

The results contained in this report should only be read in the context of the Proven Energy product that featured in the QinetiQ radar cross section measurement trial during March 2007. QinetiQ are able to offer similar trials for other wind turbine manufacturers on request.

Technical Memo: Proven Turbine RCS Study

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1.1 Introduction

QinetiQ have measured the radar cross section (RCS) of the Proven WT2500 wind turbine, kindly donated by Proven Energy Ltd. The turbine is attached to an 11 metre tower and is pictured in Figure 1.



Figure 1 The Proven wind turbine measured at the QinetiQ measurement range

1.2 RCS defined

An object exposed to an electromagnetic wave, such as that from a radar, disperses incident¹ energy in all directions. The distribution of the energy depends on the size, shape and composition of the object as well as the waveform and direction of arrival of the incident wave. The distribution of the energy is called 'scattering'. The energy scattered back to the source of the wave constitutes the radar echo of the object. The RCS of an object describes the intensity of this echo. [1][2]

The RCS is a measurement of the ability of an object (in this case, the Proven turbine) to reflect electromagnetic energy.

1.3 Method

Measurement of the Proven turbine was undertaken at the QinetiQ Funtington RCS measurement range. The turbine was located at a range of 250 metres from the calibrated instrumentation radar. The data recorded included the time, amplitude, in-phase and quadrature data (raw radar data, also known as IQ). The bi-static RCS antennas used to gather the measurements are pictured in Figure 2. The radar was calibrated by first measuring and recording the response of a 0.7 metre side length trihedral corner reflector before the turbine was winched into location.

¹ Energy that strikes the object directly, before reflection, absorption etc.
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Figure 2 Images of the bi-static RCS antenna

The radar was positioned at a bearing of 292 degrees from the turbine, placing it almost west of the turbine. Measurements were taken at sampling rates of 0.5, 1, 2, 5 and 10kHz. However, a sampling rate of 5 kHz, meaning a measurement was taken every 0.2ms, was sufficient to capture the features of the turbine. The wind conditions in which the measurements were taken were opportunistic and as a result the measurements recorded were in predominantly westerly with some north westerly and south westerly conditions. To reduce the effects of ground reflections, fences were positioned appropriately within the range. This stops the effects of multipath² impacting on the measurements. Figure 3 illustrates the fences used to control the measurements. The fences meant that the bottom 6 metres of the tower were screened from the radar.



Figure 3 Fences used to reduce interference from reflections

1.4 Analysis

The RCS measurements obtained were analysed by plotting the RCS profile and extracting the peak RCS measurement in each case. The corresponding wind conditions were noted. A range of peak RCS measurements were attained, which varied according to the orientation of the turbine and, therefore, the surface area of the turbine visible to the radar. Three RCS profiles, illustrating a single rotation of the turbine, are given below. The peak RCS return is highlighted in each case and the variations in the RCS during the rotation are clearly visible. However, the impact of a turbine on radar is not just from the physical structure. The rotating blades cause a

² Reflections from the ground cause constructive and destructive interference giving regions called peaks and nulls respectively, where the beam effectively enhances or cancels itself out; this phenomenon is called multipath.

Doppler³ return to the radar, which is of interest as if the Doppler is sufficient, the radar will classify the return as one from a moving target. In order to get a complete picture of the impact of the Proven turbine the Doppler information derived from the data is also plotted.

1.4.1 Maximum RCS profile

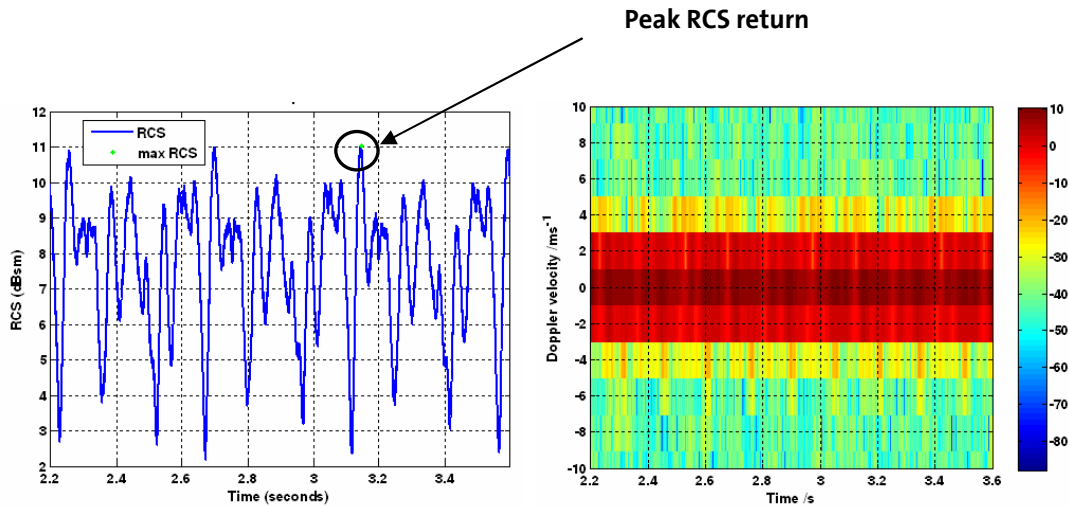


Figure 4 The RCS (left) and Doppler (right) profile for the maximum return from the Proven turbine

Figure 4 illustrates the RCS and Doppler profile that corresponds to the maximum RCS measurement obtained from the Proven turbine. The maximum RCS measurement recorded was 11 decibels⁴ relative to one square meter (dBsm) and was obtained in a westerly wind so the turbine was predominantly face on to the radar. A high RCS is expected in this position due to the large surface area of the blade that is visible to the radar. The variation in the RCS during a rotation can be caused by anything that prevents the electromagnetic energy being returned to the radar. This includes the blades obstructing the tower as plastic is not as reflective as metal or slight movements in the wind direction causing the turbine to no longer be directly face on to the radar. An 8dB variation in RCS can be seen in this profile.

In this example there is minimal Doppler visible, which is to be expected as the turbine is tangential to the radar. In this position, i.e. face on to the radar, the turbine appears static to the radar. A radar with a moving target indicator (MTI) filter should be able to remove these static returns.

³ Doppler is the change in the apparent frequency of the received electromagnetic radiation due to the motion of the target.

⁴ Decibel is a logarithmic unit of measurement used in order to visualise data covering many orders of magnitude. Decibels must always be expressed in terms of a ratio. See Appendix A. QINETIQ/D&TS/SEA/TN0705207/2.0

1.4.2 Average RCS profile

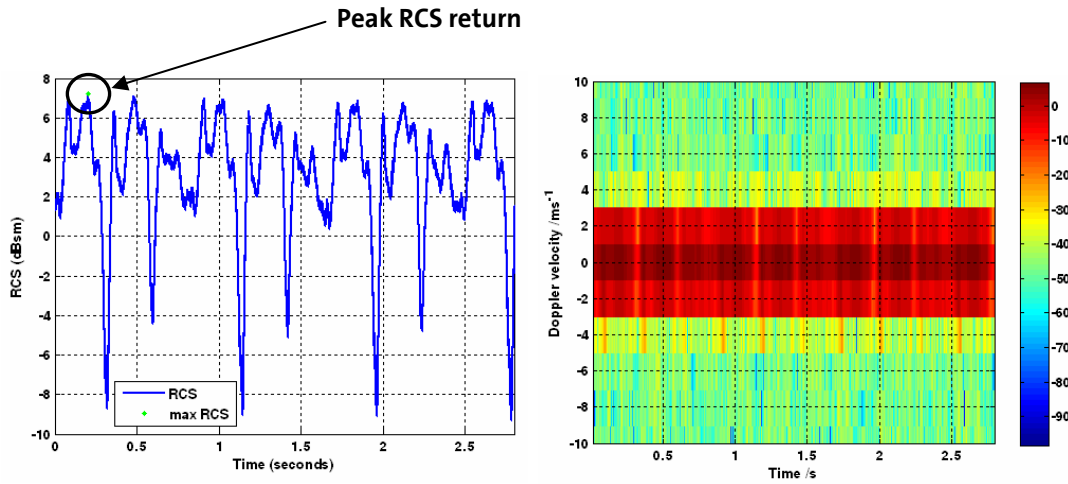


Figure 5 The RCS (left) and Doppler (right) profile for an average return from the Proven turbine

Figure 5 illustrates the RCS and Doppler profile that corresponds to an average RCS measurement of the Proven turbine. The peak RCS measurement recorded in this case was 7dBsm. This was also obtained in a westerly wind. The variation in the profile follows a pattern comparable to that obtained in Figure 4, however, the troughs are now more extreme. The RCS here changes in places by as much as 12dB. This is likely to be an impact of the wind conditions. Any rotation of the turbine will cause the radar energy to be scattered further from the radar reducing the intensity of the echo and, therefore, the RCS. This is illustrated in Figure 6. Again, in this case, very little Doppler is visible.

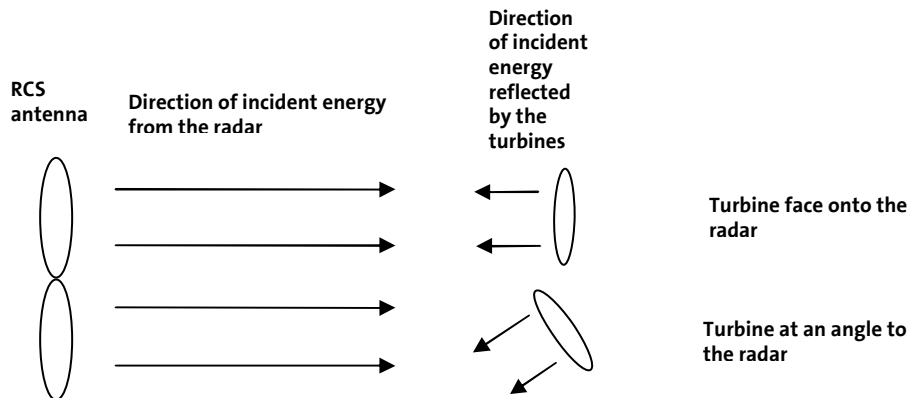


Figure 6 Illustration of the impact of the rotation of the turbine on the incident energy

1.4.3 Minimum RCS profile

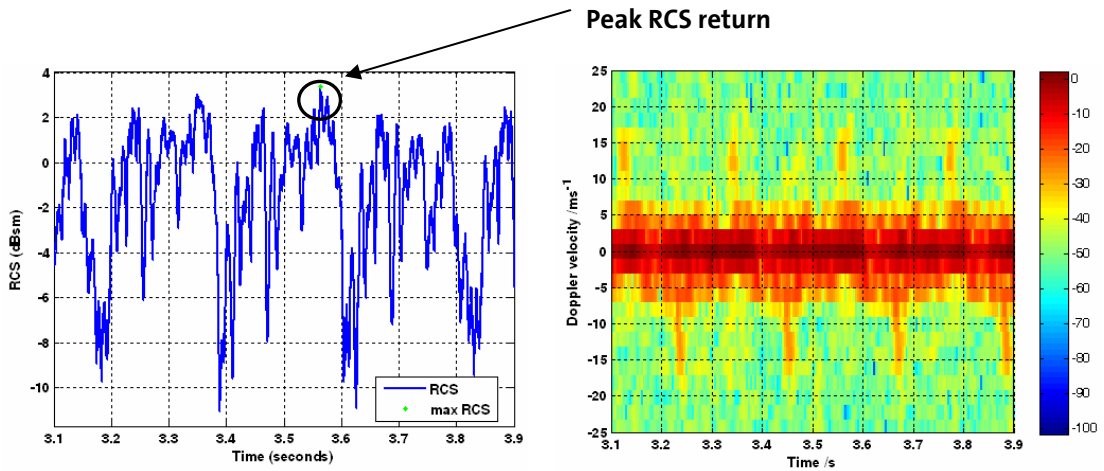


Figure 7 The RCS (left) and Doppler (right) profile for the minimum return from the Proven turbine

Figure 7 illustrates the RCS and Doppler profile that corresponds to the lowest RCS measurement recorded from the Proven turbine. The peak RCS measurement of this profile was recorded at 3dBsm. This was obtained in a west south westerly wind so the face of the turbine was angled away (less than 45 degrees) from the radar. This highlights the impact of the rotation of the turbine on the amount of energy that will be returned to the radar. Doppler returns from the blades of up to 15m/s are detected. The RCS associated with the blades is approximately -25dBsm and such small returns are unlikely to be detected by the radar.

1.5 Doppler returns

Figure 8 gives the Doppler profile corresponding to the maximum Doppler recorded for the Proven turbine. The maximum Doppler recorded was approximately 150m/s. This return was produced by the blades but the corresponding RCS is small, approximately -25dBsm, and so is unlikely to be detected.

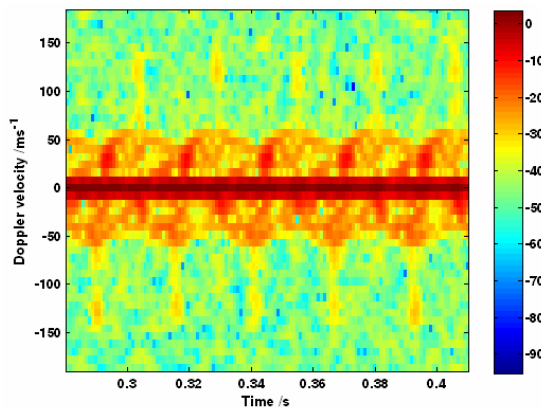


Figure 8 Maximum Doppler profile of the Proven turbine

There is a stronger RCS return (approximately -5dBsm) from a moving element of the turbine reaching approximately 50m/s, which is in line with the RCS return of the

static parts. This is believed to be from the metallic plate to which the blades are attached.

1.6 Summary

The calibrated RCS data was analysed and the peak RCS measurements from the Proven turbine ranged from a minimum of 3dBsm, when the face of the turbine was at an angle (less than 45 degrees) to the radar, to a maximum of 11dBsm when the turbine was face onto the radar. The average RCS measured was 7dBsm. The maximum RCS of the Proven turbine is comparable with that of a cabin cruiser.

Table 1 shows how the RCS of the proven turbine compares with examples of a micro and maxi wind turbine.

Turbine	Maximum RCS (dBsm)	Minimum RCS (dBsm)
Maxi, e.g. Enercon E-66	33	20
Mini, e.g. Proven	11	-25
Micro, e.g. Peak Generator	5.8	-30

Table 1 Table of RCS values for three different sizes of wind turbine

A maximum Doppler return of 150m/s was recorded when the turbine was angled to the radar but the corresponding RCS (-25dBsm) is small enough not to be detected by the radar. Also the maximum RCS return of 11dBsm was predominantly the result of the static component and so could be filtered out by any radar with an MTI (speed) filter.

1.7 Acknowledgments

QinetiQ would like to thank Proven Energy Ltd. for supplying a turbine to allow the turbine RCS to be measured.

1.8 References

[1] Skolnik, M., *Radar Handbook Second Edition*, McGraw-Hill Inc. , 1990

[2] Knott, E.F., et al, *Radar Cross Section Second Edition*, Artech House, Inc., Portland House – Stag Place, London, 1993

A RCS log to linear conversion table

Included below is a look up table showing RCS conversion from dBsm to m² this is based on the following equations.

$$10 \text{ Log}_{10}(\text{RCSm}^2) = \text{RCSdBsm}$$

$$\text{RCSm}^2 = 10^{(\text{RCSdBsm}/10)}$$

RCS (dBsm)	RCS (m ²)
30	1000
20	100
17	50
14	25
10	10
7	5
3	2
0	1
-3	0.5
-6	0.25
-10	0.1
-13	0.05
-20	0.01

Table 2 Logarithmic RCS to linear RCS conversion table