

RAND'S HIGH-RESOLUTION FORCE-ON-FORCE  
MODELING AND SIMULATION CAPABILITY

Overview

MUCH OF THE RESEARCH IN THIS VOLUME has been accomplished using RAND's high-resolution force-on-force simulation environment, which is composed of a large network of locally distributed models and simulations. The major components of the network are shown in Figure B.1. JANUS represents the centerpiece of the network. It is a system-level, stochastic, two-sided, interactive ground combat simulation/wargame. At different times it has been used for combat developments, doctrine analysis, tactics investigation, scenario development, field test simulation, and training. The RAND version of JANUS models up to 1,500 individual combat systems per side (including up to 100 indirect-fire systems). Each system can move, detect, and shoot over a 200-kilometer-square, three-dimensional, terrain representation based on National Intelligence Mapping Agency DTED level I, II, and III data.

Combat systems, such as tanks, infantrymen, and helicopters, are defined by the quantitative attributes of the real or notional systems being modeled, e.g., size, speed, sensor, armament, armor protection, thermal/optical contrast, and flyer-type (for helicopters and fixed-wing aircraft). The vulnerability of systems are characterized by prob-

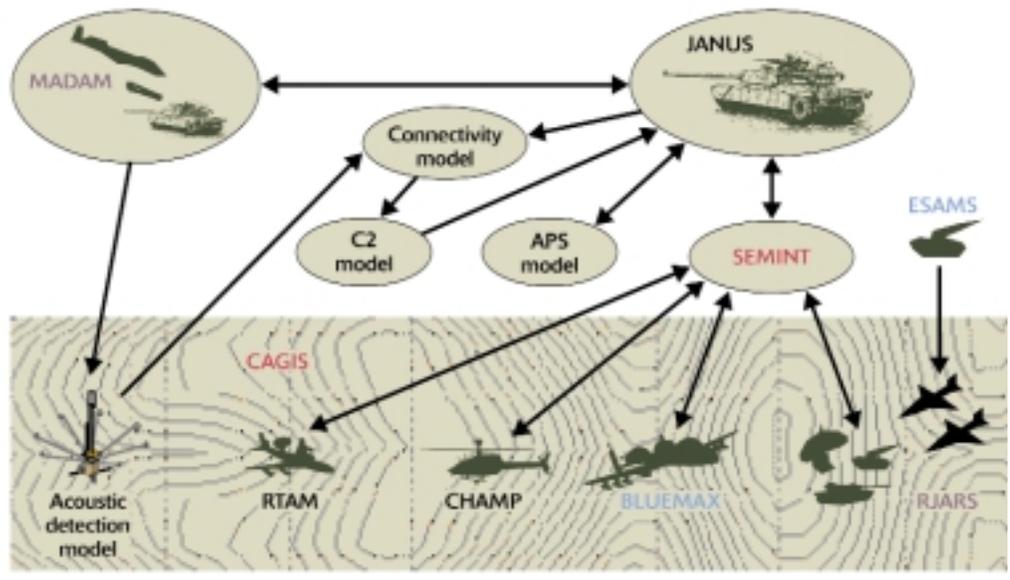


Figure B.1—Major Components of RAND's Force-on-Force Modeling Suite

ability of hit ( $P(h)$ ) and probability of kill ( $P(k)$ ) datasets individually associated with weapon-versus-system pairs. Up to 250 different systems and types of weapons may be defined per side. Each system may be armed with up to 15 different weapons, and it may search and detect with two different sensors, employing a modification of the Night Vision Electro-Optics Laboratory (NVEOL) detection model. Fixed-wing and rotary-wing systems' flight characteristics are described by two different flight modes, each composed of altitude, speed, and an associated probability of detection by various radar types.

RAND makes use of Standard High-Resolution scenarios, made available by U.S. TRADOC Analysis Center (TRAC), and modifies them as necessary to meet individual project objective needs. When no such standard scenarios are available, or necessary modifications to existing scenarios are too extensive to be practical, scenarios or vignettes are developed at RAND to isolate and examine essential elements of analysis (EEA) identified within the objectives of individual projects. An appropriate level of awareness of each scenario's validity with respect to likely "real-world" situations and contingencies is maintained, and assumptions are always based on "best available data." Vignettes are thoroughly gamed interactively, then carefully scripted to ensure "reasonable" tactics and behavior in the absence of human reaction and intervention.

Although JANUS affords the capability of modeling engagements at the division-versus-division level, typical vignettes are developed at the level of battalion task force-versus-brigade or brigade-versus-division. Vignettes are normally scripted to run for 60 minutes or less (real time). The model typically runs at or faster than real time in the batch (or systemic) mode, depending upon the complexity of the vignette. Each vignette is iterated 30 or more times for statistical validity, and the resulting statistics are analyzed, both by individual run and by the entire ensemble of runs.

The principal strength of JANUS as an analytical tool is its ability to capture the direct and synergistic effects of altering a multitude of model input parameters. The completeness of the output available to the analyst permits a detailed examination of the individual impact attributable to each parameter change, and it aids in quantifying the contribution of synergy to net outcomes. This, combined with the wide range of input data formats the model is capable of accepting—e.g., tabular, calculated, human interaction, etc.—results in a flexible high-resolution simulation, applicable to a variety of ground combat issues. Further, the model's graphic display capability gives the analyst the ability to examine spatial-temporal behavior, thereby aiding the analytic process by directing focus to causal chains occurring during simulation.

The JANUS model has some limitations. The most notable are described below.

*Scenario generation and development.* JANUS's capability may be described as cumbersome, manpower-intensive, and time-consuming. The initial route assignments relating to scheme of maneuver, as well as subsequent fine tuning, both require repeated manual inputs to each system. This time-intensive process limits the ability to examine force effectiveness across a wide range of environments in timely fashion.

*Perfect targeting information.* JANUS detects and locates targets according to accurate ground truth; that is, only live enemy targets are detected and acquired. Acquisition is at system level with no uncertainty in identification (e.g., an APC-X is always detected and identified as an APC-X). Acquired targets are located both accurately and precisely, without target location error. This often results in an overstatement of the accuracy of fires and an underestimate of ammunition consumption.

*Direct-fire suppression.* JANUS models suppression by straight probability, given a target is acquired, fired upon, and not hit and killed (typically 0.25). JANUS firing events are event driven in that a target must first be acquired, and the probability of single-shot kill (PSSK) must be calculated from the P(h) and P(k) tables to determine if it is sufficient to trigger a firing event.<sup>1</sup> This only roughly models direct-fire suppression and “reconnaissance by fire” and often results in a net understatement of both force effectiveness and ammunition consumption.

*Destroyed vehicle (hulk) representation.* Vehicles assessed as “destroyed” in JANUS are “administratively” removed from the battlefield. Although their positional data is recorded in output files, they are not considered for future acquisition and present no hindrance to allocation of fires or live vehicle movement. This results in, once hulks become abundant, an overstatement of trafficability for moving vehicles and an overstatement of the opposing force’s ability to distinguish live targets.

*Nonintelligent behavior.* Systems in JANUS often do not recognize or react to changing battlefield situations or environments. Specifically, without human interaction, a surviving tank in a task force that has been decimated will continue to follow its pre-assigned path regardless of circumstances. Systems being fired upon and suppressed will not seek cover or assume a defilade condition; vehicles trailing a vehicle that has entered a minefield will follow their preassigned paths into the minefield.

*Vertical line of sight.* JANUS does not calculate vertical line of sight as a precursor to probability of detection and acquisition. This results in a serious shortfall in the model’s ability to accurately model interactions in and around buildings and other structures.

There have also been a number of significant model upgrades to JANUS at RAND. One of the more important of these is the increase in terrain size and features. With the advent of JANUS/A, the terrain database changed significantly over JANUS/T.<sup>2</sup> The major change involved replacement of the seven city and seven vegetation densities per grid cell with seven PLOS (probability of line of sight) values per grid cell. The motivation for this was to give the user more control over PLOS values, in particular, to be able to modify them for seasonal changes in foliage density. JANUS/A terrain also added two new arrays for movement factors in urban and vegetation areas, each with seven density levels and three mover types (wheeled, tracked, and footed). Velocity through a cell then became a function of the new urban and vegetation factors instead of a function of the cell’s density level.

A second major improvement was the integration of other models through the addition of a program called the Seamless Model Integration (SEMINT). This was done to overcome some of the key JANUS representational shortcomings. SEMINT integrates multiple RAND simulation and support programs into one communicating, symbiotic system, even though the participating models may be written in different programming languages and run on different hardware under different operating systems. In effect, SEMINT gave us the ability to improve JANUS's algorithms without modifying them. By connecting the JANUS ground combat model with the RTAM target acquisition model, the RJARS ground-to-air combat model, the BLUE MAX (fixed-wing) and CHAMP (helicopter) flight planners, and the CAGIS cartographic system, we were able to conduct a much more comprehensive JANUS-based simulation. As currently configured, JANUS conducts the ground battle, calling on RTAM to provide more accurate calculation of detection probability on special low-observable vehicles. Should the conflict involve helicopter or fixed-wing operations, the flight planners determine flight paths for the missions flown against the actual JANUS threat, then RJARS conducts the defense against the aircraft—including detection, tracking, jamming and SAM operations. CAGIS provides consistent geographic information to all the simulations, while SEMINT passes messages among the models and maintains a Global Virtual Time to keep the models in synchronization.

The basic models we used are shown in Figure B.2. Generally, these include a force-on-force combat model (JANUS) with several “attached” models such as Model to Assess Damage to Armor with Munitions (MADAM) for simulated emerging smart and

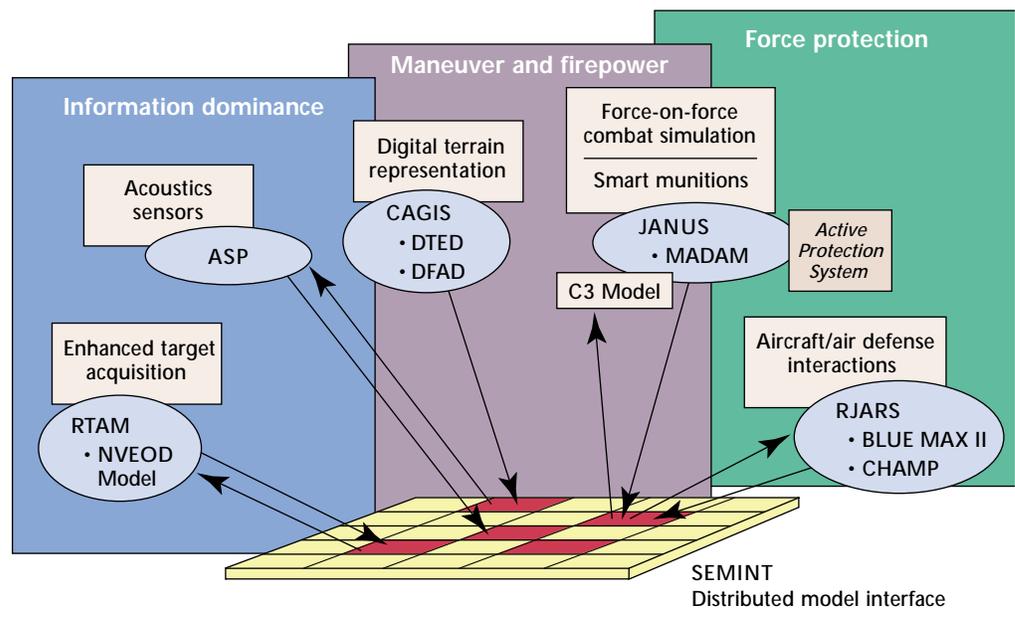


Figure B.2—Organization of Models and Their Impact on Different Aspects of Combat Missions

brilliant munitions, a C3 model for better assessing the impact and degradations of C3, and a newly created active protection model. Other models include: the Cartographic Analysis and Geographic Information System (CAGIS) for enhanced digital terrain representation, the Acoustic Sensor Program (ASP) for modeling acoustic sensor phenomenology, RAND's Target Acquisition Model (RTAM) for enhanced target acquisition techniques, and RAND's Jamming Aircraft and Radar Simulation (RJARS) for simulated surface-to-air interactions. Many of these models will be described in more detail in the sections below.

#### *Line-of-Sight (LOS)-Based Communications Model*

A simple, LOS-based communications model was added to JANUS in hopes of capturing some of the effects of communications-associated delays due to routing, and hardware and network reliability. The model accounts for the following phenomena:

- LOS communication requirement
- Communications hardware reliability
- Communications network reliability
- Packet delays (in seconds)
- Bandwidth limitations (number of messages handled simultaneously)
- Communications range limitations (kilometers)

Targeting messages, developed by sensors detecting targets for subsequent attack by indirect fire, are passed, in order, to three consecutive echelon decisionmaking nodes for allocation of indirect-fire assets. The sensor fuses the target information to determine at which echelon the appropriate asset to service the target resides. This determines the initial destination (address) for the targeting message.

The sensor will then attempt to send the message directly to that address. If that attempt fails (either due to range, LOS, or availability), an intermediate communications node with message retransmission capability will be sought for relay.

As shown in Figure B.3, each transmission of each message is recorded in an output file as an audit trail for subsequent postprocessing and analysis. This output file records message tag number, time of transmission/receipt, sending and receiving node coordinates, cumulative range of transmissions, cumulative number of retransmissions, disposition of message at each decisionmaking node, and ultimate disposition of each message.

The CAGIS display (left side of figure) is a graphic representation of the routing of a message from a Tactical Command and Control Post to a launcher with 10 intermediate hops. Decisionmaking for this process is carried out in the command and control model, described in the next section.

#### *Fire Support Command and Control (C2) Model*

Once a detection is made by a forward observer (FO) unit, the detection is passed to its first available paired launcher. After the FO unit successfully passes the detection, it cannot pass another detection for a specified time period (30 seconds).

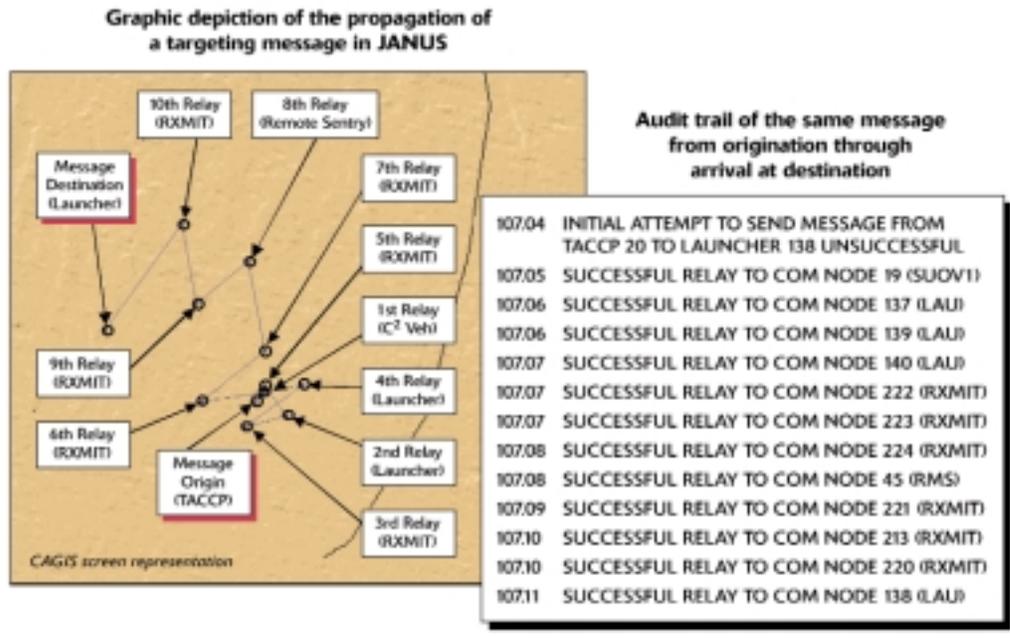


Figure B.3—Walk-Through of Command and Control Process in Simulation

When the launcher gets the detection, several things may occur depending on what type of projectile is being fired. Each different projectile (these include precision-guided munition, Copperhead, SADARM, ICM, TGW, EFOG-M, and many others) has its own logic. For example, for Copperhead, JANUS first determines the next available firing time for the launcher. Then it checks to make sure it has a valid mission to the target. A Copperhead mission is valid if the following conditions are satisfied:

- The range from the launcher to the target is within the minimum and maximum range capabilities of the launcher;
- The single shot probability of kill (SSPK), based on the range between the FO unit and the target, is greater than or equal to 0.05;
- The probability of line of sight (PLOS) between the FO unit and the target is greater than or equal to 0.1;
- There are no smoke blockages between the FO unit and the target; and
- The geometry relating to angle of fall and aimpoint offset between the FO unit and the launcher is satisfied.

Once mission validity is determined, the fire mission is planned by placing the following information into the fire queue: launcher unit, missile projectile type, number of tubes, FO unit, target unit, target aimpoints, and firing time. The missile is then launched at the appropriate firing time. Time of flight (TOF) of the missile is determined

between the launcher and the target; this is needed for calculating the delay time for the FO unit.

When appropriate, the C2 model calls the MADAM model if smart or brilliant munitions are fired. MADAM is described in a later section.

Fiber-optic guided missiles such as EFOG-M have very different representations of behavior. A given launcher may be linked with several artillery forward observers to cue a missile launching, and conversely, each FO may be linked to up to ten different launch units. Once the FO detects a target, he waits a specified delay time (assumed to be coordinate processing time) before transmitting the target information to a linked launch unit. The delay time depends upon the number of targets and whether they are clustered in a target set. If they are clustered (within 150 meters of each other), targeting is made to the calculated centroid. Targets are processed on a first come–first served (FCFS) basis.

One unique aspect of EFOG-M is that it can use its sensor to pass back additional detections. After the mission has traveled 75 percent of the distance between the launcher and the coordinates to which it was cued, it turns on its sensor and immediately passes any detections back to its launcher. If the detection is passed within the ripple time of the previous launch, then the launcher can immediately ripple another missile at new target coordinates. If the detection occurs after the specified ripple time, then the launcher must wait until all missiles in flight have been grounded.

The C2 system, configured into three echelons, is diagrammed in Figure B.4. Using this structure, a variety of organizations can be modeled.

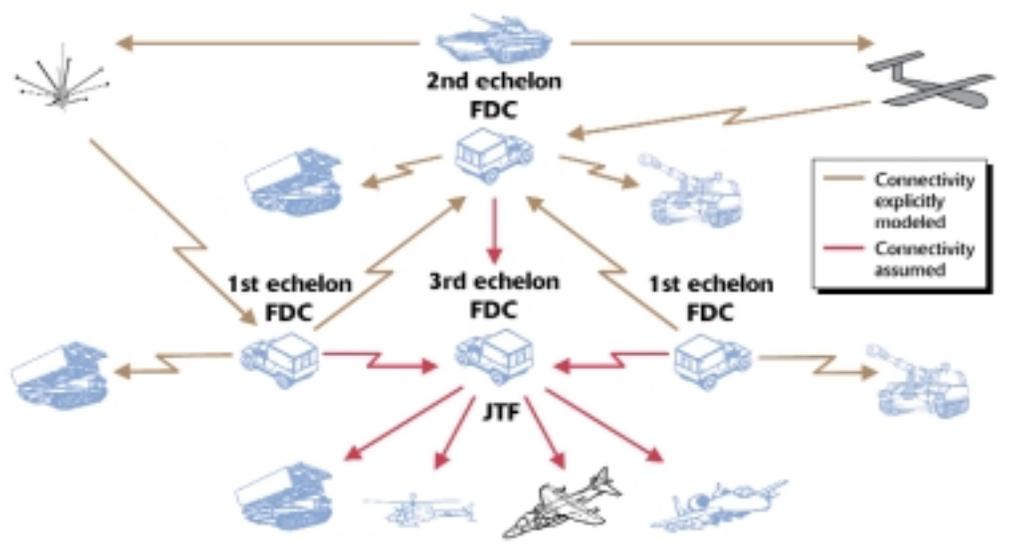


Figure B.4—Command and Control Organization in Simulation

### *Active Protection System (APS) Model*

This modeling effort had three primary objectives: (1) to create a generic, parameterized active protection system (APS) model, (2) to validate that model and use it to characterize a variety of appropriate APS concepts, and (3) to integrate those APS characterizations into a force-on-force simulation (JANUS).

The four APS threat-classification levels are based on threat and concept characteristics. The *threat* definitions are

- **F&F:** fire and forget. Weapons with onboard seekers.
- **CLOS:** command line of sight. Missiles are guided by an operator optically tracking the target. The missile corrections are then transmitted to the missile by wire or the missile searches for and “rides” a laser designation beam.
- **Ballist:** Ballistic. Weapons are fired on a ballistic trajectory and are in free flight from discharge to impact with the target.
- **EFP:** explosively forged penetrator. Examples of these are SFW (sensor-fused weapon) and SADARM (sense and destroy armor).
- **KEP:** kinetic energy penetrator. Examples of these are APFSDS (armor-piercing, fin-stabilized, discarding sabot) tank rounds and hyper velocity missiles.

The *concept* definitions are

- **Soft-kill:** this concept involves keeping the missile from landing on the target by confusing or defeating its guidance or seeker systems, and it includes measures such as dazzlers, smoke, reflectors, and so forth.
- **Hit-to-kill:** this involves actually launching a projectile(s) to strike the incoming missiles and thereby either destroy or divert them.
- **Fragmentation:** this involves the employment of a burst-type weapon that generates fragments intended to destroy, divert, or induce premature detonation of incoming missiles.
- **Momentum transfer:** this consists of launching high-velocity, high-mass projectiles intended to divert incoming missiles.

The model assigns classification levels as delineated in Table B.1.

Table B.1—Classification Scheme for APS Systems

<i>APS Classification</i>	<i>Guidance Mechanism</i>	<i>Type of Munition</i>	<i>Type of Countermeasure</i>	<i>Range</i>
Level 1	F&F/CLOS	EFP	Soft-kill	Long
Level 2	F&F/CLOS	EFP	Hit-to-kill	Medium
Level 3	F&F/CLOS	EFP	Fragmentation	Short
Level 4	Ballist	KEP	Momentum transfer	Close

The APS model then produces three basic calculations corresponding to (1) the protection provided to a vehicle by an APS, (2) the likelihood of a vehicle surviving an attack, and (3) the extent to which the protection provided by an APS is degraded when its host vehicle survives an attack.

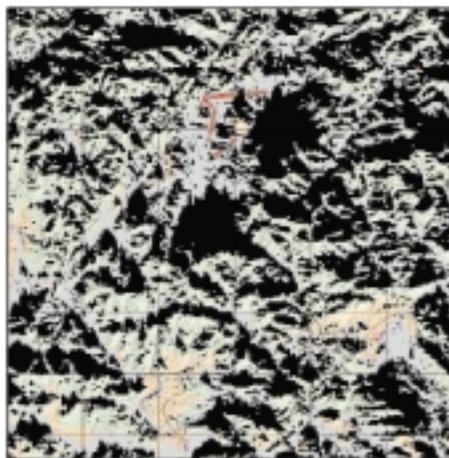
The JANUS database was supplemented by a classification designation for each weapon defined. The model modifies the standard JANUS engagement routines (detection, acquisition, fire/shoot, assess) to incorporate the effects of the APS model into simulation engagement outcomes.

*Cartographic Analysis and Geographic Information System (CAGIS)*

CAGIS was developed at RAND to support those simulations that needed to use a wide variety of terrain types and feature data. These inputs included the Defense Mapping Agency's (since renamed the National Information and Mapping Agency) standard Digital Terrain Elevation Data (DTED) and Digital Feature Attribute Data (DFAD), LANDSAT and SPOT satellite imagery, and other sources of digitized roads and features such as the TIGER data base. CAGIS is a collection of procedures that provides:



- This is a 1992 LANDSAT image of the Kuwait City harbor and its surrounding land features and facilities.
- The image was mosaiced, warped and registered to the underlying DTED Level II terrain for use in high-resolution, force-on-force simulations.
- CAGIS procedures are capable of this processing on currently available computer engines in a matter of tens of minutes.



- The black in this image depicts the terrain masking of an airborne sensor positioned 65,000 feet above mean sea-level (MSL) due south at 150 nautical miles from the center of the image.
- The light gray depicts the additional terrain masking for the same sensor positioned at only 35,000 feet above MSL due south at 150 nautical miles from the center of the image.
- The red in the image depicts the target vehicles detected at 65,000 feet but masked at 35,000 feet.
- CAGIS is capable of processing this data for analysis in a matter of minutes.

Figure B.5—Exemplary Cartographic Information in Simulation

- A user-friendly interface for interactive or batch applications based on the use of windows.
- Graphics and image display capability for geographic data.
- Image processing for DTED and similar pixel-oriented datasets.
- Graphics processing for roads, rivers, border, flight paths and similar datasets.
- Table processing for data with geographic coordinates related to the image or graphics data sets.

Examples of CAGIS images for Kuwait City and for a mountainous area are shown in Figure B.5.

#### *MADAM: Smart Munitions Model*

The Model to Assess Damage to Armor by Munitions (MADAM) greatly extends the capability of JANUS to represent smart and brilliant munitions. The core model was originally written by the Institute for Defense Analysis (IDA). RAND has added significant additional capability in the form of upgrades capable of modeling the technologies associated with the following munitions, among others:

- SADARM (sense and destroy armor)
- Sensor-fused weapons (SFW, also called Skeet)
- Damocles, a large-footprint submunition
- Low-cost autonomous attack submunition (LOCAAS)
- Terminal guidance warhead/terminally guided projectile (TGW/TGP)
- Precision-guided mortar munition (PGMM)
- Brilliant anti-tank (BAT) submunition
- Wide area munition (WAM)

MADAM exists as a stand-alone model used for parametric analyses as a precursor to force-on-force runs. The model also resides as a subroutine in JANUS, called whenever a smart munition is used. The stand-alone version of the model runs in the CAGIS environment. Threat laydowns from JANUS scenarios are imported into CAGIS to provide context and targeting information for analysts during the conduct of parametric stand-alone analyses.

The model provides capability for dealing with and analyzing chain logic, false alarm rates, hulks, submunition reacquisition, shots, hits, and kills. It also models bus, munition, and submunition reliability. Figure B.6 illustrates the operation of MADAM using the BAT submunition.

#### *Acoustic Sensor Program*

The Acoustic Sensor Program (ASP) was developed in support of the Rapid Force Projection Initiative. The model was a necessary adjunct to the JANUS model in order to satisfactorily represent one of the “leap-ahead” technologies associated with two systems in development, the wide area munition (WAM) and the air-deliverable acoustic sensor (ADAS). The model was originally developed to represent an eight-microphone



corporates the effects of weather and terrain. Each vehicle is assigned a unique signature within its classification based on a draw distributed normally about the mean SPL for each class of vehicles. This permits the tracking of vehicles and also aids in the fusion of data from multiple sensors.

Like MADAM, the ASP model was designed to run in either stand-alone mode or as a subroutine in JANUS. When running in the stand-alone mode, target laydowns may be either generated by hand or read from previous JANUS runs into the stand-alone model for analysis. In the stand-alone mode, the model is capable of running several hundred iterations in a few minutes, making it ideal for parametric analysis.

When running as a subroutine in JANUS, ASP is called once per minute to provide updated detection and target acquisition information. The subroutine feeds the fire support command, control, and communications model in JANUS. Acoustic sensors may be designated as communications nodes, and the targeting information generated by these nodes is treated in a fashion identical to the information generated by the imaging detections produced from the Night Vision Electro-Optical Division (NVEOD) algorithms. An example of the model operation is shown in Figure B.7.

#### *RAND Jamming and Radar Simulation (RJARS)*

RJARS was developed in the mid-1980s as an intermediate alternative to the excessively detailed, highly accurate ground-to-air models designed to represent specific systems, and the other extreme, excessively aggregated ground-to-air models that represented only gross effects of very nonspecific systems. Using the Jamming Aircraft and Radar Simulation (JARS) created by Johns Hopkins University Applied Physics Laboratory as

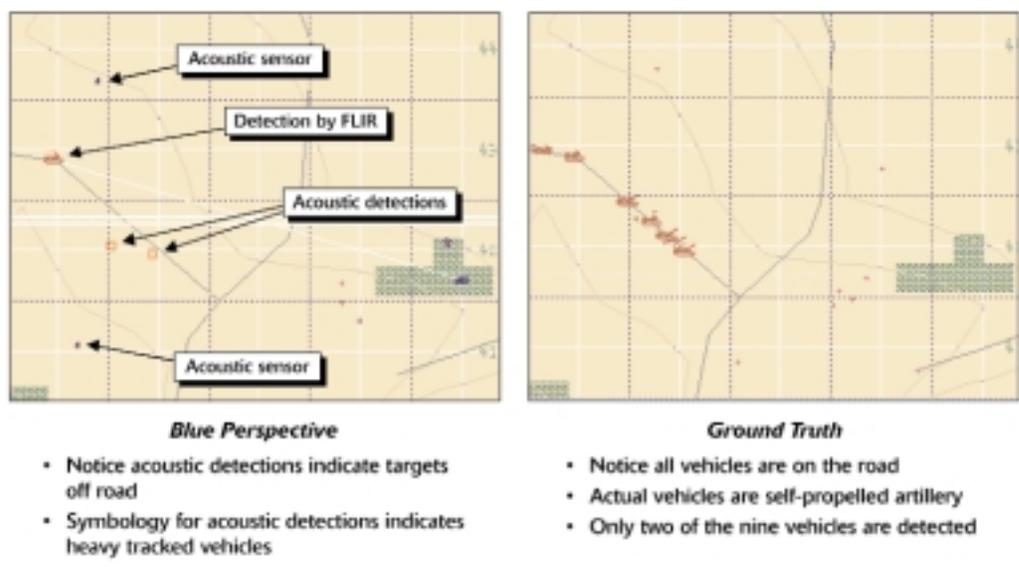


Figure B.7—Representation of the Acoustic Model in Simulation

a basis for development, RJARS is the product of years of significant enhancement and now provides a reasonable approximation of the highly detailed models, but in a more dynamic, force-on-force context.

The enhancements comprise original code and pieces and portions of previously written and tested representations from other models. For example, the portions of RJARS pertaining to clutter, multipath, and diffraction are derived from the ALARM (A Computer Model for Low-Altitude Radar Propagation over Irregular Terrain) model developed by Lincoln Laboratory. Other phenomena associated with radar were derived from the GRAM (Generic Radar Assessment Model) models developed by BDM International. Missile engagements, including fly-out and end-game assessments, are simplified versions of those contained in ESAMS (Enhanced Surface to Air Missile Simulation). The optical and infrared system representations are derived from both ESAMS and the Night Vision Electro-Optical Laboratory. Finally, the aircraft vulnerability portion of RJARS is derived from RADGUNS (Radar Directed Gun System Simulation) developed by the U.S. Army Foreign Science Technology Center.

The current model is able to evaluate the outcome of large numbers of radars and launchers engaging large numbers of aircraft; represent detection, acquisition and tracking by radar, infrared, and optical sensors; simulate both missile and gun engagements; represent airborne jamming of air defenses; model air defense command and control dynamics (battalion level and below); and quantify aircraft signatures in three axes.

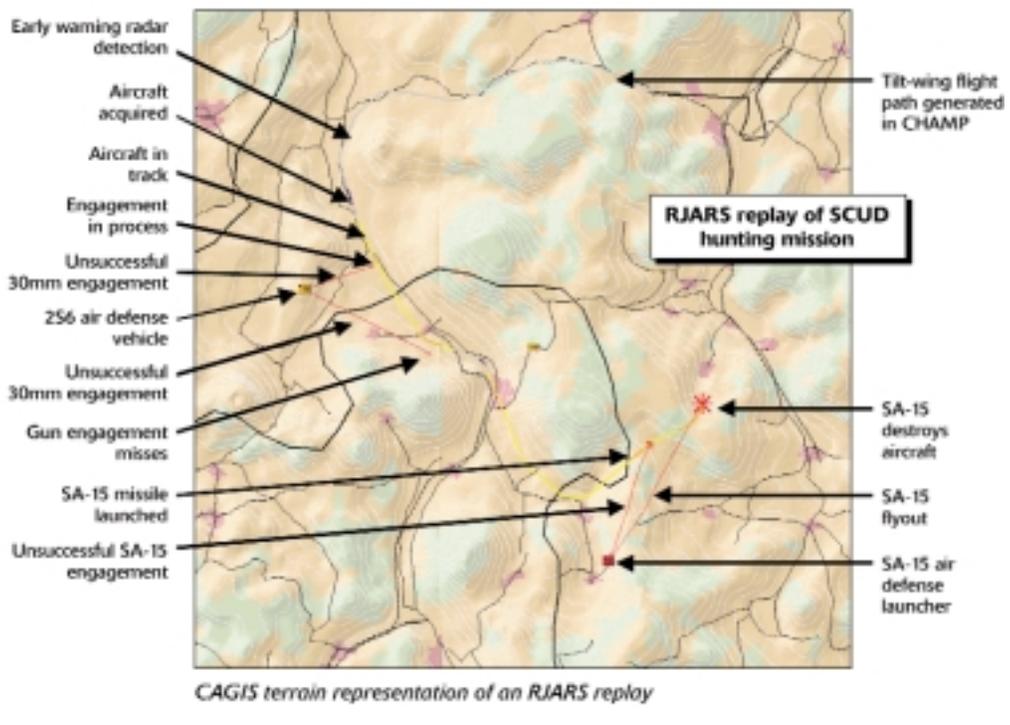


Figure B.8—Example of RJARS Graphic Output



nario inputs and cues that force or drive the analyst to fly reactively. The graphical displays include radar warning information, path profile view with potential obstacles, perspective view, and target information.

The output paths generated by these planners serve as input to be evaluated in the full force-on-force simulation environment

**RAND Target Acquisition Model (RTAM)**

RTAM was developed to evaluate low-observable technologies in a force-on-force context. Many force-on-force models such as JANUS set optical and thermal contrasts for vehicles at the simulation start and maintain them constant through the course of that run. RTAM not only allows dynamic shifts of contrast, but also represents changing background brightness and clutter. It does so by calculating a dynamic contrast of each low-observable vehicle in comparison to the background pixels it passes (provided by LANDSAT imagery). RTAM also models scene congestion, color contrast, hot spots, and glint and edge effects associated with multifaceted vehicles.

As shown in Figure B.10, the algorithms used in RTAM are based on Night Vision Electro-Optical Laboratory routines, and CAGIS is used to underlay the standard JANUS terrain data with LANDSAT data.

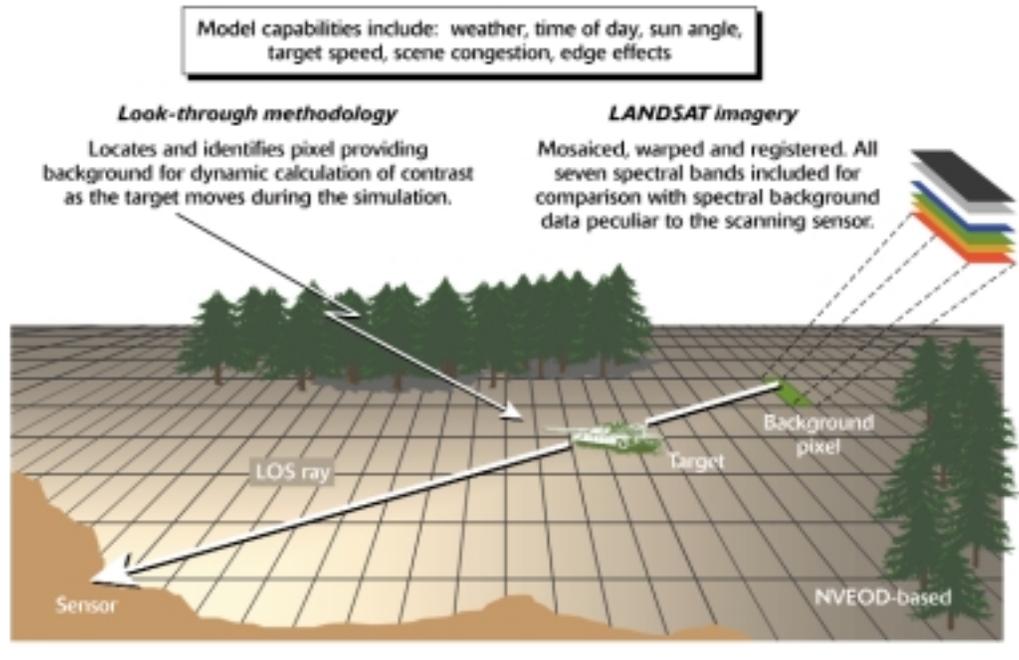


Figure B.10—Representation of RTAM Methodology in Simulation

### *Simulation Postprocessor*

The JANUS postprocessor was written in SAS (Statistical Analysis System) to take advantage of the enormous sorting, ordering, manipulative, and computational power offered by that software when dealing with prohibitively large, free-form datasets. This was necessary due to the large datasets (hundreds of gigabytes) for each excursion.

The postprocessor also prepares data for plotting on terrain maps in order to spot spatial-temporal relationships. These graphic displays use varying icons and colors to represent large numbers of different parameters in a single display.

Current options available in the postprocessor include Blue and Red killer-victim scoreboards, means and confidence intervals, summary statistics such as force and loss-exchange ratios, weapon efficiencies, communication system statistics, and events by time and range.

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#### *APPENDIX B ENDNOTES*

1 This level is  $P > 0.05$  in the current version.

2 The earlier JANUS/T version was concerned primarily with training, while JANUS/A facilitates the use of the model for analysis.