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GENERIC MODELS IN THE ADVANCED IRCM ASSESSMENT MODEL

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ABSTRACT

The Advanced IRCM Assessment Model (AIRSAM) simulates an infrared (IR) guided missile engaging an aircraft equipped with infrared countermeasures (IRCM). Analysts currently use AIRSAM to predict the most likely IRCM response by an aircraft when engaged. The analyst often attempts to determine responses using IRCM or threat systems that are not characterized in detail. For AIRSAM to be an effective simulation for this purpose, the models for IRCMs and threat systems must allow the user to adjust operational parameters to match the IRCMs or threat systems of interest. Much of our work over the past nine years has involved developing generic models with associated configuration tools to provide the user with this flexibility. This paper will highlight some of those generic models.

1 INTRODUCTION

AIRSAM evolved from the Threat Engagement Analysis Model (TEAM) version 1.6 developed by the Air Force Information Warfare Center (AFIWC). In 1992, the National Air Intelligence Center (NAIC) obtained this model to develop a tool for determining the optimal dispense sequence of flares from aircraft. NAIC collaborated with the Air Force Research Laboratory (AFRL) at Rome, NY to establish a program to perform this work. JE Sverdrup was awarded the contract. The relationship between intelligence, research and development, and contractor has been very successful. This success has lead to a series of awards for AIRSAM development through the present date.

The first generic models added to AIRSAM were ideal missile warning receivers (MWRs). These MWRs would initiate a flare dispense sequence when the threat closed within a user-specified range or when the estimated time to intercept crossed a user-specified threshold. Later work developed a more sophisticated generic MWR model. This model divides a user-defined sector of space around the aircraft into image pixels and processes the detected signal in those pixels to determine whether a threat is approaching.

AIRSAM includes a generic model for an IR missile seeker that continues to evolve. Initially, this model provided two simple functions. The first was a choice of methods for discriminating a flare from an aircraft. The second was a choice of track alteration methodologies when the flare detection algorithm declares the presence of a flare. (This is called counter-countermeasure and abbreviated as CCM). Subsequent work has expanded this model by allowing the user to logically combine flare detection and CCM tracking techniques, configure gain and response time parameters for these techniques, set the seeker field of view (FOV), and freeze the gain of the automatic gain control (AGC) amplifier.

The flare model in TEAM was already generic. It uses an external parameter file to define its aerodynamic and irradiance parameters. This model is too simple for emerging flare designs because it only accounts for drag forces and gravity acting on the flare. We expanded this model by adding lift and thrust forces. We developed a tool for designing flares and generating the necessary model parameter file.

Currently we are working on a generic model for an airborne laser countermeasure (LCM). This model will contain an aircraft mounted LCM system, the threat sensor, and the atmosphere in between. The goal of this development is to provide the capability to insert laser vulnerability data for a sensor (generally obtained through laboratory experiment), put that sensor on a pursuing threat, and put the laser on the aircraft. This will allow the user to take measured laser vulnerability data and correlate it to laser effectiveness in an engagement scenario. The scope for this model is high-energy impairment or damage to a sensor.

The subsequent sections describe each of these models in more detail.

2 GENERIC MISSILE WARNING RECEIVER MODEL

The generic MWR model represents a passive detection system that monitors a sector of air space for IR radiation representative of an incoming missile. The model consists of sensors, a discrimination system, and a declaration system. Figures 1 through 3 show the flow diagrams for this model.

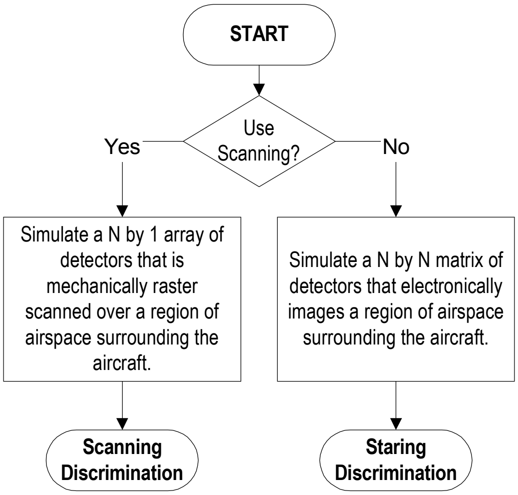

Figure 1: First Decision for the MWR Model

The model accommodates up to four sensors that the user can place anywhere on the aircraft surface. It supports two types of sensors: staring and scanning.

Scanning sensors consist of a linear array of detectors that is raster-scanned over the airspace of interest. The user sets the number of detectors in the array. Each detector has a user-specified field of view and wavelength band. The user defines the horizontal (perpendicular to the array) scan width, the number of vertical scans, and the frame rate. The model provides flexibility in how the sensor scans. The user can choose top to bottom or bottom to top for the vertical scan and left to right or right to left for the horizontal scan. The user can set the initial scan position as well. The most interesting of the initial scan positions is one just past the current position of the missile. This forces one full scan of the sensor before the model can possibly detect the missile.

The staring sensor consists of a square matrix of detectors. Like the scanning sensor, each detector has a user-defined field of view and wavelength band. The staring sensor does not move. It monitors a fixed region of airspace relative to the aircraft. The staring sensor model allows the user to configure its frame rate.

The model has several features to help discriminate a missile signal from background signals. The model can cascade these features to make a decision. Some features are dependent upon the type of sensor. The first and simplest discriminator is an intensity threshold. The received signal must exceed a certain threshold above the background average it either declares a missile or applies other discriminators.

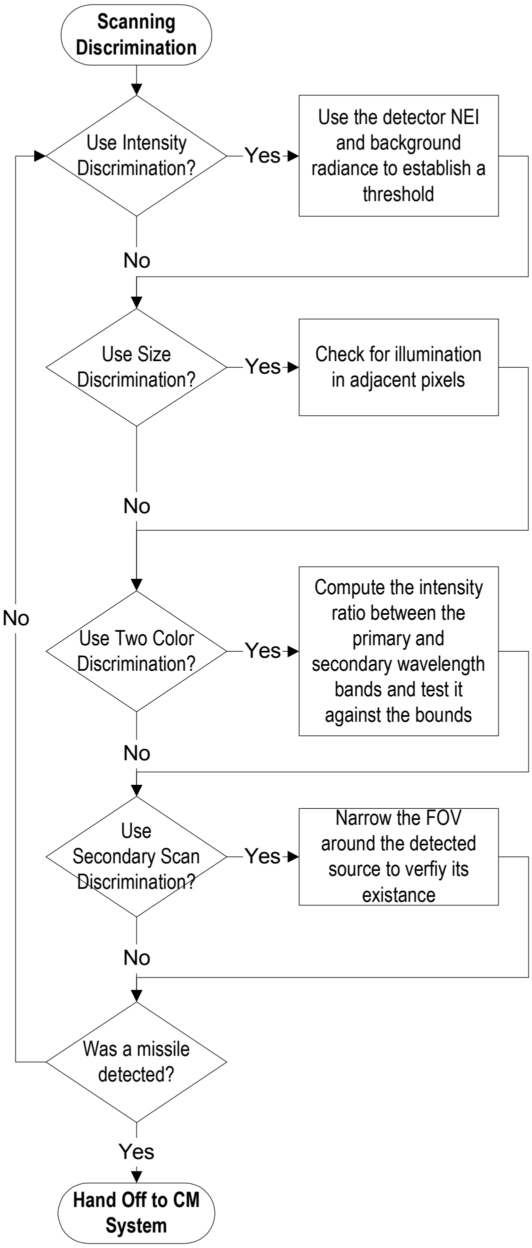

Figure 2: Scanning Sensor Discrimination Model

Because the sensor monitors a broad field of view, the model expects an incoming missile to fall within a single pixel. The second discrimination technique checks adjacent pixel for similar intensity levels. If a source appears to span more than one pixel, the algorithm rejects it as a missile.

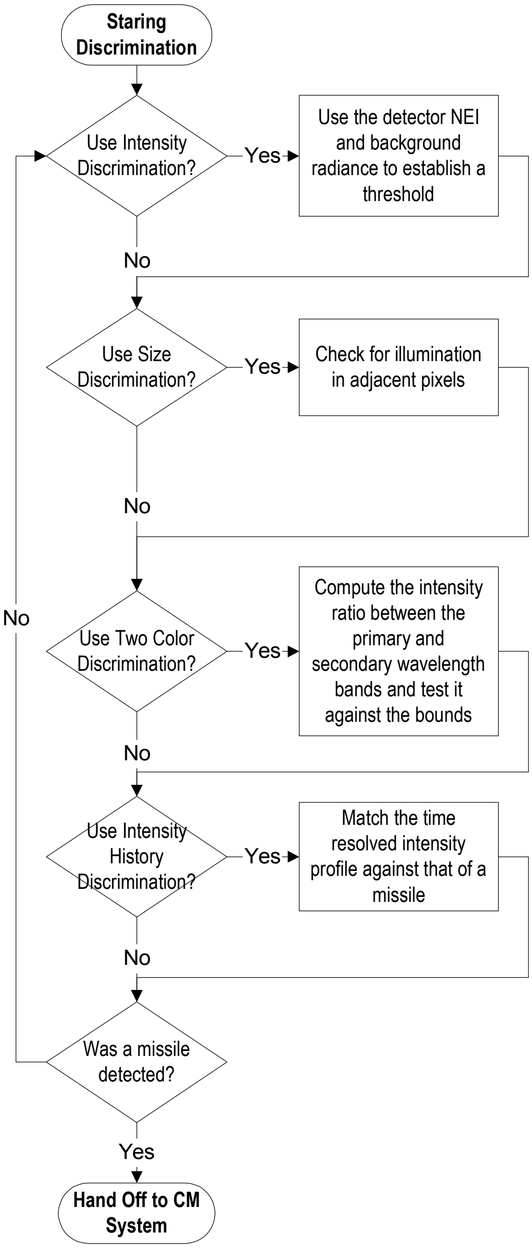

Figure 3: Staring Sensor Discrimination Model

The next discriminator is a two-color ratio test. This test requires that the system detects two wavelength bands, calculates the ratio of the detected signals, and proceeds if the ratio falls within the user-defined bounds. The user sets both bands.

For scanning sensors, the final discrimination option is a reduced total field of view. This model assumes that in primary mode, the scanning sensor monitors a large total field of view. Since the sensor mechanically scans, the frame rate is quite low. When the algorithm detects a possible missile, the total field of view reduces around that source. Since the field of view is smaller, the frame rate increases, and the time required to confirm that the source is a missile decreases.

Staring sensors do not move and typically have a narrower total field of view than mechanically scanned sensors. Their frame rates are usually much higher (perhaps two orders of magnitude). Because they can have a fast frame rate, the final discrimination algorithm used only by staring sensors maps the intensity versus time. This profile has distinctive features for a missile closing on a target. If the history of measured signals from a source closely follows that profile, the algorithm declares a missile.

3 GENERIC MISSILE SEEKERS

The generic missile seeker model consists of three modules: flare detection, CCM tracking, and normal tracking. The flare detection module attempts to determine whether flares exist within the field of view. If so, the CCM tracking module issues track commands in hopes of ignoring signals from flares. The normal tracking module issues track commands based on the weighted average of all sources within the seeker FOV. This section will discuss the algorithms for the first two modules.

Figure 4 shows the general operation of the generic missile seeker. In its simplest form, the generic seeker performs no means for flare detection. A flare is never declared so the seeker always uses normal tracking. The seeker model can provide up to two separate modes for flare discrimination. The names of these modes are primary and secondary. Each mode has a unique, user-configured flare detection and CCM tracking method. The “Conditions Met?” phrase in Figure 4 means that the state of the model makes this mode (primary or secondary) valid and the flare detection algorithm has declared a flare. The test for flares is a continuous operation.

The model uses the primary mode for all seeker configurations that try to discriminate flares from targets. This mode always takes precedence over the secondary mode. If the secondary discrimination mode is enabled, the model will use it in one of three different ways.

The first way the model uses the secondary mode is in parallel to the primary mode. If the conditions cause the primary mode to declare a flare, the seeker switches from normal tracking to primary mode CCM tracking. Else, if the conditions cause the secondary mode to declare a flare, the seeker will start tracking using secondary mode CCM tracking. Otherwise, the seeker continues using the normal tracking module.

The next method separates the modes based upon source position within the seeker FOV. If all sources are within a FOV smaller than the total FOV, the model uses the primary mode to detect flares and track in their presence. If sources are outside of this reduced FOV, it uses the secondary mode.

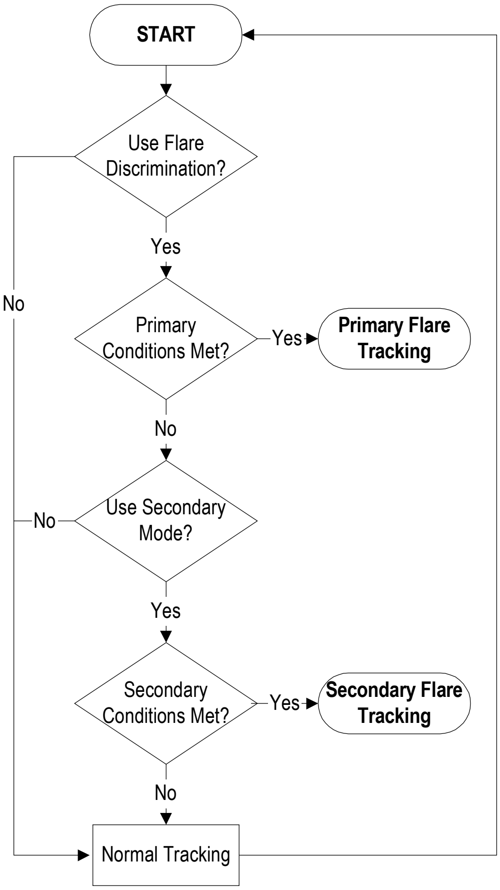

Figure 4: Generic Missile Seeker Operation

The final way the seeker uses the secondary mode is in series with the primary mode. First, the primary mode must declare a flare initiate its CCM tracking method. When this mode ends (either by timing out or believing all flares have left the FOV), the seeker tests the conditions against the secondary mode criteria. If the secondary mode detects flares, it will initiate its CCM tracking method.

The model provides three methods for detecting a flare. Figure 5 shows the operation of the flare detection module. Note that the user can uniquely configure this module for the primary and secondary modes. If the user doesn't enable any methods, the model uses perfect detection. This ideal method always declares a flare when a flare is present in the FOV.

The user selects which methods to enable. The model can use these three methods in conjunction with one another. The user can select multiple methods and have their declarations logically connected using either AND or OR operators. The first method computes the received intensity ratio for two different wavelength bands. It declares a flare if that ratio exceeds user-specified threshold. The next method tests the ratio of the instantaneous intensity to the historical average. If this ratio is above a user-defined threshold, it declares a flare. The final detection method monitors the seeker line-of-sight (LOS) rate. This method assumes the flare quickly separates from the aircraft thus causing a sudden change in the seeker LOS rate. This method declares a flare when the change in LOS rate exceeds a user-specified threshold. Because the LOS rate can vary considerably immediately following missile launch, the model waits 0.1 seconds before enabling this method.

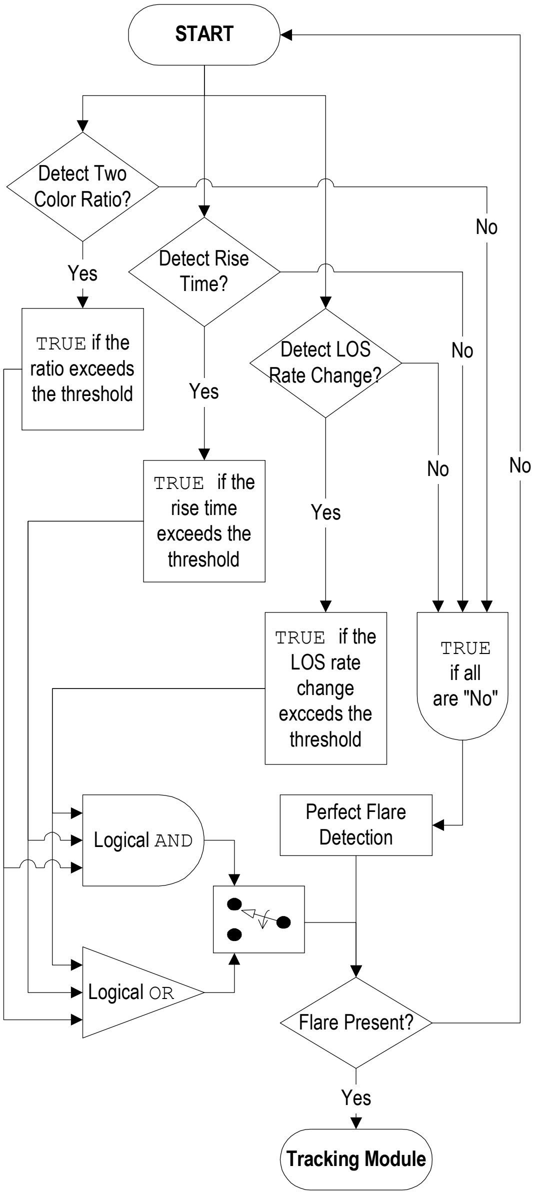

Figure 5: Generic Seeker Flare Detection Module

If the flare detection module declares the presence of a flare, the CCM tracking module tries to compensate for its presence using AGC locking and track alteration methods. The user can set a maximum time that the seeker will use

CCM tracking. When the CCM track time passes this threshold, the seeker turns off CCM and returns to normal tracking. If all flares exit the FOV before reaching this time threshold, the seeker returns to normal tracking. If the user sets this time to zero, the CCM tracking module will function until all flares exit the FOV.

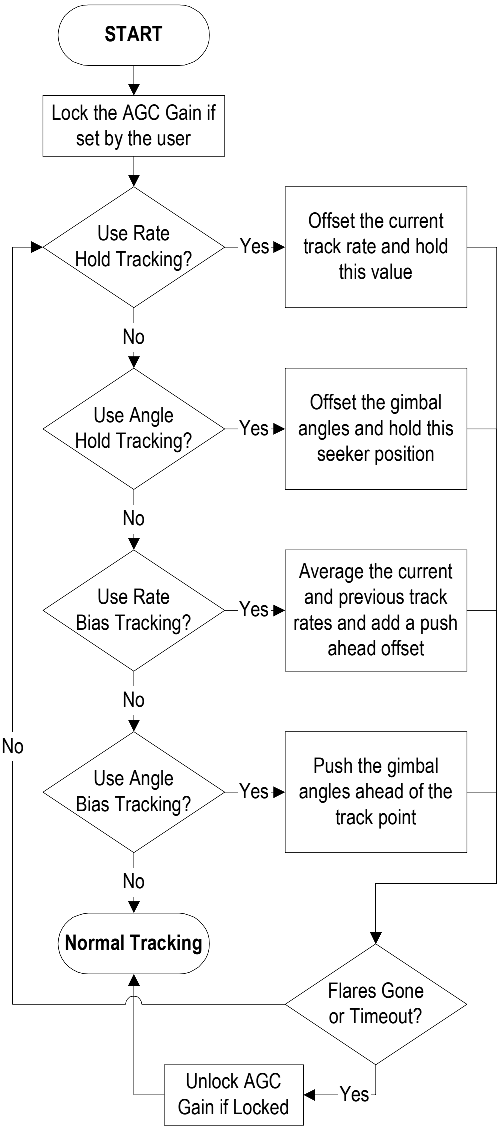

Figure 6: Generic Seeker Tracking Module

Normally, the seeker electronics adjusts its gain to always keep the target source near the center of its dynamic range. If a flare is present and its intensity is much greater than that of the target, the seeker electronics can reduce its gain such that the signal from the target will fall below the noise floor of the electronics. AGC locking stops this action. The flare intensity may cause the seeker electronics to saturate, however, the target intensity will remain within the seeker's dynamic range. The user can turn AGC locking on or off and set the dynamic range of the electronics. The model can use this in conjunction with tracking alteration methods as shown in Figure 6.

The CCM tracking module allows the user to specify one of four track methods after flare declaration. If the user doesn't select a tracking method, the seeker uses normal tracking.

The first method is rate hold. This technique adds an offset to the current tracking rate and holds that value. The next method is angle hold. This technique offsets and fixes the gimbal angles of the seeker. For these two methods, the offset causes the missile to push ahead of the target. The hope is that the flare will exit the FOV and the target will move from the edge towards the center of the seeker FOV. The next method is rate bias. This technique uses the average of the previous tracking rate and the desired track rate for normal tracking. A user-defined value offsets this track rate in an attempt to keep the seeker pointing ahead of the target. The final method is angle bias. This technique uses the desired gimbal angles for normal tracking and offsets it by a user-specified amount in the direction that the target was last moving. This attempts to keep the seeker pointing ahead of the target.

4 GENERIC FLARE MODEL

The generic flare model represents the flare as a point mass object acted upon by lift, drag, thrust, and gravitation forces. The model constrains the motion to two dimensions in reference to the flare. The x axis specifies the forward direction of the flare and the z axis specifies the downward direction of gravity. The equations of motion for the flare model are:

$$\dot{V}_x = (T - D)\cos\gamma + L\sin\gamma \tag{1}$$

$$\dot{V}_z = mg + (T - D)\sin\gamma - L\cos\gamma \tag{2}$$

where $\dot{V}_x$ is the x directed acceleration of the flare, $\dot{V}_z$ is the z directed acceleration of the flare, γ is the angle between the x axis and the flare velocity, m is the flare mass, g is the gravitational acceleration, T is the thrust force, D is the drag force, and L is the lift force.

The drag and lift forces are a function of the flare geometry, speed (V), mass, and the atmospheric mass density (ρ). The equations for drag and lift forces are:

$$D = \frac{K_D}{2m}\rho V^2 \tag{3}$$

$$L = \frac{K_L}{2m}\rho V^2 \qquad (4)$$

where K_D and K_L are parameters based on the coefficients and reference areas of drag and lift respectively.

The thrust force is dependent on the atmospheric pressure. The model computes the thrust force as the difference of the vacuum thrust force (T_v) and the product of the air pressure (p) and the nozzle area (A_n). Substituting equations (3) and (4) and this representation for the thrust force into equations (1) and (2) and rearranging terms yields the coupled differential equations describing the flare velocity.

$$\frac{2(T_v - pA_n) - K_D\rho V^2}{2m} = \frac{V_x\dot{V}_x - V_z\dot{V}_z - V_z g}{V} \qquad (5)$$

$$\frac{K_L\rho V^2}{2m} = \frac{V_z\dot{V}_x - V_x\dot{V}_z + V_x g}{V} \qquad (6)$$

The flare model interpolates time resolved data for the vacuum thrust force, mass, drag parameter, and lift parameter from an external table. The model interpolates values for air density and pressure using the tabular data from the U.S. Standard Atmosphere (1976). Using these parameters and the ejection speed and direction for the initial velocity, AIRSAM computes the flare trajectory. It numerically solves equations (5) and (6) at the time steps used to simulate the engagement.

The model represents the flare as an ellipsoidal emitting source. The radiometric data for the flare model comes from external tabular data. The data contains tables of intensity versus time for seven IR bands, relative intensity versus orientation to account for the elliptical emitting area, and relative intensity versus altitude. The model uses burn time to interpolate the intensity versus time data. It uses the position and orientation to interpolate the orientation and altitude intensity adjustments. The emitted flare intensity is the product of these three numbers. The atmosphere between the flare and the seeker attenuates this intensity.

An additional feature of AIRSAM allows the user to randomly modulate the flare intensity. The model uses a Rayleigh distributed pseudo-random number generator for the modulating function. Figure 7 shows the Rayleigh distribution. The user specifies a seed for the pseudo-random number generator with a default value set to the time in seconds as provided by the workstation. The user sets a modulation coefficient that determines the magnitude of modulation. The model bounds this coefficient between zero and one where zero indicates no modulation and one indicates full modulation (intensity bounded between zero and infinity although the probability of those values are zero).

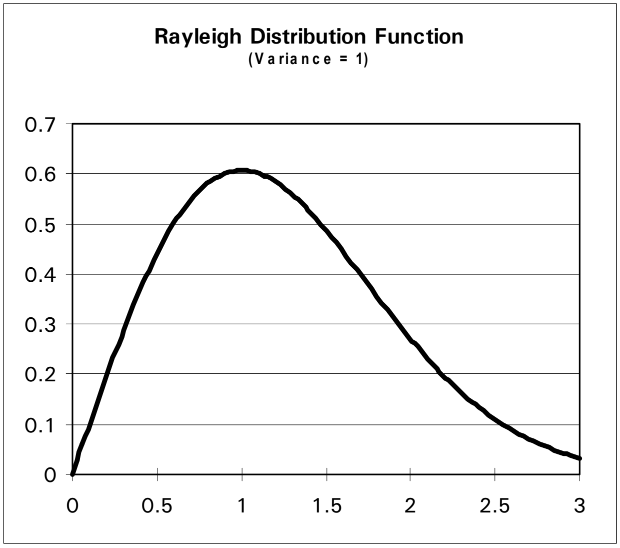

Figure 7: The Rayleigh Distribution Function

5 GENERIC LCM MODEL

Our current efforts include a model for a high-energy, aircraft-mounted laser used to counter a threat sensor by impairing or damaging it. This model does not attempt to include the physical processes that lead to sensor damage. Its goal is to allow the user to take data for laser damage, insert it into AIRSAM, and simulate an engagement to see how effective the laser is against it. The LCM model consists of three parts: The LCM system, the atmosphere, and the sensor.

The LCM system model has three subsystems: target acquisition, target tracking, and the laser. The target acquisition system model operates in two modes. The first mode is ideal. When the threat comes within a certain range of the aircraft, the model acquires the target. This ideal mode simulates a manual acquisition. The next mode attempts to declare a threat by passively detecting the IR radiation from its engine. The target acquisition system model is a derivative of the current generic MWR system models.

The target tracking system model also operates in two modes. The first mode is a passive system. This system keeps the laser pointed at the threat target by monitoring its radiant IR energy. This mode operates much like the generic missile seeker model without flare detection and CCM tracking. The other mode is an active tracker. It uses a pulsed laser to illuminate sensors on the threat. The system detects the reflections off the threat sensors and uses this information to target and queue a pulse train from the LCM. This type of tracker works best with pulsed LCM systems against scanning sensors. The fidelity of AIRSAM is too low to develop a detailed model of this process therefore the model will track and queue the LCM in ideally.

The laser model consists of the laser medium, the laser cavity, and the output parameters. This model is based on the laser description of Saleh and Teich (1991). The laser medium contains parameters for the transition wavelength, line width (full width half maximum of gain function), and refractive index. The model restricts the user to using a single transition wavelength since most sources of sensor vulnerability contain measured values at a specific wavelength. The model contains parameters for several common laser media and provides the user with the ability to define the medium. The output parameters include the beam waist diameter, the beam divergence, the output energy, and the pulse mode. The pulse mode includes continuous wave (CW), repetitive pulses, or queued pulses. For pulsed modes, the pulse width is user-defined.

The cavity bandwidth is usually much narrower than the gain bandwidth. Because the length is many wavelengths, the spectrum of the cavity is comb-like and thus the laser can support multiple cavity modes. Figure 8 illustrates this by showing the laser medium and cavity spectra. For the laser medium, ν_0 is the transition wavelength, $\Delta\nu$ is the line width, α is the loss, and $\gamma(\nu)$ is the gain. For the cavity, $\delta\nu$ is the line width and β is the spacing of the cavity modes. Unless otherwise restricted, the laser oscillates at each cavity mode where γ is greater than α. The cavity may contain optics to remove unwanted cavity modes.

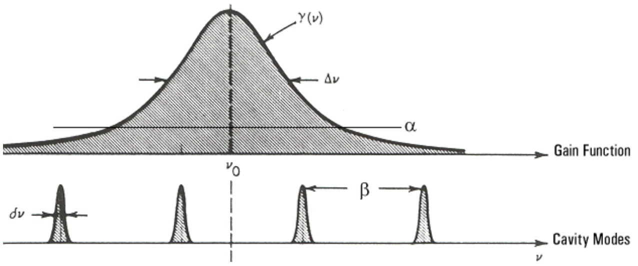

Figure 8: Spectrum of the Laser Medium and Cavity from Saleh and Teich (1991)

The model uses three parameters for the cavity. The first is the length that determines β. The second parameter is the line width $\delta\nu$. The third is the cavity bandwidth. The model imposes a constraint on the bandwidth such that it is between $\delta\nu$ and $9.95 \times \Delta\nu$. The upper bound assumes a Lorentzian line shape for the gain function and a minimum α of 1% of the maximum gain. The bandwidth represents either the losses in the laser cavity and medium or the effect of bandwidth limiting optics.

The atmosphere is a complicated propagation medium for high-energy lasers. The narrow spectral bandwidth of the laser beam requires a very high fidelity representation of the atmospheric transmission spectrum. The energy of the beam can lead to nonlinear effects. The goal of this program is not to develop a model for laser propagation in the atmosphere so AIRSAM will use an existing model. The Fast Atmospheric Signature Code (FASCODE) is a candidate for this calculation because it has a line width resolution of 0.0001 cm^{-1}. Another code is the Nonlinear Aerosol Vaporization and Breakdown Effects Module (NOVAE). It simulates high-energy laser propagation through atmospheric aerosols. We are currently evaluating these two codes for inclusion in AIRSAM.

The sensor model consists of a set of impairment and damage criteria for four different types of sensors. Those sensors include eyes, image intensifiers, solid-state detectors, and focal plane arrays. Each sensor has an associated database that provides incident energy versus wavelength for those criteria. Since the model doesn't simulate actual impairment and damage mechanisms, AIRSAM can only use laser wavelengths with a particular sensor for which vulnerability data is available. This data exists in an external database. AIRSAM will include a supplementary tool that allows the user to enter new sensor vulnerability data into the database and use it in a simulated engagement.

6 CONCLUSION

AIRSAM is an evolving simulation backed by a series of highly successful development awards. It contains several generic models that allow the user to configure performance to match a system. This paper discussed four of those models, however, that is not the complete set of generic models. The aerodynamic and IR signature models for missiles and aircraft are generic. They utilize external data files that configure many parameters that define their performance. It is possible to develop tools to generate those parameters in a user-friendly way similar to what we've developed for the flare model. This would greatly expand the capabilities of AIRSAM and provide users with a much more flexible simulator.

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