Wind Turbine/Radar System Modeling and Analysis

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Agenda

- AGI overview
- Encroachment and Operational Concerns
- Modeling Impacts of Renewable Energy
  - Wind Turbines
  - Solar Reflectors
- Wind/Radar Customized Solutions
  - AGI Wind/Radar Plugin for Developer
  - DHS WT/RMT
  - NORAD ROEMS
- Summary
AGI SPACE DEFENSE INTELLIGENCE

- Space Mission design
- Space Operations
- SSA
- Launch Operations
- Conjunction Analysis

- Multi Asset Management
- TMD/BMD
- Battlespace planning
- Mission Planning
- Electronic Warfare

- Mission planning
- C4ISR
- Sensor/Collection planning
- Geospatial Intel
• COTS software for analysis and visualization
• Models object in space over time
• Analyze and understand relationships
• Constrain relationships
• High fidelity 4D visualization
Objects & Properties
- Missiles
- Ground vehicles
- Ships
- Facilities
- Aircraft
- Satellites
- Sensors
- Transmitters
- Receivers
- Radars

Physics based object modeling

Object Data Providers

Inter-Object Data Providers
Determine values of, and “constraint” satisfaction time periods that meet mission objectives

- Geometric
- Proximity
- Pointing
- Lighting
- Line-of-sight atmospheric conditions
- Inter-object geometry
- Comm link quality, Jamming values
- Radar performance measures
- Terrain vertical profile
- GPS DOP and Nav accuracy prediction
STK Capabilities for GIS

Maps
- .kml, .shp, .mxd
- geodatabases
- custom GIS (e.g., DAFIF)

Models
- COLLADA

Imagery
- .ecw, .img, .jp2, .ntf, .sid, .tif
- CADRG, & CIB

Terrain
- DTED, DEM, ArcInfo, GTOPO, MOLA, MUSE, GEODAS

2D/3D Visualization
Terrain analysis

AzEl Terrain masking (to range, to altitude)
- Colorize flight paths within view of detection mask
Dynamic Geometry Modeling

- **Time systems**
  - UTCG, LCL, IRIG, GPS, Julian

- **Coordinate Systems**
  - ECI, ECF, ENU, NED, Custom

- **Vector geometry tool**
  - Points, Vectors, Angles, Planes, Axes

- **Relative position information**
  - RIC, AER, Intervisibility, Doppler

- **Celestial**
  - Sun, moon, etc.
RF Analysis

- **Dynamics**
  - Position/Velocity
  - Orientation

- **Transmitter/Receiver**
  - Power
  - Frequency
  - Delay
  - Waveform
  - Filtering

- **Antenna**
  - Dynamic Gain
  - Polarization
  - Losses

- **Environment**
  - Terrain (TIREM)
  - Absorption and refraction
  - Ionosphere
  - Obscuration and Diffraction (terrain, objects, etc.)
  - Weather models

- **Visualization**
  - Coverage
  - Antenna Gain Volumes
RF Environmental Effects

- Rain, Gaseous Absorption, Cloud/Fog, Tropospheric
- Terrain diffraction with TIREM
- Urban environment modeling (REMCOM Wireless Insite RT)
- Plugin points for external RF models
Urban communications

- Assess signals in urban environments
- Analyze loss using multiple paths
- Site specific
Radar

**Types**
- Mono-static
- Bi-static
- SAR

**Power**
- Peak
- Losses
- Antenna

**Operating Modes**

**Search/Track**
- Fixed PRF
- Continuous

**Filters**

**Detection**
- SNR
- Aspect dependent RCS
- Complex Scattering Matrix

**Interference (C/No+I, J/S)**
- Clutter
- Noise
- Jammers
Aircraft RCS Modeling
Route Design / Optimization
Encroachment Concerns

- **Population Growth**
  - Zoning/Planning
  - Noise (acoustic, RF)

- **Airspace / Waterways**
  - NAS Policy / Coast Guard
  - Deconfliction

- **Spectrum Management**
  - Spectrum Visualization
  - Spectrum Deconfliction
  - RFI Monitoring

- **Renewable Energy**
  - Wind Turbines
    - Airborne Radar
    - Ground Based Radar
    - Microwave Communications
  - Solar Power
    - IR Effects
    - Reflectivity Effects
Wind Turbines

Wind turbines are continuously growing in size and in numbers.
Wind Turbines

The Vestas V90 is 90 meters (98.4 yds/295 ft) in diameter or 45 meters to the center of the hub.
Turbines can be an issue because

- Speed of turbine blades closely match that of aircraft. (~150-250 mph) exhibiting spectral similarities.
- Radars perceive turbines as false targets and/or a source of noise, thus degrading sensitivity to cancel effect.
- Degradation of sensitivity is so severe it is sufficient to mask actual aircraft.
- Results in radar obscuration at various altitudes above each turbine site, depending on the radar beam width.
Turbine Blade Tip Doppler, with Aircraft

Aircraft

Sinusoidal pattern of turbine blades

Zoom Region
Zoomed in: Tip Doppler with Aircraft:

Facility-RadarFAA-Sensor-RadarSweep-FAA-Radar-FAA-To-Satellite-BladeTip1-1-

Aircraft

Aircraft
Tip Doppler with Aircraft: Wind Effect

Wind From North

Wind From West

Aircraft
Solar Power Reflectivity Effects

- Sun position
- Reflector orientation
- Solar reflection angle
- Relative position of Asset
- Determination of Hazard
Solar Power IR Effects

- Sun position
- Reflector orientation
- Collector temperature
- IR signature
- Thermal blooming
- Relative position of Asset
Wind/Radar Customized Solutions
Wind turbines in line of sight degrade radar performance

- Primary wind turbine effects
  - Reduced Sensitivity (Clutter sources)
  - Screening / Shadowing
  - False Targets (Doppler spectrum)

Radar Advanced Processing Plugin (RAPP) capabilities

- Spatial / Temporal and RF Environment
  - Radar, target, and turbine location/orientation
    - Dwell/pulse, RCS, nacelle/blade relationship
  - Atmospheric propagation and refraction
  - Terrain masking and diffraction
- Land Clutter: Billingsley Surface Clutter Model
  - Various land/surface classifications
- Turbine Clutter
  - Interferer size, shape, speed (RCS and Doppler)
Usage of the Wind/Radar UI Plugin

- Rapid evaluation of existing or proposed wind farm effects to radar detection capabilities
  - Along routes: Performs a flight path analysis along a specific route.
  - Over areas: Performs an area analysis in a circular grid surrounding a radar at a defined altitude.

- Measurable Results
  - Probability of detection
  - Turbine interference power
  - Integrated signal power
  - Clutter power

- Supported activities
  - Air traffic and defense planning
  - Range sustainment
  - Wind farm developer planning
  - Radar designers/manufacturers/consultants
Turbines are modeled as interference sources with a power spectrum.

- Turbine Blade Length and RPM - This determines the tip speed of the turbine blades which affects the width of the Doppler spectrum before accounting for turbine nacelle orientation relative to the radar.

- Turbine Nacelle Orientation – This is determined by wind direction and affects the blade orientation relative to the radar.
  - When the turbine disk is normal to the radar line of sight (LOS), there will be no width to the spectrum.
  - When the disk is parallel to the LOS, the radar will see both retreating and advancing blades at the full tip speed, resulting in a spectrum spanning the corresponding Doppler shifts of advancing and retreating tips.

- Turbine Visibility - Terrain may limit visibility of the wind turbine blades.
  - If the top of the turbine disk is below the radar horizon, the disk is excluded from consideration.
  - If the midpoint of the turbine (the nacelle) is below the radar horizon, the reflected power from the turbine is reduced in half. The spectrum is not modified. This results in a conservative “worst case” calculation.

- Turbine RCS - In combination with the incident radar power, this determines the amplitude of the spectrum.
• The turbine frequency spectrum exhibits constant power over the bandwidth defined by the min/max Doppler of the turbine blade tips.
• In the future, the RAPP will apply blade RCS spectral scaling and aspect-dependency, where blade velocity, visibility, and orientation will provide for power variation across the bandwidth
Filling an area target and with turbines for a rapid “what if” analysis
If available, coordinates can be imported via a text (CSV) file.
Turbine Group Identification

Turbines can be grouped for analyses
Area Analysis

Area analysis plots around the radar according to the radar’s azimuth/range resolutions, propagation loss, and terrain diffraction.
Area Analysis

User configurable parameters

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Turbines to analyze: 1154

Proposed
Area Analysis

Colors ranges of plots are user selectable.
Values optionally displayed upon zooming in close to resolution cells. Note 100% PD (green) in image below, possible currently as ground clutter is not being considered. Future versions will take ground clutter into consideration.
Flight Path Analysis

Example scenario is of a small aircraft flying at 300m AGL, exploiting terrain and wind farms to attempt to avoid detection en route to a target in Southwestern PA, USA. Notional data used, including the location of the radar. Radar model is also completely notional.
Flight Path Analysis

No color on flight path: Obscured by terrain
Flight Path Analysis

Colors on line below are a Propability of Detection (PD) analysis with green being > 90% PD.
PD degradation occurring above turbines. (Generic radar model used.)
Flight Path Analysis

View from directly above. (Generic radar model used.)
Area plot and flight path combined.
Additional Output Examples

Points drawn vs. mesh.
## Area Analysis Data in CSV Format

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### Analysis Results

| Latitude | Longitude | Height (WGS84) | Latitude Acc | Longitude Acc | Range (km) | Range (km) Acc | Height (WGS84) | Height (WGS84) Acc | Integrated Signal | Noise Power (W) | Probability of Detection | Single Pulse Signal |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
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### Flight Path Analysis Data in CSV Format

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Availability

- Currently available only with a special pre-release version of STK 10.
- Will be fully available to install without any custom installation upon STK 10.1 release.
- Custom radar models can be built to customer provided specifications.
Future Plans

- Future radar processor models for the RAPP (Radar Advanced Processor Plugin)
- Ability to use aspect-dependent scattering matrix for the blades as opposed to simply scaling magnitude.
Radars modeled
– ARSR-4, ASR-8, ASR-9, ASR-11, CARSR, RYC-8405

Application
– STK Engine, CAF, SQL Server
– Requires ROEMS Software Bundle
– Distributable with NORAD permission only. NORAD is generally very willing to share with others (Five Eyes)
DHS WT/RMT Development

• Teamed with Raytheon and Remcom.
• Development started.
• 2 year development program.
• 4d Globe Thin Client Interface.
• Radar systems modeling.
• Ray Path analysis.
• RCS, turbine multi-bounce and multipath.
• Signal process simulators.
• A/C Doppler shift & turbine “clutter”.
• Path loss propagation.
• Refraction and diffraction.