APPLICATION OF AIR WARFARE SIMULATION IN DETERMINING TACTICAL AIR CONTROL SYSTEM (TACS) EFFECTIVENESS

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Abstract

This paper discusses the use of SIMATR, a large-scale simulation of air battles over land, to evaluate the effectiveness of various sensor and force deployments in a Tactical Air Control System (TACS). A brief outline of a threat and of several possible TACS configurations is followed by a description of SIMATR and its applications in the context of the NATO air defense of Central Europe. Results showing the relative effectiveness of the various TACS configurations are presented.

INTRODUCTION

Analytic solutions to the problems posed by large-scale, hypothetical air engagements are impractical because of the many variables and tactical degrees of freedom available to both sides in a conflict. A computer simulation, on the other hand, easily permits variation of both offensive and defensive deployments and battle capabilities. Surveillance systems, weapons, and command, control and communications (C^3) systems are prime candidates to be specified by simulation [1]. For example, such flexibility aids defense system planners and designers in developing tactics and equipment for American forces in Europe and Korea.

SIMATR is RCA's large-scale simulation of an air battle over land. The purpose of SIMATR is to explore system and equipment tradeoffs for a TACS employed against a sophisticated hostile force with a highly developed capability in electronic warfare. It currently models the relevant friendly (blue) defensive capabilities and hostile (red) offensive air forces necessary to evaluate the relative effectiveness of each TACS component examined. The Fourth Allied Tactical Air Forces (4ATAF) in Central Europe is the nominal locale for this air battle. The blue NATO facilities to be attacked and the deployment of the red offensive forces are selected by the analysts. Operational parameters of elements of the defense and command and control logic may also be varied.

This paper briefly reviews the threat and the TACS compositions in the Central European context with particular emphasis on the network of ground radars for the counter-air mission. The simulation program SIMATR is then introduced, and its modeling of TACS, the operational environment, and red and blue forces are discussed. Following this, the application of SIMATR to a Central European scenario is treated, and several examples of comparative results with different TACS configurations and threats are given. The paper closes with a discussion of the benefits of applying SIMATR to such problems.

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A CENTRAL EUROPEAN THREAT

The highest level tactical threat to NATO defensive forces is in the Central European theater, where potential aggressors are capable of striking in force both on the ground and in the air. In particular, the NATO air defense is challenged by a numerically superior array of modern air weapons, including high performance bomber and fighter aircraft with on-board weapon systems,anti-radiation missiles (ARM), and cruise missiles. These hard-kill weapons are supported by electronic countermeasures (ECM) such as interference radiation from stand-off jammers (SOJ) and escort jammers and also chaff to blind NATO radars.

The NATO forces in the 4ATAF area might be subject to an initial attack by several hundred offensive aircraft generally seeking to:

- Develop one or more air corridors through the NATO air defense,
- Suppress NATO surface-to-air missiles (SAM) and Short Range Air Defense Systems (SHORADS) such as anti-aircraft artillery,
- Establish local air superiority by engaging the NATO interceptor aircraft aloft (the combat air patrols, or CAP) and by bombing NATO air bases, and
- Destroy high value NATO targets such as staging areas, equipment and fuel dumps, and nuclear weapon storage sites deep inside the 4ATAF area.

These aircraft will most likely be divided into squadrons of tactical bombers with escort fighter and jammer aircraft to protect them against the blue interceptors.

THE TACTICAL AIR CONTROL SYSTEMS (TACS)

NATO air defense in Central Europe comprises a wide variety of elements, including interceptors, SAM, and SHORADS. Each of these elements, in turn, consist of subsystems to perform their air defense missions. For example, the interceptors have on-board acquisition and fire control radars and air-to-air missiles to destroy the incoming hostile aircraft and missiles. The management of this defense is provided by TACS, which are integrated surveillance and C^3 systems that control the air defense and coordinate the following types of tactical air missions:

- Defensive counter-air,
- Close air support of ground troops,
- Reconnaissance,
- Offensive counter-air,
- Deep interdiction,
- Airlifts, and
- Aerial refueling operations.

TACS elements required to conduct large scale defensive air battles over land consist of:

- Ground-based air surveillance radars to search for and track red aircraft and missiles and to monitor positions of friendly aircraft,
- Airborne Warning and Control System (AWACS) radars to perform similar functions from the air, and
- C^3 facilities — such as control and reporting centers and posts (CRC/CRP) and forward area control posts (FACP) — to integrate the sensor data, control all assigned NATO aircraft, interceptors, and direct individual interceptors to their targets.

All three of these elements are modeled in SIMATR, with particular emphasis on the network of ground radars. The current generation of rotating air surveillance radars is becoming increasingly vulnerable to ECM and direct antiradar strikes. This type of radar has a mechanically rotating antenna, which limits the ability to revisit any target in either the active mode, when the radar transmits energy to obtain an echo, or in the passive angle track (PAT) mode, when the radar only listens to obtain an angular bearing on a jammer.

Monopulse phased-array radars mounted on trucks are candidates to supplement and/or replace the rotating radars to meet the growing threat. Phased-array radars have electronically steered agile beams and are capable of rapidly performing multiple interleaved functions. The phased-array radars under consideration duplicate the capabilities of the rotating radars in the absence of ECM and provide needed additional capabilities in dealing with the sophisticated ECM threat. Significant differences between the rotator and phased-array radars are modeled in SIMATR and are discussed below.

In the active mode, phased-array and rotator radars are equally capable of initially detecting a target in the absence of ECM. However, the phased-array radar requires less time than the rotator radar to confirm a detection and to establish track. The shorter time period accelerates the initiation of tracking, which is required before TACS can vector CAP into engagement position and designate a target by passing the estimated target position to the CAP onboard radar. The designation accuracy of the phased-array radar is expected to be better than that of the rotating radar. In addition, the higher target update rate of the phased-array radar will improve the tracking of maneuvering targets, thus reducing the acquisition search volume required upon handover to the CAP radars.

The rotating beam of a conventional radar limits the chaff clutter suppression; the phased-array radar, which can fix its beam, is capable of substantially better performance. A number of other performance characteristics are improved with the phased-array radar, resulting in longer detection and tracking ranges on radar targets during electronic warfare.

In the passive mode, the angular discrimination of jamming sources is assumed to be finer with the phased-array radar than with the rotator radar. More jammers may be tracked passively without merging with neighbors on the radar screen. The phased-array radar is less sensitive to signal amplitude variations in the PAT mode, making it inherently more accurate. Phased-array radar measurements of jammer targets can be made synchronously by several radars, allowing good triangulations to be made.

The phased-array radars are assumed to be more mobile than the current rotator radars, and may be deployed in dual units, which have improved protection against ARM and cruise missiles.

The purpose of simulating TACS with various configurations of ground radars is to examine the employment and military worth of the radars. The advantages of the phased-array radars should be demonstrable in the SIMATR outputs.

SIMATR

Considering the threat and also the complexity of TACS, a need exists for a tactical air battle simulation to:

- Aid in evaluating the effectiveness of tactical air control radars in air battles,
- Validate assumptions in the design of tactical air control phased-array radars,
- Assess the load on and the effectiveness of the C^3 system during a saturation raid, and
- Determine radar, computer, communications, and personnel resources needed to wage an air battle.

An air battle simulation, such as SIMATR, has specific modeling requirements for targets, weapons, sensors, and command and control. The simulation must be able to model mass raids of up to several hundred individual targets with trajectories that include maneuvers, dives, climbs, and changes of speed. The offensive capabilities of these targets, including weapons and jamming, must also be modeled. The defensive weapon models should consist of interceptor aircraft with on-board weapons, SAM, and SHORADS. Models of the interceptor detection capability, fuel consumption, weapon lethality, and effectiveness as a function of C^3 are also required.

The SAM should be modeled with respect to missile firing rates, average missile velocity, lethality, and coverage as limited by the earth's curvature and terrain masking. The large number of SHORADS installations prohibits them from being modeled individually. Therefore, the SHORADS should be represented by a distributed SHORADS zone instead of individual sites.

Tactical air surveillance radars of both rotating and phased-array type, SAM radars, airborne interceptor radars, AWACS, and gap-filler radars must be modeled with respect to detection, tracking, target designation, terrain masking, coverage diversity, and vulnerability. The command and control models must include threat evaluation and weapon selection algorithms, coordination of weapons, sensor control, message transmission and reception under various loads including saturation, information capacities and delays, degradation by jamming and physical attack, and manpower resources loading.

Many of these required models for a tactical air battle simulation were derived from MEDUSA, an extensive simulation of the Navy's AEGIS Combat System [3,4]. MEDUSA was designed and implemented by the RCA Simulation Analysis Group to support the development of the anti-air warfare functions of the AEGIS Combat System, which includes the Standard Missile-2,the PHALANX Weapon System, and combat air patrol. MEDUSA is a discrete event simulation written in FORTRAN consisting of over 400 subroutines.

For MEDUSA, a package of subroutines was used to [2]:

- Schedule, cancel and execute events on the simulation calendar,
- Dynamically create and destroy lists to describe targets, weapons, and their relationships,
- Link lists in ascending, descending, first-in-first-out, and last-in-first-out orders, and
- Access data in linked lists.

All of the MEDUSA architectural and simulation management features are directly applicable to a TACS simulation. In addition, the MEDUSA target, jamming, radar, threat evaluation, CAP assignment, and CAP intercept models fulfilled the corresponding TACS modeling requirements with minor changes. Thus, after the MEDUSA logic models for the Standard Missile and PHALANX were removed, the MEDUSA architecture and a subset of the MEDUSA models was sufficient for elementary TACS analysis.

The initial version of SIMATR was successfully used to demonstrate the viability of an air warfare simulation in determining TACS effectiveness [5]. Over the past four years, SIMATR has been greatly expanded and now models TACS defense weapon systems, attacking aircraft, and their interaction by the following twenty-four events:

a. Target Generator Event (TARGET)

TARGET is scheduled for each red aircraft in the raid at trajectory start time, an input parameter. TARGET schedules:

ENTER events at the time the red aircraft enters the coverage of each radar,

LEAVE events at the times the red aircraft leaves the coverage of each radar,

MANUVR events at the end times of trajectory legs,

SAMENG events at the time the red aircraft enters the coverage of each SAM radar,

SAMLVE events at the time the red aircraft leaves the coverage of each SAM radar,

ATTACK events at the time the red aircraft arrives at the TACS installations it is attacking, and

An AAAINT event at a randomly selected time when the red aircraft is over the SHORADS zone.

b. SHORADS Intercept Event (AAAINT)

The Short Range Air Defense System (or anti-aircraft artillery) intercept event employs a probabilistic model to assess the result of a red aircraft being engaged by SHORADS.

c. SAM Engagement Event (SAMENG)

SAMENG is scheduled for a SAM site and a red aircraft when the red aircraft enters the SAM coverage. If at least one missile is available at the site and enough time has elapsed since the last missile was fired from this site, an intercept position and time are computed, and a SAMINT event is scheduled. If no missiles are available, all SAMENG events on the calendar for this SAM site are cancelled. If at least one missile is available but sufficient time has not elapsed, another SAMENG is scheduled.

d. SAM Intercept Event (SAMINT)

SAMINT stochastically determines if a SAM intercepts a red aircraft. A successful intercept will cause the cancelling of all events for this red aircraft. If the intercept is not successful, SAMENG is rescheduled.

e. SAM Leave Event (SAMLVE)

SAMLVE cancels SAMENG and SAMINT events for the SAM and red aircraft pair.

f. Red Aircraft Maneuver Event (MANUVR)

This event is scheduled at red aircraft course changes, and cancels and schedules events affected by the course change.

g. Red Attack Event (ATTACK)

ATTACK assesses the attack on a TACS installation by a red bomber, cruise missile, or ARM. DSTROY is scheduled if the attack is successful

h. Destroy Event (DSTROY)

DSTROY is scheduled by ATTACK when a red aircraft successfully destroys a TACS installation. DSTROY may also be scheduled by input data that specifies a particular installation and its time of destruction. In both cases, DSTROY records the time of the installation destruction, after which the installation is no longer modeled or plotted on SIMATR maps. If the installation is an airbase, all aircraft at the base are destroyed.

i. Enter Event (ENTER)

ENTER is scheduled by TARGET at the time a red aircraft enters the coverage of a netted rotator or phase-array radar.

j. Leave Event (LEAVE)

LEAVE, scheduled by TARGET when a red aircraft leaves the coverage of a radar, cancels all events for the red aircraft interacting with the radar.

k. TACS Radar Detection Event (TACDCT)

TACDCT is scheduled by ENTER at the time a radar receives the return of the first surveillance pulse from a red aircraft. The ratio of signal-to-noise plus jamming power (S/N+J) is computed as a function of the geometry, radar parameters, and the jamming model. The success or failure of each detection is stochastically obtained by comparing the probability of detection, a function of S/N+J, with a random number from a uniform distribution. TACTRK is scheduled for a successful detection, and another TACDCT is scheduled one radar scan time in the future for an unsuccessful detection.

l. TACS Radar Track Event (TACTRK)

The TACS radar track event is scheduled by TACDCT when the radar acquires its target. TACTRK then schedules the threat evaluation event TEWS.

m. Passive Angle Track Event (PATTRK)

This event models the passive angle track of red jammers by TACS radars. Performance factors include a limit on the number of jammers in a beamwidth and, for rotating radars, a probability factor to account for lack of data synchronization. Three radars must detect the jammer to perform the track.

n. Handover Event (HANDOV)

HANDOV is scheduled when a radar can no longer track a target. This occurs when either the target is out of range or the radar is destroyed.

o. Threat Evaluation Event (TEWS)

The threat evaluation event calls the blue aircraft and red aircraft assignment doctrine subroutines, which in turn initiate the air-to-air engagements.

p. CAP Trajectory Update Event (CPUPDT)

This event changes the trajectory of a blue aircraft by updating its velocity components.

q. Group Detect Event (GRPDCT)

This event marks the occurrence of a blue aircraft detecting the red group to which it has been assigned. The blue aircraft then proceeds to engage one member of the group.

r. CAP Detection Event (CAPDCT)

CAPDCT simulates a blue aircraft detecting a red aircraft by computing signal-to-noise probability of detection and by stochastically determining success or failure.

s. CAP Track Event (CAPTRK)

CAPTRK is scheduled when a blue aircraft successfully acquires its target. It then estimates when the target will be within missile range and schedules a FIRE event for that time.

t. CAP Fire Event (FIRE)

FIRE computes the intercept time of a blue air-to-air missile fired at a red aircraft and schedules CAPINT for that time.

u. CAP Intercept Event (CAPINT)

CAPINT stochastically assesses the blue air-to-air missile intercept of the red aircraft. A successful intercept causes the cancelling of all events for this red aircraft. After an unsuccessful intercept, the red aircraft will be reengaged by the same blue aircraft if possible.

v. Red Aircraft Fire Event (REDFIR)

REDFIR computes the time at which the red air-to-air missile will intercept a blue aircraft and schedules a REDINT event for that time.

w. Red Aircraft Intercept Event (REDINT)

REDINT stochastically determines if a red aircraft intercepts a blue aircraft. When a successful intercept occurs, all events related to that blue aircraft are cancelled. If the intercept is unsuccessful, the red aircraft fires again.

x. Map Event (MAP)

MAP is scheduled for each input data set that specifies a time for a TACS map plot.

The event sequencer, an executive subprogram, controls the operation of SIMATR by accessing the event calendar, a time-ordered list of all events that have been scheduled but not executed. The initial events are established as specified by the input. After the input is read and the initial events are placed on the calendar, control is transferred to the event sequencer, which drives the simulation by the following steps:

1. Remove the top event from the event calendar.
2. Advance simulation time to the time of this event.
3. Call the event subprogram corresponding to the removed event.
4. Repeat the above steps until either the event calendar is empty or a user specified end time is reached.

OPERATION OF SIMATR

The following paragraphs describe the operation of SIMATR with respect to the enemy scenario, the TACS surveillance and tracking radars, the C^3 models, the ground-to-air models, and the air-to-ground models. The performance differences between phased-array and rotating radars presented in the previous section are used by most of the SIMATR models to compare the effectiveness of the two types of equipment in realistic operational situations.

SIMATR is driven by an air attack of red aircraft groups composed of any number of the following (Individual aircraft may have a combination of the above capabilities):

- Attack aircraft to bomb blue facilities,
- Fighter escorts to counterattack blue interceptors, and
- Escort jammers that aid the attack aircraft by jamming the defensive radars and communications.

The blue facilities that may be designated as targets for the attack aircraft include AWACS and the following ground facilities:

- Netted Phased-Array Radars,
- Netted Rotator Radars,
- Airbases,
- Forward Area Control Posts (FACP),
- Control and Reporting Centers/Posts (CRC/CRP),
- SAM sites, and
- High Value Targets (HVT).

Each red attack aircraft may be designated to bomb more than one blue facility. The red attack may also be aided by SOJ aircraft deployed behind the FLOT (forward line of troops) to suppress the detection capability of the blue radars. Interaction between the red and blue forces begins by means of the blue radar detection models. These models represent a network of radars that include:

- Three-dimensional air surveillance — Phased-Array,
- Three-dimensional air surveillance — Rotating, and
- AWACS (airborne rotating).

Radar detection is modeled by calculating a signal-to-noise plus jamming ratio as a function of:

- Target radar cross section,
- Target state vector,
- Antenna pattern,
- Transmitter power,
- Radar signal losses, and
- Jamming environment.

Curved-earth geometry with average terrain is used to determine the line of sight. An important part of the radar models is the calculation of the contributions for each jammer to the signal-to-noise plus jamming ratio as a function of power and location. SIMATR thus achieves more realistic results in a dynamic environment than models that assume an average jamming level.

For non-radiating targets, the detection model computes a probability of detection and compares it with a random variable to determine the success or failure of each detection attempt. Failed detections cause another detection attempt in one scan time and successfully detected targets are tracked.

A passive jam strobe model is used for detecting jammers. Each radar is modeled as being able to discriminate a maximum number of jammers in a beamwidth.

The differences between phased-array radars and rotator radars are represented by way of their effects on ground controlled intercepts (GCI) and warnings to interceptors. The GCI and warning effects are modeled in aircraft assignment logic and probabilities of kill.

The SIMATR C^3 models control the radar track management by assigning targets detected by more than one radar to ground-based netted radars whenever possible. If more than one radar of the same type has detected a red aircraft, the first detecting radar tracks it until:

- The aircraft leaves the radar's coverage,
- The radar drops track because of jamming or multipath,
- The radar is destroyed, or
- The target is killed.

If the target has not been killed, the handover model assigns the track to the closest radar.

The key C^3 models assign blue aircraft to intercept the attacking red aircraft. The blue aircraft are initially at air bases or on CAP stations, and are assigned under constraints of:

- Air-to-air missile inventory,
- Fuel on board,
- Maximum speed, and
- Staying on the blue side of the FLOT.

SIMATR attempts to maintain local blue air superiority in any engagement by assigning a larger group of blue aircraft to intercept each group of red aircraft. The analysts may vary the degree of superiority, providing that sufficient blue aircraft are available. Three-dimensional geometry is used to compute intercept time and position for all underengaged red groups and available blue aircraft. The blue groups are formed by the earliest times to reach a red group, and more blue aircraft are assigned if additional red aircraft are detected.

When blue aircraft are within radar range of the red group, the airborne radar models determine detection. The signal-to-noise plus jamming ratio is calculated as a function of:

- Red aircraft radar cross section,
- Range between the aircraft,
- Airborne radar antenna pattern,
- Radar signal losses,
- Transmitter power,
- Radar scan time, and
- The individual contributions of all red jammers.

The probability of detection is computed as a function of the S/N+J ratio and of a ground control factor that is higher for aircraft assigned from the more accurate phased-array data than from rotating radar data. Detection is stochastically determined and failures are retried in one scan time.

The selection of the target within a red group for detection by each blue aircraft is a function of red aircraft type and the type of radar controlling the intercept. Red jammers have the highest priority, attack aircraft have the next highest priority, and fighter escorts have the lowest priority.

For intercepts controlled by phased-array radars, the superior tracking capability is modeled by pairing the blue aircraft with red aircraft until all red aircraft in the group have been paired. Only then are more than one blue aircraft assigned to a red aircraft. For intercepts controlled by rotator radars, the less accurate tracking data is modeled by assigning blue aircraft to red aircraft without checking the engageability status of the red aircraft. This may result in some red aircraft not being engaged, even if there are superior blue forces, because other red aircraft may be engaged by more than one blue interceptor.

Successful detections cause the blue interceptor to track the red aircraft. If there is sufficient time for filter settling and a fire control solution, an air-to-air missile firing and intercept model is executed as a function of missile and aircraft parameters. The success of the intercept is determined stochastically, where the probability of kill is a factor of red aircraft type and controlling ground radar type. An unsuccessful intercept will be followed by refiring if the red aircraft is within missile range. After a completed engagement, the blue aircraft is available for reassignment from the ground.

The red fighter escorts may attack when the blue interceptors are within missile range. The red aircraft radar models are the same as the blue except there is no ground control factor and, because each red escort acts autonomously, there is no attempt at pairing.

The blue interceptors are supported by a network of SAM sites and SHORADS, which may be located anywhere on the blue side of the FLOT. Modeled characteristics for each site include:

- Missile inventory,
- Maximum firing rate,
- Radar coverage, and
- Engageability contours.

A fire control solution is used to select the time and location of each intercept, which is assessed stochastically as a function of altitude and missile lethality.

Because many ground-based weapons exist that constitute the SHORADS, an excessive amount of computer time would be required to model them individually. Therefore, SIMATR employs a distributed model that represents SHORADS by zones, and target vulnerability is directly proportional to aircraft time over the zone. A SHORADS kill is evaluated no more than once for a target, and a stochastic model is used if intercept occurs when the target is below the SHORADS maximum effective altitude. The kill probability is zero for higher altitude targets.

If red bombers are not destroyed by blue interceptors, SAM, or SHORADS before reaching their targets, then the air-to-ground effectiveness model is executed. This model evaluates red attacks stochastically as a function of ground facility vulnerability and aircraft altitude. If a ground facility has been destroyed by a previous red strike, an alternate target is selected if the aircraft is within the weapon lethality range.

Many outputs are available from a SIMATR run, the three most important for giving an overview of system performance being:

- The overall aircraft exchange ratio:
  $$\frac{\text{\# red aircraft intercepted}}{\text{\# blue aircraft intercepted}}$$
- The fighter exchange ratio:
  $$\frac{\text{\# red fighters intercepted}}{\text{\# blue aircraft intercepted}}$$
- The attacker success ratio:
  $$\frac{\text{\# completed red missions}}{\text{\# planned red missions}}$$

Other data provide insight into the tactics and doctrine used in a particular run. These data are not easy to quantify in the abstract but are very valuable to the system analysts.

SIMATR also produces the following types of output:

- Chronologies showing the outcome of each air-to-air, air-to-ground, and ground-to-air engagement (Figures 1 and 2),
- Matrices showing TACS radar traffic, including both red and blue aircraft visibility (Figures 3 and 4),
- Periodic tables showing the status of the TACS installations (Figure 5), and
- Maps of the 4ATAF area showing the existing TACS network (Figure 6).

Figure 1
PORTION OF SIMATR OUTPUT ENGAGEMENT CHRONOLOGY

AT	2511.82	AN AAA		MISSED	RED A/C	100
AT	2514.26	SAM SITE	51	MISSED	RED A/C	73
AT	2516.64	BLUE A/C	56	MISSED	RED A/C	97
AT	2517.96	BLUE A/C	35	KILLED	RED A/C	81
AT	2519.64	BLUE A/C	55	MISSED	RED A/C	94
AT	2521.35	SAM SITE	62	MISSED	RED A/C	84
AT	2523.35	SAM SITE	8	MISSED	RED A/C	84
AT	2527.05	SAM SITE	48	MISSED	RED A/C	76
AT	2529.20	BLUE A/C	55	MISSED	RED A/C	94
AT	2529.36	RED A/C	84	MISSED	AIRBASE	9
AT	2530.36	RED A/C	85	KILLED	AIRBASE	9
AT	2531.36	RED A/C	86	MISSED	SAM SITE	62
AT	2532.36	BLUE A/C	56	KILLED	RED A/C	97
AT	2532.36	RED A/C	87	KILLED	SAM SITE	62
AT	2535.28	SAM SITE	19	MISSED	RED A/C	56
AT	2535.73	RED A/C	96	KILLED	BLUE A/C	55
AT	2537.05	RED A/C	97	MISSED	BLUE A/C	7
AT	2544.56	SAM SITE	46	KILLED	RED A/C	65
AT	2555.01	BLUE A/C	36	KILLED	RED A/C	57
AT	2558.02	RED A/C	84	MISSED	HVT	2
AT	2559.02	RED A/C	85	MISSED	HVT	2
AT	2560.02	RED A/C	86	KILLED	HVT	2
AT	2561.02	RED A/C	87	KILLED	SAM SITE	8
AT	2561.98	SAM SITE	51	MISSED	RED A/C	73
AT	2567.50	SAM SITE	9	MISSED	RED A/C	84
AT	2584.73	RED A/C	96	MISSED	BLUE A/C	7
AT	2593.35	SAM SITE	48	KILLED	RED A/C	76
AT	2597.05	AN AAA		MISSED	RED A/C	113
AT	2599.49	SAM SITE	9	KILLED	RED A/C	84
AT	2616.79	BLUE A/C	7	KILLED	RED A/C	116

Figure 2
PORTION OF ENGAGEMENT CHRONOLOGY SORTED BY RED AIRCRAFT NUMBER

AT	2599.49	SAM SITE	9	KILLED	RED A/C	84
AT	2567.50	SAM SITE	9	MISSED	RED A/C	84
AT	2558.02	RED A/C	84	MISSED	HVT	2
AT	2529.36	RED A/C	84	MISSED	AIRBASE	9
AT	2523.35	SAM SITE	8	MISSED	RED A/C	84
AT	2521.35	SAM SITE	62	MISSED	RED A/C	84
AT	2485.06	SAM SITE	9	MISSED	RED A/C	84
AT	2478.50	SAM SITE	62	MISSED	RED A/C	84
AT	2431.78	SAM SITE	9	MISSED	RED A/C	84
AT	1900.06	AN AAA		MISSED	RED A/C	84
AT	2855.02	BLUE A/C	7	KILLED	RED A/C	85
AT	2658.09	SAM SITE	9	MISSED	RED A/C	85
AT	2559.02	RED A/C	85	MISSED	HVT	2
AT	2530.36	RED A/C	85	KILLED	AIRBASE	9
AT	1683.95	AN AAA		MISSED	RED A/C	85

Figure 3
RED AIRCRAFT VISIBILITY MATRIX

-----------TIME IS NOW 2579.76-----------

Red A/C Load at Time 2600.00 (* = Jammer)

	SAM	1	2	3	4	5	6	7	8	9	10
1			V			V	T				
2			V		V	V	T	V	V		
3					V	V	T				
4					V		V	V	V	T	
5							V	V	T	V	
6							V		V	T	
7*		T	V	V		V	V	V	V	V	
8*		V	V	T		V	V	V	V	V	
9*		T	V	V		V	V	V	V	V	
10*			V			V	V	V	T	V	
11*		V	T	V		V	V		V		
12*		V	V	V		V	T				
13*		T	V		V	V	V	V	V	V	
14*		V	V	V	V	T	V	V	V	V	
15*		V	V	T	V	V	V	V	V	V	
16*		V	V	V	V	V	V	V	V	T	
17*		V	V	V	V	V	V	V	T	V	
18*		V	V	V	T	V	V	V	V	V	
19*		V	V	V	V	V	V	V	V	T	
20*		T	V	V	V	V	V	V	V	V	
62		V	V		V	T	V	V	V	V	
73											T
85											T
86											T
87											T
92		T									
94		T									
96		V	V		V	T	V	V	V		
103						T	V		V		
104						T	V		V		
111						T	V				
116*					T	V	V	V	V	V	
118						T					
123*					V	V	T	V	V	V	
130*			V		V	T	V	V	V	V	
131						T	V				
132						V	T				

Radar Visibility,Track Summary at 2600.00

	1	2	3	4	5	6	7	8	9	10
# Tracks	6	1	2	2	9	6	0	3	4	4
# Visible	17	19	12	16	28	30	20	24	19	4

33 Visible to Netted Phased Array Radars
4 Additional Visible to Netted Rotators
0 Additional Visible To SAM

Figure 4
BLUE AIRCRAFT VISIBILITY MATRIX

Blue A/C load

	1	2	3	4	5	6	7	8	9	10
1		T		V						
2		V		V	V					T
3		T		V	V					
4		T		V	V	V				
5		T								
6		T			V					
7		T		V	V	V				
8		T		V	V	V				
10		V		V	V					T
20				T						
23				T	V	V	V			
28		V		V	V	V	V			T
30				T	V	V	V	V		
31				V		V	V	T	V	
33				V	V	V	V	T	V	
35		T		V	V					
36		V		V	T	V	V	V		
38		T								
39				V		V	T	V	V	
40				V		V	T	V	V	
41				V		V	T	V	V	
42				V		V	T	V	V	
44		T								
45		T								
47		V		V	T	V				
49		V		T	V					
50		V		T	V					
51		V		T	V					
52		V		V	T	V		V		
53		V		V	T	V		V		
54		V		V	T	V	V	V		
56		V			T					
57				V			T	V		
58							V	V	T	
59							V	V	T	
60							V	V	T	

Blue A/C Visibility,Track summary at 2600.00

	1	2	3	4	5	6	7	8	9	10
# Tracks	0	11	0	6	6	0	5	2	3	3
# Visible	0	23	0	27	21	17	15	15	9	3

Figure 5
PERIODIC TACS INSTALLATION AND AIR BATTLE SUMMARY

STATISTICAL SUMMARY TIME=2600.00

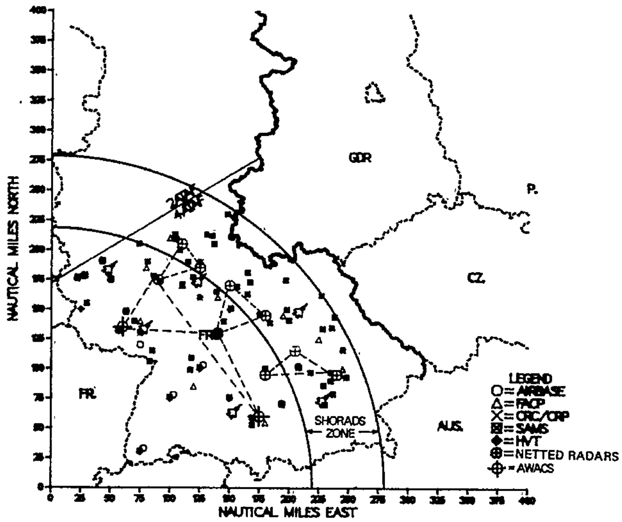
	INST	ATTK	DEST
AIRBASES	12	6	1
FACPS	10	2	1
412L	0	0	0
CRP/CRC	2	6	1
SAM SITES	62	21	8
HVTS	6	3	1
NETTED RADARS	10	11	2
RED A/C	152	307	79
BLUE A/C	60	83	21
PASSIVE FACS	41	28	6

RED A/C SUMMARY

LAUNCHED	152
DETECTED BY NETTED RADARS	128
TRACKED BY NETTED RADARS	126
ASSIGNED TO BLUE A/C	92
DETECTED BY BLUE A/C	78
TRACKED BY BLUE A/C	78
KILLED BY BLUE A/C	65
BLUE MISSILES FIRED	188
KILLED BY SHORADS	5
KILLED BY SAMS	9
ATTACK POINTS REACHED	51

A/C EXCHANGE RATIOS:
OVERALL= 3.10 (65/21) FIGHTERS= 1.81 (38/21)

Figure 6
THE DEFENSE



APPLICATIONS AND EFFECTIVENESS RESULTS

In this section, the application of SIMATR to a scaled 1-1/4 hour red offensive attack on the blue NATO 4ATAF area in southern West Germany is discussed and the effectiveness of various components of the TACS defense is examined. The modeled TACS includes nine ground-netted radar sites (rotators or phased array), two CRC/CRP, ten FACP, and two optional AWACS. Additionally, sixty blue interceptors, twelve airbases, sixty-two SAM sites, and six high value targets are included.

All defensive facilities are shown individually in Figure 6 except for SHORADS, which are modeled by means of the distributed zone sixty nautical miles wide.

The nine netted ground radars are located in three groups of three, with two forward (toward the FLOT) and one back. Two AWACS aircraft with rotating radars are shown at a standoff distance from the FLOT (close enough to see, far enough away to be protected). The AWACS are modeled as being stationary radars at an altitude of 30,000 feet. The back radars are in communication with the two CRC stations on the ground, as are the two AWACS aircraft.

The netted radar parameters varied in SIMATR to model the differences between rotating and phased-array radars are:

- ECM detection ranges,
- Radar scan time, and
- Angle between resolvable jammers.

Each of the six CAP stations at 30,000 feet altitude, shown by the aircraft symbols in Figure 6, is assumed to have three fighter aircraft, armed with eight air-to-air Sparrow missiles each. The remainder of the sixty defensive fighter aircraft are distributed at the twelve airbases. Other parameters of the defensive air component that are varied in the simulation input include:

- Blue interceptor scramble time,
- Blue interceptor velocity,
- Sparrow missile range,
- Sparrow velocity,
- Sparrow kill probabilities against different red aircraft types, and
- Sparrow fire rate.

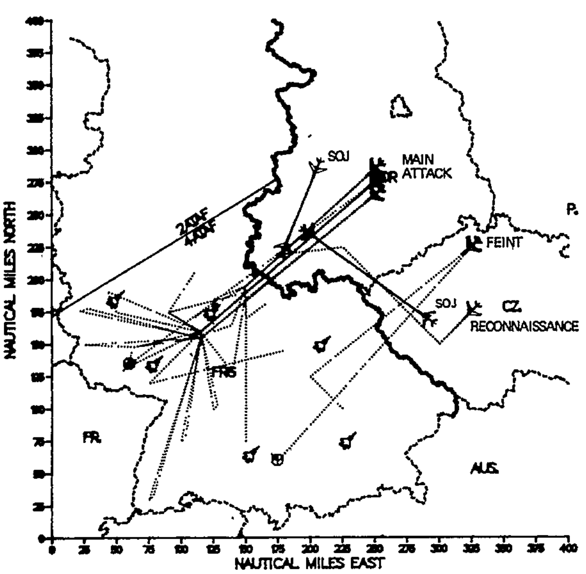
Behind the SHORADS zone, each defensive facility has at least one SAM site in its vicinity to provide point defense. The SAM sites have eight missile each. The attrition of red aircraft in the SHORADS zone is governed by the length of time any one aircraft spends in the zone and by its actions while within the zone.

Other defensive ground facility parameters that may be varied in a SIMATR run are:

- SAM range,
- SAM fire rate,
- SAM kill probability,
- SHORADS zone ceiling, and
- SHORADS zone attrition rates.

To model the threat, a specific red offensive scenario must be postulated. A map of one such scenario used with SIMATR is given in Figure 7. This scaled red attack consists of 152 red aircraft.

Figure 7
RED OFFENSIVE SCENARIO



In this model, twenty high altitude reconnaissance and SOJ aircraft fly along the eastern side of the FLOT before hostilities start. The former gather last-minute intelligence and the latter transmit wideband noise, attempting to screen the subsequent attack from NATO radars.

The red aircraft that attack across the FLOT, shown in Figure 7, consist of two groups of anti-AWACS fighters, each having four aircraft led by an escort jammer. The mission of these two groups is to deny the defenders the look-down capability provided by AWACS radars, by destroying the AWACS near the beginning of the battle or by forcing the AWACS to retreat out of range.

The main attack into the northern part of the 4ATAF area is by 112 aircraft, and twelve fighter aircraft feint an attack in the southern part to draw defending aircraft away from the main thrust. The main attack aircraft fly in compact formation through the corridors so that they are protected by accompanying escort jammers and chaff; they then break off into groups to attack their assigned targets. Each seven-plane group consists of four low-altitude fighter bombers, protected by two fighter escorts and one escort jammer. These aircraft fly at 900 fps and are spaced one second apart within groups. The interval between groups is about one nautical mile, or seven seconds of flying time.

Each fighter bomber is assigned to hit two targets, and all the bombers in one group have the same assigned targets. If an assigned target is destroyed by red aircraft, the SIMATR air-to-ground model automatically chooses another nearby defensive facility as an alternate target for succeeding bombers in that group. The offensive kill probabilities per sortie for each type of defensive site (selected for SIMATR after an assessment of single sortie effectiveness) are shown in Table 1.

TABLE 1. OFFENSIVE KILL PROBABILITIES USED

Target	Kill Probability	Target	Kill Probability
Netted Radar-Rotator	0.3	FACP	0.1
Netted Radar-Phased-Array	0.1	HVT	0.1
CRC	0.1	SAM site	0.3
Airbase	0.1		

The red bombers are modeled as having no air-to-air missiles, but the two fighter escorts and the escort jammer in each group carry eight air-to-air missiles with capabilities similar to those of the Sparrow missles. The kill probabilities of the air-to-air missiles used with SIMATR are based on analytical study of individual engagements, and are shown in Table 2.

TABLE 2. MISSILE KILL PROBABILITIES USED

Target	Condition of Target	Kill Probability
Blue Aircraft	Warning by Rotating Radar Network	0.42
Blue Aircraft	Warning by Phased-Array Radar Network	0.3
Red Aircraft	Jamming	0.5
Red Aircraft	Non-Jamming	0.42

An opening red cruise missile attack on pretargeted airbases and high value targets or an air-launched ARM attack on the netted radars and AWACS is postulated for some SIMATR runs. Both the cruise missile and the ARM are difficult targets to detect because in addition to having small radar cross sections, the subsonic cruise missile flies at treetop level following the terrain and an ARM flies supersonically after launch from an attacking aircraft. The four cruise missiles trajectories in Figure 8 represent five missiles each; Figure 9 shows the seven targets of twenty ARM.

Figure 8
CRUISE MISSILE ATTACK WITH PREHOSTILITY PHASE

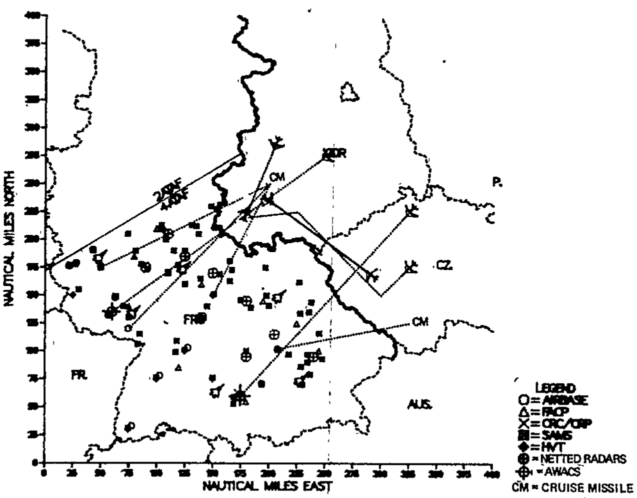


Table 3 is a summary of the components of the modeled red air attacks.

This scenario can be executed by SIMATR on the Digital Equipment Corporation 2060 computer at RCA Moorestown, using about three hours of central processing unit time.

The effectiveness of various defensive and offensive tactics and dispositions may be evaluated quantitively by means of SIMATR. Because the defense's primary objectives are to prevent the attacking force from reaching its targets and to maintain control of the defensive air space, effectiveness of the defense is measured by the percentage of missions denied to the attacking force and also by the ratio of hostile combat aircraft destroyed to friendly combat aircraft lost in the air battle. These measures may also be shown graphically by mapping the locations of red aircraft destroyed as the attack is vitiated. More detailed corroborative outputs from the engagement chronology allow the user to follow the fate of any particular blue or red aircraft or of any blue facility (see Figure 2).

The fundamental problem currently being addressed by SIMATR is to measure the military worth of netted sets of radars in providing fundamental surveillance and tracking information to the NATO defense for the purpose of air engagement designations.

Figure 9
ARM ATTACK

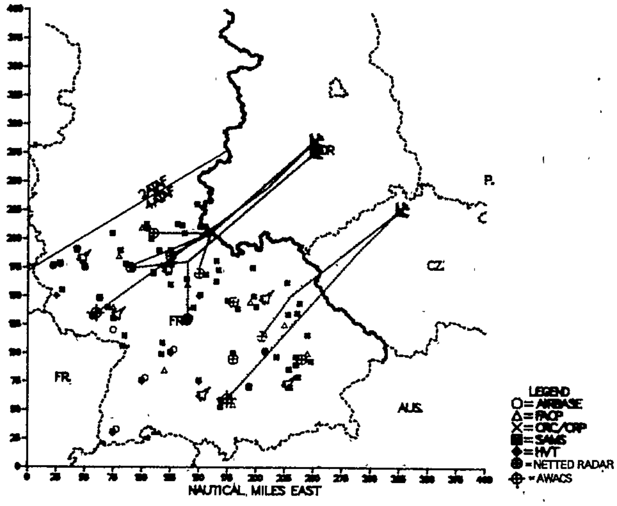


TABLE 3. SUMMARY OF MODELED RED OFFENSE

Red Aircraft	Number of Groups	Number of Aircraft	Number of Bomb Sorties
Reconnaissance and SOJ	3	20	0
Anti-AWACS	2	8	16 (16 air-to-air)
Main Attack	16	112	128
Feint	1	12	0
Cruise Missile	—	—	20 air-to-air
ARM	—	—	20 (8 air-to-air)

Other aspects of the air battle that are being examined using SIMATR include:

- Defense against cruise missile attack,
- Defense against ARM attack,
- The engagement tactics of blue aircraft to intercepting red aircraft visible to the netted radars, taking into account that jamming and chaff may conceal a portion of the attacking force, and
- The capability and importance of performing PAT on jammers, communicating strobe lines to adjacent netted radars for de-ghosted fixes, and of burning through the jamming.

Repeated SIMATR runs show that for the red attack and blue defense postulated, a rotator radar network without AWACS support results in 52% of the red missions being denied, with an overall aircraft exchange ratio of 2.7 : 1. A phased-array network denies 65% of the red missions, with an aircraft exchange ratio of 3.1 : 1. Table 4 shows these results in more detail, and Figures 10 and 11 show concentrations of red air-to-air losses to the blue interceptors in typical runs.

Figure 10
RED AIR-TO-AIR LOSSES WITH
ROTATOR RADAR NETWORK

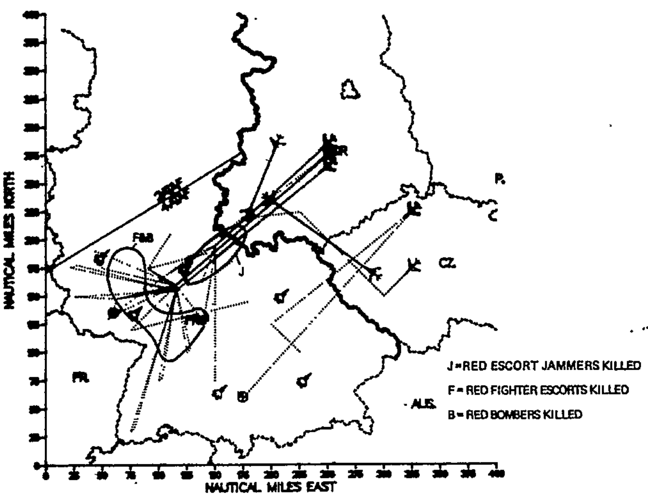


Figure 11
RED AIR-TO-AIR LOSSES WITH
PHASED ARRAY RADAR NETWORK

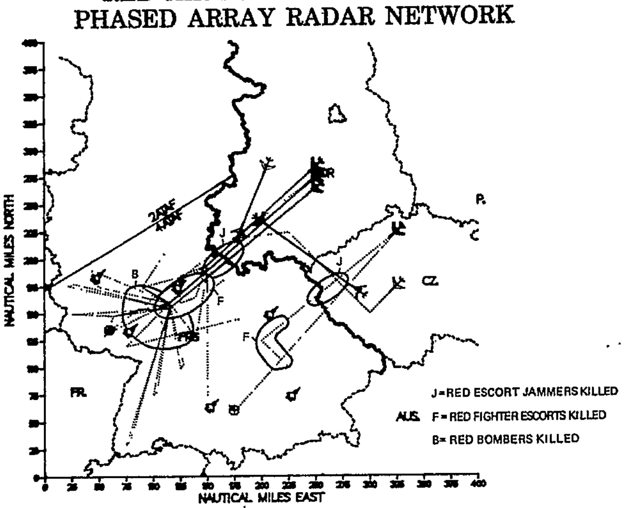


TABLE 4. EFFECTIVENESS OF TACS RADAR NETWORK

Effectiveness Measure	Network		% Increase for Phased-Array Network
	Rotator Radar	Phased-Array	
Red Missions denied	52%	65%	25%
Offensive red aircraft killed	66%	83%	26%
Killed by CAP	39%	62%	59%
Killed by SAM & SHORADS	27%	21%	-22%
Blue CAP losses	32%	44%	38%
Aircraft exchange ratio (Reds killed by CAP to CAP killed)	2.7	3.1	15%
Fighter exchange ratio	1.6	1.9	19%

A number of observations can be made:

- The air-to-air battle is much fiercer when using phased-array radars, and more air-to-air casualties occur on both sides, but proportionally more on the red side.
- There is a definite order in which red aircraft casualties by aircraft type predominate: first, escort jammers, which are resolved by PAT; next, the high altitude fighters, and last, the low altitude bombers. In the phased-array radar case, these combat phases occur sooner and also closer to the FLOT. In the rotator case, most fighters and bombers are not engaged until the red groups split up at the end of the corridor. Therefore, the percentage of red bomb missions denied is lower in the rotator case.
- In the phased-array case, feint aircraft are engaged, whereas in the rotator case they are largely ignored. Examination of the detailed SIMATR outputs reveals that this is due to the rotators' inability to resolve and track the jammers in the feint. Consequently, the current SIMATR assignment logic does not assign CAP to engage the unresolved feint in the rotator case.
- The ground-based SAM and SHORADS are relied on more heavily for the air defense in the rotator case than in the phased-array case.

SIMATR runs show that a phased-array plus AWACS network stops 55% of the cruise missiles, while a rotator plus AWACS network stops only 35%. Both types of networks stop about 40% of the ARM , but phased-array casualties are lower. Loss or absence of the two forward phased-array sites where the main red air corridor is established results in both a lower percentage of missions denied and a slightly higher aircraft exchange ratio as more of the red aircraft survive to break out of the corridor, where red escorts are less capable of "ganging up" on a CAP interceptor.

The preceding analyses were made with a CAP assignment logic that sent N+1 CAP against N tracks visible to the rotator or phased-array ground net. If the logic is changed sending N+2 CAP against N tracks, the percentages of red missions denied stay roughly the same, while the exchange ratios improve slightly in favor of the blue side. If the logic is again changed sending N+3 CAP against N tracks, the percentages of red missions denied goes down, and the fighter exchange ratio also goes down, drastically so in the all-rotator case. The reason for this latter anomaly is that while CAP casualties remain roughly the same, fewer red fighters are being attacked because of the restrictive assignment logic. More varied assignment logic is necessary to achieve better force multiplication.

CONCLUSIONS AND FURTHER WORK

Several TACS problems have been analyzed with SIMATR. The large number of offensive and defensive parameters changed for the different analyses testify to the impracticality of performing these studies without using a large-scale simulation.

SIMATR has proven to be a valuable aid in evaluating the effectiveness of TACS dispositions by allowing the user to isolate the contribution of each modeled defensive component, individually and by aggregate type. SIMATR outputs give conceptual insight on how various existing and projected elements of a TACS interact to provide an air defense. The analysis of the improved effectiveness of a phased-array ground radar network compared to the present rotator network shows the usefulness of SIMATR in demonstrating system level benefits obtained from improved equipment. SIMATR is also useful for educating civilian and military personnel about the operation of current and projected TACS.

Further effects to be investigated with SIMATR include the role of CAP assignment logic in achieving force multiplication, and the importance of radar site visibility and spacing in effectively conducting the defense. Also being considered is the replacement of phased-array radars with 360 degree visibility by two 180 degree modules, placed back-to-back on opposite sides of hills and ridges. Finally, the effect of various delays in communications between netted radars and between groups of radars, especially in performing PAT, is to be studied using SIMATR.

LIST OF ACRONYMS

ARM	Anti-Radiation Missile
AWACS	Airborne Warning and Control System
C^3	Command, Control, and Communications
CAP	Combat Air Patrol
CRC/CRP	Control and Reporting Centers/Posts
ECM	Electronic Countermeasures
FACP	Forward Area Control Posts
FLOT	Forward Line of Troops
GCI	Ground Controlled Intercept
HVT	High Value Target
PAT	Passive Angle Track
SAM	Surface-to-Air-Missile
SHORADS	Short Range Air Defense System
S/N+J	Signal-to-Noise plus Jamming Power
SOJ	Stand-off Jammers
TACS	Tactical Air Control System
4ATAF	Fourth Allied Tactical Air Forces

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