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IFT&E Industry Report

Wind Turbine-Radar Interference Test Summary

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Abstract

Wind turbines have grown in size and capacity with today's average turbine having a power capacity of around 1.9 MW, reaching to heights of over 495 feet from ground to blade tip, and operating with speeds at the tip of the blade up to 200 knots. When these machines are installed within the line-of-sight of a radar system, they can cause significant clutter and interference, detrimentally impacting the primary surveillance radar (PSR) performance.

The Massachusetts Institute of Technology's Lincoln Laboratory (MIT LL) and Sandia National Laboratories (SNL) were co-funded to conduct field tests and evaluations over two years in order to:

I. Characterize the impact of wind turbines on existing Program-of-Record (POR) air surveillance radars;
II. Assess near-term technologies proposed by industry that have the potential to mitigate the interference from wind turbines on radar systems; and
III. Collect data and increase technical understanding of interference issues to advance development of long-term mitigation strategies.

MIT LL and SNL managed the tests and evaluated resulting data from three flight campaigns to test eight mitigation technologies on terminal (short) and long-range (60 nmi and 250 nmi) radar systems. Combined across the three flight campaigns, more than 460 of hours of flight time were logged.

This paper summarizes the Interagency Field Test & Evaluation (IFT&E) program and publicly-available results from the tests. It will also discuss the current wind turbine-radar interference evaluation process within the government and a proposed process to deploy mitigation technologies.

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ABBREVIATIONS

AMOSS	Air and Marine Operations Surveillance System
ARAP	Adjunct Radar Analysis Processor
ASR	Airport Surveillance Radar
ARSR	Air Route Surveillance Radar
C2	Command and Control
CARSR	Common Air Route Surveillance Radar
CFAR	Constant False Alarm Rate
DHS	Department of Homeland Security
DOD	Department of Defense
DOE	Department of Energy
DUSD(I&E)	Department of the Under Secretary of Defense-Installations and Environment
FAA	Federal Aviation Administration
GW	Gigawatt
IFT&E	Interagency Field Test and Evaluation
MIT LL	Massachusetts Institute of Technology Lincoln Laboratory
mph	Miles per hour
MW	Megawatt
NAS	National Airspace System
nmi	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
P_D	Probability of Detection
P_{FA}	Probability of False Alarm
POR	Program of Record
PSR	Primary Surveillance Radar
RFI	Request for Information
SNL	Sandia National Laboratories
SSR	Secondary Surveillance Radar
STARS	Standard Terminal Automation Replacement System
WT/RI	Wind Turbine/Radar Interference

1. Background

It is known that wind turbines can present a source of interference with radar systems. With the nation's objectives for increased renewable energy, the number and size of operating wind turbines is expected to grow. The electromagnetic interference of wind turbines on the nation's radar systems is a concern to flight safety, homeland security, national defense, and severe weather warning missions.

In May 2011, the White House Office of Science and Technology completed an internal decision-making study at the request of the National Security Staff entitled "Report of the Interagency Task Force on the Impacts of Wind Turbines on Electromagnetic Sensing and Communications Capabilities." The report found that wind turbines were interfering with government radars used for national defense, national security, aviation safety, and weather forecasting "by creating clutter, reducing detection sensitivity, obscuring potential targets, and scattering target returns. These effects on radar systems tend to inhibit target detection, generate false targets, interfere with target tracking, and impede critical weather forecasts." Since 2000, wind generation capacity in the United States has increased from 5 GW to over 61 GW by the end of 2013 and could be as high as 330 GW supplying 20 percent of the nation's electricity by 2030. In order to accommodate future wind energy growth in the U.S., new technologies are needed to mitigate the wind turbine-radar interference problem. Because multiple agencies rely upon radar systems to meet their mission requirements, interagency collaboration is vital to the acceptance of new wind turbine-radar mitigation technologies.

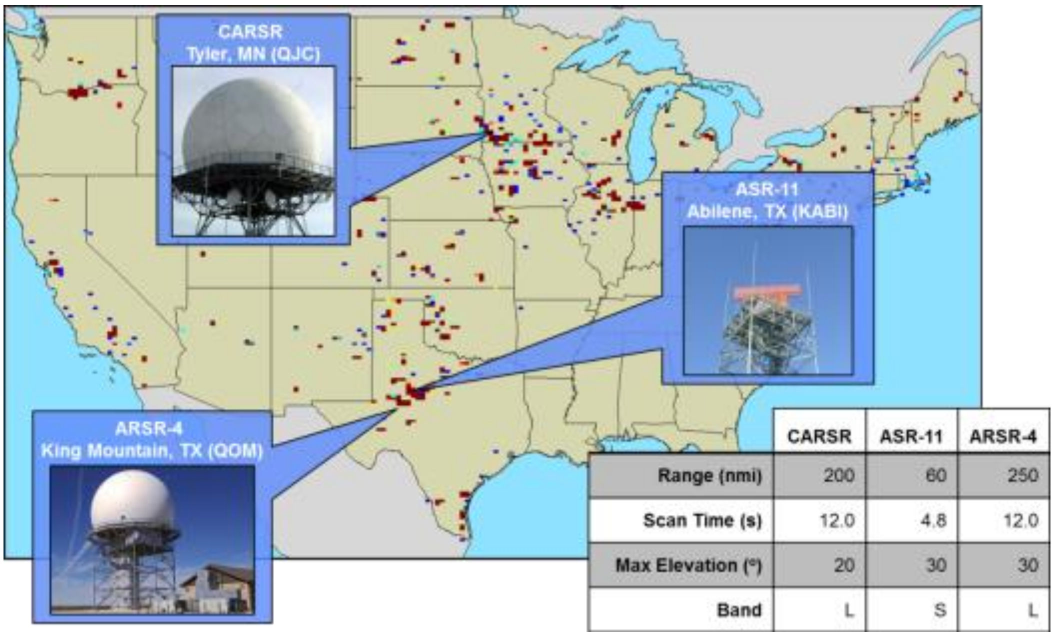
The Interagency Field Test and Evaluation (IFT&E) program was established in response to Congressional directives and White House recommendations to address the competing objectives of wind energy growth and national air surveillance requirements.

2. Interagency Field Test & Evaluation

Supported by directives from Congress, the Administration recommended that key government radar stakeholders establish the IFT&E program to investigate and address the concerns of growing barriers resulting from wind turbine interference on the nation's air surveillance radars. The program had three goals: i) characterize the impact of wind turbines on existing Program-of-Record (POR) air surveillance radars; ii) assess near-term mitigation capabilities proposed by industry; and iii) collect data and increase technical understanding of interference issues to advance development of long-term mitigation strategies.

This program was established as a two-year effort, funded and supported by Department of Energy (DOE), Department of Defense (DOD), Department of Homeland Security (DHS), and the Federal Aviation Administration (FAA) with collaboration and assistance from the National Oceanic and Atmospheric Administration (NOAA). The program included a total of three flight campaigns. Each campaign was conducted near an existing POR radar which had a large number of wind turbines in its field of view. The three POR radars tested were a long-range Common Air Route Surveillance Radar (CARSR), a short-range, terminal Airport Surveillance

Radar (ASR, in this case, an ASR-11), and a long-range, Air Route Surveillance Radar (ARSR, in this case, an ARSR-4)[1]. Eight different mitigation concepts were assessed during these campaigns. Each two-week flight test campaign involved the collection of data from the federally-owned radar systems, several types of government and private aircraft, a variety of wind-radar mitigation technologies, and wind turbines in the test area.



	CARSR	ASR-11	ARSR-4
Range (nmi)	200	60	250
Scan Time (s)	12.0	4.8	12.0
Max Elevation (°)	20	30	30
Band	L	S	L

Figure 2-1: IFT&E test locations and tested POR radar systems

The federal agencies used two national laboratories—DOD's Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) and DOE's Sandia National Laboratories (SNL)—to manage the test and evaluation program because of their world-class expertise on radar and wind technologies, their ability to access and protect sensitive and proprietary data, and their credibility in providing objective and independent assessments.

2.1 Proposed Mitigation Technologies

In September of 2011, SNL issued a public notification through a Request for Information (RFI) to acquire information from radar developers, radar-related software producers, radar operators, wind turbine and wind turbine component manufacturers, service providers, and others on the availability of the marketplace to provide for and participate in a technology demonstration of Commercial Off-the-Shelf or other mature technology mitigation capabilities.

The six general categories of wind turbine mitigations are shown in **Error! Reference source not found.** below.

[11] Weather radar were note included in the field test, and because of the differences between air surveillance and weather radar targets and concepts of operation, the data taken and many of the mitigation concepts are not relevant to weather radar.

Each of these concepts could be used alone or in conjunction with other approaches.

There are inherent advantages and disadvantages associated with each category. What matters most is the ability to maintain overall mission performance within acceptable resource limits. This includes ability to detect and track targets while minimizing false tracks. However, concepts must also demonstrate robustness, reliability, and long-term viability to meet the stringent availability requirements without undue maintenance burden.

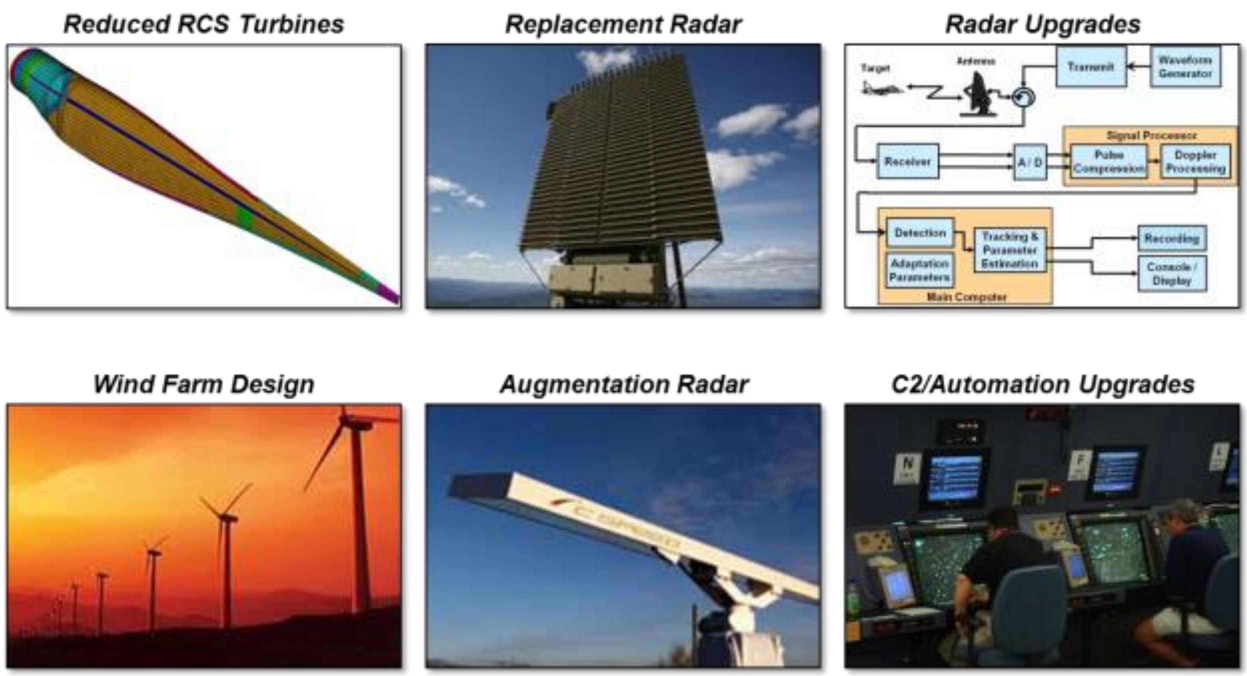


Figure 2-2: Proposed Wind Turbine/Radar Interference Mitigations (NOTE: Not all mitigation types were selected for testing)

- **Reduced Radar Cross Section (RCS) Turbines.** There are proposed concepts to modify the size, shape, or materials of the wind turbines themselves, especially focusing on the blades. The objective is to reduce the radar reflectivity of the wind turbine so that it is no longer a meaningful source of clutter to the primary radar.

- **Wind Farm Design.** By changing the overall layout, number, or specific locations of turbines within a wind farm, the total impact on surveillance operations may be mitigated. One example of this approach is already frequently applied by placing wind farms out of the line-of-sight of radars. This approach can compromise wind developer priorities seeking the best wind resource.

- **Radar Replacement.** This approach replaces the existing radars with more advanced radars, typically phased array radars with narrow 3D beams and advanced clutter mitigation techniques. These could be placed at current radar sites, or in some cases at alternative, more desirable locations.

- **Augmentation Radar.** Also called infill radars. This approach would add radars in or around wind farms to augment the coverage of the existing radar. These radars tend to have a shorter range and higher resolution with the intention of tracking targets in areas that would be lost to the existing radar.

- **Radar Upgrades.** This category includes concepts that would only make changes to the processing within the front or back end of existing radars, and focus on improving the detection process. These improvements may include modifying clutter maps, Constant False Alarm Rates (CFAR), or other filtering or preliminary tracking routines.

- **C2/Automation Upgrades.** This category includes concepts for improving the process at the automation system (e.g., STARS or AMOSS). Generally, this deals with improving tracking performance given the detections. Some examples include improving the tracking logic, or in the fusion process between different radars viewing the same aircraft or area.

Eleven responses were received from the RFI. After a technical review of private sector proposals by a technical panel of Government and Laboratory experts, the Interagency Steering Committee invited ten companies with eleven technologies to participate in the three IFT&E tests; in the end, eight mitigation technologies were evaluated. The responses were evaluated based on the following criteria:

- Level of maturity of the candidate technology solution.
- Cost effectiveness of the candidate technology solution (including cost of production, total ownership, and transition).
- Complexity of integration with existing infrastructure.
- Applicability of the candidate technology solution to mitigate wind turbine interference for the specific IFT&E site and type selected for each of the three test and evaluation events.
- Applicability of the candidate technology solution to mitigate wind turbine interference for other systems (e.g., existing wind turbines, short-range and long-range radars).
- Potential to address a range of desired performance parameters such as: Probability of Detection (P_d), Probability of False Alarms (P_{fa}), Plot Accuracy, Probability of Track, Probability of False Track, Track Continuity, Demonstrated Target Performance, Doppler Performance, Vertical Coverage, Range Accuracy, Azimuth Accuracy, Two Target Range Resolution, Clutter Rejection, Data Latency, Update Rate, Reliability, Availability, Data Transmission, etc.

The IFT&E program evaluated eight mitigation proposals including infill radar systems, radar upgrades, and replacement radars.

2.2 IFT&E Flight Campaigns: Testing and Analysis

The agencies wanted the tests to take place in safe airspace in a location with a high concentration of wind turbines during times of year when wind turbine farms generate the greatest electromagnetic interference effects on radar systems. Each selected POR radar is located within the line of sight of hundreds of wind turbines and the test were conducted during the spring and fall seasons when winds blow most consistently at high velocities. In order to fully assess the POR radars and the selected mitigation technologies using known targets (test program aircraft), the test area was chosen and test flights were timed to avoid disrupting the local traffic patterns. Additional aircraft data were leveraged from local air traffic as they provided targets of opportunity with little incremental cost to the government.

Key stakeholders from the federal agencies provided guidance and support to MIT LL and SNL as they designed, executed, and analyzed the tests. The FAA provided extensive support in managing the flight operations and air traffic control, as well as technical support regarding the POR radars. DOD's 84th Radar Evaluation Squadron also provided technical radar support. DHS, DOD, DOE, and NOAA provided critical test aircraft, flight tracking, and air operations as well as weather information for field test planning.

Eight to twelve different aircraft types were flown at varied speeds and altitudes for an average of about 150 hours of flying time over the eight to ten day campaigns. This ensured that tests were conducted under a wide range of wind turbine-related interference conditions to evaluate the effectiveness of different mitigation technologies in improving radar surveillance coverage in test areas with a high concentration of wind turbines. Neither the government radar operators nor the test participants were provided with advanced information about the test program aircraft regarding their type, number, speed, altitude, or flight routes.

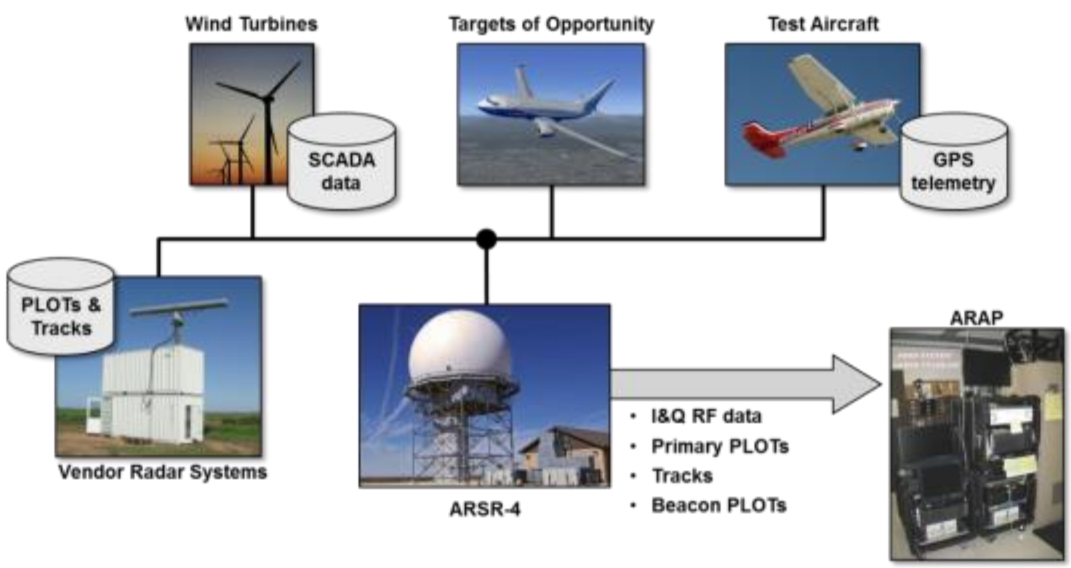


Figure 2-3: Data streams gathered during flight test campaigns

MIT LL built an Adjunct Radar Analysis Processor (ARAP). This computer hardware was attached to each of the POR radars in turn to gather echo returns from the aircraft with radio frequency signal measurements (the In-Phase and Quadrature data), as well as detection messages from the primary surveillance radar (PSR) and secondary surveillance radar (SSR)[2]. All primary test aircraft carried Global Positioning System (GPS) receivers and other equipment to analyze the POR radars' and the mitigation technologies' performance following the flight tests. These data were used to baseline the POR radars' performance when aircraft flew over and around wind farms and to compare performance with the mitigation technologies. Aircraft were selected to represent a variety of radar target types of interest to the FAA, DOD, and DHS.

Combined across the three flight campaigns, more than 460 hours of flight time were logged.

For purposes of analyzing the vendor proposed mitigations, many of which have relatively limited coverage volumes, a "Primary Test Area", about 22 nautical miles on each side, was defined for each flight campaign. Each vendor was allowed to select its own location to maximize surveillance of the test area.

Flight test patterns were developed to provide a range of altitudes and radial velocities, as highlighted in Figure 2-4. Figure 2-5 shows several example flight patterns that were flown during the testing; the different colored tracks in this figure represent the different aircraft during this example period. Most flights were flown around the Primary Test Area with aircraft performing straight paths, turns, and maneuvers inside the box to test detection performance and tracking capability.

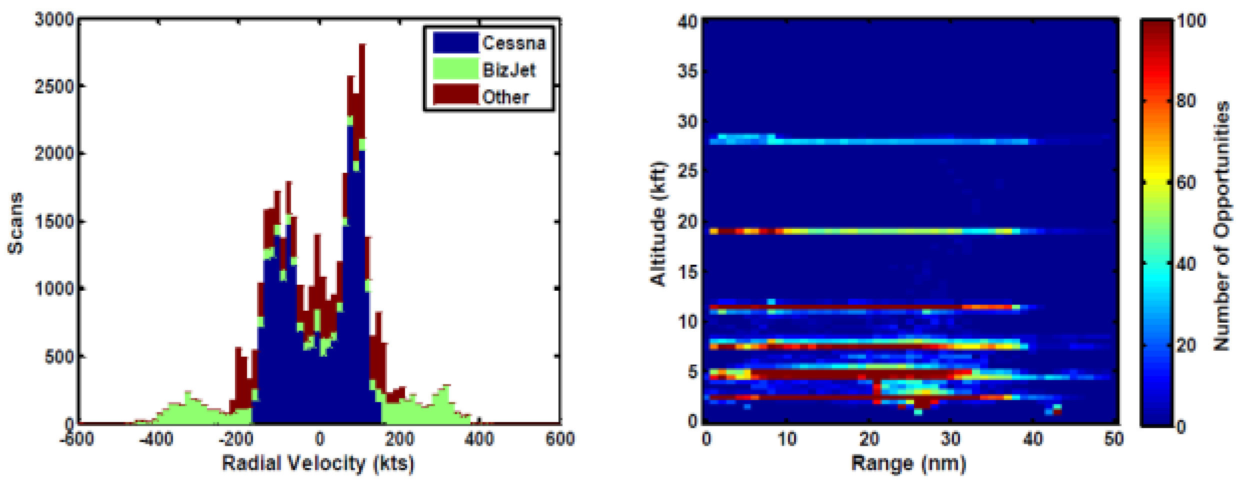


Figure 2-4: Example radial velocity (left) and altitude (right) distributions from a test campaign

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[2] Primary surveillance radars (PSRs) send out an electromagnetic signal in a known direction which reflects off of objects and returns to the radar. The PSR reports detections based on the signal reflected off of the object, the orientation of the antenna, and the time taken for the signal to reach the object and return. Secondary surveillance radars (SSRs) are based on a transponder aboard an aircraft which sends a reply with additional information to the radar when the transponder receives a radar signal—so it is more of a communication system than it is a radar system.

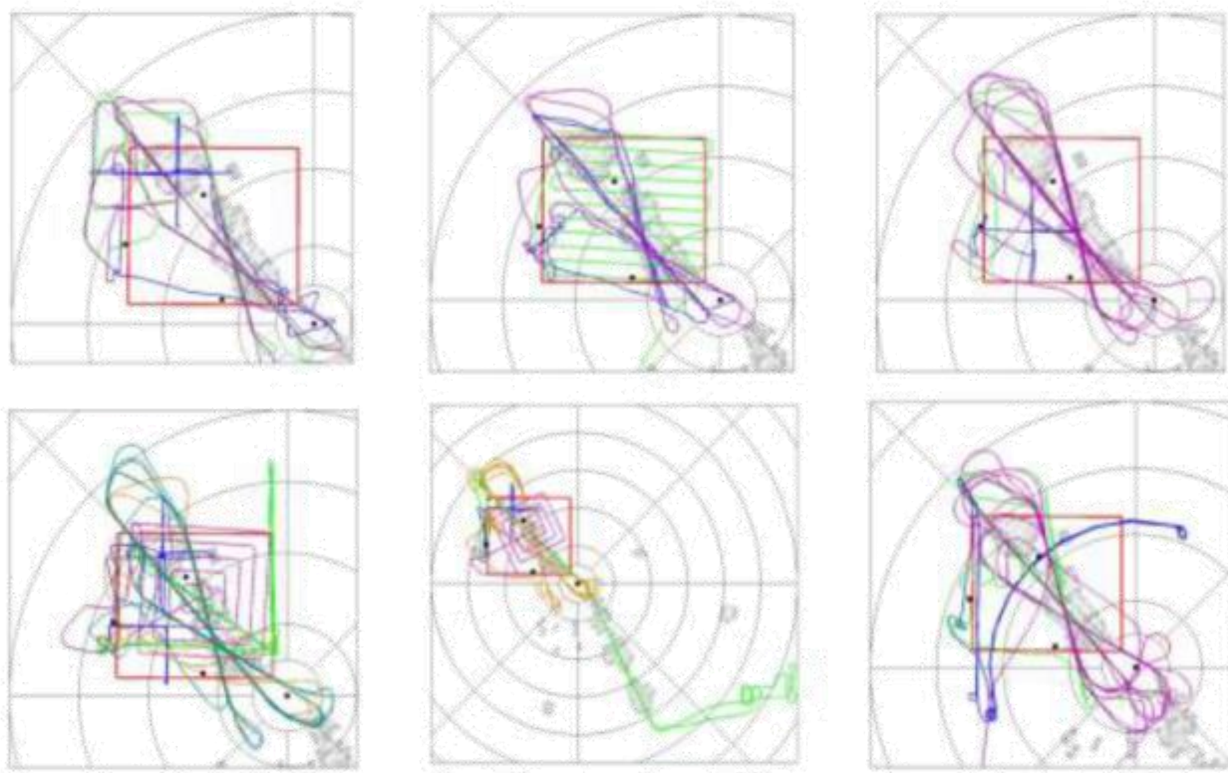


Figure 2-5: Examples of flight test patterns from a test campaign

SNL coordinated the data collection effort from wind farm owners in the three test areas. Wind turbine characteristics and operating data including wind speed, wind direction, and rotation rate were gathered from hundreds of wind turbines in and around the test areas. These data, when combined with the radar and flight data, enable the Laboratories to characterize the effects of wind turbine interference and predict effects on similar radar systems in other locations with a high level of confidence.

The analysis performed was based upon four regions relative to each wind turbine in the test area. The extent of each region is defined by the specific radar's resolution, which is the minimum two-target separation in one dimension allowing each target to be detected by the radar, in each of three spatial radar dimensions: range (radial distance to the radar, also referred to as slant range), azimuth angle (radar scan direction), and elevation angle. The four regions are named Within, Near, Above, and Far as depicted in Figure 2-6.

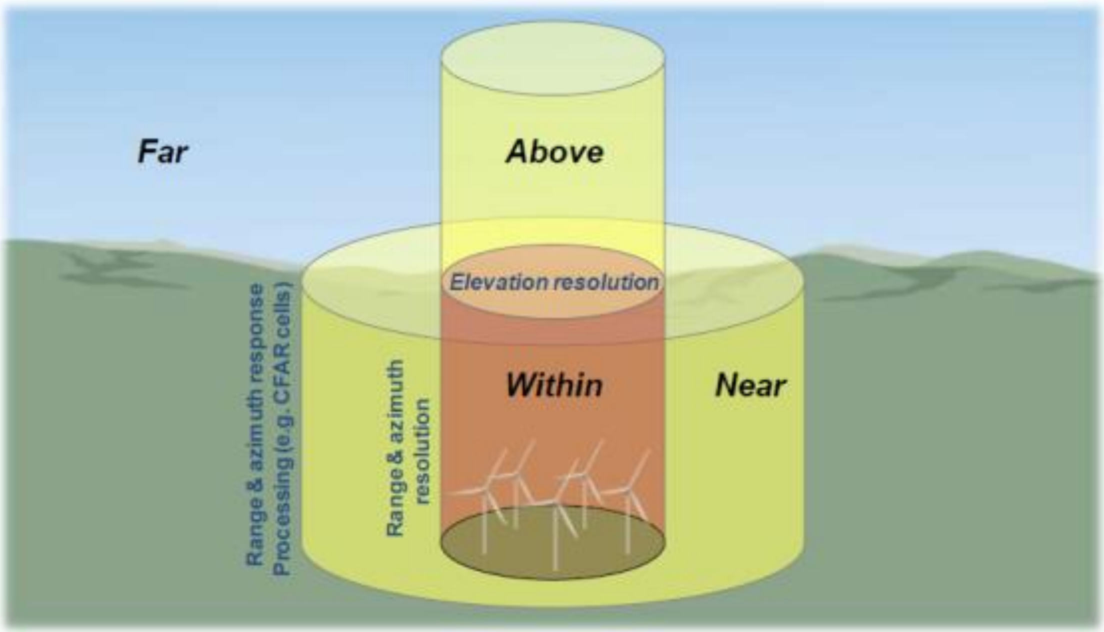


Figure 2-6: Spatial wind turbine interference regions utilized in the analysis

The Within region is plus and minus one resolution cell in range, azimuth, and elevation from a wind turbine. For those radars with elevation resolution, the Above region is one elevation resolution cell above a wind turbine. The Near region extends beyond the Within region in both range and azimuth, based upon the range and azimuth processing extents used by the radars. The Far region is the remainder of the coverage volume.

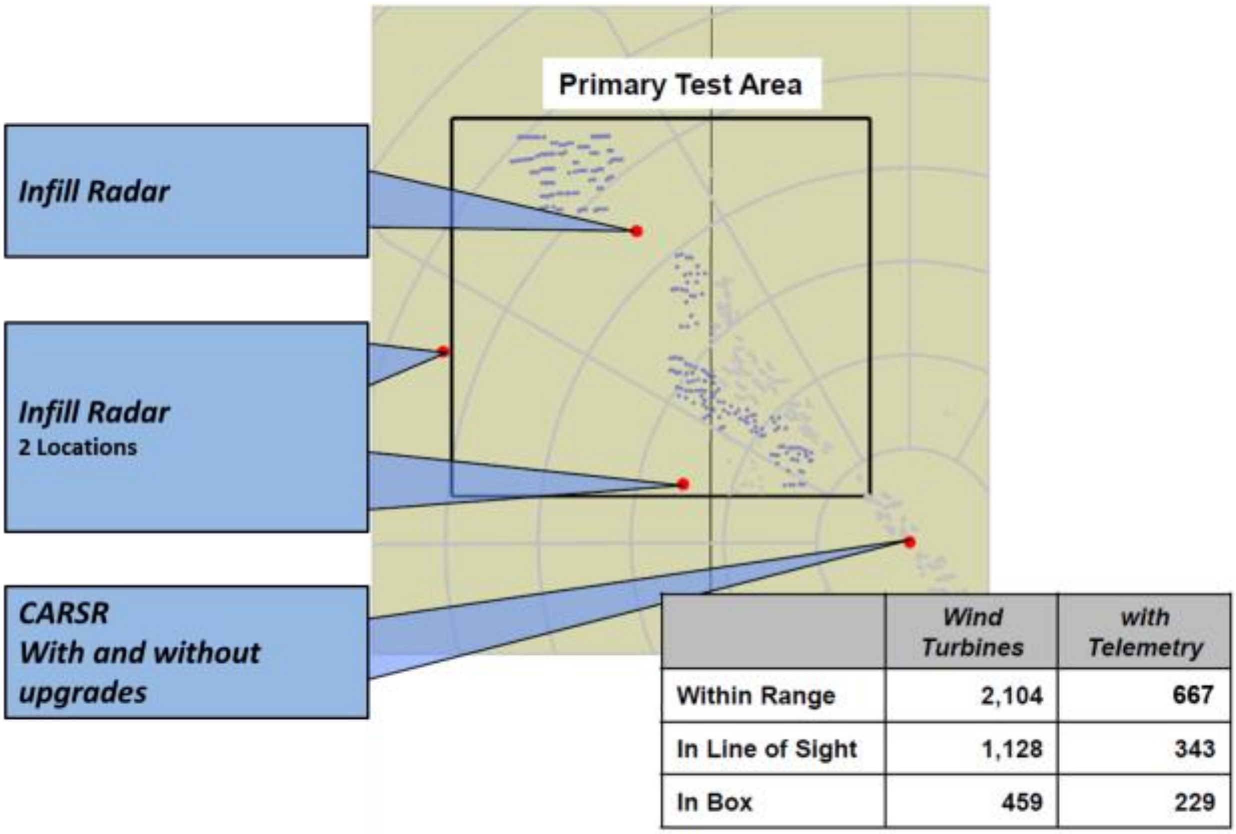
Of the six categories of wind turbine mitigations considered for the IFT&E (shown in **Error! Reference source not found.**), representatives from three categories participated in the flight campaigns: augmentation or infill radars, replacement radars, and radar upgrades. The other three categories, wind farm siting, reducing wind turbine radar signature, and C2/automation system upgrades, were not field tested due to either the lack of vendor response to the RFI or the impracticality of field testing the vendor concept. Table 1 lists the companies that brought proposed mitigation technologies to the various tests for evaluation.

Table 1: IFT&E Vendor Participants

Company	***Test Campaign***
C Speed	Tyler, MN (CARSR)
Raytheon	
SRC	
Booz Allen Hamilton	Abilene, TX (ASR-11)
Terma	
Aveillant (collaboration with Saab Sensis)	King Mountain, TX (ARSR-4)
Lockheed Martin	
Raytheon	

2.2.1 Test 1: CARSR – Tyler, MN

The first campaign took place in April 2012. The purpose of the first test was to characterize the performance of a newly upgraded Common Air Route Surveillance Radar (CARSR), a long range surveillance radar system, in Tyler, MN. The proposed mitigation technologies tested along with the CARSR were two infill radars and a radar processing upgrade.



	Wind Turbines	with Telemetry
Within Range	2,104	667
In Line of Sight	1,128	343
In Box	459	229

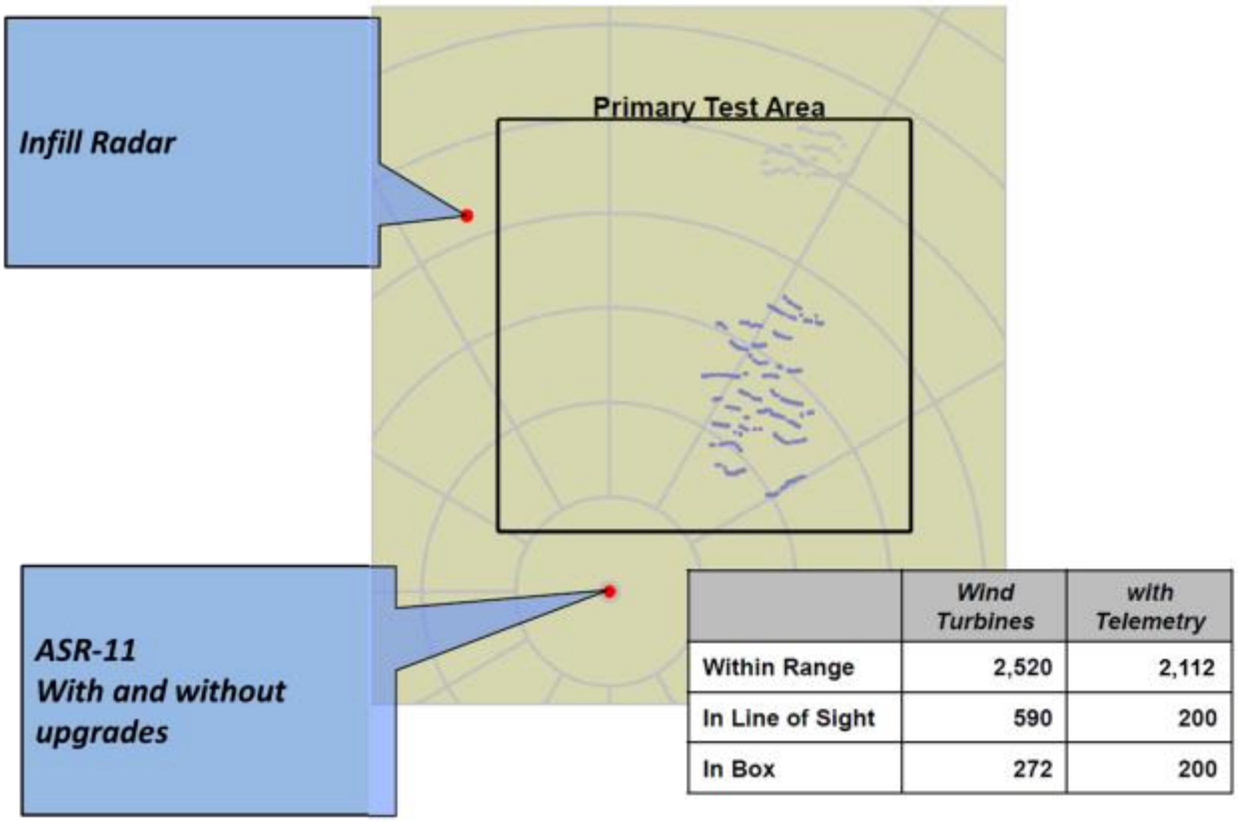
Figure 2-7: Primary Test Area for Tyler, MN CARSR flight campaign

Within the 200 nautical mile range of the CARSR there were 2,104 utility scale wind turbines. In the identified Primary Test Area there were 459 wind turbines. Data was collected from 667 wind turbines in the Tyler, MN region of which 229 were within the Primary Test Area. The majority of wind turbines that provided data were General Electric's (GE) 1.5s and 1.5sle models, though data was also collected from Suzlon and Gamesa wind turbines.

A total of 132 flight hours were flown during the CARSR test campaign.

2.2.2 Test 2: ASR-11 – Abilene, TX

The second campaign took place in October 2012. The purpose of the second test was to characterize the performance of the Airport Surveillance Radar (ASR-11), a terminal airport surveillance radar system in Abilene, TX. The proposed mitigation technologies tested along with the ASR-11 were an infill radar and a radar hardware upgrade.



	Wind Turbines	with Telemetry
Within Range	2,520	2,112
In Line of Sight	590	200
In Box	272	200

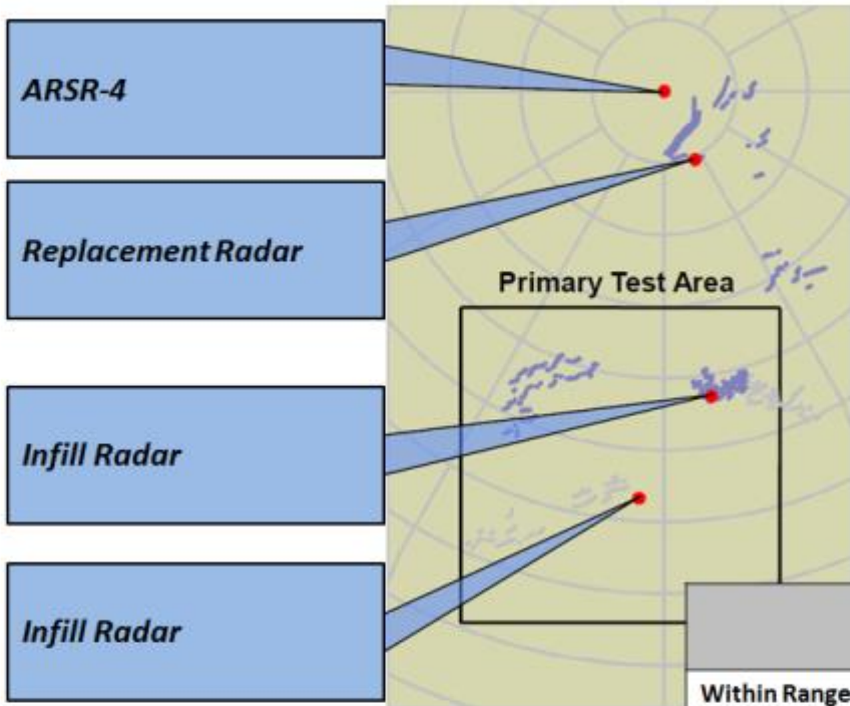
Figure 2-8: Primary Test Area for Abilene, TX ASR-11 flight campaign

Within the 60 nautical mile range of the ASR-11 there were 2,520 utility scale wind turbines. In the identified Primary Test Area there were 272 wind turbines. Data was collected from 2,112 wind turbines in the Abilene, TX region of which 200 were within the Primary Test Area. The IFT&E team selected the Primary Test Area over a subset of wind turbines that are highly visible to the ASR-11 and had relative ease for flight operations. The majority of wind turbines were that provided data within the Primary Test Area were Gamesa wind turbines, though data was also collected from GE, Mitsubishi, Siemens, and Vestas wind turbines.

A total of 166 flight hours were flown during the ASR-11 test campaign.

2.2.3 Test 3: ARSR-4 – King Mountain, TX

The third campaign took place in April 2013. The purpose of the third test was to characterize the performance of the Air Route Surveillance Radar (ARSR-4), a long-range surveillance radar system in King Mountain, TX. The proposed mitigation technologies tested along with the ARSR-4 were two infill radars and one replacement radar.



	Wind Turbines	*with Telemetry*
Within Range	**988**	**798**
In Line of Sight	**718**	**454**
In Box	**517**	**454**

Figure 2-9: Primary Test Area for King Mountain, TX ARSR-4 flight campaign

Within the 250 nautical mile range of the ARSR-4 there were 988 utility scale wind turbines. Data was collected from 798 wind turbines in the King Mountain, TX region of which 454 were within the Primary Test Area. Data was provided from multiple wind turbine makes and models including older Bonus and NEG Micon models, Clipper turbines, and Vestas turbines.

A total of 164 flight hours were flown during the ARSR-4 test campaign.

The cumulative total amount of data collected during the three flight campaigns amounts to over 380 terabytes.

2.2.4 Analysis Metrics

Probability of Detection and Probability of False Alarm

The Probability of Detection (P_D) is a fundamental radar performance metric and effectively represents the likelihood that the radar will declare that a target is present in the surveillance area for each opportunity that it had to detect that target, which is generally every scan of the radar. Without successful detections an operator may never be aware that a target is within the surveillance area. The P_D in each of the regions was calculated as the ratio of the detected plots, or hits, from an aircraft to the total number of opportunities available to detect the aircraft. The source of the opportunities consisted of GPS data and beacon data, which were resampled at the scan time for the radar of interest.

The Probability of False Alarm (P_{FA}) is also a fundamental radar performance metric and was calculated as the number of false alarms per scan per radar processing cell in each spatial region. From an operational perspective, a false alarm is a radar report based upon anything that is not an aircraft (e.g., ground clutter, birds, ground vehicles, thermal noise, and RF interference); false alarms may lead an operator to believe that aircraft that do not actually exist are present in the surveillance area. While some false alarms are unavoidable in a real-world cluttered environment, high false alarms rates cause confusion for the operator and any subsequent processing, such as tracking.

For this analysis, a good approximation to an operational false alarm is a radar report based upon anything that is not a confirmed aircraft, based upon GPS instrumentation, an operational beacon transponder, or a solid primary radar track with the characteristics of an aircraft. Detections from a completely non-instrumented aircraft may not be solidly tracked or may not meet the aircraft characteristic criteria used and therefore would be considered false alarms in this analysis; however, their low expected density within the Primary Test Area, a somewhat controlled airspace, should not have a significant impact on the false alarm analysis presented. Unlike some current P_{FA} test procedures used for some operational radars, this type of false alarm testing relies on a fully functional radar, so the receiver was not terminated.

Binomial confidence intervals were used for all P_D, P_{FA}, and other probability calculations in this report, using a confidence of 95%.

Plot Accuracy

Assuming that the radar achieves detection for a given target, the accuracy of the plot determines how well one can determine the location of that target. When assessing the radar measurement accuracy, the range error and azimuth error of the radar were calculated with respect to the truth data. The radar accuracy was then reported in the form of the root mean square (RMS) error metric for both the range and azimuth dimensions. This report examines measurement accuracies from a different perspective to provide a more consistent comparison basis between various radars across different tests and to be more relevant to the recommended approach for integrating an infill radar at the C2/automation system: RMS geodetic accuracy. Geodetic accuracy is effectively the distance across the surface of the Earth geoid between the measured position of the aircraft (with altitude estimated as necessary) and the true position of the aircraft, or more simply a map-perspective of the measurement error.

Probability of Track and Probability of False Track

The Probability of Track for each spatial region was calculated as the ratio of the number of opportunities to detect an aircraft in that region with associated track reports to the total number of opportunities available. Similar to P_D, the Probability of Track represents the likelihood of having a track on a target when the target location met the criteria for that particular analysis. In many operational scenarios, the lack of a track on a target is equivalent to an operator not being aware that a target is in the surveillance area.

The Probability of False Track was calculated as the number of false track reports per scan per radar processing cell (in range and azimuth) in each of the spatial regions and represents the likelihood per radar processing cell per scan for the tracker to report a track based primarily on false alarm detection (e.g., from clutter). More simply, a false track is any track reported that is not associated with a confirmed aircraft; source of false tracks were both wind turbines and other forms of clutter.

Track Continuity

Once a track has been initiated there is a possibility that it might break on every subsequent scan of the radar. A track break occurs when the track on an actual aircraft is either dropped or begins to report positions that diverge from the true aircraft position; in the latter case, the track often begins to follow clutter or a different target. Neither of the cases is desirable for an operator attempting to follow the track of an aircraft. The Probability of Track Break is the ratio of the number of track breaks that occurred for a true target to the number of opportunities for a track break to occur in each of the spatial regions. It is the average of the reciprocal of the number of track reports before each track breaks. For this metric, the opportunities for a track break are those in which the target was associated with a track before that track broke away from the target. Effectively, this metric can be interpreted as the probability of a track break per radar scan, but not for the entire existence of a given track.

The practical impact of track breaks can be illuminated by a related statistic, the Probability of Track Survival across a region. The metric used in this analysis uses the Probability of Track Break to estimate the 80% chance of Track Survival across a canonical wind farm region, estimating the time of flight within a wind farm where an aircraft with an associated track can emerge unbroken from the region with the same associated track.

2.3 IFT&E Test Results

2.3.1 Existing POR Radar Performance

The primary surveillance radars (PSRs) were significantly impacted by operating wind turbines at both the detection and tracking levels for regions within and above the wind turbines. For many of the existing POR radars the impacted region includes all altitudes above the wind turbines within the coverage volume of the radar. The dominating wind farm factors include the RCS of the aircraft of interest and the fact that wind farms cover a relatively large geographical area and are composed of many wind turbines. Coupled with the design limitations of these primary surveillance radars, these factors contribute heavily to observed performance impacts. For example, these radars have relatively poor spatial and Doppler resolution compared to the spacing and operating tip speeds of wind turbines, resulting in impacted regions on the order of the wind farm itself as opposed to small regions around each individual wind turbine.

Based upon the performance of the one secondary surveillance radar tested in these field tests, no impacts from wind turbines were apparent, which is consistent with expectations since the dominant factor affecting the primary surveillance radars, the RCS of the wind turbines, is irrelevant to the secondary surveillance radars, which behave more like communication terminals than radars.

The following figures summarize the detection and tracking performance of the existing POR primary surveillance radars for the General Aviation and Business Jet aircraft classes. Results are shown for both the Far region and the Within/Above regions for comparison. In these probability figures, there are vertical bars centered on the estimate symbol which represent a 95% confidence bounds for that estimate. Where no bars are visible, the uncertainty bounds were smaller than the symbol. The line connecting the two points is only for convenience in seeing the relationship between the performances in the two regions and does not represent intermediate performance. For security purposes the scales and names of the POR radars have been removed. However, the decrease in detection and increase in false alarm is not notional.

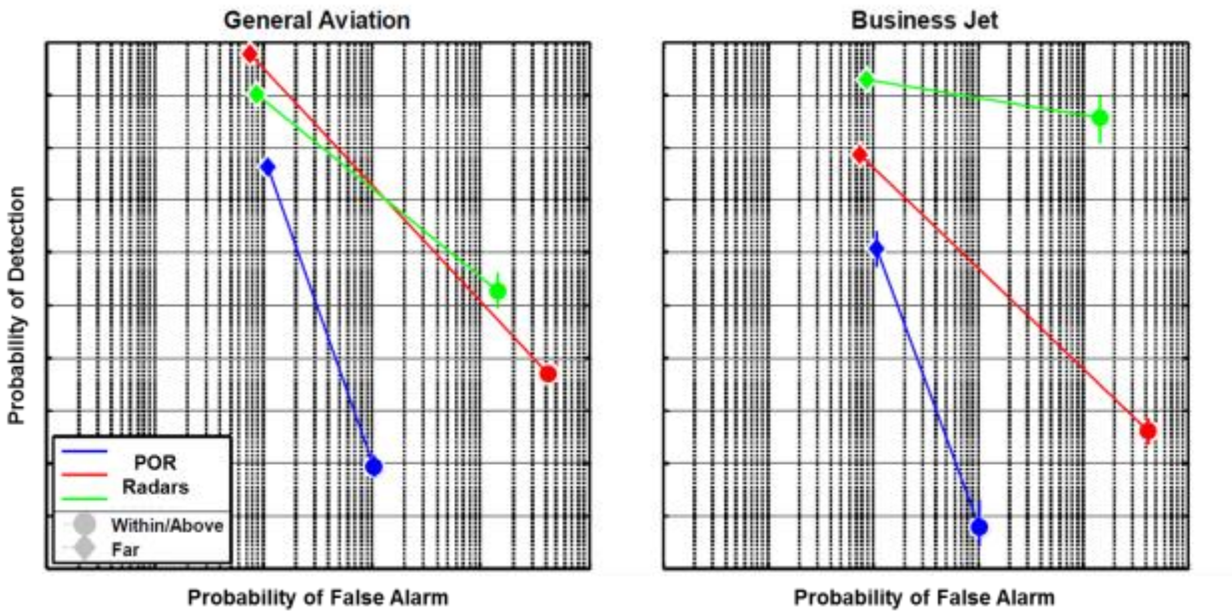


Figure 2-10: Existing POR radar Probability of Detection and False Alarm for General Aviation and Business Jets

Figure 2-10 illustrates that the Probability of Detection decreases significantly and the Probability of False Alarm increases significantly from the Far to the Within/Above wind turbine region, highlighting the impact of wind turbines on the performance of the radars.

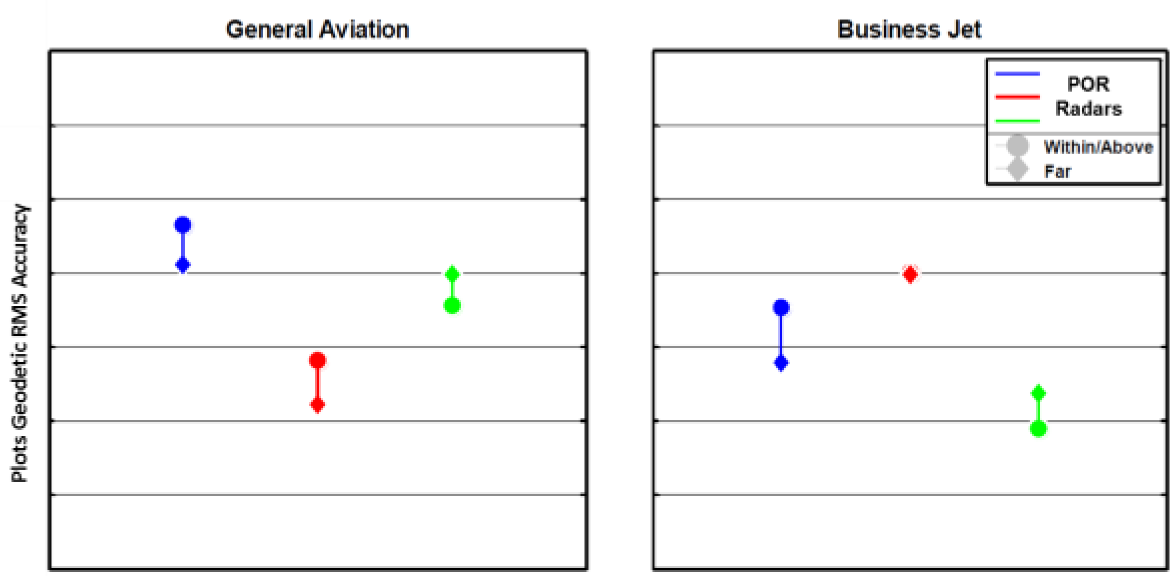


Figure 2-11: Existing POR radar plot accuracy for General Aviation and Business Jets

For cases where aircraft detection was successful, the measurement accuracy does not appear to be significantly impacted by wind turbines, as shown in Figure 2-11.

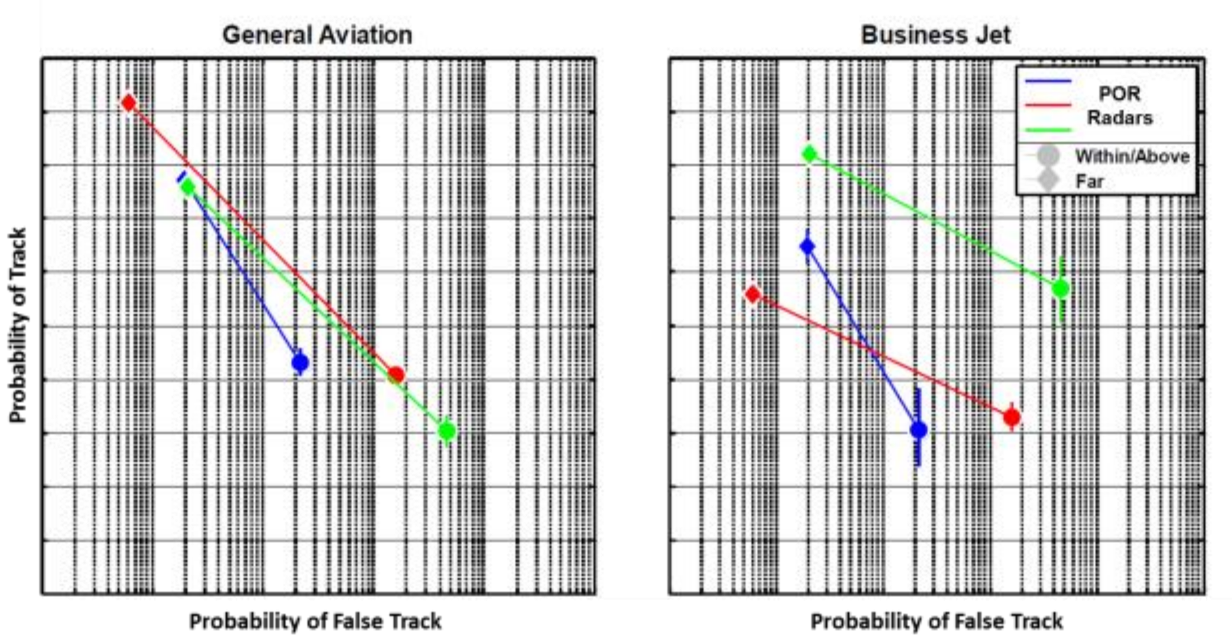


Figure 2-12: Existing POR radar Probability of Track and False Track for General Aviation and Business Jets

Figure 2-12 and Figure 2-13 show how the ability of these POR radars to track aircraft is also significantly impacted by wind turbines. Figure 2-12 shows that there is a decrease in the Probability of Track and an increase in the Probability of False Track from the Far region to the Within/Above wind turbine region while Figure 2-13 shows that the Probability of Track Break increases and the associated Track Survival Time decreases from the Far region to the Within/Above wind turbine region.

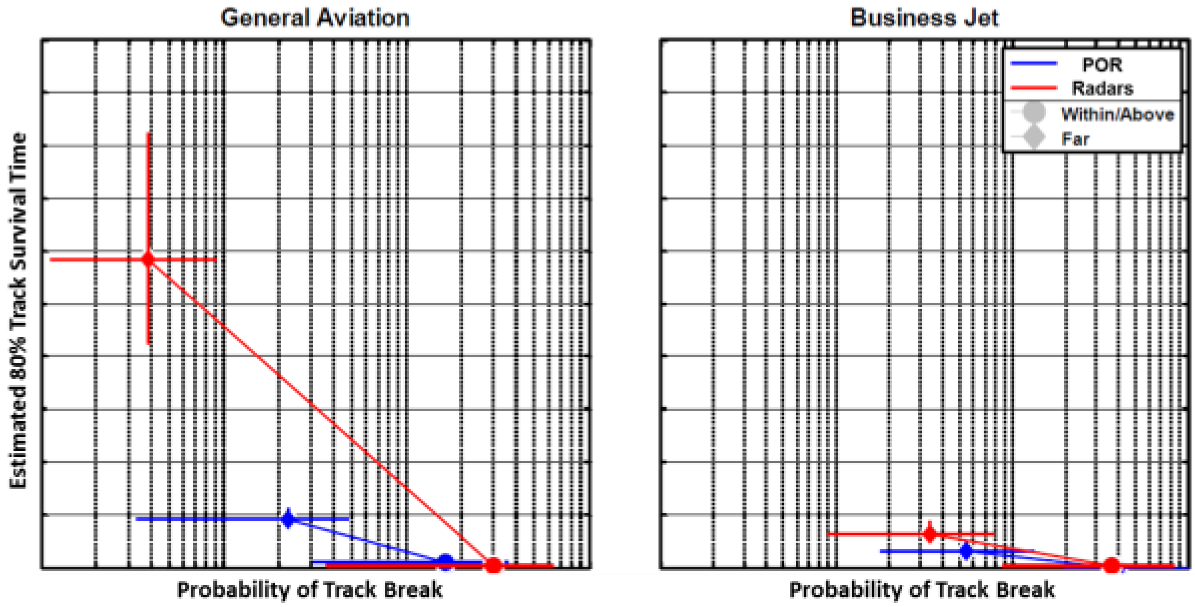


Figure 2-13: Existing POR radar estimated Track Survival duration and Probability of Track Break per 12 second period for General Aviation and Business Jets

2.3.2 Proposed Mitigation Technology Performance

Figure 2-14 summarizes the detection performance of the majority[3] of the IFT&E tested radars and mitigation technologies by category, comparing the performance in the Far from wind turbines region with the performance in the Within/Above wind turbine region. The categories shown include the existing POR radars and the three mitigation categories tested. The analysis regions are based upon the general resolution capabilities of the existing POR radars over the Primary Test Areas but slightly modified for the infill radars to accommodate their coverage constraints.

[3] Due to the unique nature of one of the radar upgrades, it was not evaluated in the same way as the other concepts, and is not included in the summary plots. This tested upgrade proved to have shortcomings in its performance and was not considered to be an effective mitigation.

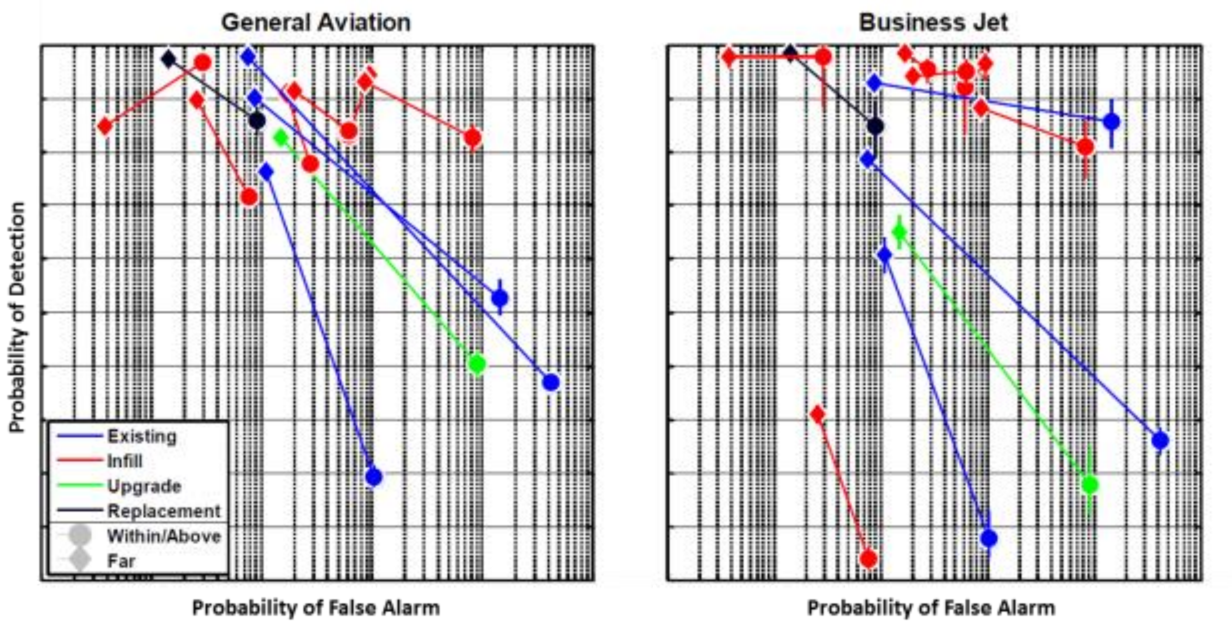


Figure 2-14: Existing POR radars and tested mitigations Probability of Detection and False Alarm for General Aviation and Business Jets

While all systems tested were impacted by wind turbines, many of the mitigation systems were significantly less impacted by wind turbines than the existing POR radars. The replacement radar and most of the infill radars performed better than the existing POR radars in the Within/Above wind turbine region. Relative infill radar performance in the Far region is more ambiguous due to slightly lower Probability of Detection and/or higher Probability of False Alarm than the existing POR radars.

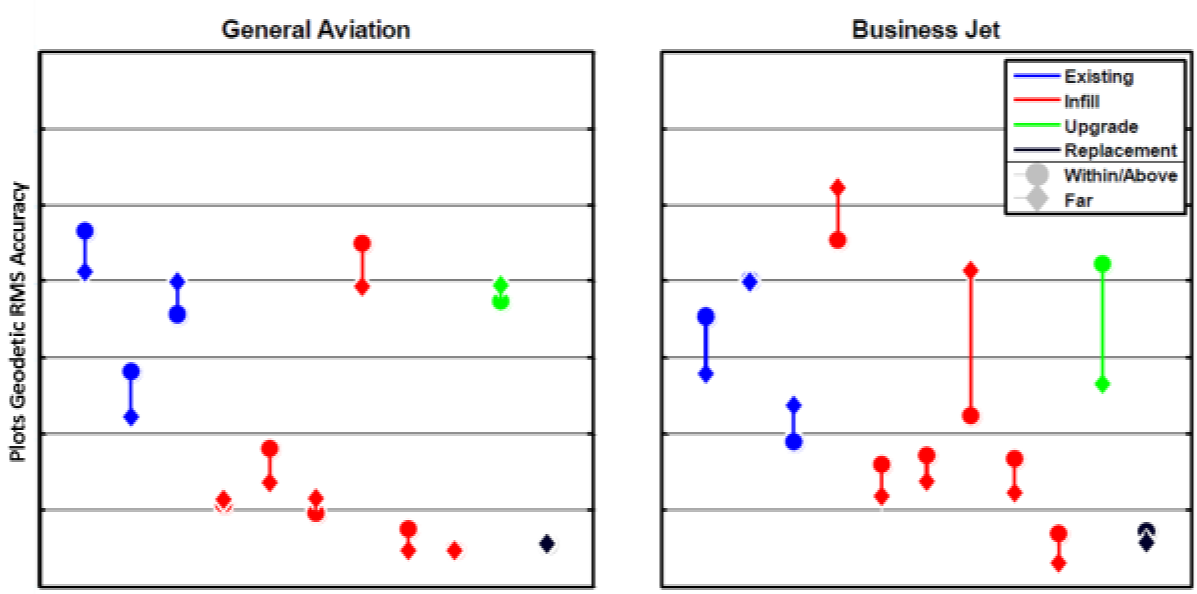


Figure 2-15: Existing POR radars and tested mitigations Plot Accuracy for General Aviation and Business Jets

For cases where aircraft detection is successful, the measurement accuracy of the mitigation systems is typically comparable to or better than the measurement accuracy of the existing POR radars and does not appear to be impacted by wind turbines, as shown in Figure 2-15.

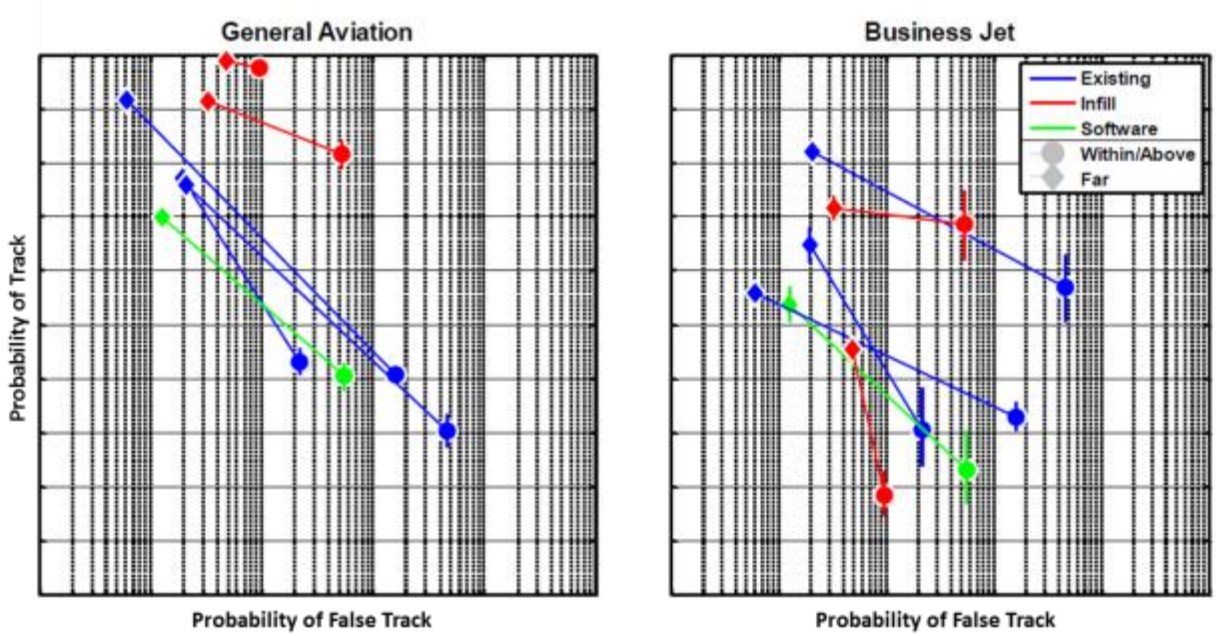


Figure 2-16: Existing POR radars and tested mitigations Probability of Track and False Track for General Aviation and Business Jets

As shown in Figure 2-16 and Figure 2-17, the ability of the proposed mitigations to track targets is also impacted by wind turbines; note that the replacement radar and several infill radars did not provide track data for evaluation as it was not mandated. The tracking capability of the radar upgrade is comparable to the existing POR radars but some infill radar track performance is clearly better in the Within/Above region, but more ambiguous in the Far region (i.e. higher Probability of Track but also higher Probability of False Track and Track Break).

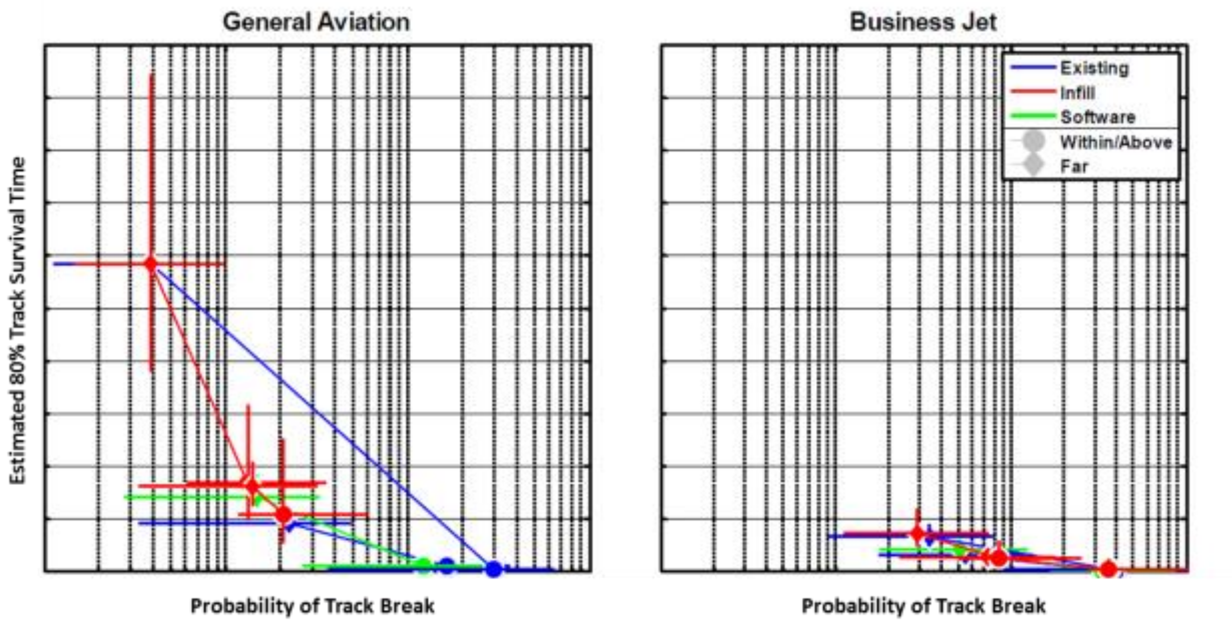


Figure 2-17: Existing POR radars and tested mitigations estimated Track Survival duration and Probability of Track Break per 12 second period for General Aviation and Business Jets

The infill radar systems tested generally performed better than the existing POR radars in detecting aircraft in the Within/Above wind turbine region. While most of these radars were still impacted by wind turbines, their improved resolution typically resulted in a smaller area affected. While questions still persist about infill radar integration and scalability, the systems tested show promise.

The replacement radar tested performed better in both the Far and Within/Above regions than the existing POR radars. From a technical performance standpoint, this could be the nearest term mitigation option. However, it would also likely carry the highest capital cost of the mitigation options.

Based upon these results of the IFT&E program, any of the five infill radar technologies and the one replacement radar evaluated could be utilized as a potential mitigation in an appropriate environment and for specific government identified mission sets.

3. Current Governmental Review Procedures

There are a number of federal organizations that have an interest in wind turbine siting. The formal, regulatory-based process for review of wind turbine siting as it pertains to national radar assets comes through the Federal Aviation Administration's (FAA) Obstruction Evaluation / Airport Airspace Analysis (OE/AAA) and the DOD's Siting Clearinghouse. This section provides a brief summary of the current federal review processes. There are also informal review processes used by other federal agencies.

3.1 FAA Obstruction Evaluation / Airport Airspace Analysis

The FAA has legal jurisdiction for siting of structures 200 feet tall and above. Developers must submit an application to the FAA's Obstruction Evaluation / Airport Airspace Analysis (OE/AAA) for a proposed development to allow for an aeronautical study to be performed based upon the location and height of the individual wind turbines as required by Title 14 of the Code of Federal Regulations (14 CFR) Part 77. The results of the aeronautical study will either be a Determination of No Hazard, in which case construction can begin, or a Determination of Presumed Hazard, which may initiate a process of negotiation and appeal between the developer and the government.

Other federal agencies with radar assets, such as DO and DHS are notified of proposed projects and have the opportunity to raise objections throughout the FAA OE/AAA Review Process.

3.2 DOD Siting Clearinghouse Review

The Office of the Deputy Under Secretary of Defense-Installations and Environment (DUSD(I&E)) has created the Siting Clearinghouse "to address these potential impacts [from renewable energy projects] and to provide timely and fully coordinated reviews of proposed energy projects." As part of this effort the DOD has created the Preliminary Screening Tool for renewable energy developers.

The tool allows developers to screen a potential project against long-range radars (air defense and homeland security radars), weather surveillance radars, and military operations. Based on user inputs, the tool creates a map relating the proposed development to any of the DOD/DHS and NOAA resources and provides a preliminary result on the impact of the proposed project to DOD/DHS and NOAA assets. However, the site clearly states that the tool in no way replaces the full FAA aeronautical study that will most likely still be required.

In addition, per Title 32 of the Code of Federal Regulations (32 CFR) Part 211, the DOD has a process that allows developers to request either a formal review or an informal review of their proposed project. The formal review ties in with the FAA OE/AAA process and applies to projects that have formally filed an application with the Department of Transportation. The formal review process also deals with projects that may affect military training routes or special use airspace. The informal review process is triggered when a developer requests a preliminary determination in advance of filing a formal application. To request an informal review, the developer is required to provide relevant project information regarding the proposed project. More information can be found in [9].

3.3 NOAA Informal Review Process

NOAA has an informal review process based on a mutual understanding between NOAA and the wind energy industry, which was coordinated with the American Wind Energy Association (AWEA) and is documented in AWEA's Siting Handbook. In addition, NOAA has had an extensive outreach program with the wind energy industry. NOAA usually receives notification of a proposed wind energy project through the Department of Commerce's National Telecommunications and Information Administration (NTIA), acting as a clearinghouse for federal agencies other than the FAA and DOD.

NOAA evaluates potential impacts of wind projects using an in-house GIS tool, which determines in which of four impact zones the turbines would be located. Those zones are defined by NOAA's expectation for the developer: "No-Build," "Mitigation," "Consulation," and "Notification." The results of the analysis are provided to the developer via the NTIA. NOAA's evaluation tool is available to developers for their own in-house evaluation through several sources, including the National Weather Service Radar Operations Center and OE/AAA.

4. Going Forward

With the fast paced growth of the wind industry and the public necessity for air surveillance, the paths of these two industries are now converging. The best solution to meet the needs of both is structured collaboration and timely communication. The tests were conducted, the data has been analyzed, the results are presented and the question remains; Where do we go from here?

Despite the extensive testing that was completed in the IFT&E and other programs, the U.S. utilizes numerous radar types, wind turbine configurations, wind farm layouts, in a variety of terrain, and each with different mission requirements, all which complicate the problem. These tests, the results, and the large amount of data gathered, have greatly increased the technical understanding of interference issues and will allow us to advance development of long-term mitigation strategies. However, they only scratch the surface of the needs of the nation and a strategic way forward is necessary to make effective use of limited time and resources to address the wind turbine/radar interference issue. The Department of Energy is creating a national strategic approach that hopes to provide an opportunity for U.S. activities in policy, research and development, and project adjudication and deployment of mitigation technologies to be strategically organized.

Based on the interagency's successful collaboration in formulating and carrying out the IFT&E test campaigns, the participants agreed to extend the partnership and develop a way forward in dealing with appropriate near-term challenges. Further, by continuing to work as a team, it would help limit the financial impact on any one agency by pooling existent agency budgetary commitments. A key element of the concept is based around establishing what the interagency team termed a "Pilot Mitigation Project" (PMP) initiative. This is further described in Section 4.1.

In addition, the IFT&E Team proposed a joint way forward based on the results of the three test campaigns. From this recommendation, a consensus was reached within the IFT&E Steering Committee on a path forward for near-term challenges without significant financial commitment. That near-term path forward is the Pilot Mitigation Project initiative which is described in Section 4.1.

4.1 Pilot Mitigation Project (PMP)

A framework for the development of the Pilot Mitigation Project has been signed by senior representatives of DOD, DOE, DHS, and FAA (the cover letter can be seen in Appendix A). While all co-sponsoring agencies signed this letter indicating their support for this new initiative, it is the Department of Defense and the Department of Homeland Security which are specifically implementing the initiative.

The purpose of the Pilot Mitigation Program (PMP) is to develop interagency supported interim solutions to mitigate the growing barriers resulting from the effects of wind turbine / radar interference on air surveillance radar systems. This way forward builds on the results of the IFT&E Program and incorporates multi-agency collaboration by engaging with industry to identify, develop, and implement acceptable near-term and economically feasible mitigation solutions. The concept is based on pilot mitigation project solutions that would be funded by the wind industry. It will target new wind projects that are seeking approval through the FAA's OE/AAA Review process.

The key objectives are to maintain the quality of the air picture that exists today, reduce the time required to implement mitigation solutions, not impact the cost of delivering effective air surveillance services to government users, and meet renewable energy goals, all while managing the risk to stakeholders. Given the complexity of federal acquisition law, maintaining performance and safety requirements of the National Airspace System, and achieving deployment timelines, this approach is primarily centered on DOD and DHS requirements independent of FAA's air traffic operations.

This structure is meant to afford wind project developers an acceptable level of certainty for achieving project approval. As importantly, it also provides the wind project developer an opportunity to consider mitigation investment costs in light of the anticipated economic return in determining whether to pursue or modify a proposed project. Additionally, this concept is consistent with mitigation reimbursable funding developers are authorized to support through FAA's Title 14, Part 77 airspace adjudication procedures and 2011 NDAA Section 358 provisions.

Bottom-line: the PMP will be used to provide an affordable cushion against further degeneration of critical surveillance capability until such time as more capable systems that are less vulnerable to wind turbine generated radar interference can be developed, funded, and brought on line.

5. Conclusions

The IFT&E Program has proven successful collaboration with government and industry partnership aimed to address pressing concerns of our Nation's energy and security needs. The program leveraged government resources to test and evaluate eight different wind turbine/radar interference technologies proposed as mitigations. The vendors of these proposed mitigations came to the table using their own funds with no guarantee of government acceptance. Wind farm owners graciously provided data to the IFT&E team with the simple desire of definitively determining the impacts wind turbines have on land based radar systems. The IFT&E Program conducted three very significant and successful flight test campaigns at three existing POR radar sites with multiple, utility-scale wind farms within the line-of-sight of each of the radars. These radar sites included a CARSR in Tyler, MN, an ASR-11 in Abilene, TX, and an ARSR-4 in King Mountain, TX. Multiple aircraft classes, such as General Aviation, Business Jets, Helicopters, and multiple specialty aircraft, flew hundreds of flight hours at multiple altitudes, speeds, and headings over major wind farms to collect statistically significant samples to characterize the impacts of wind turbines on these existing POR radars under various aircraft and wind turbine conditions.

The data shows that the existing POR primary surveillance radars are severely impacted by wind turbines while the beacon transponder-based secondary surveillance radars was not affected by wind turbines. In addition, eight mitigation systems representing three mitigation categories, participated in these three flight tests. While all systems tested were impacted by wind turbines, the replacement radar and most of the infill radars performed better than the existing POR radars in the Within/Above wind turbine region. The infill radars demonstrated either sufficient, or near sufficient, detection performance but elevated false alarm rates in general or poor detection performance for aircraft at higher elevation angles. These issues are likely resolvable, but may require additional tuning, development, and/or testing. The radar upgrades tested did not significantly improve the surveillance capability over wind farms, and therefore the technologies tested were not considered an effective mitigation. Nevertheless, data collected during the tests suggest alternative upgrade approaches which may be more successful; meaning this category of mitigation should not be altogether dismissed. The bottom line, based upon these results of the IFT&E Program, is that any of the five infill radar technologies and the one replacement radar evaluated could be utilized as potential mitigations in an appropriate environment and for specific government identified mission sets.

National goals of providing clean, affordable, reliable and domestic energy while ensuring national safety and security can only be accomplished through continued dialogue between those developing renewable energy technologies and plants and those charged with protecting the nation. The U.S. government is committed to the advancement of renewable energy deployment and remains active in research and development to mitigate wind turbine / radar interference.

While the current process for federal review of wind turbine siting primarily utilizes the FAA (the OE/AAA Review Process), a new option has been offered by DOD and DHS for early coordination with the government via the Pilot Mitigation Project process.

For more information regarding the IFT&E program please visit:

http://energy.gov/eere/wind/environmental-impacts-and-siting-wind-projects

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APPENDIX A: Cover Letter: DOD/DHS Wind/Radar Pilot Mitigation Projects

18 December 2013

FOR: Mr. John Conger, Deputy Under Secretary of Defense (I&E), Department of Defense
Dr. Daniel Davidson, Assistant Secretary, Energy Efficiency and Renewable Energy, Department of Energy
Dr. Daniel Gerstein, Under Secretary (Acting) for Science and Technology, Department of Homeland Security
Mr. Edward L. Bolton, Jr., Assistant Administrator for NextGen (ANG), Federal Aviation Administration

FROM: The Interagency Field Test & Evaluation (IFT&E) Program Steering Committee

SUBJECT: Memo for the Record: DOD/DHS Develops Wind/Radar Pilot Mitigation Projects

For your information: The Department of Defense and the Department of Homeland Security are implementing a "Pilot Mitigation Project" initiative that leverages the significant investment and comprehensive results garnered from the two-year, $8 Million Interagency Field Test & Evaluation (IFT&E) Program. The IFT&E program investigated eight technologies to mitigate wind turbine - radar interference. The IFT&E Team proposed a joint way forward that DOD and DHS intends to adopt, where appropriate. The following pages describe the Pilot Mitigation Project concept and this cover memo serves to demonstrate consensus on the approach.

The key objectives addressed by this way forward are to maintain the quality of the air picture that exists today, reduce the time required to implement mitigation solutions, minimize the cost of delivering effective air surveillance services to government users, and meet renewable energy goals, all while managing the risk to stakeholders. Given the complex requirements of federal acquisition law, maintaining performance and safety requirements of the National Airspace System (NAS), and achieving deployment timelines, this approach addresses DOD and DHS requirements independently of FAA's air traffic operations.

Private industry's contribution toward pilot mitigation projects can address wind farm interference concerns through rapidly deployed, short-term interim solutions. From the industry point of view, this structure affords developers an acceptable level of certainty for project approval and allows a wind plant's economics to dictate developer's funding decisions. Additionally, this concept is consistent with mitigation reimbursable funding developers experience through FAA's Title 14, Part77 airspace adjudication procedures and 2011 NDAA Section 358 provisions. The government's bottom line is that this initiative can better address near-term concerns about the potential loss of radar coverage, and in more cases, maintain critical surveillance capability until new more expanded surveillance systems are developed.

The success of this way forward requires a commitment from all government stakeholders to work in collaboration with industry to establish the ways and means to fund and deploy wind turbine - radar interference mitigation solutions. In establishing such a commitment, this approach allows for an expeditious path to deliver mitigation solutions while maintaining government mission requirements for safety, security, and system performance.

For questions or further information, Megan McCluer, the DOE Team Lead, is the IFT&E Program Steering Committee POC. She can be reached by phone at: (202) 297-6565, or by e-mail at Megan.McCluer@ee.doe.gov.

Sincerely,

José Zayas
Director, Office of Wind and Water Power Technologies
Department of Energy

Michele Merkle
Director, NAS Systems Engineering Services (ANG-B)
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Michael Aimone
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