AIRSAM: A Tool for Assessing Airborne Infrared Countermeasures

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Abstract

Intelligence data is a key component to command and control (C2) decisions. Often intelligence analysts have to provide commanders with timely data in order for them to execute their missions. The Advanced Infrared Countermeasures Assessment Model (AIRSAM) is a tool used by analysts at the National Air Intelligence Center (NAIC) to predict the most likely infrared countermeasure (IRCM) response from aircraft when engaged by a threat using electro-optic (EO) and infrared (IR) weaponry. The Air Force Research Laboratory (AFRL) develops this tool for NAIC. The goal of this tool is to allow the analyst to perform multiple engagement scenarios involving different geometries and IRCM responses in a relatively short period of time (e.g. one day).

1. *Introduction*

The Advanced Infrared countermeasure (IRCM) Assessment Model (AIRSAM) is a software tool used by National Air Intelligence Center (NAIC) analysts to determine the most likely IRCM response by an aircraft when engaged by a threat using electro-optic (EO) IR technology. The Air Force Research Laboratory has been developing this tool since 1992. The goal of AIRSAM is to provide analysts with a flexible user-configurable tool for rapidly simulating air-to-air and ground-to-air engagements. The data generated and presented by AIRSAM is not the end product for the analyst but rather a supplement to the other intelligence data he or she has. The intelligence reports generated by the analysts directly influence the command and control (C2) decisions made by commanders when planning missions. NAIC uses this tool in its assessment of IRCM responses from foreign aircraft. Their reports help commanders develop plans of attack with IR guided missiles that maximize the vulnerability of the target aircraft.

There are two key features of AIRSAM that make it attractive as an IRCM assessment tool. The first is its run time. AIRSAM does not model the circuitry of EO-IR systems in detail. AIRSAM represents the internal circuitry of EO-IR systems with analytic functions that simulate the circuit operation at the time steps required for the aerodynamic models. This greatly reduces run time and allows the analyst to generate data rapidly. This does not impose a limitation on the analyst because he or she is not interested in the effectiveness of the threat but rather the IRCM response of the target. In most cases, the analyst is interested in generating data over a broad range of engagement scenarios from which he or she will determine the most likely IRCM response by the target. Minimal run time is highly desirable for this usage due to the large number of runs. When performing a large number of runs over a broad range of scenarios, the geometry of the engagement and the aerodynamic limitations of the aircraft are the primary factors in determining the outcome.

The second key feature is flexibility. A tool with static models of specific systems does not allow the analyst to use it when assessing new or conceptual IRCM techniques. AIRSAM contains several models for foreign pyrotechnic flares, foreign aircraft, and United States (US) IR guided missiles. In addition to these static models, AIRSAM contains generic, user configurable IR missile seekers that allow the user to set IRCM discrimination techniques and IR counter-countermeasure response. It contains a separate tool for designing flares for use in AIRSAM. The flare types include traditional pyrotechnic flares, tethered flares, spatially extended flares, aerodynamically shaped flares, and thrusted flares. AIRSAM includes a generic, user configurable missile warning receiver (MWR) that detects an incoming threat, initiates IRCMs, and invokes the target aircraft to maneuver. The MWR model allows the user to configure the missile discrimination techniques, detector parameters, and scan parameters. Such flexibility helps the analyst assess the credibility of purported capabilities when more thorough intelligence data is unavailable.

2. *History*

AIRSAM is a continuing technology development that has evolved through a series of developments over the past seven years. It grew from the Threat Engagement Analysis Model (TEAM) developed by the Air Force Information Warfare Center (AFIWC), Kelly AFB, TX. The TEAM model integrated parts or all of each program listed below.

- HOME: A missile seeker model developed and maintained by AFIWC.
- TRAP (Trajectory Analysis Program): An aircraft and missile aerodynamic model developed, managed, and maintained by NAIC.
- DISAMS (Digital Infrared Surface-to-Air Missile Simulation): An IR missile engagement model developed and maintained by Georgia Tech Research Institute (GTRI). TEAM extracted DISAMS flare model.
- IVIEW: A three-dimensional visualization model developed jointly by NAIC and AFRL.
- LOWTRAN: A low resolution atmospheric transmission model developed, maintained, and distributed by the Air Force Geophysics Laboratory.

In 1993, NAIC and AFRL (Rome, NY), acquired TEAM and began a series of developments. These developments proceeded incrementally based upon funding availability. This funding was obtained through AFRL managed programs to develop tools for NAIC. Each development has expanded the capabilities of AIRSAM to its present form and what it will be by 2001.

The initial development by AFRL, NAIC, and Sverdrup added foreign flares, foreign aircraft, a user-configurable flare ejection systems that simulates actual hardware, generic missile seekers, and perfect MWR systems. In addition, this effort upgraded the atmospheric model from LOWTRAN to MODTRAN.

The next step added the AIM-9M missile and validated the Stinger missile model. A toolkit was designed and inserted to add aircraft data into AIRSAM. This effort ported the software from a Silicon Graphics/IRIX environment into a Sun/Solaris environment.

The next section described the third development effort and section 4 it describes the ongoing development. Many of the changes and additions to original TEAM model are new software code unique to AIRSAM. Every release of AIRSAM was regression tested against it predecessor.

3. *Recent Developments*

Recent work has focussed on providing the analyst with simulation capabilities that offer insight into developmental IRCM technologies. The recently concluded work provides the analyst with an external tool for designing flares for use in AIRSAM, additional flare models in AIRSAM, a user-configurable MWR, and a missile detect initiated aircraft maneuver.

3.1 *Flare Models and Design Tool*

The flare design tool is extremely flexible. It allows the user to enter aerodynamic properties of the flare and predict trajectories or enter trajectories and estimate aerodynamic properties. The flare model in AIRSAM uses time histories for the mass, drag force, drag reference area, lift force, lift reference area, and thrust force to predict the flare trajectory. The flare design tool implements the same model for compatibility. There are two limitations to this model. First, the thrust is not vectored so the trajectory of the flare, in its own reference coordinates, is two dimensional (from the thrust direction and gravity). Second, there is no altitude dependence given to these parameters except for thrust. The thrust force works in conjunction with a fixed nozzle aperture and the ambient atmospheric pressure to give altitude dependence.

When the flare design tool is given a trajectory to predict aerodynamic properties, it can only determine two parameters. The tool hardwires the drag and lift forces as variables. All other parameters are set to constants. The thrust is zero if the drag force is always negative otherwise it is set to the largest positive value of the drag force. If the user enters time histories for mass, drag reference area, lift reference area, and/or thrust force prior to entering a trajectory, the tool will use those histories in its prediction of the drag and lift forces and not set those parameters to constant values. The user can break the time space into multiple regions of differing resolutions and enter data for each region using either method. It is up to the user to ensure that the data is smooth regions.

The user can define the spectral response using three different methods. The first method is time histories for graybody parameters. Three parameters define the graybody: Temperature, emissivity, and emitting area. For some of the modern flare materials, a graybody spectrum isn't sufficient. The flare design tool provides two methods for direct entry of the spectrum. The first has the user enter two separate curves. One is the absolute intensity versus the wavelength and the other is the relative intensity versus time. For this spectral model, the wavelength distribution never changes with time. The other method of entry enables the user to enter a time-resolved spectrum. With this method, the user enters an absolute spectrum at various time steps. A cubic spline interpolation algorithm determines the intensity in between the time steps. The user can break up the spectral space into regions of varying resolution and enter data into each region using any of
the three methods. The time space regions must match that used for the aerodynamic data. It is up to the user to ensure that the data is smooth across regions.

AIRSAM uses a simple model for altitude dependence of the radiated intensity. A single curve defines the intensity gain as a function of altitude relative to the sea level intensity. The design tool has the user enter this data separately from the spectral data. AIRSAM also has a gain factor for the off axis intensity for point flares. The point flare model assumes the plume is ellipsoidal in shape. This gain maximizes at 90 degrees where the major axis of the ellipsoid is perpendicular to the line of sight. This is where the emitting area is largest. The design tool has the user enter this data separately from the spectral data.

Once the user has entered in spectral and aerodynamic data, the design tool allows user to write and install AIRSAM flare data. The tool saves two sets of data. One is an internal set that maintains the original data and the other is the data file for the AIRSAM flare model. The internal data can be saved whether the flare definition is complete or not. The AIRSAM flare model data must be complete to write this set. Once the user has saved AIRSAM flare model data, that flare is available for immediate use in AIRSAM.

3.2 ***User-configurable MWR***

AIRSAM inherited several MWR models from the Air Force Information Warfare Center's (AFIWC's) Threat Engagement Analysis Model (TEAM). Since TEAM doesn't model missile signatures, its MWR models estimate probability of detection based upon the engagement geometry and empirical estimates of the MWR performance. Some models estimate the received IR signature based on the missile thrust. NAIC wanted a model that could scan a user-defined sector of the surrounding airspace and detect a missile based upon the received IR signature and user-selectable discrimination algorithms.

The missile signature model in AIRSAM uses measured plume spectral data, a simple approximation for angular pattern of the plume, and a simple equilibrium based thermodynamic model for aerodynamic heating of the missile dome. This was the best model we could develop under the constraints of time, budget, and data availability. We did not have time history data for the plume signature so we scaled the plume signature to the thrust. We implemented this model in AIRSAM, ran the AIRSAM, and recorded the incident signature on the target versus time and range. Since we had no verification data, NAIC reviewed these plots to verify they were subjectively representative of a signal received by an MWR.

The user-configurable MWR consists of up to four sensors, a detection system, and a hand-off system. There are two types of sensors available: scanning array or staring matrix. The user can not mix sensor types in a system. For scanning sensors, the detector is a linear array of detectors. It is mechanically raster scanned. The elevation field of view (FOV) is the product of the element FOV, the number of elements, and the number of vertical scans. The user sets all three of these parameters. The azimuth FOV is a single value set by the user. The staring detector consists of a square matrix of elements. It monitors a fixed region of airspace surrounding the aircraft. Its azimuth and elevation FOV comes from the number of azimuth and elevation elements and the element azimuth and elevation FOV. As with the scanning array, the user defines these parameters. The user also sets parameters for the noise equivalent irradiance (NEI) of the elements, the wavelength passbands (one or two passbands are allowed), and the frame rate for each sensor type.

The detection system consists of five techniques for discriminating incoming missiles: intensity threshold, size of the source, the ratio of intensity in two wavelength passbands, a secondary scan, and the temporal history of the source. The user can use any combination of these techniques. The intensity threshold is a simple test that triggers detects a missile when the received intensity rises above a fixed threshold. The size discriminator compares adjacent pixels to see if the signal is from a large source such as a cloud. The ratio of intensity in two wavelength passbands is often referred to as a two-color test. The missile signature is largely a result of molecular vibrations in the engine plume. This technique compares the received intensity between two passbands where the molecular radiation is most intense and checks that this ratio is within bounds typical for an engine plume. The user sets the lower and upper limits for this ratio. The secondary scan applies only to scanning sensors. With this technique, the scanned angle is decreased and the frame rate increased around a suspected missile. This allows give the MWR finer resolution and faster response time to detect the missile. The final technique monitors the growth of intensity over time. This technique applies only to staring sensors where the frame rates are sufficiently fast enough to gain an accurate profile. This technique tries to match the detected intensity to the known behavior of a pursuing missile.

Hand off consists of either initiating a flare dispense sequence, initiating an evasive maneuver by the target, or both. Each sensor can start a unique flare dispense sequence. The sequence depends upon the countermeasure system of the target. It can dispense various types of flares at defined time intervals. The user defines these parameters. If the user chooses have the target initiate a maneuver, the current maneuver stops and the new maneuver begins. The user can specify a delay time between missile detection and initiation of the maneuver.

4. *Current Developments*

Of current interest is the response by a target aircraft when it illuminates an approaching threat with a high-energy airborne laser. We call this a laser countermeasure (LCM) system. This effort requires the development of models for various electro-optic sensors, an airborne laser transmitter, laser atmospheric transmission, a target acquisition system, and a target tracking system. The goal of this model is to provide the analyst with the ability to take present and future data from independent sources for LCMs and sensors, enter them into AIRSAM, and simulate an engagement. The results of that simulation will provide analysts with information about how effective particular laser countermeasure (CM) system is against the sensor.

4.1 *Sensor Models*

We are currently developing several models for electro-optic (EO) sensor vulnerability for AIRSAM. The sensors include the eye of the human pilot, the IR search and track sensor on the threat aircraft, a forward-looking IR receiver on the threat aircraft, and the IR sensor of an IR guided missile. These models assume that their corresponding systems operate ideally up to a point that the incident laser energy induces temporary or permanent damage. It provides the analyst with the following information: The amount of energy reaching the sensor, the possible effects this level of energy has on system performance, and the likelihood of damage to the sensor.

The basic model is generic and draws from a database to establish optical parameters and damage thresholds. We are currently researching data for laser damage to sensors. We will populate the database with this information. We will also provide the user with graphical interface so that he or she can enter their own data and continue to grow the database.

4.2 *Laser Transmitter and Atmospheric Propagation*

The user will be able to configure parameters for the laser transmitter. These include the laser medium, cavity, beam divergence, beam diameter, pulse characteristics, and output power. The user can enter line wavelength, refractive index, and linewidth for the laser medium. The cavity parameters include length and bandwidth. The laser medium and cavity properties determine the precise spectral output of the laser transmitter.

The resolution of the laser spectrum requires that AIRSAM use a new atmospheric propagation model. Currently, AIRSAM uses MODTRAN for atmospheric propagation. MODTRAN has a 2 cm^{-1} spectral resolution. This resolution is too coarse for laser radiation. AIRSAM will use FASCODE with the HITRAN database to calculate atmospheric propagation combined with a gaussian beam model. The propagation model will include spreading and bending of the gaussian beam but will not incorporate speckle due to atmospheric aberrations.

4.3 *Target Acquisition and Tracking*

The fidelity of AIRSAM does not permit detailed models for target acquisition and tracking systems. These systems are also of little concern to the analyst unless they don't function correctly and render the LCM system ineffective. We will add two acquisition models to AIRSAM. The first is an ideal model based on the perfect MWR systems. This model would acquire the threat based on whether it was within the FOV of the acquisition sensor and either its range from the target or the estimated time to intercept. This simulates an aircrew driven acquisition. The other acquisition system is the generic MWR model. When the target employs a LCM system, the generic MWR will hand the target off to the target tracking system instead of initiating a flare dispense sequence.

Both of the target acquisition models hand off the threat to the target-tracking model. AIRSAM will incorporate two target-tracking models. The first is a passive detector that functions similarly to the missile seeker. The tracking sensor will attempt to keep the laser pointed on the threat. As the threat moves off axis of the sensor, the laser and sensor direction will adjust to keep it on axis. The second system will use the retro-reflections from a laser to establish the pointing direction. This system is particularly useful with pulsed LCM systems against scanned detectors. The retro-reflected signal triggers the LCM system for pulsing.

5. *Future Development*

There are many opportunities to enhance AIRSAM. Foremost would be the addition of toolkits to build the aerodynamic data that represent different aircraft and missiles. The generic missile seekers could be enhanced to raise their fidelity and provide the user a set of control blocks that he/she could construct tracking systems from. Improved seeker fidelity would allow the simulation of pulsed jamming. The LCM systems could be enhanced to simulate pulsed jamming systems.

6. *Conclusion*

AIRSAM is an effective and evolving tool for determining the IRCM response from target aircraft. With this model's focus on rapid generation of intelligence data, it can assist analysts in processing intelligence data and ultimately provide commanders with reports that give them an advantage when planning missions.