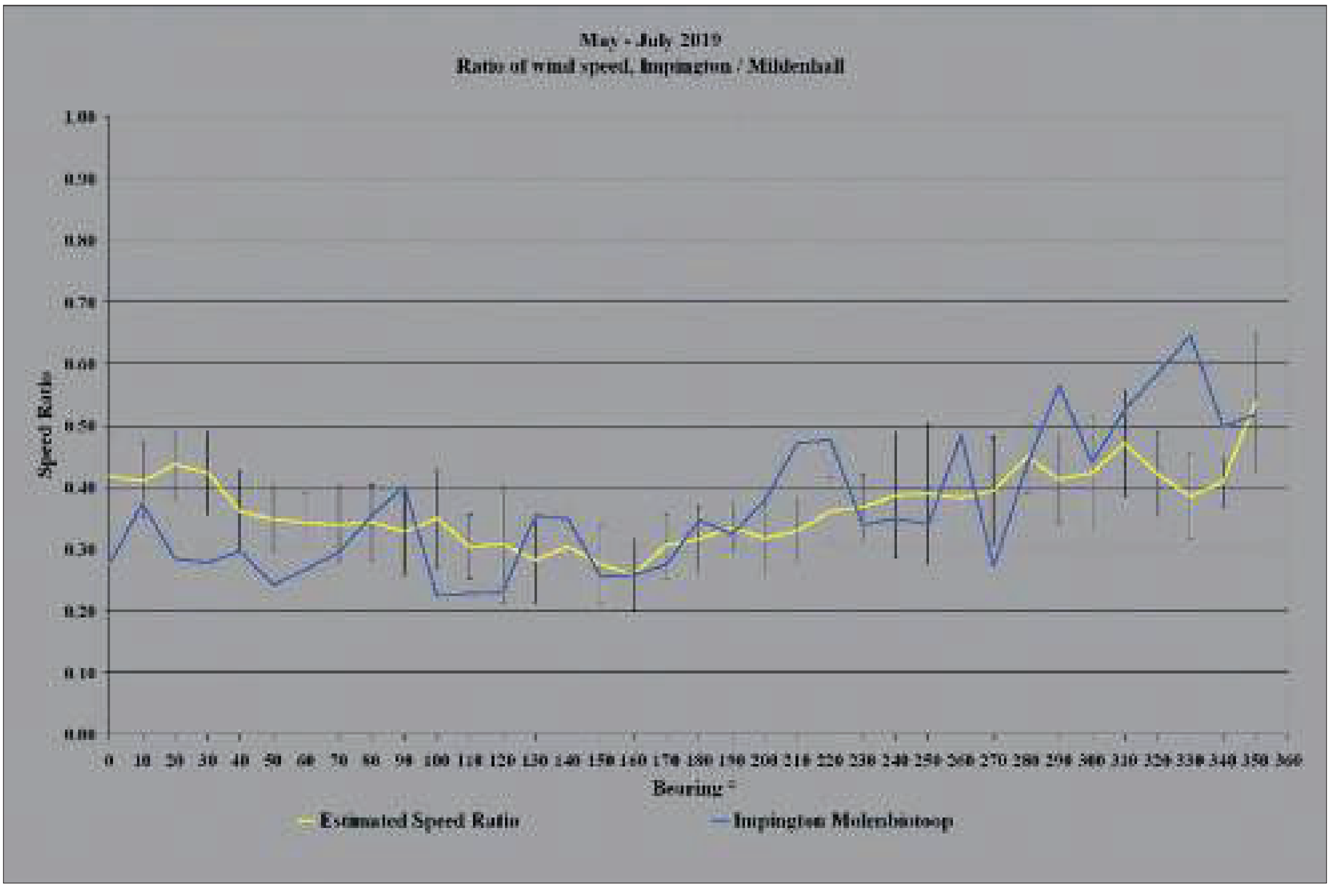

Fig. 9. Comparison of measured and calculated speed ratios for Impington Mill.