Application of Computer War Gaming in the Evaluation of Missile Performance Requirements for Air to Air Engagements

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Joy F. Berman
University of Central Florida

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APPLICATION OF COMPUTER WAR GAMING
IN THE EVALUATION OF MISSILE
PERFORMANCE REQUIREMENTS FOR
AIR TO AIR ENGAGEMENTS

BY

JOY F. BERMAN
B.G.S., Rollins College, 1964

RESEARCH REPORT

Submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Graduate Studies Program of
Florida Technological University

Orlando, Florida
1974
ACKNOWLEDGMENT

A special thanks is due two gentlemen whose efforts were a prime factor in the success of the analysis described herein. Mr. Donald M. Cramer presided over my "initiation" into the techniques of war gaming, while Dr. Robert G. McLeod developed the computer model utilized in the analysis simulations.
PREFACE

The bibliography contains publications that were used as references for this paper as well as those which were strictly bibliographic in use. The primary references employed herein could not be cited due to their government classification.
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I. INTRODUCTION

War gaming is by definition the simulation of military engagements between two opposing forces. The concept of war gaming as a decision making tool is probably as old as the practice of war itself. It is believed that even those categorized by historians as primitive peoples employed some means of pictorially representing the scenario of their conflict—perhaps by arrangement of stones, twigs, and berries on the ground—thereby providing for themselves a crude decision making tool. Just as modern warfare began among groups that used printing and the gun, modern war gaming began with the advent of the electronic computer. Aided by computers, more and more strategy complexity has been introduced into the games thereby closely approximating real-life situations. This enhanced capability for simulating the components of complex engagements has resulted in widespread acceptance of the techniques for a diversity of decision making situations ranging from cost effectiveness studies aimed at optimizing quantities of military hardware and personnel to evaluating the performance of a particular weapon such as a missile.

The goal of this paper is to document the application of computer war gaming in evaluating performance effectiveness of a missile being employed as a penetration aid. Specifically, its mission is to defend its launch aircraft (the penetrator) against an opponent's airborne interceptor capability. There is no presumption of uniqueness in the
techniques employed in this analysis nor is it the intent of this paper to imply that the questions prompting this analysis have been fully answered. The parametric output of the analysis was intended to provide a basis for subsequent analyses. Some of these analyses are currently underway.

In any combat situation the best defense is, logically, avoidance. If detection by the opponent does not occur, attack by the opponent will be avoided. If non-detection and hence avoidance cannot be assured, the options available include degrading the opponent's detection capability (such as by radar jamming), or employing the ultimate defense of destroying the opponent's capability for detection. This analysis does not include the degrading option. It does include avoidance and when avoidance becomes infeasible defense of the launch aircraft (penetrator) becomes dependent upon the missile's ability to destroy the opponent's detection equipment.

The detection equipment being avoided or destroyed, as the case may be, is contained in a surveillance aircraft which depends for its defense on airborne interceptors patrolling a designated area relative to the aircraft. High penetration and low penetration scenarios were included in the analysis. The high penetration (or high altitude) scenario is characterized by penetration of the opponent's boundary at high altitude, launching a missile upon detection of the opponent's surveillance aircraft, and post-launch descent to an altitude below the radar horizon of the surveillance aircraft. For the penetrator, high altitude penetration affords fuel economy and permits earlier detection of surveillance aircraft. In the low penetration scenario the penetra-
tor crosses the opponent's boundary at a very low altitude and remains at low altitude after missile launch. Figures 4 and 5 present the representative high penetration results; sample low penetration results appear as Figures 6 through 9.

A simple Monte-Carlo-structured digital computer program was used for the simulations. The Monte Carlo structure was chosen for several reasons: first, little time was allotted for completion of the analysis and a Monte Carlo structure has the property of being relatively quick to implement and is extremely flexible to evolving changes in the requirements for additional output data or sensitivity testing on the important system parameters. The high degree of experimental control and repeatability achievable with this type of approach is conducive to making statistical inferences not fully possible with other methods. An additional factor in the decision was the ever-present problem of budget constraint which limited computer time available for the analysis. Performing the same analysis with a more sophisticated model (a six-degree of freedom missile trajectory program, for example) would have involved a phenomenal amount of computer time.
II. MODEL DESCRIPTION

The computer program logic reflects assumptions and "ground rules" basic to the game. Several of these assumptions and ground rules that are fundamental to the "game" deserve mention at this point. First, penetrator survival is assured if it can detect and kill the surveillance aircraft (SA) prior to SA transmission of a vector to interceptors on patrol. If the SA does detect the penetrator and transmit a vector, penetrator survival is a function of many parameters, including quality of the vector, location of the interceptor relative to the penetrator at the time of last vector receipt, the interceptor closure rate, interceptor sensor performance, number of interceptors engaging the penetrator and number of interceptors engaged by the penetrator's defense system. Outcome of a penetrator-interceptor duel was not included in this analysis. The emphasis was on calculating penetrator exposure time, missile performance required for surveillance aircraft engagement, and number of interceptors that could acquire the penetrator as a function of exposure time.

In the "handgaming" exercises (involving both graphical analysis and hand calculations) which preceded development of the computer model, definitions of missile range and velocity requirements for SA engagement were based on worst case conditions which assumed maximum sensor performance for both the penetrator and surveillance aircraft, highest SA operating altitude, and fixed values for missile launch delay and SA
vector delay times. For this analysis, missile requirements were determined by "randomizing" the critical variables which cannot be assumed to have a fixed magnitude.

An additional assumption or "ground rule" of the "game" is that if the penetrator is detected by the SA the SA continually computes and transmits updated vectors to the interceptor until the SA is killed or the penetrator is acquired by an interceptor. Penetrator/interceptor geometry is shown in Figures 1 and 2.

The program variables listed in Table I are represented in the program as random variables uniformly distributed between fixed bounds. The program calls a random number ranging from 0 to 1 and computes the value of the appropriate variable in accordance with the program equations. Program variables listed in Table II depend on either input or calculated values for their magnitude. Equations for computing penetrator exposure times (TE) and required missile range (RM) vary with the SA tactic being employed in a particular simulation. The program user may elect to simulate a non-diverting SA, the SA tactic of diverting upon penetrator detection, or a third tactic simulating SA divert upon missile detection. Table III presents essential program equations for the non-divert SA tactic.

Upon receipt of all required input quantities, the program determines SA altitude and calculates detection ranges. Penetrator exposure time and missile flight range requirements based on input SA diversion tactic are computed next. The flight range is compared with a range value (input plus DR) representing a postulated missile capability. If the calculated value is less than or equal to the comparison value,
Figure 1.—Basic penetrator/interceptor geometry.
\[ \theta = \tan^{-1}\left(\frac{R}{RI}\right) \]
\[ \phi = \theta + \sin^{-1}\left(\frac{VB - VI}{RI}\sin\theta\right) \]
\[ RS = \frac{RI}{\cos\theta} \]
\[ RC = \frac{RS\sin\theta}{\sin\phi} \]

Figure 2.—Penetrator/interceptor geometry—interceptor forward of penetrator.
<table>
<thead>
<tr>
<th>HS</th>
<th>Surveillance Aircraft Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>RSB</td>
<td>Detection Range of SA by Penetrator</td>
</tr>
<tr>
<td>TMLD</td>
<td>Missile Launch Delay Time</td>
</tr>
<tr>
<td>TAVD</td>
<td>SA Vector Delay Time</td>
</tr>
<tr>
<td>RI</td>
<td>Range of Interceptor Relative to SA (along penetrator flight path)</td>
</tr>
<tr>
<td>R</td>
<td>Lateral Range of Interceptor Relative to SA</td>
</tr>
<tr>
<td>VI</td>
<td>Interceptor Velocity</td>
</tr>
<tr>
<td>Symbol</td>
<td>Definition</td>
</tr>
<tr>
<td>--------</td>
<td>------------</td>
</tr>
<tr>
<td>ATAC</td>
<td>SA Divert Tactic Index</td>
</tr>
<tr>
<td>DR</td>
<td>Range Increment Associated with Missile Flight Range Capability</td>
</tr>
<tr>
<td>DRI</td>
<td>Fixed Increment of Range Associated with Interceptor Location Relative to SA</td>
</tr>
<tr>
<td>DT</td>
<td>Time Increment (Size of exposure time cell)</td>
</tr>
<tr>
<td>DTAVD</td>
<td>Fixed Increment at Time Associated with Vector Delay</td>
</tr>
<tr>
<td>HBI</td>
<td>Initial Penetration Altitude (high level)</td>
</tr>
<tr>
<td>HB2</td>
<td>Low Level Penetration Altitude</td>
</tr>
<tr>
<td>HS</td>
<td>Altitude of SA</td>
</tr>
<tr>
<td>IAC</td>
<td>Interceptor Location Index</td>
</tr>
<tr>
<td>IVV</td>
<td>Interceptor Speed Selection Index</td>
</tr>
<tr>
<td>MEB</td>
<td>Angular Excursion Error of Penetrator after Interceptor Receipts Last Vector</td>
</tr>
<tr>
<td>MES</td>
<td>SA Sensor Resolution Error</td>
</tr>
<tr>
<td>PACQ</td>
<td>Probability of Penetrator Acquisition by Interceptor</td>
</tr>
<tr>
<td>RBS</td>
<td>Detection Range of Penetrator by SA</td>
</tr>
<tr>
<td>RC</td>
<td>Closure Range of Interceptor</td>
</tr>
<tr>
<td>RH</td>
<td>Radar Horizon</td>
</tr>
<tr>
<td>RI</td>
<td>Range of Interceptor from Penetrator Along Penetrator Flight Path at Time of Initial Vector</td>
</tr>
<tr>
<td>RIF</td>
<td>Range of Interceptor Forward of SA</td>
</tr>
<tr>
<td>RL</td>
<td>Missile Launch Range</td>
</tr>
<tr>
<td>RM</td>
<td>Missile Flight Range</td>
</tr>
<tr>
<td>RMM</td>
<td>Minimum Missile Flight Range Capability</td>
</tr>
<tr>
<td>RMS</td>
<td>Detection Range of Missile by SA</td>
</tr>
<tr>
<td>RN</td>
<td>Random Number</td>
</tr>
<tr>
<td>RSB</td>
<td>Detection Range of SA by Penetrator</td>
</tr>
<tr>
<td>SR</td>
<td>Search Range of Interceptor Sensor</td>
</tr>
<tr>
<td>TAVD</td>
<td>SA Vector Delay Time</td>
</tr>
<tr>
<td>Abbreviation</td>
<td>Description</td>
</tr>
<tr>
<td>--------------</td>
<td>-------------</td>
</tr>
<tr>
<td>TE</td>
<td>Penetrator Exposure Time</td>
</tr>
<tr>
<td>TEM</td>
<td>Minimum Exposure Time</td>
</tr>
<tr>
<td>TMLD</td>
<td>Missile Launch Delay Time</td>
</tr>
<tr>
<td>VB</td>
<td>Penetrator Velocity</td>
</tr>
<tr>
<td>VI</td>
<td>Interceptor Velocity</td>
</tr>
<tr>
<td>VM</td>
<td>Missile Average Velocity</td>
</tr>
<tr>
<td>VS</td>
<td>SA Divert Velocity</td>
</tr>
<tr>
<td>DTMLD</td>
<td>Fixed Increment of Time Associated with Missile Launch Delay</td>
</tr>
<tr>
<td>MEI</td>
<td>Mean Angular Error Associated with Interceptor Pilot's Ability to Fly Vector Provided by SA</td>
</tr>
</tbody>
</table>
### TABLE III

**ESSENTIAL PROGRAM EQUATIONS**

#### Detection Ranges

**SA by Penetrator**

\[ RSB = RH1 \times (1 + 0.10 \times RN2) \]

where: \( RH1 = 1.23 \times (\text{SQRT}[HB1] + \text{SQRT}[HS]) \)

**Penetrator by SA**

\[ RBS = 1.23 \times (\text{SQRT}[HB2] + \text{SQRT}[HS]) \]

#### Penetrator Exposure Time - No Divert Tactic

\[ TE = RL/VM - (RL - RBS)/VB1 \]

where: \( RL = RSB - VB1 \times TMLD \)

#### Missile Flight Range

\[ RM = RL \text{ for no divert tactic} \]
then the missile has sufficient range capability to engage the SA. The corresponding exposure time is then employed in the calculation of the number of interceptors which acquire the penetrator. The program records the exposure time and determines the position of the first interceptor, the type of interceptor, computes the interceptor closure time, and determines if the first interceptor engages the penetrator. The interceptor position is determined by employing a series of random numbers which select interceptor coordinates from input boundaries. Three types of interceptors may be selected. If multiple interceptor types are desired, the program employs a random number to select one of three interceptor velocities. These velocities are equivalent to the maximum velocities of known interceptor types. The method of selection is such that all three have an equal probability of being selected. With interceptor velocity selection complete, closure time equations are solved and the program determines, again stochastically, how many interceptors acquire the penetrator as a result of vector information from the SA. The model assigns up to six successive interceptors to engage the penetrator, provided the SA survives long enough. If the SA is killed while an interceptor is being vectored to the penetrator, the probability of its radar acquiring the penetrator is computed as a function of the error in the SA vector to the intercept point, the interceptor distance from the penetrator when the SA is killed, and the range of the interceptor radar in detecting the penetrator.

The preceding processes are repeated for 1000 SA altitudes and
Figure 3a.—Program flow diagram.
Figure 3b.—Program flow diagram.
Figure 3c.--Program flow diagram.
missile launch delay times. Upon completion of all replications, statistics are printed. For each missile range, exposure time and interceptor statistics are tabulated, as well as the number of times missile range is insufficient. Figure 3 presents a simplified diagram of the computer program logic. Computer output for a sample run appears in Appendix A.

The first line of data printout provides the number of replications in which the penetrator exposure time is within two time bounds. Column 1 (of line 1) corresponds to the number of times the exposure time is less than or equal to the minimum input exposure time (TEM). Column 2 of line 1 corresponds to the number of times exposure time is less than or equal to TEM plus input delta (input minimum time plus one increment), so that column 2 presents a cumulative total for one delta t increase over the minimum input exposure time. Similarly, succeeding columns provide cumulative totals for exposure time values between the minimum of column 1 and one delta t over the previous column. The value appearing in column 1 of the second line corresponds to the number of replications in which no interceptors acquire the penetrator; a value in column 2 to the replications in which 1 interceptor acquires the penetrator, and so on up through column 6. Column 7 of line 2 provides the number of replications in which missile range capability was less than range required. The next and succeeding line pairs correspond to larger values of missile range capability (MRC), incremented in steps of range equal to the input value of delta R.
III. SELECTED RESULTS

Figures 4 and 5 are representative of analysis results obtained for the high penetration scenario. Figure 4 depicts, for the SA no divert tactic, boundaries for each of several missile launch altitudes. The range-velocity combinations shown are the minimum values required to assure with the probabilities shown that the missile reaches the SA before the SA detects the penetrator. The probability contours for each altitude were obtained from crossplots (for interpolation) of numerous parametric computer runs in which missile velocity was the only parameter varied. "Success," for this scenario, is the condition of maintaining zero penetrator exposure time coupled with sufficient missile range to engage the SA. An overview of the figure shows the sensitivity of missile performance requirements to changes in launch altitude. An increase in launch altitude from 2500 to 5000 feet dramatically reduces the velocity required to achieve the same success probability, but imposes an increased range requirement. As launch altitude is increased to 5000 feet the incremental effect of launch altitude on missile performance requirements is less pronounced. It should be noted that on each constant probability contour the vertical portion represents a minimum range boundary such that any increase in velocity is of no value in reducing the range capability requirement. Mathematically, $\frac{\partial R}{\partial V} = 0$ (where $R =$ minimum range required and $V =$ velocity) on this portion of the contour. Conversely, along the
Figure 4.—Missile performance requirements for high altitude launch.

NOTE: Actual values for missile range and velocity eliminated due to security classification.
Figure 5.—Minimum velocity performance boundaries for penetrator non-detection at high altitude launch.
horizontal portion, any increase in minimum missile range capability does not diminish the velocity requirement. Here, $\frac{\partial V}{\partial R} = 0$ ($V =$ minimum missile velocity requirement, $R =$ missile range capability). A "failure" along the vertical portion is due to inadequate range, while a "failure" along the horizontal portion is due to insufficient missile velocity. The optimum point along each contour occurs in the region of greatest curvature. With increasing probability of success, this region becomes smaller so that when the probability of success is 1.0 the "region" is a single point characterized by a unique combination of minimum required velocity and range capability. The coordinates describing the constant probability contours of Figure 5 are represented in Figure 4 by the horizontal portion of each probability boundary where range is always sufficient, and failures are a result of non-zero exposure time due to insufficient velocity.

Figures 6 through 9 are representative low penetration scenario data. Since for this scenario achieving penetrator exposure of zero is not feasible (exposure may occur after missile launch) a new definition of "success" must be established. Probability of success, or "confidence level" refers to the combined probability of sufficient missile range to engage the SA and assurance that penetrator exposure time will never be greater than a particular discrete value. Figure 6 is a parametric illustration of the change in achievable maximum exposure times as missile performance changes. The varying parameters are missile velocity and range. The figure also illustrates, for discrete exposure times, the change in achievement probability as performance changes. While Figure 6 is for the SA no divert tactic, similar results were obtained
Figure 6.—Effect of missile performance on penetrator exposure time—no divert tactic.
Confidence level denotes probability of range sufficiency and assurance that penetrator exposure time is less than indicated value.

NOTE: Actual values for missile range and velocity eliminated due to security classification.

Missile Range (nautical miles)

Missile Velocity (feet per second)

<table>
<thead>
<tr>
<th>Confidence Level</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
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<tr>
<td>6</td>
<td></td>
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</tr>
<tr>
<td>12</td>
<td>12</td>
<td>12</td>
<td></td>
</tr>
</tbody>
</table>

Note: numbers 6-12 are penetrator exposure time in minutes.

Figure 7.—Effect of missile performance on penetrator exposure time—no divert tactic.
for the other two SA tactics. The data of Figure 6 was interpolated to extract, for a discrete set of probabilities (confidence levels) and a limited range of exposure times, the minimum performance required to achieve particular combinations of exposure time and confidence level. Figure 7 is an example of results obtained from the interpolation. As was the case with Figure 4, a "failure" on the vertical portion of the boundary is due to insufficient range while a "failure" on the horizontal portion of a boundary signifies that missile velocity is insufficient to assure achieving the exposure time designated by the boundary label. Figure 8 is an example of the interceptor allocation data derived from low penetration scenario simulations. The number of penetrators vectored by the SA to the penetrator is a function of penetrator exposure time, interceptor location and velocity, interceptor radar range and the vectoring accuracy of the SA. At the reference velocity, the probability of assuring engagement by 0 or no more than 1 interceptor is 0. However, there is a high probability of assuring engagement by no more than 2 interceptors. As velocity is increased, the probability of engagement by 0 or no more than 1 interceptor also increases. Interpolating the data of Figure 8 for specified confidence levels (probabilities) yielded velocity-range combinations necessary to assure that no more than 1 interceptor will engage the penetrator. Figure 9 is representative of such interpolations for the no divert tactic.
Figure 8.—Effect of missile performance on penetrator vulnerability to interceptor engagement—no divert tactic.
Figure 9.—Missile performance required to assure penetrator engagement by no more than 1 interceptor for specific confidence levels—no divert tactic.
IV. CONCLUSIONS

The analysis was deemed a successful venture in that the desired result was achieved. Namely, a basic set of parametric data was generated which provided the genesis for additional analyses. In retrospect, the time element involved in interpolating data from a vast quantity of simulations could have been significantly reduced by the addition of some interpolation routines into the computer model structure, thus eliminating much of the crossplot drudgery encountered.

Many desirable options could be added to the model, such as inclusion of a missile-interceptor duel option. However, with the addition of too much sophistication or too numerous options the model would lose its primary virtue—that of being a simple, efficient analysis tool.
### APPENDIX A

Sample Program Output

```
1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
2 1 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
3 2 2 0 0 0 0 0 0 0 0 0 0 0 0 0 0
4 3 3 0 0 0 0 0 0 0 0 0 0 0 0 0 0
5 4 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0
6 5 5 0 0 0 0 0 0 0 0 0 0 0 0 0 0
7 6 6 0 0 0 0 0 0 0 0 0 0 0 0 0 0
8 7 7 0 0 0 0 0 0 0 0 0 0 0 0 0 0
9 8 8 0 0 0 0 0 0 0 0 0 0 0 0 0 0
10 9 9 0 0 0 0 0 0 0 0 0 0 0 0 0 0
11 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
12 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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14 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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16 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
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