A RAND NOTE

RAND's Concept Analysis Environment: A Briefing

Eugene C. Gritton, Bruce Don,
Randall Steeb

May 1990

RAND

The research described in this report was sponsored by the Defense Advanced Research Projects Agency under RAND's National Defense Research Institute, a federally funded research and development center supported by the Office of the Secretary of Defense, Contract No. MDA903-85-C-0030.

Published by The RAND Corporation
1700 Main Street, P.O. Box 2138, Santa Monica, CA 90406-2138

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N-3004-DARPA

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PREFACE

The annotated briefing documented in this Note describes the early development phase of a new analysis capability at RAND supported by the Defense Advanced Research Projects Agency. The Concept Analysis Environment (CAE) is housed in an existing secure (cleared) facility, and contains simulation models for determining the effectiveness of advanced military system concepts in simulated battlefield environments. The research is carried out by the Applied Science and Technology Program within RAND's National Defense Research Institute, a federally funded research and development center sponsored by the Office of the Secretary of Defense and the Joint Chiefs of Staff

Some of the models mentioned in this briefing are described in more detail in the following RAND publications:

W. Sollfrey, *RJARS: RAND's Version of the Jamming Radar and Aircraft Simulation,* N-2727-AF, December 1988.

P. K. Davis and H. E. Hall, *Overview of System Software in the RAND Strategy Assessment System,* N-2755-NA, December 1988.

A. L. Zobrist and L. J. Marcelino, *LHX Mission Analysis Using MOSF Sun Terrain Procedures: An Overview of System Logic,* N-2760-A, May 1989.

SUMMARY

The Concept Analysis Environment (CAE) at RAND is a secure set of systems for analysis, exploration, and evaluation of advanced military concepts. The environment currently includes the JANUS, CAGIS, and APEX simulations. Efforts are under way to integrate the RJARS, VIC, and TLC models into the system. Eventually, the environment will have coordinated simulations ranging from detailed vehicle-on-vehicle combat models to theater-level engagement models. The coordinated simulations should aid in system initial conceptualization, identification of desirable system characteristics, and determination of probable military effectiveness.

This Note describes each of the component simulation models and illustrates their use in two projects: the Tactical Armor/Anti-Armor Study and the Joint Close Support Study.

CONTENTS

GLOSSARY

APC	Armored Personnel Carrier
APEX	The current RAND theater-level model
BFDF	Battlefield Development Plan
BLUE MAX	A fixed-wing aircraft maneuver model
CAGIS	Cartographic Analysis and Geographic Information System
CHAMP	A helicopter maneuver model
ESAMS	Enhanced Surface-to-Air Missile Simulation
FASCAM	Family of Scatterable Mines
FLOT	Forward Line of Own Troops
GAMES	A guided artillery effectiveness model
JANUS-R	RAND's version of the JANUS battalion-level engagement model
IR	Infrared
JMEM	Joint Munitions Effectiveness Manual
KEM	Kinetic energy missile
LAV	Light armored vehicle (Marine Corps)
LOS	Line of sight
MASTER	A theater-level outcome calculation program
MSFD	Multispectral force data
MADAM	Model to Assess Damage to Armor with Munitions
RF	Radio frequency
RJARS	RAND's version of the Jamming Aircraft and Radar Simulation Model
TACSAGE	Tactical Air Command—Sequential Analytic Game Evaluation (a theater-level air sortie allocation model)
TASK	A detailed tasking model for air assets
TLC	Theater Level Conflict integrated model
TOW	Tube-launched, optically-tracked, wire-guided missile
VIC	Vector In Commander (a corps-level two-sided engagement model)

I. INTRODUCTION AND OVERVIEW

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- **Background**
- **Simulation models**
- **Applications and examples**
- **Status and future work**

Fig. 1—Overview

The briefing is organized roughly into four sections. The first section provides background on the purpose, methodology, and initial applications of the Concept Analysis Environment (CAE). It also describes the hierarchy of simulation models now operating or being integrated into the environment. The second section reviews the Tactical Armor/Anti-Armor Study and walks through some scenarios and analyses. The third section describes the Joint Close Support Study and the final section concerns the CAE and future work planned for it.

OBJECTIVES

Establish a secure system to determine the effectiveness of advanced military system concepts in simulated battlefield environments

- **Aid in system initial conceptualization**
- **Identify desirable system characteristics**
- **Determine probable military effectiveness**

Fig. 2—Objectives

One of the primary missions of the Defense Advanced Research Projects Agency (DARPA) is to develop innovative system concepts for improving the effectiveness of U.S. military forces. The development process includes three interrelated steps: (1) initial conceptualization, (2) identification of desirable system characteristics, and (3) determination of probable military effectiveness. In some instances, it is necessary to build and test system prototypes to accomplish steps (2) and (3). It is always necessary, however, to make analytic tradeoff studies to accomplish these steps; the more rigorous and realistic these studies are, the less the need to resort to expensive prototype development and testing.

To assist DARPA in achieving this capability, RAND has established the Concept Analysis Environment, a secure framework that incorporates simulation models for determining the effectiveness of advanced military system concepts in simulated battlefield environments. Because many of the systems of interest to DARPA are being developed in special access programs, a secure (SCIF) facility is required.

INITIAL APPLICATIONS

- **Advanced ground vehicle systems**
- **Fixed-wing, rotary-wing, and indirect fire systems to carry out close support missions**

Fig. 3—Initial applications

The initial goal for the environment during the first year will be to develop a capability to evaluate advanced ground vehicle systems. In addition, fixed-wing, rotary-wing, and indirect fire systems will be examined for carrying out close support missions.

ANALYTIC METHOD

- **Start with fundamentals**
  - **Identify mission requirements**
    - **What is it you want the system to do?**
    - **How is it to be used?**
    - **In what threat and geographic environment?**
  - **Perform initial engineering configuration analyses**
  - **Estimate survivability and lethality using appropriate engineering-level models**
    - **Signature and detectability analysis (static and dynamic)**
- **Estimate detection range against threat sensors across threat spectrum**
  - **Develop tactics to minimize exposure**
- **Determine ability to engage and kill threats**

Fig. 4—Analytic method

It is important to start with the fundamental characteristics of the advanced weapons systems under consideration. These characteristics combine with other factors to determine the system capabilities, which are in turn evaluated by the analytic method chosen. The missions performed by the system must be clearly identified, and the threat, geographic, and weather environments the systems will operate in must be defined. The developers of the system concept should have analyzed the initial engineering configuration and the analysis must be clearly understood by the analyst using the CAE facility. In some cases, an independent analysis must be made to verify system capabilities being projected by the proponents of the system.

Once the engineering design is well understood, the analysis proceeds to an evaluation of system performance, principally that of operational effectiveness as described by:

- Survivability—the ability to avoid detection, or if detected, to minimize exposure to threat systems and survive attack by appropriate use of tactics.
- Target acquisition—the ability to locate, detect, and track targets.
- Lethality—the ability to engage and kill targets.

- **Evaluate performance of the system at the unit level using combat analysis simulation models and relevant data from the previous engineering analysis**
  - **Determine if technical differences make any operational difference**
    - **Survivability**
    - **Lethality**
  - **Identify what affects operational differences**
    - **Threat**
    - **Equipment performance**
    - **Environment**
- **Consider use of corps- and theater-level assessment**

Fig. 5—Analytic method (continued)

The analysis is first carried out on individual systems operating against representative threats to gain a general perspective of their performance levels. The systems are then evaluated at the unit level using combat analysis simulation models and relevant data from the previous engineering analysis. This will allow the analyst to determine if the technical differences make any operational differences in terms of survivability and lethality. The analysis will also allow identification of those characteristics that affect operational differences (e.g., threat capabilities, equipment performance, environment). To understand the impact of such measures as cross corps mobility, multiple mission capability, and speed, range, and payload tradeoffs, we are considering the use of corps and theater level models.

HIERARCHY OF MODELS

- **RJARS: RAND's analytic model of RF and IR sensing of airborne penetrators**
- **CAGIS: A detailed model of line-of-sight and terrain dependence that supports tactical combat models**
- **JANUS-R: RAND's version of the Army JANUS model of tactical combat**
- **VIC: An Army model of corps-level combat**
- **APEX: RAND's combined model of theater-level combat**

Fig. 6—Hierarchy of models

The CAE will be composed of a linked set of simulation models, each of which is responsible for a different level of abstraction or echelon of command.

At the lowest, most detailed level is RJARS, RAND's version of the Jamming Aircraft and Radar Simulation. RJARS is a many-on-many stochastic simulation of radar and thermal sensor physics for air penetrators. RJARS also models the phenomena of electronic warfare and missile flyouts in great detail.

The next level up in the set of models is CAGIS (Cartographic Analysis and Geographic Information System). This system provides high-resolution terrain representations, including cover, culture, trafficability and other geographic features. It focuses on the interactions between air and ground vehicles and terrain, particularly with respect to line-of-sight and maneuver dynamics.

JANUS-R is RAND's version of the Army JANUS model. It stochastically models air and ground combat up to the battalion or brigade level. It is the highest level model in the group that models terrain using Defense Mapping Agency (DMA) data.

VIC is a complex Fortran simulation that models corps-level operations. Resolution is down to individual battalions and companies. VIC can add such aspects as logistics and deep operations to the analysis.

Finally, APEX simulates operations at the theater level, including air asset allocation and sortie generation.

COMBAT MODELING

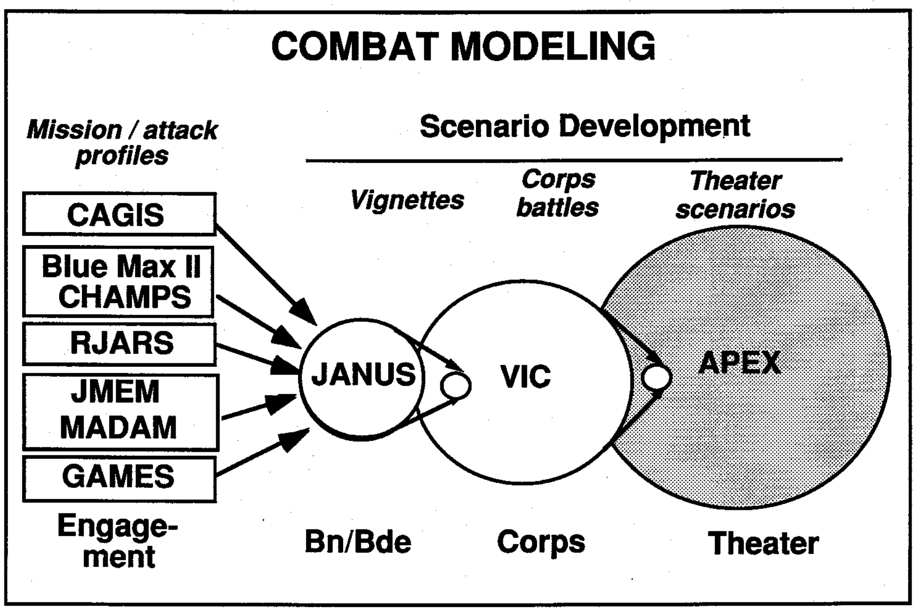

Fig. 7—Combat modeling

Each of the linked set of models will feed into the next level. The tactical-technical models shown on the left side of the chart will be used to analyze vignettes taken from JANUS, and then provide inputs back to JANUS. Among the technical models are CAGIS, augmented by the Blue Max (fixed-wing) and CHAMP (helicopter) maneuver models. There are also three weapons effectiveness computation models: JMEM, MADAM, and GAMES (a guided artillery model).

JANUS receives these inputs and focuses on subsets of VIC corps-level scenarios, while VIC in turn analyzes subsets of TACSAGE theater operations. All of the interactions are two-way in nature. The higher level models specify scenario fragments for the lower level models to run, and the lower level models provide inputs for the higher level, more aggregated analyses.

As indicated on the right side of the diagram, the previous set of theater-level models (TACSAGE/TASK/MASTER) has been integrated into a single entity called APEX. The current generation of RAND's theater-level model will serve as the basis for the next generation model, TLC (Theater Level Conflict), which is now being developed.

COMPLEMENTARY RESEARCH IN PROGRESS

- **Tactical Armor/Anti-Armor**
  - **Improve crew and vehicle survivability and armor-defeating capability for existing and future ground combat vehicles**
- **Close Support Operations**
  - **Determine needs of commanders in the Central European theater during the mid to late 1990s**
  - **Ascertain preferred, achievable characteristics of systems that can satisfy these needs**

Fig. 8—Complementary research in progress

Two projects are now using the Concept Analysis Environment: Tactical Armor/Anti-Armor, sponsored by DARPA, and the Joint Close Support Study, sponsored by the U.S. Army and the U.S. Air Force.

The Tactical Armor/Anti-Armor project is looking at new ground vehicle designs and assessing system effectiveness at both the engineering and operational levels. New concepts for armor, weapons, mobility, sensors, displays, and networking are being explored in this project.

The Joint Close Support Study is a larger scale effort. It is examining a wide range of aircraft and indirect fire systems for the close battle. The time frame is the mid to late 1990s.

II. TACTICAL ARMOR/ANTI-ARMOR STUDY

II. TACTICAL ARMOR/ANTI-ARMOR STUDY

- **Uses JANUS and CAGIS**
- **Compared reduced-crew designs for future main battle tanks and light armored vehicles**
- **Examined effectiveness of a wide range of scenarios: defense, counterattack, and meeting engagements over both short and long range**
- **Determine system robustness under differing conditions: armor mix, artillery, FASCAM (family of scatterable mines), helicopters, and bispectral smoke**

Fig. 9—Tactical armor/anti-armor study

This study has focused on development and exploration of reduced crew, two- and three-man designs for main battle tanks (MBTs) and KEM-equipped Bradleys and LAVs.

Using the JANUS and CAGIS simulations, we have compared the system effectiveness of reduced crew advanced vehicles to conventional systems such as the M1-A1 and Bradley with TOW. The comparisons were made under a variety of conditions: threat type, force mix, and engagement type itself.

The next few charts illustrate some examples of the use of JANUS for Armor/Anti-Armor analysis.

JANUS ABSTRACT

JANUS characteristics:

- **A stochastic, time-stepped ground combat model**
- **Model engagements with hundreds of entities**
- **Includes both air and ground systems**
- **Focus on ground combat dynamics**

JANUS is not:

- **A campaign-level model**
- **A surface-to-air attrition model**
- **An engineering-level model**

Fig. 10—JANUS abstract

JANUS is primarily a battalion-level ground combat model. It has a moderate resolution terrain representation (normally 100 meters), and models movements, sensings, and firings of individual air and ground vehicles.

The simulation is Monte Carlo in form, written in Fortran, and designed to run quickly. As will be seen shortly, it does not have the detail and fidelity of the engineering models used in RJARS and CAGIS. It also does not have the scale of the corps- and theater-level models.

Most JANUS runs at RAND are automated, with maneuvers preplanned on both sides. The system was recently expanded to also allow interactive control of Red and Blue forces.

JANUS EXAMPLE

This chart is a screen image from JANUS. It shows both Red and Blue forces in a Blue defense, short-range engagement. It is early in the scenario, with two Red battalions moving to contact with three Blue platoons.

The user can halt the simulation at any point and change the characteristics of any of the Red or Blue units. He can also ask for display of line-of-sight (LOS) fans or request highlighting of key events.

Normally, a player can only see his own forces and those enemy forces he has acquired. This image shows both sides—essentially what a game controller might see.

Fig. 11—JANUS example

BLUE DEFENSE SHORT-RANGE SCENARIO

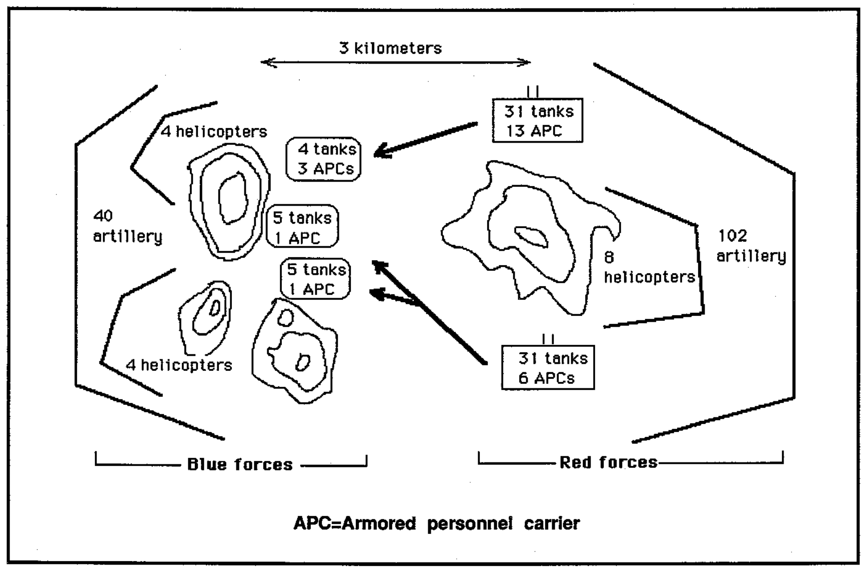

Fig. 12—Blue defense short-range scenario

The engagement itself is diagrammed here. The three Blue platoons are dug in, but will be able to engage Red only at short range because of terrain blockage.

The first runs with this scenario were of pure tank forces (with current and future U.S. and Soviet vehicles). Later runs incrementally supplemented the advanced tanks with APCs, artillery, mines, helicopters, and bispectral smoke. The rough circles in the diagram indicate air operations regions for the helicopters.

BLUE DEFENSE SCENARIO, OVERALL SYSTEM KILLS

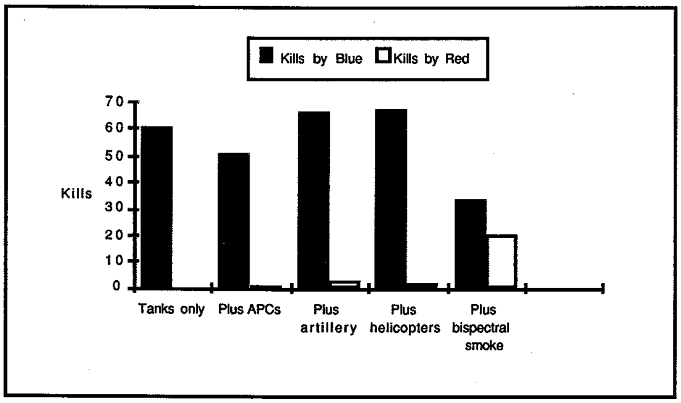

Fig. 13—Blue defense scenario, overall system kills

This chart shows the type of comparisons that have been made with JANUS in the Tactical Armor/Anti-Armor project. Because JANUS is probabilistic, the statistics are summed over 10 runs.

Across the bottom of the chart are the mix of forces on both sides, starting with pure tank forces, then tanks with APCs, then tanks plus APCs plus artillery, and so forth.

The ordinate is the number of system kills, with each group divided into two categories—Blue kills of Red systems (with future Blue and Red tanks), and corresponding Red kills of Blue systems.

As can be seen in the chart, each additional system results in more Blue losses, with almost unity loss exchange ratios under bispectral smoke. Similar analyses have been made for detections, force exchange ratios, ranges, and the like for five scenarios.

The runs have shown the need for millimeter wave radar under bispectral smoke, the importance of heavy frontal armor in tank engagements, and the influence of firing rate on survivability.

CAGIS ABSTRACT

CAGIS characteristics:

- **A deterministic, cartographic data assessment system**
- **Includes some engagement capability**
- **Includes engineering-level flight path generators**
- **Focus on interaction between air vehicle, terrain, and ground systems**

CAGIS is not:

- **An attrition simulation or combat model**
- **A ground attack model**

Fig. 14—CAGIS abstract

JANUS has limitations in modeling terrain detail and maneuver realism. Accordingly, we developed CAGIS to examine vignettes taken from JANUS runs. Written in the C language and running on Sun workstations, CAGIS allows the analyst to refine the simulation of tactics, detections, flyouts, and kills.

CAGIS produces terrain representations down to 8-meter resolution, with discrete trees, buildings, bridges, and other features. Vehicle paths can be specified and LOS checks made down to the individual terrain cell.

Visual aids such as image shading, three-dimensional wire frames, zoom windows, and path side profiles can be overlaid to help the user plan movements and set deployments.

CAGIS also has improved versions of the Army's Night Vision and Electro-Optics Laboratory (NVEOL) optical and thermal sensing algorithms used in JANUS, along with sophisticated air maneuver models such as Blue Max and CHAMP.

The system is a deterministic, step-by-step graphic tool and computational engine. It is not a full-scale attrition simulation or combat model.

CAGIS COLOR IMAGE I

This photograph, shot from a Sun color monitor, shows the type of image produced from CAGIS. Terrain elements are highlighted by different colors, contour lines are indicated in white, and computations are shown in the window on the right.

The upper left windows in the screen image show a zoom of the cursor area, along with a cross-section view of a flight path.

Users often add overlays to show intervisibility and detection fans for different combinations of sensors, targets, and conditions.

Fig. 15—CAGIS color image I

CAGIS COLOR IMAGE II

This is another CAGIS color image, with additions of road networks, vehicle paths, and an inset zoom patch. Shadowing is from a simulated sun shining from the southeast.

In the northeast portion of the image, a radar visibility fan shows the 50 percent probability of detection region for a particular vehicle and clutter background. Similar fans can be generated for IR and optical sensors, and for more stringent criteria of recognition and identification.

Fig. 16—CAGIS color image II

RJARS ABSTRACT

RJARS characteristics:

- **A stochastic, time-stepped attrition model**
- **Model engagements involving a few entities, primarily airborne penetrators and surface-to-air threats**
- **Focus on phenomenology in RF and IR spectrum**

RJARS is not:

- **A raid or campaign-level model**
- **A ground attack model**
- **An engineering-level model**

Fig. 17—RJARS abstract

Once JANUS provides the operational context and CAGIS defines specific few-on-few snapshots of maneuver and intervisibility events, then RJARS can calculate detections, flyouts, and attrition.

RJARS accepts discrete path input data from CAGIS, and then estimates such parameters as effective radar cross section, glint, clutter, and atmospheric losses.

RJARS also models jamming, communications losses, and equipment failures. Like JANUS, RJARS models many of the parameters statistically, and the simulation may be run in a Monte Carlo form.

III. JOINT CLOSE SUPPORT STUDY

III. JOINT CLOSE SUPPORT STUDY

- **Will use TLC, VIC, JANUS, CAGIS, and RJARS**
- **Will examine options for rotary-wing aircraft, rocket and missile artillery, and fixed-wing aircraft**
- **Will model close support operations as an integral, coordinated part of the ground battle plan**
- **Modifications to JANUS, CAGIS, and RJARS have been completed**
  - **New sensing algorithms**
  - **Terrain modeling tools**
  - **Dynamic maneuver models**

Fig. 18—Joint close support study

The Joint Close Support Study is an ambitious project that will eventually use all of the modeling capabilities we are planning to incorporate into the Concept Analysis Environment. Among the weapon systems being examined are the AH-64, LHX, tilt-rotor, A-16, the Multiple Launch Rocket System (MLRS) with the Army Tactical Missile System (ATACMS), and MLRS with TGW (Terminally Guided Warhead).

The Close Support Study concentrates on the close support operations problem in the context of the larger ground battle plan. Accordingly, it must model far more than the individual airframes and indirect fire systems.

So far, the work has resulted in modifications to the JANUS, RJARS, and CAGIS sensing algorithms, the CAGIS terrain modeling tools, and the CAGIS dynamic maneuver models. Additional changes are planned for the Vector In Commander (VIC) and Theater Level Conflict (TLC) models.

SYSTEM DATA REQUIREMENTS

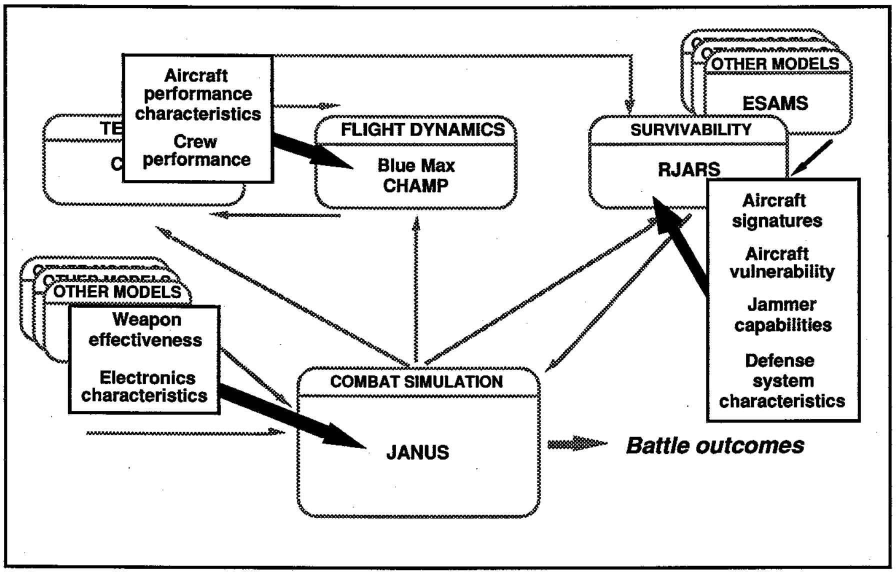

Fig. 19—System data requirements

This chart shows the major inputs to the CAE models in the Joint Close Support Study:

- Aircraft and crew performance characteristics, such as speed, g-loads, and payload.
- Aircraft detection and vulnerability data, such as radar cross section, detection time window, jamming power, and air defense response time.
- Weapons effectiveness and sensor performance characteristics.

SYSTEM INFORMATION FLOW

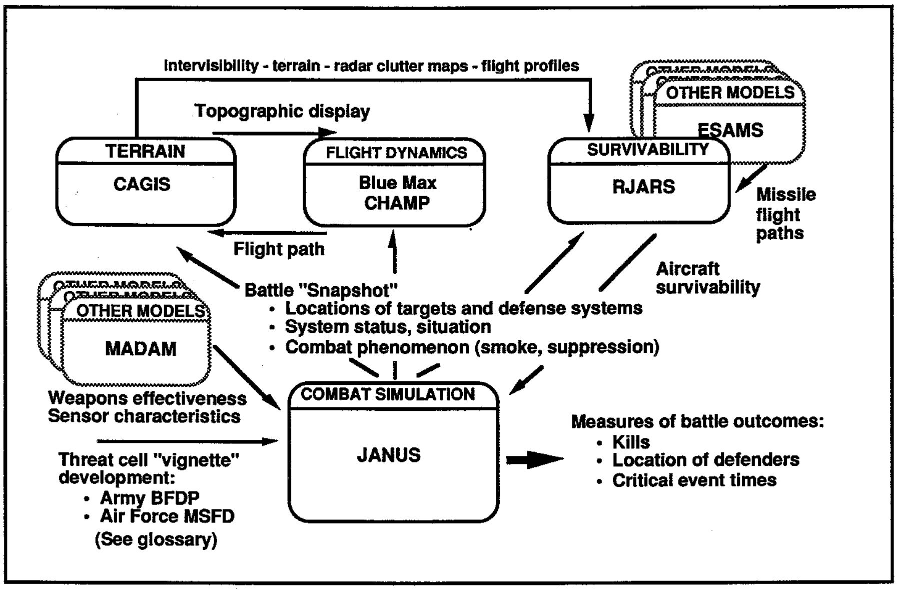

Fig. 20—System information flow

This chart diagrams the interchange of data between the terrain model, flight dynamics simulations, survivability models, weapons effectiveness calculations, overall combat simulation (JANUS), and other models. The outcomes of a simulation run include kills by system and side, movement of the FLOT (Forward Line of Own Troops), and timing of critical events.

AIRCRAFT ATTRITION ANALYSIS

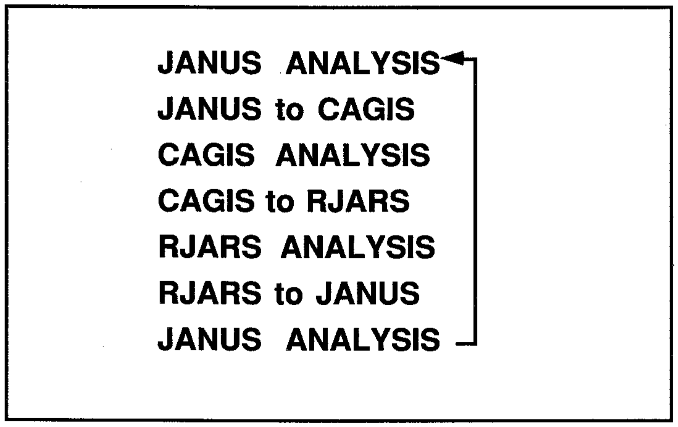

Fig. 21—Aircraft attrition analysis (fixed wing and penetrating rotary wing)

In the Joint Close Support Study, JANUS, CAGIS, and RJARS will be used in a tightly coupled manner, as illustrated in the next seven slides.

The examples use fixed-wing and penetrating helicopters, but the analysis may involve other systems as well.

JANUS SNAPSHOT

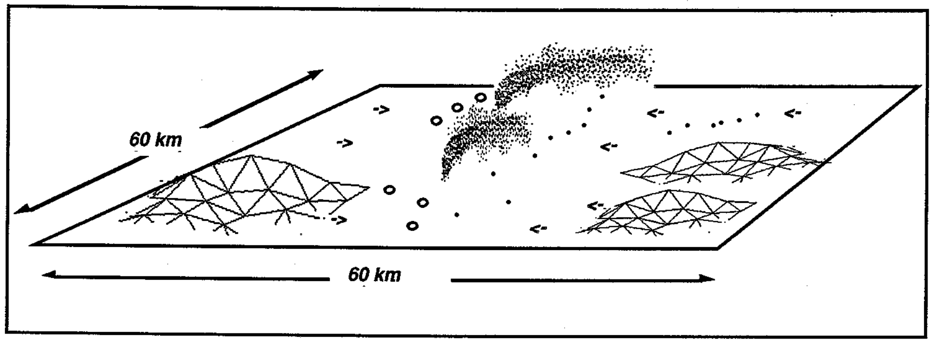

Fig. 22—JANUS snapshot

We begin with the battalion-level JANUS ground combat model. Diagrammed here are terrain, smoke, ground forces, and air penetrators. Key vignettes from subsets of the 60-km-square terrain area will next be designated for CAGIS modeling.

JANUS TO CAGIS

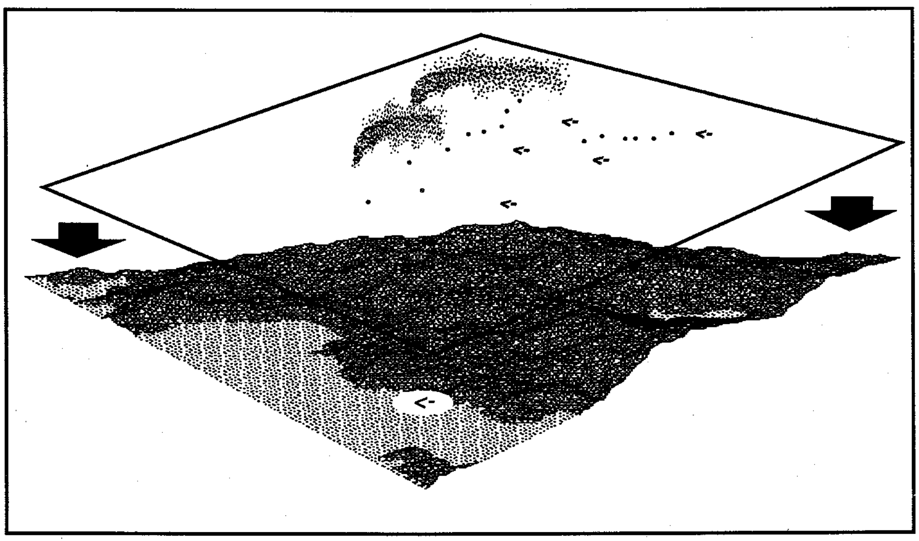

Fig. 23—JANUS to CAGIS

CAGIS models the terrain subset with much greater detail, and provides the user with visualization tools.

JANUS sends a snapshot of the vignette to CAGIS, including all position, speed, and status descriptors for the vehicles.

CAGIS TERRAIN ANALYSIS

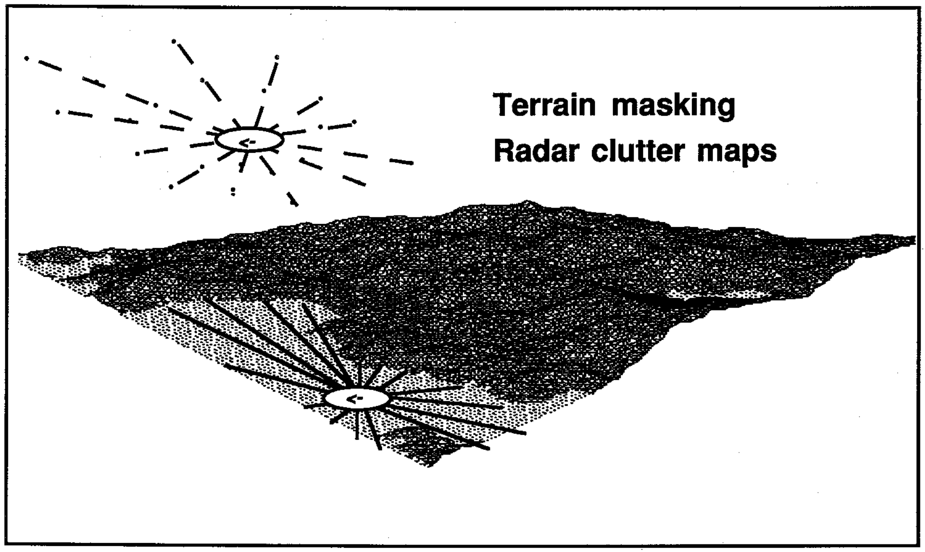

Fig. 24—CAGIS terrain analysis: point-to-point line of sight, line-of-sight horizon

CAGIS cycles through each threat and friendly position, producing line-of-sight calculations and background clutter maps. These may be portrayed as intervisibility and detection fans.

Different fans may represent detection, recognition, and identification under varying assumptions of target type, status, and activity.

CAGIS FLIGHT PATH ANALYSIS

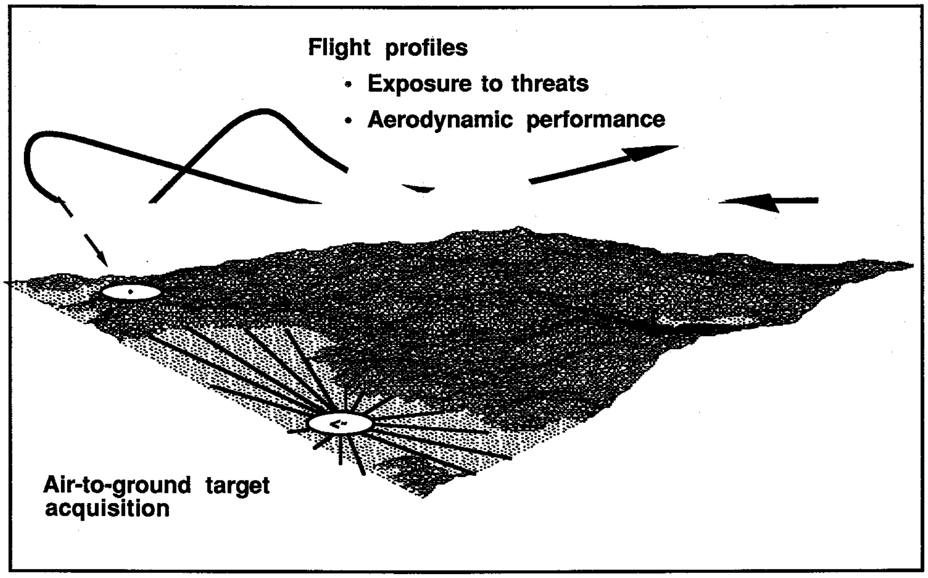

Fig. 25—CAGIS flight path analysis: CHAMP (rotary wing), Blue Max II (fixed wing)

In combination with CHAMP (helicopter) and Blue Max (fixed-wing) maneuver models, CAGIS will produce flight profiles for each aircraft. These profiles will be used to determine exposure likelihoods and ground target acquisition events.

CAGIS TO RJARS

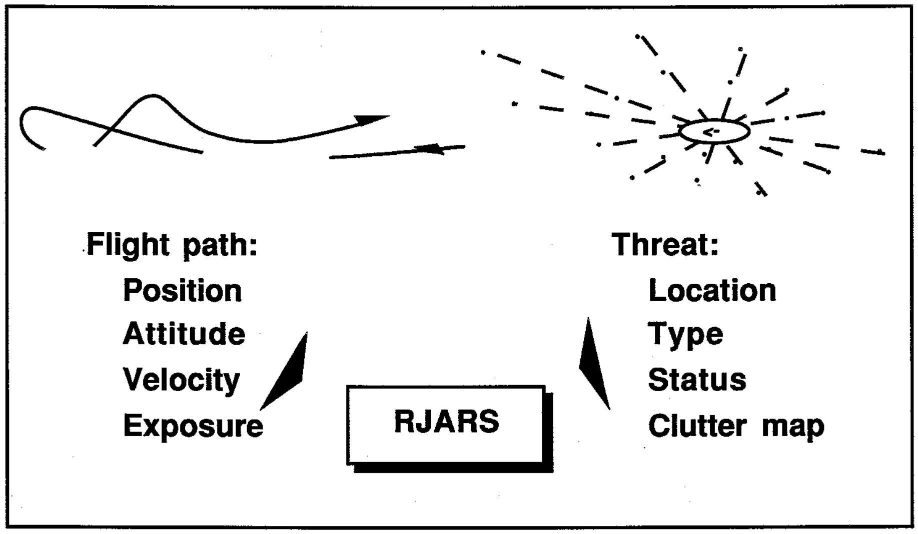

Fig. 26—CAGIS to RJARS

This chart shows how CAGIS sends discrete flight path states to RJARS.

The flight path information includes position, velocity, aspect (to allow for aspect dependent aircraft signature levels), exposure, and other maneuver information. The threat information includes position data along with a clutter map.

RJARS TO JANUS

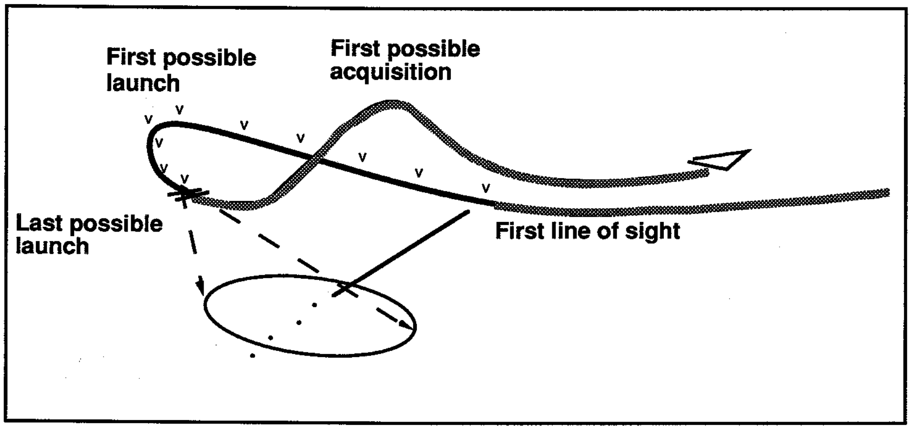

Fig. 27—RJARS to JANUS

RJARS then processes the maneuver and threat data from the exposed portion of the flight path. This analysis results in estimates of detections, launches, kills, and misses.

ATTACK "STUB" IN JANUS

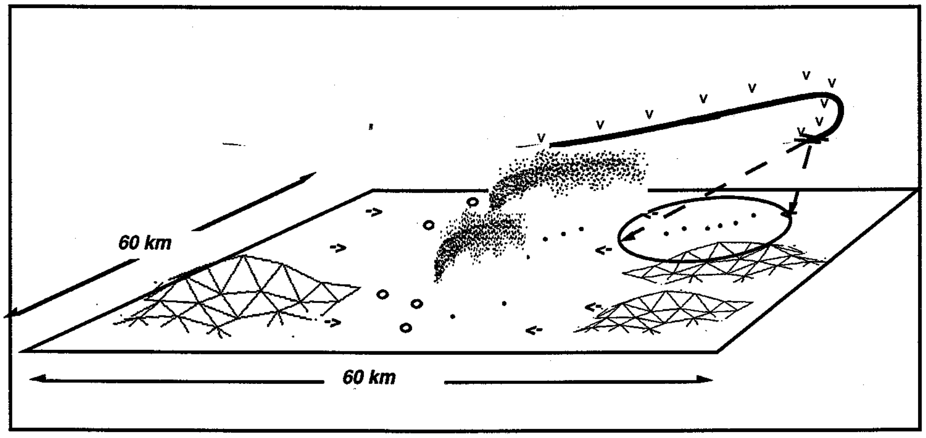

Fig. 28—Attack "stub" in JANUS

As shown above, outcome data from RJARS data can be used to refine the JANUS conclusions directly, by passing to JANUS the effectiveness and survivability data associated with an attack "stub." Alternatively, the data can be integrated in the JANUS detection and probability of kill tables, resulting in more accurate runs.

IV. STATUS AND APPLICATIONS

CONCEPT ANALYSIS ENVIRONMENT STATUS

- **Currently in place:**
  - **CAGIS**
  - **JANUS-R (automated and interactive modes)**
  - **TACSAGE/TASK/MASTER**
- **To be integrated:**
  - **RJARS**
  - **VIC**
  - **TLC**

Fig. 29—Concept analysis environment status

CAGIS, JANUS, and the TACSAGE models are installed in the Concept Analysis Environment. JANUS is running in both automated and interactive modes. Additional monitors and partitions were added to allow interactive gaming.

RJARS is not yet installed in the environment, but it is running in the C language on a Sun in RAND's Military Operations Simulation Facility (MOSF). It can readily be transferred by tape to the CAE.

VIC is up and running on Suns in both the Santa Monica and Washington offices. Transfer to the CAE will require continued debugging along with installation of at least a Sun 4/110 with 32 megabytes.

TLC, the future integrated version of TACSAGE/TASK/MASTER, is in its early developmental stages. It will need such improvements as a road approach model instead of a piston model, special graphics, and an integrated database system for scenario specification and postprocessing. It will also require Sun 4 support.

FY 90 APPLICATIONS

- **Advanced ground vehicle systems**
- **Fixed-wing, rotary-wing, and indirect fire systems to carry out close support missions**
- **Reconnaissance, surveillance, and target acquisition (RSTA) systems capable of supporting close support missions and the attack of follow-on forces**
- **Decoy and deception systems for ground combat forces**

Fig. 30—FY 90 applications

The Tactical Armor/Anti-Armor project is expanding to include a wider range of ground vehicle systems. Operational modeling will cover some of the higher echelons of command, as well as vehicle-on-vehicle engagements.

The Joint Close Support Study will continue with its current objectives of evaluating fixed-wing, rotary-wing, and indirect fire systems.

New projects are being added for exploring RSTA and decoy and deception systems. Their incorporation into the CAE will be made possible by the continued support by DARPA of this program in FY 90.

We expect the CAE to make a major contribution in all of these efforts and to provide an ongoing capability for programs throughout DARPA in the future.