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ON THE IDAGAM I COMBAT MODEL

Alan F. Karr

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INSTITUTE FOR DEFENSE ANALYSES
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This paper is a review and critique of the IDAGAM I theater-level simulation model of conventional air-ground warfare. The principal emphasis is on identification and analysis of assumptions underlying the attrition equations used in the model. Also treated are organization, geography, resources, and FEBA movement computation. Critical evaluations and suggestions for improvements in the model are presented. While not a complete description, this paper does represent the most detailed and next pg

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20. continued

careful report on the IDAGAM I model that has been prepared by an independent reviewer.

CONTENTS

1. INTRODUCTION

This paper is a review and criticism of the IDAGAM I combat simulation model, similar in purpose and spirit to earlier reviews by the same author of the Vector-I, Lulejian-I, and CONAF Evaluation Models [11, 12, 13]. For a related comparison with emphases complementary to our own, the reader is referred to [15]. Our principal goal is identification and analysis of the major assumptions underlying the model and, in particular, the attrition equations. The report [4, 5, 6], which has been our main source of information concerning IDAGAM I, is unusually specific in discussions of assumptions and limitations, which has made the author's work easier.

2. ORGANIZATION

The IDAGAM I model is a computerized, deterministic simulation of bilateral conventional combat at the theater level. As usual, the two sides are called Blue and Red, respectively. Time steps are fixed and only with difficulty can represent periods of less than one day, since all time periods are identical. Both air and ground forces (and appropriate interactions among them) are modeled. Principal outputs of the model are losses of various weapon systems, including attribution of losses to different types of shooting weapons (i.e., "killer-target scoreboards"), losses of personnel and movement of the FEBA. Only force structures and their evolution over time are represented in detail. Aspects such as terrain and logistics are highly stylized; weather, political events, command and control, morale, and cost structures are not included at all. In the opinion of the author, these are not serious omissions; indeed such simplifications are necessary in a theater-level model and, to their credit, the developers of IDAGAM I list in [5] such omissions as "limitations" of the model. The principal analogous models, namely the CONAF Evaluation Model, the Luiejian-I model, and the Vector-I model make essentially similar (but not in all cases identical) simplifying assumptions. Of course, it is impossible to represent, in a deterministic model, stochastic events (such as political events) of such magnitude that the ultimate result of the combat may depend on only one event.

The overall structure of the model--for one run--is the following:

1) Inputs are read;

2) Special calculations are performed for time zero including geographical aspects, theater structure, and so on;

3) The air combat model is executed for each day of simulated combat;

4) The ground combat model is executed for each day of simulated combat;

5) Possible parameter changes, arrivals of new forces, user-directed force movements, replacements, and supply movements are effected for each day of simulated combat;

6) Outputs are prepared.

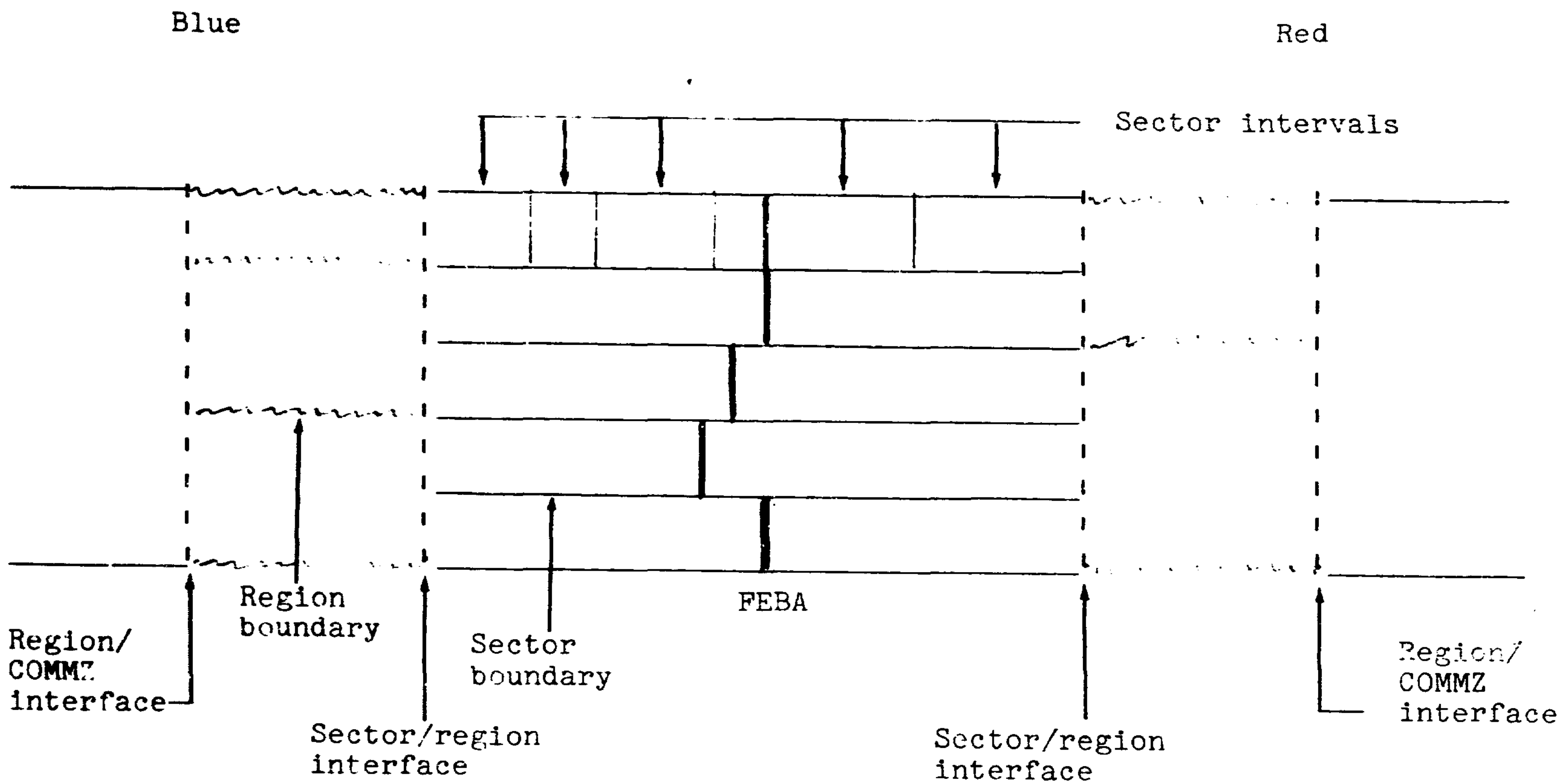
The major emphases of the IDAGAM I model are representation of ground weapons by type, representation of aircraft and air munitions by type, the air combat model (which is unusually detailed) as a whole, the interconnections between the air and ground combat models, some well-intentioned but flawed attempts to provide the user with choices among alternative equations for certain computations, avoidance of "firepower scores" in computations of losses of ground weapon systems, and introduction of asymmetric force ratios in computations of personnel losses. Each of these emphases is discussed in more detail in an appropriate section below.

3. GEOGRAPHY

The geographical representation in IDAGAM I is essentially standard. *Sectors* are the principal type of geographical unit in the sense that combat interactions do not occur across sector boundaries, that attrition and FEBA movement computations are performed on a per-sector basis, and that FEBA position is constant within each sector (although, of course, possibly varying with time). The theater is divided into sectors by non-intersecting boundaries running essentially the full depth of the theater. Sector widths need not be constant in terms of real geography; the model accounts for true sector widths in certain computations, such as that for FEBA movement. Varying sector widths and differing terrains are represented by division of sectors into *sector intervals* as illustrated in Figure 1 below; a sector interval is geographically homogeneous.

It should be emphasized that sectors are geographical units independent of the organization of either side. Sectors are assumed to be large enough to contain several division-sized units in combat. For organizational purposes each side may create ***regions***, which are obtained as groupings of sectors and are, geographically, rear areas in which direct combat does not take place. As indicated in Figure 1, region boundaries need not be the same for both sides, but cannot change over time. One should envision the sector/region interfaces as moving with the FEBA in such a manner as to remain roughly the same distance from the FEBA throughout the campaign.

Still further to the rear on each side is a single communications zone, hereafter called COMMZ, which also moves as



Note: Terrain intervals may be different for different sectors.

Figure 1. THEATER GEOGRAPHY IN IDAGAM I

the FEBA does. Obviously no ground combat can occur in either side's COMMZ. The distinction between regions and the COMMZ is in terms of distances from the FEBA (which, as pointed out above, remain roughly constant over time). The distance differential affects vulnerability of resources to enemy aircraft attacks and the time in which reserves can be dispatched to combat in sectors. Each region contains two notional air bases; each COMMZ contains one. One air base in each region is to be considered a forward air base and the other a rear air base. For a detailed discussion of the rationale underlying this distinction, the reader is referred to [5, pp. 12-14].

One must therefore understand Figure 1 to have omitted sector boundaries and intervals which, because of the current position of the FEBA, are irrelevant to combat interactions; these are masked by the regions and COMMZs in Figure 1 but could become unmasked if the FEBA were to move sufficiently far. To summarize, sectors and sector intervals are fixed geographical units independent of the state of the combat; regions and the COMMZ of each side are movable organizational units of prescribed width (in terms of numbers of sectors) and constant depth and distance from the FEBA.

Representation of the FEBA itself, as shown in Figure 1, is conventional: the FEBA is piecewise constant and constant at least over each sector. Large discrepancies in FEBA positions in sectors within a region cause potential difficulty with the interpretation of regions and definition of the sector/region interface, although careful use of the model would minimize the severity of the problem.

4. RESOURCES

The IDAGAM I model differs significantly from the CONAF Evaluation, Lulejian-I and Vector-I models in terms of numbers and types of resources allowed in two possibly rather important respects:

a) IDAGAM I places no theoretical limitation on the number of weapon types allowed on each side; numbers of types of divisions, types of aircraft, types of air munitions, sectors, sector intervals, and regions are similarly essentially unlimited. The values of such parameters are limited by DIMENSION statements in the FORTRAN implementation of IDAGAM I, and can be changed, albeit not easily. Of course, computer storage and running time constraints will limit the sizes of these particular variables. In the comparable models these numbers are generally fixed (although not entirely irrevocably) within the computer programs.

b) The level of detail of air combat resources and accounting is greater than those in the other models. In particular IDAGAM I treats aircraft and air munitions independently, which none of the other models does. Moreover, the number of different aircraft missions is greater in IDAGAM I than in the other three models.

On the negative side, IDAGAM I fails to include the hierarchical command structure of the CONAF Evaluation Model, the level of supply and logistics representation of the Lulejian-I and Vector-I models and the explicit representation of attack helicopters appearing in the Lulejian-I and Vector-I models. The latter models also differentiate combat personnel in ways that IDAGAM I does not.

IDAGAM I models the following resources, which we detail here:

A. Personnel

Four types only, namely, combat, combat support, service support, and theater support.

B. Ground Force Units

Number of types of units on each side essentially unlimited. Units of different sizes permitted but no unit may be a subset of another. Units are notional except under severe restrictions. Number of types of ground weapon systems on each side essentially unlimited; SAMs and AAA are included. Surface-to-air missiles counted explicitly. Unit characteristics are:

TOE weapons strength

Actual weapons strength

TOE personnel strength

Actual personnel strength

Degradation function

Reorganization rate

Movement rate

Personnel levels for withdrawal and return

Location (sector, region or COMMZ).

C. Tactical Aircraft

Number of types of each side essentially unlimited. Aircraft characteristics are:

Kill probability in air-to-air engagements and in attacks on air bases (as attacker)

Munition load (notional)

Sortie rate

Range

Shelter priority

Fraction of time spent on ground (a measurement of vulnerability).

Primary aircraft missions are:

CAS = close-air support in combat sectors
CAS escort
BD = battlefield defense
ABA = air base attack
ABA escort
ABD = air base defense
IDR = interdiction of divisions in reserve.

Secondary aircraft missions are:

SI = supply interdiction
SAM suppression in combat sectors
AAA suppression in combat sectors
SAM suppression at target air bases
AAA suppression at target air bases.

Aircraft assignments (by type) to primary and secondary missions fixed by input.

D. Air Munitions

Number of types of each side essentially unlimited. Each aircraft type has notional load. Air effectiveness on CAS computed solely from air munitions.

E. Prelocated Minefields

Minefields can be added by input during campaign.

F. Supplies

One type, related only to personnel strength.

G. Aircraft Shelters

In geographical positions and numbers fixed by input; available to air bases depending on current location of FEBA; destroyed if overrun by FEBA.

Of the four types of personnel, the first three are treated identically in all computations and the fourth can exist only in the COMMZ. There is a personnel replacement pool for the first three types, along with both ground unit and COMMZ pools for replacement weapons. The model developers envision a ground force unit as being of division or brigade size (although other choices are possible, including units of different sizes, so long as no unit is contained in another). We shall adopt the term "division" for the remainder of this paper. Divisions may be located in sectors (and are then in combat), in regions, and in the COMMZ. A division in the latter two locations can incur (by air attack) but cannot inflict casualties. Permissible locations for a particular type of division may be restricted by input. Divisions are notional in the sense that two divisions of the same type in the same location are indistinguishable, and suffer the same casualties, for example. This may create difficulties in assessment of unit effectiveness.

Air munitions are not accounted for explicitly as supplies, and enter into attrition computations only through numbers of aircraft and notional munition loads. The assumption that air effectiveness on CAS depends only on numbers of munitions delivered and individual munition effectiveness implies that aircraft affect the ground combat only through differential abilities to ultimately deliver their munitions. It is not clear that this assumption is entirely reasonable; some aircraft and munitions may be particularly well-suited to one another. One might represent this by artificially increasing the number of munition types.

Aircraft on suppression missions are an input fraction diverted from those on the associated primary missions.

As noted in Section 2, each side is allowed a forward and rear air base in each region and one air base in the COMMZ. These air bases are notional in that they move with the FEBA and can make use of any of the geographically fixed aircraft shelters over which they currently lie. The location of each air base, in terms of the width of the geographical unit containing it (i.e., the vertical coordinate of Figure 1), must be taken to be central. Shelters are of only one type and can be added during the campaign by input. All aircraft sheltering is based on user-input priorities by aircraft type. Air bases can be defended by SAMs, AAA, and aircraft.

The geographically fixed shelters should be envisioned in clusters representing previously constructed and fortified airfields. As the FEBA moves, certain of these airfields may become untenable, which forces the air bases to change airfields. Shelters that are overrun by the FEBA are destroyed, but it is assumed in IDAGAM I that the rest of an airfield can be rebuilt and used again should the FEBA recede. This entire structure is unique and plausible.

5. AIR COMBAT ATTRITION PROCESSES

In terms of numbers of aircraft types, numbers of aircraft missions, representation of air munitions, and numbers of air combat interactions, the IDAGAM I model is without question more complex than CONAF Evaluation Model, Lulejian-I, and Vector-I. For this the model developers should be commended. Moreover, the interconnections with the ground combat evaluation are more numerous and plausible than in the other models. Of the four models IDAGAM I alone gives the impression of having been an integrated model of air/ground combat from its inception. So far as actual attrition assessment is concerned, IDAGAM I is less clearly superior and, indeed, seems inferior in some senses.

Let us elaborate on the nature of that inferiority, most of which the model developers brought upon themselves in a well-intentioned but poorly executed attempt to be careful about attrition computations. In a feature unique among the four models, IDAGAM I allows the user a choice of attrition equations for certain attrition computations. These particular equations are discussed in more detail below. The idea of a choice among attrition equations is eminently reasonable in itself. Different equations arise from different families of underlying assumptions and, to any particular physical process, not all these sets of assumptions are equally applicable; the reader is referred, for example to [7,9,10,14] for arguments along these lines. Incredibly, however, [5] provides virtually no guidance to the model user to aid in choosing appropriate attrition equations from those available, other than references to some of the papers noted above. Only passing mention is made of the underlying sets of assumptions, there is no serious attempt to compare and contrast the various available equations, and there is not even a discussion of which particular air combat interactions might best be described by which attrition equations. No attention is given to the possibility that inconsistencies may arise from certain combinations of choices of attrition equations (separate choices can be made for eight different interactions); such inconsistencies can be logical, conceptual, or even computational. Not all choices, of course, lead to inconsistencies.

Instead of providing guidance and advice for choices of attrition equations on the (proper) basis of underlying assumptions, the report provides an essentially unannotated list of equations from among which to choose. The potential for error and abuse is enormous. Some users will vary their choice until the model produces outputs conforming to their preconceptions and then claim to have found the "right" attrition equations. Others will choose through ignorance or prejudice. Still others may be dissuaded from using the model because of an honest understanding of their inability to choose. Of course, careful research and study may lead to a reasonable choice; the user deserves some help from the model developers, however.

As presently constituted this aspect of the model, despite its apparent purpose, is a significant blunder and should be modified if possible, preferably by adding to [5] a careful presentation of the assumptions underlying each equation and possibly by limiting the number of choices (since, as we shall see below, there are essentially only three distinct equations available).

Before discussing the air combat attrition interactions and computations, we shall consider the equations listed as choices in [5]. Consider a one-sided heterogeneous engagement in which S_i searchers of types $i = 1, \ldots, M$ are seeking T_j

targets of types $j = 1, \ldots, N$. The first equation given for the expected number ΔT_j of type j targets destroyed by the searchers is

$$(1) \qquad \Delta T_j = T_j\left(1 - \prod_{i=1}^{M}\left[1 - \frac{k_{ij}}{T}\left(1-(1-d)^T\right)\right]^{S_i}\right) ,$$

where d is the probability that a given searcher detects a given target and k_{ij} is the conditional probability that a searcher of type i destroys a target of type j given that the searcher in fact detects and chooses to engage that target. Observe that the detection probability is independent of the type of target. As demonstrated in [10], the principal assumptions underlying (1) are those of independence of detections for each searcher, of at most one target attacked by each searcher, and of probabilistic independence among searchers. This equation is of Lanchester linear form, which is seen by making the approximations:

$$(1-d)^T \sim 1 - dT$$

and

$$\prod_{i=1}^{M} (1-k_{ij}d)^{S_i} \sim 1 - d\sum_{i=1}^{M} k_{ij}S_i ,$$

so that (1) becomes

$$(2) \qquad \Delta T_j = T_j d \sum_{i=1}^{M} k_{ij}S_i .$$

Equation (2) is the sixth of the equations presented in [4]; since the second equation in [4], namely

$$(3) \qquad \Delta T_j = T_j\left(1-\exp\left[-\frac{1}{T}\sum_{i=1}^{M} k_{ij}S_i\left(1-e^{-dT}\right)\right]\right)$$

is a straightforward exponential approximation to (1), which is not justifiable except on grounds of computational savings; the first, second, and sixth choices are not significantly different and should be merged into one choice. The experimental work necessary to see if computational savings in (2) or (3) justify the loss of accuracy does not belong in a model of this kind, it belongs instead in the process of model development.

The second distinct alternative available for attrition computations is the exponential equation

$$\Delta T_j = T_j\left(1-\exp\left[-\frac{1}{T}\sum_{i=1}^{M} d_i k_{ij} S_i\right]\right) \quad , \tag{4}$$

where d_i now has the very vague interpretation of the number of targets engaged by an average shooter of type i. In the Lulejian-I model the product

$$P_{ij} = d_i k_{ij}$$

is termed the "kill potential" of one searcher of type i against targets of type j. It is shown in the author's analysis [12] of the Lulejian-I model that equation (4) can be viewed as an approximation to the exact equation

$$\Delta T_j = T_j\left[1 - \prod_{i=1}^{M}\left(1 - \frac{k_{ij} d_i}{T}\right)^{S_i}\right] \quad , \tag{5}$$

where d_i is now the probability that a particular searcher of type i detects <u>some</u> (not each particular) target and k_{ij} retains the interpretation valid for equation (1). Underlying (5) are the standard independence assumptions and the assumption that each searcher can attack at most one target. As noted in [12], standard approximations change (5) into the Lanchester square equation

$$\Delta T_j = \frac{T_j}{T} \sum_{i=1}^{M} d_i k_{ij} S_i \quad . \tag{6}$$

We refer the reader to [9] for further analysis of this particular equation and the underlying continuous time stochastic attrition process.

The fifth alternative in IDAGAM I is the equation (6). The author believes that the third and fifth alternatives should both be replaced by (5).

Finally, the third distinct alternative available for calculation of air combat attrition in IDAGAM I is the equation

$$\Delta T_j = T_j \left(1 - \prod_{i=1}^{M} (1-d_i k_{ij})^{S_i}\right) \quad , \tag{7}$$

where d_i is the probablity that a particular searcher of type i detects each particular target (independent of the type of target). Underlying (7) are independence assumptions and the assumption that each searcher can attack <u>every</u> target it detects.

The three equations (1), (5), and (7) are clearly--based on underlying assumptions--conceptually distinct. We recommend that the authors of [5] revise their work in a manner that emphasizes and elucidates the distinctions.

We next proceed to a more detailed description of the order and nature of the air combat interactions in IDAGAM I. First we give a summary of the basic structure of the air combat model. For each day of simulated combat, computations of the following quantities are performed:

1) The number of shelters available at each air base;
2) Supply consumption at each air base, with the number of usable aircraft reduced by a factor proportional to the supply shortage if such a shortage exists;

3) Mission assignment for aircraft, including both assignment to one of the primary missions listed in Section 3 and selection of targets;

4) Numbers of aircraft diverted from the CAS mission to SAM and AAA suppression missions in combat sectors;

5) Numbers of aircraft diverted to suppression missions from the ABA mission;

6) Attrition of aircraft in air-to-air and ground-to-air interactions and attrition of SAM and AAA weapon systems by aircraft in suppression missions;

7) Attrition of aircraft on the ground as a result of enemy attacks on air bases.

Of these we shall discuss only the last two in further detail; the reader is referred to [5] for additional information concerning the others.

In determination of air combat interactions that can occur, the following assumptions are in force:

a) Attacking aircraft are vulnerable not only to aircraft defending the attackers' targets but also, although possibly to a lesser degree, to any enemy aircraft on defense missions in locations between the FEBA and the attackers' targets;

b) AAA can attack only aircraft attacking the guns themselves or the targets the guns are defending;

c) SAM weapon systems can attack not only aircraft attacking them and the targets they defend but also, although possibly less effectively, aircraft flying toward targets further toward the rear.

These principles yield the following complete list of air combat interactions. In those interactions denoted by an asterisk, the vulnerability of attacking aircraft is less than that of aircraft whose targets actually lie in the location under consideration, which is certainly reasonable.

1) Aircraft on the <u>CAS</u> mission are vulnerable (in this order) to:

a) enemy aircraft on BD mission

b) enemy SAMs in sectors

c) enemy AAA in sectors.

2) Aircraft on the <u>ABA</u> mission whose target is a <u>forward</u> region air base are vulnerable to:

a) enemy aircraft on BD mission in sectors in that region*;

b) enemy SAMs in sectors in that region*;

c) enemy aircraft on ABD mission at the particular air base;

d) enemy SAMs defending the air base;

e) enemy AAA defending the air base.

3) Aircraft on the <u>ABA</u> mission whose target is a <u>rear</u> region air base are vulnerable to:

a) enemy aircraft on BD mission in sectors in the region*;

b) enemy SAMs in sectors in the region*;

c) enemy aircraft on ABD mission at the forward air base in the region*;

d) enemy SAMs defending the forward air base in the region*;

e) enemy aircraft on ABD mission at the target air base;

f) enemy SAMs defending the target air base;

g) enemy AAA defending the target air base.

4) Aircraft on the <u>ABA</u> mission whose target is the (one) COMMZ air base are vulnerable to:

a) all enemy aircraft on BD mission*;

b) all enemy SAMs in sectors*;

c) all enemy aircraft on ABD at forward region air bases*;

d) all enemy SAMs defending forward region air bases*;

e) all enemy aircraft on ABD at rear region air bases*;

f) all enemy SAMs defending rear region air bases*;

g) enemy aircraft on ABD at the COMMZ air base;

h) enemy SAMs defending the COMMZ air base;

i) enemy AAA defending the COMMZ air base.

No explicit modeling of attrition to outbound attacking aircraft is done in IDAGAM I; outbound attrition is a user-input fraction of inbound attrition. This sort of treatment of outbound attrition is nearly universal; the author feels that it may represent an undesirable and unnecessary simplification.

In order to determine the order in which air combat interactions occur it is necessary to impose essentially arbitrary assumptions concerning the order in which attacking aircraft cross the FEBA. To their credit (and unlike the developers of some of the three comparable models), the authors acknowledge explicitly that their assumptions are arbitrary. Such assumptions are necessitated by the limited extent of development of mathematical models of attrition; the reader is referred to [10,14] for discussions of the substantial technical difficulties involved.

In IDAGAM I it is assumed that each day attacking aircraft cross the FEBA in the following order:

1) Aircraft on missions of CAS, CAS escort, and SAM and AAA suppression in sectors;
2) Aircraft on missions of ABA whose targets are forward region air bases, together with associated escorts and SAM and AAA suppression aircraft;
3) Aircraft on missions of ABA whose targets are rear region air bases and associated aircraft on escort and suppression missions;
4) Aircraft on missions of ABA whose target is the COMMZ air base and associated aircraft on escort and suppression missions.

Each attacking group encounters various defenses in the order previously noted.

It remains to specify the order of air-to-air interactions for each of the four groups above. That order is the following:

1) Escort aircraft are envisioned as sweeping out air space in front of attack aircraft and seeking to engage defending enemy aircraft. The results of this interaction are computed by two applications of one of the six alternative attrition equations. The inputs to both equations are the total numbers of

various types of escorts and defenders present. It is required that the same equation form be used to compute both kills of defenders by escorts and kills of escorts by defenders. We fail to see a logical necessity for this, especially in view of the asymmetric roles of the escorts and defenders; the latter, it seems, would seek to avoid engagement in order to remain able to engage attacking aircraft. Escort aircraft appear to be involved in no further air-to-air interactions; in some circumstances escorts are vulnerable to ground-based weapon systems.

2) The defending aircraft that have survived interactions with escorts next interact with attacking aircraft and associated suppressors. No attempt is made--as is done in the Lulejian-I model--to differentiate those surviving defenders that have not been engaged by escorts from those that have; the latter are presumably less effective. A single one of the six alternative attrition equations must be chosen to represent both interactions. Here also the symmetry appears both illogical and unnecessary.

3) Attacking aircraft with targets (strictly) further to the rear that have survived interactions (if any) with defending aircraft are next fired upon by SAMs; the attrition equation chosen to model this interaction must be used to represent all other attrition of attacking aircraft inflicted by SAMs.

4) Consider now aircraft that have survived all previous defenses and reached their target location. The following attrition computations are then made:

a) losses of SAM suppressor aircraft caused by SAMs;
b) losses of SAMs caused by surviving aircraft on SAM suppression missions;
c) losses of AAA suppressor aircraft caused by AAA;
d) losses of AAA caused by surviving aircraft on AAA suppression missions.

The interaction 4a) must be represented by the same form of attrition equation chosen for interaction 3); the user may make unrestricted choices for the interactions 4b) through 4d), but no dependence on the target area is permitted.

5) Surviving attacking aircraft are then vulnerable first to SAMs and then to AAA in the target area; the forms of the attrition equations must be the same as those in 4a) and 4c), respectively.

Aircraft on the CAS mission that survive all interactions then deliver their ordnance. The effect of CAS aircraft on the ground combat is described in Section 6 below.

Aircraft attacking air bases proceed to attack their targets in the following manner. At most one attack is assumed to occur each day at each air base (there may be no attack under certain circumstances). The number of aircraft at risk is an input fraction of those assigned to the air base, but with air-to-air and ground-to-air losses subtracted first; this choice is arbitrary but no less reasonable than the alternative arbitrary choices. If there are A attacking aircraft, B_s sheltered and vulnerable aircraft at the air base, and B_u unsheltered and vulnerable aircraft, then the number A_u of attacking aircraft that attack unsheltered aircraft is given by

$$(8) \qquad A_u = bB_u + \frac{B_u}{B_u+B_s}(A-bB_u)$$

and the remaining attackers attack sheltered aircraft. Here b is an input number of attacking aircraft per unsheltered aircraft that attack unsheltered aircraft before any attacking aircraft attack sheltered aircraft If $bB_u \geq A$ then $A_u = A$ and no attacking aircraft attack sheltered aircraft. For each of the two attrition computations, one of the six alternative equations must be specified. Further assumptions are that sheltering of aircraft at the air base is strictly on the basis of priority as a function of aircraft type, that all shelters are filled before any aircraft are left unsheltered, and that attacking aircraft cannot distinguish occupied and unoccupied shelters. As a consequence, if there are unoccupied shelters, the number of targets is the number of shelters and actual aircraft losses are the same fraction of hit shelters as occupied shelters are of all shelters. An input fraction of hit shelters are destroyed; the remainder are repairable overnight. In either case, the aircraft occupying a hit shelter are destroyed.

Nowhere does the IDAGAM I model permit engaged attacker aircraft to abort their missions in an attempt to return unharmed to their bases, an option which is either available or unavoidable in the CEM, Lulejian-I and Vector-I. The reviewer is uncertain of the significance of this omission; the authors of [15] imply that it is fairly serious. Modification of IDAGAM I to include aborted missions should not be too difficult, however.

6. GROUND COMBAT ATTRITION PROCESSES

All ground combat attrition assessments are performed on a per-sector basis, so in the exposition below we assume for concreteness that the Blue side is on defense, with a fixed defensive posture, in the particular sector under consideration. Parameters appearing in the equations below are functions of the defensive posture. The basic structure of the ground combat attrition computations is the following:

1) Potential weapon losses as a function of weapon type are computed from the actual numbers of weapons present, the ordnance delivered by aircraft on the CAS mission, and model inputs;

2) Potential casualties on each side are computed from potential weapon losses and inputs specifying casualties per weapon lost as a function of weapon type;

3) Actual casualties are computed from actual numbers of weapons present using (modified) force ratios and loss functions derived from historical data;

4) Actual losses of weapon systems are computed by scaling potential losses by the ratio of actual to potential casualties.

We shall now described these steps in more detail.

First we consider the computation of potential weapon system losses. From other parts of the model, the ground combat submodel obtains the quantities

$B(i)$ = actual number of Blue type i weapon systems in the sector;

$A(\ell)$ = actual number of Blue type ℓ aircraft surviving to deliver ordnance on CAS mission in the sector.

The following inputs are also required:

$B^*(i)$ = number of Blue type i weapons in a "standard" Blue force;

$\alpha^*(j,i)$ = fraction of Blue type i weapons that fire upon Red type j weapons when the opposing Red force is "standard;"

$k(j,i)$ = number of Red type j weapons destroyed in one day by one Blue type i weapon that allocates all its fire to Red weapons of type j;

$m(q,\ell)$ = number of type q air munitions in notional load of one Blue type ℓ aircraft;

$\beta^*(j,q)$ = fraction of Blue type q air munitions directed to targets of type j when the opposing Red force is "standard;"

$k'(j,q)$ = number of Red type j weapons destroyed by one Blue type q air munition directed solely at Red weapons of type j.

Analogous quantities exist for the Red side. Losses to the Red side are calculated below; those to the Blue side are obtained entirely analogously.

The concept of a "standard" force is left too vague. Moreover, as equation (10) below shows, only the relative composition of a standard force and not its absolute size is relevant. Furthermore, model users have reported extreme sensitivity to this set of parameters. The "kill potentials" $k(j,i)$ and $k'(j,q)$ suffer the same problems of ambiguity, lack of empirical means of computation and lack of a rigorous mathematical basis discussed in detail in [12]; the reader is referred there for more on this important matter. The other inputs are self-explanatory.

The number $\Delta_p R(j)$ of potential losses of Red weapons of type j is then given by

$$\Delta_p R(j) = \sum_i \Delta_p R(j,i) + \sum_q \Delta_p \tilde{R}(j,q) \quad , \tag{9}$$

where $\Delta_p R(j,i)$, the potential losses of Red weapons of type j to Blue weapons of type i, is given by

$$(10) \qquad \Delta_p R(j,i) = \left(\frac{R(j)\alpha^*(j,i)/R^*(j)}{\sum_\nu R(\nu)\alpha^*(\nu,i)/R^*(\nu)} \right) k(j,i)B(i) \quad ,$$

and where $\Delta_p \tilde{R}(j,q)$, the potential losses of Red weapons of type j caused by Blue air munitions of type q, is given by

$$(11) \quad \Delta_p \tilde{R}(j,q) = \sum_\ell \left(\frac{R(j)\beta^*(j,q)/R^*(j)}{\sum_\nu R(\nu)\beta^*(\nu,q)/R^*(\nu)} \right) k'(j,q)m(q,\ell)A(\ell) \; .$$

Here, of course, $R(j)$ is the number of Red weapons of type j actually present and $R^*(j)$ is the number of Red weapons of type j in a "standard" force.

The fire allocation used in (10) and (11) is derived from some simple axioms in [8]; see also [9,14] for further discussion. We observe that the results obtained can be highly dependent upon the structure of the "standard" force.

Potential Red personnel casualties, $\Delta_p R_0$, are then given by

$$(12) \quad \Delta_p R_0 = \sum_j \left[\sum_i c(j,i)\Delta_p R(j,i) + \sum_q \tilde{c}(j,q)\Delta_p \tilde{R}(j,q) \right] \quad ,$$

where

$c(j,i)$ = actual number of Red casualties arising from destruction of one Red weapon of type j by a Blue weapon of type i;

$\tilde{c}(j,q)$ = actual number of Red casualties arising from destruction of one Red weapon of type j by a Blue air munition of type q.

These latter quantities are inputs to the model.

The most involved portion of the ground combat attrition calculation is computation of actual casualties using functions (of force ratios) that have been constructed from historical combat data. Advantages and disadvantages of such a methodology have received frequent treatment in combat simulation literature, so will not be treated in detail here. Let

$\hat{B}(i,d)$ = actual number of Blue type i weapons in all Blue type d divisions in the sector;

$\hat{B}_0(d)$ = actual number of personnel in Blue type d divisions in the sector,

and let F be the (piecewise linear) function giving fractional Blue personnel casualties as a function of the (appropriately defined) force ratio.

IDAGAM I allows several options for use of force ratios and history-based loss functions in determining weapon system losses. One of these is the option to eschew force ratios entirely and to take potential losses computed above as actual losses; when IDAGAM I is used in this manner its attrition structure is similar to, but less detailed than, that in the Vector-I model. Below we describe in some detail a procedure whereby force ratios and loss functions are used only to compute actual personnel casualties and scaling factors that transform potential weapon system losses (as calculated above) to actual weapon system losses. Yet another method, that of antipotential-potential, is discussed at length in [2,3] and will not be treated here; this method values weapons in terms of their ability to destroy the other side's destructive capabilities and has been criticized as unstable with respect to parameter variations and as introducing certain spurious dependences. The method of linear weights (≡ firepower scores) is also available and is sufficiently well-known not to require discussion here. For discussion of another method based on linear weights and of the relations among the various available methods the reader is referred to [4, pp.11-16].

The process begins by computing the "value" of various types of weapons. Roughly speaking, the value of a weapon is the number of opposition casualties it can cause by destroying opposition weapon systems. Note that combat casualties occur only as a consequence of weapon system losses. The value $v_B(i)$ of one Blue weapon of type i is given by

$$v_B(i) = \frac{1}{B(i)} \sum_j c(j,i)\Delta_p R(j,i) \ . \tag{13}$$

These weapon values are multiplied by adjustment factors for

a) personnel strength relative to TOE strength,
b) supply shortages,
c) divisional reorganization, and
d) less-than-full effectiveness of newly arrived personnel,

all of which are functions of the division type d and the weapon type i, and then summed to obtain the effective Blue ground value $V_g(B)$, namely

$$V_g(B) = \sum_d \sum_i f(i,d)\hat{B}(i,d)v_B(i) \ , \tag{14}$$

where $f(i,d) \in [0,1]$ is an overall adjustment factor representing the four phenomena noted above. The reader is referred to [4,5] for further information concerning these adjustment factors.

The effective Blue air value $V_a(B)$ is given by

$$V_a(B) = \sum_j \sum_q \tilde{c}(j,q)\Delta_p\tilde{R}(j,q) \ . \tag{15}$$

Effective Red ground value $V_g(R)$ and effective Red air value $V_a(R)$ are computed in entirely analogous fashion.

The fractional casualties f_B to Blue are then computed to be

(16) $$f_B = F\left(\frac{V_g(R)+V_a(R)}{V_g(B)}\right)$$

and fractional casualties f_R to the Red side are

(17) $$f_R = F'\left(\frac{V_g(R)}{V_g(B)+V_a(B)}\right) ,$$

where F' is the loss rate function for the Red side when it is the attacking side. Hence IDAGAM I contains four loss rate functions: one for each side when it is defending and one for each side when it is attacking.

The asymmetric force ratios appearing in (16,17) are justified at length in [1]; a summary of the reasoning follows. If, to choose a particularly nasty example,

$$\frac{V_g(R)}{V_g(B)} = \frac{V_a(R)}{V_a(B)} ,$$

then the force ratio including both ground and air values

(18) $$x_{ag} = \frac{V_g(R) + V_a(R)}{V_g(B) + V_a(B)} ,$$

and the force ratio

$$x_g = \frac{V_g(R)}{V_g(B)}$$

that includes only ground values, are identical and hence produce the same fractional casualties. It is clearly implausible that (possibly substantial) air values might produce no effect on casualty rates; that this can happen is a mathematical defect of the force ratio x_{ag}. Further reflection easily convinces one that there exists neither physical nor logical justification for the Red-Blue symmetry in (18); cf. [1] for details. Indeed, a force ratio should be interpreted as a ratio of shooting weapons to targets and, for the purpose of ground combat assessment, aircraft are shooting weapons but not targets. Consequently, for computation of casualties to the Blue side, one should use the force ratio

$$x_B = \frac{V_g(R) + V_a(R)}{V_g(B)} ,$$

which represents all Red shooting weapons and all Blue targets. In the same way, casualties to Red should be calculated using for force ratio

$$x_R = \frac{V_g(R)}{V_g(B) + V_a(B)} ;$$

by convention the attacking side always appears in the numerator of force ratios. This reasoning justifies the forms of the force ratios used in (16,17) and appears to be eminently reasonable and to represent a significant improvement over the predecessor models of IDAGAM I and over the extant comparable models.

The report [5] also notes that IDAGAM I includes an option to employ symmetric force ratios that yield

$$\text{(16')} \qquad f_B = F\left(\frac{V_g(R) + V_a(R)}{V_g(B) + V_a(B)}\right)$$

and

$$\text{(17')} \qquad f_R = F'\left(\frac{V_g(R) + V_a(R)}{V_g(B) + V_a(B)}\right) .$$

As does the choice of attrition equations, this represents a poorly executed attempt at flexibility and reasoned comparison. More guidance and discussion are necessary than appear in [5]. Here the desirability of a choice is not clear either.

Actual Blue casualties ΔB_0 are then calculated using the relation

$$(19) \qquad \Delta B_0 = f_B g_B \Big(\sum_d \hat{B}_0(d) \Big) ,$$

where $g_B \in [0,1]$ is an adjustment factor representing the effects of severely imbalanced forces and supply shortages (and is discussed in more detail in [5]), and where $\sum \hat{B}_0(d)$ is the total number of Blue personnel in the sector. Similarly, actual Red personnel casualties ΔR_0 are given by

$$\Delta R_0 = f_R g_R \Big\{ \sum_d \hat{R}_0(d) \Big\} .$$

Finally, actual losses of Red weapon systems of type j, $\Delta R(j)$, are

$$(20) \qquad \Delta R(j) = \frac{\Delta R_0}{\Delta_p R_0} \Delta_p R(j)$$

and actual losses of Blue weapon systems of type i, $\Delta B(i)$, are given by

$$(21) \qquad \Delta B(i) = \frac{\Delta B_0}{\Delta_p B_0} \Delta_p B(i) .$$

Observe that if actual and potential casualties coincide, then so do actual and potential weapon system losses. Except for this property and that of linearity, the scaling methodology appearing in (20) and (21) is arbitrary; we are unable, however, to propose an obviously superior alternative.

Finally, attrition to divisions in reserve is computed on a per-region basis. Such attrition can arise only from enemy aircraft on the IDR mission that have survived all appropriate defenses. Let

$\tilde{k}(j,q)$ = actual number of Red weapons of type j destroyed by one Blue air munition of type q used on the IDR mission;

$L(\ell,q)$ = number of type q air munitions carried on the IDR mission by one Blue aircraft of type ℓ (notional load).

These are inputs to the model. Further, let

$\tilde{A}(\ell)$ = number of Blue aircraft of type ℓ on the IDR mission in the region that successfully deliver their ordnance;

$R_r(j)$ = number of Red weapons of type j in reserve divisions in the region;

R_r = number of Red personnel in reserve divisions in the region;

these latter quantities are computed within the model. Then losses of weapon systems of type j, $\Delta R_r(j)$, are given by

$$(22) \quad \Delta R_r(j) = \sum_{\ell} \tilde{A}(\ell)\left[\sum_{q} L(\ell,q)\left(\frac{R_r(j)\tilde{\alpha}(j,q)/R^*(j)}{\sum_{\nu} R_r(\nu)\tilde{\alpha}(\nu,q)/R^*(\nu)}\right)\tilde{k}(j,q)\right],$$

where

$\tilde{\alpha}(j,q)$ = fraction of Blue air munitions of type q that are directed at Red weapon systems of type j in divisions in reserve, when the opposing Red force is "standard,"

and where the standard Red force is as for equations (10) and (11). Similarly, casualties ΔR_r to personnel in Red divisions in reserve are given by

$$(23) \quad \Delta R_r = \sum_{j}\sum_{\ell}\sum_{q} \tilde{A}(\ell)L(\ell,q)\left(\frac{R_r(j)\tilde{\alpha}(j,q)/R^*(j)}{\sum_{\nu} R_r(\nu)\tilde{\alpha}(\nu,q)/R^*(\nu)}\right)\tilde{k}(j,q)\tilde{c}(j,q) \quad ,$$

where

$\tilde{c}(j,q)$ = number of personnel casualties caused by destruction of one Red weapon system of type j by a Blue air munition of type q.

Equations (22) and (23) are Lanchester square equations, cf. [14], and seem appropriate in this particular context.

Observe that aircraft on the IDR mission can make no direct contribution to the evolution of the ground battle; to the reviewer this seems to be a reasonable way of distinguishing the CAS and IDR missions.

Finally, we note that the model includes crude but adequate representations of nonbattle casualties and repair of some damaged weapons; for details the reader is referred to [5,6].

7. FEBA MOVEMENT COMPUTATION

In this section we describe the methodology used in IDAGAM I for calculation of FEBA movement; this methodology is essentially standard, but incorporates some unique features. For the purposes of the following discussion, let the Blue side be the defender and let the defensive posture be fixed. The computations described below are performed on a per-sector basis.

The basic assumption of the IDAGAM I model is that FEBA movement is a function of the following factors:

1) force ratio
2) defender posture
3) terrain
4) mobility of attacking divisions
5) concentration of air forces by the attacking side.

The principal dependence is on the force ratio, through a basic FEBA movement function denoted below by M. Posture of the defending side and terrain are treated parametrically, with one movement function for each (posture, terrain) combination. Mobility of attacking divisions is treated by means of a factor that multiplies the basic FEBA movement, while concentration of air forces by the attacking side is represented as a modification of the force ratio that constitutes the input to the FEBA movement function. We now proceed to a more detailed discussion.

Let

m_d = mobility factor of a Red division of type d (relative to a "standard" division);

s_d = size of a Red division of type d (relative to a "standard" division);

$M(\cdot)$ = basic FEBA movement function;

w_r = minimum effective width on which Red air forces can be concentrated.

The preceding quantities are inputs to the model; the "standard" Red division is presumably that previously discussed in Section 5. As noted before, the FEBA movement function M depends parametrically on the defensive posture and type of terrain and is a piecewise linear function whose argument is a force ratio; which side is attacking (Red, in this exposition) is also represented parametrically. Further, let

w = sector width at beginning of current day

and let $V_g(R)$, $V_a(R)$, $V_g(B)$ and $V_a(B)$ be the effective Red ground and air values and effective Blue ground and air values, respectively, for the sector under consideration, as computed in equations (14) and (15) in Section 5.

The overall mobility factor m for Red is, at the choice of the user, one of the following four factors:

1) A fixed constant m(1);

2) The minimum of the mobility factors of Red divisions present in the sector, namely

(24) $$m(2) = \min\{m_d: \text{ at least one Red division of type d is present}\};$$

3) The maximum of the mobility factors of Red divisions present in the sector:

(25) $$m(3) = \max\{m_d: \text{ at least one type d division is present}\};$$

4) The weighted average of the mobility factors of Red divisions present as given by

(26) $$m(4) = (\sum_d s_d m_d \bar{R}(d))/(\sum_d s_d \bar{R}(d)) ,$$

where $\bar{R}(d)$ is the number of Red divisions of type d present in the sector. Once more we commend the developers of IDAGAM I for the flexibility that such choices allow and for the opportunity to make empirical comparisons of different assumptions, but criticize the lack of guiding comments. IDAGAM I gives the user too many opportunities to bend the model to fit and justify his own prejudices and preconceptions concerning combat.

FEBA movement in the sector is taken to be the maximum of movements computed in three ways described below, which represent different strategies by which the attacking side can attempt to employ its air forces in seeking to create sites of local superiority that eventually force the defending side to withdraw. Several comments are in order concerning this methodology. First, since such withdrawal occurs in order to prevent violation of constraints on the defending side's front-to-flank ratio, it is uncertain whether the resultant effect represents a real-world phenomenon or is an artifact of the IDAGAM I model. Second, the methodology favors the attacking side, which can choose the best of three strategies for deployment of air forces; the defending side has no similar opportunity to choose, even if it possesses an air advantage. Finally, there is implicit in this methodology the assumption that the attacking side has sufficient information to compare the three strategies in order to choose the one most advantageous to it. The validity of this assumption is questionable and, in any case, the assumption should be made explicit.

The first strategy, that of continual concentration of air forces, is argued to be advantageous to the attacking side when its ground advantage is less than its air advantage but still exceeds one; that is, when

$$(27) \qquad V_a(R)/V_a(B) > V_g(R)/V_g(B) > 1 .$$

In this situation successive concentrations of the attacking side's air forces on 2/3, then 4/9, then 8/27, of the sector lead to creation of salients that eventually force the defending side to withdraw in order not to violate its front-to-flank ratio constraints. A lengthy argument, for which the reader is referred to [5, pp. 79-89], leads to the force ratio

$$(28)\qquad x_1 = \frac{\frac{w_r}{w} V_g(R) + 2^{\log(\frac{w_r}{w})/\log 3} V_a(R)}{\frac{w_r}{w} V_g(B) + 2^{\log(\frac{w_r}{w})/\log 3} V_a(B)}$$

The effect is to weight air forces relatively more than ground forces, depending on the extent to which air forces can be concentrated. For example, if $w_r = w$ (no concentration is possible) then

$$x_1 = \frac{V_g(R) + V_a(R)}{V_g(B) + V_a(B)} ,$$

while if $w_r/w = 1/3$ then

$$x_1 = \frac{V_g(R) + \frac{3}{2} V_a(R)}{V_g(B) + \frac{3}{2} V_a(B)} .$$

Note that the defending side concentrates its air forces in precisely the same manner as the attacking side.

If the strategy of continual air concentration were employed by the attacking side, then FEBA movement would be

$$(29)\qquad \Delta_1 = mM(x_1) ;$$

for further computations involving this "potential" movement the reader is referred to equation (39) below.

This sort of representation of differential mobility and concentration is strikingly original; the developers of IDAGAM I are to be praised for it.

For the case where the attacking side's air superiority is less than its ground superiority, but the attacking side has ground and overall superiority, that is, when

$$V_a(R)/V_a(B) < V_g(R)/V_g(B) \ , \tag{30a}$$

$$V_g(R) > V_g(B) \ , \tag{30b}$$

and

$$V_g(R) + V_a(R) > V_g(B) + V_a(B) \ , \tag{30c}$$

it is argued in [5] that the attacking side should not concentrate its air forces in the same places throughout the day. Instead, it should attempt to create salients at the beginning of the day and then flatten the FEBA, by concentrating on the locations previously omitted, at the end of the day. The defending side is asserted to do best by keeping its air forces uniformly distributed over the sector throughout the day. Whether this is so is neither obviously true, nor patently false. In any case, [5] at least presents a plausible and interesting argument in favor of the choices made. FEBA movement in sites of concentration during the portion of the day during which the attacking side's air forces are concentrated is given by

$$f_1 = \rho m M \left(\frac{V_g(R) + \frac{3w}{2w + w_r} V_a(R)}{V_g(B) + V_a(B)} \right) \ , \tag{31}$$

where ρ is the fraction of the day during which concentration occurs, and is chosen to satisfy equation (35) below. Observe that only the attacking side concentrates its air forces. FEBA movement in sites of earlier concentration during the remainder of the day is

(32) $$f_2 = (1-\rho)mM\left(\frac{V_g(R)}{V_g(B) + V_a(B)}\right) .$$

During this portion of the day, the attacking side's air forces are concentrated on sites not previously attacked.

In those locations initially omitted by the attacking side's air forces, FEBA movement during the first part of the day as a result only of the attacking side's advance is

(33) $$f_3 = \rho mM\left(\frac{V_g(R)}{V_g(B) + V_a(B)}\right) ,$$

and that during the second part of the day is

(34) $$f_4 = (1-\rho)mM\left(\frac{V_g(R) + \frac{3w}{w - w_r} V_a(R)}{V_g(B) + V_a(B)}\right) .$$

The fraction ρ must then be chosen so that

(35) $$f_1 + f_2 = \frac{1}{2}(f_1+f_3) + f_4 .$$

Underlying (35) is the following reasoning: $f_1 + f_2$ is the advance of the FEBA in sites in which early air concentration occurs, while f_4 is FEBA movement during the second part of the day in sites of late air concentration. Movement during the early part of the day in sites of late air concentration, however, consists of two components, namely, f_3 as given by (33) and withdrawal of the defender forced by front-to-flank ratio constraints, so that actual movement in such sites during the early part of the day is

$$\frac{1}{2}(f_1+f_3) > f_2 .$$

Therefore ρ is chosen to produce a smooth (indeed, constant within the sector) FEBA at the end of the day. Under reasonable monotonicity assumptions on the movement function M, there exists a unique $\rho \in [0,1]$ such that (34) holds, which yields for this strategy a movement

$$\Delta_2 = f_1 + f_2 = \frac{1}{2}(f_1 + f_3) + f_4 \ . \tag{36}$$

Finally, for the case in which the attacking side has a ground disadvantage (but is attacking because of a sufficiently large air advantage) it is asserted in [5] that the attacking side cannot benefit from concentration of its air forces and hence distributes the air forces uniformly over the sector, to which the defending side must respond by also distributing its air forces uniformly. In this case the force ratio is

$$x_3 = \frac{V_g(R) + V_a(R)}{V_g(B) + V_a(B)} \tag{37}$$

and potential FEBA movement is

$$\Delta_3 = mM(x_3) \ . \tag{38}$$

Actual FEBA movement Δ in the sector is then given by

$$\Delta = \max \{\Delta_1, \Delta_2, \Delta_3\} \ , \tag{39}$$

where Δ_1, Δ_2, Δ_3 are given by (29), (36), (38), respectively. Sector-to-sector FEBA adjustments, based on constraints on front-to-flank ratios and imposed on the attacking side first, complete the computation of FEBA movement.

8. SUMMARY

To summarize, we offer the following comments concerning the IDAGAM I model.

1) The ground combat model in IDAGAM I is more detailed in most respects than those in the CONAF Evaluation and Lulejian-I models, but less detailed than that of the Vector-I model.

2) The air combat model in IDAGAM I is, in our opinion, clearly superior to those in the CONAF Evaluation Model, the Lulejian-I model and the Vector-I model. It incorporates a greater and more consistent level of detail, more plausible assumptions, and a carefully constructed sequence of interactions. The contribution of air forces to the evolution of the ground combat is particularly well represented.

3) The several points at which the model user is offered choices among different underlying assumptions represent at once a singular potential of the IDAGAM I model and its most significant flaw. To this author, the basic idea is superb, but the execution--especially in terms of the report [5]--is inadequate. The opportunity to compare and further understand different assumptions is of great importance, yet the user receives no guidance for making his choices, no mathematical or physical comparison of the assumptions themselves, and no instructions for making empirical comparisons. Instead, he is invited to make those choices that tend to confirm his prejudices and perpetuate his misconceptions. Moreover, in the air combat attrition calculations, the availability of seemingly different but essentially identical alternatives further obscures the

true issues. It should be the first priority to modify the model and especially the documentation to allow full and reasoned use of the capabilities present in the model.

4) In fairness, we wish to point out that the difficulties discussed in 3) above can be minimized by careful and sophisticated choices among the several options. Quite possibly some users are able to make such choices, which must be based upon thorough study and research. However not all potential users can or will make reasoned choices.

5) The ground combat attrition process is interpreted in terms of vaguely defined and uncomputable kill potentials. In IDAGAM I this is a less serious shortcoming than (for example) in the CONAF Evaluation Model and the Lulejian-I model in the sense that potentials need only be known up to a scalar multiple rather than absolutely; nonetheless, alternatives should be sought. Also, more precise and meaningful definitions of the model variables involved are possible but simply don't appear in [5]. Despite its own limitations, the ground attrition process in the Vector-I model is at least based on physically definable quantities. The usual problems of iterative deterministic approximations to expectations of random variables are present in IDAGAM I to no greater or lesser extent than in the three analogous models.

6) Many resource allocations in IDAGAM I are effected by inputs rather than adaptive schemes internal to the model (as is done, in particular, in the CEM and also in the Lulejian-I and Vector-I models). Both approaches have advantages--the former in terms of simplicity and empirical experimentations and the latter in terms of flexibility and realism--as well as disadvantages, so neither is clearly preferred. The point to be noted is that allocation methodology is one point in which IDAGAM I differs rather significantly from the other three models.

7) To a greater extent than the published documentation of the CEM and the Lulejian-I and Vector-I models, the report [5] is explicit and specific about the limitations of the model it describes, about the assumptions underlying IDAGAM I (although not about assumptions underlying attrition equations) and about many of the arbitrary but necessary choices required in construction of any model. In themselves, this explicitness and specificity constitute a significant contribution. The user of IDAGAM I may not agree with all such assumptions and choices, but he at least can deal with them on a rational basis when he is aware of what they are.

8) As do the three other models, IDAGAM I introduces unknown but possibly substantial errors by replacing random variables by their expectations in iterative calculations and by executing events in the same sequence on every day of simulated combat. Within current knowledge there is no way to estimate the errors so arising; in the opinion of the reviewer understanding of the first type is a most pressing need.

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