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Customer Success Is Our Mission

Overview of Raytheon Wind Farm Mitigation Techniques and Test Results

Peter Drake

15 June 2011

CNS/ATM Conference

Discussion Overview

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- What's our stake in the NAS
- What's the issue
- What is our current capability and some results
- How we have approached the problem
- The UK study contract
- What is Concurrent Beam
- How do we implement for test
- EU test results overview
- JST test and results overview
- Transition to US ATC systems (DASR, LRR, ASR8, ASR9)
- Link between Turbine mitigation and GBSAA
- Our path forward – current and future technology
- Low cost X Band 3D Radar
- Overall Conclusions / Recommendations
- Patent References

Raytheon Domestic NAS Involvement

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Long Range Radar (CARSR)

Digital Airport Surveillance Radar (DASR)

Introduction – Wind Turbines and Radar

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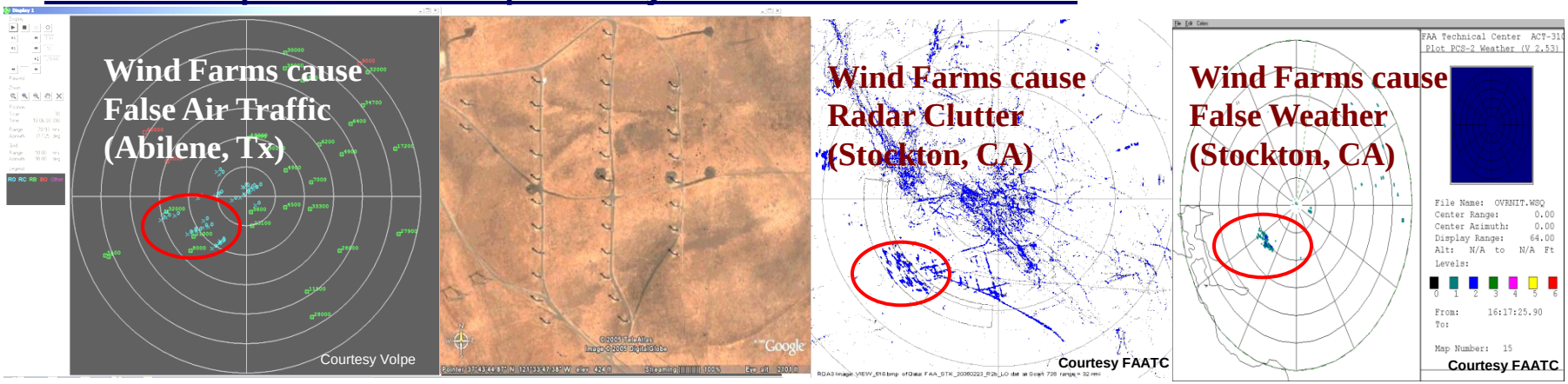
Air Traffic Operations are impacted by Wind – Radar Interaction



How are we approaching Wind Turbine – Radar Coexistence?

- We are engaged with Wind Energy Suppliers, Air Traffic Management authorities, and Governments to develop a mutually beneficial solution for Wind – ATC Radar coexistence
- We are investing in advancing L-Band and S-Band ATC Radar capability, augmenting with low cost X-Band Short Range 3D Radars, to enable both standalone and an integrated suite of solutions
- Currently there is no known certified cost effective Silver Bullet solution based on our extensive field experience

What is the Wind Farm - Radar Problem?

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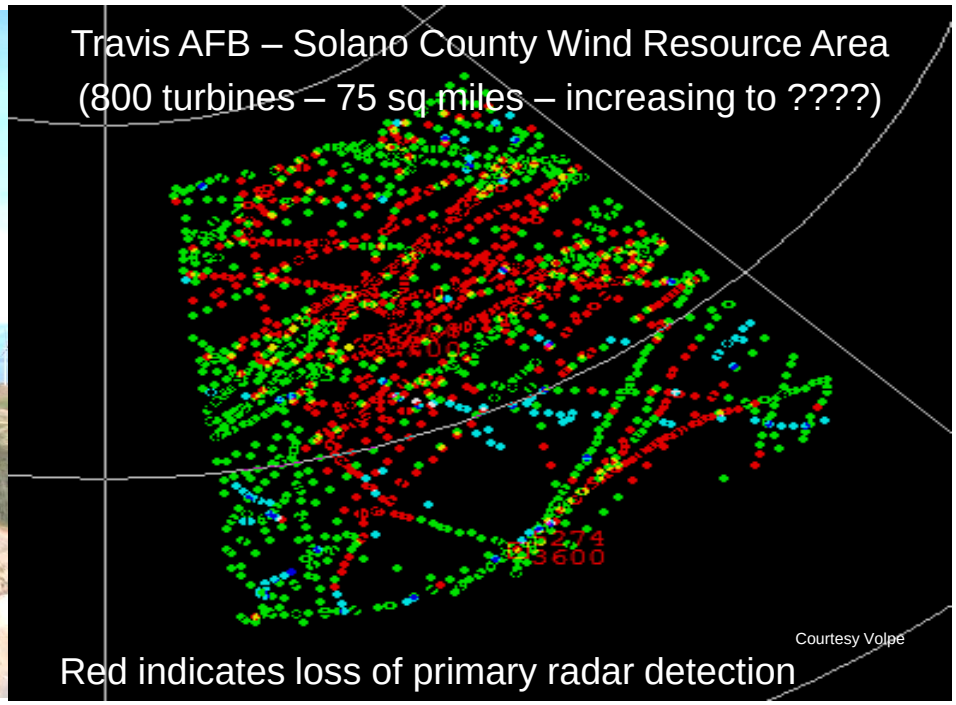
- Moves to clean energy sources have resulted in worldwide deployment of a large number of highly populated wind turbine farms
- Characteristics of wind turbine returns resemble those from aircraft (including Doppler frequencies), resulting in –

- Radar Blind Zones
- Missed aircraft detections
- Aircraft track seduction
- High false alarm rate

(Pictorial - Fire Island, AK)



Red indicates loss of primary radar detection

Wind Farm Mitigation Techniques

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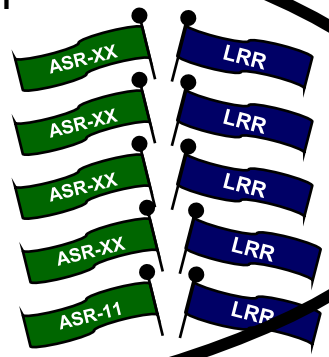
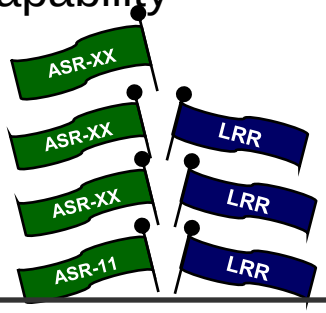
IMPLEMENTED – but result in loss of detection

- **Sensitivity Time Control (STC)**
- **Range Azimuth Gating (RAG)**
- **Track Initiation Inhibit**
- **Velocity Editing**
- **Plot Amplitude Thresholding (PAT)**



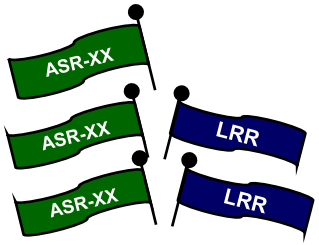
UNDER DEVELOPMENT for UK – Regains detection capability

- **Concurrent Beam Processing**
- **Improved Constant False Alarm Rate (CFAR)**
- **Clutter Map per Doppler Filter**
- **Optimization and Enhanced Tracking techniques**



PROSPECTIVE – Extends capability

- **Polarimetrics (Dual Polarization)**
- **Pulse-burst (High PRF)**
- **Blind Spot / Gap-filler**



Examples of Regained Detection: Stockton, Abilene, and Travis AFB

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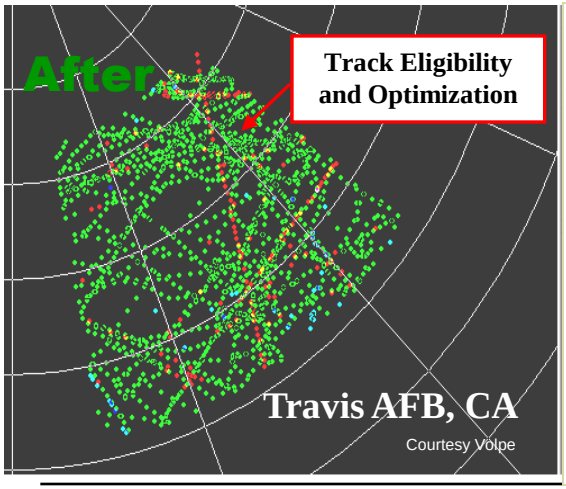

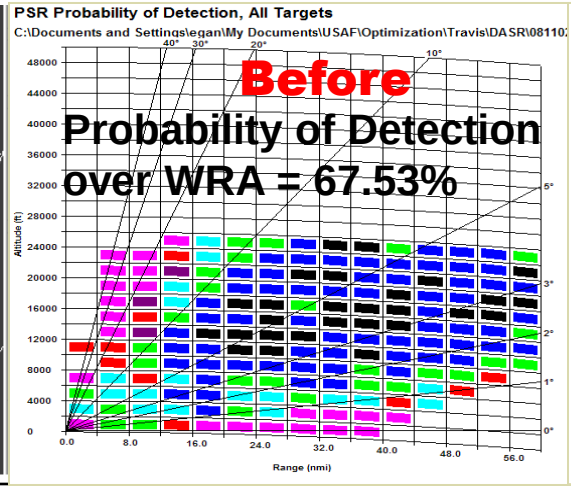

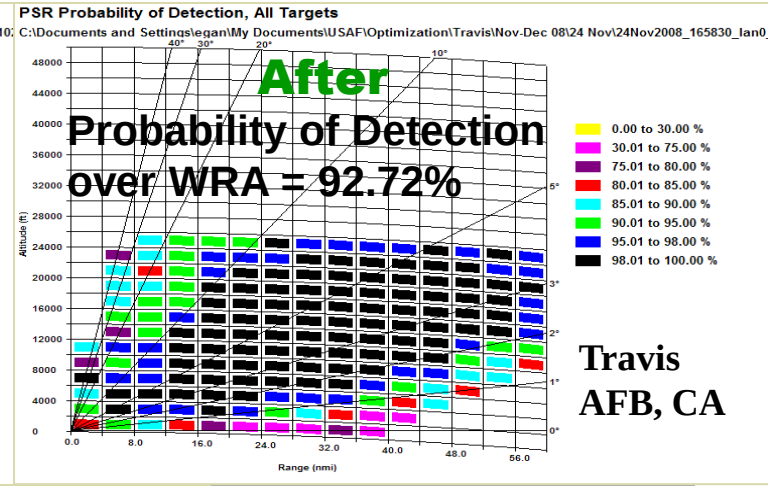

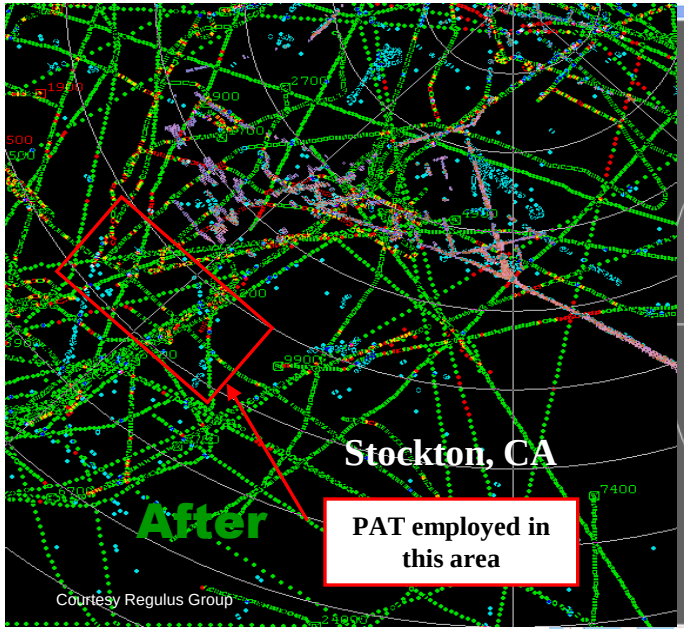

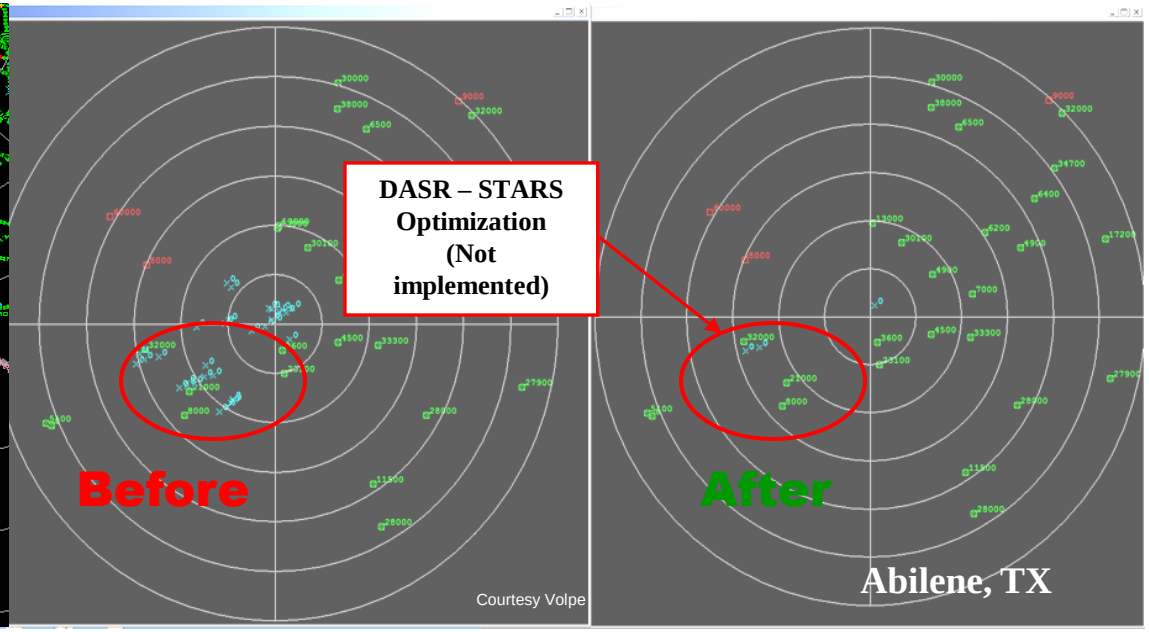

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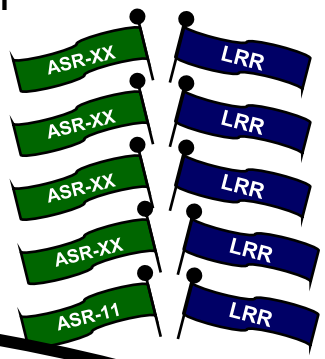

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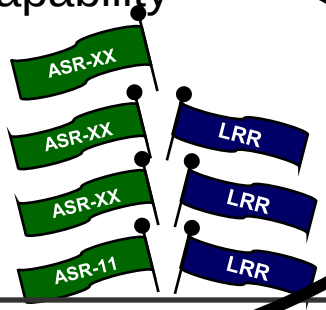

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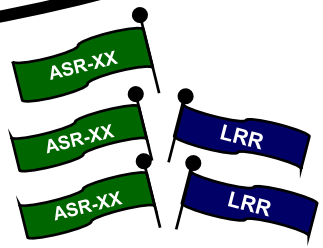

Raytheon Wind Farm Mitigation contract

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- Raytheon was initially awarded a Study contract in 2005 to assess the impact of wind farms and suggest mitigations for the observed impacts
- Raytheon initiated investment in Advanced Signal Data Processor (ASDP) to enable
  - Testing completed 2009
- Study was publicly released in Dec 2006 with recommendations for a Phased approach
  - Phase 1: Feasibility Study
  - Phase 2: Mathematical Modeling
  - Phase 3a: Factory Testing
  - Phase 3b: Field Testing
  - Phase 4: Formal Qualification
  - Phase 5: Roll Out
- Raytheon was awarded a Feasibility contract in Nov 2009 for Phases 1 through 3 to develop and evaluate the effectiveness of a suite of proposed wind farm mitigation techniques
  - ASDP backbone for processing
- Funding for contract was provided by:
  - 39% from Crown Estates (UK Govt)
  - 30 % by Department of Energy and Climate Change (DECC)
  - 31% by Aviation Investment Fund Company
- We anticipate a similar type of arrangement to fund the qualification and implementation follow-on phases (Phases 4 and 5)

MITIGATION SOLUTIONS
Solution Description

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- **The Raytheon approach mitigates or eliminates the effect of wind turbine returns without adversely affecting aircraft detection**
- **The solution suite is based on a combination of discrimination techniques applied at the pre-detection, detection and post detection stages of the radar signal processing chain**
- **The suite of mitigation solutions is designed for retrofit to existing ATC primary surveillance radars (ASR10SS, ASR23SS, ASR11, and LRR)**
- **The four techniques prototyped in the ASR are:**
  - **Concurrent High and Low Beam Processing**
  - **Clutter Maps for each Doppler Filter**
  - **Enhanced Constant False Alarm Rate (CFAR) processing**
  - **Enhanced (Interactive Multiple Model) Tracking with Classification**
- **These enhancements were trialed in a Netherlands ASR10 SS system in Nov-Dec 2010, and adapted and re-trialed in the Johnstown (JST) DASR system Mar 2011**

What is Concurrent Beam Processing?

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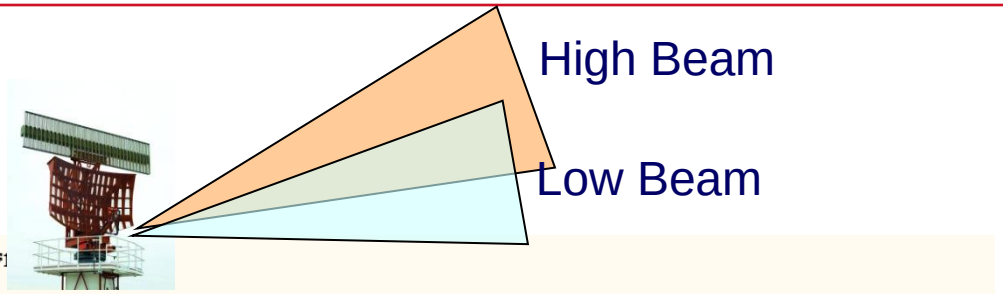

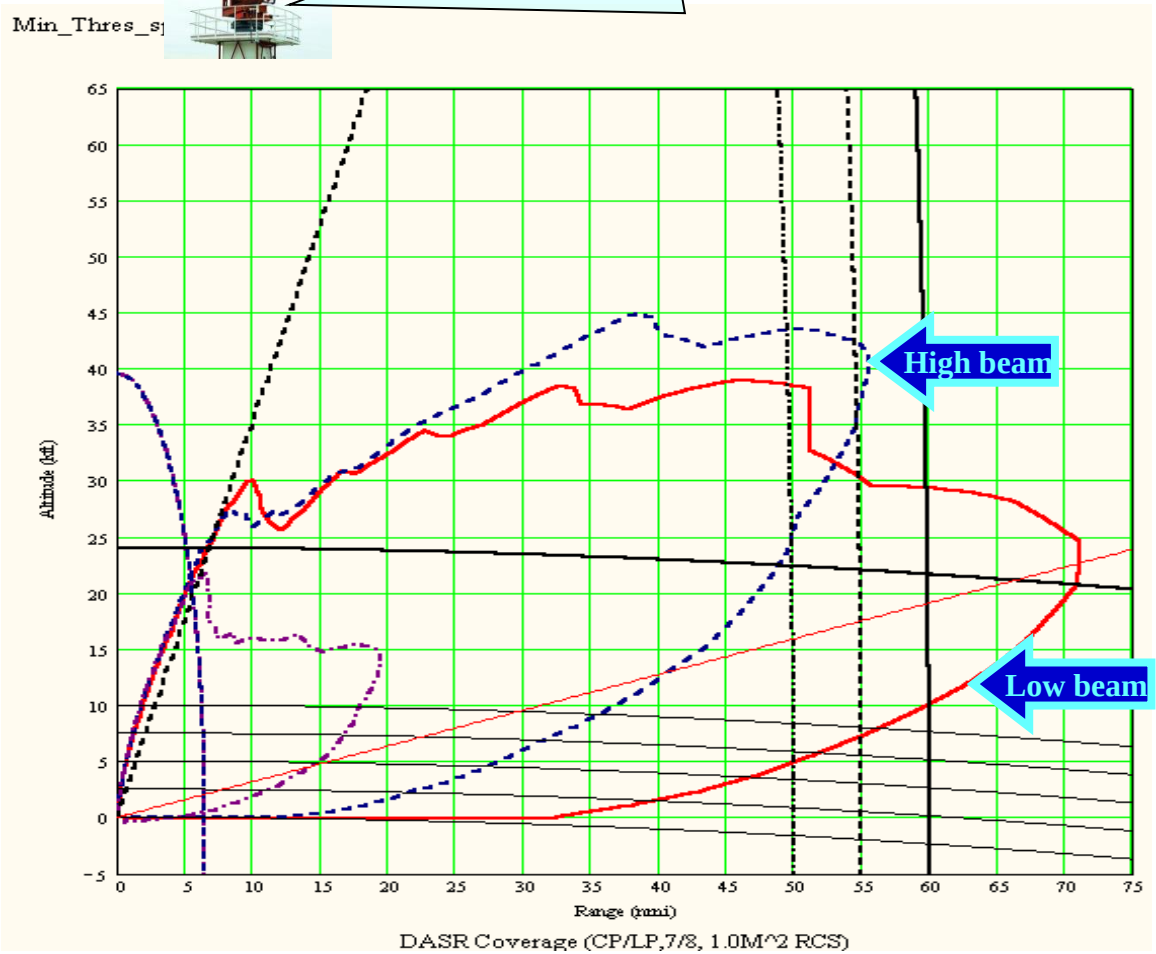

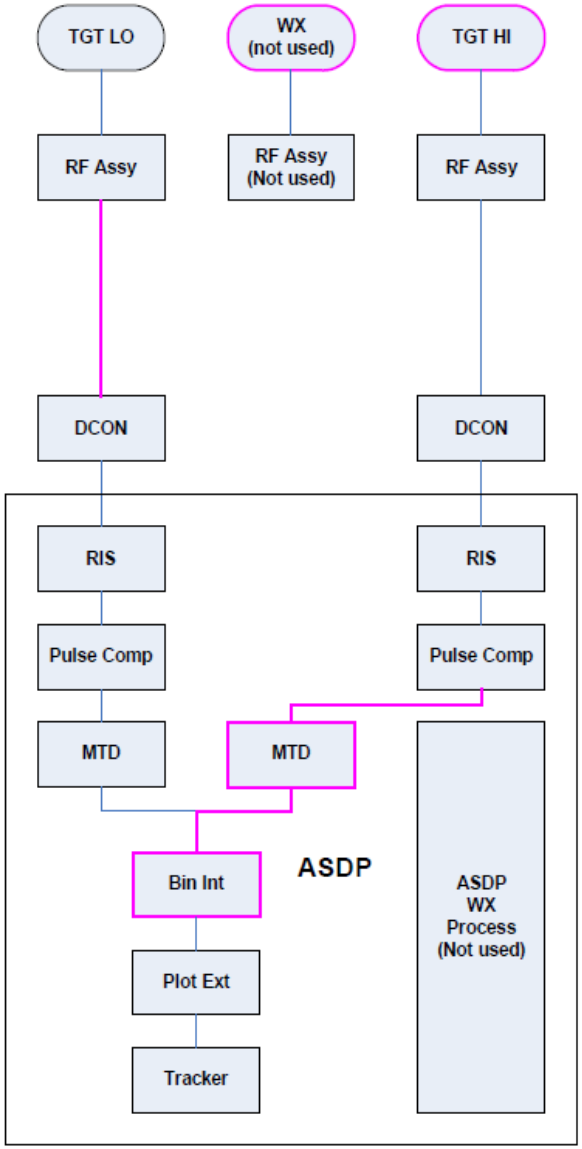

ASR-10SS / DASR with ASDP (Test Configuration)

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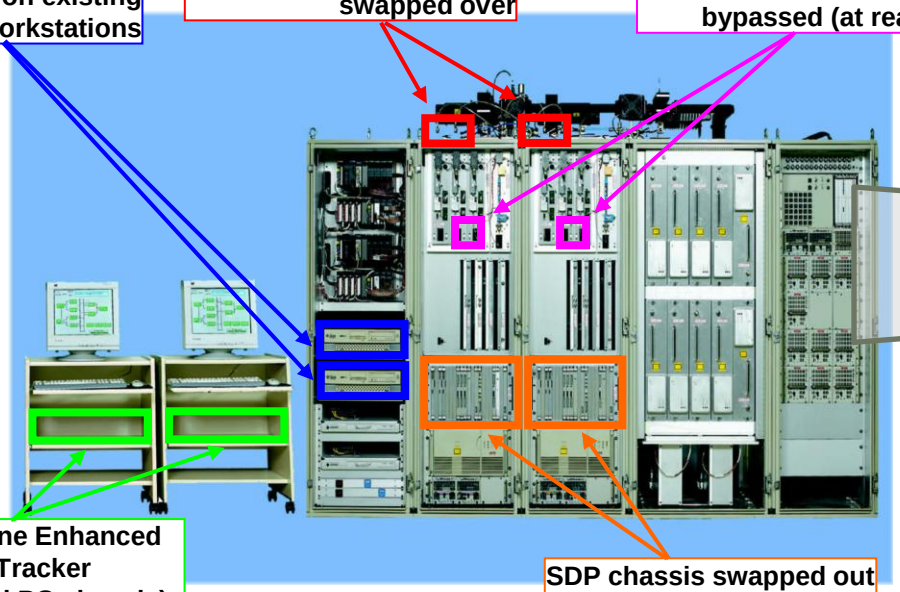

- FAA/DoD ordered ASDP retrofit kits for fielded systems
- Raytheon awarded contract to develop Concurrent Beam Processing for UK ATC radars

Data Analysis – Wind turbine area

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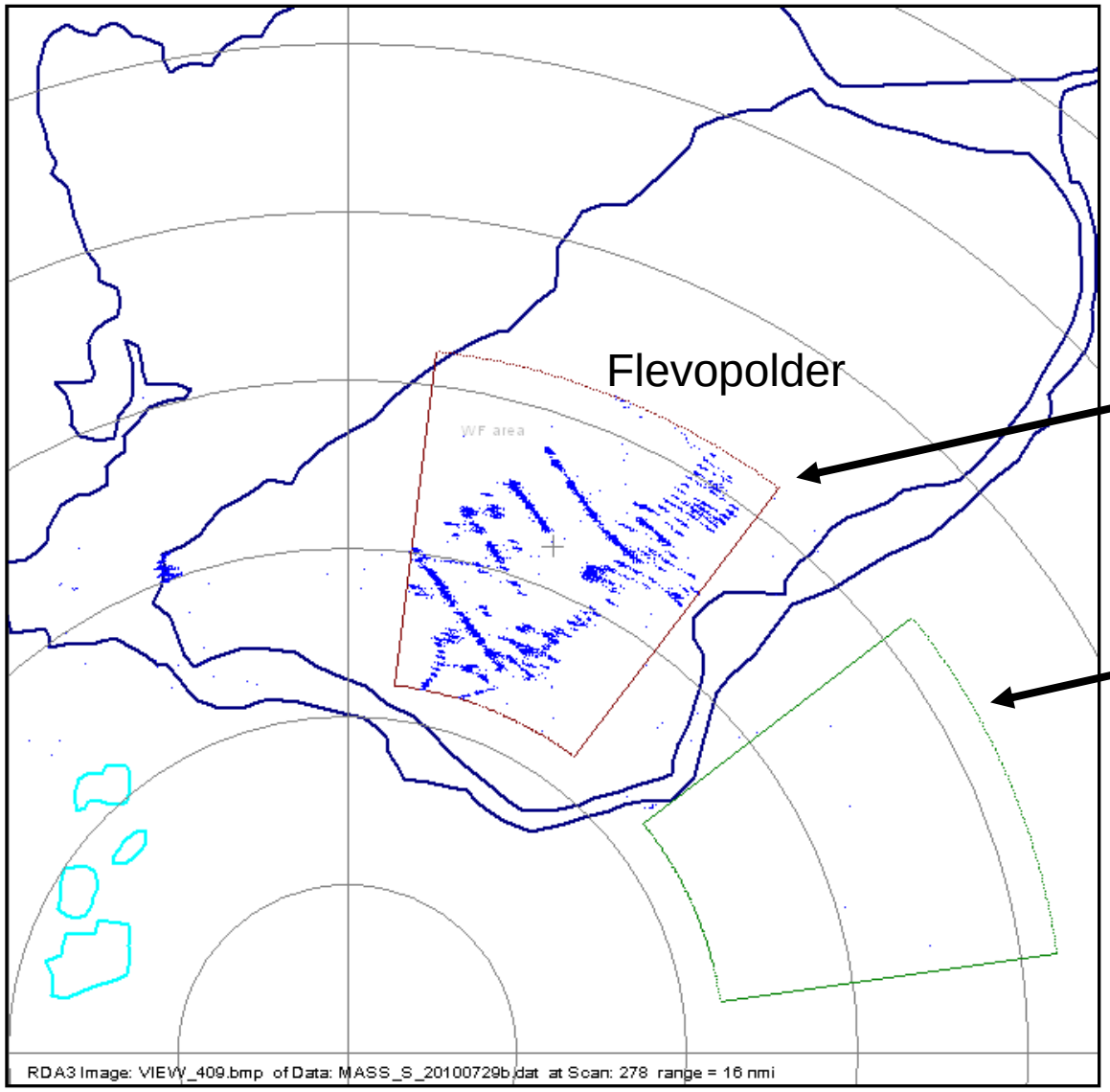

Wind turbine area chosen for analysis

11 nm to 21 nm

7 deg to 37 deg

262 Turbines

“Clear” area

11 nm to 21 nm

52 deg to 82 deg

1 Turbine

Operational Prototype Evaluation Configuration

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- To allow for accurate measurement of the Enhancements the PSR is configured with channel B emulating the SDP performance and channel A running all the Enhancements. This removes any ambiguity in data samples as both channels are processing the same input data.
- This configuration also supports the simultaneous recording of both outputs so that subsequent off-line analysis can determine the actual measured differences in performance between the two PSR channels.
- Some of the major set up differences are;-

Parameter	SDP channel	ASDP channel
Beam processing	Switched HI / LO Beam	Full Dual Beam
Adaptive Clutter Map	Single F0 Clutter Map	5 Clutter maps
CFAR	SDP values	Optimized for dual beam
RAG Map blanking	ENABLED	DISABLED
Suppression Zones	ENABLED	DISABLED

Operational Prototype
Measured Results - 30/01.NOV.2010

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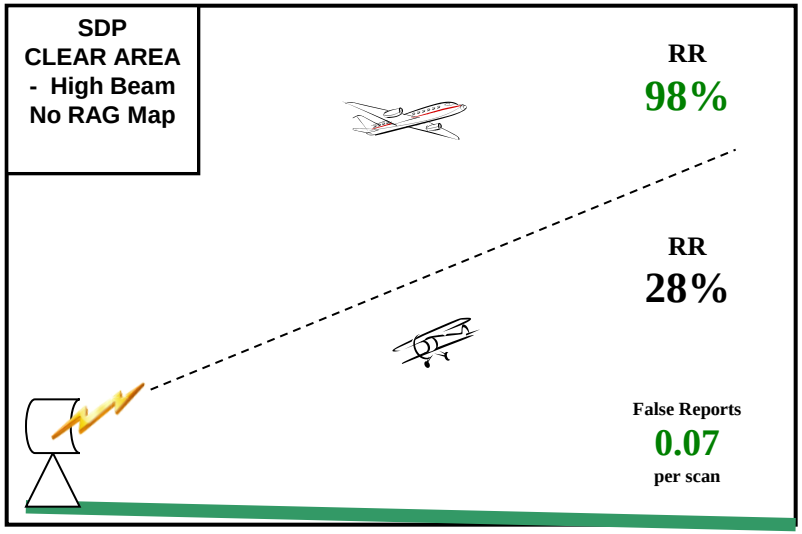

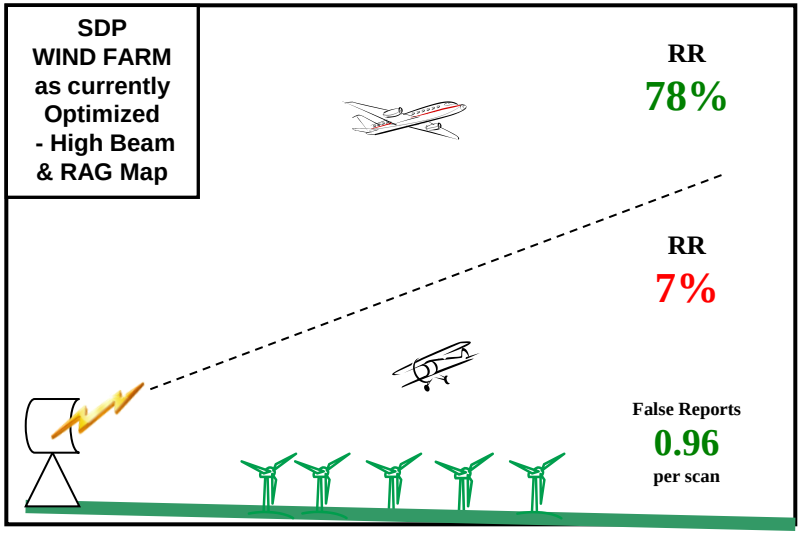

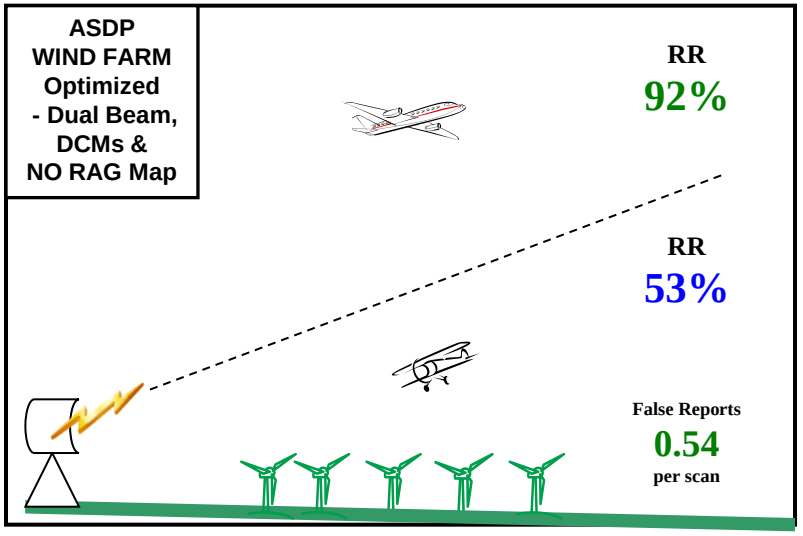

A Picture is worth a Thousand words

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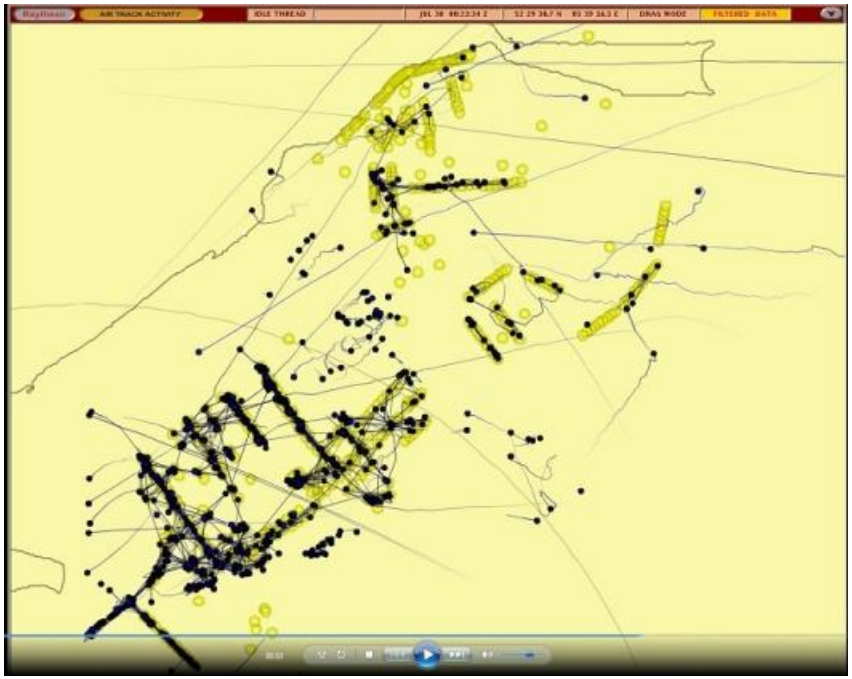
- In order to get a better visual appreciation of the benefits of the enhancement performance, Raytheon recorded a short live video which compares the performance of the current conventional signal processing system versus the enhanced signal processing with all enhancements including the tracker.



PSR Conventional

PSR Enhanced

JST Prototype
Results Summary - 24-30.MAR.2011

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- The EU system is very similar to the NAS DASR/ASR-11 which allows us to utilize it for initial integration, test, and evaluation with STARS ELITE on a US site
- DASR System was configured to replicate the EU test set-up, and integrated with STARS ELITE equipment for visual side-by-side comparison / evaluation
  - The DASR plot channel provided data to the STARS ELITE tracker (NAS Baseline)
  - The DASR track channel provided data to the EU enhanced tracker (EU baseline)

The Test Site

The Test Aircraft –
Piper PA-28-161

JST Prototype
Results Summary - 24-30.MAR.2011

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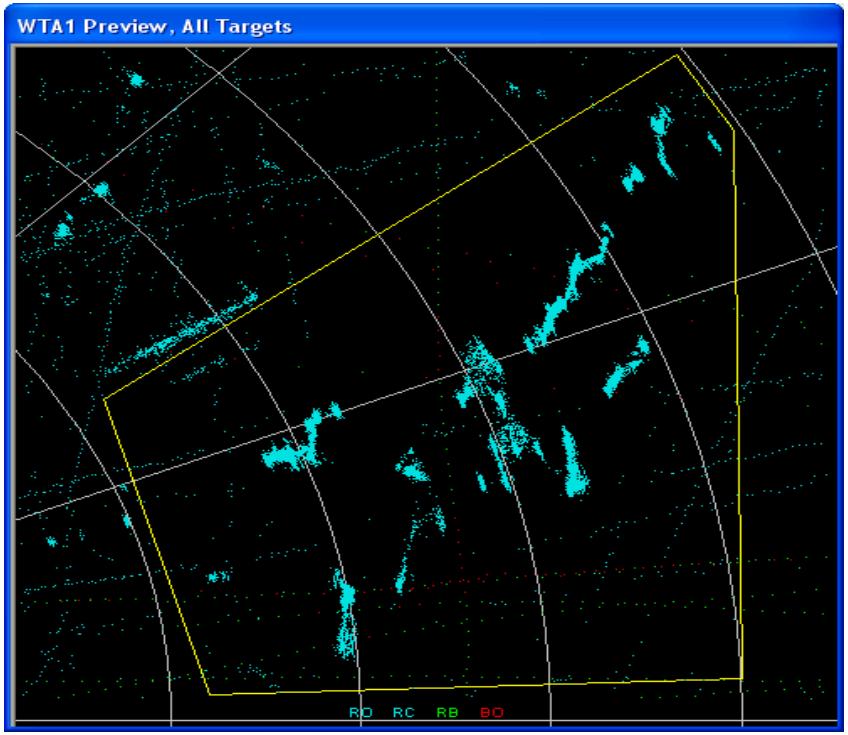
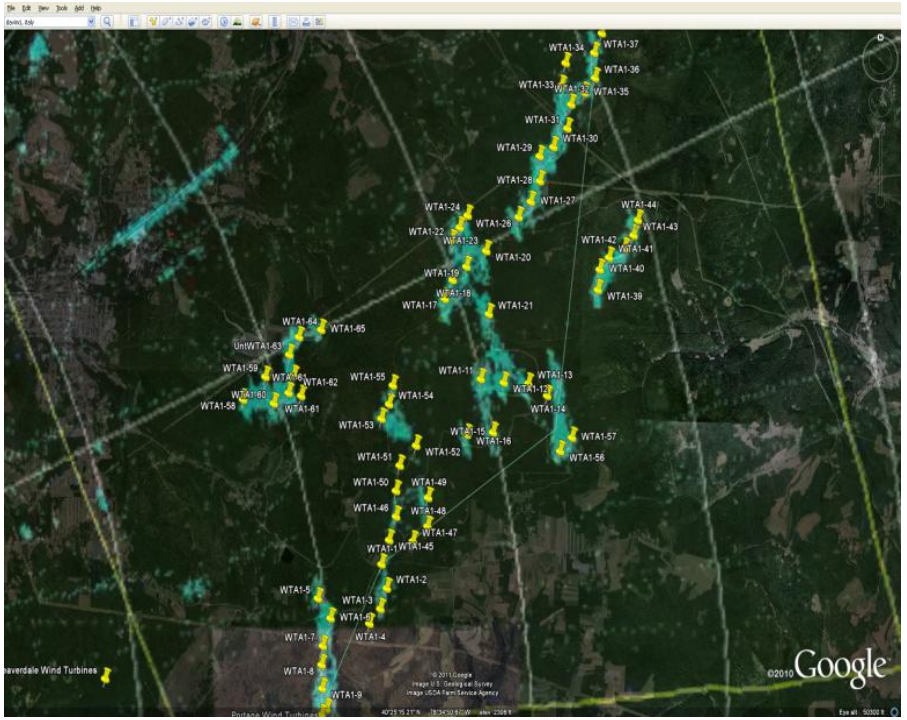
- The turbine detections, as shown below, are clearly visible on the radar
- The planned focus area for the test aircraft was the Wind Resource Area east of the radar system within the polygon
- Test Flights were run at 4kft, 6kft, and 8kft - Turbine tips at 3300ft nom (turbulent at 4kft)

Wind Farm Area





JST Prototype - InBound
Results Summary - 29.MAR.2011

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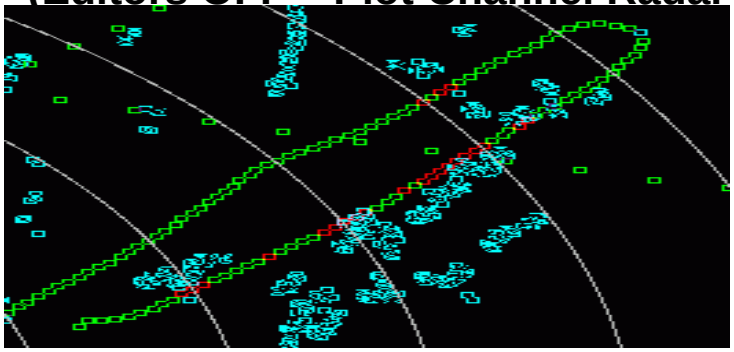
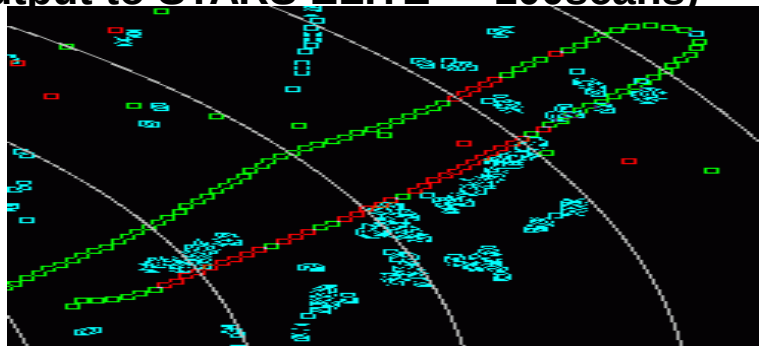
Enhanced **Baseline**

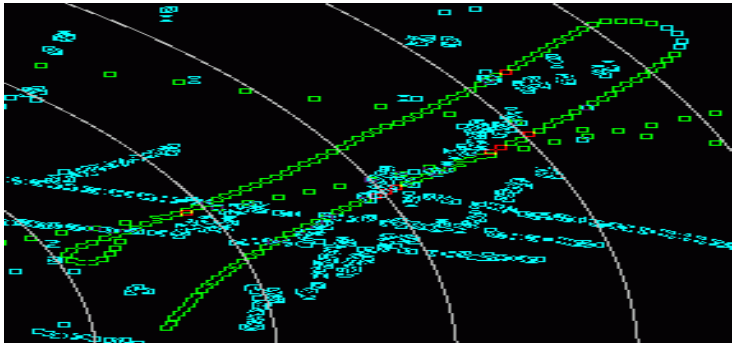
(Editors OFF – Plot Channel Radar output to STARS ELITE - ~100scans)

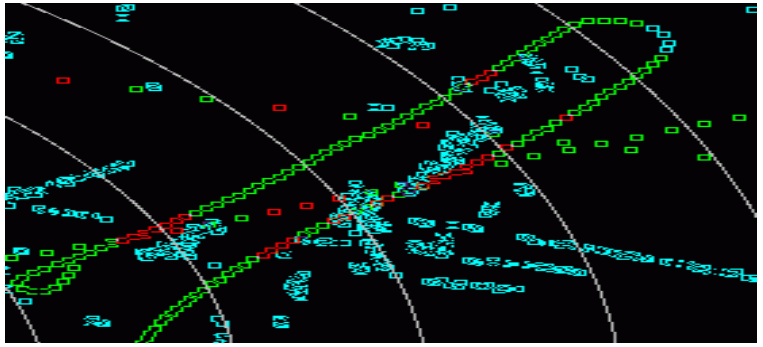
4kft



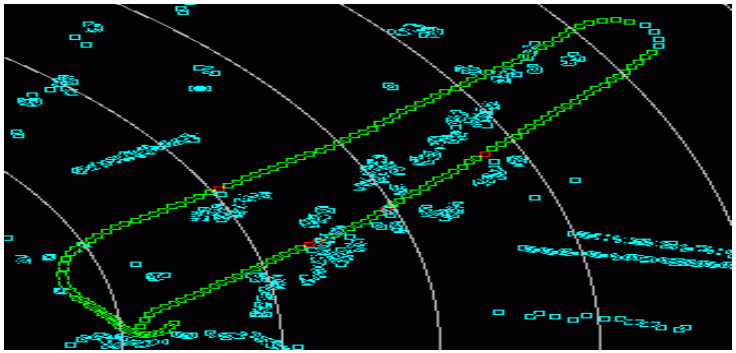


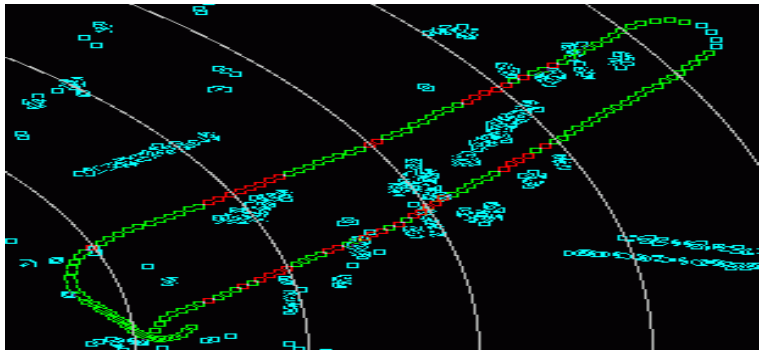
6kft





8kft





JST Prototype
Results Summary – 23,24.MAR.2011

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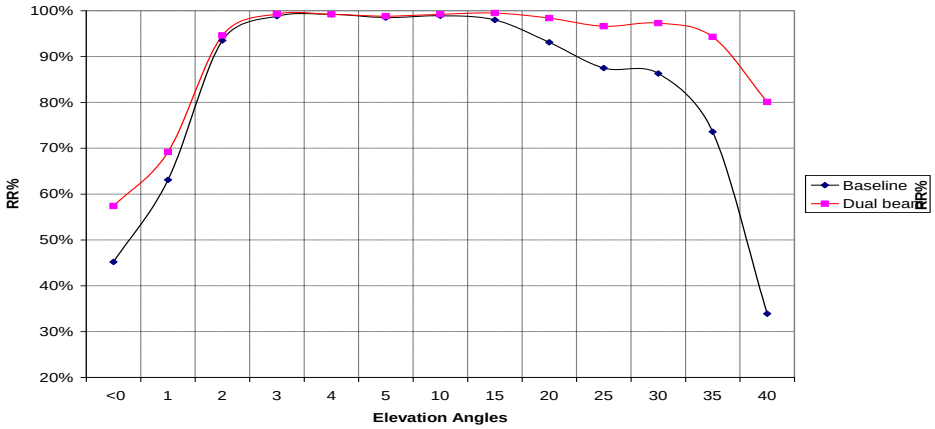
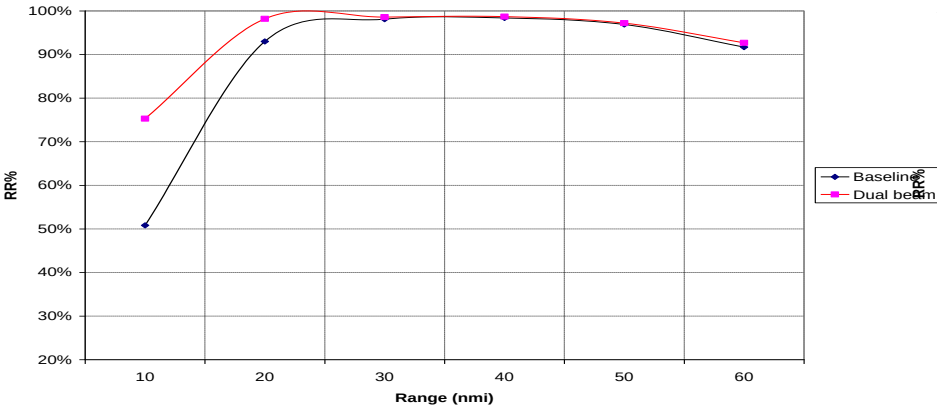
- Results indicate that there is significant RR improvement from Concurrent Beam & CFAR enhancements both in elevation and range coverage, which is even more pronounced under active weather conditions

Clear Day

DASR JST - RR% by Elevation Angle

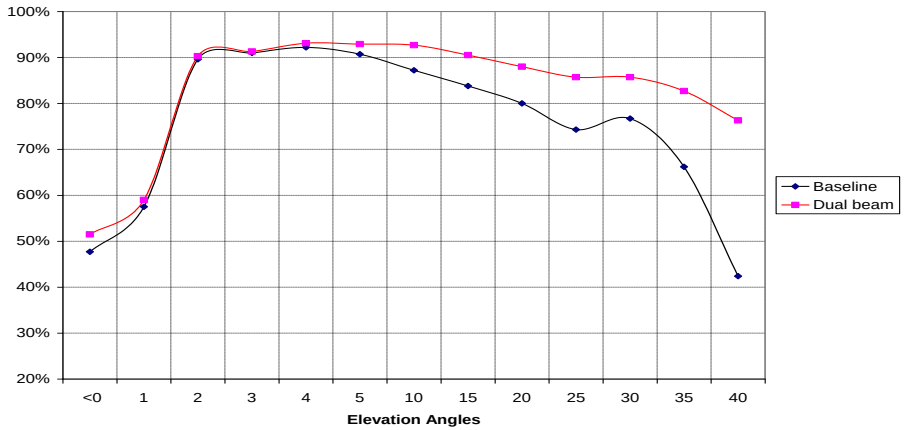


DASR JST - RR% by Range

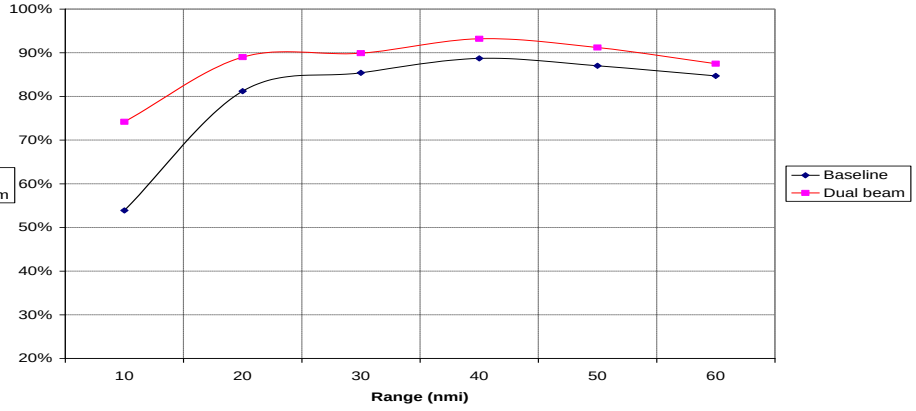


Active Weather

DASR JST - RR% by Elevation Angle - 23rd March



DASR JST - RR% by Range - 23rd March



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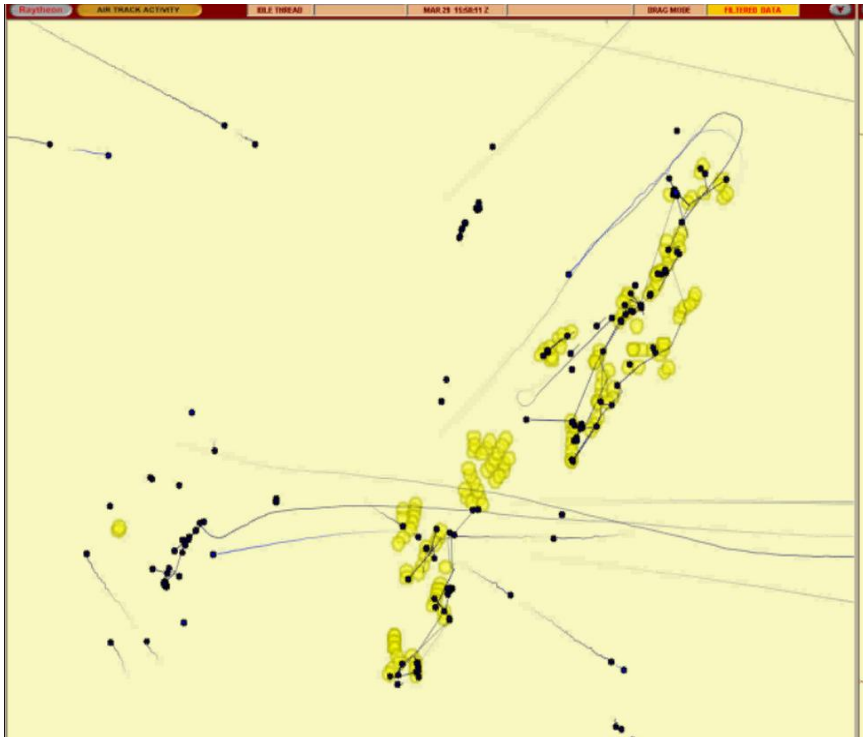
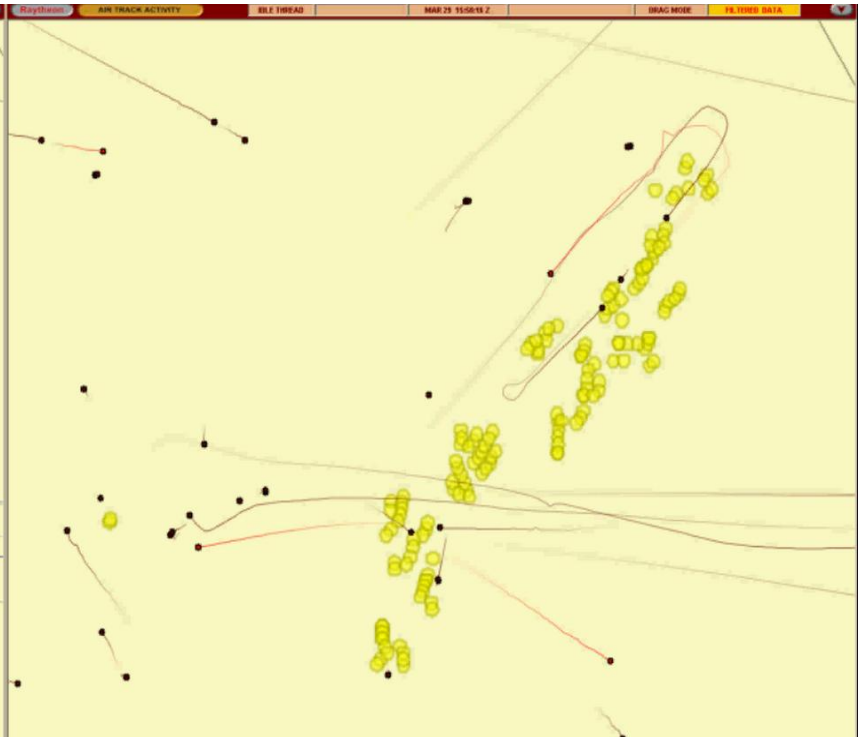
- In this case, Raytheon has created an additional set of short live videos from the JST flight testing of the EU baseline with all enhancements including tracker versus the conventional tracker



PSR with conventional tracker



PSR with enhanced tracker

Enhanced Processing - Transition to DASR & CARSR (LRR) systems

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- All proposed techniques and algorithms can be directly applied to the DASR system
  - UK NATS does not use Weather Channel therefore the implementation and evaluation of concurrent beam processing is accomplished by using Weather channel as the additional target channel
  - For implementation for DASR, an integrated additional RF chain is under development which allows concurrent beam Target processing with Weather

- From a CARSR (LRR) perspective
  - Peak editing CFAR algorithm is already implemented
  - Clutter map per Doppler filter processing requires modification
  - Concurrent beam processing, other than to ARSR-3, could be applied but would require antenna upgrade and additional channel to process dual beam
    - Dual Beam Modification kit for ARSR-2 previously developed and tested
    - Requires additional RF chain and software

Wind Turbine Mitigation and GBSAA

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- Wind Turbine Mitigation techniques are essential backbone for GBSAA to ensure improved detection (Pd) while maintaining low false alarm rate (Pfa)

- Additional capabilities required for GBSAA include (to be discussed at this Conf in another presentation);
  - Optimization of ASR-11 and Advanced Signal Data Processor
    - ☐Diminish velocity filtering used for ATC to remove detections of slow movers, and adjust other optimization parameters
  - Use of concurrent beam processing configuration for altitude estimation
    - ☐Data to be correlated with 3-D Sentinel radar data
  - Provision of dual output - separate GBSAA optimized radar feed to STARS LITE
  - Development and qualification of an architecture that supports a third RF path
  - Update of system architecture to manage role arbitration and status/timing distribution across dual processing units in each channel

Initial Analysis Summary and Next Steps

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- The performance of the enhanced radar in the Wind Farm area is meeting the objective of significantly restoring detection for aircraft above the turbine tips.
- Data analyses shows that enhanced capability provides global improvements:
  - Improved Pd, including detection of low altitude targets such as ultra-lights
  - Reduced False Plots / Tracks
  - Improved Reinforcement Rate over expanded elevation angle and range, even more pronounced in adverse weather conditions
  - Increased Back-Angle Coverage
  - SP/LP transition range can be moved beyond 7.5nm mitigating eclipsing region
  - Enabler for PSR altitude processing for GBSAA
- DASR – STARS LITE (Automation) combination being upgraded to perform as well as the EU baseline:
  - Wind Turbine Mitigation and Altitude Processing being ported to DASR
  - Enhanced Tracker functionality being ported to STARS LITE
  - Track Eligibility will be enabled
- Next set of tests on full DASR – STARS LITE configuration anticipated to take place in September 2011 for both Wind Turbine Mitigation and GBSAA

Applicability to ASR8 and ASR9 systems

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- Raytheon has also developed a Windfarm Retrofit Kit with varying degrees of upgrade, allowing equipments to be upgraded to achieve ASR-11 performance capability

- Options are as follows:

  Option 1 – Complete change-out of facility to ASR-11

  Option 2 – Upgrade from ASR-8 to ASR-11 utilizing existing facilities inc changing out Antenna / Pedestal and Tower (similar to that implemented at FAATC)

  Option 3 – Upgrade from ASR-8 to ASR-11 assuming no change to Antenna / Pedestal or Tower.

  Option 4 – Wind Turbine Kit Installation.

  This option upgrades PSR Electronics suite to Concurrent Beam with Wind Turbine Mitigation

eSCAN LPR as Wind Farm Mitigation Radar

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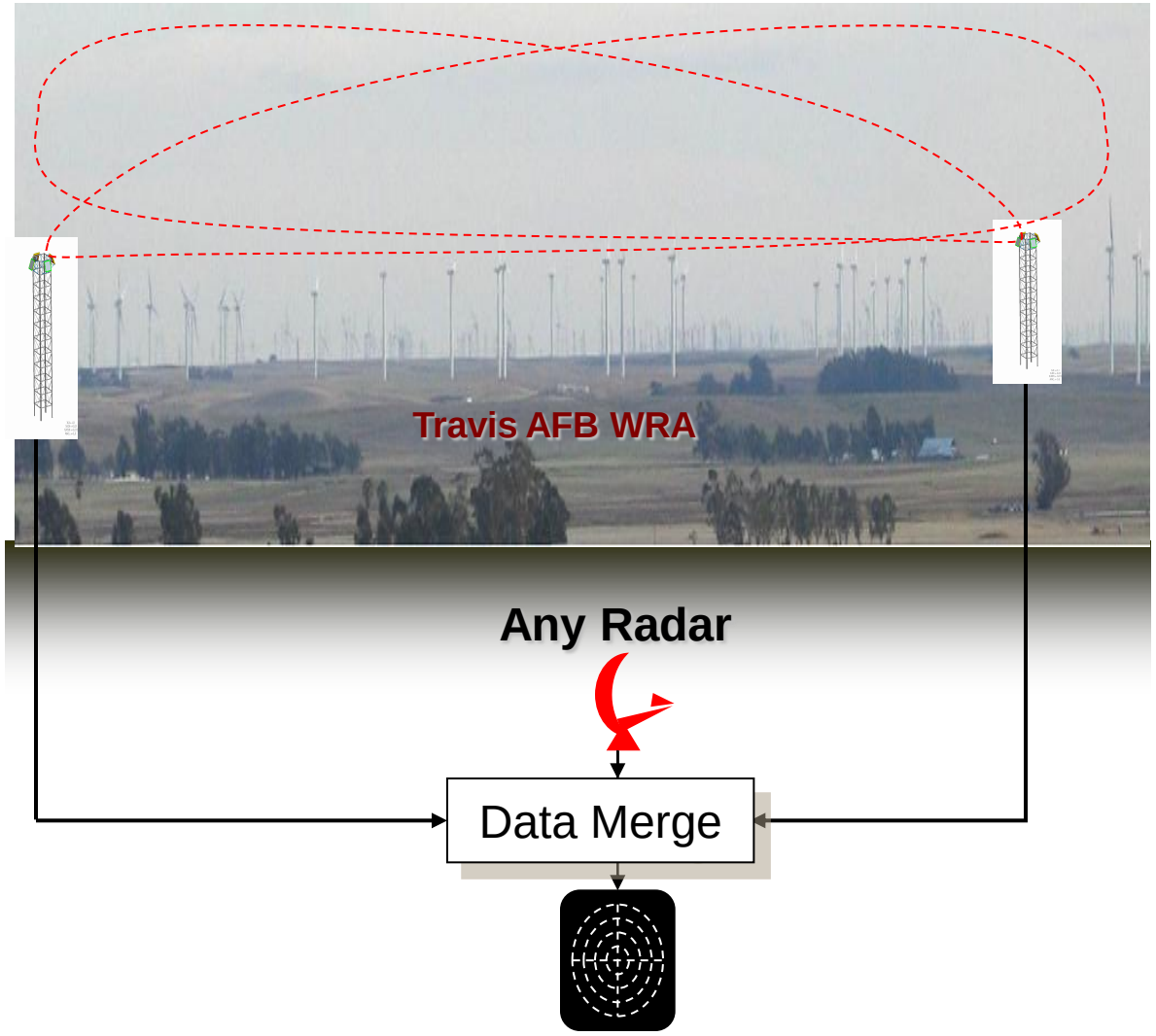
- Raytheon is developing a low cost X-Band mini-phased array
- This is viewed as a very suitable candidate for wide application wind turbine interference mitigation
  - Stand-alone or integrated solution
  - Offshore (Oil Rig / wind turbine mountable)
- Merging the data after target classification provides the lowest data rate and highest confidence of mitigation
- Offers cost effective mitigation and integrates with non-ATC radars



ATC Radar with eSCAN LPR

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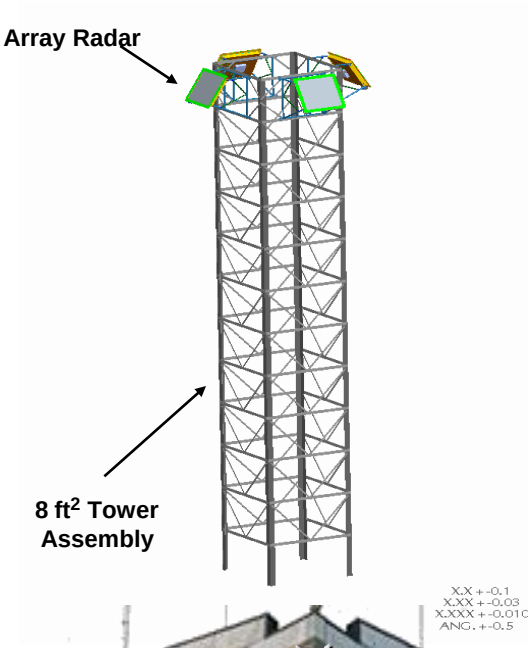
eSCAN LPR (2012)



Array Radar Characteristics:

- 1 m x 1 m x 0.25m X-band antennas
- 2 degree pencil beam
- Single and dual V & H polarization
- 10's Watt average power

Current Mech Scan Technology (2005)

Summary and Way Ahead

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- Raytheon, along with the Government, is investing heavily in a suite of advanced mitigation techniques as a set of 'clean' solutions that may eliminate the effect of wind turbine returns
- These advanced solutions do not appear to adversely affect aircraft detection and can be applied to all Raytheon ATC radars (ASR10/11/23 and LRR) and other ATC radars such as ASR8 / ASR9 with different degrees of modification
- Data collection and optimization, in support of evaluating mitigation techniques, has been conducted using the ASR11 at Stockton, FAA Tech Center, Travis AFB, and Johnstown, where there are existing wind turbine fields
- The first live test of some of these mitigation techniques as contracted by BWEA and UK NATS has been successfully conducted on the ASR10SSMk2 installed at Soesteberg (Netherlands) 3Q2010 – and has been repeated at an ASR11 site
- Raytheon currently working with DoD and FAA planning future testing for both Wind Turbine Mitigation and GBSAA evaluation

Raytheon is investing heavily in a suite of mitigation techniques for Radar – Wind Coexistence and is ready to partner for the next phases of investment, test and qualification/certification

Patent References

- METHODS AND APPARATUS FOR DETECTION/CLASSIFICATION OF RADAR TARGETS INCLUDING BIRDS AND OTHER HAZARDS
  - Peter R Drake, Yuchoi F Lok
  - US 7948429
- CLASSIFICATION SYSTEM FOR RADAR AND SONAR APPLICATIONS
  - Reza M Dizaji, Hamid Ghadiaki
  - US 7567203
- TWO AND ONE-HALF DIMENSIONAL RADAR SYSTEM
  - HAROLD R. WARD
  - US 4961075
- DUAL BEAM RADAR SYSTEM
  - Oliver H. Hubbard, Jian Wang
  - US 7675458 B2
- TRACK QUALITY BASED MULTI-TARGET TRACKER
  - Ding et al
  - US 7626535 B2
- METHODS AND APPARATUS FOR INTEGRATION OF DISTRIBUTED SENSORS AND AIRPORT SURVEILLANCE RADAR TO MITIGATE BLIND SPOTS
  - Peter R Drake, Yuchoi F Lok
  - App - US 2010/0265120 A1