

Modeling and Simulation for Sensor Craft Multi-Mission Radar

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Abstract— The objective of this paper is to review the tools available for modeling and simulating the Sensor Craft radar system concept and assess the challenging role and potential for STAP processing to support its intended missions in severe clutter. Airborne surveillance radar systems such as those proposed for Sensor Craft, will operate in a severe and dynamic interference environment. This interference is a sum of clutter, electronic counter measures (ECM), electromagnetic interference (EMI), and noise. The ability to detect weak airborne and ground targets requires the suppression of interference in real time. STAP techniques offer promise of superior interference suppression capability. Extensive research into STAP for the AMTI mission, i.e. high radial velocity targets competing with clutter from the antenna sidelobes, has proven its superiority over non-adaptive techniques. Looking to the future, the advantages of STAP for the AMTI mission needs to be extended to GMTI, i.e. slow targets competing with clutter from the antenna main beam.

component of a fully integrated ISR system that cohesively integrates Space, Air and Ground segments. The advanced sensor payload, RF aperture and processing requirements for Sensor Craft's new sensing capabilities should result in continuous all-weather, theater air and ground target acquisition, geo-positioning, and tracking of time-critical targets employing heavy Camouflage, Concealment, and Deception (CC&D) tactics. While Sensor Craft is a vision, several technologies must be brought to bear on the problem such as sensors, air vehicle, and propulsion and although no single design currently exists, several candidate airframes are being studied for the Sensor Craft concept such as that depicted in Figure 1.

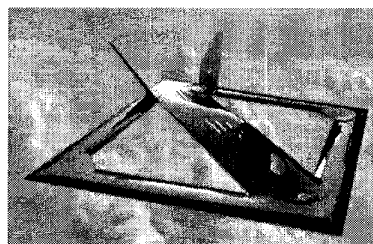


Figure 1. Example Sensor Craft Air Vehicle

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1. INTRODUCTION

Sensor Craft, an Air Force Research Laboratory technology concept program, holds high promise in providing revolutionary Intelligence, Surveillance, and Reconnaissance (ISR) capabilities for the future Air Force. This technological vision blends a wide spectrum of emerging technologies to produce an unmanned air vehicle configured to conduct multiple advanced sensing modes integrated into an airframe that sustains an enduring theater presence. Sensor Craft can be considered as the future airbreather

The advanced sensor functionality being designed into the Sensor Craft vehicle includes advanced RF capabilities – radar and Electronic Support Measures (ESM) fully integrated into the aircraft structure. Radar functions will include Air Moving Target Indication (AMTI), Ground Moving Target Indication (GMTI), Synthetic Aperture Radar (SAR), foliage penetration SAR with these functions operational in both monostatic and bistatic modes.

2. SITE-SPECIFIC CLUTTER MODELING

In response to the Sensor Craft vision, several radar system modeling and analysis tools are under development by AFRL/SN to develop and evaluate the radar system and signal processing algorithm performance. One simulation tool, referred to as Research Laboratory Space-Time Adaptive

Processing (RLSTAP) generates high fidelity radar data for evaluation of radar system performance. RLSTAP can generate and analyze data for several radar modes including Air Moving Target Indication (AMTI), Ground Moving Target Indication (GMTI), and Synthetic Aperture Radar (spotlight and strip). Additionally, RLSTAP can be used to model ground-based, airborne and space-based radar systems, and a limited bistatic modeling capability exists, which is still in development. Current emphasis is on high-fidelity data generation, adaptive system performance characterization.

RLSTAP is being developed within the Khoros software development environment for user-friendly operation via Graphical User Interface (GUI) programming and is designed to support a wide variety of user and mission needs. By connecting together a series of "glyphs" representing various functional elements of a radar system and the environment, as illustrated in Figure 2, a user can

build a simulation that represents a conventional or conceptual radar, deploy it against a user-specified target, in a given geometry and with specified environmental conditions such as clutter and jamming.

RLSTAP can process and evaluate measured radar data, simulate airborne, spaceborne or ground based multi-channel radar data in jamming and clutter environments, combine measured and simulated radar data, develop and evaluate new STAP algorithms, and assess the performance of advanced radar systems and advanced signal processing technologies. RLSTAP is a time domain simulation, updating object positions for every radar pulse. This allows the tool to model realistic effects such as targets "walking" across range bins and Doppler filters over successive pulses. Table 1 shows the prominent capabilities of RLSTAP.

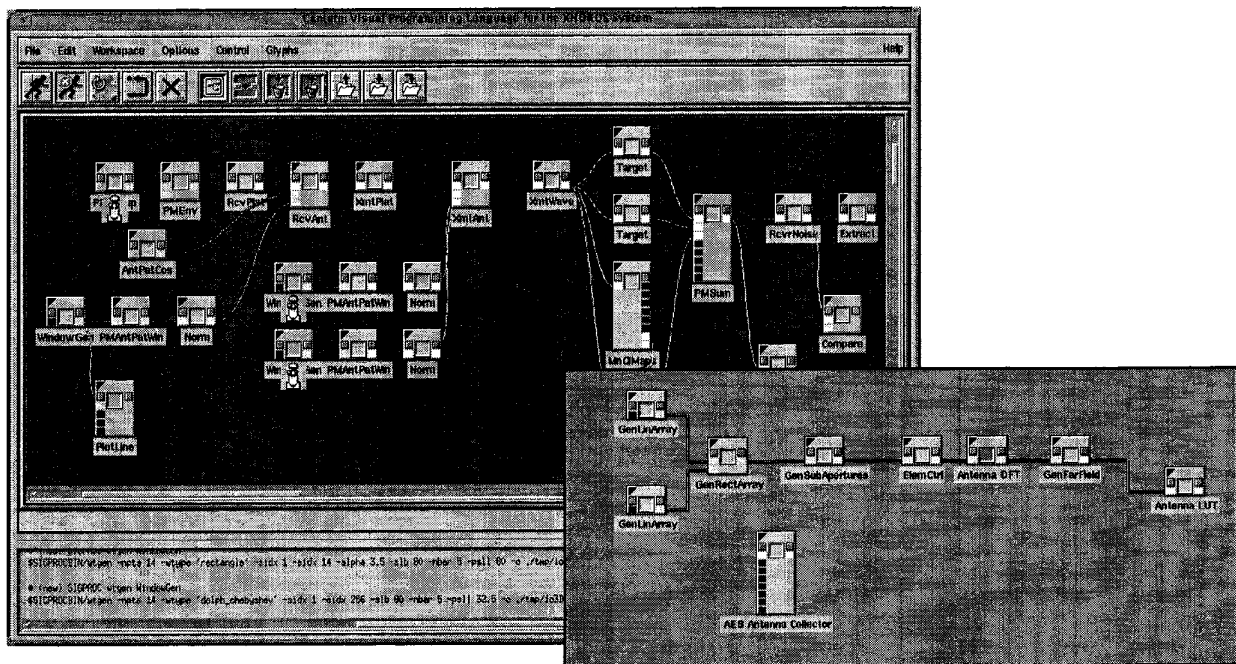


Figure 2. Example Glyph Lineup in RLSTAP GUI

Table 1 CURRENT CAPABILITIES OF THE RLSTAP TOOL

Antenna Modeling	Rectangular Phased Arrays
Multiple Subarrays, Beams	Non-overlapped/Overlapped
Narrowband, Single Polarization	Platform Effects
Airframe, Radome	Yaw (Crab Angle), Pitch, Roll
Transmitter/Receiver	Monostatic/Bistatic
Receiver Noise, Blanking	IF and PC Filtering, Range Folding
Waveforms	Low, Medium, and High Fixed PRFs
LFM, Phase and Barker Coded	Staggered PRI
Targets	Single/Multiple Scatterer
Straight Path, No Shadowing	Swerling Models (1&3)
Earth	Spherical, Non-Rotating
Platforms	Radars, Targets, Jammers
Linear Flight Paths	User Specified via LUT
Low Simulation Artifacts (High Fidelity)	80 dB Dynamic Range
Clutter	UHF through X-Band
Homogeneous/Site Specific	Importing of Sigma Zero vs Grazing Angle Curves
Bistatic Equivalence Theorem	Jammers
Direct Path Noise Jammers	Can Set Bandwidth and Location/Speed
Temporal Modeling	Updates Positions of All Platforms on Each Pulse
Models Range-Walk and Doppler-Walk	Signal Processing
STAP Algorithms	CFAR Algorithms
Digital Beamforming, DPCA, MTI	Interfaces With Other Software
Matlab - Signal Processing Flexibility	Matlab - Visualization
CS-PAAS - More Complex Antenna Modeling	
Import Antenna Patterns Generated by Third Party Software	

The antenna is one of the most complex radar subsystems to accurately model as the antenna pattern has a fundamental and profound impact on the ability of a radar system to accomplish its mission. Therefore, wide-body airframe and radome interaction effects are modeled by RLSTAP; Figure 3 shows results of modeling the airframe antenna in free space (Figure 3a), and with the added interaction effects of the airframe, engines and engine mounts (Figure 3b). The presence of various aircraft structures such as wings, engines, and the fuselage are realities with which the radar antenna and system designer have to contend. If a realistic radar system were to be modeled to high fidelity, such as what is required for Sensor Craft, higher order effects such as airframe and radome interactions must be accounted for in the simulation. Additionally, emerging radar concepts must consider the use of conformal arrays where the element patterns are not identical, the element spacing is non-uniform, and the elements are not necessarily arranged in a linear or planar geometry. Such array configurations must be included in modeling and simulation tools for future radar systems design, development and evaluation. Conventional adaptive processing approaches assume

elements, but this fundamental assumption is violated in systems using conformal array technology thus making it imperative that adaptive algorithm designers have a high-fidelity tools for modeling such systems and generating data to support their algorithm design and evaluation efforts.

The clutter environment can be defined to a level of detail and fidelity that suits the user's needs. For first order analysis or statistical studies, homogeneous clutter environments can be modeled. However, one of RLSTAP's greatest advantages is that for detailed studies or operational analysis, more realistic clutter returns can be generated for a user-specified location using terrain height and terrain cover information available from the United States Geological Survey (USGS) database. This key feature of RLSTAP provides a valuable tool for experiment planning or system analysis in environments where measured data might not exist. The site-specific clutter model simulates the clutter environment for a specified location using terrain elevation and terrain cover information available in the USGS database to derive the line-of-site visibility, grazing angle, and clutter type for each range-angle cell in the surveillance volume. Spatial and temporal clutter statistics are ap-

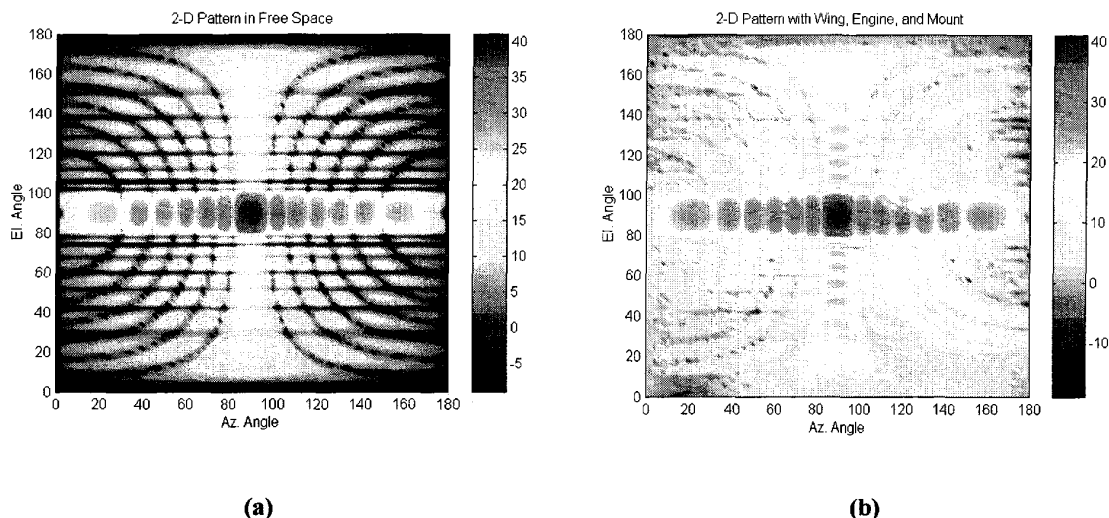


Figure 3. Airframe Antenna pattern in Free-Space and with Wings, Engine Mounts and Engines

plied to each clutter cell based on the clutter type selected, or as defined by the user. The clutter simulation treats each range-angle cell as an individual point scatterer whose signal strength at the receiver is a function of the backscatter coefficient, range, atmospheric attenuation, antenna gain, and system gains/losses. Targets are modeled as fluctuating or non-fluctuating point sources, or as distributed scatterers.

3. MODEL-BASED CLUTTER SIMULATION

The second tool under development is a MATLAB-based simulation tool for modeling and analysis of multi-channel bistatic radars. The simulation models various bistatic geometries including airborne-to-airborne, space-to-airborne and space-to-space systems. The simulation, referred to as SMS-MBS is a Signal Modeling and Simulation for Multichannel Bistatic Systems, will be used to develop and evaluate bistatic adaptive algorithms and to analyze bistatic clutter characteristics for Sensor Craft bistatic modes. The simulation calculates the data cube for multiple-channel radars. This data cube is the clutter return (amplitude, phase) as a function of radar range, receiver channel and pulse number. Both uncompressed and compressed narrow-band pulse waveforms are modeled. Arrays can be positioned arbitrarily on the platform (aircraft, spacecraft) having arbitrary speed, direction and crab angles

Random antenna errors, such as position and gain errors, can occur at the element, transmit/receive module and/or channel level. Mutual coupling and near-field scattering are emulated with a statistical approach. The GUI for SMS-MBS is illustrated in Figure 4. In the main menu (Figure 4a), the green buttons in the upper right allow the user to establish the configuration settings for: system and geometry, transmit antenna, receive antenna, and the environment. The system and geometry menu appears as Figure 4b. The green buttons in Figure 4b labeled "Geometry" and "Iso-Range" allow the user to see plots of the geometry including transmitter, receiver and target locations (Figure 4d) and the iso-Doppler contours (Figure 4c) for the system specifications the user has entered. Features such as these are included in SMS-MBS for visualizing the bistatic geometries to aid the user in creating and evaluating sensor performance over a variety of complicated ground, air, and space bistatic geometries.



A capability recently added to SMS-MBS is the ability to generate Monte-Carlo analysis for analyzing Probability of Detection (P_D) and Probability of False Alarm (P_{FA}) performance for various monostatic and bistatic radar system configurations. The tool includes approximately 15 adaptive algorithms for analysis and as new algorithms for analysis and as new algorithms are developed, they are easily integrable into SMS-MBS for analysis and evaluation. The functionality of the new Monte-Carlo Analysis module in SMS-MBS is shown in Figure 5.

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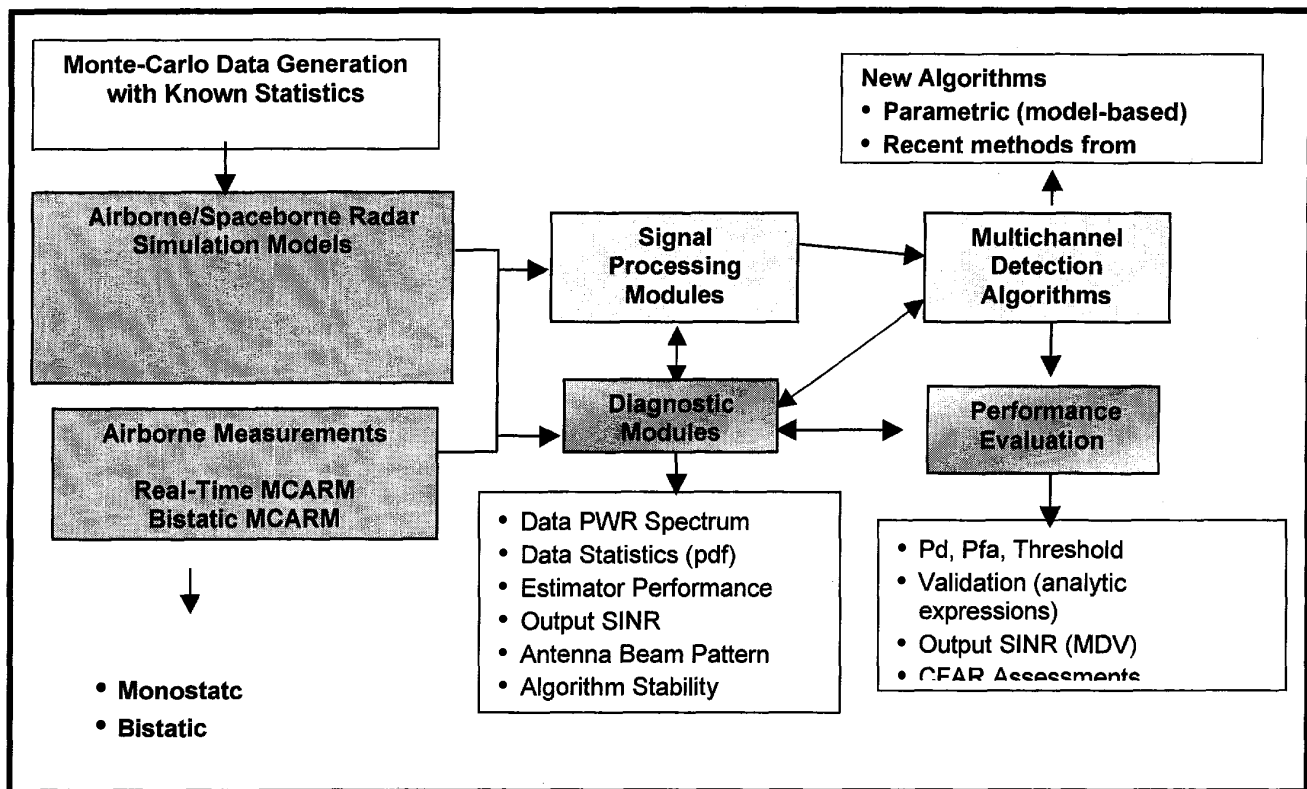


Figure 5. SMS-MBS Monte-Carlo Module Functional Flow Diagram

The Monte-Carlo analysis module is cable of generating large quantities of independent identically distributed (iid) data sets suitable for establishing false alarm probabilities for various adaptive algorithms. Probability of detection vs. signal-to-interference plus noise ratio (SINR) plots can also be generated. These are useful plots for analyzing an adaptive processors clutter rejection performance and the extent to which it can detect low radial velocity targets, known as minimum discernible velocity. Finally, a user can generate plots of the Doppler frequency content of various range cells adjacent to the range cell under test. This is particularly insightful in bistatic geometries as it shows that secondary data support for interference covariance matrix estimation must be done prudently as there is a great deal of spectral dispersion. Sample output plots such as these are shown in Figure 6.

4. SUMMARY

Sensor Craft concept holds promise in providing revolutionary Intelligence, Surveillance, and Reconnaissance (ISR) capabilities for the future Air Force. The advanced sensor payload, RF aperture and processing requirements for Sensor Craft's new sensing capabilities should result in continuous all-

weather, theater air and ground target acquisition, geo-positioning, and tracking of time-critical targets employing heavy CC&D tactics. Airborne surveillance radar systems such as those proposed for Sensor Craft, will operate in a severe and dynamic interference environment. This interference is a sum of clutter, electronic counter measures (ECM), electromagnetic interference (EMI), and noise. The ability to detect weak airborne and ground targets requires the suppression of interference in real time. STAP techniques for the AMTI mission and extended to GMTI offer promise of superior interference suppression capability. A review of the currently developed tools for modeling and simulating the Sensor Craft radar system concept was provided. The challenging role and potential for STAP processing to support its intended missions in severe clutter was also assessed. Looking to the future in for Sensor Craft RF sensor suite, the application of STAP processing, airframe/aperture interaction, bistatic modes all need improved modeling and simulation capability to achieve the high performance desired to meet the Air Force missions.

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BIOGRAPHY



Gerard J. Genello

Gerard (Jerry) Genello received his BSEE from the University of Detroit in 1973, a MSEE from Syracuse University in 1979 and in 1989 a MBA from RPI. In 1973, he began his career at Rome Air Development Center (now Air Force Research Laboratory -AFRL) working as a electromagnetic compatibility (EMC) research engineer. His major activities included high power microwaves, EMC and weapon system vulnerability test and evaluation. In 1988, he joined the Surveillance Division as Chief of the Signal Processing Branch. In 1997, he became manager of the Radar Signal Processing Branch, Sensors Directorate of AFRL. His current responsibilities include managing and directing the basic research, exploratory and advanced development programs for radar signal processing applications. Technologies of

interest include space/time adaptive processing (STAP), knowledge -based techniques, space-based radar, subsurface target detection and SAR image detection and data compression applied to airborne and space-based sensor platforms. Mr. Genello is a senior member of the IEEE and chairman of the local Mohawk Valley Aerospace and Electronics Systems Chapter of the IEEE.



William J. Baldygo Jr.

Mr. William Baldygo is currently the Technical Advisor in the Radar Signal Processing Branch of the Air Force Research Laboratory's Sensors Directorate. He earned his B.S. in Electrical Engineering from Clarkson University in 1990 and his Master's Degree in Electrical Engineering from Syracuse University in 1996. His current research interests include adaptive multi-channel signal processing, waveform diversity, combat identification, AMTI signal processing and Space-Based Radar, and he has authored more than 25 conference and refereed journal papers in these research areas.

Mr. Baldygo is a Senior Member of the Institute of Electrical and Electronic Engineers (IEEE) and is actively involved in the IEEE at the local level serving as Secretary, Treasurer and Chair of the IEEE Mohawk Valley Section. He also serves on the IEEE Region 1 Board of Governors and served on the Technical Program Committee for the 1997 IEEE National Radar Conference. Mr. Baldygo is also a member of the Association of Old Crows.

Mr. Baldygo devotes most of his spare time to his wife and two boys and also enjoys fly fishing, hiking, camping, bicycling, skiing, computers, reading and hopes to learn to golf in the near future.



Michael J. Callahan

Mr. Callahan joined Rome Air Development Center, in Rome, New York (now a part of Air Force Research Laboratory) in 1987. Over the past 13 years, Mr. Callahan spent much time using the various modeling and simulation tools resident at the laboratory, most notably RLSTAP. His current research interests include monostatic and bistatic aerospace surveillance radar and adaptive radar signal processing. Mr. Callahan, an IEEE member, is currently serving as the Secretary of the IEEE Region 1 Mohawk Valley Section. He has been approved to work at Georgia Tech Research Institute (GTRI) as a visiting scientist under the Intergovernmental Personnel Act (IPA) program during the first half of 2001.

Mr. Callahan received a Bachelor of Science degree in Electrical Engineering from Wilkes College (now Wilkes University) in 1987, and a Master of Science degree in Electrical Engineering from Syracuse University in 1998.

Mr. Callahan has authored or co-authored several publications.