Wind Turbine Analysis for

Cape Cod Air Force Station Early Warning Radar

and Beale Air Force Base Upgraded Early Warning Radar

Spring 2007

EXECUTIVE SUMMARY

The Missile Defense Agency (MDA) analyzed the potential impact of utility class wind farms on radars.

- Utility class wind farms could have a significant impact on radars, including the missile defense early warning radars (EWRs), the PAVE PAWS radar at Cape Cod AFS, MA, and the Upgraded Early Warning Radar (UEWR) at Beale AFB, CA.
- To mitigate this impact, establish and enforce a wind farm offset zone within the effective "line-of-sight" of the radars, taking into account the direct, refracted, and diffracted signals from the radar. This effectively establishes a zone around the radar of approximately twenty-five kilometers, assuming relatively level terrain.
- Within twenty-five kilometers, further study would be required to assess the impact accounting for location within the radar's field of view and the relative height of the wind turbine.
- After establishing this offset zone, eliminate any remaining impacts on the radar by using gain control and range gating techniques.

History

Studies on the effects of windmill farms on military readiness were documented in a 2006 Report to Congressional Defense Committees. That report focused on the effects of wind farms on radars and the resulting potential impact on military readiness.

The primary historical data and research efforts were focused on air defense radars, characterized as "Primary Surveillance Radars" (PSR) and Air Traffic Control (ATC) radars. Two fixed-site missile Early Warning Radars (EWR) were mentioned in the report but not examined in detail. A testing campaign was planned and executed to establish a technical baseline on the radar cross section and Doppler behavior of a modern utility-class wind turbine that could be used to support development of future mitigation approaches.

Subsequently, the Missile Defense Agency (MDA) was requested to analyze the effect on the early warning radar (EWR) at Cape Cod Air Force Station (AFS) and the upgraded early warning radar (UEWR) at Beale Air Force Base (AFB). This report responds to that request and establishes appropriate offset distances where modern utility-class wind turbines can be constructed without adversely impacting the performance of these radars.

Missile Early Warning Radars

PAVE PAWS is an Air Force phased array radar system with two primary missions: missile warning and space surveillance. While providing surveillance, it is capable of detecting and tracking Inter-Continental Ballistic Missiles (ICBMs) and Submarine Launched Ballistic Missiles (SLBMs) that enter its field of view. After detection, the objects are continuously tracked. The second mission is to support the Space Surveillance Network, which involves the surveillance and tracking of earth satellites and identification of other space objects.

The PAVE PAWS has two faces, as shown in Figure 1, that contain elements that transmit and receive the radio frequency (RF) signals generated by the radar and reflected from the target. The array faces are tilted back 20 degrees from vertical to allow the beam to be scanned from 3 degrees above the horizon (beam center) to 85 degrees above the horizon. At this time the PAVE PAWS radar at Cape Cod AFS is not an Element of the Ballistic Missile Defense System (BMDS).

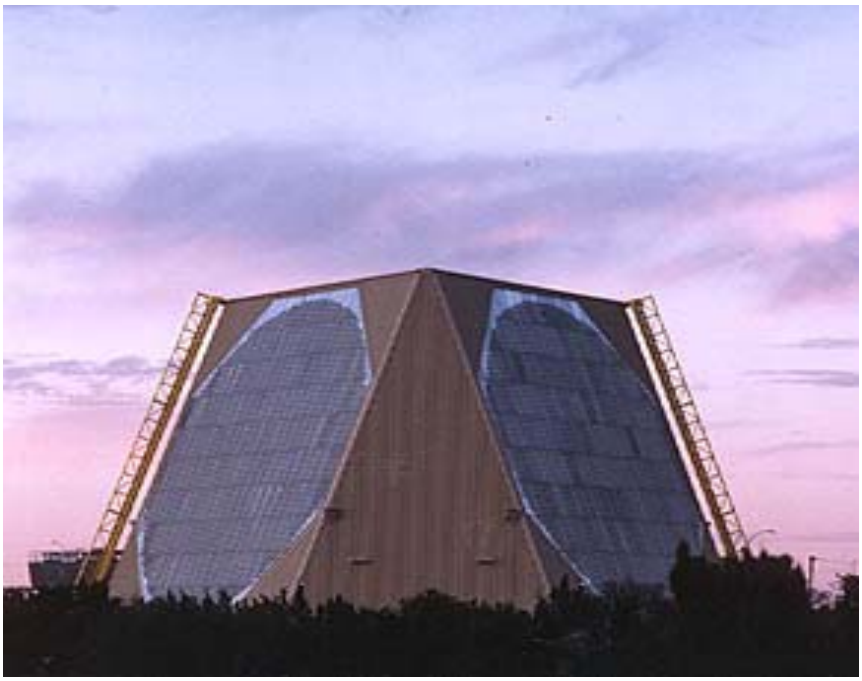

Figure 1. PAVE PAWS Radar

PAVE PAWS at Cape Cod Air Force Station

A PAVE PAWS radar is located at Cape Cod AFS, near Otis AFB. Figure 2 depicts how the PAVE PAWS radar is situated operationally with the north face of the radar covering the 120 degree sector from 347° to 107°; the south face of the radar covering from 107° to 227°. The figure also shows the twenty-five kilometer range extent.

There are two wind farms proposed near the Cape Cod AFS. One of these, known as the Hull turbines, is located, as indicated at the top of Figure 2.

(1.) Hull One: 42 deg 18 min 15.73 sec N, 70 deg 55 min, 19.80 sec W. Ground elevation 9 ft, Turbine height 150 ft with 75 ft blades.

(2.) Hull Two: 42 deg 15 min 41 sec N, 70 deg 51 min 26 sec W (approximate position, seeking verification). Ground elevation approx 25 ft, Turbine height 250 ft with 130 ft blades.

The second wind farm is known as Cape Wind™. Planned for a location near Horseshoe Shoal in Nantucket Sound, it will contain 130 wind turbines, generating 420 megawatts of electricity. Its approximate location is also indicated on Figure 2 near the bottom.

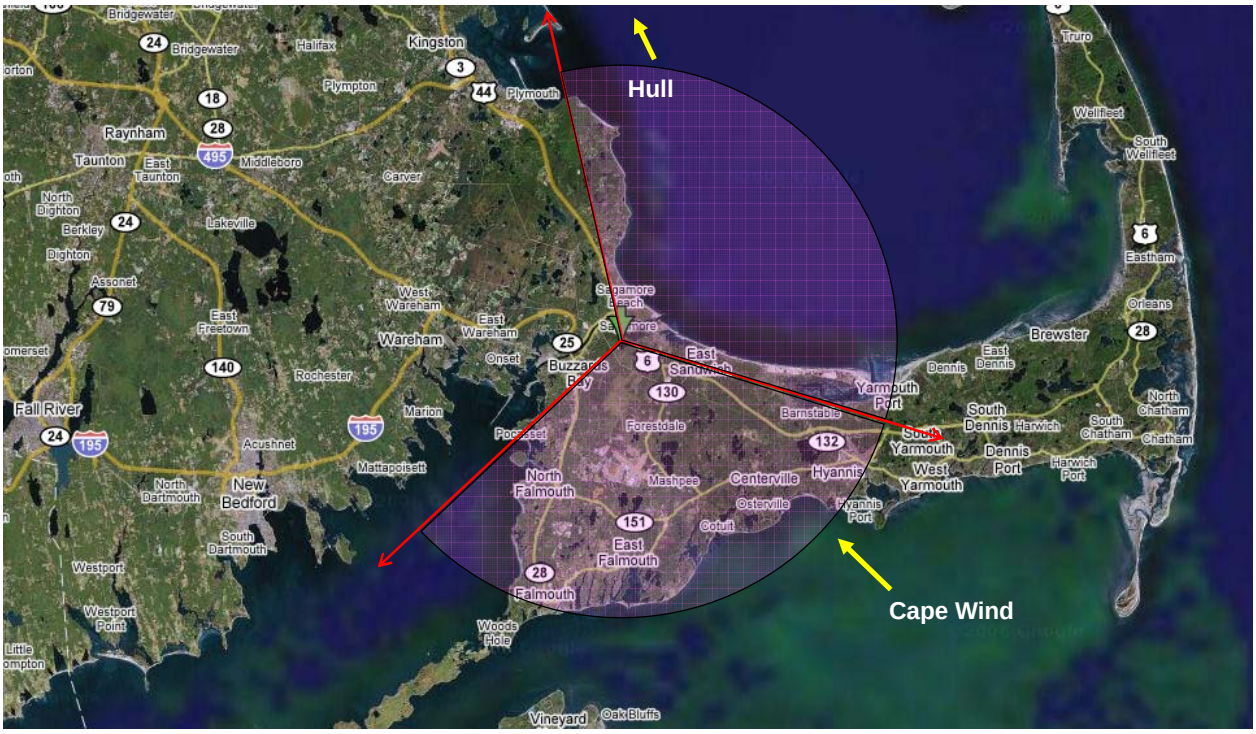

Figure 2. PAVE PAWS Location at Cape Cod

Upgraded PAVE PAWS at Beale Air Force Base

The PAVE PAWS radar at Beale AFB has been upgraded to improve its performance for the Ballistic Missile Defense missions. Consequently, it is referred to now as an Upgraded Early Warning Radar (UEWR). The Beale UEWR is located in the northern Sacramento Valley as shown in Figure 3.

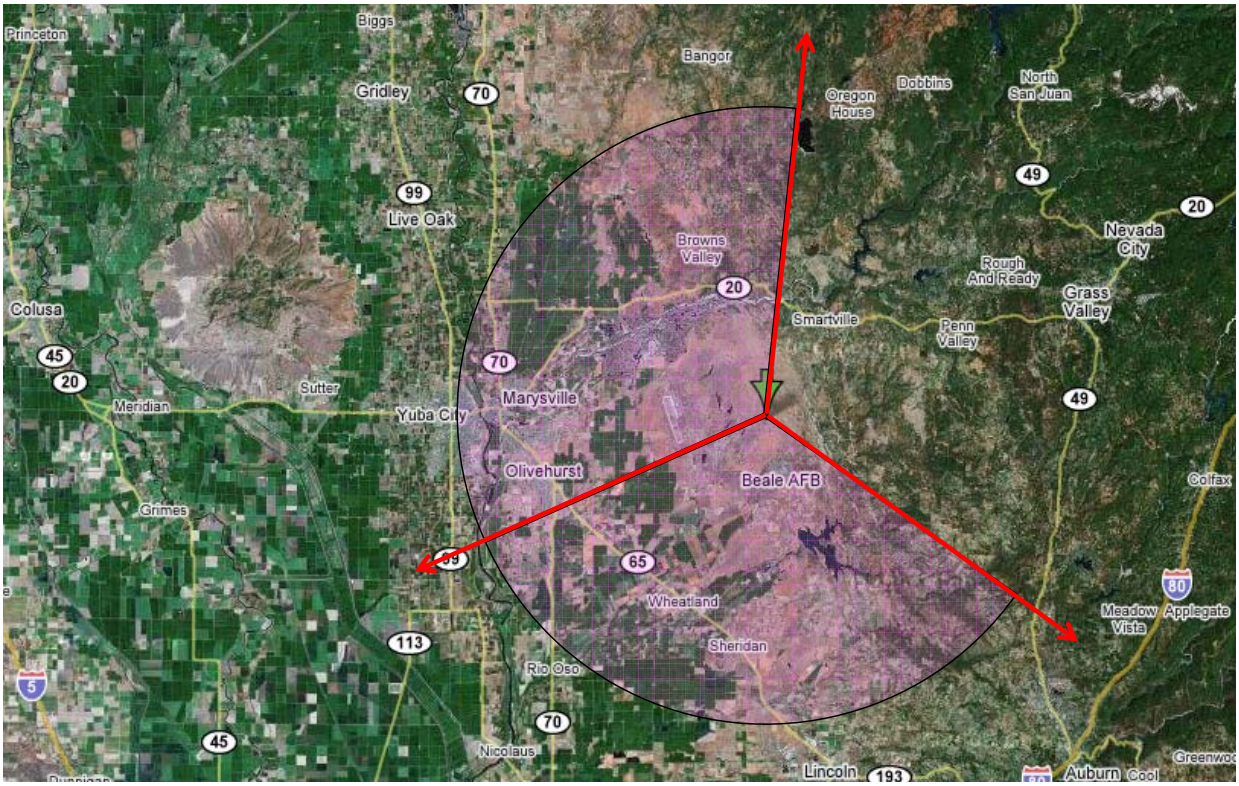

Figure 3. UEWR at Beale Air Force Base, CA

The runways of Beale can be seen immediately west of the UEWR. In the radar's line of sight, the Sutter Buttes, approximately 40 km west of the radar, provide a large radar return that is mitigated through range gating and data processing techniques which could be used to alleviate returns from wind turbines in the radar side lobes.

There are currently no wind farms in the line of sight or the immediate area of Beale AFB. However, three of the largest wind farms in the world are located in California. One of the largest is in Northern California, in Altamont Pass, south of Beale in the San Francisco Bay Area.

Impact and Mitigation of Interfering Signals

As described in the 2006 Report to the Congressional Defense Committees on The Effect of Windmill Farms On Military Readiness, the refraction effect for the frequency band of the EWRs can be approximated by employing a "4/3 earth model." In this approximation, a geometric line of sight is calculated using an effective radius for the earth equal to the actual radius of the earth multiplied by the factor 1.33. Using the 4/3 earth model, the minimum height of the main beam and the height of the bottom of the beam are shown in Figure 4.

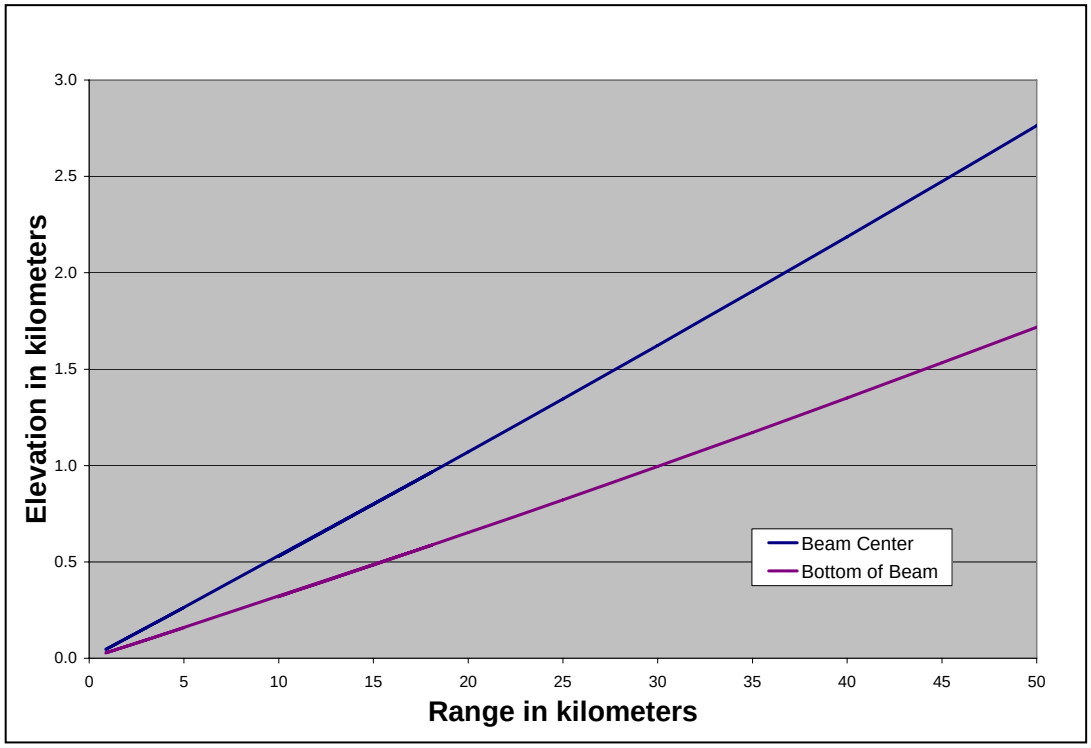

Figure 4

Wind turbines in the main beam, back lobes or side lobes of the radar, as shown in Figure 5, can impact radar performance if not mitigated.

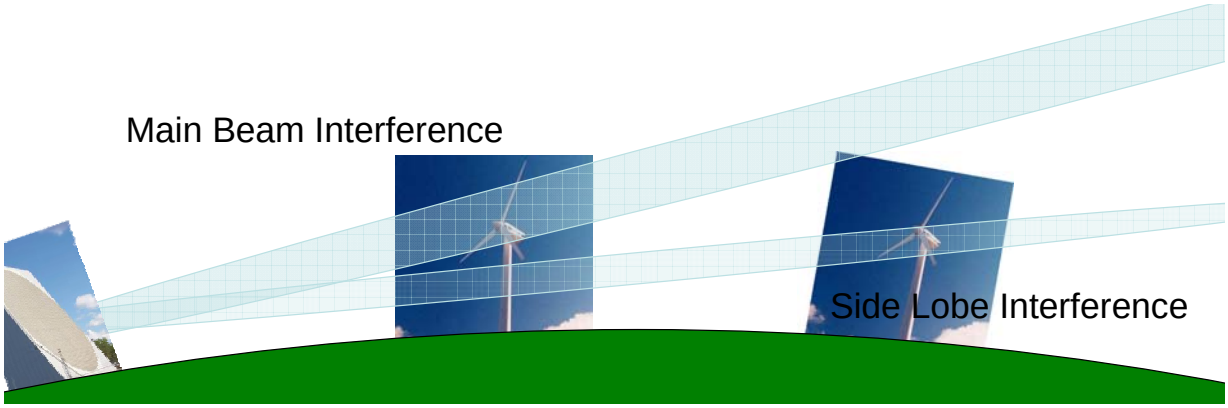

Figure 5

Objects in the path of an electromagnetic wave affect its propagation characteristics. The radar energy may be blocked and reflected (terrain masking) or diffracted around the encountered objects. This reduces the total energy of the beam beyond the objects and is not easily characterized, since the terrain and man-made structures can have a significant impact on the signal strength. This energy reduction substantiates a need to establish keepout zones in the effective line of sight of the main beam of the radar to provide effective mitigation.

The principle impact of wind turbines in the radar sidelobes are the reflected returns. If not mitigated, these could provide false targets to the radars. Since the EWRs are designed to search and track at long ranges (beyond 1000 km), only a small portion of the transmitted energy could be received from objects reflecting energy at ranges less than 100 km, where sidelobe energy may reach wind turbines. At these short ranges, the impact of the energy return from targets is mitigated by pulse eclipsing and range gating, which prevents the radar from receiving the full transmitted pulse energy. In addition, data processing techniques for automatic gain control can mitigate returns from targets close in range, as is performed on the energy reflected from the Sutter Buttes west of Beale AFB.

CONCLUSIONS AND RECOMMENDATIONS

The discussion above supports the following recommendations and conclusions applicable to placement of wind farms in the vicinity of Cape Cod AFS and Beale AFB.

- Utility class wind farms could have a significant impact on radars, including the missile defense early warning radars (EWRs), the PAVE PAWS radar at Cape Cod AFS, MA, and the Upgraded Early Warning Radar (UEWR) at Beale AFB, CA.
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