U.S. DEPARTMENT OF ENERGY

Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

2021 PROJECT PEER REVIEW

U.S. DEPARTMENT OF ENERGY
WIND ENERGY TECHNOLOGIES OFFICE

E02 – Wind Turbine Radar Interference Mitigation

Environmental, Siting, Workforce, and Grid – Regulatory and Siting

Jelena Ryvkina
Massachusetts Institute of Technology Lincoln Laboratory (MIT LL)

August 2, 2021

This material is based upon work supported by the Department of Energy under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the Department of Energy.

FY21 Peer Review - Project Overview

Project Summary:
This effort aims at resolving wind turbine-related radar performance issues and thereby reducing deployment barriers for new wind energy systems. In FY19-20 MIT LL performed quantitative evaluation of two key mitigation options: infill radars and wind farm geometry optimization.

Stakeholders: Department of Defense (DOD), Federal Aviation Agency (FAA), Bureau of Ocean Energy Management (BOEM), National Oceanic and Atmospheric Administration (NOAA)

Project Objectives 2019-2020:

Task 1
- Led analysis of radar and test flight data within first effort to integrate infill radars with FAA's air traffic control systems at Travis Air Force Base (AFB).
- Evaluated infill radars' ability to co-operate with the native systems and improve aircraft tracking above nearby wind farms.

Task 2
- Performed the first large-scale quantitative analysis of wind farm layout impacts to homeland air surveillance and air traffic control radar systems.
- Assessed potential of wind farm layout as mitigating measure for radar impact.

Overall Project Objectives (life of project):
The work plan for FY19-20 is aligned with the Federal Interagency Wind Turbine Radar Interference Strategy published by DOE:
- Improve the capacity of government and industry to evaluate the impacts of existing and planned wind energy installations on sensitive radar systems
- Develop and facilitate the deployment of mitigation measures to increase the resilience of existing radar systems to wind turbines
- Encourage the development of next-generation radar systems that are resistant to wind turbine radar interference

Inter Agency Agreements:

No. 892...05, Mar 2018 to Mar 2020
No. 892...47, Mar 2020 to Mar 2025

Total expected duration: 7 years

FY19 - FY20 Budget: $1,010,000

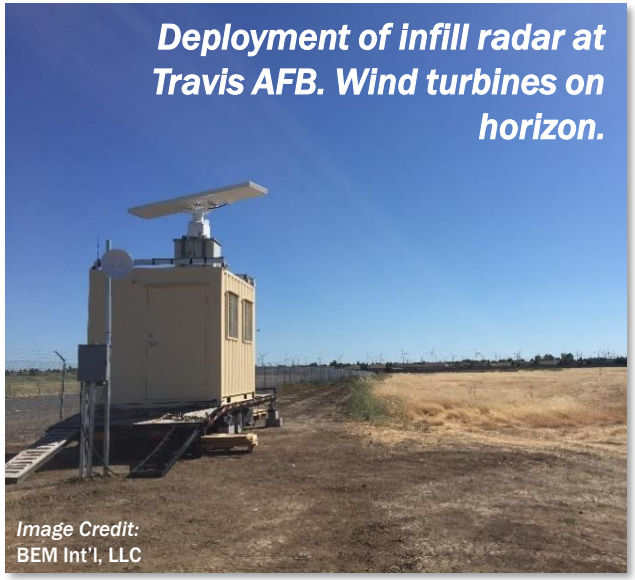
Key Project Personnel: Jelena Ryvkina, David Brigada, Jason Biddle

Key DOE Personnel: Patrick Gilman

Project Impact: Travis AFB Pilot Mitigation Project

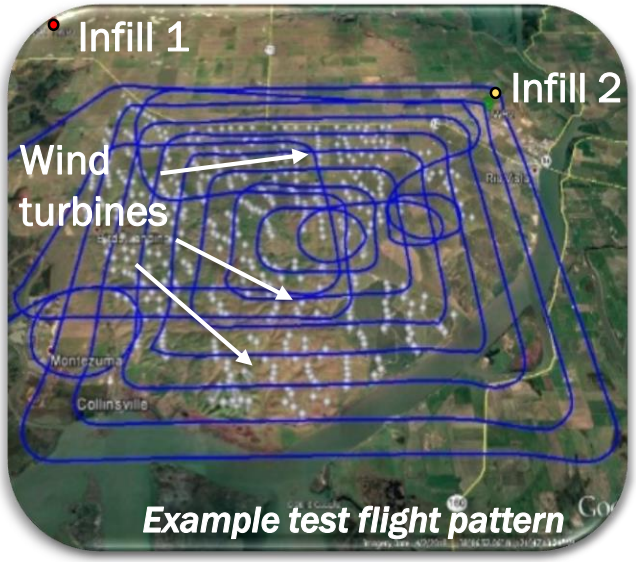
1

- First demonstration of infill radars integrated into FAA's air traffic control (ATC) system in realistic operational environment
  - → Initial step towards utilization for wind turbine clutter mitigation
  - → Enabled currently ongoing development of certification process by FAA
- Demonstration of improved tracking validates feasibility to use infills for radar impact mitigation
  - → Performant infill radars not always sufficient to provide operationally-acceptable output for ATC
  - → Integration with native sensor crucial for improved operations
- Test flight campaign produced a corpus of operationally relevant data to build upon in future work.
  - → Study's data used to develop wind turbine clutter model for FAA and validate above wind farm flight simulator



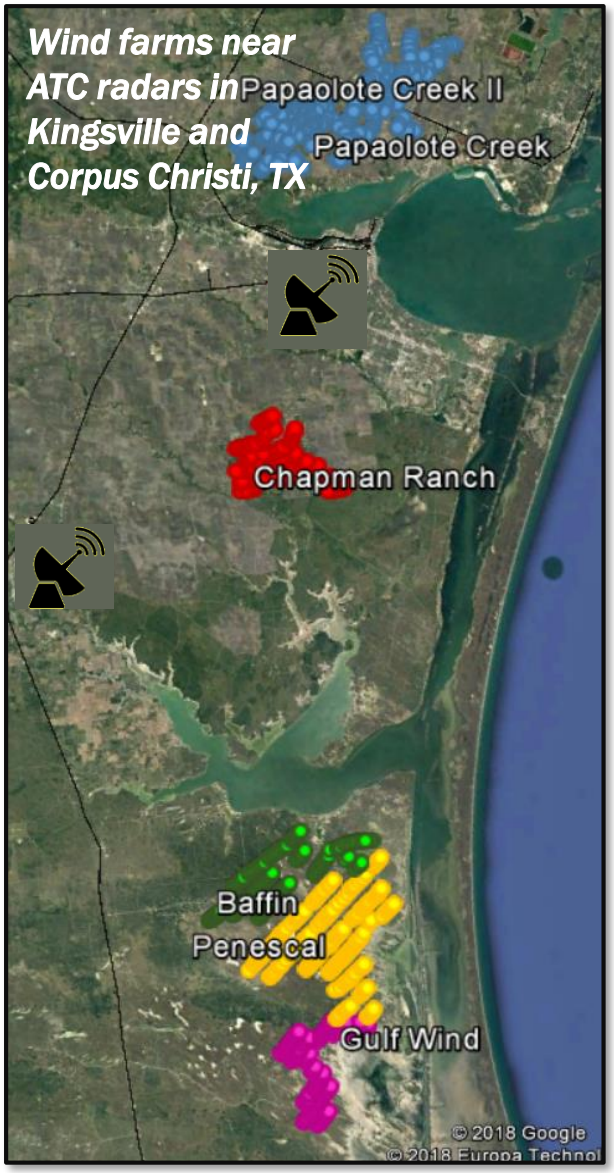
Deployment of infill radar at Travis AFB. Wind turbines on horizon.

Image Credit: BEM Int'l, LLC

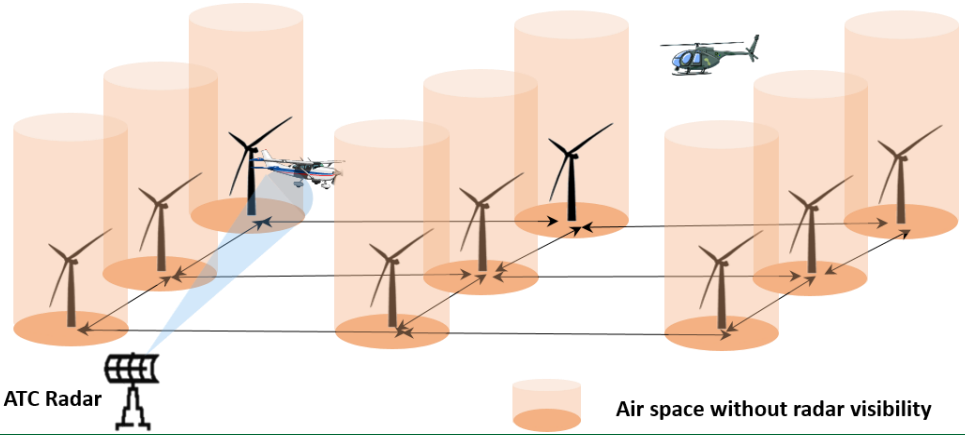


Example test flight pattern

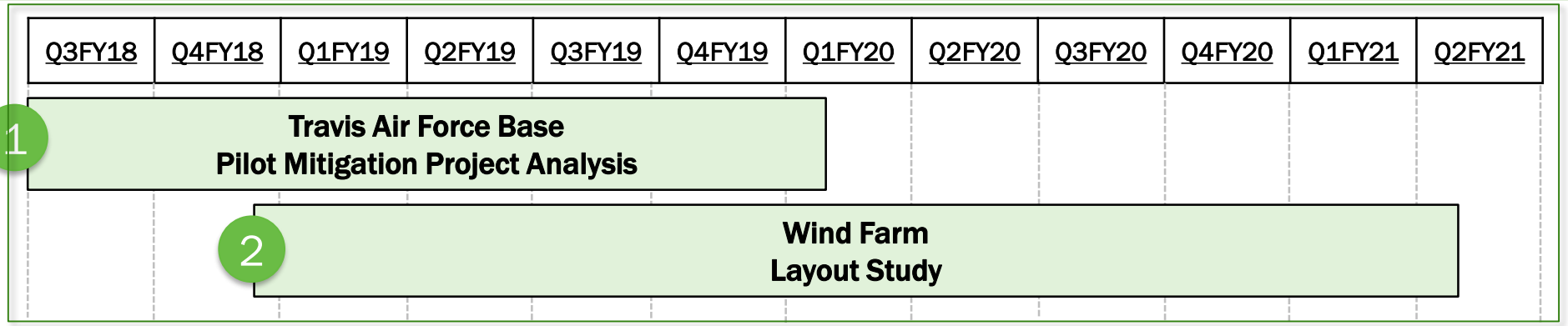
Project Impact: Wind Farm Layout Study



- Statistical analysis of radar data and wind farm layouts revealed wind farm layout features affecting radar performance
  - → Data driven understanding of wind farm's radar impact
  - → May be incorporated in future wind farm design considerations and help mitigate siting concerns
- Wind farm – radar interaction model used to find optimized siting based on radar parameters and distance to radar
  - → Informs future radar needs as well as preferential wind farm layouts



Program Performance – Scope, Schedule, Execution

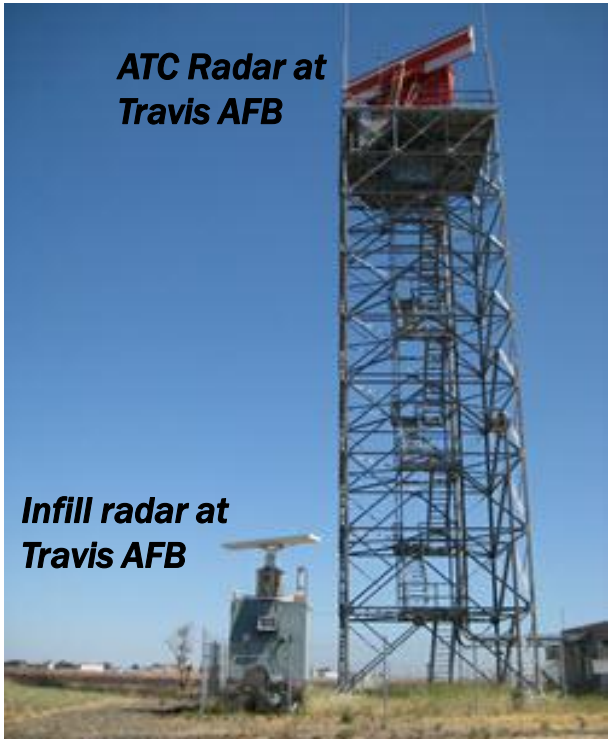


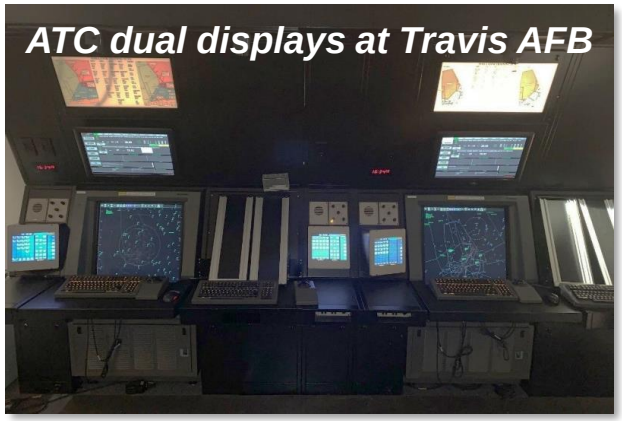
	Task 1	Task 2
Scope	• Analysis of hundreds of hours of test flight data from multiple flight tests and various experimental conditions in support of system setup and performance evaluation.	• Statistical analysis of radar data and wind farm layouts. • Modeling of radar performance above wind farms for various radar capability and wind farm layout combinations.
Status	• Completed in January 2020.	• Completed in April 2021.

Program Performance – Accomplishments & Progress

Task 1 : Pilot Mitigation Project

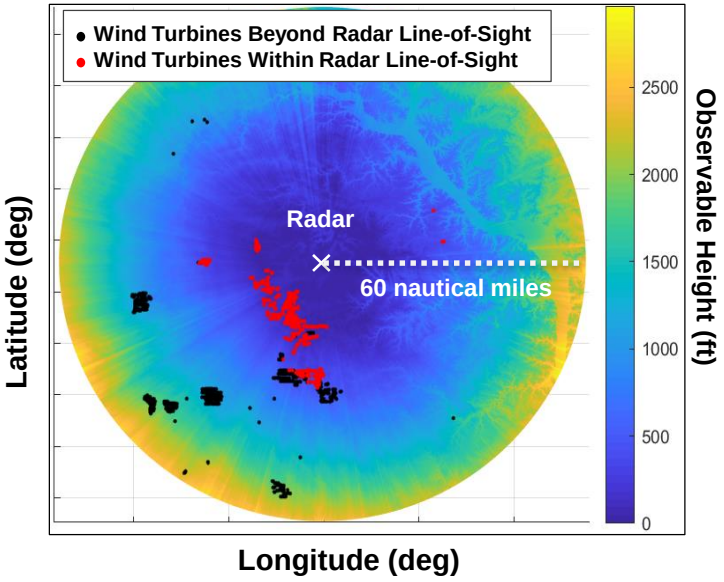
- Completed analysis of hundreds of hours of flight data in support of optimal system setup, as well as system performance assessment.
- Major findings:
  - → Infill radars can be integrated into FAA's tracking systems
  - → Infill radars can improve target tracking ability above wind farms but work remains to achieve operationally acceptable air picture
  - → Some details of system setup and performance specific to particular location





Program Performance – Accomplishments & Progress

Radar Coverage Example



Radar capability vs. wind farm layout changes

Wind Farm Layout Changes	Radar Capabilities: Current Radar Capabilities	Increased Azimuth Resolution	Increased Elevation Resolution	Increased Range Resolution
Current Wind Farm Layout				
Increased Wind Turbine Spacing				
Wind Farm Orientation wrt. Radar				

No improvement to radar impact → Improvement to radar impact

Task 2: Wind Farm Layout Study

- Completed statistical analysis of radar data and wind farm layouts from 18 radars and 86 wind farms
- Developed model for above-wind farm radar performance
- Major findings:

→ Certain wind farm layout features, (e.g. increased range to radar, reduced wind farm density, etc.) correlate with reduce radar impact

→ Taking radar's signal processing approach into consideration in siting may benefit radar's performance

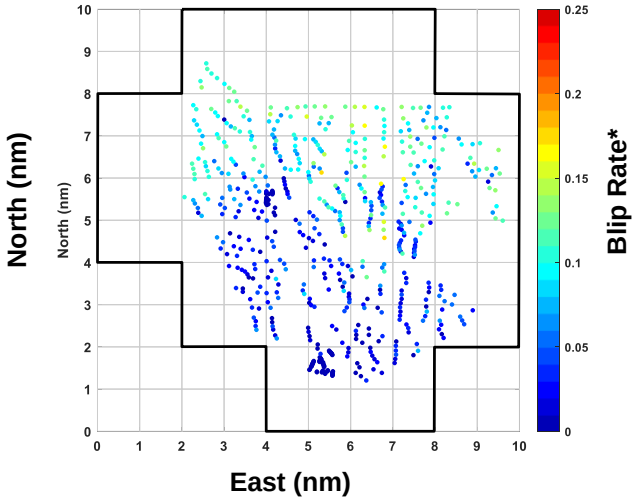
→ Increasing radar resolution and aligning wind farms with respect to the radar could address radar performance issues

Project Performance - Upcoming Activities

Radar Clutter Classification

- Use Pilot Mitigation Project data to classify radar clutter from wind turbines
- Support FAA's development of simulator for flights above wind turbines
- Inform ongoing development of infill radar certification process

Wind turbine activity, Travis AFB



*Blip Rate: Frequency at which a wind turbine is detected on subsequent radar scans.

Infill Radar Integration with DoD Automation Systems

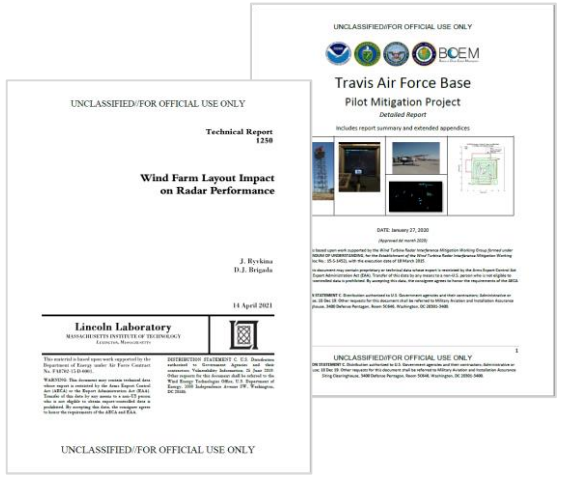
- Determine feasibility and difficulty of integrating infill radar output with mission systems used for homeland air defense
- Optimize system setup and infill radar fusion with output from native radars
- Assess performance of the fused result


Homeland air defense control center

FY2021 Tasks: New studies capitalize on data and lessons learned from PMP

Stakeholder Engagement & Information Sharing

- Study updates regularly shared with Wind Turbine Radar Interference Mitigation multi-agency working group
- Limited Distribution Publications
  1. *Travis Air Force Base Pilot Mitigation Project*, Summary Report, WTRIM, January 2020.
  2. *Wind farm Layout Impact on Radar Performance*, MIT LL Technical Report 1250, April 2021.
- Open Source Publications
  1. *Travis Air Force Base Pilot Mitigation Project*, Summary Report, WTRIM, February 2020.
  2. *Wind farm Layout Impact on Radar Performance*, Executive Summary, To be published on DOE website in 2021.
  2. *Radar-Optimized Wind Turbine Siting*, D. Brigada, J. Ryvkina, paper draft submitted to IEEE Trans Sustain Energy, April 2021.



Key Takeaways and Closing Remarks

- MIT LL continues to apply subject matter expertise in radar systems to help accelerate development, evaluation, and deployment of mitigations to wind turbine interference impacts on radar performance
- Our analyses in FY 2019-2020:
  - Informed FAA's ongoing development of a certification process for infill radar systems for air traffic control usage
  - Quantified the utility of wind farm layout optimization as a mitigation approach
- We will build upon this work in the future to inform requirements for radar acquisition programs to ensure resilience from wind turbine interference
  - Spectrum Efficient National Surveillance Radar (SENSR)
  - Airport Surveillance Radar–Replacement (ASR-R)