U.S. DEPARTMENT OF
ENERGY
Office of
ENERGY EFFICIENCY &
RENEWABLE ENERGY

Offshore Wind Turbine Radar Interference Mitigation (WTRIM) Series

Air Traffic Control Terminal Radar

Patrick Gilman, DOE Wind Energy Technologies Office

October 26, 2020

OSW Turbine Radar Interference Mitigation Webinar Series

Objective

- Building relationships between key industry stakeholders and federal agencies
- Sharing perspectives on potential impacts of wind turbine induced radar interference on critical radar missions and offshore wind development
- Identifying research and development (R&D) needs to address these impacts

Webinar attendees will

- Achieve a better understanding of agency perspectives on potential impacts of offshore wind on radar missions and industry perspectives on offshore wind development
- Hear about government and industry-led wind-radar interference research, including potential impacts of offshore wind on radar missions and technical mitigation options
- Share perspectives on the strengths and weaknesses of the current state of knowledge of potential technical impacts and mitigations
- Help identify research needs for offshore wind-radar mitigation and assist in identifying a pathway forward for future government-industry collaboration
- Network with professionals representing domestic and European offshore wind developers, OEMs, radar vendors, the WTRIM Working Group, and technical radar experts.

Future Wind-Radar Webinar Agenda & Information

TBD, 2020

Long-Range Radar

- *Technical and operational issues regarding each system in an OSW environment*
- *State of Current Understanding*
- *Mitigation Options*

Webinar Information (Past & Future) is on the DOE Website:

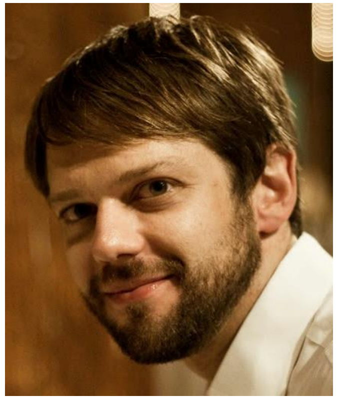
https://www.energy.gov/eere/wind/articles/offshore-wind-turbine-radar-interference-mitigation-webinar-series

Agenda

Monday, October 26th, 2020 11AM-1PM Eastern	
11:00 a.m.	Welcome, Meeting Objectives *Patrick Gilman U.S. Department of Energy Wind Energy Technologies Office (WETO)*
11:05 a.m.	Terminal Radar Overview & Application to Offshore Wind *Stuart Francis| Federal Aviation Administration (FAA)*
11:30 a.m.	Mitigation Techniques Investigated and Applicability to Offshore Wind ***Radar Upgrades and Wind Turbine Siting*** *Jason Biddle| MIT Lincoln Laboratory*
11:40 a.m.	***Infill Radars*** *David Mazel | Regulus Group* *Megan Wolterman | FAA*
12:00 p.m.	***Reduced Signal Turbines*** *Ben Karlson | Sandia National Laboratories*
12:10 p.m.	Group Discussion for Offshore Mitigation Opportunities This session is an opportunity for industry participants to ask questions, provide feedback, and propose ways to support mitigation efforts. Moderators: *Steve Sample | Department of Defense Military Aviation and Installation Assurance Siting Clearinghouse* *Patrick Gilman | DOE WETO* Participants: *ALL*
1:00 p.m.	Closing and Information for Next Webinar *Patrick Gilman| WETO*

Briefers

Stuart
Francis,
FAA



Jason
Biddle,
MIT LL

David
Mazel,
Ctr, FAA

Megan
Wolterman,
FAA

Ben
Karlsons,
Sandia

Offshore Wind Turbine Radar Interference Mitigation

FAA Terminal Airport Surveillance RADAR

Presented to:	WTRIM Webinar
By:	Stuart Francis
Date:	October, 2020

Federal Aviation Administration

Airport surveillance radar systems (ASR)

Airport surveillance radar systems (ASR) are one type of primary radar system used by the FAA.

- ASR Systems primary function is to provide surveillance of airports for aircraft approach and departure
- This may include outlying airports in addition to the one located closest to the sensor
- This mission typically includes altitudes from ground level to 10000ft

Examples of other radar system types include:

- Air Route Surveillance Radar (ARSR) – En route air traffic
- Airport Surface Detection Equipment (ASDE) – Airport surface surveillance
- Weather radar (NEXRAD / TDWR) – Controller situational awareness

Air Traffic Control use of Surveillance sources

In accordance with air traffic order 7210.3BB, section 3-6-2 “ATC Surveillance Source Use”:

- Surveillance sources that are approved for Air Traffic Control (ATC) use are Primary Radar, Secondary Radar, ADS-B and Wide Area Multilateration (WAM)
- Approved ATC Surveillance Sources may be used for:
  - Surveillance of aircraft to assure the effective use of airspace
  - Vectoring aircraft to provide separation and radar navigation
  - Vectoring aircraft to final approach
  - Vectoring IFR aircraft to the airport of intended landing.
  - Monitoring instrument approaches
  - Providing radar traffic, weather, chaff, and bird activity information.
  - Providing assistance to pilots of aircraft in distress
- Approved terminal ATC Surveillance Sources may also be used for:
  - Conducting precision or surveillance approaches
  - Formulation of clearances and control instructions based on runways and movement areas observable on the ASDE.

ATC Services that use primary radar data

FAA Air traffic Control services that use primary radar data:

- Surveillance of non-equipped aircraft
- Surveillance of aircraft with Avionics failures
- Provide weather, chaff, and bird activity information
- ASR Surveillance approaches

The FAA also provides and receives surveillance data and to and from other agencies and users per national agreements.

Maintenance, support, and use of airport surveillance radar systems is shared between the FAA, Department Of Defense (DOD), and other agencies.

Common ASR characteristics

- Maximum range of 60 nautical miles for targets and weather
- Scan rate of 4.7 to 5.0 seconds
- Dual beam antenna system (High/Low) with a fixed elevation angle
- Operate in s-band (2700MHz to 2900MHz)
- Use vertical polarization during clear weather and circular polarization during precipitation
- Use Constant False Alarm Rate (CFAR) target detection
- Provide 6 level weather capability
- Coupled with a secondary (beacon) radar system

Currently deployed ASR systems

Airport Surveillance Radar 8 (ASR-8)

- Initial deployment ~1975
- Klystron Transmitter
- Receiver and processor updated with Common Terminal Digitizer (2020)

Airport Surveillance Radar 9 (ASR-9)

- Initial deployment ~1989
- Klystron transmitter
- Provides both tracked (correlated) and plot (uncorrelated) target outputs.
- Processor updated with 9-PAK modification

Airport Surveillance Radar 11 (ASR-11) / Digital Airport Surveillance Radar (DASR)

- Initial deployment ~2003
- Solid state transmitter with pulse compression beyond 6.5nmi or 8.5nmi (site selectable)
- Provides both tracked (correlated) and plot (uncorrelated) target outputs.
- Updated with advanced signal data processor (2012)

Existing ASR systems were not designed to cope with wind turbine clutter

Performance in wind farm clutter areas was not specified when the currently operational systems were acquired:

- No Mention of wind turbines in FAA-E-2704B specification
- No Mention of wind turbines in Design Documents
- No Mention of wind turbines in 6310 Series Technical Instruction Books

The FAA's current inventory of terminal radar systems were designed between 1970 and 2003 prior to significant wind power capacity growth.

Wind farm impacts on ASR systems

- False primary plots (in the sense that they are not aircraft)
  - False plots may occur over the wind farm area and may also appear in antenna side-lobe areas.
- False primary tracks
  - ASR-9 and ASR-11 provide both track and plot outputs from the radar
  - False plots sent to the automation system can create false tracks
- Track seduction
  - Tracks that jump from aircraft targets to adjacent wind turbines
- Reduced probability of aircraft detection in:
  - In the clutter cell containing the wind turbine(s)
  - In the CFAR lead/lag region in front of and behind the turbine(s)
  - In the dynamic geo-censor cell containing the turbine(s)
  - In the pulse compression window ahead of and behind the turbine(s) (ASR-11)
  - The region beyond wind farm area due to screening and/or distortion of the radar beam

A publicly available report published by Sandia National Laboratories summarizes the impacts of wind farm clutter on several radar systems including the ASR-11 located at the Abilene Regional Airport in Abilene, Texas.

Offshore Impacts

The types impacts are expected to be similar for terrestrial and off-shore cases.

Significant factors related to off shore wind farms are the size of the turbines, lack of terrain screening, and increased ducting conditions over the ocean.

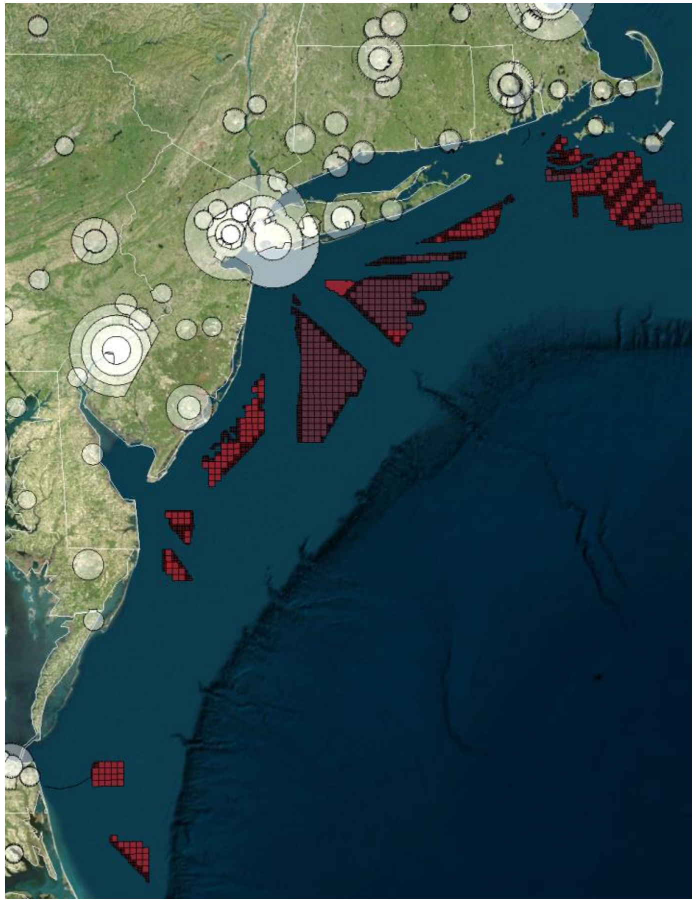
The assumption is that with larger turbines and the lack of terrain screening the impacts will be greater than those seen with terrestrial wind farms. Issues with performance degradation beyond the wind farms and in side lobe regions may be increased but this can not be confirmed without modeling or test data.

Unlike some ARSR systems, existing ASR systems do not incorporate sea clutter processing which would alter performance in the off shore versus terrestrial case.

An examination of several weeks of RADAR data from the Falmouth-Otis ASR-8 which is 46 nautical miles from the Block Island wind turbines showed no discernable performance impact from this small wind farm.

ASR Sites potentially impacted by BOEM lease areas

Site	Coast	Location	Type	Maintainer	Impacted area
ACK	East	Nantucket, MA	ASR-9	FAA	Significant
ACY	East	Atlantic City, NJ	ASR-9	FAA	Significant
CHS	East	Charleston, SC	ASR-9	FAA	Some
DOV	East	Dover AFB, DE	ASR-11	AF	Some
EWR	East	Newark, NJ	ASR-9	FAA	Minor/none
FMH	East	Falmouth, MA	ASR-8	FAA	Some
ILM	East	Wilmington, NC	ASR-8	FAA	Minor
ISP	East	New York, NY	ASR-9	FAA	Significant
JFK	East	New York, NY	ASR-9	FAA	Some
KNTU	East	NAS Oceana, VA	ASR-11	Navy	Significant
MYR	East	Myrtle Beach, SC	ASR-11	FAA	Significant
ORF	East	Norfolk, VA	ASR-9	FAA	Minor
PVD	East	Providence, RI	ASR-9	FAA	Significant
WRI	East	McGuire AFB,	ASR-11	AF	Minor/none
HNL	Hawaii	Honalulu, HI	ASR-9	FAA	Significant
SMX	West	Santa Maria, CA	ASR-11	FAA	Minor/none



The impacted area represents radar visibility of the lease areas, not operational impacts.

General ASR Clutter Mitigations

- Antenna tilt adjustment
  - Reduce exposure of the wind turbines to the radar beams
  - Effectiveness is subject to varying atmospheric propagation conditions

- Weather clear day clutter maps
  - These maps are used by weather processing algorithms to exclude ground clutter
  - Existing system designs assume that ground clutter has a minimal Doppler component

System Specific Mitigations – ASR-8

- Vertical clutter canceller (VCC): Provides an altitude based null in the antenna pattern.
  - Enabled via a geographic map
  - Dynamically activated and deactivated
  - Applies to both target and weather channels
- Geo-censor map
  - Geographic map that deletes all detection in the specified region
  - Can delete low beam only but this functionality disables VCC
  - Applies to target and weather channels
- Soft STC
  - Geographic map that deletes target detections based on amplitude above clutter
- False plot analyzer
  - Uses primary derived 3D height and other target characteristics to classify targets as real or false
- Weather slow clutter canceller
  - Filter based on Doppler signature and scan to scan movement

System Specific Mitigations – ASR-9

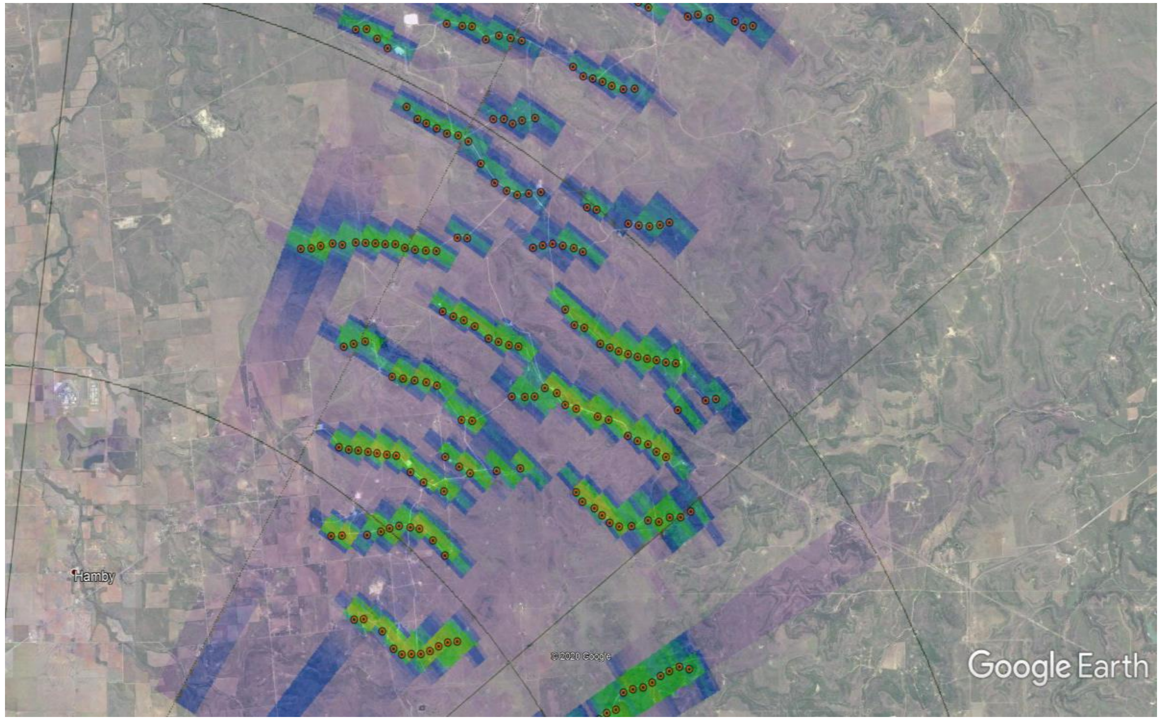
- High\low beam map
    - Default high to low beam switch point at 14nmi to 15nmi
    - Main high to low switch point is adjustable
    - 0 to 4 Isolated Range Azimuth Gated (RAG) windows available
    - Useful in a limited range window and effectiveness is limited by variation in atmospheric propagation
- A Geo-censor map with editing based on peak target amplitude can be enabled over wind farm areas.
    - Dynamic mode – Creates, promotes, demotes and deletes geo-censor cells automatically
    - Static mode – Fixes geo-censor cells in place
    - Effectiveness against wind farm clutter is limited as this is an amplitude based editor
- Weather geo-censor map
    - Deletes specific weather levels in a region
    - Example: Censor levels 1 and 2 if only those levels appearing
    - Prevents display of real weather at the censored levels

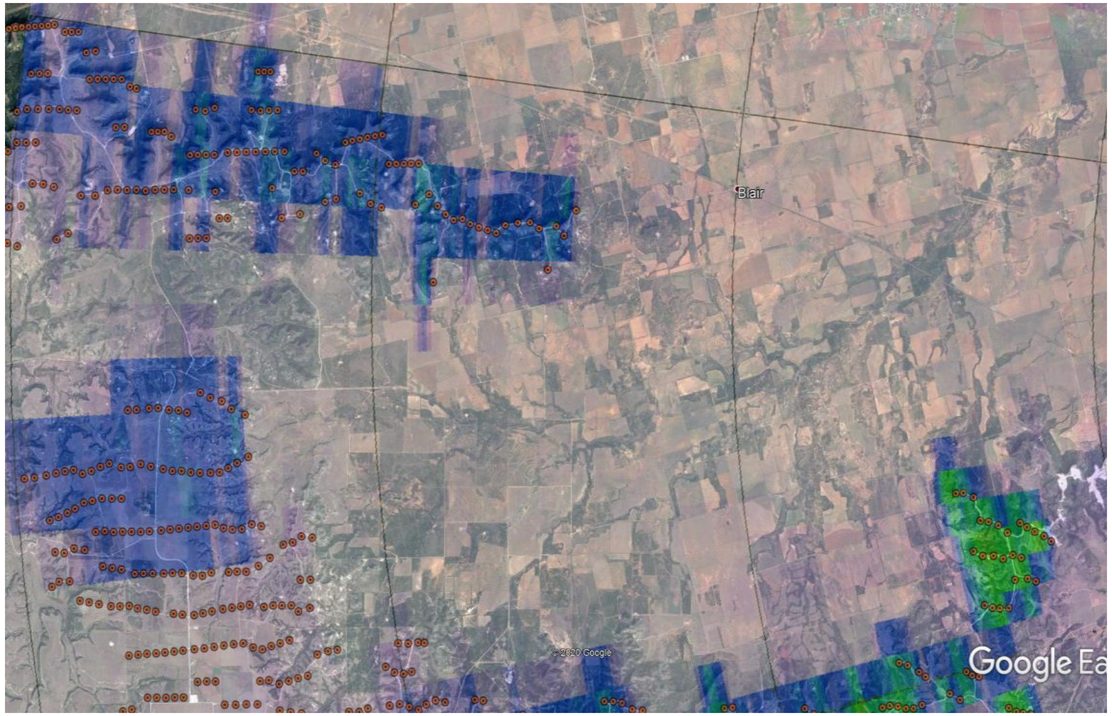
System Specific Mitigations – ASR-11 / DASR

- Target RAG map
  - Geographic map that deletes primary targets based on amplitude
  - Sets a track eligibility flag on retained targets to inform the automation system that the target is in a clutter area
  - Effective at reducing false plots and false track imitation but suppresses aircraft returns
- Doppler clutter maps
  - Feature added after initial system deployment
  - Informal investigation shows some improvement in wind farm areas but low Doppler resolution and averaged nature of the clutter maps limits effectiveness
- Plot amplitude threshold
  - Deletes or tags primary targets based on mean amplitude in regions that have a large number of primary detections
  - Dynamically activated
  - Regions are large and activation causes suppression of aircraft targets in the region
- Weather RAG map
  - Geographic map to disable weather detection in a region and fill the area in with surrounding weather levels.
- There are two studies proposed for FY21:
  - Change the way weather edge tagging is used to qualify radar plots sent to the automation system.
  - Determine if the CARSR SDTS algorithm can provide benefits to the ASR-11 system.

Wind farm layout

- The effectiveness of the existing mitigation strategies is dependent on the layout of the wind farm:
    - A higher density of wind turbines in the wind farm area reduces visibility between turbines
    - Individual turbines and small groups are well tolerated by existing ASR systems





Mitigations at the automation stage

- The automation system typically excludes display of slow moving primary targets
    - This prevents the automation system from displaying false targets from individual turbines and low density wind farm areas
    - The automation system can use track filtering to identify aircraft-like behavior to reduced the impacts of false targets
- Fusion (combination) of multiple sensor inputs can increase the probability of aircraft detection in areas where it is reduced for a given sensor
- Likewise, exclusion of sensors with excess false target contamination in regions with overlapping coverage can improve target tracking
- The automation system can make use of target quality estimates provided by the radar systems to improve target tracking at the automation stage
    - This information is supplied by ASR-8 and ASR-11 systems

Limitations of existing mitigation strategies

- With the exception of the Vertical Clutter Canceler on the ASR-8, none of the available clutter rejection algorithms were designed with wind farm clutter mitigation as a goal.
- Existing mitigations involve a trade off between aircraft detection and false target suppression.
- Many of the existing false target suppression algorithms are based on mean or peak target amplitude and assume that false targets have a smaller Doppler radar cross section than aircraft. This is not the case for wind turbines.
- Use of high beam can provide some relief for regions that are typically in the low beam region (beyond 6 15 nautical miles from the sensor) but may become ineffective during periods of beam bending and can reduce the detection of aircraft targets.
- System clutter maps are designed to suppress non-Doppler (ground) clutter which is not appropriate for the dynamic clutter presented by wind farms.
- None of the existing mitigation strategies restore 'in the clear' performance over wind farm areas.

Summary

- Existing ASR systems were not designed to mitigate wind farm clutter.

- Existing ASR systems have algorithms that can be adjusted to reduce false targets in the presence of clutter. These tools can be used to reduce the impact of wind farm clutter but may not restore the level of performance achievable outside of wind farm areas.

- Wind farm clutter interferes with weather processing. Existing mitigation strategies for weather processing are limited.

Wind Turbine Radar Interference Mitigation R&D Overview

Jason Biddle

DOE Offshore Wind Turbine Radar Interference Webinar Series

26 October 2020

LINCOLN LABORATORY
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

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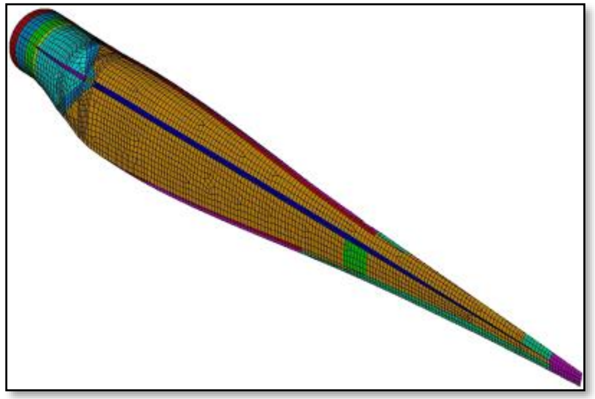
Mitigation Options

Reduced Signal Turbines

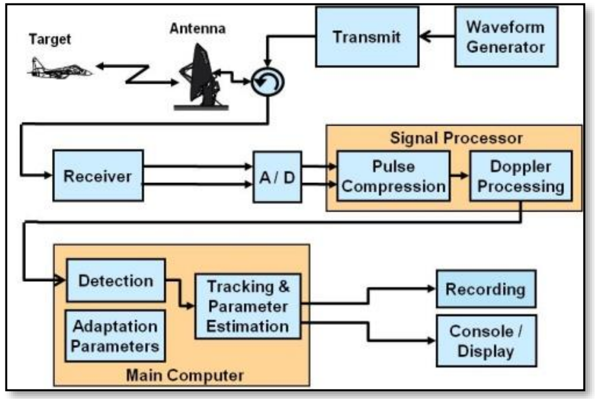


*Infill Radar**

*Replacement Radar**

Wind Farm Siting

Radar Upgrades

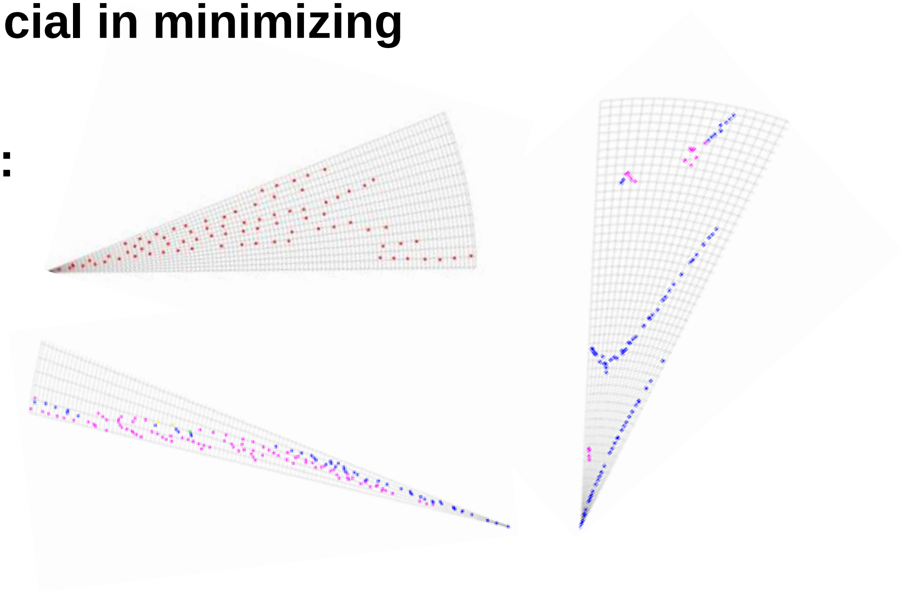


C2/Automation Upgrades

* Radar photo used for illustrative purposes and does not reflect a technology endorsement

MIT LL Wind Turbine Spacing Study

- **Study objective is to evaluate the dependence between radar performance and wind farm layout for current radars near land-based wind turbines**
- **Statistical models were fit to data from ASR-11 and CARSR sites across the US to determine whether certain wind farm layouts are beneficial in minimizing radar interference**
- **Relevant wind farm descriptors in the above models were:**
  - **Wind farm distance to the radar**
  - **Portion of wind turbines within radar line of sight**
  - **Density of wind turbines in the wind farm area**
  - **Density of wind turbine per radar range-azimuth cell**

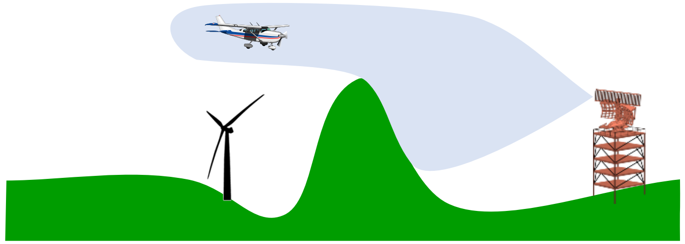


Effectiveness of different siting strategies depends on wind farm geometry relative to the local radar and the mission(s) served by that radar

Potential Wind Farm Siting Strategies

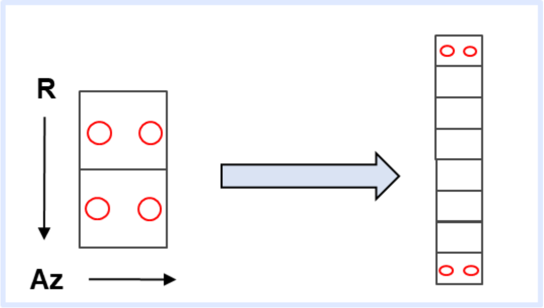
Distance and visibility to radar

Strategy: Place wind turbines beyond radar line of sight



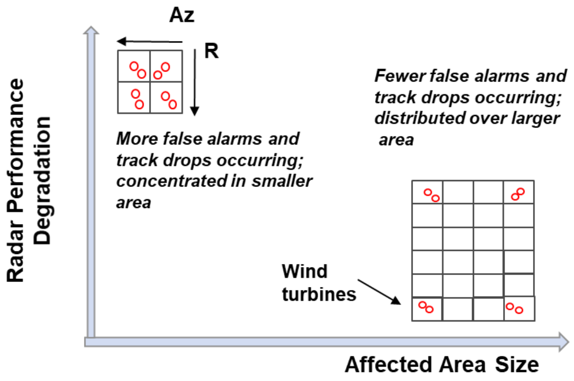
Empty/clear radar cell distribution

Strategy: Separate consecutive wind turbines (e.g., in range) to increase tracker performance



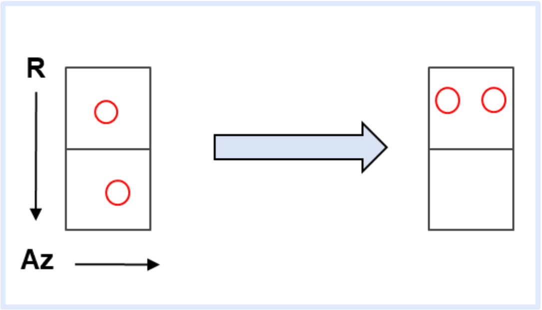
Areal density

Strategy: Distribute wind turbines geographically to reduce overall density



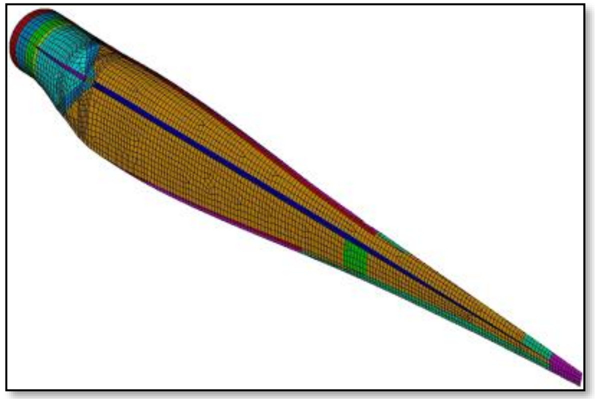
Density with respect to radar resolution

Strategy: Group as many wind turbines into individual radar cells as feasible to minimize impact



Mitigation Options

Reduced Signal Turbines



*Infill Radar**

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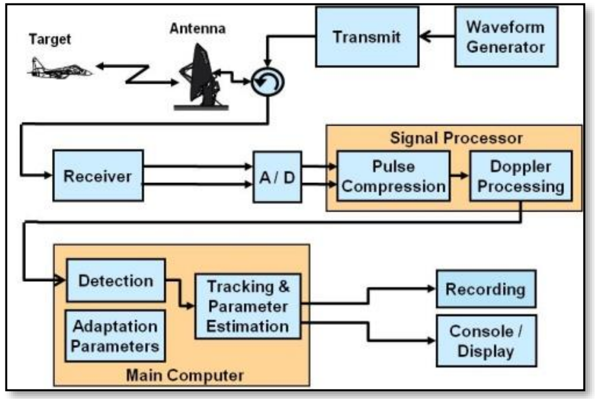
Wind Farm Siting

Radar Upgrades



Target

Antenna

Transmit

Waveform Generator

Signal Processor

Receiver

A / D

Pulse Compression

Doppler Processing

Detection

Adaptation Parameters

Tracking & Parameter Estimation

Main Computer

Recording

Console / Display

C2/Automation Upgrades

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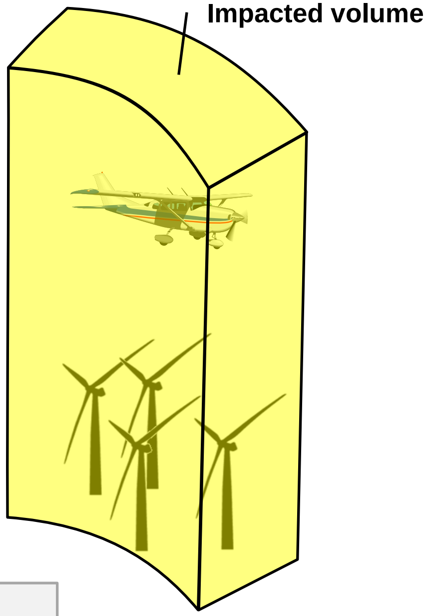
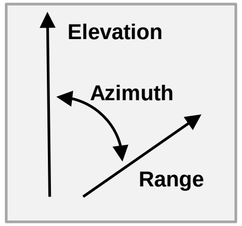
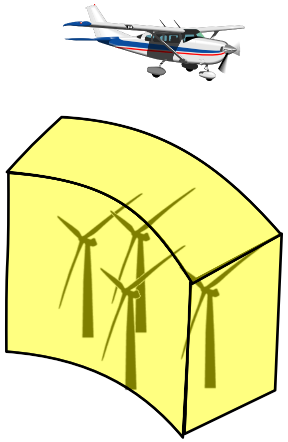
Potential Resolution Improvements

Baseline

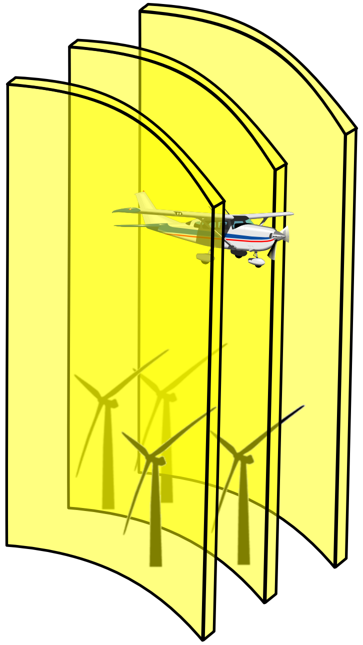




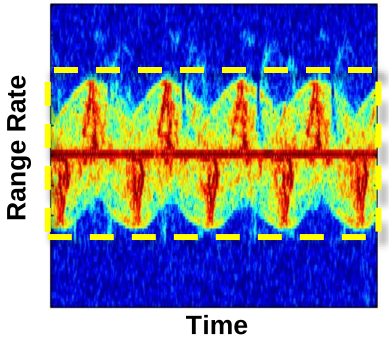
Elevation

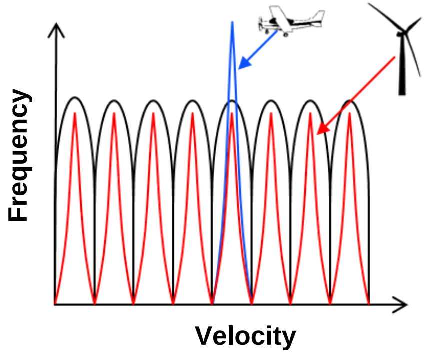


Range

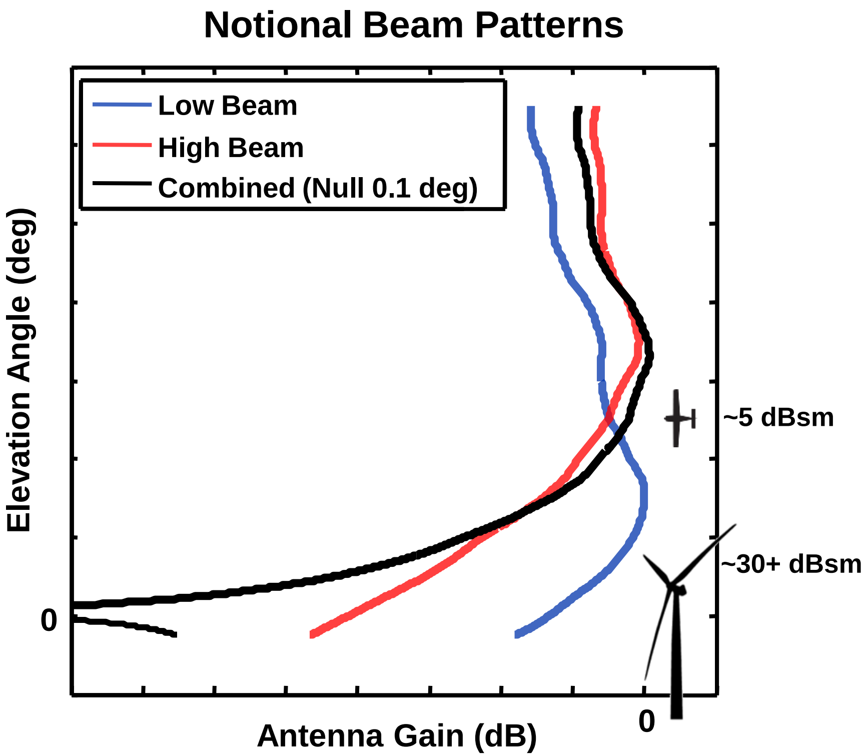


Doppler

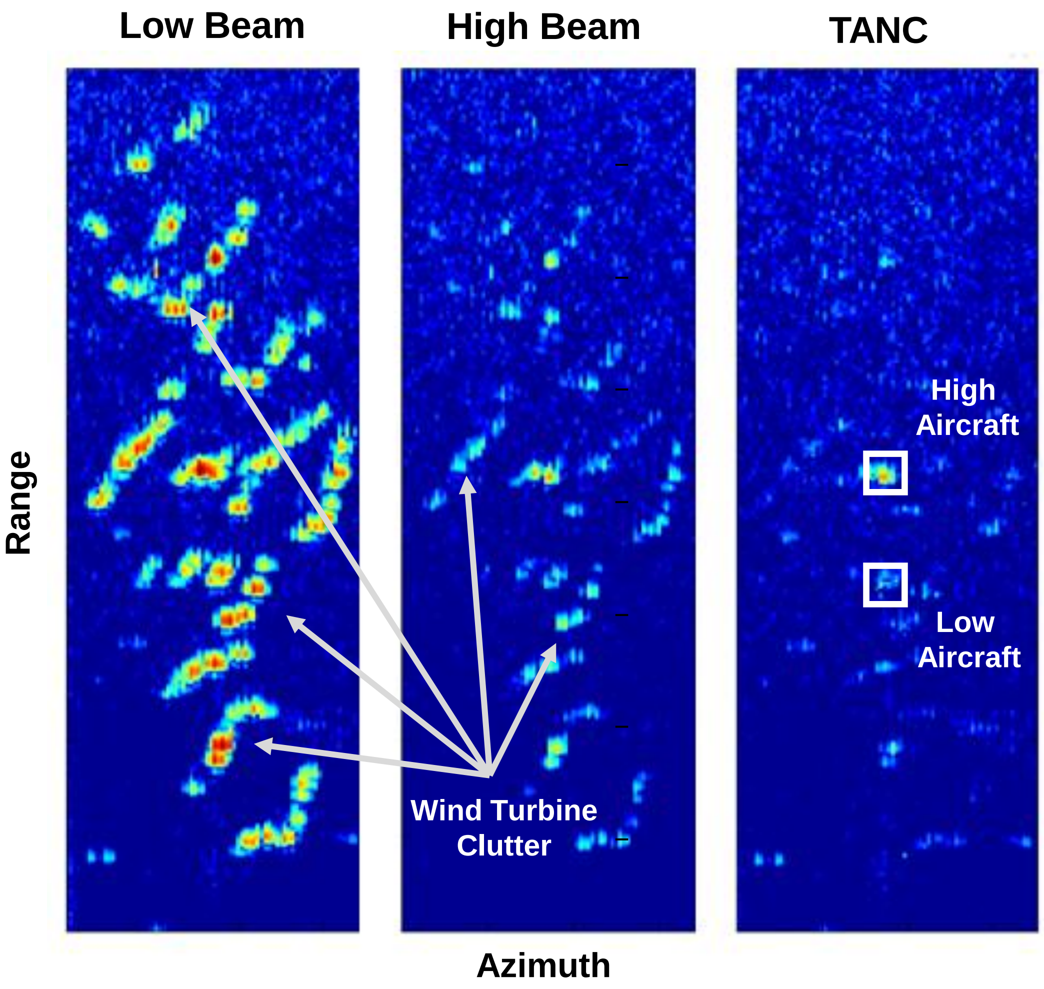




Turbine Adaptive Nulling Concept (TANC)

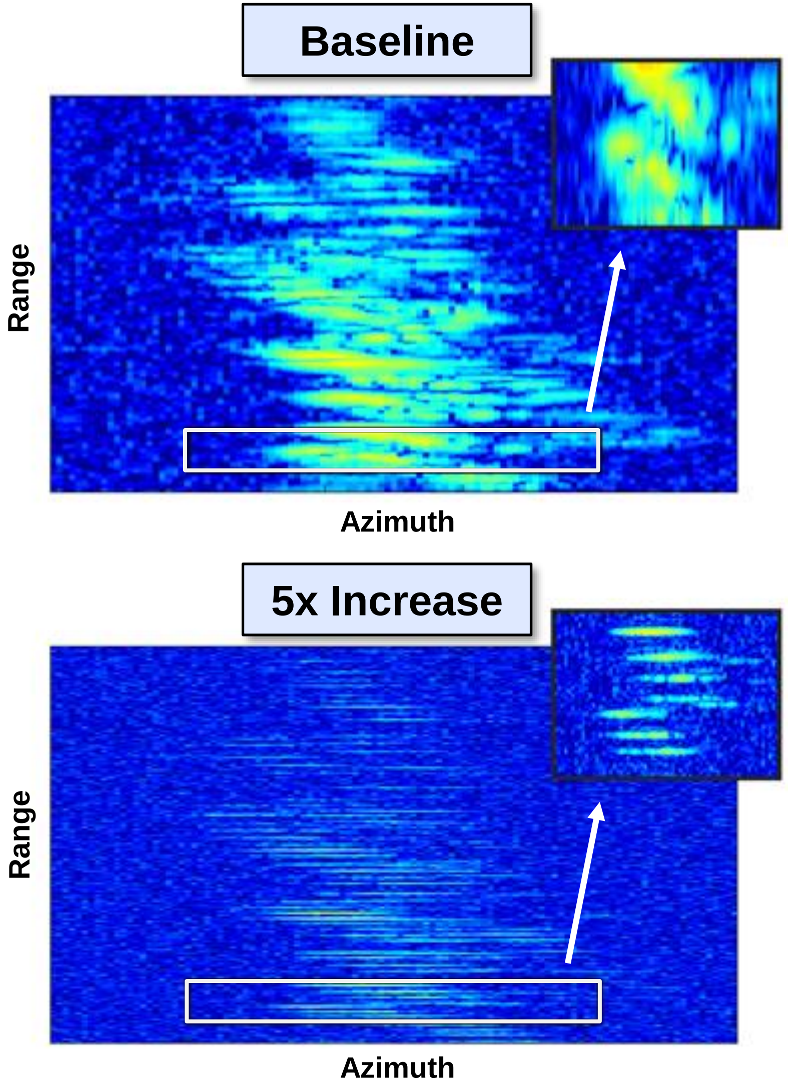


- Coherently combine low and high beams to place a null on wind turbines at low elevation angles
- Restores performance against higher-altitude targets
- Low altitude target detection remains a challenge



Increased Range Resolution (IRR)

- **Transmit and receive higher bandwidth waveforms**
- **Regain ability to detect targets "in between" wind turbines**
- **Targets flying directly over wind turbines are still not detectable**
- **Most trackers can maintain custody of target within wind farm given sufficient numbers of detections**
- **Wind turbine clutter will contaminate a smaller fraction of the area, and RAG mapping can eliminate false alarms from these cells**
- **Mitigation performance depends on range to wind turbines, density, layout, and target trajectory**



RAG Range Azimuth Gating

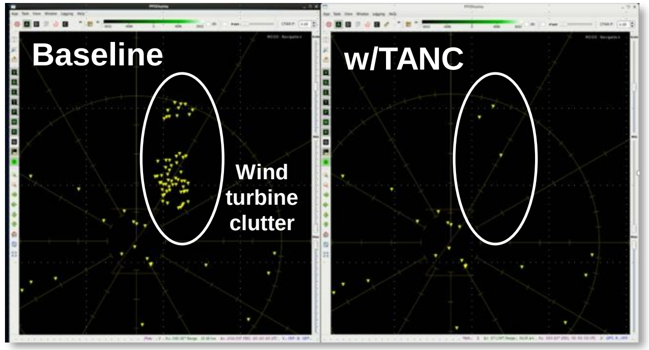
MIT LL TANC and IRR Demonstrations

- Real-time radar sidecar testbed was used to implement and evaluate the mitigation approaches on two ASR-11 radars located near land-based wind turbines
- Sidecar testbed taps into the RF chain of the existing radar, performs its own analog-to-digital conversion, and mimics downstream processing (e.g., matched filtering, Doppler processing, CFAR) with the mitigation technique applied
- Mitigations were tested side-by-side with the baseline radar without the risk or cost of fully implementing the mitigation in the native hardware and software of the existing radar

Sidecar Testbed

Radar Taps

Side-by-side Display

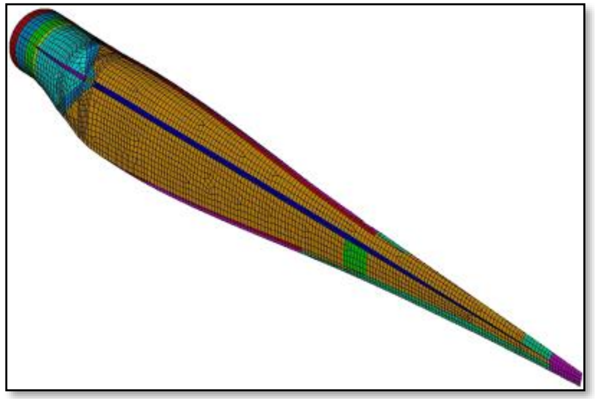


Retrofits to implement these techniques on existing radar systems may be cost prohibitive given legacy hardware and processing capabilities

CFAR	Constant False Alarm Rate
IRR	Increased Range Resolution
TANC	Turbine Adaptive Nulling Concept

Mitigation Options

Reduced Signal Turbines



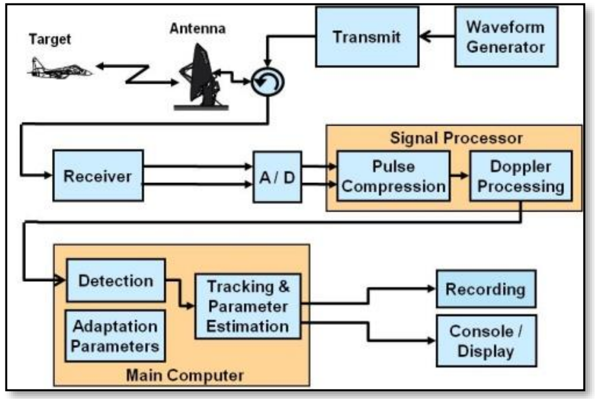
Next Speakers

Infill Radar*

Replacement Radar*

Wind Farm Siting

Radar Upgrades



C2/Automation Upgrades

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Infill Radars for Wind Turbine Clutter Mitigation

By: Megan Wolterman, FAA, AJM-4130

Date: October 26, 2020

Federal Aviation
Administration

Part I: The Travis Pilot Mitigation Project

Part II: Infill Radar Certification

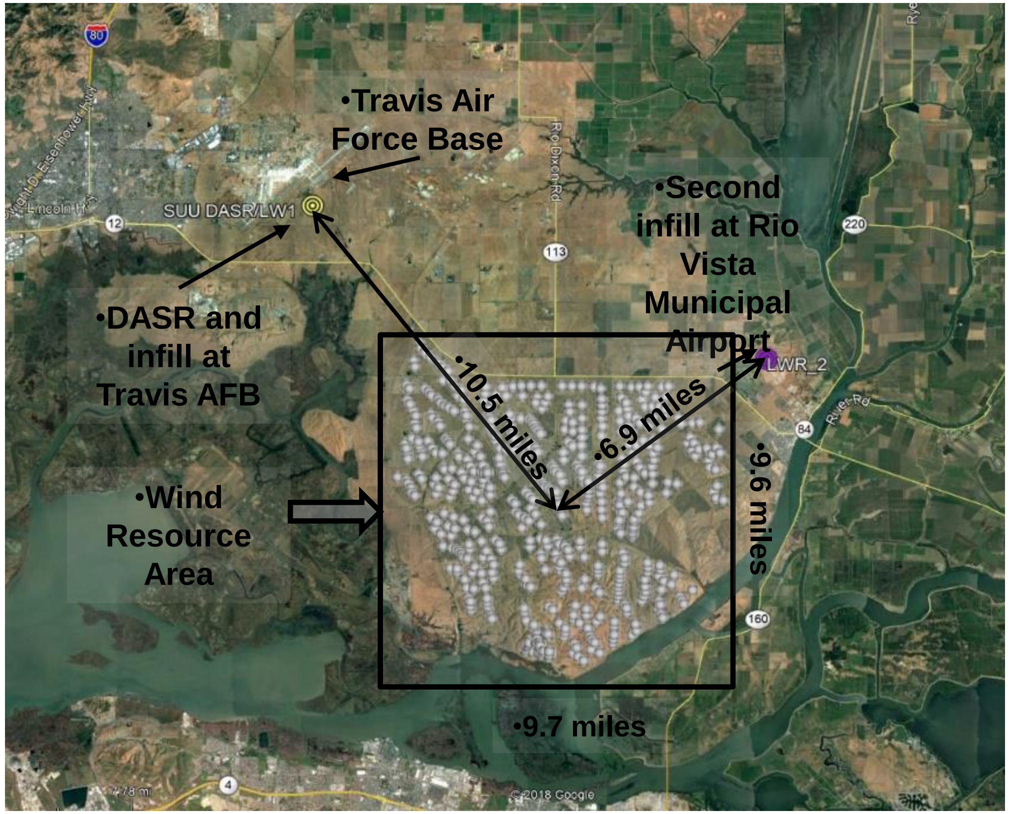
Part I: Travis Pilot Mitigation Project Outline

1. Problem statement
2. Integration scheme of hardware and software
3. Standard Terminal Automation Replacement System (STARS) processing
4. STARS adaptation and evolution
5. Civil Air Patrol (CAP) flights
6. Example result
7. Conclusions

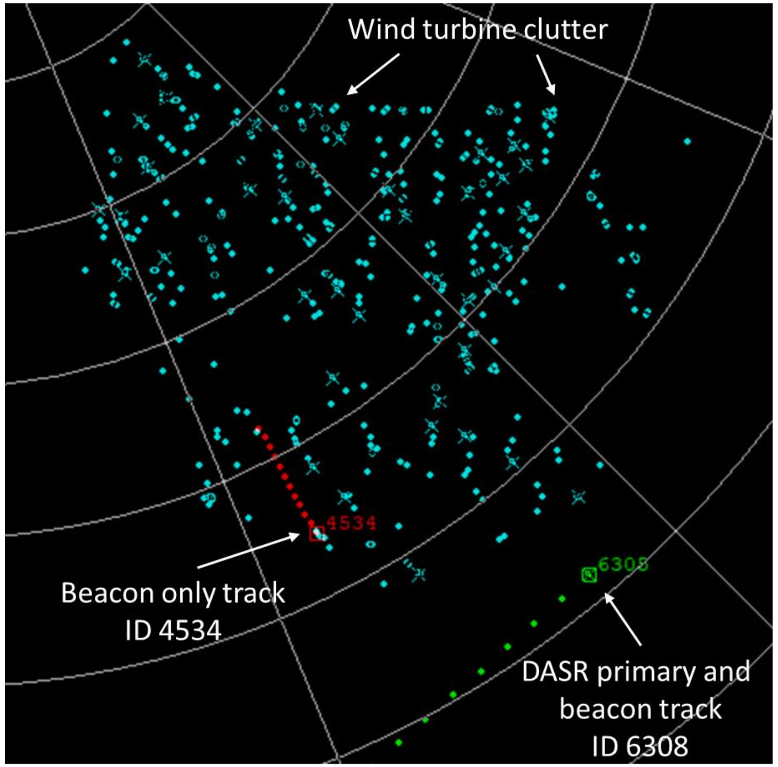
This brief focuses on integration as its theme

Problem statement: Geography and wind turbine clutter

Geographic view



DASR view



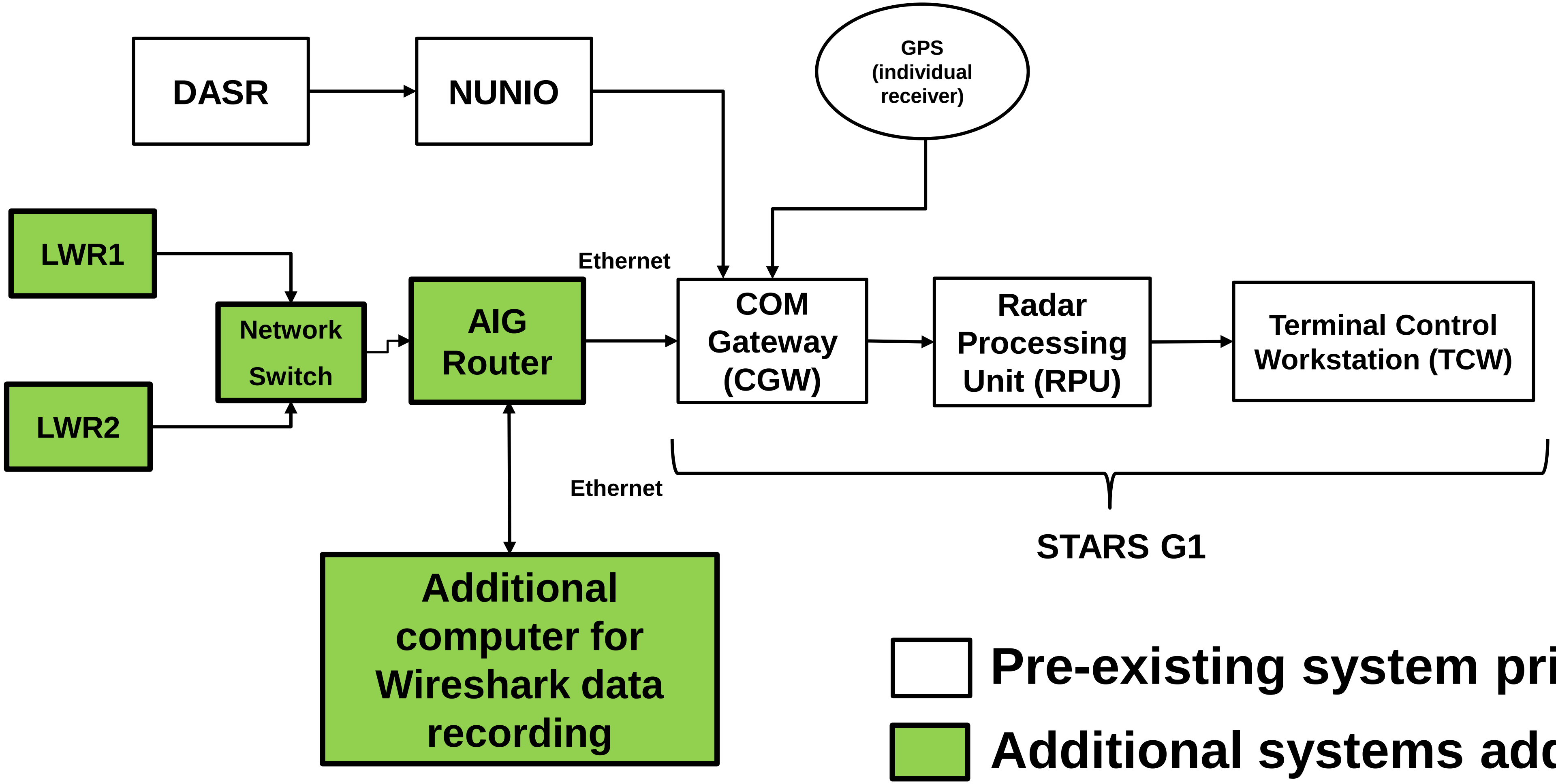
DASR: Digital air surveillance radar (ASR-11)

Proposed solution: Infill radar

- **Manufacturer: C Speed, LLC**
- **Name: LightWave radar**
- **Primary-only**
- **S-band (2-4 GHz)**
- **Scan rate: 4.8-seconds (matches DASR)**
- **High PRF: 11.4 kHz**
- **Small form factor**
- **Transportable**
- **Sites**
  1. Travis Air Force Base (with DASR)
  2. Rio Vista Municipal Airport

Infill radar co-located with DASR at Travis Air Force Base

Integration: Hardware systems



DASR

NUNIO

GPS (individual receiver)

LWR1

LWR2

Network Switch

AIG Router

Ethernet

COM Gateway (CGW)

Radar Processing Unit (RPU)

Terminal Control Workstation (TCW)

Ethernet

STARS G1

Additional computer for Wireshark data recording

☐ Pre-existing system prior to PMP

🟩 Additional systems added for PMP

Integration: Software systems

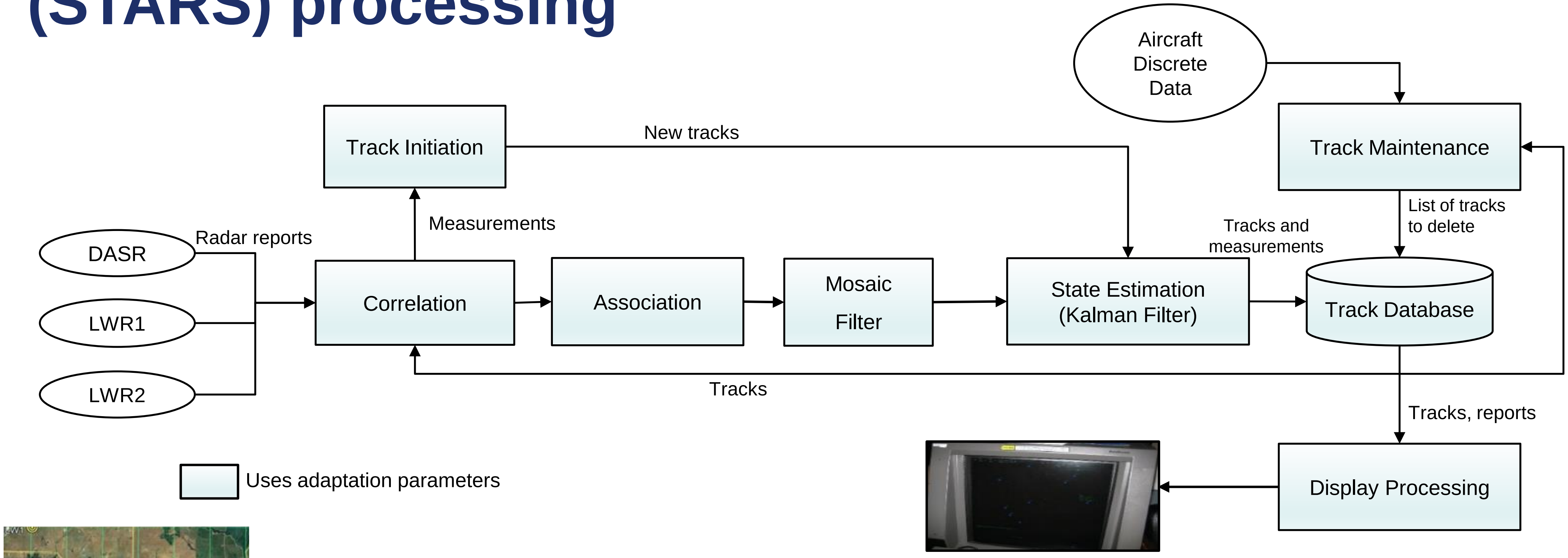
- Incorporated Internet Protocol (IP) messages over Ethernet

- Similar to all-purpose structured EUROCONTROL surveillance information exchange (ASTERIX) messages

1. CAT 34 (Monoradar Service Messages)
    a) North marker messages
    b) Sector crossing messages

2. CAT 48 (Monoradar Target Reports)
    a) Plot data
    b) Permanent echoes
    c) Search Real Time Quality Control messages

Standard Terminal Automation Replacement System (STARS) processing



STARS glass for display

Tiling

- Radar priorities
- Track decisions

- Track fusion
  - Primary returns
  - DASR secondary and infill
- Hand-offs inside-to-outside WRA tiling

STARS adaptations

Adaptation #1: Prototype

- DASR, LWR1, and LWR2 equally treated across Travis airspace.

Adaptation #2: Sensor Prioritization

- LWR1, LWR2 initiate tracks in WRA.
- DASR updates in WRA.
- LWR1, LWR2 not adapted outside WRA.

Adaptation #3: Fusion mode Fusion display enabled on glass (*Operational mode for ATC*)

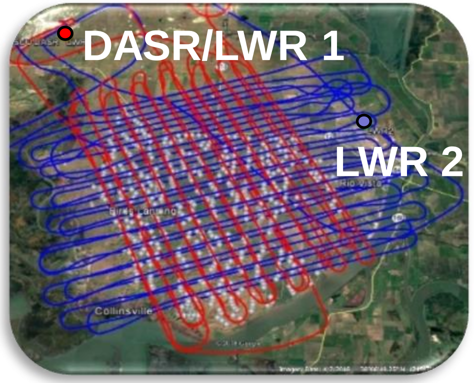
Adaptation #4: Fusion mode with correction

- 0.1-deg added to North marker to compensate for LWR1 azimuth bias
- Track firmness set to 2 to reduce clutter tracks in WRA

Adaptation #5: Fusion mode, DASR initiation

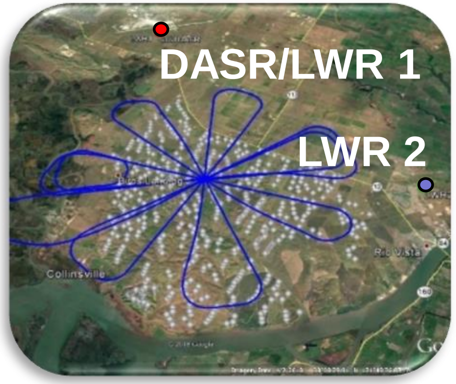
- DASR permitted to initialize tracks inside the WRA

Civil Air Patrol (CAP) flights



Spring patterns

Spiral patterns

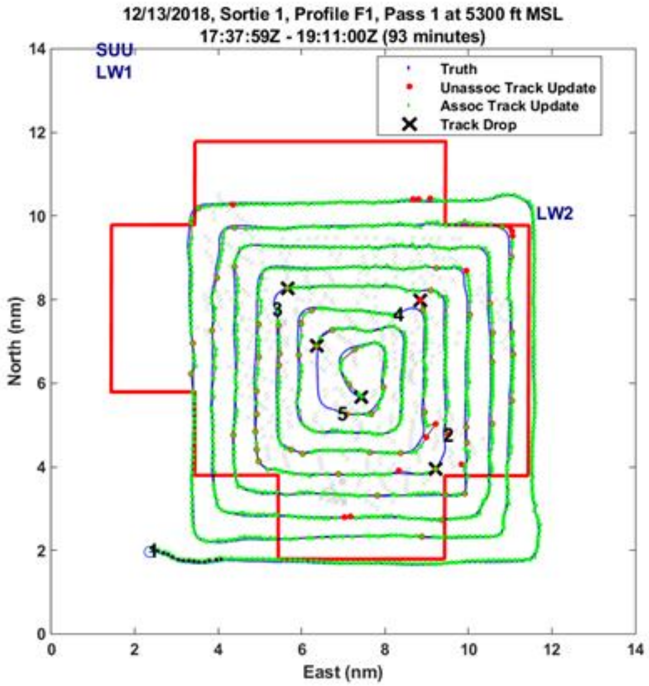


Petal patterns

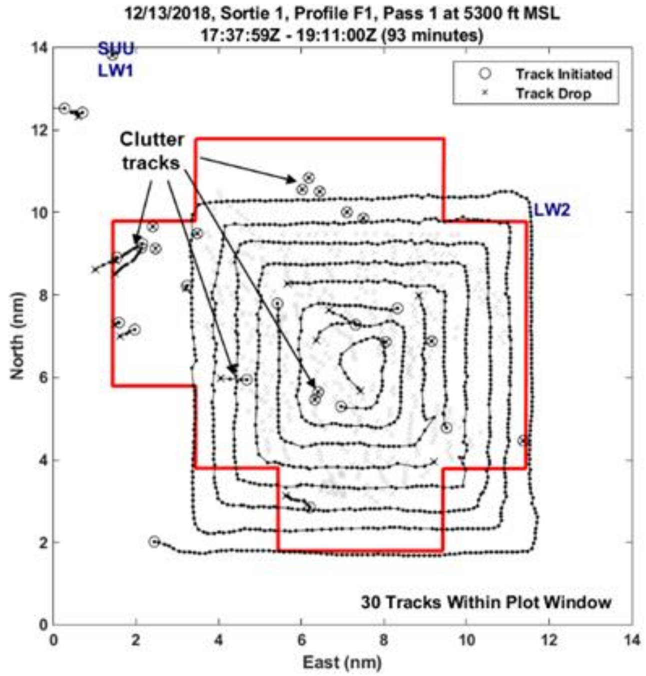
Benefits to CAP flights

1. Controlled flights
2. Space filling patterns (stress radar and tracker)
3. Controlled speed
4. Controlled altitudes
5. Frequent crossings (track steal exhibited)

Example flight and results: CAP #8



Track of a CAP flight



Time lapse ATC operator display

- STARS maintained continuous track for 70-minutes
- Hand-offs with DASR
- Few track breaks
- Few clutter tracks

Conclusions of the Travis PMP

1. **Hardware and software**
   - Team successfully integrated two (2) infill radars into STARS
2. **Operational demonstrations**
   - Team flew 15 Civil Air Patrol flights with complex flight paths
   - Team demonstrated use and interaction of infill radars with DASR to display tracks on STARS
3. **Infill radars showed improved performance**
   - Higher probability of detection (Pd) than the DASR
   - Lower probability of false alarm (PFA) than the DASR

Part II:

Infill radar certification process

Megan Wolterman: FAA Project Lead

Introduction to Certification Process

Goal: Develop a process to certify infill radars for use in the National Air Space (NAS)

Steps to this goal

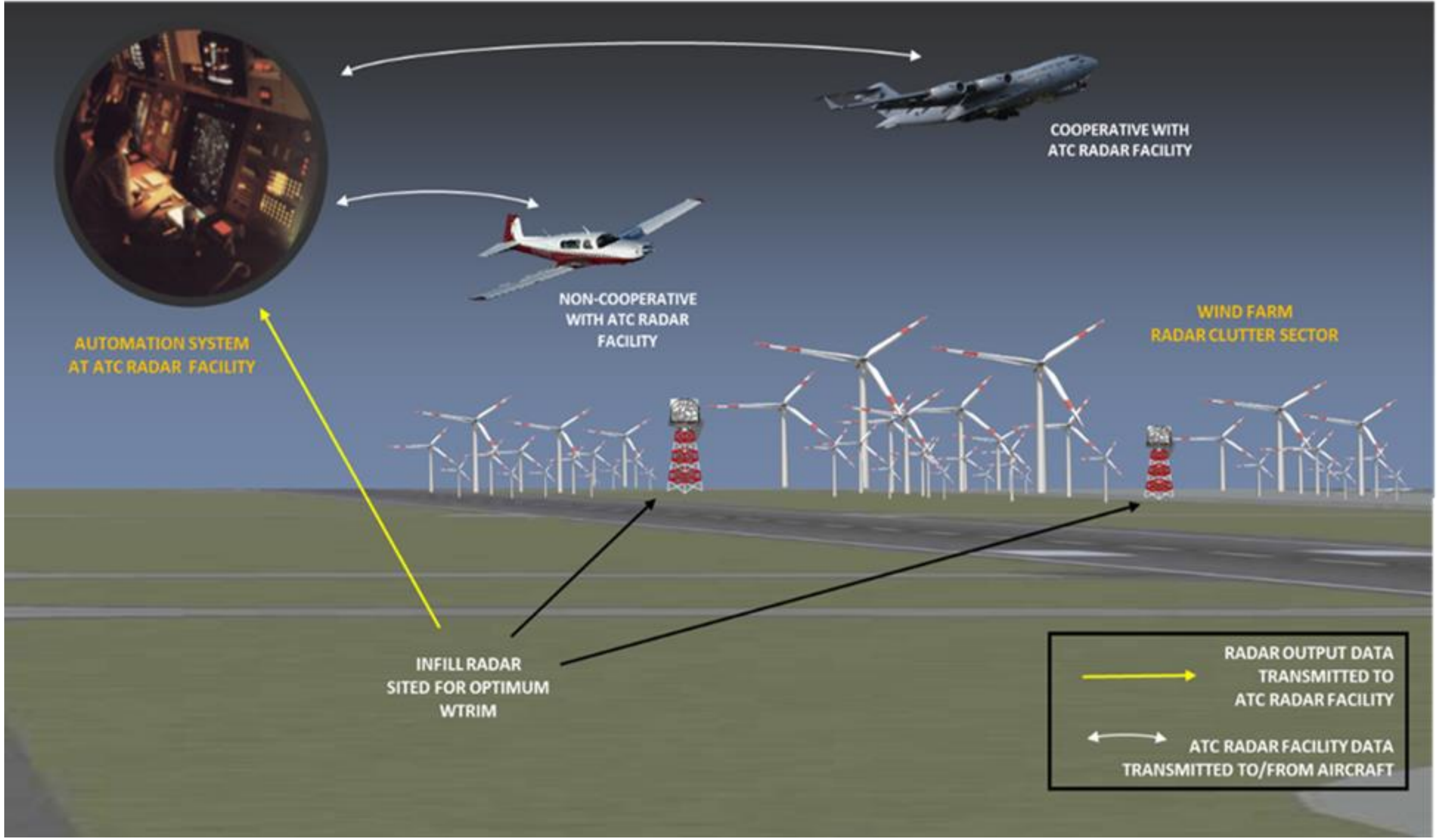
1. Develop the processes for the FAA to execute with Air Force concurrence
2. Determine the appropriate documentation
3. Compose documentation and obtain necessary approvals

Outline of this brief

1. Operational concept
2. Products and Activities

Working in collaboration with USAF to develop this process

Operational Concept



Infill radars provide primary (non-cooperative) radar coverage over a wind resource area, interface with the automation system, and integrate with other radar sensors in the coverage volume

* OV-1 diagram of system from the Concept of Operations

Infill radar certification: Products and Activities

1. **Concept of Operations**
   - Summarizes the case for infill radars and expected scenarios
   - Status: In signature cycle
2. **Functional Analysis**
   - Hierarchy of expected infill radar functions; drives requirements
   - Status: In review
3. **Requirements document**
   - Delineates infill radar requirements for certification
   - Status: In development
4. **Test Plan**
   - Details test scenarios and execution plan based on requirements
   - Status: Not started
5. **Request for Information (RFI)**
   - An industry survey of current systems
   - Status: Completed (RFI response period closed)

Objective: Define the process and associated documentation to test candidate COTS infill radars as a solution for wind turbine clutter mitigation

For Further Information:

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Wind Turbine Blade RCS Reduction Studies at Sandia National Laboratories

PRESENTED BY

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Wind Energy Technologies
Sandia National Laboratories, Albuquerque, NM

Sandia National Laboratories is a multimission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

SAND2020-11135 PE

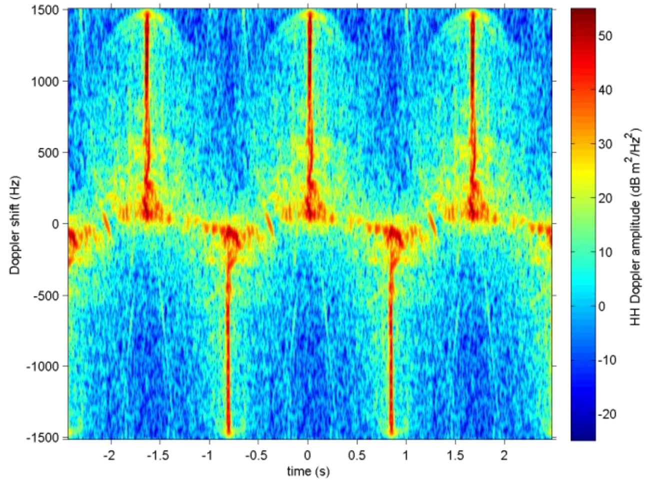
RCS Reduction of Wind Turbines Using Radar Absorbing Material - 2012

SNL developed treatments that can be economically implemented into blade-fabrication processes in order to reduce radar cross section (RCS) of a wind-turbine blade by at least 20 dB.

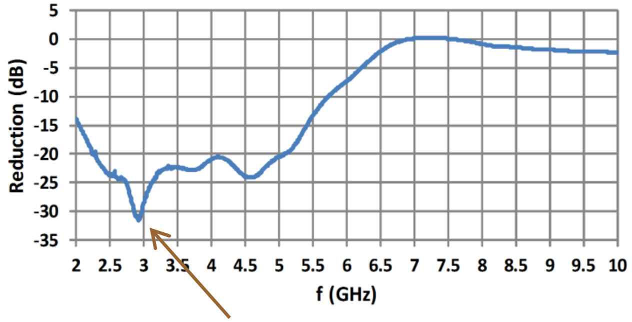
Summary/Accomplishments

- Characterized Blade Materials and Fabrication
- Developed RCS Reduction Treatments at S-band (2 - 4 GHz)
- Integrated RAM Designs into Blade Fabrication Process
  - Low impact integration into standard Vacuum-Assisted Resin-Transfer Molding process
  - As simple as adding two layers with no process changes
  - Predicted cost increase less than **10% per blade, 2% per turbine**
- Measured Flat Panels with and w/o RCS Reduction Treatment
  - **–20 dB or less reflection coefficient measured** for both spar and sandwich panels
- Analyzed Three-Blade Rotor using Realistic Blade Construction and Materials (126-meter Diameter)
  - Generated static RCS and Doppler spectrum responses
  - Compared composite and perfect electric conductor (PEC) rotor scattering
  - Identified significant scattering elements

Full rotor Doppler Spectrogram, AZ = 90°

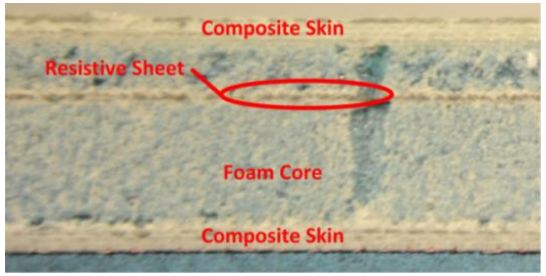


Measured RCS Reduction (PEC Reference)



Broadband (2.3 to 5.1 GHz) reduction (≥ 20 dB) in reflection coefficient

Integrated RAM Cross-Section



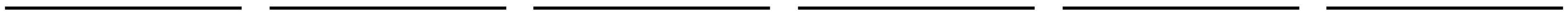
Blade Material Samples

Wind Turbine Lightning Protection System RCS Reduction – 2018

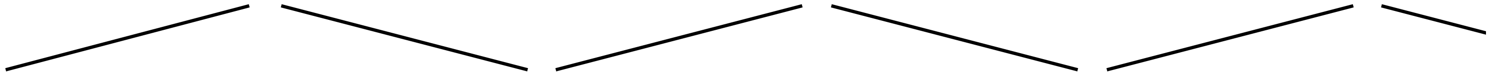
SNL modeled new lightning protection cable configurations that show promise to reduce radar cross section (RCS) of a wind-turbine blade at specific frequencies.

Summary/Accomplishments

- Modeled RCS of a 50m metal straight LPS cable and compared against new LPS configuration
  - Straight Segmented Cable

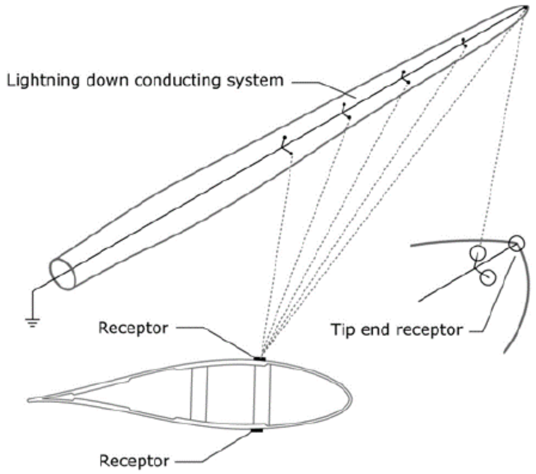


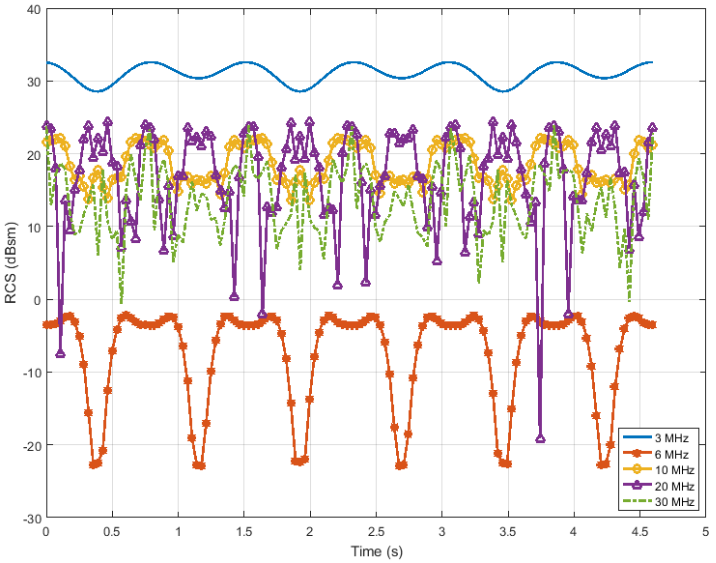
    - Segmenting the cable makes smaller cables that resonate at higher frequencies. This can be used to shift resonance above frequencies of interest.
    - More segments require more spark gaps.
  - Zig-Zag Cable



    - No significant changes produced by bending the cable into a Zig-Zag
    - Segmenting results similar to straight wire case
  - Reactively Loaded Cable

    - An example case was investigated by splitting the cable into two segments and loading each segment with a reactive impedance (inductor).
    - Example at 6MHz showed promise in RCS reduction





Summary

- 2012 Radar Absorbing Material Study
  - 20 dB or greater reduction can be achieved by integrating RAM into the existing blade fabrication process
    - However, 20 dB return loss does not necessarily correspond to 20 dB RCS reduction for a complete turbine
  - Predicted cost less than 10% per blade, 2% per turbine
  - A full blade and rotor test plan was developed but was not funded
  - Report can be found at:

https://www.osti.gov/biblio/1038185-radar-cross-section-reduction-wind-turbines-part

- 2018 Wind Turbine Lightning Protection System RCS Reduction Study
  - Segmenting shows promise for RCS reduction depending on length of segments and frequency of impacted radar
  - Inductively loading the lightning protection cable may produce better results and can be tuned for frequencies of interest in a relatively narrow band
  - Study did not look at feasibility or cost of implementation into wind turbine blades

MORE RESEARCH & DEVELOPMENT IS NEEDED TO PROVE OUT THESE APPROACHES

Questions and Group Discussion

How Industry Can Engage the WTRIM On Potential Technical Good Ideas

- **WTRIM Agencies since its inception have partnered in the pursuit of various technologies that might lead to mitigating the various Wind Turbine Interference issues**
  - These R&D projects have largely been generated from within the agencies' various technical organizational elements including government supported labs

WHAT'S NOT BEEN GIVEN SUFFICIENT ATTENTION….

Obtaining Input from the Wind Industry Itself

- **As an initial step to rectify this issue, its being proposed that the WTRIM adopt an "Industry Idea's Exchange"**
  - If you're from industry and have a recommendation that will help us address the wind turbine interference problem, here's how you can get it to us now and until a more formal path is established by the WTRIM leadership. Email your idea including a point of contact to:

Cc SCH Executive Director, Steve Sample - steven.j.sample4.civ@mail.mil

SCH R&D Programs Support, Louis Husser – Louis.A.Husser.ctr@mail.mil 540 659-7088

Future Wind-Radar Webinar Agenda & Information

TBD, 2020

Long-Range Radar

- *Technical and operational issues regarding each system in an OSW environment*
- *State of Current Understanding*
- *Mitigation Options*

Webinar Information (Past & Future) is on the DOE Website:

https://www.energy.gov/eere/wind/articles/offshore-wind-turbine-radar-interference-mitigation-webinar-series

Backup Slides

Offshore Wind Technologies Market Report: Summary

- The U.S. offshore wind energy project development and operational pipeline grew to an estimated potential generating capacity of 25,824 megawatts (MW), with 21,225 MW under exclusive site control
- Four U.S. regions experienced significant development and regulatory activities
- State-level policy commitments accelerated, driving increased market interest
- Increased U.S. market interest spurred strong competition at offshore wind lease auctions
- Several U.S. projects advanced in the development process
- Industry forecasts suggest U.S. offshore wind capacity could grow to 11–16 gigawatts by 2030
- Offshore wind interest accelerated in California
- New national R&D consortium aims to spur innovation
- Global offshore wind annual generating capacity installed in 2018 set a new record of 5,652 MW
- Industry is seeking cost reductions through larger turbines with rated capacities of 10 MW and beyond
- Floating offshore wind pilot projects are advancing
- *2018 Offshore Wind Technologies Market Report*.

LCOE forecasts for offshore wind indicate fixed bottom wind may be near $50/MWh and floating wind may be as low as $60 MWh by 2032 (COD)

Additional Resources

2018 Wind Market Reports

- 2018 Offshore Wind Market Report
- 2018 Wind Technologies Market Report

WINDExchange Wind Turbine Radar Interference

- Wind Turbine Radar Interference Mitigation Fact Sheet
- All public OSW-Radar Summaries
- Federal Interagency Wind Turbine Radar Interference Mitigation Strategy

American Wind Energy Association

Bureau of Ocean Energy Management Renewable Energy Fact Sheet