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Assessment of Likely Effects on Marine Radar Close to the Proposed Nantucket Sound Offshore Wind Farm

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For

CAPE WIND ASSOCIATES LLC

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Assessment of Likely Effects on Marine Radar close to and within the Proposed Nantucket Sound Offshore Wind Farm

Prepared for: **CAPE WIND ASSOCIATES LLC**

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EXECUTIVE SUMMARY

This assessment takes the observations of effects on marine radar in the Kentish Flats offshore wind farm in the Thames Estuary of the United Kingdom and applies them to the proposed Nantucket Sound Offshore Wind farm in Massachusetts. The Kentish Flats observations were obtained during a project specific investigation of the effects and used real observations taken aboard vessels entering and leaving the Thames en-route to ports such as London and Medway.

Early in the Kentish Flats project it was noted that the wind farm array returned a strong target but the fact that different vessels in the trials experienced widely varying effects should make it obvious to the experienced observers that the strong target is only a factor in the effects. Other causes were therefore sought and found, most being due to construction features of the vessels involved. Others were due to constructional features of other vessels in the near vicinity that provided strong reflecting surfaces.

Comparisons between the vessels identified in the ESS Revised Navigational Risk Assessment for Cape Wind Associates – the developers of the Nantucket project – and the vessels passing the Kentish Flats showed that most, if not all of the vessels and small craft operating in the Nantucket Sound area have equivalents in the Thames Estuary that have been investigated for the Kentish Flats radar project. Similarly, the Kentish Flats and Nantucket Sound offshore wind farms have similarities that are known to contribute to the effects witnessed in the UK study. It therefore follows that predictions can be made of the effects in Nantucket based on the UK experiences.

This assessment identifies the vehicle ferries as the most likely to experience the more prominent effects on radar but being significantly smaller and less rectangular in their designs than similar vessels in UK waters this is not certain. It is likely that effects will be proportionately less on the US vessels for reasons directly relating to their size and the style of the designs of their antenna installations although one ferry does possess characteristics of antenna disposition that could produce interference but this is likely to be extremely limited.

It is also predicted that small craft in and around the wind farm, will experience similar effects to those of their counterparts in UK with which they share similarities in key features of design in relation to antennas and surrounding structure.

The overall conclusion of the assessment is that like the UK study, effects that cause any concern to mariners will be few. Those that do stimulate additional mariner concentration can be mitigated by operational procedures, in very much the same way as they would if caused by a cause other than a wind farm.

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It is understood by European mariners navigating in their vicinity that wind farms, when constructed in matrix arrays such a Kentish Flats and Nantucket Sound can return higher than usual strength radar signals and these can in turn create responses in automated radar equipment on board vessels. These automated systems however are able to be overridden and the mitigation for such responses is for the operator to intervene, which can be done provided that the operator is alerted to the possibilities. Such alerts are routinely promulgated on other navigational anomalies via notices to mariners and more immediately and permanently, notations on the printed (or electronic) chart.

There are a number of perceptions often held by concerned parties with regard to the impact of a proposed wind farm on marine radar. The findings of the Kentish Flats trials used in this assessment of the Nantucket Sound wind farm provide facts that are contrary to these perceptions.

1 INTRODUCTION

The potential for the proposed Nantucket Sound wind farm structures to affect marine radar systems has been raised by the United States Authorities as part of the consents process for establishing the facility. Marine & Risk Consultants Limited (MARICO Marine) has been commissioned by Cape Wind Associates LLC to carry out an assessment of the likely effects that the proposed wind farm in Nantucket Sound may have on the marine communications and/or navigation systems of vessels operating in the area.

To undertake this task, MARICO Marine has used the findings of research work carried out on the effects of existing offshore wind farms on marine radars in UK waters from 2005 to early 2007. The research most referred to in this report however will be that of various trials and observations made in an around the Kentish Flats Wind Farm in the Thames Estuary of the United Kingdom in 2006. The quality of the evidence is governed by the conditions experienced at the time, which in all cases quoted were free of external effects other than those being observed or identified in the findings.

This study aims to produce validated simulations from trials carried out at the Kentish Flats Wind Farm that when they were carried out were current evidence, which matches a specific quality category defined in the UK Department of Trade and Industry (DTI) Guidance on such assessments[1]. In a scale of acceptable evidence listed in that document "current situation" is defined as its best category. Based on

[1] DTI GUIDANCE ON THE ASSESSMENT OF THE IMPACT OF OFFSHORE WIND FARMS: Methodology for Assessing the Marine Navigational Safety Risks of Offshore Wind farms. (UK)Department of Trade and Industry. www.dti.gov.uk/DTI/Pub 8145/0.5k/12/05/NP. URN 05/1948

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this criterion the source material for this assessment is considered to be of the best quality.

2 PROJECT SCOPE AND OBJECTIVES

2.1 Study Aims

The study aims to make a project specific assessment predicting and producing samples of the effects of the proposed Nantucket Sound Offshore Wind Farm on ship, fishing vessel and yacht radars and electronic navigation and communication systems with (but not exclusively) special focus on the regularly used routes linking the harbours in Nantucket, Martha's Vineyard and the Cape Cod, Massachusetts mainland, which surround the site.

2.2 Data Source

This project uses firm data from the direct monitoring of vessels' radar installations recorded onboard a variety of vessel types, including bulk carriers, tankers, gas carriers, RoRo ferries, dry cargo ships, fishing and recreational vessels, operating in the area of the existing Kentish Flats offshore wind farm. Analysis of this data has allowed Marico Marine to gain a deeper understanding of effects present in the vicinity of wind farms and their causes sufficient to form a realistic assessment of the likely interference that may be seen on marine radar displays at the Nantucket location.

Data in the Nantucket Sound area were derived directly from the ESS Navigation Risk Assessment for the project and supported by information provided by a local ferry captain who, additional to his ferry experience, has long standing experience of navigating in the area in various types of locally trading vessels. Further information has been gleaned by the writers in visiting the area and key vessels in the study. Internet sites for the ferry companies and localities around the Nantucket Sound were also consulted and these provided further verification in relation to the vessel types to be expected and areas subject to navigation by those vessels.

2.3 The Assessment

The assessment is based on the plans of the proposed wind farm to be sited on Horseshoe Shoal in Nantucket Sound provided by Cape Wind, copies of which are included in **Section 6** below. Communication and electronic navigation systems were used by vessels taking part in the study, which provided opportunities to assess their performance.

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The format used is to provide samples of effects recorded on vessel's radar displays from our previous work followed by the prediction of that effect for the proposed Nantucket Sound wind farm.

The assessment predicts and produces samples of expected effects that the proposed Nantucket Sound wind farm may have on vessels' radars in the routes joining Nantucket, Martha's Vineyard and the Cape Cod, Massachusetts mainland.

MARICO Marine carried out the required assessment as a study using their in-house database of the effects of wind farms structures on shipboard marine radars. In the original research in the Thames Estuary the following potential effects were investigated:

1. Linear reflections in several sectors;
2. Sector distortions;
3. Mirror images – signals reflected from ship's structures;
4. Intermittent detection of targets through a wind farm;
5. Radial distortions;
6. Shadowing behind wind farm WTGs;

The research showed that these effects were generated by factors both onboard and external to the vessels being studied.

During the research the following ship radar equipment types were observed:

- Type approved marine radar X-Band (3 cm wavelength)
- Type approved marine radar S-Band (10 cm wavelength)
- Non type approved marine radar X-band (Leisure Craft and Fishing Vessels)

The same radar types were assumed in this assessment.

There are similarities in layout and design between the proposed Nantucket Sound and Kentish Flats Wind Farms where the research was carried out. Distances off and aspects of vessels proceeding along routes adjacent to the wind farm were observed as similar in both locations and it is therefore with confidence that the predictions are made.

Of the vessels expected in Nantucket Sound the most regular that may experience effects on their radars consist of Roll on Roll off (RoRo), passenger and high speed ferries. Fishing vessels and yachts - both power and sail – are the other prominent grouping of vessels using the waters. Other vessel types do occasionally transit the waters but because of limited depth of water these are likely to be smaller versions of similar vessels in the Thames. Cruise vessels and small cargo vessels and tankers are included in this group and they are discussed later in the report but because they are all likely to be categories that revealed very few effects in the study detailed predictions of those effects are not incorporated. A variety of vessel types are included in the analysis of the recorded trials for the benefit of those reading the report to grasp the true influences on radars. This may help in planning future vessel designs so as to avoid some of the effects recorded in the UK.

Whilst no high speed craft were studied in the Thames Estuary trials the layout of the radars on these vessels is very conventional and we are confident that they will experience similar effects to the larger displacement craft. Where they differ may be in the mitigation they may need to invoke in order to compensate for their higher speeds of interception of other craft but this will almost certainly already be part of the operating practices aboard such vessels if they operate to procedures similar to or derived from the IMO High Speed Code[2].

[2] High Speed Craft (HSC) Code. Available from IMO Publications. Because of copyright restrictions the code cannot be reproduced in this document.

3 THE UK EXPERIENCE

When the first UK offshore wind farm was completed at North Hoyle[3], off the north coast of Wales, practical tests on marine radar and communications were undertaken. The report on these[4] was published in November 2004 and indicated that the most significant potential effects were those on marine radar systems. As a result the UK Maritime and Coastguard Agency refined its guidance to developers on assessing marine navigational safety risks and its requirements concerning marine communications, navigation and radar systems[5].

At a national meeting, in September 2005, the British Wind Energy Association (BWEA) proposed[6] the setting up of a working group to:

"…build on the research that has been undertaken, both in the UK and abroad, in order to clarify the extent of the problem; consider a range of possible practical and technological solutions; and develop a set of principles that could be employed when navigating around a wind farm"

This group, comprising BWEA, UK Maritime & Coast Guard Agency (MCA), Port of London Authority (PLA) and UK Department for Transport representatives drew up general specifications[7] for trials to be undertaken, and in February 2006 Marine & Risk Consultants Ltd (MARICO Marine) were contracted by BWEA to carry out the research. The report on the work was issued in February 2007 and is downloadable from the BWEA website[8]

The recordings were made between April and June 2006 in the area of the Kentish Flats wind farm to the south of the Princes Channel in the Thames Estuary.

The research project was designed to obtain detailed data on the reported effects observed on ship's radar displays close to offshore wind farm structures. Information and data collection included:

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[3] *The first offshore wind farm in the UK was at North Hoyle and comprised 30 two megawatt WTGs located about 7 km off the north Wales coast. The 67 metre high towers are located in about 11 metres of water and are spaced 350 metres apart in north south direction and 800 metres apart in the east west direction. The 80 metre rotor diameter gives the structures a total height of 107 metres above mean high water.*

[4] *"Results of the electromagnetic investigations and assessments of marine radar, communications and positioning systems undertaken at the North Hoyle wind farm by QinetiQ and the Maritime and Coastguard Agency"* MCA MNA 53/10/366 or QINETIQ/03/00297/1.1 November 2004

[5] *Proposed UK Offshore Renewable Energy Installations (OREI) – Guidance on Navigational Safety Issues"* MGN 275: Marine Guidance Note 275(M) Maritime and Coastguard Agency, August 2004

[6] *"Proposal from BWEA for a Working Group"* 3rd NOREL WP 8 , Shipping Policy, Department for Transport, September 2005

[7] "*Offshore Wind Farm Effects on Marine Radar and their Mitigation" Paper submitted by the Radar Working Group to NOREL , Shipping Policy, Department for Transport*

[8] BWEA website link :www.bwea.com/pdf/BWEA_Radar.pdf/.

- Collecting sets of radar recordings taken from a wide range of vessels with various type approved and non-approved radar types, including representative fishing and recreational vessels;
- Recording information gained by discussion with the Pilots, Masters, Pilot Exemption Certificate (PEC) Holders and Navigating Officers onboard the ships;
- Using the MARICO Marine survey vessel "MORVEN" in conjunction with some of the observed voyages to provide a controlled small target around and within the wind farm.
- Collecting data from the Port of London Authority (PLA) London Vessel Traffic Services (VTS); and
- Personal comments from Pilots, mariners and observers.

3.1 Observers

Observers used consisted of experienced Master Mariners and Vessel Traffic Service (VTS) qualified officers who boarded vessels at berth, or at the Pilot Station with the Pilot, to record by video and still photography the vessel's radar display(s) in use. Other relevant data and observations were also recorded.

Information and related experiences of the effects on radar from conversations and interviews were recorded by MARICO staff throughout the period of the study.

3.2 Terminology

Terminology used in the report derives extensively from that used by mariners, but is translated where necessary to language more universally used. The term WTG (Wind Turbine Generator) is used to include the tower, nacelle and blades of conventional wind WTG. The blades during observations were variously turning or static. No significant difference was detected on the marine radars in use between the two modes. This is not unexpected because the blades are constructed largely of composite fibres that are relatively opaque to static radar as used in the marine environment. Radars using doppler shift to detect motion such as are used in defence and aviation radars may detect the WTGs differently but the subject of this assessment is the marine radar.

English maritime terminology and spelling has been used throughout and has been checked for commonality with the US equivalents.

The term "Mariners" has been broadly used in this report to include Masters, Pilots, Boat Skippers, Pilot Exemption Certificate (PEC) holders (usually masters and senior deck officers of commercial vessels), VTS staff, Harbour Masters and other experienced senior marine personnel. It is fair to assume that this captures a variety of active seagoing experience in a capacity of a navigating officer or equivalent.

3.3 Peer Group Assessment

The report and information recorded was assessed by an independent Peer Group from a wide range of Maritime stakeholders, including:

Department for Environment, Food & Rural Affairs	Royal Yachting Association
Department for Transport	Shell Wind
DONG Energy Ltd	Stena Line
DTI – UK Department of Trade & Industry	Terma Radar Systems
MCA -Maritime and Coastguard Agency	The British Chamber of Shipping
Npower Renewables	The Scottish Executive
National Federation of Fisherman's Organisations	The Crown Estates
Nautilus UK (NUMAST) I(Seagoing officers' trade union)	Trinity House Lighthouse Authority
PLA - Port of London Authority	UK Major Ports Group
Quarry Products Association	UK Offshore Operators Association
Renewable Energy Systems Ltd	Westminster Dredging Company
RNLI - Royal National Lifeboat Institution	

3.4 Ship's Radar - Background

Radar has changed little in more than sixty years of use on merchant ships. However, recent introductions of technology have changed the display. The more traditional monochrome analogue device inside a hood was usable by only a single operator in daylight. At night it was open and viewable by more than one. The more modern display features a digital flat screen in colour that not only makes the display usable by more than a single user, but also enhances the effects displayed so as to improve the navigator's ability to interpret the picture. The picture itself however is still fundamentally represented in the same way. It provides a plan view of the area around the ship as though the operator were viewing from above, in a similar way to that of a chart.

The display contains certain standard items that include:

- Heading Marker: indicating the ship's heading or direction of the bow (not the direction of travel as this is subject to drift due to wind and current effects). The heading marker must be displayed at all times by international regulation;
- Range Rings: these concentric rings are subject to the display range selected (3, 6, 12 miles etc) but will mark the screen at rounded values such as 0.5, 1 or 2 miles from the centre of the display. Range rings are permitted to be turned off but many navigators choose to keep then on as a ready point reference for ranging targets;
- Electronic Bearing Line (EBL): indicating a direction of bearing from the observer. It can look like a heading marker and on some radars care should be taken not to confuse the two. The bearing marker is not required to be switched on except when required and many navigators prefer to use it then switch it off, to prevent the above confusion; and

- Variable Range Marker (VRM); indicating range of any selected target from the ship. The VRM describes a line at a radius from the centre corresponding to the range of the target being measured. The range is then displayed separately in a section of the screen, or in older radars on the dial used to operate it. Like the EBL, the VRM is an optional feature that is not required to be switched on all of the time. Many navigators prefer to keep it switched off except when in use.

The most common form of display selected is with north at the top and the ship's bow indicated as a line corresponding to her gyro compass heading. This presentation is popular with foreign-going mariners as it equates to the navigation chart and in modern integrated systems can be combined with it. Other types of presentation however were encountered, the most common of which was "ship's head up". This tends to be more popular with smaller craft and inshore mariners (such as pilots) as it equates to the immediate visual perspective.

In the trials the observers experienced all types of radars, some of them very old but still performing efficiently. Many variations on radar installation quality were experienced, most of them in relation to antenna siting. Most of the images produced later in the report are included to illustrate anomalies in radar display. However, about one third of the vessels that took part in the trials at Kentish Flats wind farm did not experience any adverse effects on their radar displays, which should suggest that interference is ship specific and not as dependent on the wind farm as sometimes purported. A good quality radar display is shown below that is typical of this - see **Figure 3.1**.

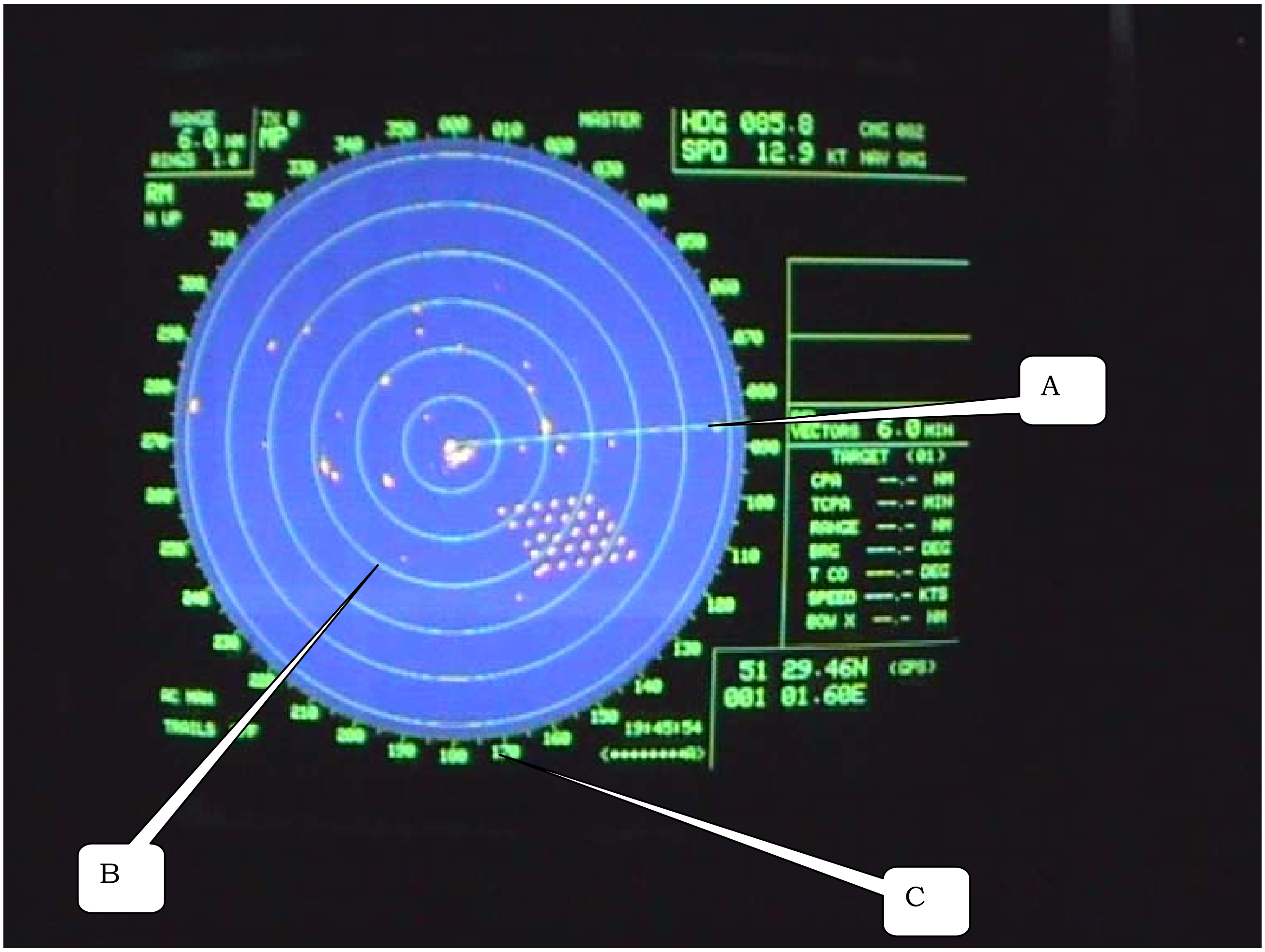

Figure 3.1: Conventional Radar Display

The radar screen in **Figure 3.1** shows a display that is relatively clear of any anomalies, thus proving that interference from wind farms is selective and subject more to features within the design of the vessel than external influences. In the picture the ship's heading marker is labelled **'A'**. The six concentric range rings are 1 mile apart with the 3 mile range ring labelled **'B'**. The screen is surrounded by a graduated scale showing the full 360 degree compass **'C'** from which the ship's heading can be checked. It is possible to offset the picture, in which case the outside scale reverts to being a reference to the chart to which it can be related. In this report there are examples shown that feature offset displays.

The display above was recorded on a passenger vessel that was fitted with radars in a traditional configuration in which two antennae were positioned on a central mast in such a way as to be well clear of each other. The mast and other possible obstructions were themselves of a "raked" design featuring a slope, which deflected any possible reflected radar beams up and away from the antenna. Ironically, this feature is unlikely to have been designed for the benefit of radar observers. It is more likely that it is an aesthetic feature in which the passengers are persuaded that the vessel is fast and sleek (despite, in this case being fairly elderly). See **Figure 3.2**.

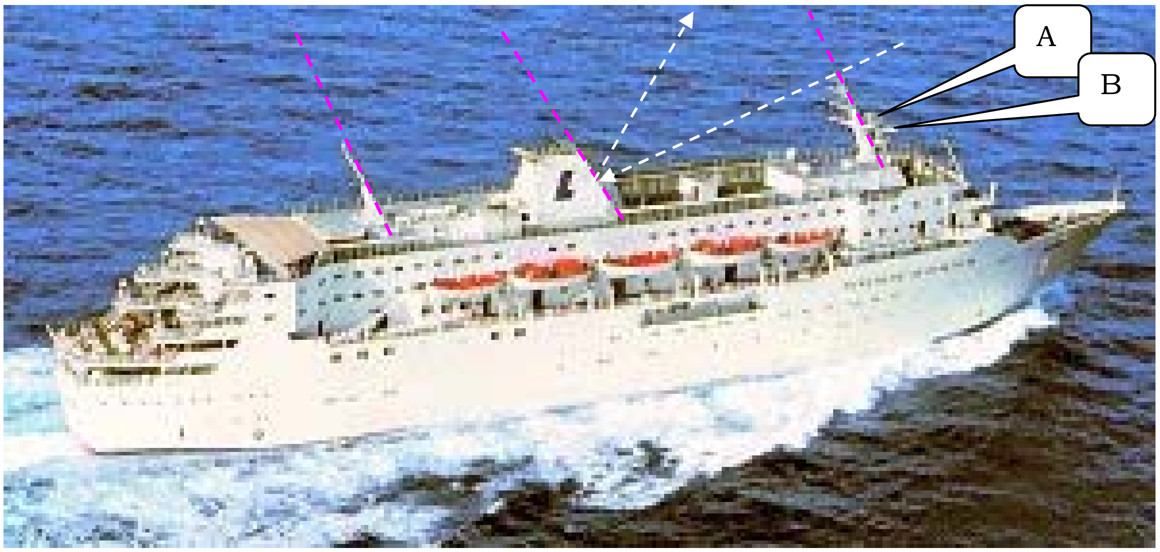

Figure 3.2: Passenger vessel with optimally installed radars

In **Figure 3.2** the dashed magenta lines indicate the "rake" angle of the masts and other obstructions. The rake ensures that incoming radar beams are not reflected by the obstructing surfaces to cause spurious effects on the display. The white dashed arrows are inserted to illustrate the effect if an incoming radar beam were to intercept the funnel. The incoming signals are redirected upwards and away from the antennae. The same would be true of all the raked structures. The radar Antennae **'A'** and **'B'** are positioned on the centre line of the vessel with no obstructions except those directly astern but, as can be seen from the example in **Figure 3.1**, they did not cause a reflection problem. The two antennae are also well separated vertically.

It is noted that most of the ferries operating in the Nantucket Sound area possess similar qualities of antenna layout.

The radar displays of a third of the vessels taking part in the Kentish Flats trials exhibited similar clear pictures as they passed the wind farm.

4 LARGE VESSEL RADAR EFFECTS

4.1 Introduction

This assessment of the likely effects of the proposed wind farm on ship's radar is based on the MARICO Marine observation of 53 vessels of various types including some vessels on both inward and outward passages while passing the Kentish Flats wind farm. The Kentish Flats wind farm is situated in the Thames Estuary and possesses similar characteristics to the Nantucket Sound site; both in wind farm layout and in proximity to vessel traffic flows. The principal difference being that one of the traffic flows at Nantucket Sound passes between the site and the coast. However, observations made in the Thames Estuary from commercial vessels are

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representative of similar aspects and ranges that will be encountered in the Nantucket Sound area.

During trials in the Thames Estuary, phenomena on ship's radar screens induced by large structures were evident on some but not all vessels' radar displays. About one third of vessels experienced no unwanted effects at all (see **Figure 3.1**) although caution should still be exercised in relation to automated automatic gain control suppression that can lead, in more extreme and unmanaged cases to obliteration of small targets.

It became quickly evident during the trials that when interference did occur there was usually more than one effect being observed. The pattern of these effects varied and the observers investigated their causes onboard the ships as they were noted. From the many observations made a pattern emerged that can be applied in other locations.

Evidence of onboard influences for the observed effects on many of the vessels emphasised the fact that the wind farm structures were but one of a number of strong radar targets in the area capable of generating effects on the radar displays. The wind farm however was prominent on the radar screens because of its geometrically regular form and it therefore alerted a number of interested parties to the phenomena that are described below. It was possible to separate different sources of observed effects and gain a better understanding of the causes of each element of interference observed.

Unexpectedly, soon after the beginning of the trials it became evident that the effects caused by factors onboard the ships were proving to be more significant than those caused by factors outside the vessels. The observers found that many of the vessels were fitted with radar antennae whose position with respect to onboard structures gave rise to reflected (or secondary) echoes. This inevitably has been labelled as interference from any large targets producing strong radar echoes such as wind farms, which in strict terms is only part of the issue. The fact that different vessels in the trials experienced widely varying effects should make it obvious that the strong target is only a factor in the effects. Shipboard specific factors must also be in existence to cause the variation.

The modern practice of mounting the two radar antennae low and athwartships[9], although expedient for structural purposes in reducing vibration at the antennae, appears to have ensured an increase in target reflections, shadow sectors and other unwanted effects on radar displays. In more traditionally fitted vessels with Antennae mounted on the ship's centreline, shadow sectors and reflections were still sometimes evident but these were in sectors right astern and thus less intrusive on the navigator's radar view. Masters would also consider the sector right astern to be a

[9] *Athwartships = in line with the transverse axis across the vessel*

much lower threat than any other by virtue of the fact that the observing vessel would inevitably be heading away from the threat.

The tendency of many modern ship designs with lighter constructed and more flexible structures has been to move away from optimized positions for radar antennae in relation to operation. Instead the policy appears to have been towards positioning where the structure has least vibration, itself a major negative mechanical influence on antenna turning unit performance. Vessels built in this way will be in service for many years to come. However, it was found during trials that mariners have learnt the characteristics of the new arrangements and operate vessels successfully despite an increase in anomalous propagation.

The observers very quickly recognised that they were actually viewing radar phenomena with which they were familiar, having been taught about them and identifying them during their radar training (required, at various levels, for all commercial and naval navigators as part of their professional competence certification). However, the strength of the radar signals returned from the geometrically repetitive wind farm WTGs was found to create effects that, when wind farms were a new development, would have been less familiar to radar observers. They were not used to navigating near or between wind farms. During trials it was noted that a very strong return signal could be guaranteed from multiple row arrays such as that of Kentish Flats – strong enough to warrant a possible warning on charts or similar media for navigators in relation to the effect, particularly on modern radars with automated suppression.

Observations on signal strength returns from wind farms have been the subject of the reports produced by QinetiQ, the UK Maritime and Coastguard Agency[10] and the Port of London Authority[11]. As in those reports, it was found that there was some ability to improve the visual detection of small targets hidden in spurious echoes on the radar display where it was appropriate, by manually but carefully reducing the gain.

Throughout the research work, the Spaniard Buoy, which presented a small target beyond the Kentish Flats wind farm, was used as a reference when operators were adjusting the radar settings. Providing the Spaniard Buoy, which is fitted with a radar reflector, could still be seen, the operator was confident that the settings had not been reduced too far to cause smaller targets of equivalent reflecting qualities outside the wind farm to be lost to the radar display.

[10] *Results of the electromagnetic investigations and assessments of marine radar, communications and positioning systems undertaken at the North Hoyle wind farm by QinetiQ and the Maritime and Coastguard Agency" MCA MNA 53/10/366 or QINETIQ/03/00297/1.1 November 2004*

[11] *A Report compiled by the Port of London Authority based on experience of the Kentish Flats Wind Farm Development. 2nd NOREL WP4, Shipping Policy, Department for Transport, March 2005*

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Those effects caused by the presence of the wind farm were also accentuated by the very regular interceptions with large “slab sided” vessels such as vehicle carriers and some RoRo vessels at relatively short range. The spurious echo types described below were identified.

4.2 Effects Generated by Structures onboard Ships

Our research has shown clearly that onboard vessels of the study, structures that were sited within the radar beam caused a number of effects to appear on radar displays. Examples of these effects are given below. How these may occur at the proposed wind farm at Nantucket Sound will be covered in section 7.

4.2.1 Linear or Small Sector Multiple Targets: Principles

This category of interference was familiar to the observers but not in open waters to the extent experienced during the Kentish Flats radar trials. The effect is primarily due to surfaces from intercepting structures reflecting incoming radar beams into the antenna as it aligned with those structures. As the antenna aligns with the structure the transmitted beam deflects it to another sector. Round surfaces are particularly able to do this such that the deflected beam may be intercepting targets in sectors that are largely separated from the direction of the antenna. As a consequence targets on either side of the vessel will come into view, particularly if like wind farm arrays, they are able to return a strong echo. The echo beam is also “seen” by the radar in the same sector as the structure reflecting it. If the surface is round the reflected sector will be extended in very much the same way as a visual image is extended by a convex mirror. Targets that would otherwise be but a dot on the screen will thus become extended on either side. This is known as beam width extension and is one of the concerns of coastguards relating to identifying small targets close to WTGs.

Sometimes the reflected beam would also be affected by “side lobe” interference, i.e. that part of a radar antenna’s transmitted power that escapes on either side of the dominant beam. All antennae have this effect to a greater or lesser extent. It is therefore one with which mariners are familiar and they therefore tend to interpret the radar picture with confidence, making allowances for such imperfections.

Tubular structures, such as stanchions or masts were a common cause of reflection. Plane surfaces were also but the significance of these will be discussed in the section referring to “mirror images” **(4.2.8).** The reflecting properties for radar of tubular structures are similar to those of light and if a polished tube is viewed it will be seen to reflect a vertical bar of light when viewed from any direction. The same is true for radar, which is similar to light, differing only in its place in the electromagnetic spectrum.

4.2.2 Linear or Small Sector Multiple Targets: Internal Reflectors.

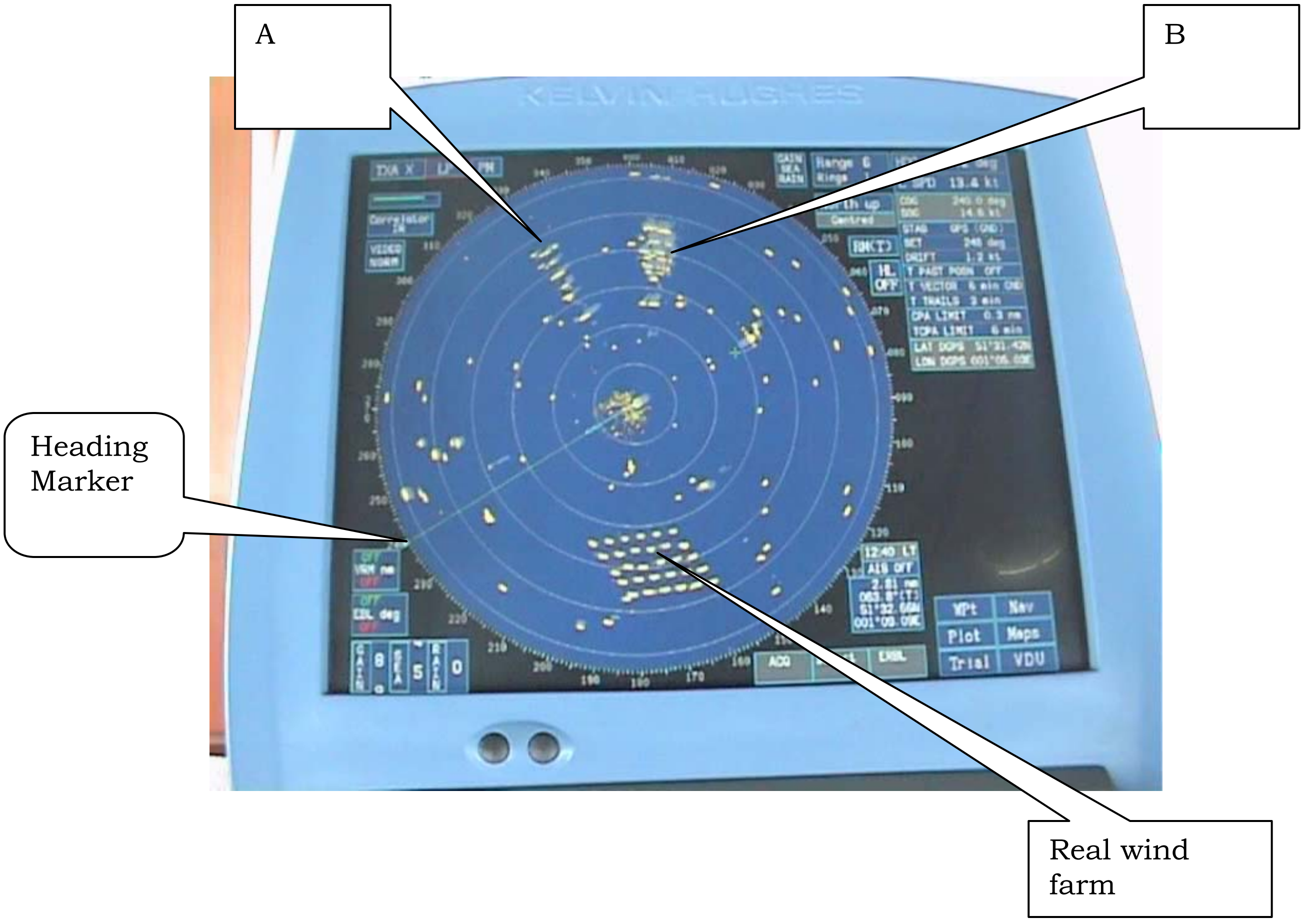

Figure 4.1: Examples of Reflected Targets

In **Figure 4.1** the vessel is heading from Northeast to Southwest. The radar in use and producing the screen of Figure 5.1 is the port radar located to port and forward of the signal mast. The antenna is just visible the left of the picture in Figure 4.2. Labels refer as follows:

A: This linear reflection appears related to the wind farm as suggested by the spacings between the multiple echoes. Its origin is from a round stanchion to starboard on which the other radar antenna is positioned ("a" in Figure 4.2). The reflection is more linear than "B" because the stanchion is smaller in diameter than the mast causing "B".

B: This linear reflection is distorted by beam width extensions caused by "side lobe" effects from the antenna but also by the larger diameter mast forming the reflector. It is thus providing a distorted "mirror" image of the wind farm. The specific cause of the reflection however is the signal mast ("b" in Figure 4.2), in this case abaft and to starboard of the observing radar. The reflection remains static in relation to the display, which identifies it as a shipboard source of

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interference; (if it were caused from an external source the reflection would move radially in relation to the observer vessel see **4.2.3**). The reflection is a distorted "mirror" reflection due to the larger circumference of the reflecting surface (the signal mast) that forms a larger radius convex reflector.

See photo in **Figure 4.2** below. (The direction of the wind farm would be from "a1" and "b1")

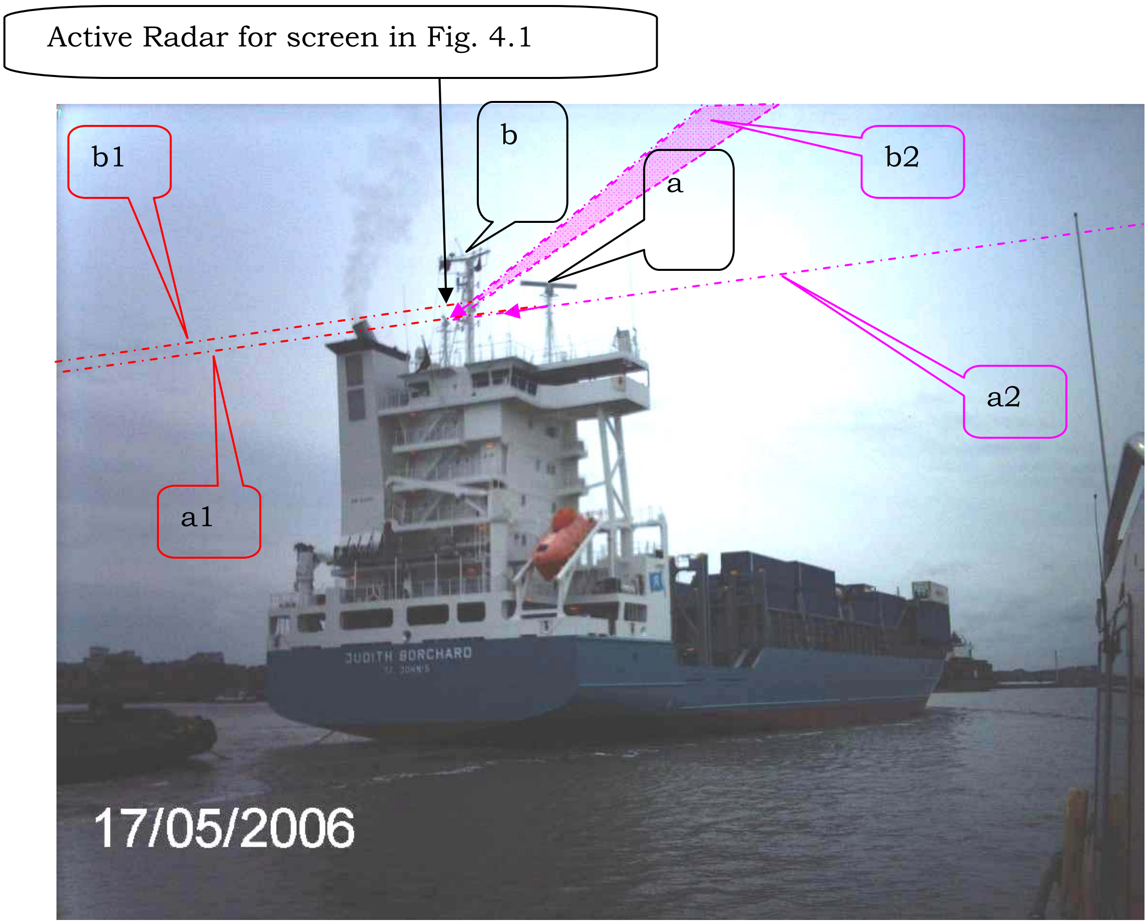

Figure 4.2: Reflected Targets. Reflecting obstructions

Stanchion for starboard radar (a) is to starboard and abeam of port radar – the active radar in Figure 4.1 causing reflections from the incoming beam a1 to appear along the bearing line a2.

Signal mast (b) is abaft and to starboard of the active radar causing reflections from the incoming beam b1 to appear along the bearing line b2.

Linear reflections or small sector multiple target effects create the illusion of targets in the direction of the obstruction (lines "a2" for the other radar stanchion and small sector "b2" for the signal mast in **Figure 4.2**). These reflections occurred in more than one direction in many vessels but the ranges of the false echoes was always coincidental with the range of the WTGs or whatever was the source target being reflected (other targets were also reflected but because they lacked the repetition associated with wind farm arrays they were less detectable). The geometric regularity evident in many of the targets suggests multiple echoes[12] but closer analysis in the area of the wind farm showed that each such target was a reflection of a separate real target, this was evident up to six nautical miles (nm) and beyond. Six nm was the range of radar mostly commonly used in the trials (e.g. **Figure 4.2**) until in close proximity when three nm was used. Some twelve nm range observations were also made and these again showed similar characteristics to the lower range observations except that the effects occupied far less of the available space on the display.

4.2.3 Linear or Small Sector Multiple Targets: External Fixed Reflectors.

Reflections are also possible from structures beyond the vessel's own boundaries. The method of discerning between them is in the behaviour of the effects caused. Those from within the vessel stay static in relation to the display, whilst those from outside move radially around the centre of the display in conjunction with the object causing the reflection. The effects can be generated from other vessels in the vicinity or from structures such as towers and offshore installations.

Wind farms provide a multitude of reflecting structures and it was observed during the Kentish Flats trials that certain phenomena were commonplace although the distinction of their presence was more obvious during replay of video recordings than it was at the time. This was due to the transience of the effects, the speed of which varied directly with the speed of progress through the array.

[12] Multiple echoes are a recognised phenomenon amongst radar observers. The cause is usually multiple rebounds of a radar beam between two substantial surfaces in close proximity to each other. Typically the effect is generated between the topsides of two high sided vessels passing fairly close and the most common occasion would be during an overtaking manoeuvre in a narrow channel.

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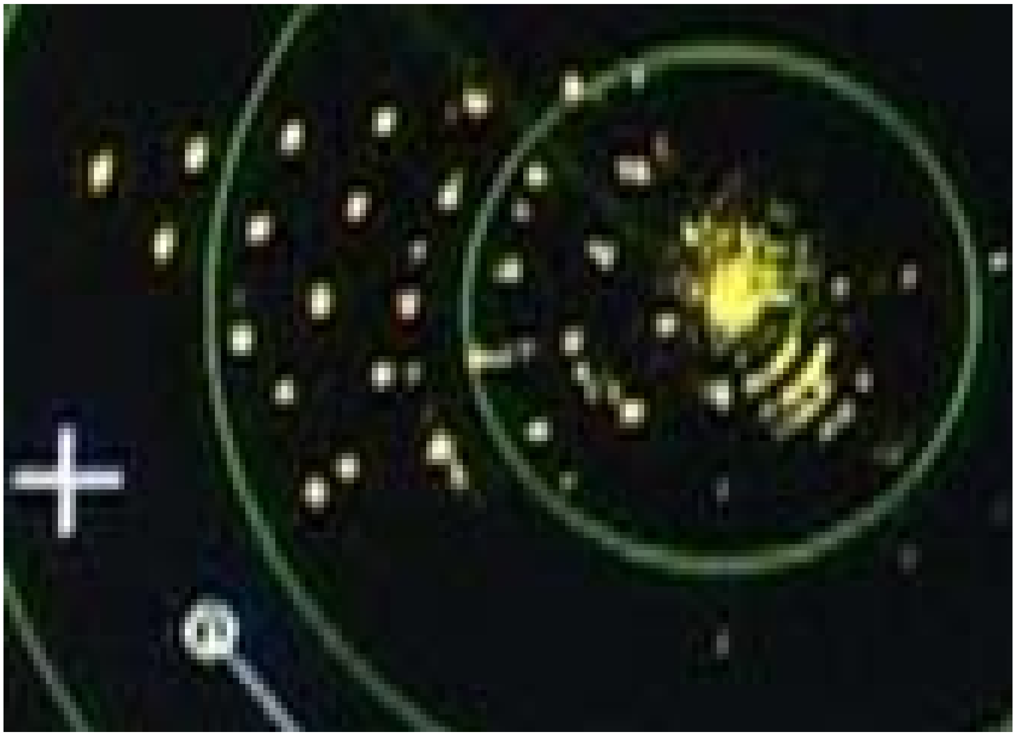

Figure 4.3: Reflected Targets: External reflecting obstructions

Figure 4.3 shows a photograph of a radar screen belonging to the survey vessel MORVEN during trials in the Kentish Flats wind farm. The vessel was moving through the array from south to north along a roughly north westerly course (the phasing of the video recording has suppressed the heading marker, because it moves more in relation to the rest of the display than do the range rings. The heading marker is often in a different position on subsequent scans and is consequently a less persistent image). The centre of the range rings depicts the position of the vessel and the heading marker is faintly visible, emerging north westerly from this point. The photograph is an extraction of a larger still of a video image, hence being slightly out of focus. Nevertheless the image illustrates the anomalous propagation that can typically be seen at any one time on a radar screen. The effects captured would have been fleeting at the time of observation; so much so that they are often not spotted by observers. With the benefit of replay however images can be frozen at critical stages and the effects viewed as above. It can be seen that the stronger targets coincide with the wind WTGs but between them there are a number of smaller targets. Some of these are "ghosts" i.e. they are reflections of other WTGs in the one being targeted at the moment of recording. Other small targets are small craft but it is impossible from the above still to determine those which are real and those which are not. **Figure 4.4** repeats the image but with annotations to explain what is being viewed.

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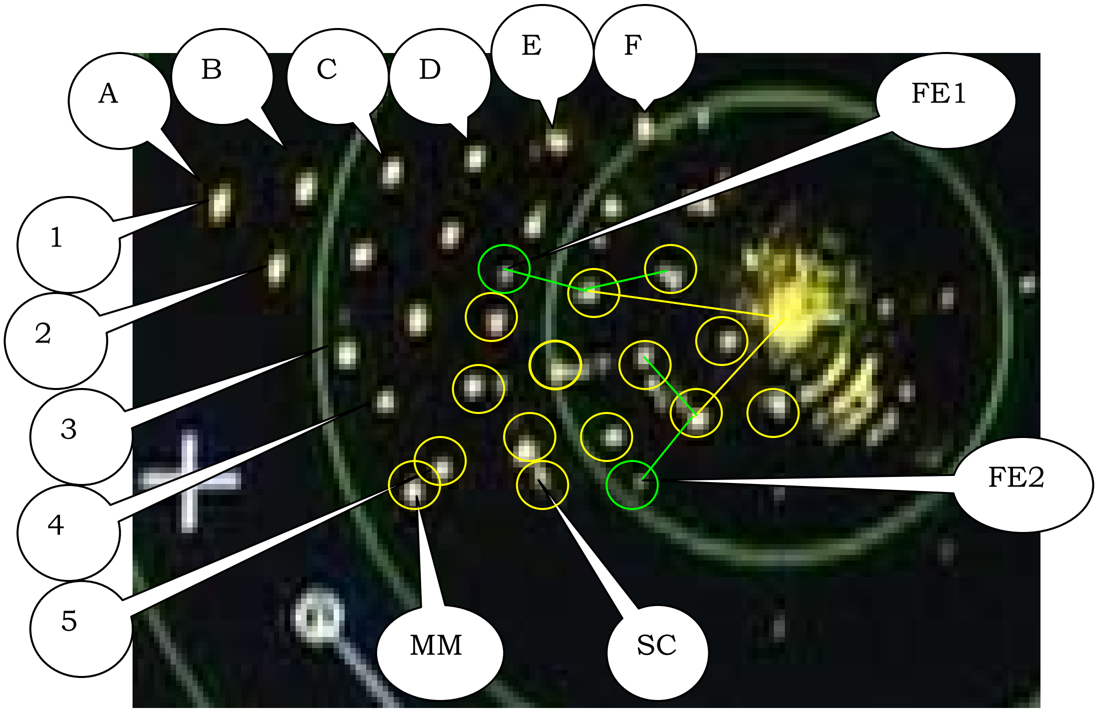

Figure 4.4: Reflected Targets: External reflecting obstructions

In **Figure 4.4** – a repeat of **figure 4.3** all yellow circled targets are true targets. All of the stronger targets except MM and SC are WTGs. Not all WTGs have been ringed so as to maintain a clearer picture. Those that have been ringed are in some way relevant to other targets or the reflected images ringed in green. WTGs are identified by Column (Alpha) and Row)(Numeric). The columns and rows are labelled at the top (north) and left (west) side.

FE1(ringed green) is a false target; reflection of E3 off D3. FE2 is a false target; reflection of D4 off D5 but almost in the shadow of D5. SC is a real target – the service craft at B5 and MM is also a real target – the Met. Mast. In still image the display looks confused but when moving the distinction is much clearer. The false targets appear and disappear as the observing vessel alters its position relative to the reflecting targets – in this case the WTGs - and the true targets remain constant. The exception might be a small craft like the service craft moving into the "shadow" immediately behind a WTG but it should be noted that because of attenuation the radar shadow is closer in than the visual one. Targets will remain visible on radar after they have entered the visual shadow. As with other effects however the shadow is transient. The obliteration of targets is neither widespread nor sustained.

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It should be noted that in the expanded image (hence softened focus) the observing vessel is proceeding on a Northwesterly (NW) course close to and almost parallel to the FOXTROT column of WTGs. Note the side lobe distortion astern, caused by the presence of the signal mast immediately astern of the radar antenna.

Apparent intermediate echoes (**Figure 4.3 and 4.4**) - i.e. echoes appearing on the display between the known targets of the WTGs - were at first thought to be attributable to WTGs further back into the wind farm and off-set from the line of the antenna. It became evident however that the most likely origin of the reflections was an immediate neighbour of the target WTG. The effects would become apparent in close proximity (one nm or less) to and within the wind farm. The conclusion that these echoes are reflections of near neighbours is derived from measurement between the true and false echoes. It is consistent that "false" echoes occur in line with or nearly in line with and behind a true echo[13]. The false echo however is a distance beyond the WTG tower that is equal to the WTG's distance from its nearest neighbour. This indicates that the false echo is in fact a reflection of the near neighbour from the surface of the targeted WTG. The phenomenon is a version of secondary echoes taught on the Radar Observer Course for Merchant Navy cadets and junior navigating officers.

Like many other phenomena identified during the Kentish Flats trials these effects were rapidly transient and often not identified by the observers at the time. Video replay allowed for an in-depth analysis time which is not usually available to on-the-scene operators. To establish whether or not this matters section 11, Experience of Navigators and Pilots has been included

4.2.4 Linear or Small Sector Multiple Targets: External Floating Reflectors.

An effect similar to that described in 4.2.3 was also observed. The effect was caused by reflections off other vessels that were themselves moving. An example is shown below where the reflector was an approaching vessel.

[13] "In line with" means in a line with any part of the reflecting surface apparent to the radar antenna. Close in to the WTG tower therefore this can be slightly off to one side as the offset surfaces are large enough to reveal reflected neighbouring WTGs. This is evident in Figure 5.2.4 where FE1 is fairly strong and off to the Northeastern side of the reflecting WTG (E3)

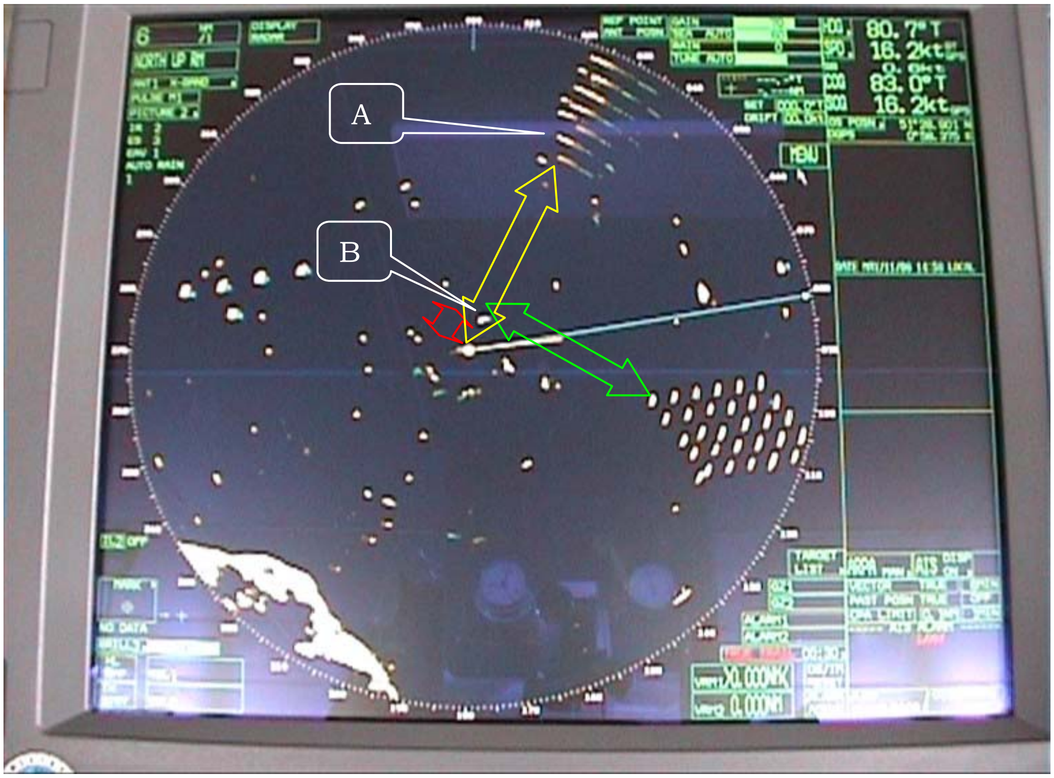
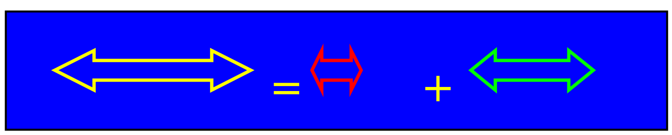


Figure 4.5: A large dredger using 3cm radar (port scanner)



The reflections **'A'** of the wind farm are caused by the approaching vessel **'B'** on the port bow. The distance off, indicated by the yellow arrow is the distance between the observing vessel and the reflecting vessel plus the distance between the reflecting vessel and the reflected target(s).

These effects were noted to be rotating around the reflecting vessel. The repeated arcs caused by the WTGs would have swept counter-clockwise through an arc beyond the reflecting vessel as it passed along the port side. This sweeping behaviour makes it obvious to the observer that the targets are spurious, even if the cause is not immediately apparent. The effect is more readily apparent than those described earlier due to the line of echoes – often distorted - that increases its visibility on the display but as with other phenomena its importance to the practising mariner needs

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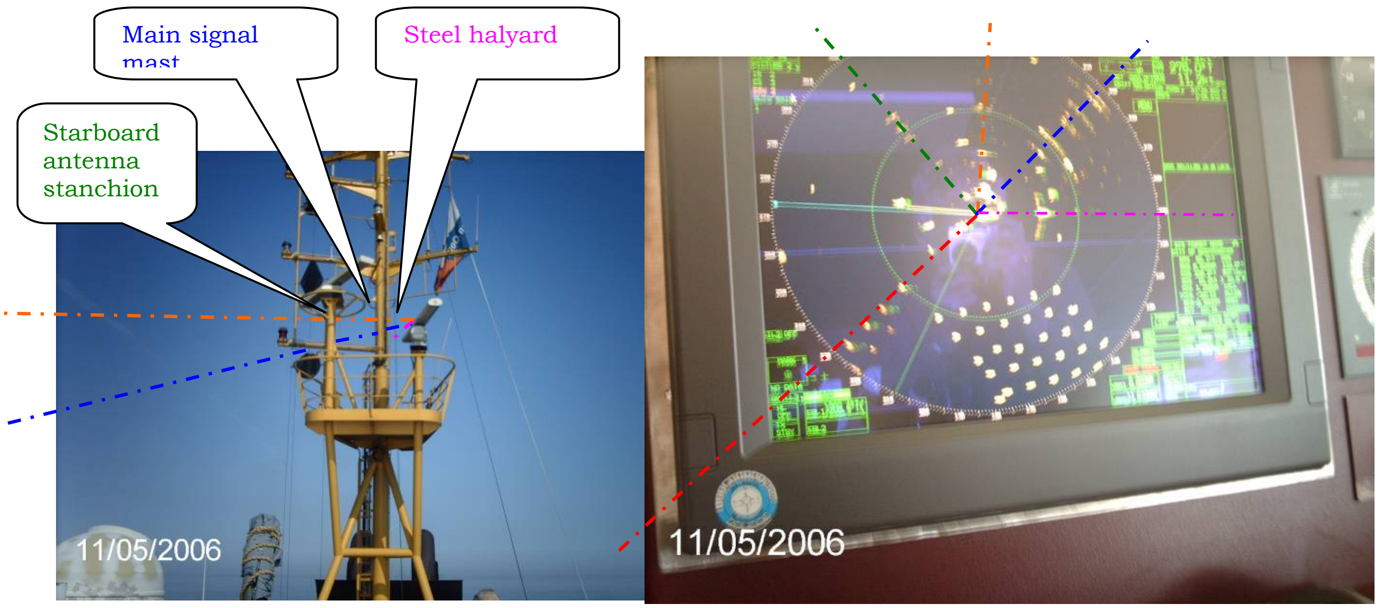
to be judged in relation to other activities at the time. This is discussed in the section on operational procedures.

4.2.5 Linear or Small Sector Multiple Targets: Observations

Depending on the efficiency of the radar antenna the number of spurious responses varied, but side lobe effects would also vary. Modern radar antennae are constructed such that the beam is produced by a line of emitters and the combination of multiple emissions produces a narrow beam. Side lobes are the residual emissions that do not combine with neighbouring emissions and as their name implies they emerge from the ends of the array of emitters. The result of this type of construction is that the longer the array – i.e. the longer the antenna – the larger the proportion of main (narrow) beam to side lobes. As expected smaller radar antennae of the type found on yachts, workboats and fishing craft produced more side lobes and greater distortion when combined with the multiple reflected targets. Some very small commercial craft were equipped with radars that were either yacht/fishing vessel radars (i.e. non-approved) or for reasons of operational restrictions their antennae were relatively short.

The pattern of interference was a sector, sometimes narrowing to a line of multiple targets aligned with and beyond the reflecting obstruction, irrespective of whether it was internal or external to the observing vessel. Depending on the antenna efficiency, side lobe echoes could also appear outside this narrow sector or line.

In every case the direction of each occurrence of linear targets was investigated onboard the vessel when detected. Obstructions onboard the vessels themselves were consistently found that aligned with the interference patterns observed. Frequently the obstructions were tubular sections of signal masts, aerial stanchions (often including the vessel's own second radar antenna when this was mounted higher than the subject antenna). In some cases exhaust uptakes, particularly from off-set funnels appeared to create the effect when they were sufficiently high.



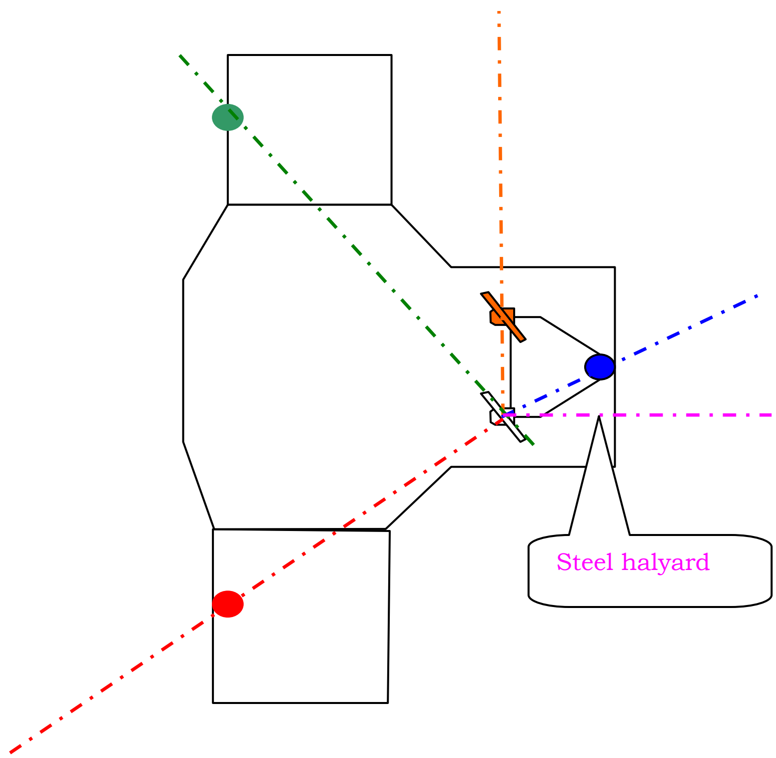


Figure 4.6. Linear reflections.

Above: Photograph of mast

Above right: Display

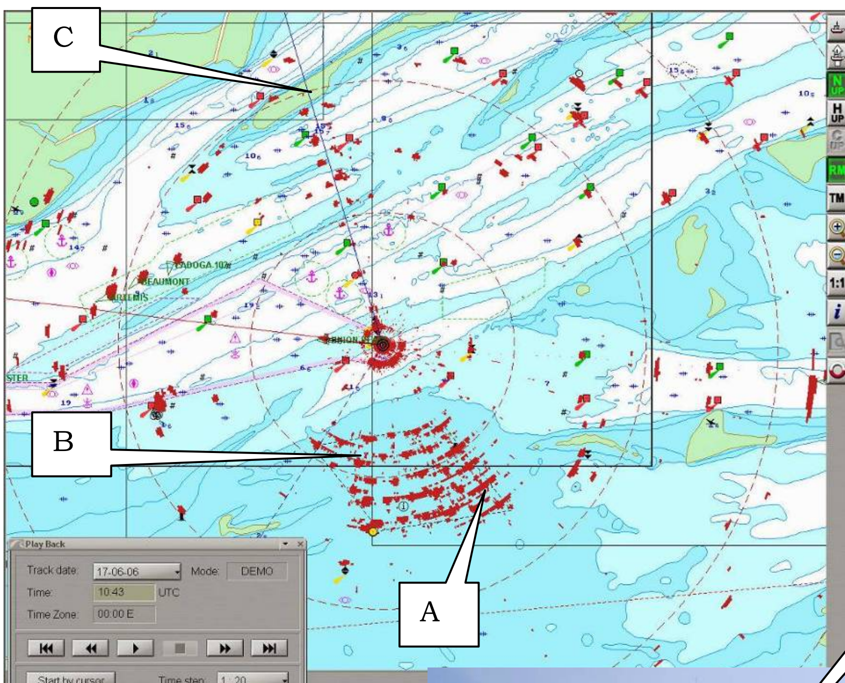
Right: Plan layout of antennae and masts

Depending on the width of the obstructions and their distance from the antenna, the width of any reflected target images was seen to vary in proportion. It was noted that stanchions as small as 50mm (2 inches) in diameter were consistently able to produce reflections of the WTG structures. In the case illustrated in **Figure 4.6** above, a dredger's port antenna was obstructed by the main signal mast, the starboard antenna stanchion, and two forward signal masts on either side of the bridge. Even the steel wire halyard on the port side of the signal mast was substantial enough to cause targets from astern to create targets with extended beam width due to the large proportion of side lobes captured by the close proximity of the halyard. The side lobes from the antenna were reflecting off the halyard wire and back into the antenna after it had swept past the target, hence the extended beam width. It was found during trials that whenever there were vertical or near vertical surfaces close to the antenna this effect was prevalent. If the surfaces were sufficiently sloped from the vertical the effect disappeared as the reflected signals were redirected away from the antenna (see also **Figure 3.2**).

4.2.6 Sectored Distortions: Principle

Introduction

The effect described here appears to be caused by the same influences as linear reflections, in that the sectors in which spurious echoes are noted correspond to the same directions and appear to be caused by the same obstructions. The effect however takes the form of a sector emanating from the centre of the screen. The distorted real targets are in a direction aligned with and beyond the obstruction.



A	Distortion
A1	Signal Mast
B	Distortion
B1	Stanchion
C	Reflection
D	3cm Scanner (in use)

Figure 4.6: View of Sectored Distortions

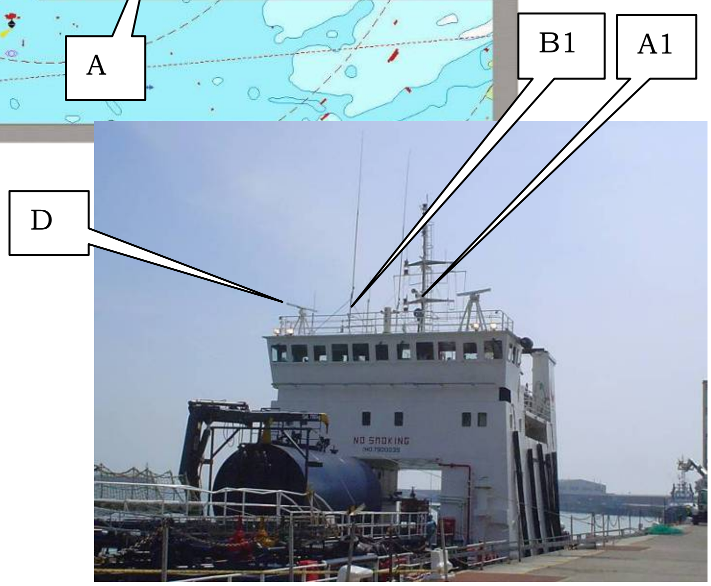


Figure 4.7: The Bunkering Tanker

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Shown in **Figure 4.6**, above, is the radar display image from a tanker headed slightly north of west and east bound for Coryton with her radar display overlaid on an electronic chart. The 3cm (starboard) Antenna **'D'** is in use. The narrow sector distortion **'A'** is due to signal mast **'A1'**, and **'B'** is due to forward central stanchion **'B1'**. **'C'** is a linear reflection from the Thames WWII Forts at Shivering Sands Forts, which are close to her starboard side. In the video recording, this reflection is seen to rotate in alignment with the Forts as they are passed. The same target is producing the effects that can be seen close to the ship in the southern sector.

Figure 4.8: Radar display of a dredger working in the Channel north of Kentish Flats

This dredger's radar display was particularly affected by spurious echoes caused by the many masts located around her bridge as well as having athwartships mounted radar Antennae. The line of distortions **'B'** is caused by the starboard Antenna stanchion (**Figure 4.9**) and the distortion line **'C'** is caused by a signal mast at the forward starboard bridge wing, which is outside the boundaries of the photograph to the left (starboard).

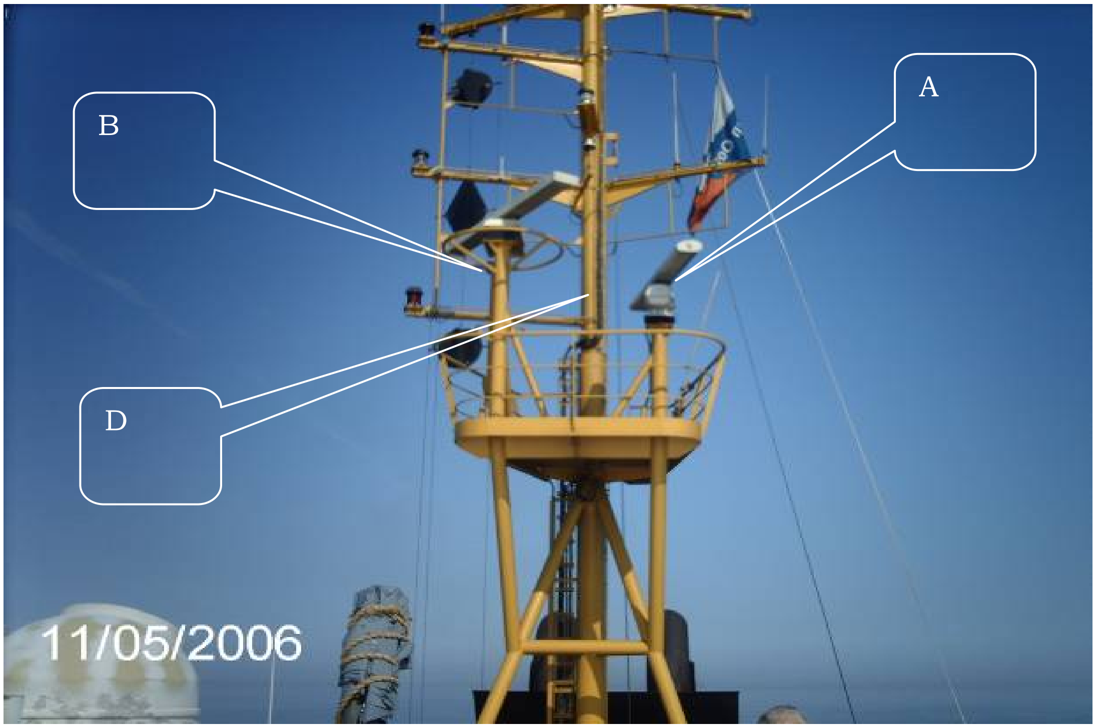

Figure 4.9: Dredger Antenna Installation

Viewing from ahead; the port side 3cm radar **'A'** is affected by obstruction **'B'**, the stanchion mounting of the 10cm radar Antenna located abeam[14] on the starboard side of a radar platform mounted on the mainmast **'D'**. The dredging signal mast **'C'** is out of view to the left of the photograph but is situated to starboard and forward of the Antenna.

The effects thus observed were seen to move across the radar display with the movement of the observing vessels, indicating that the reflector causing the effect was internal (onboard) that vessel. The target distortion was particularly noticeable in the wind farm as it could be seen to travel through the multiple targets provided by the WTGs. Undistorted targets were seen either side of the sector as it moved. The distortion took the form of width extension of the target, similar to the effects of beam width and side lobes and possibly combined with these. On investigating each occurrence, the observers noted that candidate obstructions were most often tubular sections of signal masts and aerial stanchions. Depending on the width of the obstructions and their distance from the Antenna, the width of any distorted target images would vary in proportion. A variation is seen above in the images from a bunkering tanker above in which the effects of close World War II forts appears similar in the static display to other linear reflections but in the video the effect is seen to be rapidly rotating around and centred on the forts in the opposite direction to the movement of the observing vessel. The external obstruction has the same

[14] "Abeam" = in the same line of direction across the vessel. In an "athwartships" direction

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reflective effect as the internal one, but it is transient depending on the speed at which the observing vessel is passing the reflecting object – in this case the forts.

4.2.7 Sectored Distortions: Predicted Radar Image at Nantucket Sound

This prediction is incorporated into **Figure 4.5** in Section 4.2.4 above, which is indicative of how, on some headings, reflection and distortion effects can become combined. The distortion is created by attenuation and other effects caused by the intrusion of an obstruction into the radar beam but the effects are imposed on targets beyond the obstructions, not reflected by them. The effects on the display however become superimposed, hence the grouping of effects in **Figure 4.5**, which is intended as a reasonable prediction of what the navigator would observe. The operator does not have the ability to selectively filter out the effects to their different causes.

4.2.8 Mirror Images

Introduction

Mirror images are generated by interceptions of radar waves with plane or nearly plane surfaces. These may occur either within the vessel's own boundaries such as plane surfaces of masts, funnels, gas risers or even as in one case encountered, the gearbox of the opposite radar that was housed in a rectangular box with a plane surface aligned with the opposite radar Antenna. **Figure 4.12** illustrates this type of reflection and the image generated on the radar screen. It is a simulation. The real image may appear slightly different depending on a number of factors such as the number and size of reflecting plane surfaces on the vessel concerned. Some vessels will have no surfaces, others may have more than one and some may not be obvious to the observer. For example, a gas riser may be forward of the bridge by a considerable distance. It may also be below the apparent line of the radar beam but it is known that where the differences in height are small, it is possible to generate mirror images in line with such surfaces.

4.2.9 Mirror Image Reflections: Principle

Spurious echoes were seen when a complete or nearly complete mirror image of the wind farm would appear in a sector of the display away from the direction of the wind farm. A number of examples were witnessed and prior to the Kentish Flats trials the team had also been shown photographs taken by Thames Pilots that depicted this phenomenon. Still photographs however do not distinguish the origin of the effect in the same way as the video footage. This report will inevitably use still photographs but description will be attached to distinguish the differing types of mirror image.

The effect is generated when a surface (on or off a vessel) large enough to create a "mirror" image, is positioned within the radar beam. (See also section on external effects below.) Depending on its size and/or distance from the Antenna, the image thus created could be a full or partial mirror image, i.e. it might be cut off within the extremes of the "target". The mirror effect – usually a sector of the screen - if generated within the vessel can be recognised by the way in which it moves directly with the observing vessel.

A representative example is shown in **Figures 4.10 and 4.11** below in which the effect was detected on a vessel participating in the radar study in the Thames Estuary.

Although the image is quite dramatic, it occurred in a sector of the radar display that was of less concern to the ship.

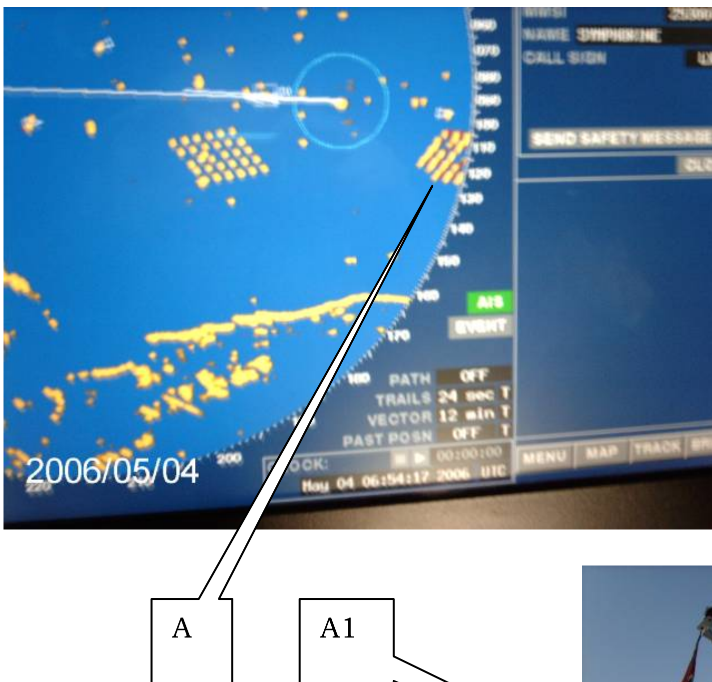

Figure 4.10: RoRo Vessel Radar Image

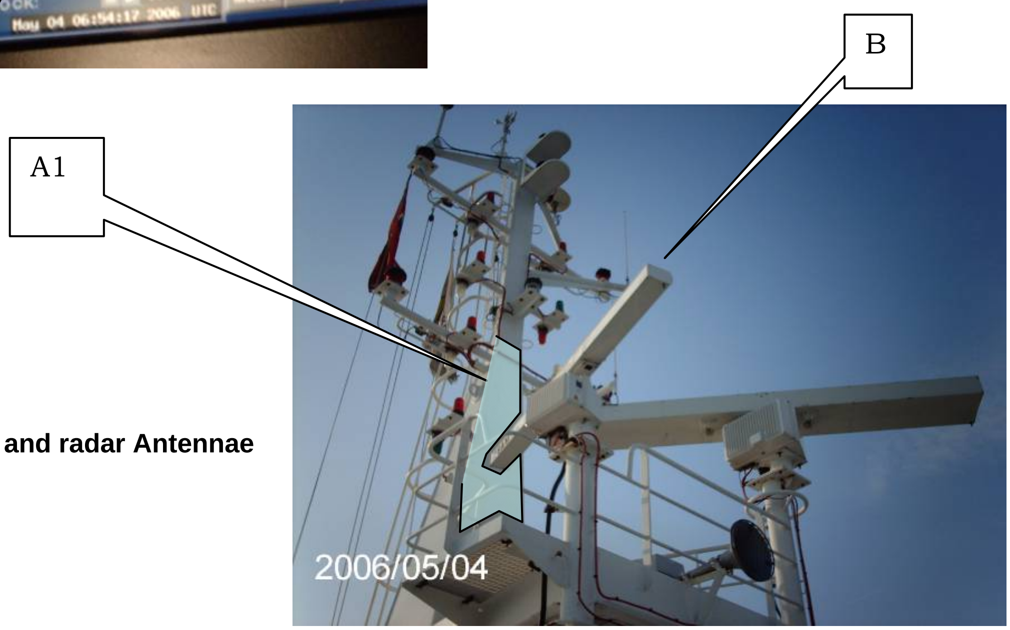

Figure 4.11: Layout of mast and radar Antennae

The mirror image **'A'** in **Figure 4.10** was found to be caused by the forward surface of the rectangular section signal mast shown as **'A1'** and shaded light blue in **Figure**

4.11. The mast was located abaft[15] and to port of the 3cm starboard side radar Antenna **'B'** (left of picture) from which the screen image is taken.

On this ship the mast would also generate mirror images of other strong radar targets but the wind farm was prominent due to its distinctive layout. Despite this the Master of the vessel did not have difficulty in using the radar as the effect was always displayed towards the stern. Other vessels with this unfortunate configuration would also experience a similar effect.

The significant properties of the typical mirror image from an "internal" surface are the likely partial and reversed image of the target – in this case the wind farm – in the direction of the reflecting surface. It is identifiable as an internal reflection if the sector remains fixed on the screen relative to the centre of the scan. The image moves across the fixed sector as though it were viewed through a "window". The direction of the movement of the image is not parallel to the vessel's course but is governed by the angle of reflection between the antenna and the reflecting surface – in this case the flat forward facing surface of the signal mast.

Precisely the same effect can be generated by "external" reflecting surfaces - those beyond the boundaries of the vessel such as other large slab sided vessels, dockside buildings or similar. Section 4.3 addresses this version of mirror images.

[15] "Abaft" = positioned aft of the subject item i.e. towards the stern of the vessel.

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4.2.10 Mirror Image Reflectors: Proving Experiment

As an experiment a version of the effect was generated within the confines of the observing survey vessel "MORVEN". The effect may be generated if a surface large enough to create a "mirror" is positioned within the radar beam. Depending on its size and/or distance from the Antenna, the image thus created could be a full or partial mirror image, i.e. it might be cut off within the extremes of the "target". Typical of surfaces identified thus were a rectangular section signal mast as shown in **Figure 4.11**.

Figure 4.12: Result of the mirroring experiment on survey vessel "MORVEN"

An experiment was conducted aboard "MORVEN" – the 20m long survey vessel operated by Marico Marine. The intention was to simulate a flat plate mast or other similar structure as shown in **Figure 4.11**. In the experiment a small wooden board (about 0.1 m^2 – approximately the size and proportions of a clipboard) was covered with aluminium foil, placed on a short pole and positioned within the radar beam at various positions around the vessel.

As above, the display clearly showed the mirror images **'A1'** and **'B1'** of both the wind farm **'A'** and the war time fort at "Shivering Sands" **'B'** respectively. A partial mirror image was seen to align with the board wherever it was positioned provided its

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attitude was such that a direct reflection could be obtained from the object targeted to the Antenna.

This was not intended as a strict scientific experiment but rather as an example of how even a small reflective surface, combined with a very strong radar target, could easily reproduce the mirror effect, especially if it is located close to the Antenna.

4.2.11 Mirror Image Reflectors: Distorted images

A variation of the effect may be seen on vessels with a similar disposition of Antennae and signal mast but where a circular section signal mast is of sufficiently large diameter to expand what would otherwise be a sectored linear reflection into a distorted "mirror" reflection. The sectored linear reflection is expanded to an image approaching the plane reflected mirror image but remains distorted because of the curved surface that is the intercept.

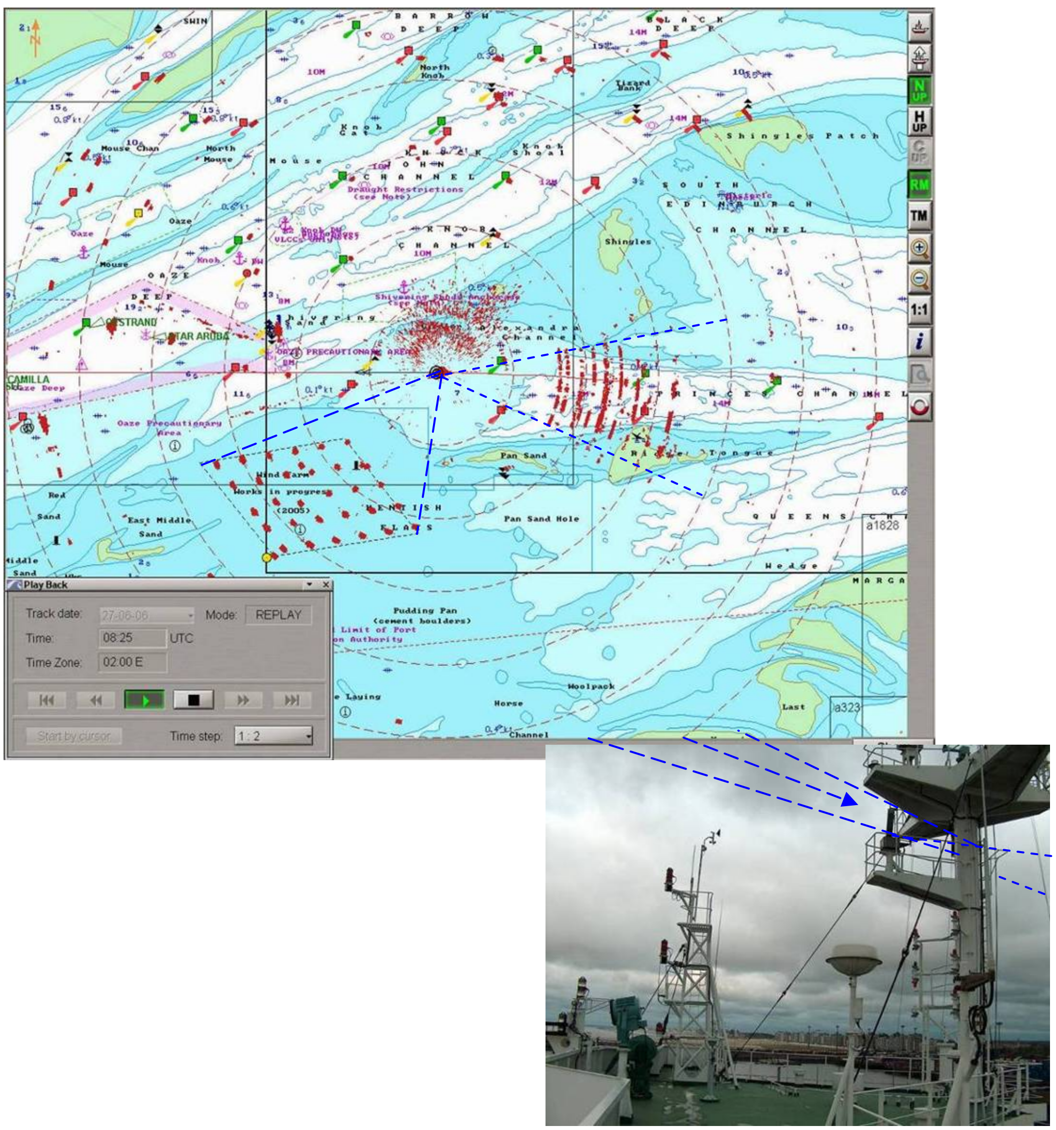

Figure 4.13: Curved Surface Mast Directly Abaft the Observing Antenna

Figure 4.13 shows an example with the vessel having two radar antennae mounted on the centreline. The lower radar antenna (3cm) is immediately ahead of a circular section mast, the diameter of which is sufficiently large that it intercepts a large sector indicated in the photo by the blue dashed lines. The effect is the distorted mirror image shown in the radar display picture above, again between the blue dashed lines. The illusion created is of an array, albeit distorted, in this case slightly to port of right astern.

4.3 Effects Generated by Factors External to Vessels

4.3.1 Plane Reflectors: Principle

Complete or nearly complete mirror images of the wind farm were sometimes observed on the display during radar trials in the Thames Estuary. They were found to be due either to interceptions with "slab sided" vessels passing in close proximity to the observing vessel or to interceptions with plane surfaces onboard the ship. Because of the transient nature of their origins in relation to the view of the wind farm the effects lasted for short – sometimes very short – periods only.

Vessel overtaking situations were the most prominent cause and persisting interceptions would only occur if the plane surface – usually the other vessel's side - passed a position and at a suitable attitude to present a clear reflection of the wind farm. In other words, if the vessel (it was usually a high sided vessel such as a vehicle carrier) passed between the observing vessel and the wind farm the reflection would not appear. However, if the overtaking or passing of the "reflector" vessel occurred on the opposite side of the ship to the wind farm, the reflection would normally appear in the direction of the passing vessel. Fast video replay techniques are best at illustrating the effect, leaving little doubt as to the source of the effect. The reflection can be seen to move with the other vessel as it passes. It also alters in azimuth as the other vessel changes heading although this is usually less obvious because of the need to remain in navigation channels ensuring headings alter very little in the area under investigation. The same effects were seen both for overtaking vessels and those passing on opposite headings but in the latter circumstance, because the "reflector" passed quickly, the reflected image passed even faster and could often be missed. The replay of the video recordings taken on each vessel was often the first time that the effects were recognised.

The effect is not confined to wind farms but can be generated by any strong radar echo. The significance of isolated single echoes however is rarely perceived by navigators. Their persistence is usually too fleeting to be assessed as a target requiring more detailed analysis. The prominence and clearly identifiable form of the wind farm array makes the effect more easily identifiable. The effect was also seen to be generated by a coast line caused by the same interceptions with passing high sided vessels. Observers were familiar with the phenomenon from their own experience but in former times it was usually associated with reflections observed in ports from buildings or other shore structures. High sided vessels are a feature of more modern shipping trends and these have moved the phenomenon to the more open water of port approaches.

4.4 General Discussion on Mirror Image Reflections

It was established by observation that mirror images in particular were not uncommon on the vessels of the trial and this was seen on about two thirds of the vessels. They were noted as the vessels passed a number of suitable targets. The reflections thus caused would, depending on the speed of the vessel, be transient and of short duration as the angles of reflection altered. Most targets would not be as clearly identifiable as the wind farm array and therefore the effect had not been commonly recognised by the crew.

The technique of fast replay of video (not available to the crew) allows distinctions to be clearly made between the effects caused by:

- External reflectors which change rapidly in position relative to the observing vessel; and
- Those that are created onboard the individual ships, which stay a constant azimuth angle in the direction of the reflecting obstruction, the image movement being synchronised directly with the observing vessel.

Many other vessels boarded would have the primary radar operated with the own ship centre offset on the radar display to gain maximum look ahead forward of the ship with the optimum resolution. Therefore, the ship’s staff was not aware of the level of reflections on the display generated astern where the distance displayed was small, especially on the 10cm radar.

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Figure 4.14: Examples of Incomplete External Mirror Images

Image **'A1'** is reflected from the Shivering Sands Towers **'A'** and Image **'B1'** is reflected from an overtaking car carrier **'B'**.

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4.5 Other Spurious Effects

4.5.1 Spurious Targets Generated by Topping Cargo Crane Jib

Other Effects will be constantly observed by mariners on an everyday basis and it reasonable to assume that they will be familiar enough with the use of radar not to be distracted by them. During the trial however, one type of spurious echo was captured in the sequence of photographs displayed here. The process of raising crane jibs prior to entering port is a common event. It should be noted from the observations that if crane jibs are raised into the radar beam the effects shown can easily be generated.

Figure 4.15 (Right): Geared (i.e. one equipped with its own cranes) bulk carrier inbound: Vessel passing wind farm with no significant effect noted

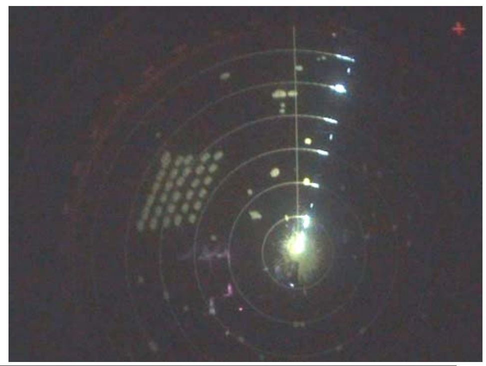

Figure 4.16 (Right): Crew were seen to raise cargo crane jib and partial reflection of wind farm generated in the line of the raised jib (ringed line of targets between 3rd and 5th range rings)

Note: The radar was a particularly elderly design with a traditional Cathode Ray Tube screen within a hood for viewing. As a result the image fades as the sweep progresses and the wind farm image fades accordingly. The low intensity image can be seen to the left of the image centre.

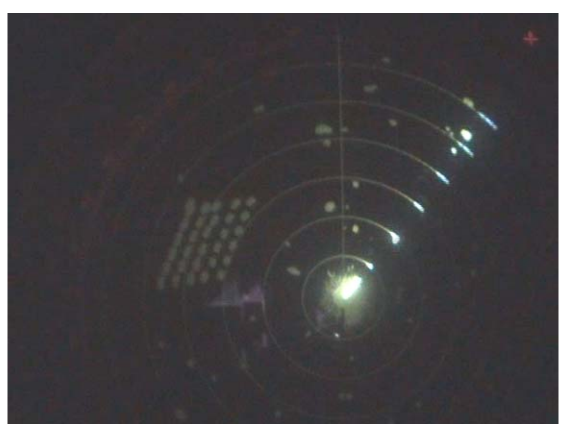

Figure 4.17: Master ordered the cargo crane jib to be re-stowed and effect disappeared

4.5.2 Intermittent Detection of Targets through Wind Farm

Before and during the research carried out in the Thames Estuary there had been concerns for loss of targets, particularly small boats within and even behind the wind farm. All of the above conditions can certainly confuse displays so as to make detection more difficult but with the exception of shadowing, close behind WTG towers (see Shadowing or Eclipsing **Section 4.5.3**) the phenomenon involving floating targets was never witnessed.

It was however established that radar adjustments could be influenced by the strong signals returning from the wind farm array and in particular this was found to be possible with automatically adjusted radars of which there are increasing numbers being fitted. The loss of targets as a result of over adjustment of gain and clutter controls, whether manually or automatically in response to the strong return signal is a very real possibility that could eliminate targets within the zones affected by the controls in any sector of the radar display, not just the area occupied by the wind farm. This applies to the more sophisticated radars carried on modern commercial vessels. Yacht and small fishing vessel radars are much more rudimentary with less automation and therefore less opportunity for the phenomenon provided the operator does not over-correct for the strong returns.

Because of the enhanced return phenomenon the conclusion of the original Kentish Flats report emphasised the need to adjust the radar using a small target such as a buoy as a guide to retain sensitivity at appropriate levels. (See also reference to “Spaniard Buoy” in **section 4.1** above). It is emphasised that this is merely restating something that the competent radar observer should be doing routinely, i.e. checking and cross-checking the radar performance, in particular the gain and tuning, against known targets. In circumstances where the enhanced echo returns are expected, notations could be placed on navigation charts, in the same way that magnetic anomalies are in some parts of the world.

Section 6 addresses small craft issues in more detail and provides more data about the findings of the trials as they are relevant to this topic.

4.5.3 Shadowing or Target Eclipse

Some shadowing or target eclipsing was observed but only of the WTGs and small craft within the wind farm, and then not frequently. The strong target returns from rows further back in the array is assumed to be due to the narrow shadow sector (the WTG towers are only 16ft in diameter) and the diffraction of the beam around the shadowing WTG. It is important to note that WTG targets rarely disappeared through this effect and if they did the event was fleeting, depending on the speed of the observing vessel. The effect when observed was transient when the observing vessel

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was moving and usually affected only a single WTG target in the Kentish Flats array at any one time. A detailed scientific analysis of the effect has not been conducted but first principles knowledge was applied to the behaviour of the images. It suggested a phase cancellation of signals between reflected signals from neighbouring WTGs. The image fades and builds again quickly enough not to be noticed by observers at the time if not directly viewing the screen at that moment. Smaller targets, such as small craft, were more likely to disappear but again the effect was transient provided that they were a sufficient distance from the shadowing WTG. In the latter case the greater likelihood was of a smaller target merging with the larger WTG target when they came close. (See also Small Craft **Section 6** below). The effect, by virtue of the fact that it would occur on the far side of at least one row of WTGs was always a distance away from the observer to be of little immediate concern to mariners. If the target was the subject of a search for a craft within the array the transience of the effect would make it possible to quickly establish contact with the target after it reappeared if the effect was experienced during the search and after first contact.

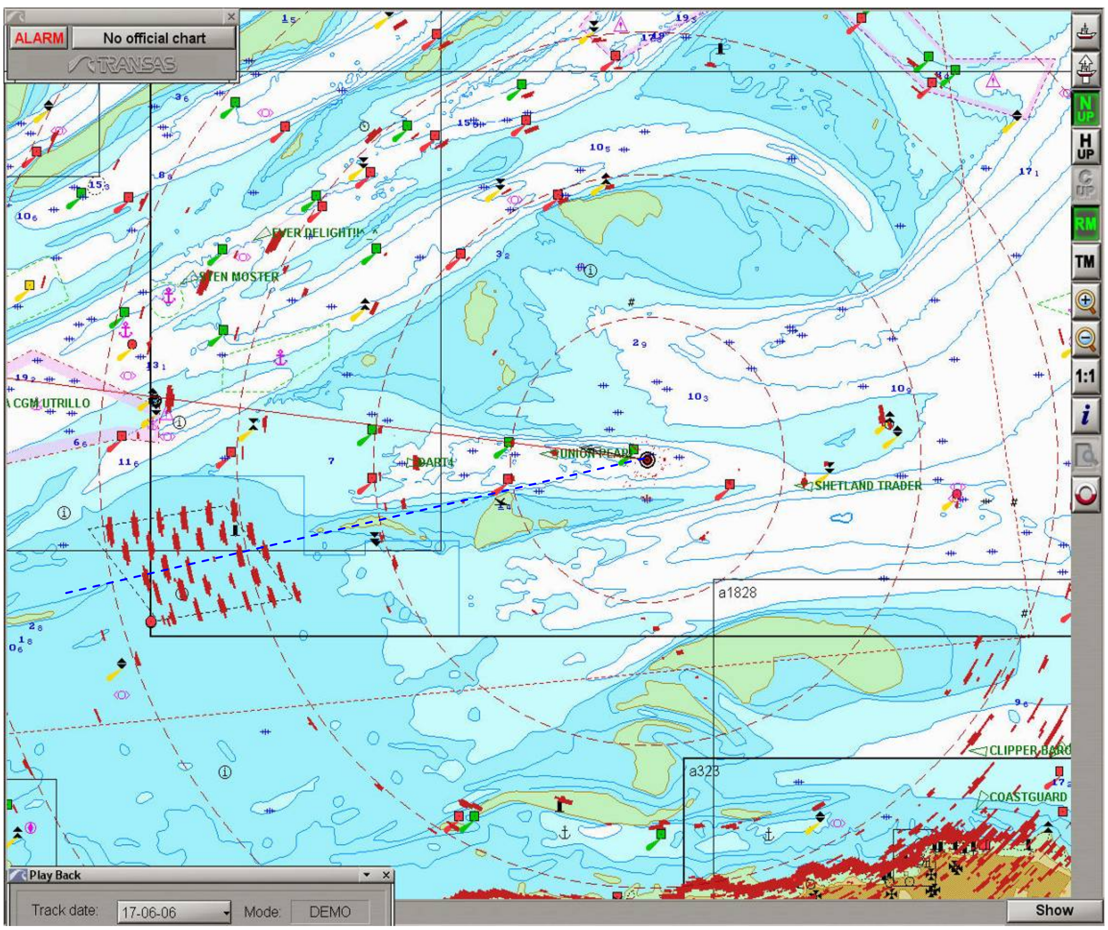

Figure 4.18: Image from RoRo vessel with electronic chart overlaid with radar

Note that WTG **'D3'** (in line with the blue dashed bearing line) has almost disappeared and appears to be eclipsed by WTG **'E3'**.

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5 SMALL CRAFT RADAR EFFECTS

5.1 Small Craft Detection when Operating within the Wind Farm

The recordings were made onboard trial vessels passing the Kentish Flats wind farm of the MARICO Marine survey vessel "MORVEN" (20m long and of GRP construction) as she navigated through the array. These recordings showed that the target ("MORVEN") remained visible throughout with the exception of those times when it merged with the larger WTG targets as it passed or stopped close by one of them. To achieve this however the MORVEN had to be very close – within approximately 5 metres. For vessels between one and two nm away the service craft of the wind farm was identifiable as a separate target from the WTGs. This was the case even when it was attached to them by a 6 metre (20 feet) mooring line when attending a WTG for an extended period.

In the event that the target vessel had approached so close to a WTG that the echoes merged, it was normally found that after a short period, (about 15 seconds at the usual speeds of the observing and observed vessels), the individual echo of the target vessel would separate from that of the WTG. Other small craft in the area were visible on the radar of passing vessels in the same way. There was some differential between 3cm (X-band) and 10cm (S-band) radars in that the S-band returned a much coarser display and merging of targets was more likely. In Europe, X-band is the preferred option for navigation purposes and S-band for anti-collision work. The observers found however that navigators often gave equal importance to both. This was often due to the positioning of the display in the wheelhouse (pilothouse).

Small craft radars were normally of the X-band frequency giving a sharper image, even if beam widths are twice or more those of the approved equipment aboard commercial vessels.

When the radar tracking (ARPA) function was employed to track the target "target capture" often resulted when the target vessel passed or stopped close by the WTGs but this was the only circumstance where such loss of target continuity was experienced. A human observer; however, in most circumstances would be able to monitor an acquired craft.

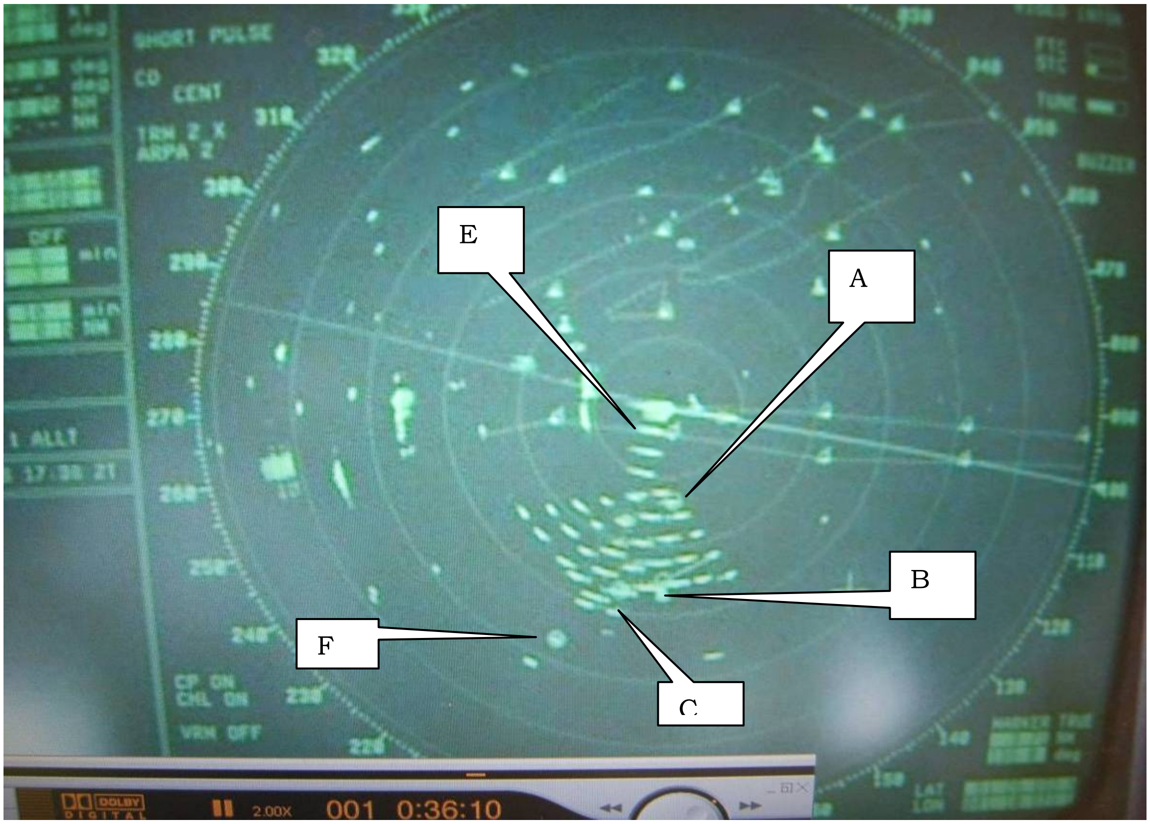

Figure 5.1: Radar image from a Bulk Carrier

In **Figure 5.1,** the small Fishing Vessel **'A'**, survey vessel "MORVEN" **'B'** and wind farm Service Vessel **'C'** are all visible despite multiple echoes from Car Carrier **'E'** passing between observing vessel and the wind farm. The Spaniard Buoy **'F'**, used as a reference, remained identifiable throughout. It is also notable that targets on the other side of the wind farm did not appear to be adversely affected and therefore the possible intermittent detection of targets through the wind farm was not manifest on this or any of the other vessels observed.

The multiple targets associated with the passing car carrier and closest to the observing vessel were of the car carrier itself and had nothing to do with the wind farm. This multiple echo effect is commonplace in close passing and is a result of multiple rebounds of radar beams between the observer and reflecting vessels.

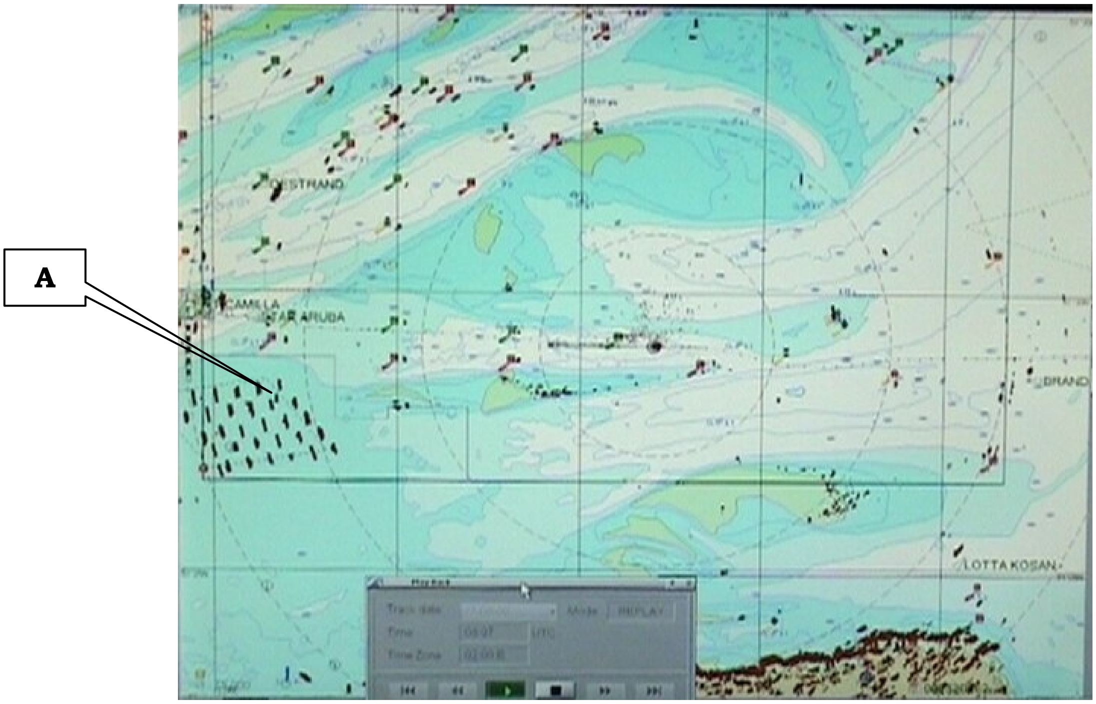

Figure 5.2 (above): Image from a tanker with electronic chart display overlaid with radar

Figure 5.3 (below): the same craft visually identified.

While passing a wind farm, a ship's radar was found to be capable of detecting small vessels operating within the wind farm. This is demonstrated in **Figure 5.2 and 5.3** above where the small craft in the wind farm **'A'** is clearly visible from a distance of about 6.5 miles.

5.2 Observations of Small Craft Radar

The observer aboard the small craft recorded radar displays of the small non-approved radar equipment fitted on board those vessels. All vessels were fitted with small Antennae that generally produce a wider beam width compared with larger "approved" versions found aboard commercial vessels. These wider beams resulted in target images, which combined with beam width extension, were large in azimuth. However, all the vessels had Antennae that were well sited above the majority of obstructions and therefore effects due to on-board structure were minimal.

Inside the wind farm array the clarity of picture was good and it was possible to identify the WTGs individually as well as other craft, most notably "MORVEN" within the same area.

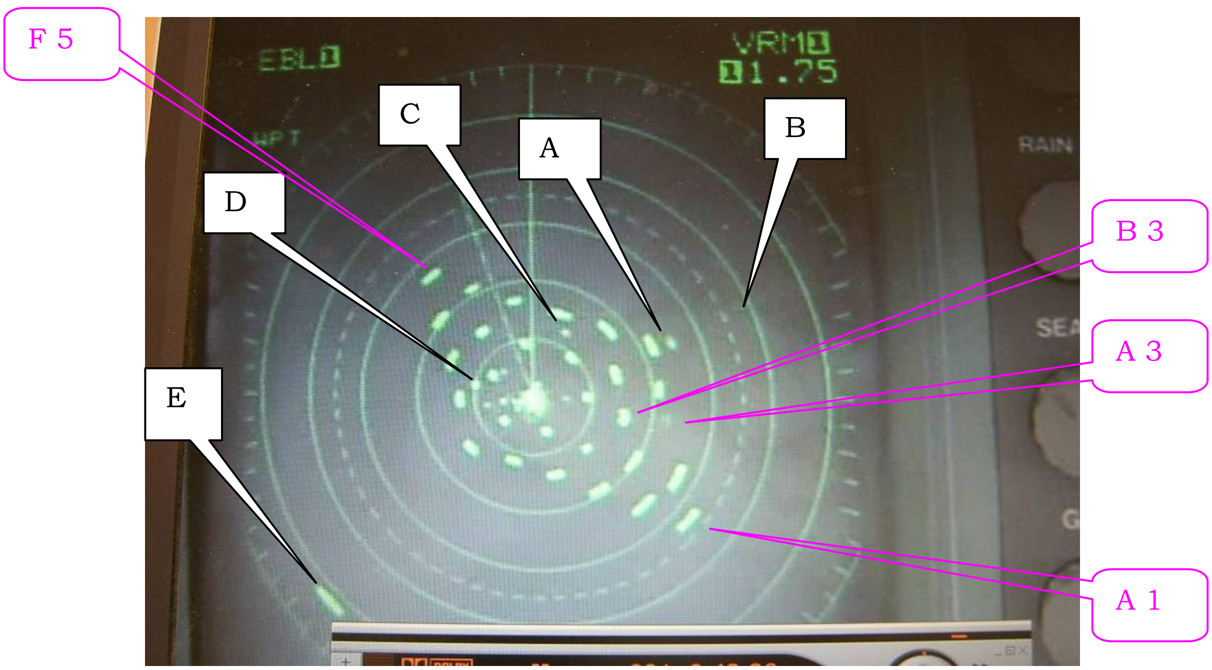

Figure 5.5: Motor yacht radar, head up display with heading south (Ship's head up mode)

Survey vessel "MORVEN" **'D'** is visible within the wind farm as is the service vessel - "CELTIC STORM" - **'C'** between WTGs **C4** and **C5**; the Met Mast **'A'** is clearly visible while the Spaniard Buoy **'B'** is only just visible but this is as much due to the phasing of the video "snapshot" as it is to the consistency of the display. In the next sweep it was visible again, such is the transience of such effects.

Note: WTG **A3** appears to be in shadow behind WTG **B3**. WTGs **A1** & **F5** are identified for clarity.

Also visible from the yacht well within the wind farm is the vessel **'E' passing** on the outside in the shipping channels.

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The fishing vessel radars produced a similar picture to that shown in **Figure 5.5,** which is to be expected as they tend to carry the same radars. Furuno and Raytheon are popular manufacturers in Europe, just as they are in Nantucket Sound.

Figure 5.6: Sailing yacht radar, ship's head up display with yacht heading south east

In **Figure 5.6** a similar situation to that of the motor yacht has been shown. Note that the WTGs are fairly coarse, due to the small antenna but also sea-clutter is more intense and represents the most prominent interference on the display. This higher intensity of sea-clutter is occurring because the antenna for sailing craft tend to be mounted fairly high on the mast (see **figure 5.7** for typical arrangement) and the rebound from close vicinity waves is increased over the more horizontal aspect achieved by the motor yacht and the fishing vessels. Sea-clutter is a manageable phenomenon well known to mariners. It is not dependent on the proximity of any structures - just wave tops.

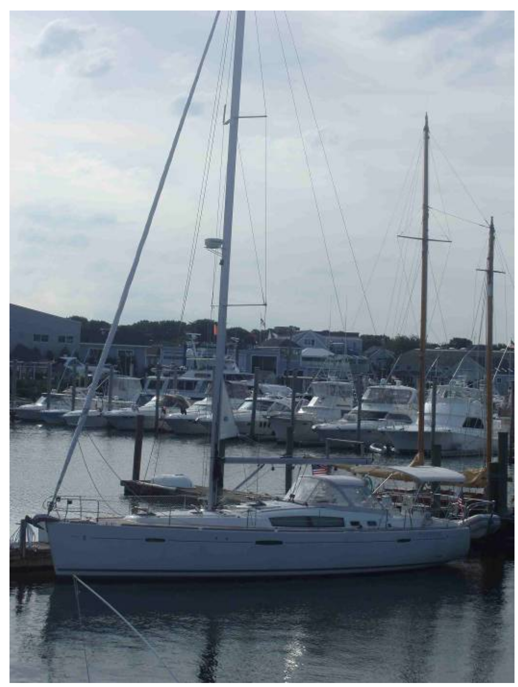

Figure 5.7: Sailing yacht: Note radar antenna (enclosed) at almost half height of mast just above lower cross-trees.

5.2.1 Detecting Small Targets within a Wind Farm: Sensitivity Trial

Concerns had been expressed before and during the research in the Thames Estuary on the ability of ship's radar to detect a small target in the wind farm while the observing vessel was operating also within the wind farm. This was investigated by placing a plastic buoy overboard from a wind farm service launch and monitoring the boat radar display and shown in the following sequence.

Figure 5.6:

The plastic buoy was placed overboard and the boat moved away to increase the distance

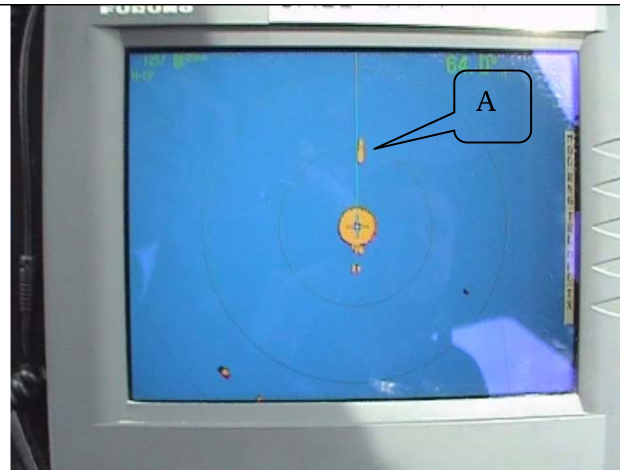

Figure 5.7:

The buoy **'A'** shows ahead at a range of about 100 metres

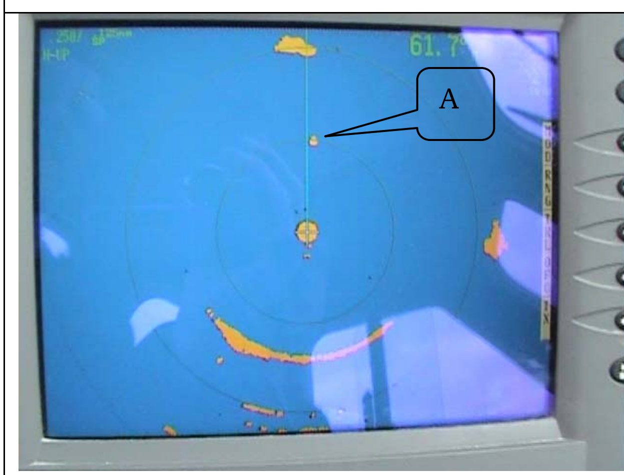

Figure 5.8:

The display range was changed and the buoy **'A'** was still clearly displayed at about 350 metres. Note the echo from the nearby WTG distorted by side lobe effects

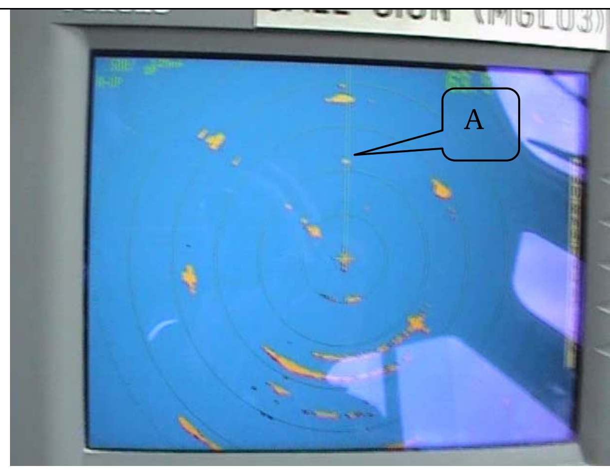

Figure 5.9:

At a range of about 500 metres the buoy **'A'** was still clearly visible ahead despite the increasing effects displayed from the WTG towers although it should be noted the effects are concentrated astern. They are caused by the signal mast immediately abaft the antenna

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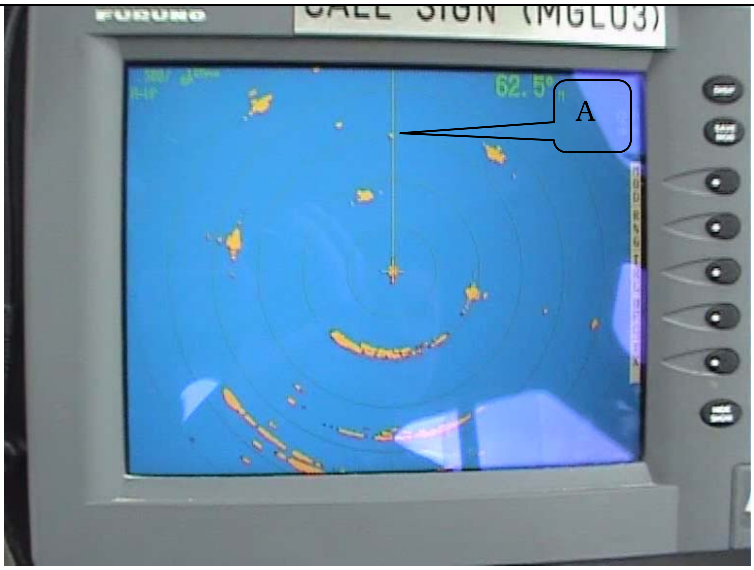

Figure 5.10:

At a range of about 700 metres the buoy **'A'** could still be identified and the boat Skipper was confident that he could effectively find small targets within the wind farm. This was based on his experience that had included such need.

While this experiment was not as thorough as a full Search And Rescue (SAR) exercise, it did indicate that the use of radar within a wind farm was not as degraded as had been postulated by parts of the shipping industry.

The crew of the service vessel from which the above observations were made used their radar constantly, whether they were on passage to and from the wind farm or transiting through it. The skipper advised us that the radar was used in preference to other navigational instruments because it was possible to navigate round the wind farm using the grid identifiers (which were superimposed on the electronic plotter).

It can also be seen in the sequence of figures above that fairly large side lobes are in evidence on some echoes but it should be noted these are all in the aftermost sector and they are caused by the signal mast that is positioned immediately abaft the radar antenna. In the ahead sectors the effects of side lobes is minimal and this is on a small craft radar with a beam width of about 3 degrees – double that of an "approved" radar that would be found on larger commercial vessels.

6 NANTUCKET SOUND OFFSHORE WIND FARM – CAPE WIND PROJECT

6.1 Nantucket Sound Area

The proposed wind farm is located offshore, south of the Port of Hyannis on the Massachusetts mainland as shown in **Figure 6.1** below.

The figure also shows outline ferry routes around the wind farm. Of these it has been established that the largest ferries in the area pass on the track to the east of the Horseshoe Shoal where the proposed wind farm is to be sited. By calculation of the schedules of the Steamship Authority ferry company, which operates the two largest vehicle carrying ferries there are two areas in which the vessels pass each other. It has been advised that the ferries on opposing runs to and from Nantucket Island pass at a distance off each other of about 0.5nm – the point of closest approach as advised in the ESS Revised Navigation Risk Assessment. The significance of this event will be explained in **section 7.2.3** below.

Figure 6.2 shows the ferry routes in greater detail and includes expected stand-offs of those routes from the array in a number of key positions labelled A to G.

The shoals in the area have a controlling influence on what routes are possible for larger vessels, leaving the shallower areas usable by smaller light displacement craft. These craft will conceivably continue navigating in the area after the wind farm has been constructed. The UK experience indicates that small vessels such as fishing vessels and leisure craft can and do continue to navigate without undue difficulty close to and within the Kentish Flats wind farm and the same has been observed to be true in other arrays.

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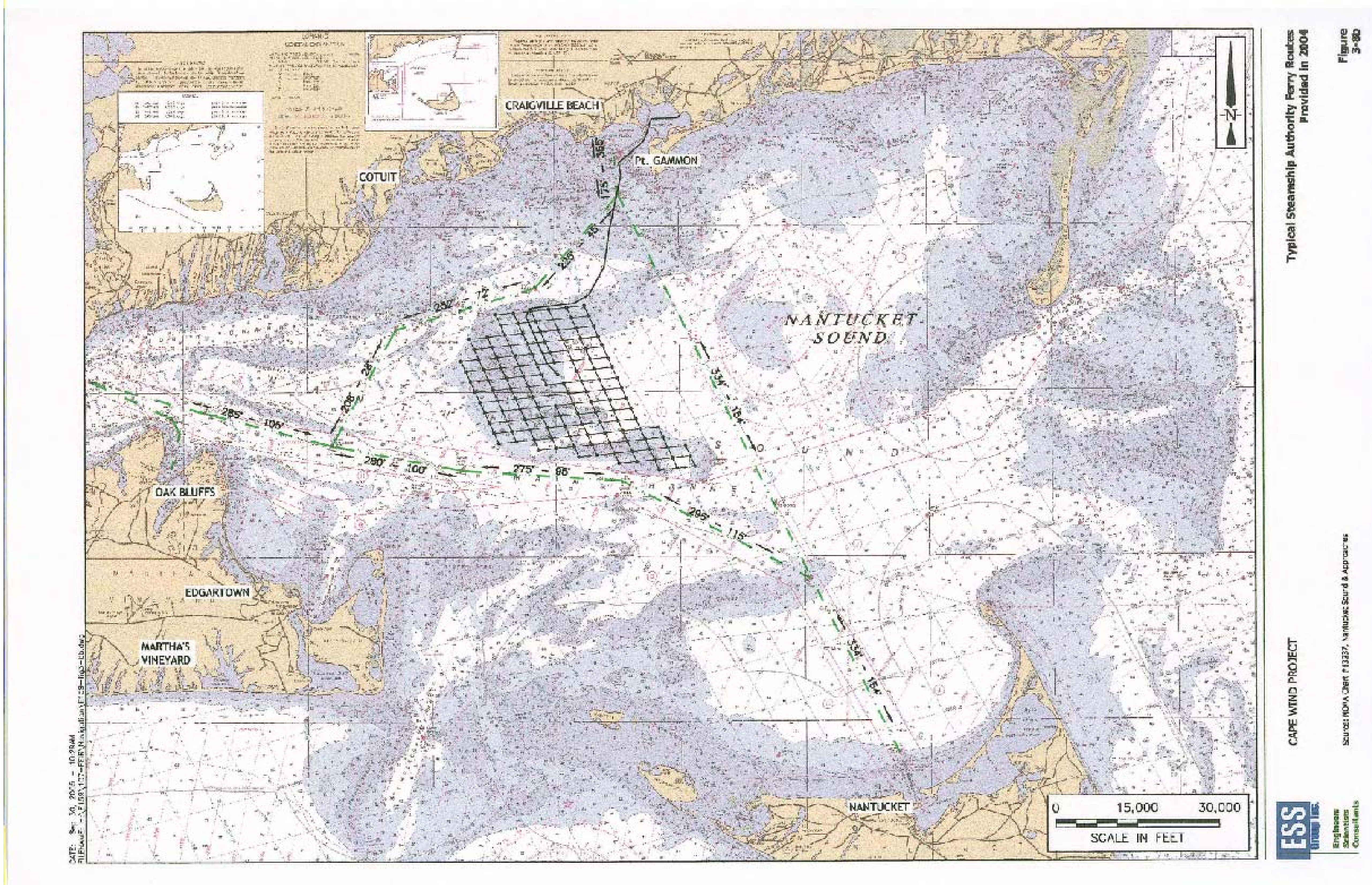

Figure 6.1: Chartlet of the wind farm proposed for Nantucket Sound

6.2 Layout of Proposed Wind Farm

From **figures 6.1** above and **6.2** below it will be seen that it is proposed that the wind farm will comprise:

- 130 WTGs installed in parallel rows and columns set at a little over a right angle to each other;
- Installed within the north, west and southerly boundaries of the Horseshoe Shoal sea area with an exceptional area to the east in deeper water between the north east and south east extremes of the shoal.
- The Nearest WTG to shore will be about 4.5 nautical miles (nm) offshore (Wianno Head); and
- The inter-array distance will be 0.34nm on the axis running approximately NNW/SSE, referred to hereinafter as the North/South (N/S) axis and 0.54nm on the axis running approximately E x N/W x S[16] referred to as the East/West (E/W) axis.
- Additional information regarding the distances between WTGs and Main Channel are provided in the ESS Revised Navigational Risk Assessment and represented on the chartlet shown in **Figure 6.2.**

[16] E x N/ W x S = East by North / West by South, taken from the compass in points. There are 8 points in a quadrant and 32 points in a complete 360°. The alignment of the wind farm is approximately one point off East/West. Hence East by (one point) North. This is a coarse measurement of the compass still used on modern ships for lookout purposes because of its ease of estimation, points being relatively simple to assess by bisecting the readily discernable quadrant and then progressively bisecting lesser sectors. The other axis is approximately NNW/SSE

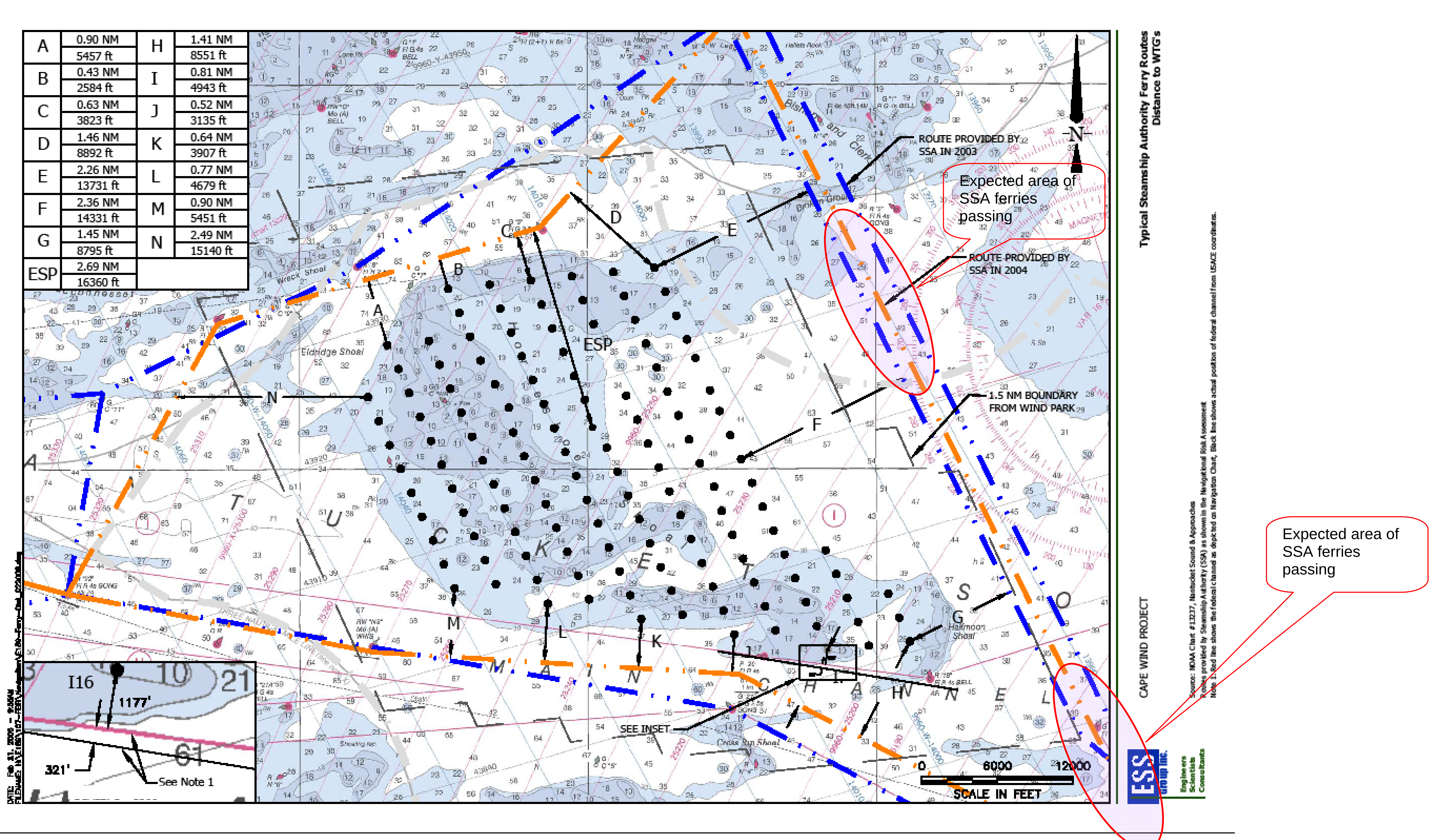

Figure 6.2: Chartlet of Proposed Wind Farm at Nantucket Sound

Courtesy of ESS Group Inc

6.3 Vessel Traffic Flows

This study is not a vessel traffic analysis. The area is however transited by a variety of different vessels, some local commercial and others fishing or leisure. It is also possible for the area to be transited by ocean going vessels such as cruise vessels but these would be under pilotage and, because of their draught, only the smallest of such vessels could penetrate the sound to the vicinity of the proposed wind farm.

Another aspect of visiting larger (cruise) vessels is that they would most probably be transiting the area without any other similar vessels in the close vicinity. This differs significantly from the busy port approaches serving the multiple ports and terminals on the Thames and Medway river that pass the Kentish Flats wind farm. The cruise vessels visiting Nantucket would be infrequent by comparison and the largest other vessels would generally be much smaller than those found in the Thames Estuary. This is important as the presence of other vessels, particularly those with high sides, could affect radar interference. It is established practice that cruise vessels entering Nantucket Sound do so via Vinyard Sound (to the west) and do not transit or anchor east of Edgartown, some seven nm to the west of the proposed site of the wind farm. More detail is contained in the ESS Revised Navigation Risk Assessment.

In terms of radar profile, cruise vessels have a similar shape to many of the ferries transiting the area on a routine basis so it is these regular (ferry) vessels that are the main subject of the study.

No definitive data for actual tracks was available to us other than the tracks shown in **Figure 6.1** and in more detail in **6.2**. These were supplied by local ferry operators for the navigational risk assessment. They represent base courses, not tracks and it is possible that many of the scheduled ferries could navigate some distance away from these courses. Nevertheless the base courses will be used to illustrate what should be expected on radar in certain positions as it is assumed that to maintain schedules, ferry captains would be unlikely to make large deviations from the base courses excepting emergencies or during tacking manoeuvres by sailing craft. It is known that “tacking” is used by ferry captains to achieve a better ride during inclement weather but this will always be measured against the need to maintain a schedule as punctually as possible. It is unlikely that such manoeuvres will deviate very far off the marked routes.

Regarding the tracks of smaller craft such as fishing and leisure vessels it will be assumed that these follow relatively random tracks both within and outside the proposed wind farm site. Since our data from trials at Kentish Flats in UK includes similar craft in and around that wind farm we are confident that any radar effects will be realistically modelled.

In the Nantucket Sound area there are three main routes followed by vessels on a regular basis. These surround the roughly triangular outline of the Horseshoe Shoal - the proposed wind farm area. Of these the easterly route between Hyannis and Nantucket is the route used by vessels that are most significant in relation to their expected radar target profiles. This route is also the one most likely to involve vessel to vessel passing encounters between such vessels – an important factor when considering effects on radar.

There is a crossing point at the SE corner of the wind farm between the above routes and that along the southern boundary used by through traffic in the Main Channel. The significance may be that certain types of antenna configuration could create interference in the same direction as the passing traffic. The characteristics that are necessary are very specific. Even in Europe these characteristics tend to be found only on vessels like dredgers that have additional masts forward of, or in line abeam with, the radar antenna. The profiles of most vessels known to be navigating in the Nantucket Sound do not possess these characteristics and it is therefore expected that any effects will, if they occur at all, be in sectors, at worst, on the beam, but in most cases astern or in relatively limited sectors either side of astern.

6.4 Comparison of the Kentish Flats Wind Farm and the Nantucket Sound Proposal

Both the Kentish Flats and Nantucket Sound sites have navigation channels that pass within one nautical mile of the array. At 0.34/0.54 nm, the proposed array of WTGs at Nantucket Sound is a little more widely spaced in the East/West direction than the 700 metres (0.38nm) at Kentish Flats. In the north/south direction the two wind farms have similar spacing at 0.38nm (Kentish Flats) and 0.34nm (Nantucket). At Kentish Flats the 30 WTGs are placed, with one exception, in five parallel rows aligned almost East/West. The proposed lines of WTGs at Nantucket Sound are also parallel. Apart from being more widely spaced in the East/West direction than the North/South direction the proposed Nantucket Sound array also has a larger number of WTGs arranged such that the basic parallelogram shape is extended on the West side and at the South East corner. At close range however the two wind farms will appear very similar on radar.

	No. of WTGs	WTG tower diameter	Spacing		Closest Navigation through route
			N/S Axis	E/W Axis	
Kentish Flats	30	4m (about 13 feet)	0.38nm	0.38nm	0.80nm
Nantucket Sound	130	About 16 feet (4.9m)	0.34nm	0.54nm	0.52nm

Table 6.3: Comparison of dimensional data Kentish Flats vs Nantucket Sound

The plots below give a scale and layout comparison between the Kentish Flats and Nantucket Sound wind farms. As can be seen, although the overall scale of the array is very much larger in Nantucket Sound the layout is very similar.

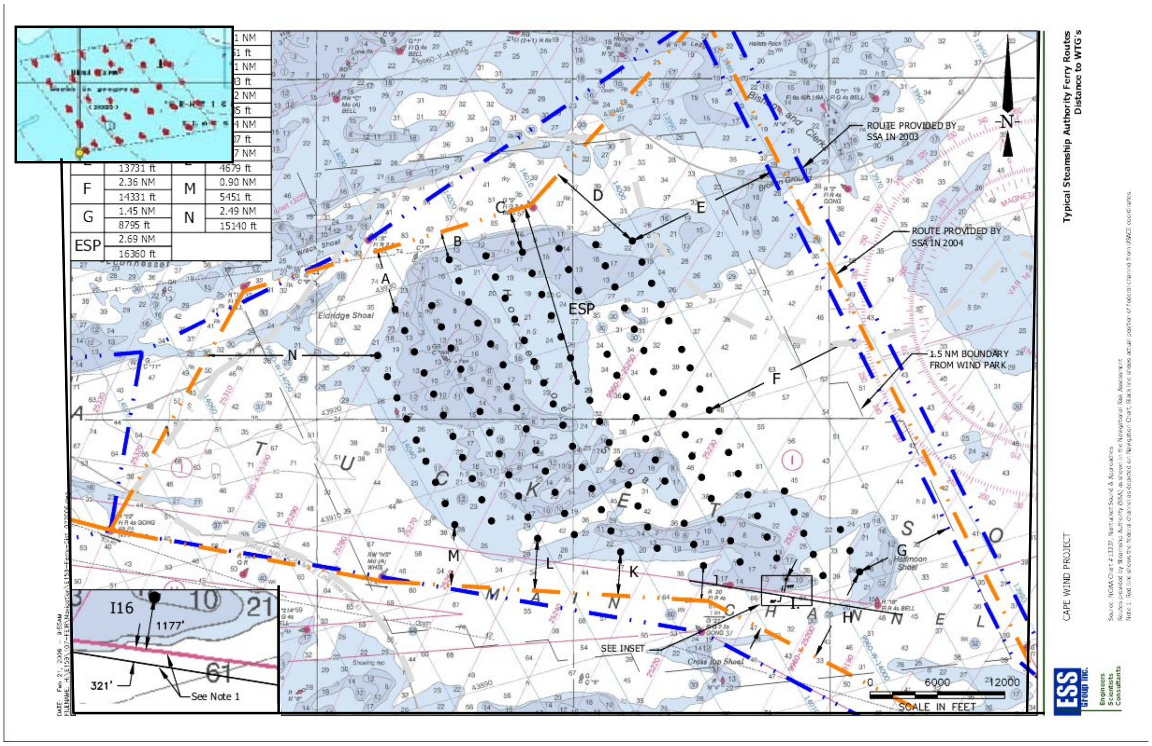

Figure 6.4: Plot of Kentish Flats (inset, top left) and Proposed Nantucket Sound Wind Farms to approximately the same scale.

Sources: Marico Marine Traffic Analysis Unit and ESS Group Inc

The images in **Figure 6.4** are derived in the case of the Kentish Flats inset from an extract of a real shipboard radar display overlaid on an electronic chart. The Nantucket Sound array is represented by a projected plan on an electronic chart, i.e. it is not a real radar image and therefore appears sharper. The real radar image could be expected to be more like the Kentish Flats version. Later in this report we provide a number of simulations made up from actual images of radar screens. These again will resemble the Kentish Flats example because they are constructed from real data. Whilst the WTGs at Nantucket Sound will be spaced further apart in the East/West direction, we would not expect the strength of return from each to be significantly different from those at Kentish Flats – the WTGs are very similar and ranges are marginally increased in one dimension only. This assumption is based on our observations of the effects of solitary targets in the same study and the fact that radar beams may also be reflected to and from other WTGs in the array that may be out of the direct line of the vessel's observing beam. Such secondary reflections at the WTG "in view" will tend to enhance the returned radar beam in very much the same way as the elements of a chandelier will enhance the light returned from it.

6.5 WTG Location Identification

In this document, the Kentish Flats Wind Farm WTG position reference system used is two dimensional: Alpha for columns (West to East) and Numeric for rows (north to south).

The proposed system for Nantucket Sound differs only in beginning at row zero (0). References to the WTGs will use the Nantucket Sound convention in this assessment.

7 POTENTIAL EFFECTS ON MARINE RADAR – NANTUCKET SOUND WIND FARM

The effects caused by obstructions sited within the boundaries of the vessel have been illustrated in section 4.2.2. Masts, stanchions and other structures, some of which are of relatively small diameter and usually round in section have been found to regularly reflect radar beams both outgoing and incoming. The typical layout of vessels in Nantucket Sound however does not closely resemble that of the European and Far Eastern built RoRos, dredgers and feeder container vessels frequenting the Thames Estuary. Instead, most of the larger vessels, of which ferries are the most prominent group have radar antenna layouts similar to the more traditional designs found on cargo vessels and passenger vessels in Europe that were also boarded in the Kentish Flats trial. It is noted also that the US patterns follow more closely the arrangements recommended by IMO regarding the siting of radar antennae and possible obstructions. With possibly one notable exception among the ferries (EAGLE[17]) and the fishing craft with large booms and associated masts and spars, the direction of interference of the typical local Nantucket vessels will almost exclusively be right astern or nearly so. This is the direction of least threat to the vessel when underway. The majority of the radar screens therefore - a greater proportion than in the Thames Estuary – will, it is predicted, remain relatively unblemished from internal interference. The situation therefore will be very similar to that illustrated in **Figure 3.2.** and is illustrated and simulated below (**Figures 7.7 and 7.8**).

7.1 Methodology for predicting effects

The prediction of effects that follows is based on the known effects already described. Vessel types are compared between the two locations – Thames Estuary and Nantucket Sound. The areas themselves are also assessed with regard to relationships between traffic routes and the wind farm arrays. Prediction of images is not based on software. The task would be in danger of missing effects that can be inserted manually using the experience of the observers. Such effects can be numerous and of varying intensity and transition. i.e. in a single radar display

[17] EAGLE, unlike other ferries in the area has transversely positioned radar antennae. The potential for internal reflections from the stanchion of the higher (Port) antenna when using the lower (starboard) antenna is significant.

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there may be a number of effects affecting the image at one time. Although modelling by computer would be possible it would be time consuming to write the code to capture the complexity of the interludes being studied.

Instead, images relating to the layout of the proposed Nantucket Sound Offshore Wind Farm are constructed out of existing real images obtained in the Kentish Flats area using data obtained from vessels with similar radar antenna layouts and cloning target data, again from Kentish Flats data, adjusting positional relationships and numbers of targets using a proprietary software image manipulation package[18]. It should be noted that echoes illustrated are of relatively low intensity. Depending on the radar in use the real image may have echoes of greater intensity but a number of variables, not least of which is the actual band in use, make it difficult to predict specific displays. Nevertheless the actual display should be a similar representation of the one predicted below.

Certain assumptions are made to make the predictions that follow:

1: That the vessels possess suitable reflective characteristics to produce the results shown; and

2: That the behavioural characteristics of the vessels such as susceptibility to motions (pitch and roll) are suitable for sustained reflections.

In both cases, smaller vessels will tend to be less compliant with these assumptions so the images predicted below are, we believe, worst case (smooth water) scenarios.

Furthermore, the quality of reflective surfaces may be good for returning a real echo but poor for a reflected one. Hence slab sided vessels in the Thames Estuary provide good reflecting surfaces for secondary reflections because the sides are smooth, but equally high sided container stacks were seen not to provide strong secondary reflections. This was attributed to the multitude of corrugations in the containers that although highly radar visible as a primary (real) target, tends to scatter the radar beams that would otherwise enter from other sources such as the wind farm. One could draw an analogy in the visible spectrum. Brightly painted surfaces might provide a high profile visual image of the target but return very little else, whereas a mirrored, chrome plated or highly polished surface will also reflect other targets and in extreme cases depending on background may itself become relatively invisible due to distraction.

7.1.1 Principal criteria

The predictions below are for vessels that may incorporate some of the effects shown in earlier sections but it is emphasised that the distinctly smaller profiles of the main contenders – the Hyannis/Nantucket Island (local) ferries makes them

[18] Jasc Paintshop Pro and Serif PhotoPlus 7

much less likely to generate lasting effects seen in the cases of their much larger counterparts in the Thames Estuary. It is also significant that the design of the hulls of the local ferries incorporates certain traditional features such as "tumblehome" – the slight angling in of sides between the waterline and the deck – and end taper that is more progressive locally than in modern box-like European examples although it is still commonly found in the coasting cargo vessels plying the Thames Estuary. All of these features reduce the potential for reflection in that the surfaces will be encouraging deflection of radar beams rather than direct reflection. Other smaller ferries resemble the cruise vessel outlined in **figure 3.2** with respect to rake angles of masts and funnels. Again these are features that will all serve to reduce effects due to internal influences i.e. the majority of those expected.

All vessels, being smaller in waterplane area, will also be subject to greater rotational behaviour (roll and pitch) and this again will diminish opportunity for reflection of radar beams as the angle of reflection, being equal to the angle of incidence means that any (small) angle of roll (or to a lesser extent pitch) on the vessel will double the angular deflection of the reflected beam. The probability of it coinciding with the send antenna is significantly reduced as a result (see **Figure 7.1**).

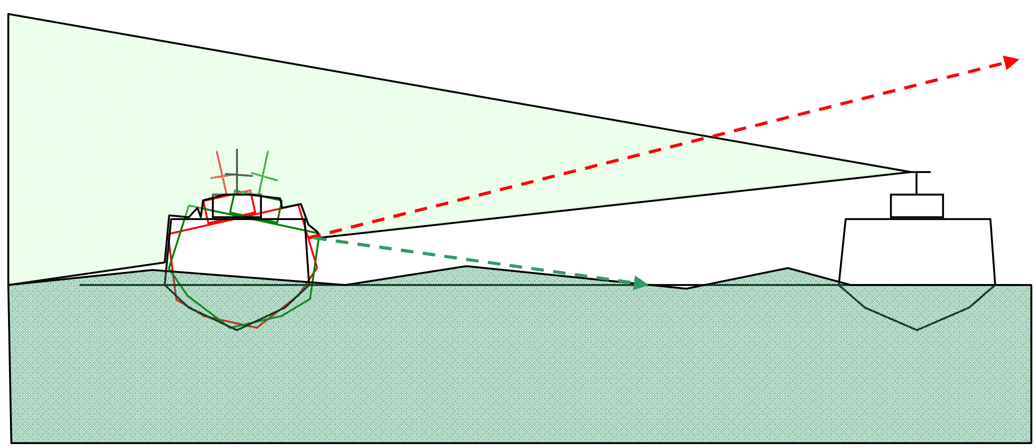

Figure 7.1: Illustration of deflection due to rolling causing intermittent reception of real echo and any secondary echoes reflecting off target vessel.

In **Figure 7.1** the target vessel (on the left) is subject to rolling. When the vessel rolls to port (red outline) the radar beams reflected off its topsides (red dashed line and arrow) are deflected up and above the receiving antenna on the observing vessel (on the right). When the target rolls to starboard (green outline) the radar beams reflected off its topsides are deflected downwards towards the sea surface (green dashed line and arrow). This would result in a fading image of the true echo but a more specifically fading reflection of any false echo from a reflected target such as the wind farm array.

7.2 Predicted effects on local Nantucket Sound vessels – larger Vessels.

7.2.1 Comparisons between Source data and local larger vessels in Nantucket Sound

Vessel characteristics can be compared below.

PASSENGER CARRIERS

Thames Estuary

Nantucket Sound

Figure 7.2: Passenger vessel comparisons: Thames Estuary vs Nantucket Sound

Nantucket Sound

Fast Craft

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RO-RO VESSELS

<u>Thames Estuary</u>

<u>Nantucket Sound</u>

Also a passenger vessel. Similarity = some measure of slab side.

Below left : MV EAGLE. Note limited "slab side" (shaded: about 4500ft2) considered capable of producing "mirror images" compared to much larger and absolutely flat equivalent zone on the European "Finnlines" freight ferry (about 7500ft2) . Note also the transversely positioned antennae on EAGLE, compared to the more traditional fore-and-aft disposition on the other Nantucket Sound ferry pictured above.

Figure 7.3: Comparison of RoRo vessels: Thames Estuary vs Nantucket Sound

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Predicted Image: Hyannis – Nantucket Fast ferry (and others).

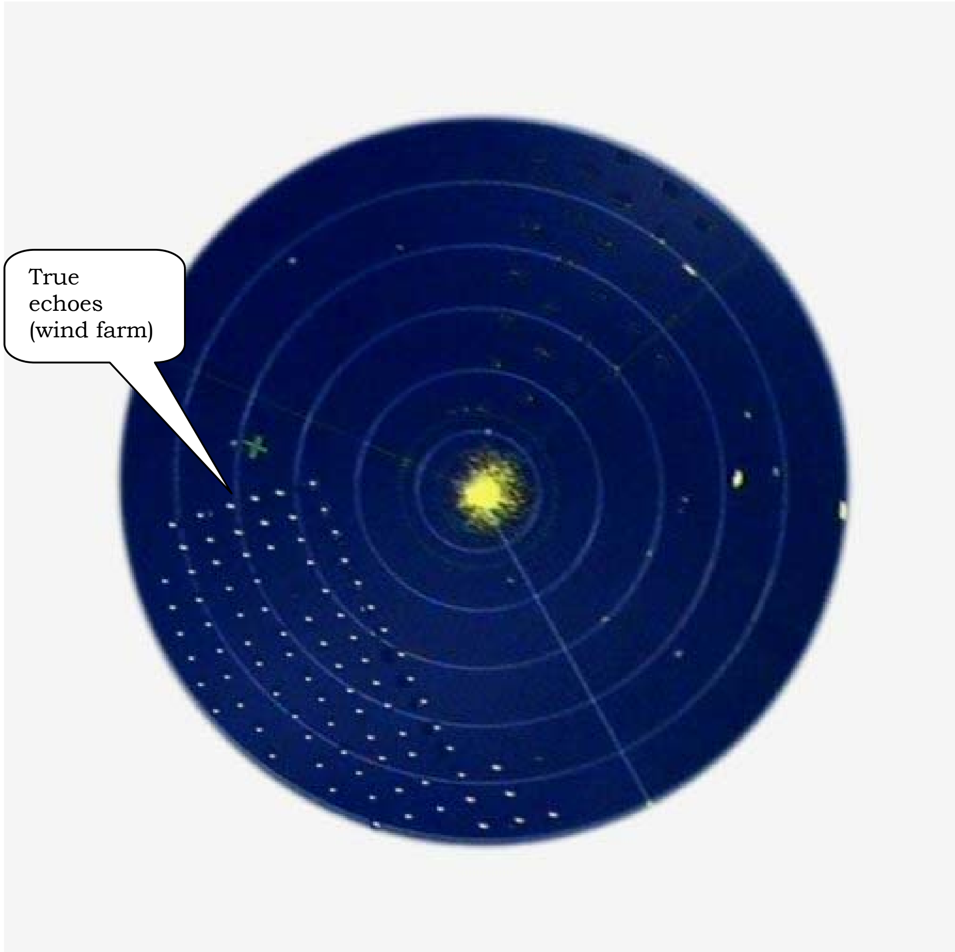

Figure 7.4: Fast Ferry Radar. 6 nm range south of Broken Ground south bound to Nantucket.

The fast ferry (inset **Figure 7.4**) has characteristics of antenna layout that are similar to large motor yachts, i.e. the antenna is positioned high and above significant obstructions that may create reflections. It is anticipated that this arrangement will achieve the least interference in the vicinity of the wind farm.

Because the antennae are positioned above other obstructions a clear display should be expected as long as no other vessels are close by that could reflect the strong signals from the wind farm. The main concern should be in the setting of the gain control. The tendency for the wind farm array to return a strong signal could result in the gain control automatically, (or manually in response to the prominent image) being reduced. The hazard then is the suppression of small targets. The same hazard already exists with rain and sea clutter adjustments.

Other vessels with raked masts should expect similar results on account of the fact that stray signals will be deflected skyward by the heavily raked surfaces. The same precautions regarding gain should be applied.

Figure 7.5: The ferries GREAT POINT and FREEDOM.

Because of the designs of their antennae and surrounding structures should expect a clear display similar to that shown in **Figure 7.3.**

Figure 7.6: Sea angling boat with similar raked mast configuration.

This is the best configuration for eliminating incoming reflected signals. It is very common in Nantucket Sound.

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7.2.2 Predicted Radar Image at Nantucket Sound: Hyannis/Nantucket Island ferry (Not EAGLE)

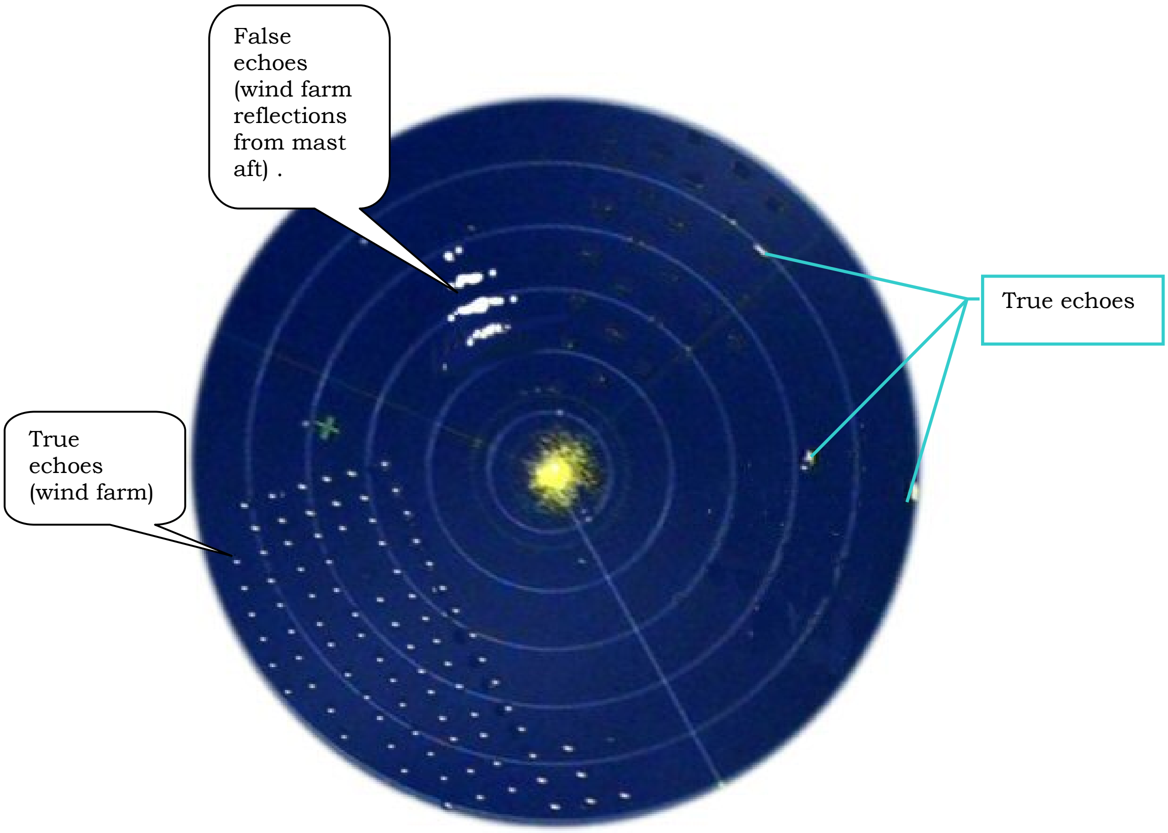

Figure 7.7: Southbound Ferry (not EAGLE)

In **Figure 7.7** the vehicle ferry NANTUCKET, unlike the EAGLE has an antenna positioned on the centreline similar to the cruise vessel of the Thames Estuary (**Figure 3.2**) and should, as a result expect a relatively clear display. There is one complication however and that is if the signal mast abaft the antennae is vertical it will not deflect incoming reflected echoes up and away from the antennae like the raked mast of the cruise vessel, smaller Nantucket Sound ferries and the sea angling boat pictured in **Figure 7.6**. **Figure 7.7** illustrates the expected result if signal masts astern are vertical or nearly so. Multiple echoes can be seen astern corresponding to the spacing of the WTGs (to starboard). The WTGs are being reflected by the tubular mast and appear therefore to be in line with it. Side lobe distortions are also evident either side of the echoes. In the case of NANTUCKET the separation of the mast and the antenna is larger than usual and this should reduce the side-lobe effects below the level of those in the figure.

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7.2.3 Predicted Radar Image at Nantucket Sound: Hyannis/Nantucket Island ferry EAGLE.

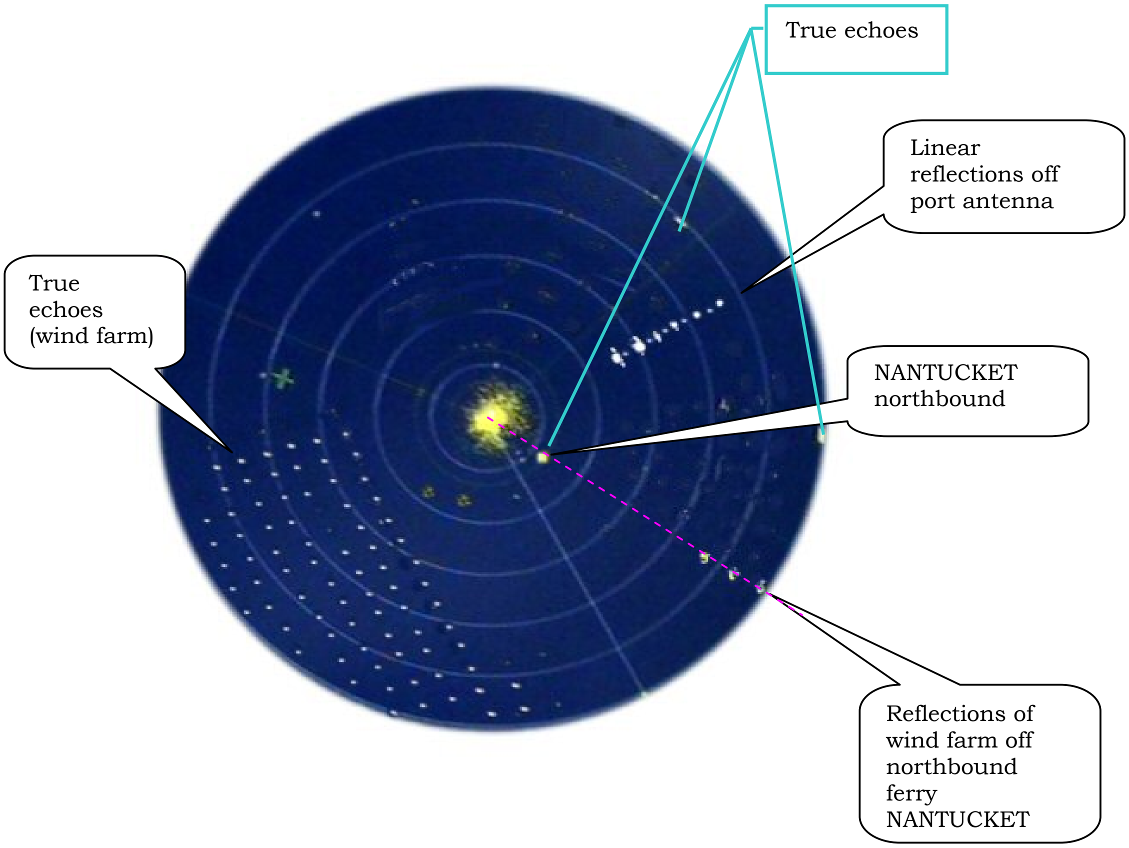

Figure 7.8: Southbound Ferry EAGLE

The ferry EAGLE has antennae that are positioned athwartships[19] and the starboard antenna is lower than the port. **Figure 7.8** illustrates the predicted display for the starboard antenna. The linear reflections seen to port are of the wind farm reflected in the tubular stanchion supporting the higher port antenna. Some side lobe distortion is also seen in the front (strongest) reflections. Also included are "ghost" intermediate reflections between the positions of the WTGs. These may or may not be apparent to the operator. The phenomenon was seen in the Kentish Flats trials but was very short lived. The precise cause of these minor targets is not established but is believed to be a result of multiple reflections between WTGs in the array – the "chandelier effect". They would not normally be detected by vessel navigators but are apparent on the replay of the videos taken at the time.

In **Figure 7.8** there are additional linear reflections apparent in the south-east. These are reflected off the approaching NANTUCKET, seen at just over one nm on

[19] "Athwartships" = in a line abreast of each aligned at right angles to the longitudinal axis of the vessel.

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the port bow. The two vessels are on opposing courses and due to pass at a closest point of approach of 0.5nm. At 1nm the profile of NANTUCKET is capable only of presenting a reflecting surface in her topsides of approximately 1 degree of azimuth. This cannot produce a mirror image as is possible with much closer slab-sided vessels. It can however produce a reflection that is linear in line and beyond the target at a range corresponding to the range of the reflected WTGs at the reflecting vessel. The echoes reflected in this way will rotate around the centre of the screen aligned with the reflecting vessel, in this case in the direction of the magenta arrow. Their intensity may vary as the reflecting vessel presents different aspects of the reflecting topside and they will vary further in intensity as the reflecting vessel rolls in the seaway causing reflected beams to be displaced vertically away from the receiving antenna. Other aspects of the design of the reflecting vessel such as any "tumblehome" of the topsides could reduce reflection further in the same way that raked masts do for internal reflections.

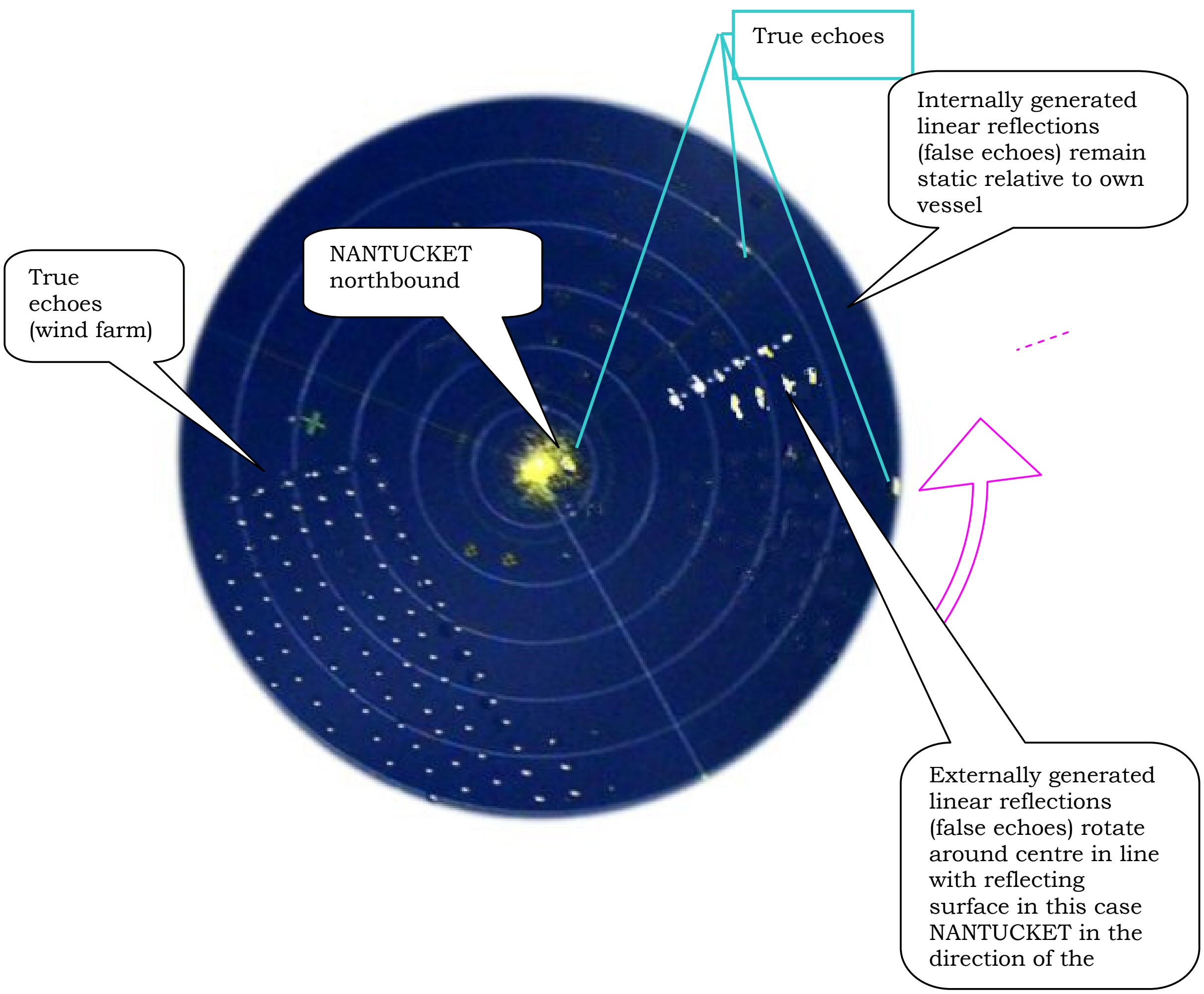

Figure 7.9: Southbound Ferry EAGLE passing northbound ferry NANTUCKET

Figure 7.9 shows a progression of the situation in **Figure 7.8** advanced by approximately two minutes as the two ferries pass at their closest points (approx.

0.5nm). The linear reflections off EAGLE's port antenna have remained although they would have faded and reappeared as the reflected WTGs altered their aspect to the observing vessel. They will however be moving with the observing vessel for as long as there are targets (WTGs on the opposite side of EAGLE) to reflect. A different line of WTGs will however be reflected, hence the fading and re-appearance as each line goes out of and comes into view. The reflections off the ferry NANTUCKET will have rotated around the centre of the screen in line with the passing target that is NANTUCKET. As with the internally reflected linear targets the echoes will have faded and re-appeared as different WTGs are reflected in the topsides of the reflecting vessel.

At 0.5nm NANTUCKET will present a target that is less than 5° of the visible horizon. This precludes the possibility of a recognizable mirror image of the wind farm but could produce a partial one similar to that shown in **Figure 7.9**. In the furthest distance it may be possible to sight two turbine rows side by side but with the speed of transit this is not likely to be visible to the operator as by the time of the next sweep of the antenna the reflecting vessel will have moved on and the same sector will not be repeated. Such conditions are able to be captured on recorded images but this has no relevance to the situation of the navigator, which is to use information immediately available to him.

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7.3 Predicted effects on local Nantucket Sound vessels – smaller vessels.

7.3.1 Comparisons between Source data and local smaller vessels in Nantucket Sound

Thames Estuary

Left: Fishing vessels

Right: Wind Farm service vessel. (crew boat)

Nantucket Sound

Left and below: Fishing vessel Signal masts are similar to Thames Estuary examples i.e tubular vertical with angled stays (usually forward). Booms when upright, and their associated masts and spars may add to reflections aft.

Figure 7.10: Comparison of Small Craft: Thames Estuary (top left and right) vs Nantucket Sound (above and right).

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7.3.2 Predicted Radar Performance at Nantucket Sound

We are confident that small craft radars will be found to be effective in the vicinity of and within the Nantucket Sound wind farm just as they were in Kentish Flats. As can be seen in **Figure 7.10** the craft are similar in respect of the interceptors for radar. Most have vertical tubular signal masts with forward sloping stays. Some have significant booms and gantries associated with these booms. The masts and spars that are vertical will potentially create linear reflections but these will always be in after sectors. Fishermen who took part in the trials at Kentish Flats were comfortable with such reflections and the side-lobes that were also apparent in the same sectors because they were completely familiar with them. Such interference is a fact of life to them with or without the presence of a wind farm. They operate within the limitations imposed, which are few.

Proposed WTG spacing at Nantucket Sound varies very slightly from Kentish Flats. At Kentish Flats the spacing between WTGs in both axes of the array is 700m (0.38nm). At Nantucket Sound the spacing is based on a matrix with WTGs separated by 0.34nm in the North/South axis and 0.54nm in the East/West axis. The differences are very small and the relative angles between the directions of axes of the two arrays is very similar. Effects registering on the radars of small craft were all within a range from the WTGs that was less than the spacing between them and detection of the small craft separate from the WTGs was possible as far away as 6nm at Kentish Flats. This was irrespective of whether the small craft were in or beyond the wind farm array. There is no reason to expect any new criteria at Nantucket Sound that were not investigated at Kentish Flats.

7.3.3 Linear or Small Sector Multiple Targets: Predicted Radar Image at Nantucket Sound

Figure 7.11: Antenna Layout: Antenna mounted centrally ahead of tubular masts and spars

Vessels with centrally mounted radar antennas but close to and ahead of tubular masts and spars, such as the fishing vessels (inset) and possibly some other small craft, should expect to view a picture similar to that shown in **Figure 7.11** The position of this vessel is west bound along the southern edge of the proposed wind farm in the Main Channel and slightly to the west of the close approach point "J" in **Figure 6.2**. The position relative to the wind farm is closer than vessels such as ferries would be expected to proceed, the distance off the southern edge being only 0.25nm (the range in use on the radar display is 1.5nm.

The prediction is included as it represents probably the worst that should be expected in or in the vicinity of the Nantucket Sound Wind farm. The effects depicted include the internal effects of the masts and spars abaft the antenna, causing the beam width extensions shown to the right of the figure.

Also shown however is the effect of linear distortions caused at each wind turbine. The effect includes beam width extension due to the side lobes of the antenna reflecting off each turbine tower in the same way that they reflect off the vessel's masts and spars. Multiple echoes radiate away from the observing vessel due to multiple reflections from other turbines in the array.

The real significance of the figure cannot however be appreciated from the still representation. The two effects behave very differently, making them clearly distinguishable in the moving representation that is the real radar display. The internal effects remain relatively constant and always astern, while the external effects from the wind turbines rotate around each turbine as the observing vessel passes. In the case of this west bound vessel the rotation would be clockwise. Because the aspect of each is different the rate of change of these effects will vary between the different turbines, an effect that is clearly visible but not in this still representation and one which brings the apparent chaotic effect to a position that the captain of the vessel can more readily interpret. Loss of small targets in the array would appear to be the main concern here but the constancy of such targets will make them stand out from the other very mobile effects.

7.3.4 Yachts and leisure craft

Yachts in Nantucket Sound are very similar to those in Kentish Flats. In many cases they are identical, as are the radar installations. Displays that should be expected in Nantucket Sound should therefore be very similar to those indicated in **section 5.2**. The small angling boats in Nantucket Sound have antenna installations very similar to those of motor yachts in relation to their lack of obstructions from which reflections could be generated. Occasionally whip antennae or large fishing rods might each create a small linear reflection in which case a lesser version of the image in **figure 7.11** might be generated with fine linear reflections in the directions of any obstructions.

8 POTENTIAL EFFECTS ON MARINE RADAR COLLISION AVOIDANCE SYSTEMS – NANTUCKET SOUND WIND FARM

8.1 ARPA

Automated Radar Plotting Aids (ARPA) are regularly referred to as a type of radar with which all but the very smallest of sea going merchant vessels must be fitted. In reality ARPA capability is an attachment to a radar that is identical to other marine radars. The ARPA facility merely enables automated acquisition and tracking of targets and thereby the calculation of collision potential from the data obtained through the radar itself. The commercial vessels used to obtain data for the Kentish Flats were almost entirely all required by legislation to carry ARPA. Some were in use at the time of observations and in accordance with the principle of not interfering with the operations on the bridge of the subject vessel the status of such radars was left to continue. Observations therefore would be able to identify any effects that could be attributed to ARPA. There was only one effect significant enough to be noted - namely that of “target capture”, sometimes referred to as “target swap”.

Target Capture is a phenomenon connected to the ARPA’s ability to track individual targets, which, if they pass close to another, can then be confused by the ARPA with the second target. The result can be the automated tracking then transfers to the second target. This phenomenon was observed during trials at the Kentish Flats Wind Farm when targets (small craft in the wind farm) passed very close to the WTGs. The phenomenon was recognised by the radar operators, who regularly experience the effect, particularly when target vessels pass close to buoys. It is an effect that is expected in the confines of port approaches. No specific cause for the phenomenon could be attributed specifically to the WTGs; the effect existed elsewhere and was well known amongst radar observers.

8.2 Tracking using ARPA within the wind farm.

Regarding ARPA tracking, observations carried out by MORVEN were followed up using her own ARPA to track other vessels. Whether she was inside or looking through the array, other small craft were successfully tracked (See **Figure 8.1**) , even if they were inside the array themselves. Target capture is the exception rather than the rule whether it is inside or outside the wind farm. It requires the same criteria in either case, i.e. a very close encounter with the capturing target. It is probable that vessels passing along a narrow channel are far more prone to target capture (from the navigation buoys) than are vessels in a wind farm as there is less reason to pass close to the WTGs than there is to navigation buoys.

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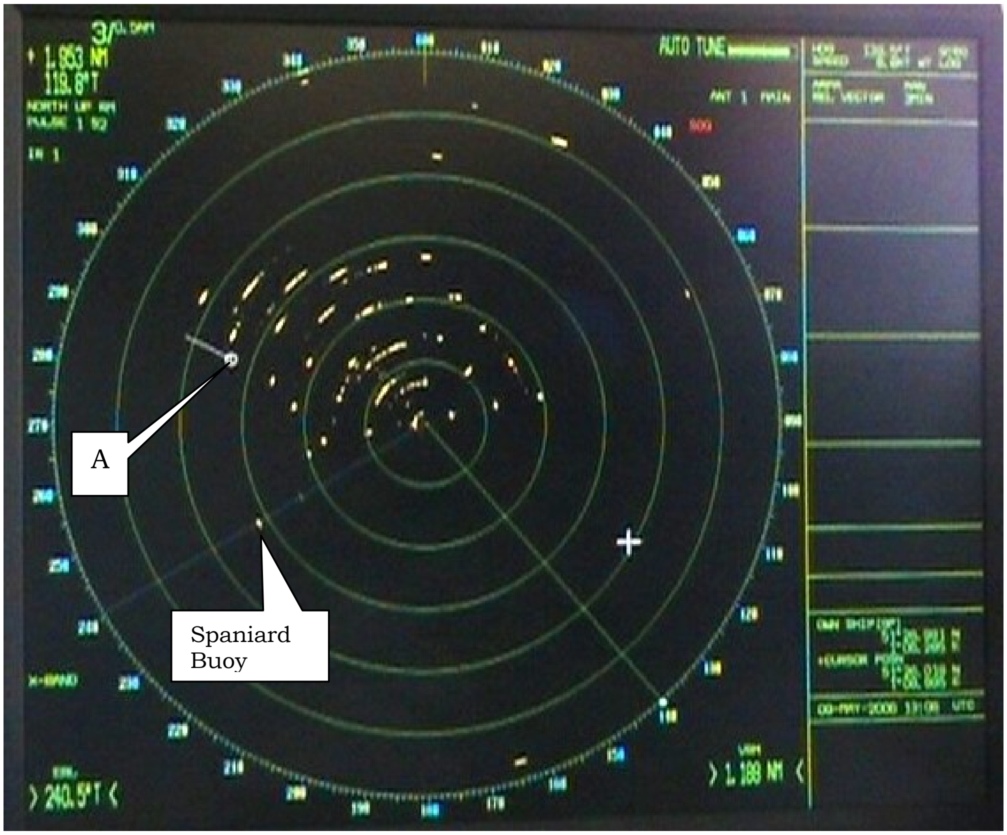

Figure 8.1: MORVEN is navigating between the Charlie and Delta columns and, despite being positioned fairly close to C5 is able to identify Spaniard buoy and target 'A', which is being tracked successfully on ARPA. The interference astern is caused by side-lobes intercepting the signal mast immediately abaft the antenna.

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9 POTENTIAL EFFECTS ON MARINE COMMUNICATION AND NAVIGATION SYSTEMS – NANTUCKET SOUND WIND FARM

9.1 GPS

We are aware of phenomena involving GPS in which anomalies can arise in position due to other influences such as re-radiation from outside antennas (such as TV aerials) or rebounding of signals off hard surfaces such as harbour walls. No such effects were experienced either in the Kentish Flats wind farm or in its vicinity.

Furthermore, navigation in and around the Kentish Flats Wind Farm was carried out using a mixture of visual, radar and GPS methods cross referencing by observation but also by noting the coincidence of AIS[20] and radar targets on overlaid displays. The observer vessel is within 1 nm of the Kentish Flats Wind Farm and is consistently experiencing this level of accuracy, which indicates that the proximity of the wind farm does not affect the GPS of either the observer or other vessels in the same area.

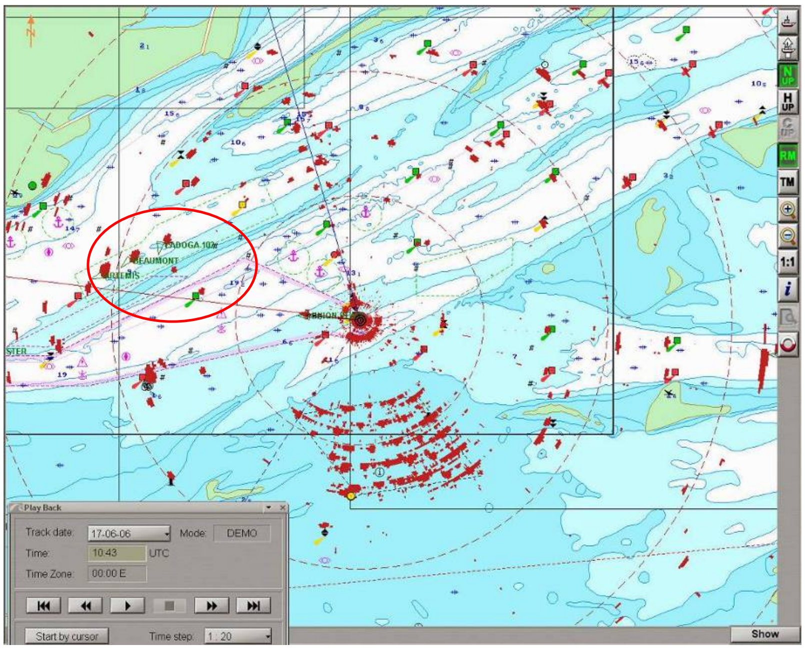

Figure 9.1 Integrated Navigation (ECS/AIS/RADAR) display. Position of radar overlay is coincident with chart display. AIS notations on vessels (ringed), which are independently obtained is also coincident. Positions of the target vessels is generated from the GPS of the vessel, not the observer.

MORVEN and some of the vessels used in the trials were fitted with integrated navigation systems that overlay information from a number of sources on the electronic chart display (see **Figure 9.1**). If there are discrepancies between radar and GPS it will be noticed on the display by disparity between targets from radar and AIS, which derives its position from GPS. No such disparities were witnessed either in or in the vicinity of the wind farm other than those that are understood between radar and AIS due to the historical lag of radar compared to the instantaneous transmission by AIS of information, in particular heading of the target. Radar takes longer to recalculate changes in heading or speed due to the

[20] AIS = Automated Identification System. A marine electronic beacon system for ships of over 300 GT

need to integrate several sweeps of the radar. Such disparities are few and far between and when they do occur they are understood by the navigators. It should also be noted that MORVEN regularly carries out high definition hydrographic surveying. The crew are well acquainted with integrated displays and have witnessed minor disparities on other occasions.

We are aware that GPS can acquire errors due to interference but it is usually associated with reflected signals off very hard surfaces such as granite breakwaters in the British Isles. Another source of interference is resonance of other antennae such as TV aerials that in Marinas can re-radiate the frequency of the GPS signal and cause errors. WTGs are much larger than the dipole necessary for such resonance and the lack of effects at Kentish Flats appears to verify this.

Nantucket Sound Wind Farm, although larger than Kentish Flats is very similar in layout and spacing. The possibility of resonance or reflection is therefore considered similar to that of Kentish Flats.

9.2 AIS

As indicated above, AIS information appeared unaffected by the presence of the wind farm during the Kentish Flats trials (see **Figure 9.1**). The method of transmission is by broadcast from the vessel concerned using a VHF frequency signal. It is possible that VHF signals can be attenuated in wind farm arrays due to alignment effects of the rows of WTGs but in the case of a broadcast such as AIS this does not matter. The quality of the signal and the input data is what matters, which is from the target vessel's own instruments and as can be seen above, the positional data, namely GPS is apparently unaffected by the presence of WTGs. In the Kentish Flats trials no deterioration of AIS quality was seen.

Nantucket Sound Wind Farm uses WTGs that are similar in dimension and spacing to those of Kentish Flats. Just as there was no detectable deterioration of signal in Kebtish Flats we would expect the same in Nantucket Sound.

9.3 Marine Band VHF

During the trials at Kentish Flats communications were maintained on marine band VHF as well as by mobile telephones. At no time in any of the extensive trials was any degradation of signal experienced and it was also noted that service craft are regularly working in the wind farm using the same methods of communication. The crews of those service craft reported the same lack of any degradation.

Marine band VHF is also used in Nantucket Sound and there is no reason to suspect that conditions will be any different. Full communications should therefore be expected although some alignment of signals with WTG rows may cause small errors in direction finding (DF) VHF radio receivers. It is expected however that in such an event, which is normally associated with an emergency, other Search and Rescue techniques will be used. At close range, where any DF errors might be

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noticed it would normally be possible to detect targets by visual, radar and, if carried, EPIRB transmissions.

9.4 DSC and Rescue 21

Digital Selective Calling and Rescue 21 both use marine band VHF as their waterborne transmission medium. Any effects applicable to VHF therefore will also be applicable to DSC and Rescue 21. During the trials at Kentish Flats MORVEN and other vessels in the trial were constantly connected with DSC. No degradation in the performance of the equipment was experienced. DSC alerts continued to operate either in or in the vicinity of the wind farm array.

Nantucket Sound is covered by marine band VHF networks and based on the UK experience in and around the Kentish Flats and other wind farms the medium should be able to remain fully active without any discernable interference.

9.5 EPIRBs

EPIRBs transmit terrestrially on 121.5MHz and to Satellite on 406 MHz., 121.5MHz is in the aviation band of VHF and used for homing. It is just below the main sector of marine band VHF (150 MHz). Attenuation and modification of direction of VHF radio beams could be experienced in a wind farm array. The effects, if they occurred, would only give cause for concern if they interfered with any ability to track the emitting device and from experience with VHF that should not be expected.

If the device does not incorporate a GPS derived position in its transmission such modification of direction might be viewed as of significance but the 406MHz signal to the satellite is just such a broadcast. Position fixing is achieved by triangulation between different satellites. The accuracy of position obtainable by triangulation would be expected to be in an area rather than at a point and realistically any SAR operation would not expect to be led directly to a casualty.

It is more probable however that if close enough to the wind farm for signal deflection phenomena to occur, the search for missing craft would be at the final stages of homing. Other options would, by that time be available to any SAR craft. It has been shown for example that radar targets of small craft can be tracked right through a wind farm array from either outside the array or from within it. This was ascertained at Kentish Flats on the surface and at North Hoyle (off north Wales) from a Coastguard Helicopter prior to the Kentish Flats trials. Additionally VHF communication can be established. It may be that homing is very slightly interfered with but as above, the search will be in its final stages and voice communication can use other position determining references, not least being the visual identification of the WTG nearest to the craft being sought. It is important that a quickly readable system of reference is visually marked on each WTG. The alpha/ numeric columns and rows system has the same qualities as Latitude and Longitude, or commonly understood spreadsheet notation.

9.6 E-Loran

E-LORAN is a US hyperbolic terrestrial system. No such system exists in the UK waters that was used by any of the vessels used in the trials. It is not possible therefore to determine if such systems are affected by the presence of wind farm arrays. GPS appears unaffected and it is the most widely used electronic positioning system used in Europe aboard both commercial and leisure craft. It is expected that the same is true in the U.S.A. in which case interference with E-LORAN is less important due to alternative systems that are now available.

Other hyperbolic position systems are known to acquire small errors from the presence of land masses. If E-LORAN is similar then the same or similar errors could be detectable but in Nantucket Sound the land mass surrounds the water mass where the wind farm is proposed. If there are any such corrections to be made they will already exist. Without further research it cannot be established that multiple towers, such as the WTGs in a wind farm are likely to create similar errors but as with other media the vessels in the area are unlikely to be relying on a single source of position finding, not forgetting that both visual and radar can be used for position fixing as well as GPS.

10 POSSIBLE MITIGATION

To mitigate the possible effects on ships' or boats' radar near the proposed wind farm at Nantucket Sound, we suggest the following:-

- The provision of designated reference buoy(s) or other appropriate known targets to aid adjustment of radar settings when vessels are operating near the proposed Nantucket Sound wind farm, could provide a valuable aid to the operation of all marine radars near and within the wind farm;
- Alternatively mariners could be advised to tune on existing buoys, designated if considered necessary, by notation on the chart;
- Pilots and other local users of the waters, both commercial and recreational, should be informed as to the type of radar interference they may encounter when guiding ships with certain Antenna / mast configurations;
- Masters should be encouraged to always discuss the radar shadow sector diagram of their vessel with Pilots, who should make the master aware of the additional effects that could be created by the positioning of obstructions in the radar beams;
- Mariners should familiarise themselves with likely effects to be expected close to the wind farm arrays. This enables the mariners to pass on their knowledge of possible effects close to the wind farm to masters who may be less familiar;

- In case a geared vessel is to pass the wind farm, we would recommend that port procedures be put in place to prohibit the topping of crane jibs or the movement of any other equipment likely to provide a reflective surface until the ship has cleared the area;

- It would be helpful to Mariners to be forewarned of the possibility of spurious echoes in the region such as may be annotated on navigation charts;

- Issues of correct operation of radars, and particularly automated controls could be emphasized in radar training by incorporation of effects like those found on wind farms into training and simulation. Local academies and other training schemes for both commercial and leisure mariners could incorporate the additional knowledge into their courses;

- VTS operators, should such services develop in the area, should be made aware that it is likely that both large slab sided vessels and the wind farm turbine towers within the reflected beam width may generate reflections; but

We believe that these procedures and/or measures will ensure that any effects from the proposed wind farm at Nantucket Sound can be safely mitigated.

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11 THE EXPERIENCE OF NAVIGATORS & PILOTS

During our research in 2006, Navigators and Pilots who had experience of navigating ships in the vicinity of wind farms were very helpful in sharing their experiences with our observers, the topics discussed included:

- radar shadow areas;
- description of effects;
- ranges and relative angles;
- consequences;
- mitigation measures taken; and
- other phenomena observed elsewhere by Masters/Pilots/Watch Officers.

The comment most frequently recorded by observers concerning the reactions of regular run Masters and Pilots in these pilotage waters in relation to the effects caused by the Kentish Flats wind farm specifically was that they were "unconcerned". This comment, we believe did not reflect a disinterested operator which might be misunderstood as unprofessional.

Most of the effects observed were either in a similar direction relative to the intended course of the vessel or they were very obviously spurious reflections in other directions; e.g. the mirror image and narrow sector reflections of the wind farm matrix in way of identified obstructions. To these Mariners experienced in the Kentish Flats phenomena, during these specific trials they did not represent a primary threat and were not construed as such, either mentally or automatically by acquiring the targets on the ARPA.

On three passages the pilot mentioned effects that would otherwise have been relatively unnoticed when visually verifiable. Because of restricted visibility however, spurious echoes could cause a certain amount of heightened concern.

The positioning of radar display units in the wheelhouse appeared to have a direct influence on which of the two radars was used for navigation. It was observed that in a number of cases the 10cm radar display, being located closer to the conning position, was being used as the primary source in confined waters when the 3cm radar would have presented a higher resolution picture, other than in precipitation when the superior ability of the 10cm radar to detect targets in rain would make its use preferable.

Equipment refits also appeared to have an influence on the radar set used; i.e. one vessel had a new 10cm installation with a bright daylight display. This was used exclusively whilst the older but higher resolution 3cm radar remained on standby. These observations may indicate that mariners are not using their radars to their full advantage.

The number of vessels equipped with AIS overlaid on radar or AIS overlaid onto an electronic chart system was very limited. Many Masters expressed the desirability and advantages to collision avoidance in information presentation gained by such systems as against the small difficult to read LCD displays on the AIS units themselves.

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12 FREQUENTLY ENCOUNTERED PERCEPTIONS

Having been associated with the subject of wind farms and their effects on shipping for several years in UK and Europe we are aware of a number of perceptions held by concerned parties, usually prior to establishment of factual data when a wind farm is constructed offshore. Similar concerns had been expressed in UK and Europe when the various trials were conducted. These concerns were taken seriously and trials that were conducted at Kentish Flats were largely aimed at investigating the phenomena that could be influential in radar performance. The study above, derived from the Kentish Flats trials and its comparisons to the Nantucket Sound proposed site should, we consider, answer all of those perceptions

The most commonly encountered perceptions can be reduced to a small number of main concerns that are summarized and addressed below.

12.1 Interference with radar on vessels passing the windfarm.

Experience in the UK at Kentish Flats Wind Farm showed that vessels passing within 1 nm of the array were variously affected but some were not affected at all. This proves that the principal causes of interference are located aboard those vessels where interference was experienced rather than from the WTGs. The strength of signal returning from the array, a phenomenon often referred to, was not overwhelming. The most intrusive interference was from reflections from internally mounted obstructions aboard the vessels such as stanchions and masts but even then the issue was seen not to be problematic to the mariners aboard the vessels. Most were familiar with the interference and were able to take it into account in their broader considerations in navigating their vessels. Section 4 in relation to the source data and section 7 as it affects Nantucket Sound address these effects.

12.2 Radar detection of vessels through the wind farm.

It is often thought that the presence of a matrix array of wind turbines between the observing vessel and the target will act as some kind of barrier through which radar propagation is not possible or is seriously reduced. The truth is that trials in and around the Kentish Flats Wind farm proved that it was virtually unaffected. Targets on the far side of the wind farm were as visible on radar as they were in open water. Reflections of the wind farm due to obstructions, either aboard the observing vessel or due to the presence of another reflective surface – most notably a large "slab-sided" vessel at very close range – was never in the direction of the target. This was because, by definition, a reflected image will be in the opposite direction from the target. It therefore did not affect the radar visibility of the target vessel. Section 5 addresses the phenomenon and figure 5.1 illustrates it.

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12.3 Radar detection of vessels outside the wind farm from an observing vessel within the array.

The trials at Kentish Flats included a number of passages through the array. The observing vessels, which varied between a survey vessel, the wind farm service vessel, fishing boats and yachts, both powered and sailing, were all able to detect vessels that were outside the array. Interference from nearby WTGs was restricted to reflections off each of the towers as they were passed, which created linear reflections in the direction of and beyond the towers. These reflections were transient and very obviously spurious. The strength of signal from vessels was unaffected. Section 5 addresses the phenomenon and figure 5.5 illustrates it.

12.4 Radar detection of other vessels in the wind farm from an observing vessel within the array.

Kentish Flats experience showed that detection of other vessels in the array was similar to the situations in the two previous sub-sections. The strength of signal from real targets was always more consistent than interference – most commonly linear reflections off the towers at closest proximity. The majority of craft used for these trials were equipped with small craft radars with coarse beam-width antennae but despite this the beam-width extension and enlargement of echoes on the display, which was common, was still able to cope with the presence of other vessels in the array. There were never any situations where targets were hidden behind large echoes for any length of time. The width of the WTG towers is only 16 feet and for a target to remain inline with such a slender obstruction is almost impossible. Shadowing and eclipsing behind WTGs did occur but was limited and transient. Section 4.5 addresses the shadowing and section 5 the other targets. Section 7.3 addresses the expected effects in Nantucket Sound.

12.5 Excessive strength of echoes from turbine towers and blades

It is often purported that the strength of radar signals returning from towers and blades of wind turbines is excessive to the point of obscuring all other targets on the radar display. Evidence at Kentish Flats indicates that this is an over-statement. There is a stronger signal due to multiple reflections between the turbines in an array – what we choose to call the “chandelier effect” - but the evidence also suggests that it is the towers that are the main source of them. Echoes from wind farms under construction, in which only the bases are in evidence just above the water, appear to create similar displays to those after completion. Blades are constructed from composite fibres and are expected to be somewhat opaque to marine radar and certainly no effects have been witnessed that suggest they in any way enhance returns. This may be different to the experience of Doppler radars such as are used in air traffic control or defence but experience in Europe at airports close to offshore wind farms shows that this too is manageable. Displays during the Kentish Flats trials were never so distorted that the main targets – the other vessels and navigation marks - were obscured. The suggestion that such larger echoes will hide other vessels inside or outside the wind farm array is not borne out in practice. Besides this, prudent mariners do not navigate solely on radar and they tend to aggregate the information they receive from it with the many other sources they have at their disposal including visual observation and they make their decisions based on the collective result. They also take precautions. Prudent mariners do not normally navigate so close to wind farms or other targets that in the event of an unexpected interception they cannot avoid collision.

12.6 The presence of wind farms close to shipping lanes is dangerous to shipping.

This could be valid if it were true. Although some earlier wind farms in Europe were placed in positions with little apparent consideration of the effects on navigation they are generally to one side of the navigation channels. The preferred siting of wind turbines is in shallow water. This is an obvious choice in avoiding shipping routes but is also often geologically advantageous. It follows that interceptions between larger vessels and wind farms are therefore limited as the larger vessels will require more water than is available to navigate close to the majority of WTGs. In Nantucket Sound this is true for the majority of WTGs. Those that are in deeper water are positioned within the horseshoe of shoals that give the area its name. This area is surrounded on three sides by shallow water and therefore has no through route to open water. It is therefore unlikely to be visited by vessels of any significant size. In terms of radar and electronic navigation this is significant as it ensures that the surprise situations mentioned above are very unlikely. There is no reason for their development and the distance that larger vessels stand off the array will ensure they have sufficient time to act in such an unlikely event.

12.7 Increased physical separation between wind farms and shipping lanes reduces marine radar interference

The UK MCA had, previous to the Kentish Flats trials advised an optimum distance off wind farms of two nautical miles. This was based on theoretical analysis and early but limited trials on radar interference. The Kentish Flats wind farm is situated considerably closer to the southern edge of the heavily travelled main channel into the ports of London and Medway on the Thames and it does not cause problems for the navigators in the area. The trials undertaken in 2006 for the project referred to earlier in this document further updated this criterion. It was shown by the trials that vessels of the full spectrum of sizes in the area could navigate to within this area and, dependent on their configuration of antenna and other obstructions, experience little or no interference. It was noted that in sailing craft in particular with an antenna mounted fairly high on the mast, sea clutter interference – due to reflections from the waves adjacent to the vessel – was greater than anything seen relating to the WTGs. Sea clutter exists in open water as much as it does in restricted areas such as wind farms and it is manageable.

The trials also revealed that adjusting gain on the radars was one way of reducing any interference, which was always experienced at a lower level than real targets. The technique used by many mariners in the Thames area, and recommended as a result of the trials, is to tune the radar on a known navigation buoy, which, as long

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as it remains visible will ensure that similar targets such as small craft will also remain visible, whilst any lesser spurious and transient targets that are caused by WTGs are reduced or eliminated. Given this information there is every reason to expect mariners to respond in their practices.

13 CONCLUSIONS

From the application of our knowledge of the effects of offshore wind farms on marine radar, we believe that the proposed wind farm at Nantucket Sound will not cause unmanageable concerns to ships operating within the area because:

- Experience in Europe has shown that mariners become increasingly aware of any effects as more offshore wind farms are built and can interpret them correctly. We believe that navigators will be able to effectively track other vessels from both within and behind the area of the wind farm;
- Many vessels, especially those with radar antennas mounted above and clear of masts, stanchions and other onboard structures, can be expected to experience minimum effects and many during the Kentish Flats trials displayed no effects at all;
- The majority of effects will display abaft the beam and for vessels operating within a channel and harbour area this is of lower importance;
- Ship's Officers will be aware of any tendency of their vessel to produce effects due to the configuration of the radar antennas, masts and other fittings;
- Experience in UK and Europe suggests pilots will quickly become familiar with the type of effect to be expected from vessel's with certain antenna configurations;
- The phenomena detected on marine radar displays near a wind farm can be produced by other strong echoes close to the observing ship, although not necessarily to the same extent. Trained mariners will recognise and understand the causes of these effects;
- Some of the effects will be transitory in relation to the speed of the vessels passing the wind farm site and will therefore be of little concern;
- Our previous research has shown that small craft operating in and near the wind farm were detectable by radar on ships operating near the array and we expect that the Nantucket Sound site will experience the same;
- When targets are on the opposite side of the wind farm array the quality of returned echoes does not appear to be adversely affected; and
- This study has concentrated on the channels to the east and south of the Horseshoe Shoal in Nantucket Sound – the area of the proposed wind farm. Other traffic routes such as the one passing to the north of the area will probably experience mild interference but the aspects and ranges of vessels using that route in relation to the wind farm will mean that effects should be expected to be similar.

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GLOSSARY

ASMS	Active Safety Management System
AIS	Automatic Identification System
ARPA	Automatic Radar Plotting Aid
Abaft	In a direction towards the stern of the vessel
Abeam	In a direction across the vessel laterally
Afloat	Supported by water
Aground	No longer supported by water but in contact with the bottom
Ahead	In a direction beyond the bow, viewed from a position within the boundaries of the vessel.
Aloft	In a direction above the deck relating to a viewer standing on a deck within the boundaries of the vessel.
Ashore	On land; i.e. not on a floating vessel
Astern	In a direction beyond the stern, viewed from a position within the boundaries of the vessel (opposite to ahead)
Athwartships	Positioned in a direction running across the vessel from side to side and at right angles to the longitudinal axis of the vessel
Bow	The forward or front section of the vessel.
CCTV	Closed Circuit Television
CD	Chart Datum
CNIS	Channel Navigation Information Service
ColRegs	International Regulations for Preventing Collision at Sea
Deck	Horizontal surface within the structure of a vessel equivalent to ground or floor ashore
DfT	Department for Transport
DSC	Digital Selective Calling
DTI	Department of Trade and Industry
DWT	Dead-Weight Tonnes - The mass in tonnes that a vessel can carry. Not to be confused with the volumetric Gross Tons (see below)
ECS	Electronic Chart System
EIA	Environmental Impact Assessment
ETV	Emergency Towing Vessel
Forward	In a direction towards the bow of the vessel (opposite to abaft)
FV	Fishing vessel
GIS	Graphic Information System
GMDSS	Global Maritime Distress and Safety System
GRP	Glass Reinforced Plastic or Fibreglass
GT	Gross Tonnage - a volumetric measurement of the vessel used for legal purposes. Not to be confused with displacement or deadweight tonnes.
IALA	International Association of Lighthouse Authorities
IMO	International Maritime Organisation
IHO	International Hydrographic Organization
ISM	International Safety Management Code
km	Kilometre
LOA	Length Over All
m	Metre
MAIB	Marine Accident Investigation Branch
MARICO	Marine & Risk Consultants Ltd
MCA	Maritime and Coastguard Agency
MHWS	Mean High Water Springs
MGN	Marine Guidance Note
Mt	Million tonnes
MY	Motor yacht
nm	Nautical Mile (approx. 1,852m)
NtM	Notices to Mariners
OREI	Offshore Renewable Energy Installation

PAD	Port Autonome de Dunkerque
PEXA	Firing Practice and Exercise Area
PLA	Port of London Authority
Port	The side of the vessel that is on the left side of the longitudinal centre line related to a viewer looking forward (opposite to starboard)
RACON	Radar automated transponder beacon transponder device
RNLI	Royal National Lifeboat Institution
SEA	Strategic Environmental Assessment
SQL	Structured Query Language
Starboard	The side of the vessel that is on the right side of the longitudinal centre line related to a viewer looking forward (opposite to port)
Stern	The aftermost part or back of the vessel, relating to a viewer facing forward (opposite to bow)
THLS	Trinity House Lighthouse Service
TSS	Traffic Separation Scheme
UKHO	United Kingdom Hydrographic Office
UNCLOS	United Nations Convention on the Law of the Sea
VHF	Very High Frequency
VTS	Vessel Traffic Services
WFZ	Wind Farm Zone
ZOI	Zone of Influence

ANNEX A

Record of Vessel Types Investigated

Radar display and other data was recorded near the Kentish Flats wind farm from the following vessel types:-

Vessel Type	**Transits**
Bulk Carriers	4
Car Carriers	7
Container Vessels	7
Dredgers	3
Gas Carriers	1
General Cargo Vessels**	10
LASH Carriers	1
Passenger Vessels	3
Refrigerated Cargo Vessels	3
RoRo Vessels	6
Service Vessels*	1
Tankers (large and small)	4
Tankers - Chemical	3
TOTAL	**53**
PLUS survey vessel "MORVEN"*, 3 yachts*, PLA RIB and 3 fishing vessels*	

* Vessels marked thus were small craft operating in or close to the wind farm.

** General Cargo Vessels embraced a wide variety of mainly coastal vessels, some were intended for inland waterway use and therefore fitted with very low radar Antennae, and others were more conventional.

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