

AD-A244 457



IDA PAPER P-2621

DTIC
ELECTE
DEC 3 1991
S C D

2

A STUDY OF THE EFFECTS OF TERRAIN ON
MECHANIZED COMBAT USING
THE JANUS SYSTEM

D. Sean Barnett, *Project Leader*

David Gray

September 1991

Approved for public release; distribution unlimited.



INSTITUTE FOR DEFENSE ANALYSES
1801 N. Beauregard Street, Alexandria, Virginia 22311-1772

91-16802

91 11 29 052

IDA Log No. HQ 91-39502

DEFINITIONS

IDA publishes the following documents to report the results of its work.

Reports

Reports are the most authoritative and most carefully considered products IDA publishes. They normally embody results of major projects which (a) have a direct bearing on decisions affecting major programs, (b) address issues of significant concern to the Executive Branch, the Congress and/or the public, or (c) address issues that have significant economic implications. IDA Reports are reviewed by outside panels of experts to ensure their high quality and relevance to the problems studied, and they are released by the President of IDA.

Group Reports

Group Reports record the findings and results of IDA established working groups and panels composed of senior individuals addressing major issues which otherwise would be the subject of an IDA Report. IDA Group Reports are reviewed by the senior individuals responsible for the project and others as selected by IDA to ensure their high quality and relevance to the problems studied, and are released by the President of IDA.

Papers

Papers, also authoritative and carefully considered products of IDA, address studies that are narrower in scope than those covered in Reports. IDA Papers are reviewed to ensure that they meet the high standards expected of refereed papers in professional journals or formal Agency reports.

Documents

IDA Documents are used for the convenience of the sponsors or the analysts (a) to record substantive work done in quick reaction studies, (b) to record the proceedings of conferences and meetings, (c) to make available preliminary and tentative results of analyses, (d) to record data developed in the course of an investigation, or (e) to forward information that is essentially unanalyzed and unevaluated. The review of IDA Documents is suited to their content and intended use.

The work reported in this publication was conducted under IDA's Independent Research Program. Its publication does not imply endorsement by the Department of Defense, or any other Government agency, nor should the contents be construed as reflecting the official position of any Government agency.

This Paper has been reviewed by IDA to assure that it meets high standards of thoroughness, objectivity, and appropriate analytical methodology and that the results, conclusions and recommendations are properly supported by the material presented.

REPORT DOCUMENTATION PAGE			Form Approved OMB No. 0704-0188	
Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.				
1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE September 1991		3. REPORT TYPE AND DATES COVERED Final
4. TITLE AND SUBTITLE A Study of the Effect of Terrain on Mechanized Combat Using the Janus System			5. FUNDING NUMBERS Independent Research	
6. AUTHOR(S) D. Sean Barnett, David Gray				
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Institute for Defense Analyses 1801 N. Beauregard St. Alexandria, VA 22311-1772			8. PERFORMING ORGANIZATION REPORT NUMBER IDA Paper P-2621	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) Institute for Defense Analyses 1801 N. Beauregard St. Alexandria, VA 22311-1772			10. SPONSORING/MONITORING AGENCY REPORT NUMBER	
11. SUPPLEMENTARY NOTES				
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited.			12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) This study used the Janus combat simulation to examine the effects of terrain on tactical mechanized combat and to adapt the IDA Variable Force eployment (VFM) combat model to simulate combat in Southwest Asia and Korea. The authors simulated 500 battalion-level engagements in Southwest Asia and Korea and compared those results with the results of 350 engagements simulated in Central Europe in two earlier IDA studies. The following were found in all theaters: armor-heavy forces suffered fewer casualties in mounted assaults than did balanced or infantry-heavy forces; attacking casualties were proportional to increases in defending artillery and decreases in attacking artillery; in slow dismounted assaults, artillery caused more casualties on both sides than ground fire and casualties were independent of the force sizes; otherwise, for an attacking force of a given size, casualties were roughly proportional to the defender's force size. Attack helicopters and individual air defense units were more effective in Southwest Asia than in Europe or Korea. Early defensive withdrawal from ground engagements was more effective in Southwest Asia and Europe than in Korea. To first order, attacking forces suffered more from disorder as they penetrated defensive positions in Europe or Korea than in Southwest Asia.				
14. SUBJECT TERMS Terrain, tactical, mechanized, combat, VFM, Janus, simulation, model, Europe, Southwest Asia, Korea			15. NUMBER OF PAGES 184	
			16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT UNCLASSIFIED	18. SECURITY CLASSIFICATION OF THIS PAGE UNCLASSIFIED	19. SECURITY CLASSIFICATION OF ABSTRACT UNCLASSIFIED	20. LIMITATION OF ABSTRACT SAR	

IDA PAPER P-2621

A STUDY OF THE EFFECTS OF TERRAIN ON MECHANIZED COMBAT USING THE JANUS SYSTEM

D. Sean Barnett, *Project Leader*

David Gray

September 1991

Accession For	
DTIC	☒
DTIC Tab	☐
Unpublished	☐
Classification	
By	
Distribution	
Classification Code	
Availability Code	
Dist	Special
A-1	

Approved for public release; distribution unlimited.



INSTITUTE FOR DEFENSE ANALYSES

IDA Independent Research Program



PREFACE

This paper, prepared under the IDA Independent Research Program, documents the use of the Lawrence Livermore National Laboratory Janus combat simulation to examine the effects of terrain on tactical mechanized combat and to adapt the IDA Variable Force eMployment (VFM) combat model to simulate combat in Southwest Asia and Korea. The authors simulated 500 battalion-level engagements using digitized maps of real terrain in Southwest Asia and Korea and deduced the influence of terrain by comparing the results in those two theaters with the results of 350 engagements in Central Europe simulated in two earlier IDA studies.

The authors would like to thank Col. Willard Christenson, Dr. David Sparrow, and Dr. Joel Tumarkin of IDA for their helpful reviews. Col. Christenson's advice regarding the Janus simulation, his operational assistance, and his accommodation of the authors' project schedule were greatly appreciated. Lastly, the authors would like to thank Ms. Shelley Smith for her editing and Mrs. Renee Harper for her assistance in the preparation of the paper.

CONTENTS

Preface	iii
Executive Summary	ES-1
 I. INTRODUCTION	 I-1
 II. BACKGROUND	 II-1
A. Terrain Effects on Tactical Combat.....	II-1
1. General Effects of Terrain on Tactical Combat.....	II-1
2. Terrain Effects on Operations of Different Unit Types.....	II-3
3. Use of Terrain in Specific Military Operations	II-4
4. Effects of Deserts and Mountains on Tactical Combat.....	II-5
a. Deserts	II-6
b. Mountains	II-7
B. The Variable Force eMployment Combat Model.....	II-9
1. Theoretical Basis of VFM.....	II-10
2. A Theater Offensive as Modeled by VFM.....	II-12
 III. APPROACH.....	 III-1
A. Apparatus.....	III-1
B. Procedures.....	III-2
1. Design of the Experiment	III-2
a. Rationale for the Scenario Types.....	III-4
b. Rationale for the Scenario Variables.....	III-5
2. Design of the Scenarios	III-8
3. Terrain Types.....	III-11
a. Central Europe.....	III-11
b. Southwest Asia.....	III-13
c. Korea	III-15

IV. RESULTS	IV-1
A. Experimental Data	IV-1
1. Assault on a Defensive Position.....	IV-1
2. Assault on Successive Defensive Positions.....	IV-3
3. Withdrawal from Ground Engagements.....	IV-3
4. Withdrawal and Helicopter Pursuit	IV-4
B. Experimental Limitations and Error	IV-32
1. Janus Experiments	IV-32
2. VFM Coefficients	IV-33
3. The Effects of Weapon Quality.....	IV-36
C. Data Analysis.....	IV-38
1. Terrain Effects upon Attacker Casualties.....	IV-39
2. Terrain Effects upon Defensive Withdrawal	IV-44
3. A Side Note on the Issue of Technology.....	IV-48
V. CONCLUSIONS	V-1
A. Terrain Effects upon Tactical Combat.....	V-1
B. Implications for Future U.S. Force Structure.....	V-3

Appendices

- A. TACTICAL COMBAT COEFFICIENTS FOR THE VFM COMBAT MODEL
- B. JANUS SCENARIO DATA

Tables

III-1. Scenario Types and Combat Variables.....	III-11
IV-1. Number of Vehicles, Helicopters and ADUs in the Helicopter Pursuit Scenarios	IV-4
IV-2. Average Casualties in Assaults as a Function of Technology	IV-49

Figures

IV-1.	Force Composition Effects, Central Europe.....	IV-5
IV-2.	Force Composition Effects, Southwest Asia.....	IV-6
IV-3.	Force Composition Effects, Korea.....	IV-7
IV-4.	Artillery Effects, Central Europe.....	IV-8
IV-5.	Artillery Effects, Southwest Asia.....	IV-9
IV-6.	Artillery Effects, Korea.....	IV-10
IV-7.	Force Ratio Effects, Central Europe.....	IV-11
IV-8.	Force Ratio Effects, Southwest Asia.....	IV-12
IV-9.	Force Ratio Effects, Korea.....	IV-13
IV-10.	Assault upon Successive Lines, Central Europe.....	IV-14
IV-11.	Assault upon Successive Lines, Southwest Asia.....	IV-15
IV-12.	Assault upon Successive Lines, Korea.....	IV-16
IV-13.	Withdrawal from Ground Engagements, Central Europe.....	IV-17
IV-14.	Withdrawal from Ground Engagements, Southwest Asia.....	IV-18
IV-15.	Withdrawal from Ground Engagements, Korea.....	IV-19
IV-16.	Helicopter Pursuit, Central Europe.....	IV-20
IV-17.	Helicopter Pursuit, Southwest Asia.....	IV-21
IV-18.	Helicopter Pursuit, Korea.....	IV-22
IV-19.	Withdrawal and Air Defense, Central Europe.....	IV-23
IV-20.	Withdrawal and Air Defense, Southwest Asia.....	IV-24
IV-21.	Withdrawal and Air Defense, Korea.....	IV-25
IV-22.	Pursuit and Helicopter Losses, Central Europe.....	IV-26
IV-23.	Pursuit and Helicopter Losses, Southwest Asia.....	IV-27
IV-24.	Pursuit and Helicopter Losses, Korea.....	IV-28
IV-25.	Air Defense and Helicopter Losses, Central Europe.....	IV-29
IV-26.	Air Defense and Helicopter Losses, Southwest Asia.....	IV-30
IV-27.	Air Defense and Helicopter Losses, Korea.....	IV-31

EXECUTIVE SUMMARY

A. INTRODUCTION

It has long been established, that terrain significantly influences the way armed forces conduct combat. To best plan future U.S. force structure and weapon system acquisition, military planners must understand fully the influence of the environments in which those forces and weapon systems will operate.

The Institute for Defense Analyses (IDA) performed this study to expand the body of knowledge regarding the effects of terrain upon modern tactical mechanized combat. The study had two goals. The first was to quantify effects known qualitatively by military planners and to observe heretofore unidentified differences between combat taking place in different types of terrain. The second was to derive tactical combat coefficients for the Variable Force eMployment (VFM) theater-level combat model developed at IDA. IDA originally developed VFM to model combat in Central Europe.¹ In light of recent political events, the study sought to expand the model to address combat in Southwest Asia and Korea.

The authors used Janus, an interactive, brigade-level, two-sided, stochastic computer combat simulation developed at Lawrence Livermore National Laboratory (LLNL), to perform controlled experiments in which they simulated 850 battalion-level engagements over digitized maps of real terrain in Central Europe, Southwest Asia, and Korea.² The study chose those three theaters for two reasons. First, they are potential sites for commitment of U.S. forces. Second, the terrain differs greatly between them in terms of topography, vegetation, and human development.

¹ S. D. Biddle et al., *Defense at Low Force Levels*, IDA Paper P-2380, August 1991, and S. D. Biddle et al., *Stabilizing and Destabilizing Weapons*, IDA Paper P-2548, September 1991.

² Janus combat data for Korea and Southwest Asia (500 engagements) were collected under this study. Data for Europe (350 engagements) were collected under two previous IDA studies, under which VFM was also developed. Biddle et al., *Defense at Low Force Levels* and Biddle et al., *Stabilizing and Destabilizing Weapons*, describe those studies. This paper presents all of the Janus data for Europe analogous to that collected for Southwest Asia and Korea.

The simulated engagements, or scenarios, included assaults upon single defensive positions, assaults upon successive defensive positions, defensive withdrawals from ground engagements, and defensive withdrawals with helicopter pursuit. The authors ran the assault scenarios over a matrix of different attacking and defending force mixes of armor and infantry, attacker:defender force ratios, and tactics employed by the attacker. They ran the helicopter pursuit scenarios over a matrix of tactical force ratios and defending weapon mixes. The results of the engagements were expressed in terms of the attacker's and defender's casualties and, in the case of assaults upon single defensive positions, in terms of the time it took the attacker to take the defender's position.

After performing the experiments the authors compared the results across the three theaters and deduced the effects of terrain. They drew conclusions regarding the performance, as influenced by terrain, of the weapon systems included in the study and assessed the implications for future U.S. heavy force structure. Lastly, they fit curves to the casualty data to enable the VFM model to predict tactical combat outcomes in Southwest Asia and Korea.

B. APPROACH

This section describes the Janus system and the procedures we used to perform the Janus scenarios.

1. Apparatus

The LLNL Janus combat simulation is described as follows in the model's users manual:

[Janus is] an interactive, brigade level, two sided game created to explore relationships of combat and tactical processes using a stand-alone, event sequenced, stochastic, computer simulation... Janus is an event-driven simulation that models fighting systems as entities (tank, helicopter, howitzer, etc). Entity characteristics include descriptions of the weapons carried, weapon capabilities, movement speeds and how they are attenuated by terrain effects, accountability of ammunition and fuel, crew performance, sensor data describing how the battlefield is observed, as well as supply/resupply data.³

³ *Janus Users Manual, Version 4.0*, Lawrence Livermore National Laboratories, Livermore, CA, January 4, 1988, p. 1.

Janus calculates movement rates and intervisibility using digitized Defense Mapping Agency representations of actual terrain. It incorporates explicitly surface features such as rivers, roads, towns, and vegetation and terrain elevation features such as hills, plains, and ravines. Janus displays the progress of the battle across this terrain with high resolution, real-time graphics. The authors used Janus Version 5.0 and the unclassified Janus database for this study.⁴

Although one can run Janus as an interactive game, the authors conducted all experimental runs as closed simulations; i.e., movement and engagement orders, dismount points and artillery preparations were determined as scenario conditions and were not changed during the course of any of the runs of a given scenario.

2. Methodology

The two objectives of the study shaped the design of the experiment. The first objective was to quantify terrain effects upon tactical mechanized combat, so the experiment (Janus simulations) had to cover the range of tactical engagements that would likely be fought on a modern battlefield. The second objective was to derive tactical combat coefficients for the VFM combat model for the Southwest Asian and Korean theaters.

This study simulated 500 battalion-level engagements using digitized maps of real terrain in Southwest Asia and Korea. The authors grouped the engagements into four types of scenarios likely to be fought on the modern battlefield: attacks upon single fixed defensive positions, attacks upon successive defensive positions, defensive withdrawal from ground engagements, and defensive withdrawal with helicopter pursuit. A brief description of each follows.

Assault of a single defensive line. This scenario type was designed to evaluate terrain effects on the basic tactical combat operation of an attacker taking a defensive position. In each scenario a defensive force, ranging in size from a reinforced platoon to two companies, established a fixed position on a given patch of terrain. Attacking forces were organized as a series of battalion-sized waves. Terrain effects were expressed in terms of the casualties in armored fighting vehicle equivalents (AFVEs) suffered by the attacker and the time it took him to take the position, where one AFVE was equal to one

⁴ During the Janus experiments, the progress of the battle was displayed on the screen of a Tektronix 4225 workstation, while a DEC Vaxstation 3100 Model 76 computer performed the supporting calculations.

tank or one infantry fighting vehicle plus its infantry squad. We performed 38 assault scenarios in Southwest Asia and 39 in Korea.

Assaults of successive defensive lines. This scenario type was intended to evaluate terrain effects on the increasing disorder, and subsequent loss of combat effectiveness, of an attacking force as it penetrates a defensive position. In the scenarios, three defensive positions similar to those described above were established, one behind the other, separated by a distance of 3 to 5 kilometers each. The attacking force, again organized in battalion-sized waves, advanced against the successive positions. The measure of disorder was, as a function of the depth of penetration into the defense, the increase in the attacker's casualties suffered when taking the last defensive position (after advancing through the defense) over those that were suffered taking the same position without having to advance through the defense.⁵ We performed 27 successive assault scenarios in Southwest Asia and 37 in Korea.

Defensive withdrawal from ground engagement. This scenario type measured the effect of defending units' withdrawal from a position before they were totally defeated. In real combat a defender may wish to do so to preserve his strength or to take advantage of a favorable loss exchange ratio with the attacker at long range. The effect of early defensive withdrawal was assessed by correlating attacker and defender casualties (in AFVEs) over time during each engagement. That way it was possible to determine how many fewer casualties an attacker would suffer if a defending force withdrew from a position before it was totally defeated (as it was in the single assault scenarios). We ran 14 withdrawal engagements in Southwest Asia and 11 in Korea.

Defensive withdrawal and helicopter pursuit. This scenario type measured the effectiveness of the attacker's pursuit of withdrawing defending units with attack helicopters. In these scenarios, pursuing helicopters engaged withdrawing vehicles and air defense units (ADUs), and the defender's ADUs, and vehicles in rearward positions engaged the helicopters. Defender casualties were assessed as AFVEs lost after the commencement of withdrawal. Attacker casualties were assessed in terms of individual helicopters lost during the pursuit mission. We performed six pursuit scenarios in Southwest Asia and five in Korea.

⁵ This was necessarily a point of departure in measuring terrain effects on disorder, as Janus does not simulate all of its causes or effects (e.g., reduced coordination of supporting artillery fire, psychological or workload effects on the attacking soldiers, loss of communication between commanders and units.) See Chapter III for a detailed discussion.

To define the scenarios the study had to select variables that affected tactical combat outcomes and whose effects Janus could simulate.⁶ The study explored the combat variables of *force composition*, *force ratio*, and *attacking tactics*. Within each scenario type, each scenario represented a unique combination of terrain and combat variables. *Force composition* is defined as the relative numbers of types of weapon systems (e.g., tanks, IFVs, infantry, helicopters and artillery) on each side in each scenario. *Force ratio* is defined as the ratio of the number of AFVEs on each side. *Attacking tactics*, in assaults of single lines, is defined as the attack velocity, or the distance an attack progresses to take the position, divided by the time it takes to do so.

The study explored a range of combinations of values of the different combat variables in the scenarios. In the assault scenarios the study examined the following combinations: the fraction attacking and defending AFVEs that were infantry (as opposed to armor) and attack velocity, force ratio and attack velocity, amount of artillery and attack velocity, and number of attack helicopters and attack velocity. In the scenarios of defensive withdrawal with helicopter pursuit, the study varied the number of attack helicopters pursuing and the number of ADUs supporting the withdrawing defenders. In the successive assault and withdrawal from ground engagement scenarios force composition, force ratio and attacking tactics were held constant.

C. RESULTS, CONCLUSIONS, AND IMPLICATIONS FOR FUTURE U.S. FORCE STRUCTURE

1. Results and Conclusions

The following major conclusions derived from the analysis of the results of the Janus scenarios performed in Central Europe, Southwest Asia, and Korea. As the study did not explore the entire matrix of equipment, tactics and direction of advance in all three theaters (see Chapters III and IV), some of the conclusions are necessarily preliminary pending future Janus work.

- *Attack helicopters are more effective in Southwest Asia than in Europe or Korea.* The openness of the desert in Southwest Asia and the ruggedness of the hills in Korea directly affected the results of the withdrawal scenarios. Attack helicopters in Southwest Asia pursued and destroyed withdrawing

⁶ This necessarily excluded intangible variables such as quality of command and control, troop training, or morale.

forces up to three times their number in size. Helicopters in Europe generally destroyed a number of vehicles equal to their number, while helicopters in Korea destroyed somewhat fewer and never completely eliminated a withdrawing force. However, these results are preliminary as they were probably influenced by the difference in performance between Soviet and U.S. helicopters.

- *Individual air defense units are more effective in Southwest Asia than in Europe or Korea.* The theater topography significantly affected the performance of air defense units. At typical levels of air defense (1 ADU per 5 to 10 vehicles), helicopters suffered losses on pursuit missions of approximately 40 percent, 20 percent, and 15 percent in Southwest Asia, Europe and Korea. However, at higher levels of air defense, losses were roughly equivalent (50 to 90 percent) in all theaters. Moreover the marginal return on additional air defense units decreased as the number of ADUs approached the number of helicopters.
- *Early defensive withdrawal from ground engagements is most effective in relatively open terrain, like that in Southwest Asia and even Central Europe, than in closer terrain, like that in Korea.* The measure of effectiveness of withdrawal was the attacker's cumulative casualties from the beginning of the scenario, normalized to the number he would take if the defender fought to the death, compared with the fraction of the defending force surviving (and presumably withdrawing from combat) at any given time. In the experiments, withdrawal was most effective in Central Europe, followed by Southwest Asia and Korea. The results of the Southwest Asian scenarios were probably influenced by the use of effectively longer ranged U.S. weapon systems on the attack; Soviet weapon systems were used in the other theaters.
- *To first order, attacking forces suffer more from disorder as they penetrate defensive positions in terrain with obstacles, like that in Central Europe or Korea, than they do in terrain without, like that in Southwest Asia.* Attacking casualties were found to increase at a rate of roughly 8 percent per kilometer of penetration in Europe and a rate of 5 percent per kilometer in Southwest Asia. However, as Janus cannot simulate all of the phenomena that cause disorder among attacking forces, this conclusion is preliminary pending further study.
- *Changes in ground force composition affect combat outcomes similarly in all three theaters.* Changes in the fraction of infantry of both sides affected combat significantly at high velocities, but little at low velocities. Armor-heavy forces suffered about 30 percent fewer casualties in high velocity attacks than did balanced forces.
- *Changes in artillery support affect combat outcomes similarly in all three theaters.* Beginning with a typical level of artillery support for the attacker and

the defender, halving the attacking artillery or doubling the defending artillery resulted in twice as many casualties for the attacker as did doubling the attacking artillery or halving the defending artillery. Moreover, at the lowest attack velocities, artillery caused more casualties on both sides than ground fire and attacking casualties actually increased as velocity decreased.

- *Changes in the attacker: defender force ratio affect combat outcomes similarly in all three theaters.* Above the lowest attack velocities, the attacker's casualties were found to be roughly proportional to the defender's force level, given an attacking force of constant initial size. At the lowest velocities, casualties were dominated by artillery and were relatively independent of the size of the defending force.

2. Implications for Future U.S. Force Structure

In the future, as the U.S. pulls forces back from overseas deployments, the force structure shrinks, and DoD emphasizes planning more for contingencies than for a global conflict with the Soviet Union, U.S. ground forces will have to be geared even more than now to deploy and fight in different environments. Thus, it is important to look at the impact of terrain upon tactical combat in all of the major theaters where U.S. forces might be expected to fight.

First consider the areas of force structure most affected by terrain in the Janus scenarios: helicopters and air defense. The data indicated that helicopters are both more effective and more vulnerable in the open desert of Southwest Asia than they are in Europe or Korea. In Europe helicopters were also effective on defense and in pursuit, although not as effective as in Southwest Asia. In Korea helicopters were less effective in pursuit but still effective on defense. However, in both Europe and Korea helicopters were about half as vulnerable to typical levels of air defense as in Southwest Asia, although high levels of air defense inflicted heavy losses on the helicopters in all theaters. Helicopters were effective on the tactical defensive in all three theaters, so they should support ground forces wherever one could expect an armored or mechanized enemy attack. Whether or not to use helicopters in pursuit and how to do so is a question of doctrine rather than force structure, but the effectiveness of helicopter pursuit varied across theaters so doctrine should reflect that fact.

Regarding air defense, units attacking in all theaters should be provided with higher levels of air defense to protect themselves from highly effective attack helicopters. Units defending, and perhaps withdrawing, in the desert or in Europe should also be provided with higher levels of air defense than are now typical. Even a relatively small number of

ADUs can inflict serious losses on a helicopter force in the desert. Those units may not be able to protect themselves from pursuing helicopters directly, but if the enemy knows he will pay a high price in helicopters he may be deterred from pursuing. Defending units in Europe with higher levels of air defense may actually be able to protect themselves. In Korea, on the other hand, pursuit was of limited effectiveness, so the provision of a high level of air defense to defending units is not as critical as in the other theaters. With the preceding in mind, it should be remembered that a defender begins to get diminishing marginal returns as the number of ADUs approaches the number of helicopters. The data indicate that this began to happen at a level of one ADU per three helicopters, which was roughly equivalent in the Janus scenarios to one ADU per three ground AFVEs.

Next consider the composition of the ground maneuver forces: infantry, infantry fighting vehicles (IFVs), and tanks. The data indicated that in all theaters armor-heavy forces were more effective than balanced or infantry-heavy forces at performing mounted assaults and that armor-heavy forces were at least as effective as balanced or infantry-heavy forces at performing dismounted assaults in the face of significant amounts of defending artillery. Consequently, heavy ground forces should have a higher fraction of armor than infantry: the armor is more effective on the attack and on the defense one could still put a balanced force forward and maintain an armor-heavy reserve for counterattack. However, given that IFVs are more vulnerable to artillery than are tanks, an armor heavy defense may be desirable as well. Lastly, and most importantly from the perspective of this work, these results suggest that ground forces perform equally well in all three theaters. Thus future U.S. heavy forces would not have to be tailored or "earmarked" for potential major theaters of operation—any given unit could be sent to any given theater.⁷ This flexibility would also allow the U.S. to maintain smaller ground forces—outside of consideration of simultaneous conflicts, forces with duplicate capabilities would not be needed for each theater.

Last, consider artillery. In all theaters and at all but the highest attack velocities, where artillery bombardment times were very short, attacking casualties were sensitive to the levels of artillery support on both sides. At low attack velocities artillery caused more casualties on both sides than did ground fire. From these results it is obvious that maneuver forces should be supported by as much artillery as possible within other military

⁷ This pertains to equipment and troop combat training. Troops would still have to be trained to deal with particularly harsh environments like those of the desert or of high mountains.

or budgetary constraints. Furthermore, given the effectiveness of artillery, and particularly improved conventional munitions, against dismounted infantry, light (leg infantry) forces could be expected to suffer heavy casualties in the attack unless the defending artillery was heavily suppressed by counterbattery fire, air attack, or some other means. Lastly, like the results for ground forces, these results imply that U.S. artillery support for heavy forces would not have to be tailored to major potential theaters of operation.

This study's recommendations regarding future U.S. force structures do not differ greatly from the conventional wisdom. Only the recommendations to procure all armor-heavy forces and to increase the amount of air defense provided to ground units conflict with the existing heavy force structure. The study results suggest that light forces would not fare well in combat against an enemy well supported with artillery, but the study did not specifically simulate combat with light forces.

I. INTRODUCTION

It has long been established that terrain significantly influences the way armed forces conduct combat. In order to best plan future U.S. force structure and weapon system acquisition, military planners must understand fully the influence of the environments in which those forces and weapon systems will operate.

The Institute for Defense Analyses (IDA) performed this study to expand the body of knowledge regarding the effects of terrain upon modern tactical mechanized combat. The study had two goals. The first was to quantify effects known qualitatively by military planners and to observe heretofore unidentified differences between combat taking place in different types of terrain. The second was to derive tactical combat coefficients for the Variable Force eMployment (VFM) theater-level combat model developed at IDA. IDA originally developed VFM to model combat in Central Europe. In light of recent political events this study sought to expand the model to address combat in Southwest Asia and Korea.¹

The authors used the Janus combat simulation, developed at Lawrence Livermore National Laboratory (LLNL), to perform controlled experiments in which they simulated 850 battalion-level engagements over digitized maps of real terrain in Central Europe, Southwest Asia, and Korea.² The study chose those three theaters for two reasons. First, they are potential sites for commitment of U.S. forces. Second, the terrain differs greatly between them in terms of topography, vegetation, and human development.

Janus is an interactive, brigade-level, two-sided, stochastic computer combat simulation. It models fighting systems (e.g., tanks, helicopters, howitzers, and infantrymen) as individual entities. Fighting systems move over digitized terrain as

¹ Southwest Asia is the area of responsibility defined in the charter for the U.S. Central Command (USCENTCOM) and includes, among other nations, Iran, Iraq, Saudi Arabia and Kuwait. Those nations are also often referred to as part of the Middle East.

² Janus combat data for Korea and Southwest Asia (500 engagements) were collected under this study. Data for Europe (350 engagements) were collected under two previous IDA studies, under which VFM was also developed. S.D. Biddle et al., *Defense at Low Force Levels*, IDA Paper P-2380, August 1991, and Biddle et al., *Stabilizing and Destabilizing Weapons*, IDA Paper P-2548, September 1991, describe those studies. This paper presents all of the Janus data for Europe analogous to that collected for Southwest Asia and Korea.

programmed by the Janus user and attempt to acquire and fire upon each other. System characteristics in Janus include descriptions of the weapons carried, weapon capabilities, movement speeds, ammunition and fuel supplies, crew performance, battlefield sensor data, and supply/resupply data.³

The simulated engagements, or scenarios, included assaults upon single defensive positions, assaults upon successive defensive positions, defensive withdrawals from ground engagements, and defensive withdrawals with helicopter pursuit. The authors ran the single position assault scenarios over a matrix of different attacking and defending force mixes of armor and infantry, attacker:defender force ratios and tactics employed by the attacker (in terms of the speed at which the attacker took the defending position). They ran the helicopter pursuit scenarios over a matrix of tactical force ratios, and defending weapon mixes. The results of the engagements were expressed in terms of the attacker's and defender's casualties and, in the case of the single position assault scenarios, in terms of the time it took the attacker to take the defender's position.

After performing the experiments the authors compared the results across the three theaters and deduced the effects of terrain. They drew conclusions regarding the performance, as influenced by terrain, of the weapon systems included in the study and assessed the implications for future U.S. heavy force structure. Lastly, they fit curves to the casualty data to enable the VFM model to predict tactical combat outcomes in Southwest Asia and Korea.

This study could have used historical case studies of combat, but a computer simulation like Janus offered some decided advantages. First, Janus enabled the authors to run the same scenarios in each type of terrain and thus eliminate other variables that could have influenced the outcome of the engagements; that is, they were able to "change terrain while holding all other things constant." Second, the authors were able to collect numerical data thoroughly and consistently for all of the scenarios, whereas the data in historical records often are imprecise or incomplete. Third, the authors could repeat Janus scenarios as often as desired to eliminate stochastic variations in the data; each historical incident occurred only once.

Lastly, the reader should note that, while the authors recognize that urban areas could be important military objectives in the three potential theaters of combat studied, this

³ *Janus Users Manual, Version 4.0*, Lawrence Livermore National Laboratories, Livermore, CA, January 4, 1988, p. 1.

analysis does not address combat in built up areas, except as it occurred in the villages or small towns present on the Janus maps. Additionally, this study examines conventional combat only and thus does not address nuclear, biological, or chemical weapons effects.

II. BACKGROUND

As a prelude to discussing this study's Janus experiments, it is worthwhile to examine current thinking on the effects of terrain on modern combat. It is also worthwhile to look briefly at the Variable Force eMployment (VFM) combat model, which this effort adapts to simulate combat in Southwest Asia and Korea. This chapter will first cover current thinking on terrain effects as expressed in various U.S. Army field manuals (FMs). It will then present an overview of VFM.

A. TERRAIN EFFECTS ON TACTICAL COMBAT

In FM 100-5, *Operations*, the U.S. Army states that, "terrain and weather affect combat more significantly than any other physical factors. Battles are won and lost by the way in which combatants use the terrain to protect their own forces and destroy those of the enemy."¹ This section examines U.S. Army thinking regarding the general effects of terrain on tactical combat, the ways in which different types of units operate in different terrain, the use of terrain in specific military operations, and the specific effects of deserts and mountains found in Southwest Asia and Korea.

1. General Effects of Terrain on Tactical Combat

One can characterize terrain effects generically for all terrain types, with the effects being stronger or weaker in different terrain types. One may think of terrain in terms of its potential for cover and concealment, its impact on friendly and enemy mobility, and observation and direct fire. The Army breaks down the effects of terrain on tactical combat into the following general categories: observation and fields of fire, cover and concealment, obstacles and movement, key terrain, and avenues of approach.²

Observation and Fields of Fire are affected by topography and vegetation. Reduced visibility cuts the effectiveness of direct fire weapons and makes movement less risky.³

¹ Headquarters, Department of the Army, *Operations*, FM 100-5, USGPO, Washington, D.C., May 1986, p. 24.

² FM 100-5, p. 77.

³ Ibid.

Terrain affects the range at which combat occurs, with fighting taking place at 5 to 6 kilometers in open terrain like deserts, to less than 100 meters in close terrain like forests.⁴ Jungles, built up areas, and tracts of broken ground are other examples of terrain types that limit observation and fields of fire.⁵

Effects vary according to the type of weapon system. Direct fire weapons are placed where their effects are greatest and their dead space is minimized. For example, one would place long-ranged observation posts or radar sets at the topographical crest of a hill but would place short-ranged observation posts and direct fire weapons at or below the military crest. Air weapons like helicopters may be able to use terrain for observation that is inaccessible to ground forces.⁶

Cover is protection from observation and fire; *Concealment* is protection from observation. The topography of the land provides cover via slopes, folds, and depressions that units can use for self-protection. Covered positions are important to combat support units that operate close to combat units themselves. Terrain like built up areas, broken hills, and forests can provide concealment. Maneuver forces can use concealment on the defensive to draw an enemy into prepared defensive positions or on the attack to remain hidden while approaching a defender or to achieve surprise.⁷

Obstacles reduce the speed of combat and may dictate the speed and direction of movement. Swamps, thick forests, soft sand, urban areas, and mountains are terrain types that slow combat and movement. Ridge lines, river valleys, and roads are terrain types that speed combat and movement. An area will normally contain a mixture of terrain types over some of which it is easy and some of which it is difficult to move. Difficult terrain tends to canalize the approach of an attacker to a defending position, allowing the defender to save forces and concentrate on the most attractive approaches. An attacker moving across such an area must either seize the constricting terrain before the defender can reach it, bypass it by land or air, or attempt to infiltrate the position. On the other hand, open terrain affords the attacker many potential approaches to a defender's position and thus may force the defender to fight a mobile battle in depth. Some terrain types obstruct armored or mechanized forces more than dismounted infantry or airmobile forces. Rail lines, small

⁴ Headquarters, Department of the Army, *The Tank and Mechanized Infantry Battalion Task Force*, FM 71-2, USGPO, Washington, D.C., September 1988, p. 1-6.

⁵ FM 100-5, p. 77.

⁶ Ibid.

⁷ FM 100-5, p. 78.

streams and villages, and adequately guarded forests and marshes fall into this category, although armored forces have been known to use rail lines as avenues of approach.⁸

2. Terrain Effects on Operations of Different Unit Types

Terrain affects the movement, employment, and protection of units, and different types of terrain may cause different types of units to operate differently. *Light infantry*, for example, is best used in close terrain like wetlands, forests, or mountains, where it can make good use of natural obstacles and, in fact, heavier armored forces may not be able to fight.⁹ Infantry has also proved most effective during limited visibility or when observation and fields of fire are limited, and close combat occurs.¹⁰

Mechanized infantry is designed to complement armor with its ability to take and hold ground. It can also engage enemy infantry and guided missile units. Dismounted mechanized infantry can patrol difficult terrain, infiltrate and attack defensive positions, and protect tanks in close terrain and under conditions of limited visibility.¹¹ Mechanized infantry equipped with anti-tank guided missile (ATGM)-armed infantry fighting vehicles (IFVs) can engage enemy armored vehicles at long range and has some ability to fight mounted under conditions of limited visibility.¹² Mounted mechanized infantry has equal mobility but less firepower than armor.¹³ The mobility and firepower of both mechanized infantry and armor is limited by urban, jungle, forest, precipitous, and rugged terrain.¹⁴

Armor has the most firepower and best protection of any type of ground unit. Tanks can destroy enemy armored, infantry, and guided missile units; break through defenses; and penetrate into enemy rear areas.¹⁵ Tanks are most effective when moving quickly and employing direct fire against enemy forces at extended range.¹⁶ However,

⁸ Ibid.

⁹ FM 100-5, p. 41.

¹⁰ FM 71-2, p. 1-11.

¹¹ FM 100-5, p. 41.

¹² FM 71-2, p. 1-11.

¹³ FM 100-5, p. 41.

¹⁴ FM 71-2, p. 1-3.

¹⁵ FM 100-5, p. 42.

¹⁶ FM 71-2, p. 1-11.

armor is vulnerable in close terrain such as forests and cities and under conditions of limited visibility.¹⁷

Helicopters provide extremely long-ranged direct fire against enemy vehicles during attack, defense, exploitation, or pursuit. They cannot take and hold ground and are not effective against a dug-in enemy.¹⁸

3. Use of Terrain in Specific Military Operations

Having discussed the general effects of terrain upon tactical combat and its influence on operations of different types of units, let us now look at how small units can use terrain to their advantage when attacking, defending, and delaying.

Attack. Attacking forces will try either to mitigate terrain effects that hinder them or to avoid difficult terrain altogether. They will take advantage of terrain features that hinder the defense. They will also employ unit types in different terrain according to their abilities. Attacking forces choose routes of advance that allow rapid movement and maneuver, provide cover and concealment, permit lateral shifting of reserves, allow good communications, resist obstruction by the defender, and are oriented on key terrain.¹⁹

On the attack, battalion task forces and company teams advance from one covered and concealed position to the next. Attacking units seek out and perform best on terrain that is suitable for an advance, but they may choose difficult terrain if they can surprise a defender. Attackers plan to negotiate or avoid obstacles such as urban areas, rivers, extreme slopes, large forests, and patches of soft ground. However, an attacker can use such terrain to help defend his flanks.²⁰

An attacker will use his troops according to their relative strengths and weaknesses. Dismounted infantry may be best for assaulting a defensive position in close terrain to enable armored and mechanized infantry forces to penetrate into the enemy rear. Armored forces may be best for quickly penetrating a defense in depth.²¹

Defense. Defending forces will attempt to engage the attacker in terrain in which it is difficult for the attacker to mass forces or maneuver. A defender will use natural and

¹⁷ FM 100-5, p. 42.

¹⁸ FM 71-2, p. 1-11.

¹⁹ FM 100-5, p. 121.

²⁰ Ibid.

²¹ Ibid.

man-made obstacles to canalize the attacker's movement and protect friendly forces. Restrictions on different types of units are similar to those for an attacker. Armored and mechanized units can move under artillery fire; dismounted infantry cannot. Light infantry can fight effectively in urban or mountainous terrain which limits mounted units. Mechanized forces will use their mobility, protection, and long range to fight fluid defenses and avoid the enemy's strengths. Light forces will concentrate on holding ground and bogging down an attacker in bad terrain. Mixed forces can use dismounted infantry to fight a static defense and slow down an attack, while armor and mechanized infantry launch counterattacks.²²

Delay. In delay, forces use natural obstacles, cover, and concealment extensively to protect themselves. Thus, open terrain makes delay more difficult. It favors the use of mobile armored, mechanized, and airmobile forces and requires the construction of many obstacles. Close terrain, on the other hand, slows the enemy but makes it more difficult for a delaying force to maintain contact. In terrain like woods, swamps, and mountains infantry is best suited for delay, and fewer obstacles need be constructed. In conditions of reduced visibility it is more difficult for the delaying force to avoid a large engagement; it takes more troops to man and observe the front, detection of the enemy is more difficult, and long-ranged fire is less effective.²³

4. Effects of Deserts and Mountains on Tactical Combat

Having discussed the general effects of terrain and how small units can use terrain to their advantage in specific tactical operations, we now turn to the effects of specific types of terrain. The Army discusses the effects on unit operations of terrain different from that typically found in temperate climates like those of North America and Europe: flat or rolling ground, covered with a moderate amount of vegetation. Specifically the Army discusses mountains, desert, jungle, cold climates, and urban areas. Since this study covers combat in Central Europe, Southwest Asia, and Korea, we are interested in the effects of desert, as is found in Southwest Asia, and mountains, as are found in Korea.

²² FM 100-5, pp. 142-143.

²³ FM 100-5, p. 154.

a. Deserts

Forces in the desert have great visibility and mobility.²⁴ Deserts may be characterized as large, easily trafficable areas interspersed with mountains, sand dunes, ravines, bogs, and sand seas.²⁵ The large flat areas make fighting different from that taking place in other climates. There are no obstacles to canalize an attacker's approach to a defensive position, so a defender must use man-made obstacles extensively.²⁶ There exist excellent observation and fields of fire and little key terrain.²⁷ Natural cover is scarce but some is provided by small rises and folds in the ground. Units in the desert generally dig in to achieve cover. Vegetation is also scarce, so concealment is more difficult and forces must use camouflage extensively. Extensive use of smoke, however, can conceal moving units.²⁸ This makes it hard for forces to advance or withdraw undetected. Because of the large open spaces, desert combat usually takes place at long ranges, making accurate long-ranged fire very important.²⁹

The desert allows high mobility—forces can maneuver like ships at sea and speed is important.³⁰ All types of units may be used in the desert, but this makes mechanized infantry and armored forces especially suitable.³¹ Dismounted forces may be used to establish strongpoints and blocking positions, or where vehicular movement is limited.³² Air assault and motorized forces can also be useful to exploit the openness of the desert.³³

The desert is flat, so weapons can generally be used out to their maximum ranges, although, because it is not perfectly flat, troops must still take care, as in other terrain types, to ensure that weapons provide mutual support.³⁴ Helicopters, tanks, and other

²⁴ FM 71-2, p. 1-14.

²⁵ In parts of some deserts these other terrain types are more prevalent than level, packed sand and can make an area difficult for mechanized forces to traverse (examples of such terrain are the salt marshes of the Qattara Depression in Egypt, the soft sand of the Sahara in Libya, and the swamps near the mouth of the Euphrates in Iraq and Kuwait).

²⁶ FM 100-5, p. 84.

²⁷ Headquarters, Department of the Army, *Desert Operations*, FM 90-3, USGPO, Washington, D.C., August 1977, p. 4-2.

²⁸ FM 90-3, pp. 4-8, 11.

²⁹ FM 100-5, p. 84.

³⁰ FM 90-3, p. 4-3.

³¹ FM 100-5, p. 83.

³² FM 90-3, p. 4-3.

³³ FM 100-5, p. 83.

³⁴ FM 90-3, p. 4-4.

long-ranged anti-tank units are most valuable in the desert because of the long lines of sight. Accurate first shots are important.³⁵ With high visibility and long-ranged weapons Lanchestrian effects become significant—knocking out enemy vehicles quickly can strongly affect the subsequent course of the battle.³⁶ The effectiveness of helicopters makes suppression of enemy air defense important as well.³⁷

Delay and withdrawal can be effective in the desert as units can fire at maximum range and then disengage before the enemy closes. Units must disengage under cover of smoke or darkness for concealment, although the increasing use of thermal sights makes even that difficult and increases the value of using artillery and limited counterattacks to facilitate disengagement.³⁸

b. Mountains

Mountains are characterized by rugged compartmented terrain with few natural or man-made lines of communication.³⁹ They restrict the fields of fire and movement of forces.⁴⁰ Historical operations in mountains have striven to control the heights, and that is unchanged by modern weaponry. Infantry, with its light equipment and mobility, is the chief combat arm. Its movement is not limited by terrain and it is suited to fight the close-in battles of mountain warfare.⁴¹ Mechanized infantry can also fight in the mountains but must be prepared to dismount and operate on foot.⁴² Armor must operate in passes and

³⁵ FM 90-3, p. 4-71.

³⁶ If the probability of a shooter detecting a target is proportional to the total number of targets (which is true if target detection is not automatic), it can be shown that the total losses of a side A in a fight to the finish with a side B will be proportional to the number of shooters A and the number of targets B (A. F. Karr, *Lanchester Attrition Processes and Theater-Level Combat Models*, IDA Paper P-1528, September 1981, pp. 10, 38-39.). Thus scoring early kills before the enemy returns fire reduces the number of targets and therefore friendly losses.

³⁷ FM 90-3, p. 4-34.

³⁸ FM 90-3, p. 4-66.

³⁹ Headquarters, Department of the Army, *Mountain Operations*, FM 90-6, USGPO, Washington, D.C., June 1980, Preface.

⁴⁰ FM 71-2, p. 1-14.

⁴¹ However, not all mountain warfare is characterized by close-in fighting (e.g., the fighting in Italy in World War II and the battle for Monte Cassino).

⁴² FM 90-6, Preface.

valleys.⁴³ Helicopters can operate in mountains but may be hampered by terrain and weather conditions.⁴⁴

Mountains limit ground mobility. Highways tend to run in valleys, road and trail nets are usually sparse, and cross country movement is difficult.⁴⁵ Steep grades limit the usefulness of mechanized forces, especially large units.⁴⁶ However, airmobility can overcome some of the limitations of ground movement. Although much smaller forces will generally be able to move by air than on the ground ⁴⁷

Mountainous terrain influences the effectiveness of weapons and equipment. Direct fire weapons tend to be less effective as the topography provides good natural cover. However, aerial weapons and long-ranged weapons may be more effective in that elevation offers good points of observation, even though slopes limit grazing fire and create dead spaces.⁴⁸ Dead spaces must be covered by multiple observation posts and by additional firing positions or obstacles and indirect fire.⁴⁹ Weapons with high angles of fire—like artillery, mortars, and grenade launchers—are particularly useful given their ability to reach into those dead spaces.⁵⁰

Mountains tend to favor the tactical defender as they provide him with excellent observation and firing positions. Routes of advance for an attacker are few in number and well defined. Numerous, difficult-to-assault positions are available to defending units. Obstacles are very effective, allowing the defender to conduct attacks by fire.⁵¹ Mountains are easy to reinforce with man-made obstacles, and they can hide a defending force from an attacker. Because the defender usually occupies an area longer than an attacker, he can develop a better network of trails and therefore more lateral mobility than an attacker. Delaying actions are also very effective in mountains and can be performed by smaller

⁴³ FM 100-5, p. 82.

⁴⁴ FM 90-6, Preface.

⁴⁵ FM 100-5, p. 82.

⁴⁶ FM 90-6, p. 3-4.

⁴⁷ FM 100-5, p. 82.

⁴⁸ Ibid.

⁴⁹ FM 90-6, pp. 3-4,5.

⁵⁰ FM 100-5, p. 82.

⁵¹ FM 90-6, p. 3-19.

forces than normal.⁵² Routes of withdrawal can be reconnoitered and prepared in advance.⁵³

Mountainous terrain makes attacking difficult. Mountains, because of their compartmented nature, tend to break combat into smaller engagements than typically take place in flat or rolling terrain; large engagements tend to occur only at the entrances to or exits from passes.⁵⁴ Mountain terrain prevents an attacker from massing enough force to rupture a defense or move quickly through a gap.⁵⁵ Limits on mobility and fields of fire make hasty attacks by units larger than platoons difficult. Deliberate attacks will employ darkness and other conditions of limited visibility to prevent a defender from seeing an attack develop. Dead spaces may limit the effectiveness of attacking artillery, and overwatch positions may not be available within range of company weapons.⁵⁶

Defenses in the mountains are usually organized around mutually supporting platoon and company strongpoints. Strongpoints are set up for all-around defense and use forward and reverse slopes. The lack of mobility and the importance of high ground make such a position defense necessary.⁵⁷ However, mutual support and interlocking fields of fire may be hard to maintain due to the topography. Defensive positions along slopes and ridges include as much of the slopes and ridges as possible. Positions defending a valley are generally located on adjacent heights, allowing the valley to be covered with crossfire. In wooded mountains, positions are established along woodlines as well as on heights.⁵⁸

B. THE VARIABLE FORCE EMPLOYMENT COMBAT MODEL

The VFM combat model is a computer code embodying a theory of combat that relates the outcomes of theater-level conventional land combat operations to force density.⁵⁹ IDA originally developed VFM to investigate policy issues related to the reduction of conventional forces in Europe, to contribute to the knowledge of conventional combat dynamics at low force levels, and generally to develop a better theory to predict the

⁵² FM 100-5, p. 82.

⁵³ FM 90-6, p. 3-19.

⁵⁴ FM 100-5, p. 82.

⁵⁵ FM 90-6, p. 3-18.

⁵⁶ FM 90-6, p. 3-21.

⁵⁷ FM 90-6, p. 3-29.

⁵⁸ FM 90-6, p. 3-30.

⁵⁹ VFM does address the affect of tactical air operations on ground combat outcomes but does not model strategic air warfare, nuclear warfare, low intensity conflict, or naval and amphibious warfare.

outcomes of theater-level combat.⁶⁰ In this study we are extending VFM to model combat in the terrain of Southwest Asia and Korea. This section first describes the theoretical basis for VFM and then describes how VFM models a theater offensive and where the results of the Janus scenarios come into play.

1. Theoretical Basis of VFM

VFM defines an operation to be an "interconnected series of military actions (or "engagements") of a duration corresponding to the planning horizon of the initiating combatant's theater commander."⁶¹ Examples of operations would include Operation Cobra (the American breakout from the Normandy peninsula in 1944), Operation Goodwood (the attempted British breakout from Normandy), Fall Gelb (the German invasion of France in 1940), and Operation Desert Storm (the American-led liberation of Kuwait in 1991). VFM defines the outcome of a theater combat operation to be the theater attacker's net territorial gain, or the amount of territory an attacker can take and hold against a defender's counterattack. It calculates net territorial gain using a set of independent variables representing the quantities that affect theater-level combat outcomes and a system of equations representing the military logic governing the interaction of the quantities.⁶²

The independent variables VFM uses to explain theater combat outcomes were derived from the military literature. The primary variable is the force density of the theater defender or the ratio of defending force size to the width of the theater. The secondary independent variables are broken down into four categories: the theater force ratio, weapon mix, terrain, and force employment. The theater force ratio is defined as the ratio of attacking force size to defending force size. Weapon mix is defined as the relative numbers of different types of weapons (e.g., tanks, IFVs and infantrymen, artillery, and helicopters) on each side. Terrain includes natural terrain (e.g., forests, hills, and towns) and man-made terrain or fortifications. Force employment, the heart of VFM, is described by the theater attack frontage, the attack tempo or velocity, the depth of the defense, and the deployment and use of defensive reserves.⁶³

⁶⁰ S.D. Biddle et al., *Defense at Low Force Levels*, IDA Paper P-2380, August 1991, preface.

⁶¹ Ibid., p. C-2.

⁶² Ibid., pp. C-1, 2.

⁶³ Ibid., pp. C-4, 5.

VFM models a theater operation as a single attacking thrust into a predeployed defense supported by defensive reserves.⁶⁴ The predeployed defense is characterized as a number of identical lines perpendicular to the thrust, each of which are uniform across the width of the theater and are separated by an equal distance. Defensive reserve forces can perform two functions. Some of them move after the beginning of the attack to concentrate at a point across the axis of the thrust to block it. The remainder move to points on each side of the thrust to counterattack and thus force the attacker to deploy extra forces on his flanks as he penetrates into the defender's territory. The operation ends when the blocking forces build up and stop the attacker after he has lost forces in battle and diverted forces to defend his flanks, or when the attacker breaks through the depth of the defense.

VFM defines defensive deployment and defensive strategy in terms of the defending force employment options. These options are: the fraction of his force the defender predeploys forward, the number of defensive lines he forms with the forces deployed forward, the fraction of the defensive reserves that will conduct counterattacks against the flanks of the attacker's thrust (as opposed to blocking it), and the withdrawal threshold [as each force defending a line is reduced to a fraction equal to the withdrawal threshold, it will break off the ground battle and withdraw to form new lines behind those predeployed (thus withdrawal adds to the depth of the defense)]. Each unique combination of defensive force employment choices is known as a blue (defensive) strategy vector.

VFM defines red (offensive) strategy in terms of the tactical attack velocity. The attack velocity is defined as the distance from the line of departure of an attacking force attempting to take a defensive line to the back of the defensive position on that line, divided by the time it takes the attacker to take the line. As will be demonstrated later in this paper, attacking casualties tend to increase with combat velocity. Thus in choosing his velocity the attacker trades off casualties for speed.

VFM identifies the best blue and red force employment choices, and the associated red net territorial gain, as follows. It first samples blue strategy vectors from the overall strategy space at regular intervals.⁶⁵ Red then chooses the assault velocity that yields the

⁶⁴ Attackers may make more than one thrust into a defense in a real operation. VFM aggregates multiple thrusts into a single thrust whose width is equal to the sum of the widths of the smaller thrusts.

⁶⁵ For a full description of the algorithm used, see Biddle et al., *Defense at Low Force Levels*.

largest territorial gain for each blue strategy vector. Blue then selects the vector that produces the lowest red net territorial gain.⁶⁶

2. A Theater Offensive as Modeled by VFM

Given the above theoretical approach, let us now look at a theater offensive as it unfolds in VFM.⁶⁷ After the defender fixes his defensive deployment through his force employment choices as described in the preceding section, but before the beginning of the operation, the attacker pins the predeployed defending forces by deploying, off of the axis of his offensive, a force of a size proportional to the size of the predeployed defending forces and the size of the defending reserve to be used in counterattack. The attacker then groups his remaining forces, with which he attacks, into a series of identical echelons. Each echelon is deployed uniformly across the whole attack frontage, perpendicular to the axis of the attack. The width of the attack frontage is a function of the size of the remaining attacking forces and is held constant throughout the offensive. All echelons are separated by an equal distance.

Once the defender deploys his forces and the attacker organizes his, the operation begins. As the attacker drives into the defender's territory, he fights discrete engagements against each defending line he encounters. In the engagements, attacking echelons advance against a defensive line and take casualties one at a time until they take the line. "Taking" is defined as destroying the defensive force on the line or inflicting sufficient losses upon it to induce its withdrawal. The defender withdraws from a line when the fraction of his force surviving on the line is reduced to the withdrawal threshold. After the attacker takes each defending line, he either continues with the same echelon against the next line or reorganizes and starts over with a new echelon. This process continues, with the attacker taking casualties as he penetrates the defense, until either the defender stops the offensive or the attacker breaks through the defense.

The attacker's casualties in each discrete battle for a defending line are a function of the relative size of the attacking echelon and the defending force on the line (or the *force*

⁶⁶ This systematic sampling algorithm, of course, produces only an estimate of the true optimum strategies and net territorial gain. For the advantages and disadvantages of such an approach, and consideration of alternative methods of solving for net territorial gain, see S.D.Biddle et al., *Stabilizing and Destabilizing Weapons*, IDA Paper P-2548, September 1991, Appendix B.

⁶⁷ The reader should note that the calculations of the values of the intermediate variables in VFM, including those in the equation governing casualties in tactical ground battles, are presented in great detail in Biddle et al., *Defense at Low Force Levels*, and *Stabilizing and Destabilizing Weapons*; thus, they will not be repeated here.

ratio), the weapon mixes of the two sides (or the *force composition*), and the tempo of the attack (or the *attack velocity*). The IDA studies mentioned earlier used Janus to simulate 350 battalion-level engagements using digitized maps of real terrain in Central Europe and fit curves relating the above variables to the casualty data.⁶⁸ The functional form of the casualty curve below was determined from a study of the military literature and empirical evidence from the Janus scenarios.⁶⁹ VFM uses the resulting equation to predict attacking casualties C suffered in taking a defensive line (force sizes in VFM are expressed in armored fighting vehicle equivalents (AFVEs), where an AFVE is defined as one tank or one IFV plus its infantry squad):

$$C = \alpha \gamma \frac{D}{A} \left[k_3 \phi_i v + k_2 \hat{H}_d v + k_4 \phi_T + \frac{k_1 D_a}{v + 0.01} + \frac{k_6}{A_a (v + 1.0)} \right],$$

where:

- α = the reduction in attacking casualties due to early defensive disengagement
- γ = the increase in attacking casualties due to disorder caused by penetrating a defensive position
- ϕ_i = $\phi_{ia} + \phi_{id}$
- ϕ_{ia} = fraction of attacker AFVEs that are infantry
- ϕ_{id} = fraction of defender AFVEs that are infantry
- ϕ_T = $(2 - \phi_i)$: the sum of the fractions of AFVEs that are tanks
- $\hat{H}_d$ = number of defending attack helicopters
- D = defending maneuver force strength (AFVEs)
- A = attacking maneuver force strength (AFVEs)
- v = attack velocity (kilometers per hour)
- D_a = defending artillery strength (tubes)
- A_a = attacking artillery strength (tubes).

The constants k_1 - k_6 are numerical weights determined for each term from the curve fits. The derivation of the terms α and γ is explained in Chapters III and IV of this paper. The acceptance criteria for the numerical weights and the statistical analyses of the Janus data for all three theaters are given in Appendix A.

⁶⁸ Biddle et al., *Defense at Low Force Levels*, Appendix D, and *Stabilizing and Destabilizing Weapons*, Appendix C.

⁶⁹ The theoretical basis for the functional form is covered in depth in Biddle et al., *Defense at Low Force Levels*, Appendix C. The empirical evidence from the Central European Janus scenarios is presented in Appendix D.

The earlier studies (and this study) conducted the Janus scenarios on a 2-kilometer frontage; the above equation predicts the casualties for the 2-kilometer frontage and VFM extrapolates to give the the total attacking casualties suffered across the width of the thrust (fighting is considered to take place uniformly across the whole attack frontage).

Having covered the theater attacker's ground casualties, let us now turn briefly to how VFM addresses the theater defender's counterattack against the flanks of the offensive and determines when the offensive ends. VFM assumes that as the attacker penetrates the defender's territory he will deploy just enough force on the flanks of his thrust to, with the help of his reserves, stop the counterattack and prevent his force from being cut off. Thus the counterattack never really takes place, as the defender knows that it would fail; it merely forces the attacker to defend his flanks. VFM also assumes that the defender can counterattack at any point along the attacker's flanks, so the attacker must deploy his forces uniformly along the sides of the penetration; he must divert more forces to flank defense the farther he penetrates into the defender's territory and the larger the defender's fraction of reserves dedicated to counterattack. The attacker determines his necessary flank force density from the size of the defending reserve force dedicated to counterattacking. VFM treats the counterattack analogously to the theater offensive. The attacker's flank defense consists of a number of identical, equally spaced lines perpendicular to the counterattack. The attacker's reserves are assumed to move to points opposite the counterattack, on the last flank line. The counterattacking forces take losses as they take each line. The flank defense is sufficient if the counterattacking force would just be eliminated in the taking of the last flank line.

The theater offensive ends (or reaches a *point of culmination*) in VFM when the attacking force is depleted, by battle casualties and the diversion of forces to the flanks of the penetration, to the point that the defensive forces deployed on the next line (either before the operation or after an earlier withdrawal), plus those defensive reserves allocated to blocking that have concentrated across the axis of the offensive, are sufficient to defeat the depleted attacking force. The accumulated defensive force is sufficient if, in a battle on a single line, it would inflict more casualties (in AFVEs) upon the depleted attacking force than the attacking force had remaining. Alternatively, if the defensive force is not sufficient until after the attacker has advanced through the total depth of the defense (predeployed plus that provided by withdrawal), the attacker is assumed to break through and defeat the defender.

III. APPROACH

This chapter describes the experimental approach. First, it describes the computer hardware and Janus software used to perform the experiments. Second, it describes the experiments in terms of the Janus combat simulation scenarios and the terrain in which the combat occurred.

A. APPARATUS

The LLNL Janus combat simulation is described as follows in the model's user's manual:

[Janus is] an interactive, brigade level, two sided game created to explore relationships of combat and tactical processes using a stand-alone, event sequenced, stochastic, computer simulation... Janus is an event-driven simulation that models fighting systems as entities (tank, helicopter, howitzer, etc). Entity characteristics include descriptions of the weapons carried, weapon capabilities, movement speeds and how they are attenuated by terrain effects, accountability of ammunition and fuel, crew performance, sensor data describing how the battlefield is observed, as well as supply/resupply data.¹

Janus simulates the interaction of individual weapon systems on the battlefield in great detail. Weapon systems move, hide, acquire targets, fire upon them, and kill them. Janus computes stochastically target acquisition, determination of hit, and determination of kill (given hit) for each interaction. The simulation calculates movement rates and intervisibility using digitized Defense Mapping Agency representations of actual terrain. It incorporates explicitly surface features such as rivers, roads, towns and vegetation, and terrain elevation features such as hills, plains, and ravines. Janus displays the progress of the battle across this terrain with high resolution, real-time graphics. The authors used Janus Version 5.0 and the unclassified Janus database for this study.²

¹ *Janus Users Manual, Version 4.0*, Lawrence Livermore National Laboratories, Livermore, CA, January 4, 1988, p. 1.

² During a Janus experiment, the progress of the battle is displayed upon the screen of two workstations, while a supporting computer performs the bulk of the calculations. This study used Tektronix 4225 workstations, the standard for which LLNL Janus is designed. For the majority of the Janus scenarios,

Although one can run Janus as an interactive game, the authors conducted all experimental runs as closed simulations; i.e., movement and engagement orders, dismount points, and artillery preparations were determined as scenario conditions and not changed during the course of any of the runs of a given scenario.

B. PROCEDURES

This section describes the Janus scenarios. Section B.1 describes the design of the experiment: the rationale behind the choice of the different types of tactical combat scenarios (Section B.1.a), and the variables explored within them (Section B.1.b). Section B.2 describes the different scenario types generally, in terms of the units involved, the basic actions the units took and the data the authors collected. Section B.3 describes in detail the terrain and the scenario types as they were run in each theater, including individual unit placement, movement and combat.

1. Design of the Experiment

The two objectives of the study shaped the design of the experiment. The first objective was to quantify terrain effects upon tactical mechanized combat, so the experiment (Janus simulations) had to cover the range of tactical engagements that would likely be fought on a modern battlefield. It also had to include as scenario variables those factors that affected combat and that Janus could simulate.

The second objective was to derive tactical combat coefficients for the Southwest Asian and Korean theaters for the tactical combat equations of the VFM combat model. Two earlier IDA studies calibrated the VFM model (as shown in Appendix A) by using the Janus data from Central Europe to establish coefficients to weight each of the terms in the equations.³ In the absence of further exploration, the results of the earlier analyses were not truly applicable to other regions of the world. Thus it was decided to adapt VFM to modeling combat in Southwest Asia and Korea by repeating (with some differences) the Janus scenarios run previously for Central Europe.

the authors used a DEC Vaxstation 3100 Model 76 to support the Tektronix workstations. For some of the Southwest Asian runs, they used a Microvax in lieu of the Vaxstation.

³ S.D. Biddle et al, *Defense at Low Force Levels*, IDA Paper P-2380, August 1991, and Biddle et al., *Stabilizing and Destabilizing Weapons*, IDA Paper P-2548, September 1991

The Central Europe scenarios were characterized by red (Soviet) units attacking blue (U.S.) units from east to west across terrain in northern Germany, near the former inter-German border. The red attacker employed Soviet equipment (e.g., T-72s and BMPs) and Soviet style tactics (e.g., attacking echelons were simulated by red battalions deployed line abreast assaulting the blue positions). Conversely, the blue defender employed U.S. equipment (e.g., M-1s and Bradley Fighting Vehicles (BFVs)) and tactics (e.g., vehicles were deployed in mixed companies of tank and mechanized platoons, and infantry was deployed in fireteams). All scenarios took place on a 2-kilometer attack frontage so VFM could extrapolate their results to larger, theater-level attack frontages.

Since we wished to adapt VFM to simulating combat in Southwest Asia and Korea, and we wished to maintain a level of experimental control between the different theaters, we tried to maintain consistency with the Central Europe scenarios wherever possible. However, we also wanted VFM to be able to model potential combat involving U.S. forces under the circumstances they would be likely to be found. Therefore, we had to compromise to some degree. In all theaters, all attacking units and all defending units employed the same tactics in the same types of scenarios, and all scenarios were performed on a 2-kilometer frontage. The defender employed U.S. equipment in Europe and Korea, since U.S. forces there would most likely be theater defenders and thus, at least in the early stages of a war, mostly likely tactical defenders as well. However, the attacker employed U.S. equipment in Southwest Asia, since U.S. forces were theater and tactical attackers in the recent Persian Gulf War. The attacker advanced from east to west in Europe, south to north in Southwest Asia and north to south in Korea. These factors probably influenced the Janus scenario outcomes. It would be possible, and interesting, to explore the complete matrix of equipment, tactics and direction in all three theaters, but such an effort was well beyond the resources of this study.⁴

This study groups the tactical engagements likely to be fought on the modern battlefield into four scenario types: attacks upon single fixed defensive positions, attacks upon successive defensive positions, defensive withdrawal from ground engagements and defensive withdrawal with helicopter pursuit.⁵ Within each scenario type, each scenario

⁴ However, Janus cannot simulate attackers and defenders using the same nationality of equipment.

⁵ By assessing attacks upon fixed defensive positions, the authors do not mean to imply that larger defending units will be entirely passive, but rather that some parts of a defense will be fixed at some time. In the U.S. Army, maneuver battalions within a larger formation conducting a defense may be called upon to attack, defend, delay, or screen (Headquarters, Department of the Army, *Operations*, FM 100-5, USGPO, Washington, D.C., May 1986, p. 142). The engagements simulated here are strictly

represented a unique combination of terrain and combat variables. Section B.1.a. describes the rationale for representing combat through the four scenario types. Section B.1.b. describes the scenario combat variables.

a. Rationale for the Scenario Types

A force deployed in defense will prepare static positions to control the depth and breadth of an enemy penetration if it is conducting a mobile defense, and to destroy enemy forces by interlocking fires if it is conducting a static defense.⁶ A defending force will also deploy in some depth to prevent the attacker from breaking through in one battle.⁷ The attacker will encounter these static positions as he penetrates the defense and an attack will unfold as a series of engagements. The study assesses the effect of terrain upon such engagements through scenarios simulating assaults upon single defensive positions.

As an attacker penetrates a defense in depth, his forces tend to become disordered. It is difficult for an attacker to remain organized in the face of changing terrain, enemy resistance, and the unexpected events of combat in general. As a result, formations tend to spread out and lose contact with each other; forces lose mass at the point of attack. The attacker finds it more difficult to coordinate movements and suppressive and covering fires since he does not have the time to plan during the attack that he had before it started. Commanders may lose contact with units and units may be too heavily engaged to report properly to their commanders.⁸ The net effect is that an attacking force becomes less effective, vehicle for vehicle and man for man, the further it penetrates an enemy defense.⁹ As we will discuss later in the section detailing the scenarios, Janus cannot simulate all of these phenomena, but it can capture, to some degree, the effect of disorder and the change

tactical and could be counterattacks against an attacker's flanks as well as main attacks against an overall defense.

⁶ FM 100-5, pp. 136,137.

⁷ FM 100-5, p. 140.

⁸ Biddle et al., *Defense at Low Force Levels*, p. C-19.

⁹ Of course commanders can take action to counteract the disorder suffered by their units. In the U.S. Army, units may consolidate and reorganize after taking an objective before resuming the attack; reserve units may pass through the initial objective to press on to a second (Headquarters, Department of the Army, *The Tank and Mechanized Infantry Battalion Task Force*, FM 71-2, USGPO, Washington, D.C., September 1988, p. 3-38.) Disorder would be more prevalent in a Soviet style of attack in which echelons push forward until they become ineffective.

of the effect across different terrain types. This study assesses the effect through scenarios simulating assaults upon successive defensive positions.

When a force is defending a position, it usually withdraws before being destroyed by an attacker. This is for two reasons. First, by withdrawing a defending force preserves itself and adds rolling depth to its position, delaying an attacker's potential breakthrough—the defender trades space for time. Second, tactical defenders, who are generally stationary and under cover, tend to be more effective at longer engagement ranges than attackers, who are generally moving in the open. Thus a defender can be more effective, relative to the attacker, if he withdraws after exchanging fire at long range. The study addresses the increased effectiveness of defending forces at long range through scenarios simulating defensive withdrawal from ground engagements.¹⁰

When a defender withdraws from a position, an attacker would like to (if possible) destroy the retreating force before it reaches its next fighting position. One means to do so is to pursue that force with attack helicopters and attack it with long-ranged anti-tank guided missile (ATGM) fire while it is moving in the open. A defending force caught under such fire would be at a great disadvantage relative to the helicopters, as it would be highly visible and relatively unable to return fire (although friendly air defense units (ADUs), tanks, and ATGMs in overwatch positions to the rear could provide covering fire). U.S. attack helicopters pursued retreating Iraqi vehicles with great success in the Persian Gulf War, albeit on a larger scale than is simulated here. This study assesses the effectiveness of this tactic through scenarios simulating defensive withdrawal with helicopter pursuit.

b. Rationale for the Scenario Variables

To define the scenarios the study had to select variables within each scenario type that affected tactical combat outcomes (referred to as *combat variables*, in italic type) and whose effects Janus could simulate.¹¹ This section describes those variables.

For assaults of single defensive positions, we explored different force compositions, force ratios and attacking tactics. We explored force compositions by varying the sum of the fractions of armored fighting vehicle equivalents (AFVEs) on both sides that were infantry (infantry fighting vehicles (IFVs) and infantrymen) (or *fraction of*

¹⁰ The VFM model simulates the effect of rolling depth provided by withdrawal (see Chapter II of this paper and Biddle et al., *Defense at Low Force Levels*).

¹¹ This necessarily excluded intangible variables such as quality of command and control, troop training, or morale.

infantry), where an AFVE is defined as one tank or one IFV plus its infantry squad. It was found in the Central European Janus work that the sum of the fractions of infantry rather than the individual fractions of each side really determined scenario outcomes; we explain this in more detail in Chapter IV, Section C.1.¹² In addition to the sum of the fractions of infantry, we varied the number of *artillery tubes* supporting both sides and the *number of attack helicopters* supporting the defense.¹³ We varied the *force ratio* of the attacker to the defender, defined as the ratio of attacking to defending AFVEs, simultaneously with the force composition of the two sides. Lastly, we varied the attacker's tactics in terms of the *attack velocity*, or the distance between the line of departure and the objective of the attack, divided by the time it takes to take the objective.¹⁴ The time includes the time for any pre-assault artillery bombardments or preparation of smoke screens, plus the time for conducting a mounted or dismounted assault upon the defensive position and defeating the defending force.¹⁵

There is more to attacking tactics than just the variation in the time of artillery preparation and the choice between a mounted or dismounted assault—the two things that this study includes as tactical variables and aggregates into the attack velocity. For assaults of single lines and assaults of successive lines, we tried for each scenario a variety of plausible tactics for the attacker. We varied the programmed movement of attacking vehicles and infantrymen, the laying of smoke screens, and the location and timing of artillery fire, all subject to the constraint that the attacker took the defending line(s) in the amount of time required to achieve the desired velocity in each scenario. We had found over the course of the experiments that, in assault scenarios, sub-optimal attacking tactics resulted in significantly higher attacking casualties. Since this is not a study of tactics per

¹² In the previous Janus work for Central Europe, scenarios with equal sums but different combinations produced very similar results. The one exception was a high velocity infantry-heavy attack against an armor-heavy defense, in which casualties were higher than would be expected from the sum of the fractions of infantry (see Chapter IV, Section C.1). In the interest of saving time, this study varied the sum of the fraction of infantry of forces in the Southwest Asian and Korean scenarios.

¹³ Attack helicopters were not employed in direct support of the attack. Previous Janus work (see Biddle et al., *Stabilizing and Destabilizing Weapons*) disclosed that, because emplaced defensive vehicles and infantry are very difficult for helicopters to acquire, and nearly every weapon system in the Janus scenarios can kill a helicopter, helicopters supporting an assault suffer very high losses and cause few casualties among the defenders.

¹⁴ This is an average velocity, not to be confused with assault velocity, or the speed at which an assaulting force approaches a defending position it is attempting to take.

¹⁵ Janus may underestimate the true time it takes to assault a position, as attacking troops in Janus display "perfect courage" if the operator does not intervene (as we did not) to show the effects of command, control and communications (C³) on progress.

se, we accepted the lowest casualty configuration as the optimal tactic for each given velocity, and assumed that the attacker would recognize and employ it.

This study examined the following combinations of variables in the assault scenarios: fraction of infantry and attack velocity, force ratio and attack velocity, amount of artillery and attack velocity, and number of attack helicopters and attack velocity. Combinations with attack velocity were judged to be most interesting as operational weapons effectiveness is a strong function of tactics. These combinations were examined in the earlier Central Europe Janus work. Because we had limited time and resources, and wished to maintain consistency with the earlier work, we did not explore other combinations. Some of them could be interesting (e.g., amount of artillery and fraction of infantry, since infantry and even IFVs are more vulnerable to artillery than are tanks). However, we eliminated other potential combinations as uninteresting (e.g., simultaneous variations in defender and attacker infantry fractions—as stated earlier the sum of the fractions of infantry of both sides was shown to be the significant quantity) or militarily impossible (e.g., high velocity assaults by an infantry-heavy attacker against an armor-heavy defender—the attacker suffers such high casualties that he cannot achieve a high velocity).

In the defensive withdrawals with helicopter pursuit, we varied the *number of attack helicopters* pursuing and the *number of ADUs* supporting the withdrawing defenders. The study performed these scenarios in two groups. The first varied the number of attack helicopters against a standard defensive force of ground AFVEs and ADUs. The second varied the number of defending ADUs against a fixed number of pursuing attack helicopters. It was found in the first group of scenarios in Central Europe that it was most advantageous for the attacker to pursue with a large number of helicopters. Therefore, the second group of scenarios in Southwest Asia and Korea only varied the number of ADUs against the largest number of pursuing attack helicopters employed in the first group of scenarios.

In the assaults of successive defensive lines and defensive withdrawals from engagement, standard balanced forces (with 50 percent infantry, 50 percent armor, a standard number of supporting artillery tubes, and no attack helicopters) were used for both sides for all scenarios. The attacker employed a high attack velocity (a fully mounted assault with little artillery preparation) in all scenarios as well.

2. Design of the Scenarios

The Janus scenarios used in this study are grouped into four separate types: assaults of a single defensive line, assaults of successive defensive lines, defensive withdrawals from ground engagement, and defensive withdrawals with helicopter pursuit.

Assault of a single defensive line. This scenario type was designed to evaluate terrain effects on the basic tactical combat operation of an attacker taking a defensive position. In each scenario a defensive force, ranging in size from a reinforced platoon to two companies, established a fixed position on a given patch of terrain. Attacking forces were organized as a series of battalions deployed line abreast.¹⁶ In the engagement, the attacker assaulted the position battalion by battalion until he took it (the attacker provided new battalions as necessary). Terrain effects were expressed in terms of the casualties in AFVEs suffered by the attacker and the time it took him to take the position. We performed 38 assault scenarios in Southwest Asia and 39 in Korea.

For all engagements, the Janus operator collected casualty data manually during the course of the run. Attacker casualties were assessed as AFVEs lost prior to engagement termination, where termination was determined by either defensive withdrawal or the defeat of defenders on the position. Defeat was defined as the destruction of 60 percent or more of the defending AFVE score, or alternatively, as the exhaustion of the defenders' ammunition supply (all attacking and defending units began each scenario with a full combat load of ammunition). Velocity was defined as the distance to be covered by the assault (measured in kilometers, from the attacker's line of departure to the objective line), divided by the time required to cover the given distance and defeat the defenders on the objective. Elapsed time was measured from the initiation of preparatory artillery fire to the arrival on the objective line of the first attacking unit for which the defender's defeat criterion had been met.

Assaults of successive defensive lines. This scenario type provided a point of departure for evaluating terrain effects on the increasing disorder, and subsequent loss of combat effectiveness, of an attacking force as it penetrates a defensive position. As was mentioned earlier, Janus cannot simulate all of the disordering effects of penetrating a defense; e.g. the reduced coordination of supporting artillery fire (the Janus operator plots

¹⁶ The attacking forces were organized in all theaters to simulate Soviet echelons. While we recognize that U.S. forces maneuver as units, we used the same approach in Southwest Asia for consistency, as changing tactics can influence Janus scenario outcomes.

artillery fire before the beginning of the scenarios); the psychological or workload effects on the attacking soldiers; and the loss of communication between commanders and units.¹⁷ Nevertheless, disorder is a known military phenomenon and we proceed here to capture the effects of disorder as best we can. In the scenarios, three defensive positions similar to those described above were established, one behind the other, separated by a distance of 3 to 5 kilometers each. The attacking force, again organized in battalions deployed line abreast, advanced against the successive positions. The measure of disorder was, as a function of the depth of penetration into the defense, the increase in the attacker's casualties suffered when taking the last defensive position (after advancing through the defense) over those that were suffered taking the same position without having to advance through the defense. To obtain the proper control (i.e., to obtain two engagements differing only in the opposed distance covered prior to the engagement of interest and not differing, for example, in strength as of the final assault), assault echelons advancing into the defense were opposed by non-firing defenders until the assault echelons reached the line of departure for the final defensive line to be taken. Non-firing defenders did not kill any attacking units, but the attackers reacted to the defenders by slowing down and firing upon them as though they were fully functional.¹⁸ This caused the attacking echelons to become more dispersed the farther they advanced into the defensive positions. Because the dispersal reduced their mass at the point of attack, the echelons were less effective than fresh echelons would have been when they reached the final, live defensive line, and they therefore sustained more casualties in taking the line. The authors ran the scenarios against the first line of defense with no lines turned off, against the second line with the first line turned off, and against the third line with the first two lines turned off. Thus they measured the dispersal effect as a function of the penetration depth. For this scenario type, depth was measured as the distance between the initial line of departure and the ultimate objective line, in kilometers. We performed 27 successive assault scenarios in Southwest Asia and 37 in Korea.

Defensive withdrawal from ground engagement. This scenario type measured the effect of defending units withdrawing from a position before they were totally defeated. In

¹⁷ Janus cannot simulate loss of communication in a non-interactive mode, but one could simulate loss of communication in Janus' interactive, multi-player mode if one restricted communication between players (unit commanders) on a given side.

¹⁸ In Janus non-firing defenders will not slow down attackers quite as much as firing defenders, as a firing defender who scores a near miss can force an attacker to stop and go to defilade for up to 30 seconds. Thus we may underestimate the resulting "raggedness" of the attacking force.

real combat a defender may wish to do so to preserve his strength or to take advantage of a favorable loss exchange ratio with the attacker at long range. The effect of early defensive withdrawal was assessed by correlating attacker and defender casualties over time during each engagement. In the absence of pursuing helicopters, it was assumed that defenders could, at any point in time, elect to terminate the engagement and withdraw successfully.¹⁹ That way it was possible to determine how many fewer casualties an attacker would suffer if a defending force withdrew from a position before it was totally defeated (as it was in the single assault scenarios): if we track over time the attacker's and defender's respective cumulative casualties in the attacker's taking of a single defended line, $A(t)$ and $D(t)$, we can express the attacker's casualties as a function of the defender's casualties $A(D(t))$. Thus one can determine the attacker's casualties if a defender decides to withdraw before being defeated.²⁰ All casualties were assessed in AFVEs. We ran 14 withdrawal engagements in Southwest Asia and 11 in Korea.

Defensive withdrawal and helicopter pursuit. This scenario type measured the effectiveness of the attacker pursuing withdrawing defending units with attack helicopters. In these scenarios, pursuing helicopters engaged withdrawing vehicles and ADUs, and the defender's ADUs and vehicles in rearward positions engaged the helicopters. Defender casualties were assessed as AFVEs lost after the commencement of withdrawal. Attacker casualties were assessed in terms of individual helicopters lost during the pursuit mission. We performed six pursuit scenarios in Southwest Asia and five in Korea.

Within each scenario type in each theater, each Janus scenario is defined by a unique combination of values of each of the combat variables explored. The scenario types and the combat variables explored within them are summarized in Table III-1 below. The exact values of the combat variables in each scenario are given in Appendix B.

¹⁹ On the whole, this assumption proved valid in Central Europe and in Korea, as long as the defender withdrew before the attackers engaged them decisively at very close range. The nature of the terrain generally allowed defenders to move along concealed routes of withdrawal. In Southwest Asia, this assumption is more tenuous, given the long lines-of-sight that are possible. However, this assumption was examined in an excursion. It was found that, in the absence of helicopters, the extensive use of smoke allowed, on average, roughly 75% of the defending vehicles to withdraw safely.

²⁰ The attacker's velocity and the operational situation will affect the timing of the defender's decision to withdraw. In simulating a theater-level offensive VFM examines the range of possibility, in terms of the fraction of the defending force surviving at the moment of withdrawal, and chooses the most advantageous time for the defender.

Table III-1. Scenario Types and Combat Variables

Scenario Type	Combat Variables Explored
Assault of a Defensive Position	Sum of the fractions of attacking and defending AFVEs that are infantry Number of supporting artillery tubes Number of defending attack helicopters Force ratio Attack velocity
Assault of Successive Defensive Positions	Depth of penetration before final assault
Defensive Withdrawal from Ground Engagement	Time of defensive withdrawal
Defensive Withdrawal and Helicopter Pursuit	Number of pursuing attack helicopters Number of defending ADUs

Defensive deployment was held constant across all scenarios with a given force composition and terrain sample. The attacker's lines of departure and objective lines were held constant across scenarios conducted on a given terrain sample.

For all scenarios and all engagements, the authors operated the Janus simulation in stochastic mode. Therefore it was necessary to run each scenario a number of times to limit the influence on the outcome of the study, particularly the derivation of the combat coefficients for the VFM model, of highly unlikely, but possible, events. Nevertheless, given a limit on the number of Janus runs, it was not possible to completely eliminate the effects of stochasticity. For single line assault scenarios, a minimum of three engagements were fought for each scenario. For successive line assault scenarios, and both types of withdrawal scenarios, a minimum of six engagements were fought for each scenario.

3. Terrain Types

This section describes in detail the terrain and the scenario types as they were run in Central Europe, Southwest Asia, and Korea. For each scenario type in each theater it details, in relation to terrain features on the digitized maps, the attacking and defending forces and their placement, movement, and interaction.

a. Central Europe

The Central Europe scenarios utilized five terrain samples located along or near the former inter-German border. The primary defensive position (used for most of the assault

scenarios) was deployed about a small town (which sat at the intersection of a north-south and an east-west road). A small stream formed the southern boundary of the position, and the northern boundary was marked by a stand of woods. Scattered copses of trees stood both to the north and the south of the town. The position did not contain a prominent, elevated patch of ground, and the terrain in general could be categorized as gently rolling hills. A relatively large and dense stand of woods lay 1.5 to 2 kilometers to the east of the town. Vehicle movement in the open was unimpeded by the gradual slope. Movement through woods or within the town was substantially slowed. The maximum possible line-of-sight (available only to helicopters, in general, and then infrequently) was approximately 4 kilometers. More typical lines-of-sight ranged from 2 to 2.5 kilometers.

Assault scenarios. The defense in the assault scenarios was deployed about (but not within) the town, along a 2-kilometer front. BFVs were deployed in positions that maximized their potential to engage the enemy at long range (primarily on the flanks and somewhat to the rear of the infantry defense). M1A1s were positioned in the center of the defense and to the south of the town (where long-range firing positions were scarce). Infantry fireteams were deployed both along the forward edge of the town and to the north and west of the town (along the north-south road). Dragon ATGM teams fired primarily from ambush positions. The depth of the deployed defense was roughly 1 kilometer. The defender employed artillery in few of the scenarios.

The attacking force was organized (roughly) into battalions deployed line abreast, which were separated by roughly 2 kilometers. Attacks were launched from the cover of the eastern woods and were therefore able to immediately engage the defenders at a range of approximately 1,500 to 2,000 meters. The objective line lay roughly 0.5 kilometer west of the north-south road (some 3.5 kilometers from the line of departure). Four attack velocities were attempted against this position: a slow case, in which attacking vehicles approached the defensive position and available attacking infantry were dismounted following a 60-minute preparatory artillery barrage and a 4-minute smoke preparation; a moderate case, in which infantry were dismounted following 12 minutes of preparatory artillery and 4 minutes of smoke; a fast case, in which a mounted assault followed 4 minutes of smoke and a 2-minute suppressive artillery barrage; and a very fast case, representing a hasty attack, in which a mounted assault proceeded directly from the march with only the support of suppressive artillery that could be brought to bear during the advance itself.

Successive assault scenarios. Successive defensive positions in Central Europe, developed for the successive assault scenarios, were generally similar to that described above, both in terrain and in defensive deployment. Simultaneous engagement of one attacking echelon by more than one defensive position was not possible (i.e., successive positions could not support one another). However, simultaneous target acquisition of one echelon by more than one position was possible, if infrequent. The attacker employed a very fast velocity in all successive assault scenarios. In each of the runs, defensive units on lines forward of the last line to be taken were deactivated as described in the previous section

Withdrawal and pursuit scenarios. Withdrawal and pursuit scenarios were played on a hillier piece of terrain than the assault scenarios, covered only by scattered stands of trees. The defense was positioned along a series of successive ridge lines. Successive defensive positions, as placed, could provide only sporadic covering fire to withdrawing units. Stinger ADUs were deployed to the rear but were able to provide cover to all withdrawing defenders due to the longer lines of sight from ground units to helicopters. Defenders, in general, were able to withdraw along routes that were not visible to the attacker's advancing ground units. Attacking ground units employed a very fast velocity and advanced up a moderate slope across relatively open terrain. Pursuing helicopters remained in staging areas some 6 kilometers from the forwardmost defensive position and did not begin to move until the first defensive line had begun to withdraw (i.e., until ground fire had ceased). Pursuing helicopters were able to advance along a ravine and were therefore concealed from the defender's ADUs until the helicopters were upon the defensive position.

b. Southwest Asia

The Southwest Asia scenarios were, on the whole, run on one piece of terrain, located along the northern border of the demilitarized zones (DMZ) between Saudi Arabia and Iraq, some 20 kilometers west of the intersection of the Iraqi, Saudi, and Kuwaiti borders. The terrain was very flat, with no prominent elevation features nearby, and sloped downward from south to north (i.e., the Saudi side of the border is higher than the Iraqi side). Lines-of-sight were excellent for both the attacker and the defender, often extending to maximum optical range for the longest ranged systems (6 kilometers). Vehicles were able to move at assault speed (20 kilometers per hour) with no difficulty. No concealed routes of advance or withdrawal existed.

Assault scenarios. Defending units, in this case represented by Iraqi ground forces, were deployed in accordance with standard doctrinal practices,²¹ along a 2-kilometer front. The primary defensive position (upon which most of the engagements were fought) was organized around a small hillock that allowed superior defensive lines-of-sight. Tanks (T-72s in these scenarios) were positioned some 300 to 400 meters to the rear of the forward edge of the defense. BMPs were deployed in line formation along the front edge of the defense.²² Infantry fireteams were deployed some 250 meters in front of the BMPs, separated by a distance of roughly 200 meters. Sagger ATGM teams were positioned on the flanks. The infantry fireteams had interlocking fields of fire and were supported by at least one, and, more generally, two, other fireteam(s). Vehicles were positioned so their interlocking fields of fire covered the entire front with no blind spots. Defending red artillery was deployed far to the rear of the position, and was used in all engagements to bombard the blue forces in their staging areas. The depth of the defense was roughly 600 meters.

The attacking force, in this case represented by U.S. ground forces, was organized into task forces of two companies (one tank and one mechanized infantry), with each task force separated by roughly 2.5 kilometers. The line of departure for the attack lay some 5.5 kilometers from the defender's position. The objective line lay just to the north of the defensive position, some 6 kilometers from the line of departure. Attacking forces advanced in a wedge formation, with a tank platoon deployed to the front and on the flanks of the formation. They shifted to line abreast when they came to within about 2.5 kilometers of the defender's position. The attacker attempted to advance against the position at five different velocities: a very slow case, in which accompanying infantry performed a dismounted assault under cover of smoke (a 16-minute hexachlorophane (HC) and white phosphorous (WP) barrage) following an 8-hour artillery bombardment; a slow case, in which the infantry was dismounted under cover of smoke following a 3-hour artillery bombardment; a medium case, in which the infantry was dismounted under cover of smoke following a 1-hour artillery bombardment; a fast case, in which a mounted attack under cover of smoke was launched after a one hour artillery bombardment; and a very fast case, in which the attackers launched a hasty attack consisting of a mounted assault

²¹ David C. Isby, *Weapons and Tactics of the Soviet Army*, Jane's, New York, 1988.

²² *Ibid.*, p. 74.

proceeding directly from the march with the support only of that artillery fire that could be brought to bear during the advance itself (6 minutes, in this instance).²³

Successive assault scenarios. The defensive positions for the successive assault scenarios in Southwest Asia were generally similar to that described above, with BMPs deployed in line along the front edge of the position and with tanks to the rear. Successive positions were generally separated by 4 to 6 kilometers. As a consequence, simultaneous engagement of one assaulting task force by more than one defensive position was not possible. However, given the length of lines-of-sight, simultaneous target acquisition (by the defenders of the attackers only) was a frequent occurrence. The attacker employed a very fast velocity in all assaults of successive defensive positions.

Withdrawal and pursuit scenarios. Withdrawal and pursuit scenarios were played on the same piece of terrain as described above. Defending forces were deployed in three successive positions, each as above, and attacking forces employed a very fast velocity, advancing down a gradual slope. Given the distance between successive defensive positions, vehicles in subsequent positions were not, in general, able to provide effective covering fire against helicopters. Air defense units, however, (primarily SA-13s and SA-14s) were deployed amidst the second and third defensive lines and were able to cover withdrawing vehicles with some success. Without the aid of smoke, withdrawing vehicles were not able to withdraw successfully (even in the absence of attack helicopters), as the flat terrain precluded the possibility of a concealed route of withdrawal. However, with the use of smoke (dropped in successive lines before the advancing attacking units), roughly 75% of the defending units withdrew safely. When employed, attack helicopters remained in staging areas some 6 kilometers behind the forwardmost attacking forces and did not begin to advance until the defensive withdrawal had begun. The defender used smoke to obscure the view from pursuing helicopters, but this tactic was mostly ineffective, as the speed of pursuing helicopters enabled them to penetrate the smoke cover more quickly than it could be formed.

c. Korea

The majority of the Korean scenarios were run on one piece of ground, located just south of the DMZ near the towns of Yeoncheon and Hwacheon. The general terrain was

²³ U.S. forces today would probably not bombard a position for eight hours before assaulting it. Such tactics were used here to maintain consistency with the other theaters and to provide a lower bound for attack velocity.

mountainous; scattered copses of trees dotted the slopes of the hills and mountains. The terrain was not easily traversable except along certain paths. The defensive position lay at the intersection of two such paths: a road running roughly from north-northwest to south-southeast and a (relatively narrow) valley running from north-northeast to south-southwest. Vehicle movement along these routes was relatively unimpeded, despite the rugged terrain. The maximum possible line-of-sight was roughly 3.5 kilometers for ground vehicles and 4 to 4.5 kilometers for helicopters. More typical lines of sight were 2 to 2.5 kilometers. While all fields of view suffered from blind spots (either near or far), no totally concealed route of advance was available to the attacker. Concealed routes of withdrawal, however, were relatively common as defending units could easily withdraw down the reverse slope of a hill, out of the sight of pursuing attackers.

Assault scenarios. The defenders, represented by U.S. ground forces here, were deployed along a 2-kilometer front on a bluff that overlooked the road and the valley. Defending units were positioned so as to guard against assaults launched along either avenue of advance. BFVs were deployed to the rear and on the wings, in positions that maximized the effectiveness of their long-range fire. M1A1s were, in general, deployed along the ridge line, at the front edge of the defense. Dragon teams were placed so as to cover potential blind spots in the vehicles' fields of fire (e.g., a ravine between two hills). Infantry fireteams were, in general, deployed in proximity to the BFVs. Defending artillery was deployed far to the rear. In all engagements, defending artillery fired upon the attacking units while they were still in staging areas. All defending units were placed so as to provide mutual support through interlocking fields of fire, with no part of the front covered by less than two large caliber direct fire weapons (M1A1s, BFV TOW ATGMs, or Dragons).

The attacking force, in this case represented by North Korean forces, was organized into roughly battalion-sized echelons, which were separated by roughly 3 kilometers. The attackers advanced down the valley from a line of departure some 6 kilometers from the defensive position. The objective line lay just south of the defenders' position, along the crest of the bluff. Target acquisition and engagement began at a range of some 3.5 kilometers. The attacking force advanced in line abreast formation, with the tanks (T-72s) some 250 meters in front of the BMPs.²⁴ The attacking units attempted to advance against the defending position at five different velocities: a very slow

²⁴ The organization of the attacking forces was consistent with that used in the other two theaters.

case, in which the accompanying infantry was dismounted under cover of smoke (a 16 minute HC and WP barrage) following an 8 hour artillery bombardment; a slow case, in which the infantry was dismounted under cover of smoke following a 1 hour artillery bombardment; a medium case, in which the infantry was dismounted under cover of smoke following a 16-minute artillery bombardment; a fast case, in which a mounted attack was launched under cover of smoke after a 16-minute artillery bombardment; and a very fast case, in which the attackers launched a hasty attack consisting of a mounted assault proceeding directly from the march with the support only of that artillery fire that could be brought to bear during the advance itself (16 minutes, in this case).²⁵ The depth of the defense was roughly 1 kilometer.

Successive assault scenarios. The defensive positions for the successive assault scenarios were generally similar to that described above, with BFVs deployed to the flanks and rear and M1A1s to the front. Successive positions were generally separated by 4 to 6 kilometers. The distance between positions precluded simultaneous engagement of one attacking echelon by more than one defending position. Simultaneous target acquisition was possible, but because of the ruggedness of the terrain it was rare. The attacker employed a very fast velocity in all successive assault scenarios.

Withdrawal and pursuit scenarios. Withdrawal and pursuit scenarios were played on the piece of terrain described above. The defending units were deployed as before, and the attacking force employed a very fast velocity. Given the distance between successive defensive positions, ground units in subsequent positions were not, in general, able to provide effective covering fire. Air defense units (primarily Stinger teams), however, were deployed amidst the subsequent positions and were able to engage pursuing helicopters somewhat effectively. Because of the ruggedness of the terrain, it was easy to withdraw along concealed routes (e.g., along ravines or through groves of trees), even without the use of smoke. Pursuing helicopters remained in staging areas some 6 kilometers from the defensive position and did not begin to move until the withdrawal had begun. The rugged nature of the terrain limited the field of view from the pursuing helicopters and rendered vehicles withdrawing along certain routes almost invisible to the helicopters.

²⁵ Differences in the times of artillery bombardment between Korea and Southwest Asia in the higher attack velocity scenarios was caused by the difference in the terrain: attacking units moved faster and reached the defender's position faster in Southwest Asia. We did not have sufficient time to repeat the 3-hour bombardment scenario in Korea. The effects of varying the amount of artillery support on both sides is still readily apparent from the graphs of the data in Chapter IV.

IV. RESULTS

This chapter contains the results of the Janus experiments. The first part presents the experimental data, organized by scenario type. The second part describes sources of experimental uncertainty and error discovered during the study and describes limitations to the study approach. The last part presents the analysis of the data: the events in the simulations causing the experimental results and the terrain effects on scenario outcomes.

A. EXPERIMENTAL DATA

This section presents the experimental data in graphical forms for all of the scenarios the study ran, organized by scenario type.¹ The graphs, included in sequence at the end of this section, present attacker or defender casualty data reflecting the variation of values of the combinations of combat variables explored. The data are presented in the following order: assaults upon single defensive lines, assaults upon successive defensive lines, withdrawal from ground engagements, and withdrawal and helicopter pursuit.

1. Assault on a Defensive Position

In the scenarios simulating assaults upon single defensive positions, the study examined the effects of variations in the force composition of the two sides, the attacker: defender force ratio, and the attacker's tactics or attack velocity.

Force composition variables included the fractions of infantry on both sides, the number of supporting artillery tubes, and, for the defender, the number of supporting attack helicopters. The first group of scenarios explored the effects of varying the sum of the fractions of infantry with the attack velocity. Figures IV-1 through IV-3 show the results of those scenarios for Central Europe, Southwest Asia, and Korea by plotting attacking casualties in AFVEs versus the attack velocity. The sums of the infantry fractions were roughly 0.5 (armor heavy), 1.0 (balanced), and 1.5 (infantry heavy); attack velocity

¹ Numerical data are presented in Appendix B.

varied from 0.5 km/hr to just over 8 km/hr.² Force ratios were approximately 3:1 in Central Europe and Korea; 7:1 in Southwest Asia.³

The second group of force composition scenarios explored the effects of variations of the amount of supporting artillery on both sides with attack velocity. Figures IV-4 through IV-6 show the results of the scenarios for Central Europe, Southwest Asia, and Korea by plotting attacking casualties in AFVEs versus the attack velocity. In the Southwest Asia and Korea scenarios one side had a standard number of supporting tubes (72 for the attacker or 40 for the defender), while the other side had either a higher number (144 for high attacker or 80 for high defender) or a lower number (36 for low attacker or 20 for low defender). In the Central Europe scenarios the numbers of tubes were (attacker:defender) 6:104 (low attacker, high defender), 48:104 (high defender), and 52:0 (normal attacker, no defender).⁴ In all cases attack velocity varied from roughly 0.5 km/hr to 8 km/hr.

In most scenarios there was one attack helicopter supporting the defense.⁵ The study ran a number of scenarios in which there were three to five helicopters supporting. The results of those scenarios are not shown here, but their data are presented in Appendix B and were included in the calculation of the VFM combat coefficients in Appendix A.

² We did not perform scenarios for all possible combinations of force composition (armor-heavy, infantry-heavy and balanced) and all attack velocities. In some cases the combination was impossible to achieve (e.g., a mounted, infantry-heavy assault at moderate or low force ratios could not take a defensive position fast enough to achieve a high velocity—it took too many casualties and thus had to assault the position repeatedly before it fell (see this chapter, section C)). In other cases, we did not have the time and resources, so we must interpolate between velocities to draw conclusions.

³ In VFM runs, it was found that defenders were deploying very few forces forward and thus tactical force ratios were very high at the beginning of an offensive. To match that better, the force ratio in the Southwest Asian force composition scenarios was set higher than in the Central European scenarios. However, after the Southwest Asian runs, the authors feared that a very high force ratio might obscure the effects of different force compositions, so the force ratio in the Korean force composition scenarios was set roughly equal to that of the European ones. As a case in point casualties in mounted assaults with smoke screens in Southwest Asia were not significantly lower than in those without. The force ratio (29/4) may have masked the normal effects of using smoke. The attacker may be killing defenders so quickly that the marginal effect is small.

⁴ We selected the levels of artillery support in the Janus scenarios to explore a range of possibilities rather than to represent any particular national army or doctrine. For illustrative levels of Soviet artillery support see Headquarters, Department of the Army, *The Soviet Army: Operations and Tactics*, FM 100-2-1, USGPO, Washington, D.C., July 1984, and Headquarters, Department of the Army, *Soviet Army Operations*, IAG-13-U-78, USGPO, Washington, D.C., 1978.

⁵ In the U.S. Army, helicopters normally operate in groups of two or more, but since these scenarios cover only 2 kilometers of attack frontage we used one helicopter to simulate a (low for U.S. forces) level of helicopter support equivalent to two helicopters per 4 kilometers of frontage.

The force ratio in each scenario was defined as the ratio of attacking ground AFVEs to defending ground AFVEs. The study explored variations of the force ratios with the attack velocity. Figures IV-7 through IV-9 show the results of those scenarios for Central Europe, Southwest Asia, and Korea by plotting attacking casualties in AFVEs versus attack velocity. The force ratios (attacker:defender) for Central Europe were 22:4 (high), 22:8 (medium), and 22:15 (low). For Southwest Asia they were 29:4 (high), 29:10 (medium), and 29:20 (low). For Korea they were 30:4 (high), 30:8 (medium), and 30:16 (low). In all cases but one the two sides were 50 percent armor and 50 percent infantry, with a standard number of supporting artillery tubes and one attack helicopter for the defense.⁶

2. Assault on Successive Defensive Positions

In the scenarios simulating assaults upon successive defensive positions the study examined the effect of disorder on the casualties suffered by an attacking force in the taking of a defensive position, as a function of the depth of penetration of a defense. Figures IV-10 through IV-12 show the results of the scenarios for Central Europe, Southwest Asia, and Korea by plotting attacking casualties in AFVEs versus depth of penetration in kilometers prior to the attack. In all scenarios both sides were balanced (50 percent armor and 50 percent infantry) and had the standard artillery support. In all scenarios the force ratio was approximately 3:1 and the attack velocity was high (8 to 10 km/hr).

3. Withdrawal from Ground Engagements

The study explored the effect of a defender's early disengagement from ground combat in these scenarios. Figures IV-13 through IV-16 show the results of the scenarios for Central Europe, Southwest Asia, and Korea by plotting the attacker's cumulative casualties at times from the beginning of the scenario $t_1, \dots, t_n$, normalized to the number he would take if the defender fought to the death, versus the fraction of the defending force surviving (and presumably withdrawing from combat) at times $t_1, \dots, t_n$. If the two sides suffered casualties at the same relative rates, the plots would be straight lines from (0,1) to (1,0); the data points above the lines show the defender's relative advantage as a result of his being stationary and dug-in while the attacker is moving in the open. All scenarios

⁶ The low force ratio data for Korea are averages of results for armor-heavy and infantry-heavy forces. They are included here to suggest what the balanced results might be, but they do not strictly represent the effects of changing the force ratio while holding all other things constant.

were conducted using balanced forces, standard of artillery support, and high attack velocities.

4. Withdrawal and Helicopter Pursuit

Scenarios simulating helicopter pursuit of withdrawing vehicles were broken into two groups. The first group varied the number of helicopters pursuing a ground force of a fixed size. The second group varied the number of ADUs supporting the withdrawing vehicles against a fixed number of helicopters. Table IV-1 shows the numbers of vehicles, helicopters and ADUs present in both groups of helicopter pursuit scenarios.⁷

Table IV-1. Numbers of Vehicles, Helicopters and ADUs In the Helicopter Pursuit Scenarios

Theater	First Scenario Group			Second Scenario Group		
	Number of Vehicles	Number of Helicopters	Number of ADUs	Number of Vehicles	Number of Helicopters	Number of ADUs
Europe	19	2-16	2	19	16	2-12
Southwest Asia	6	2-8	1	6	8	1-8
Korea	8	2-12	1	8	12	1-8

Figures IV-17 through IV-19 plot the fraction of vehicles that survive withdrawal versus the ratio of pursuing helicopters to withdrawing vehicles for Central Europe, Southwest Asia, and Korea.⁸ Figures IV-20 through IV-22 plot the fraction of vehicles that survive withdrawal versus the ratio of ADUs to helicopters. Figures IV-23 through IV-24 plot the fraction of helicopters destroyed versus the ratio of helicopters to withdrawing vehicles. Figures IV-25 through IV-27 plot the fraction of helicopters destroyed versus the ratio of ADUs to helicopters.

⁷ The maximum ratios of helicopters and ADUs to ground vehicles, and ADUs to helicopters may be higher than what one would expect on a battlefield given the force composition of most modern armies. However, it is possible for forces to concentrate their aviation and air defense assets in critical areas if they desire. In this study we wished to explore a wide range of possibilities.

⁸ The symbols that are grouped very close together on the pursuit scenario graphs actually represent multiple instances of the same result. Such results would show up as one point on the graphs so we moved the symbols slightly for illustrative purposes. The true data were used for the VFM casualty curve fits in Appendix A and are presented in Appendix B.

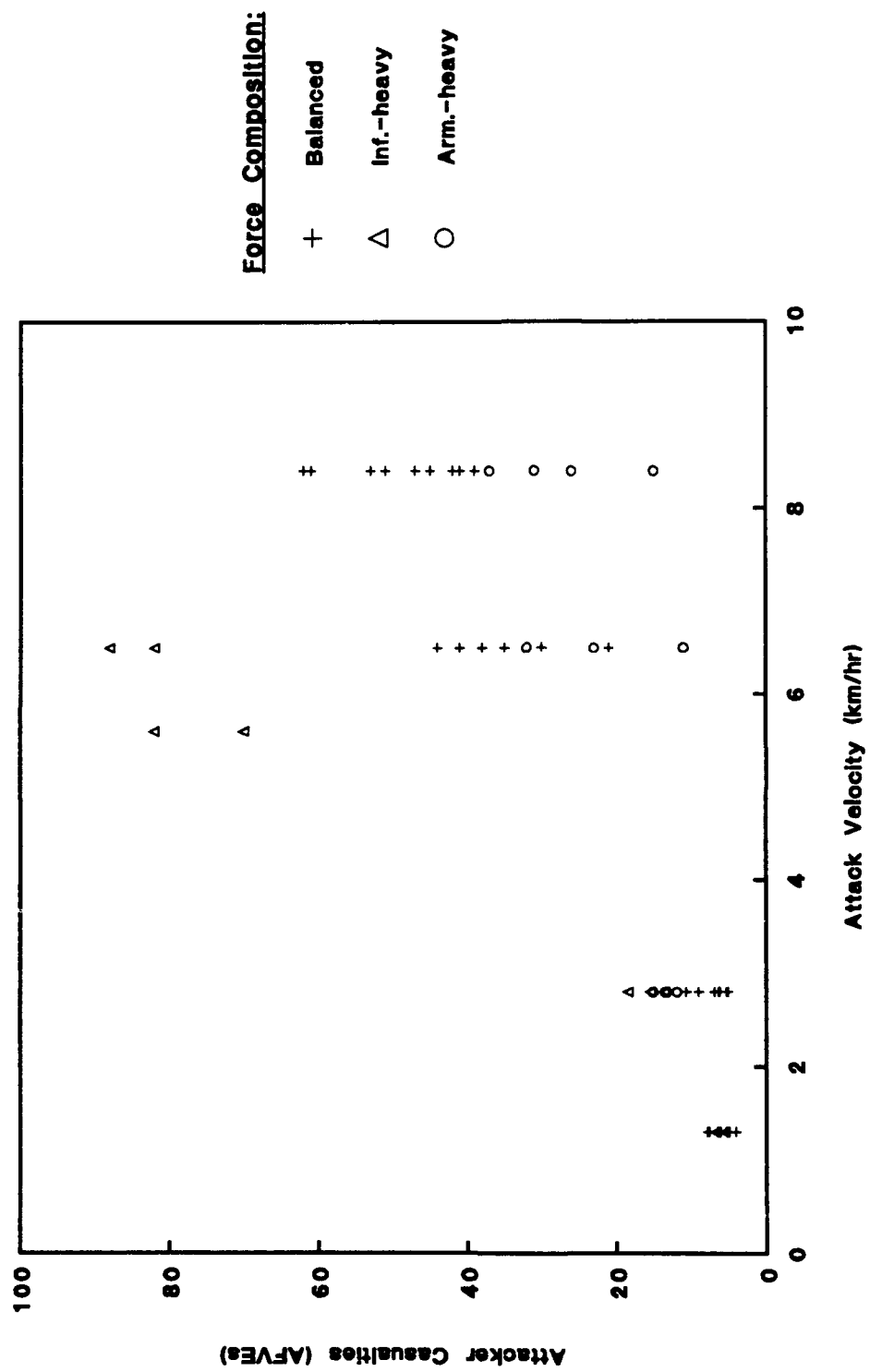


Figure IV-1. Force Composition Effects, Central Europe

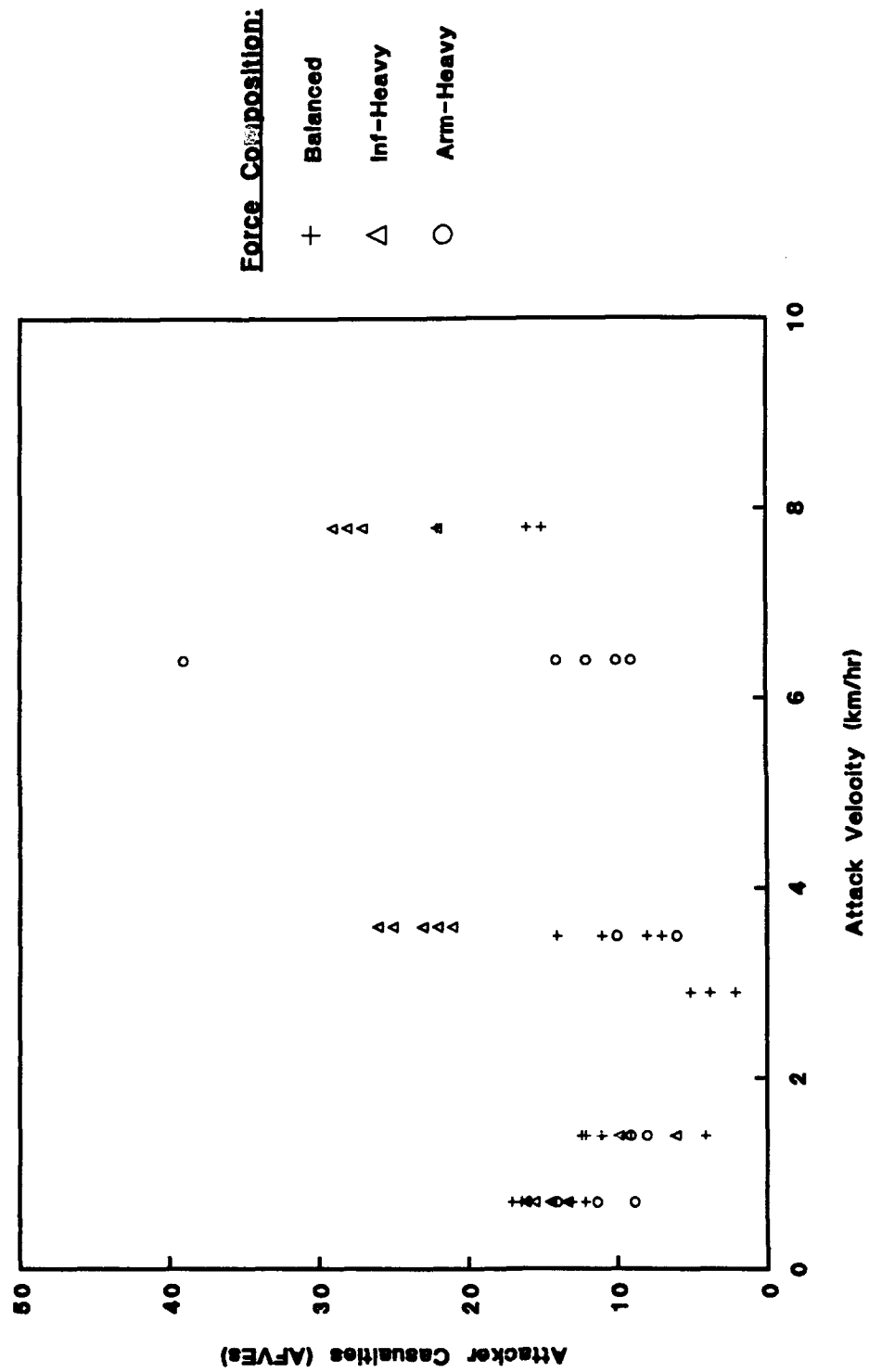


Figure IV-2. Force Composition Effects, Southwest Asia

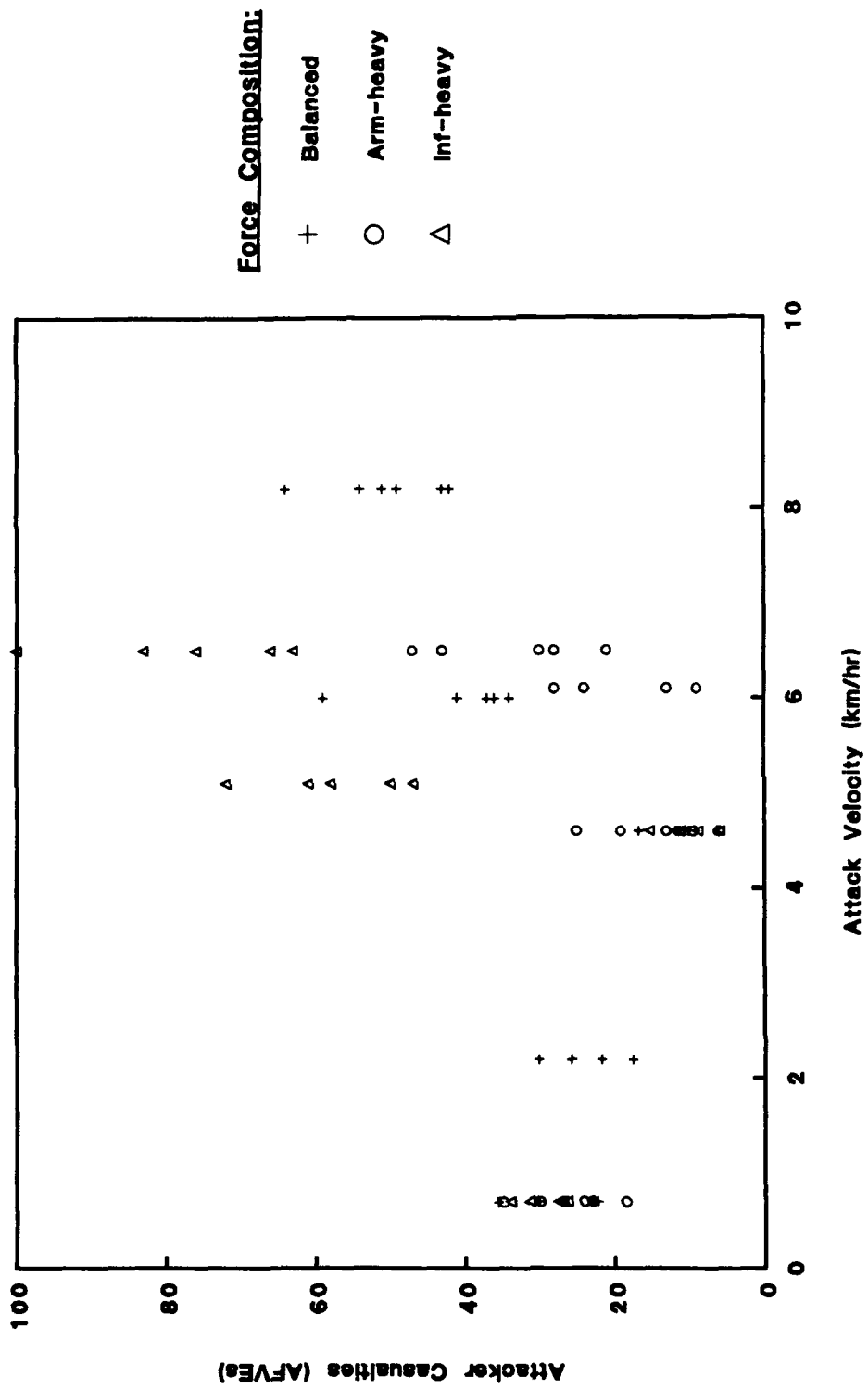


Figure IV-3. Force Composition Effects, Korea

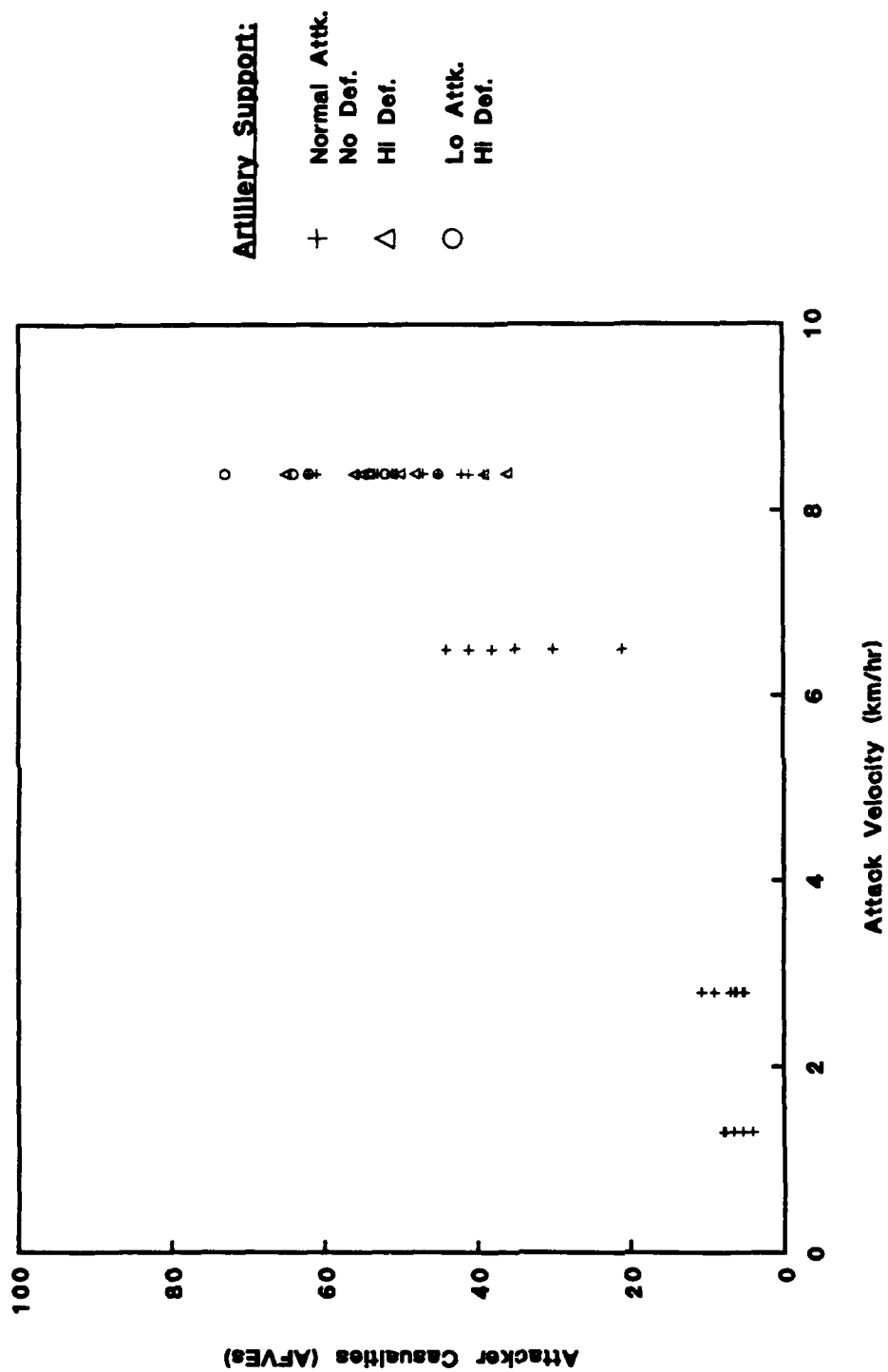


Figure IV-4. Artillery Effects, Central Europe

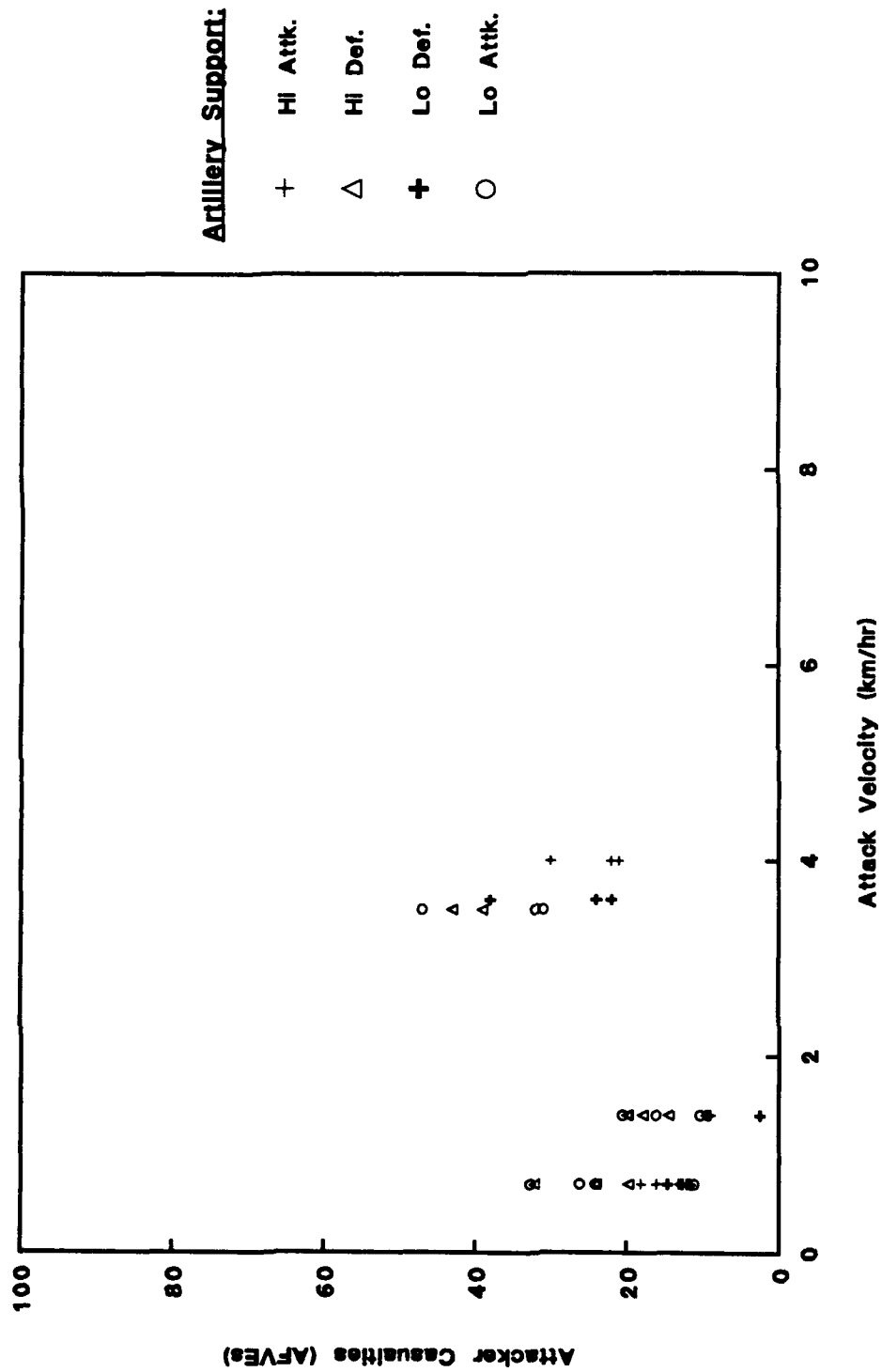


Figure IV-5. Artillery Effects, Southwest Asia

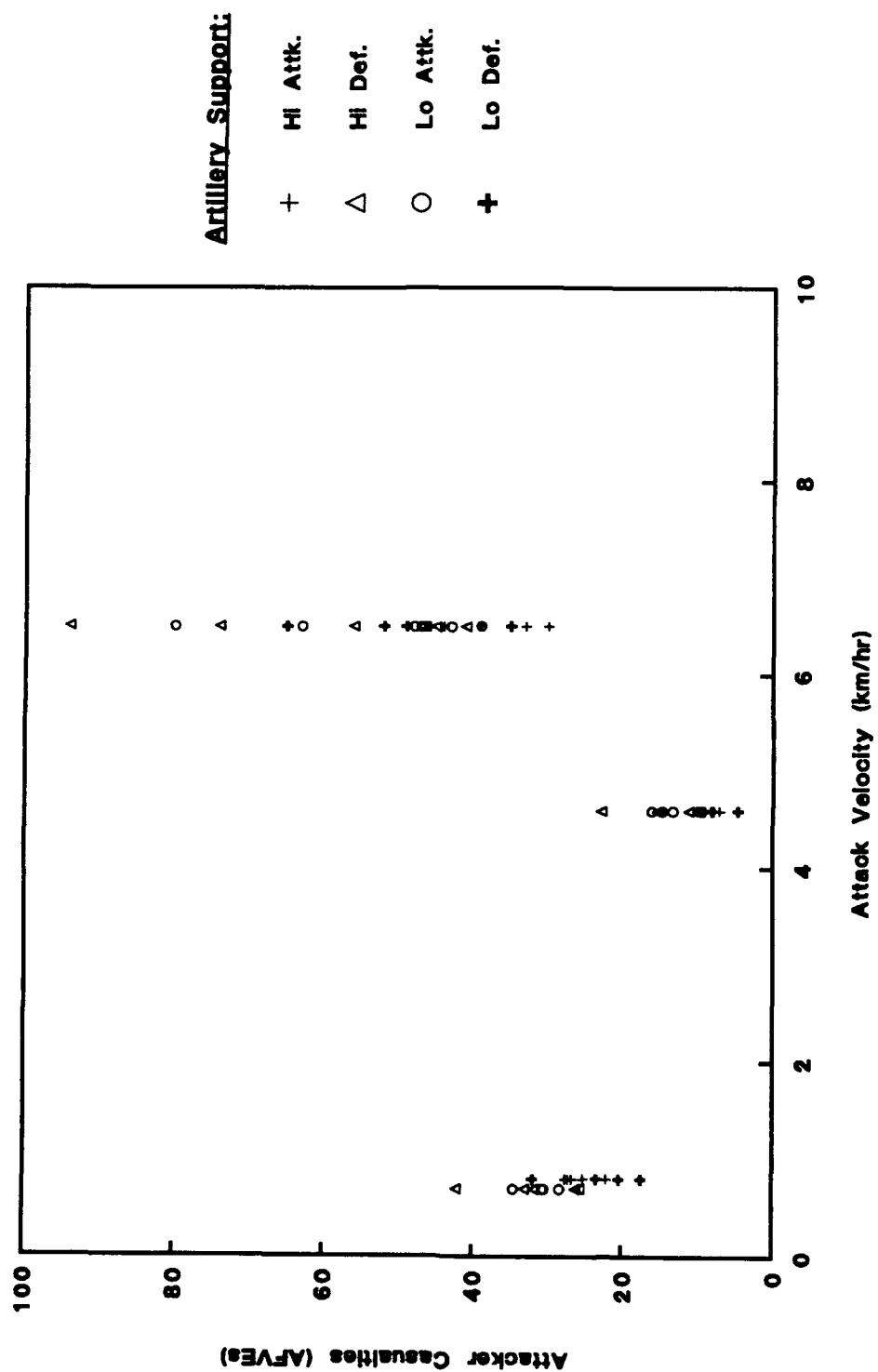


Figure IV-6. Artillery Effects, Korea

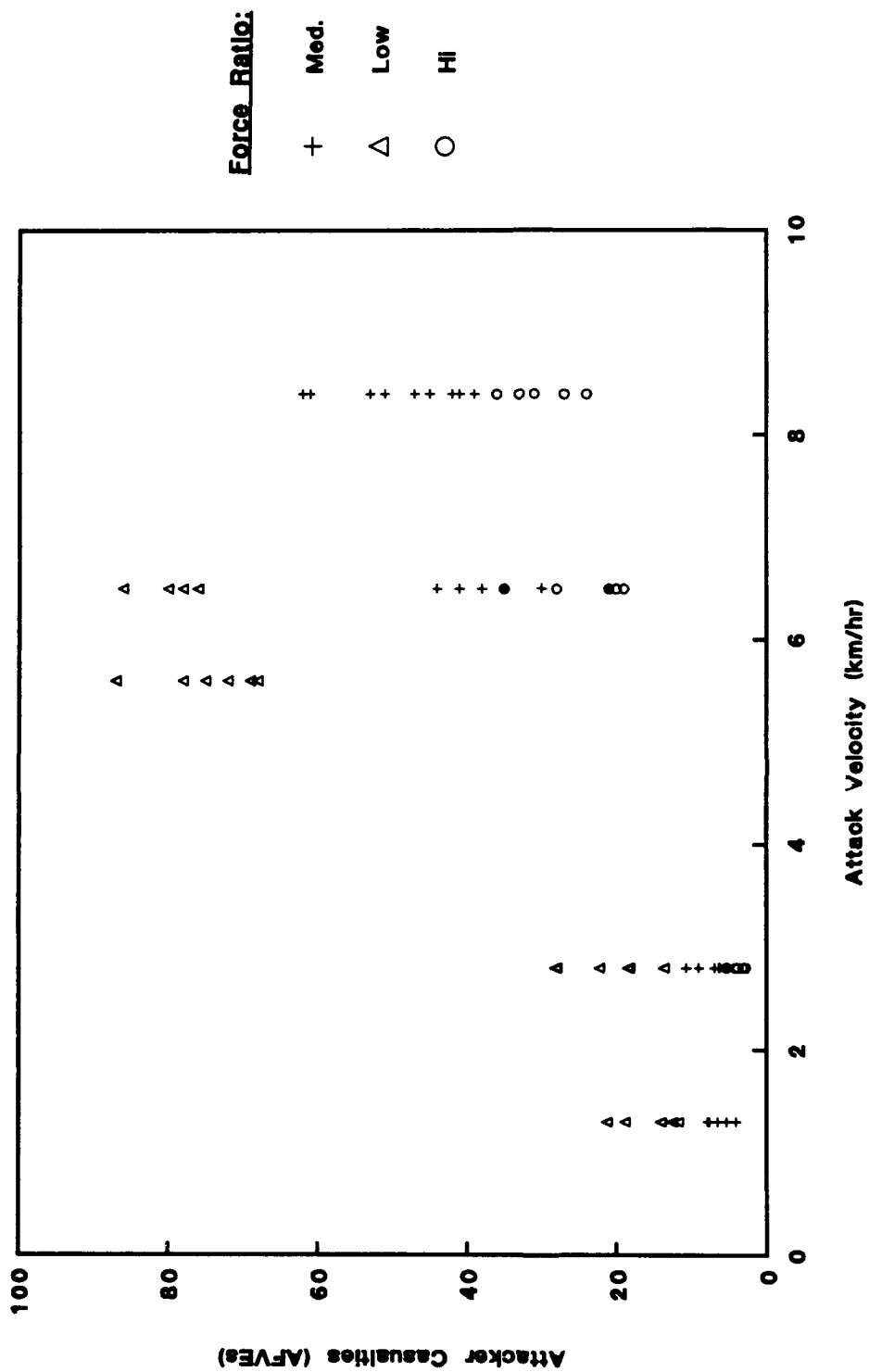


Figure IV-7. Force Ratio Effects, Central Europe

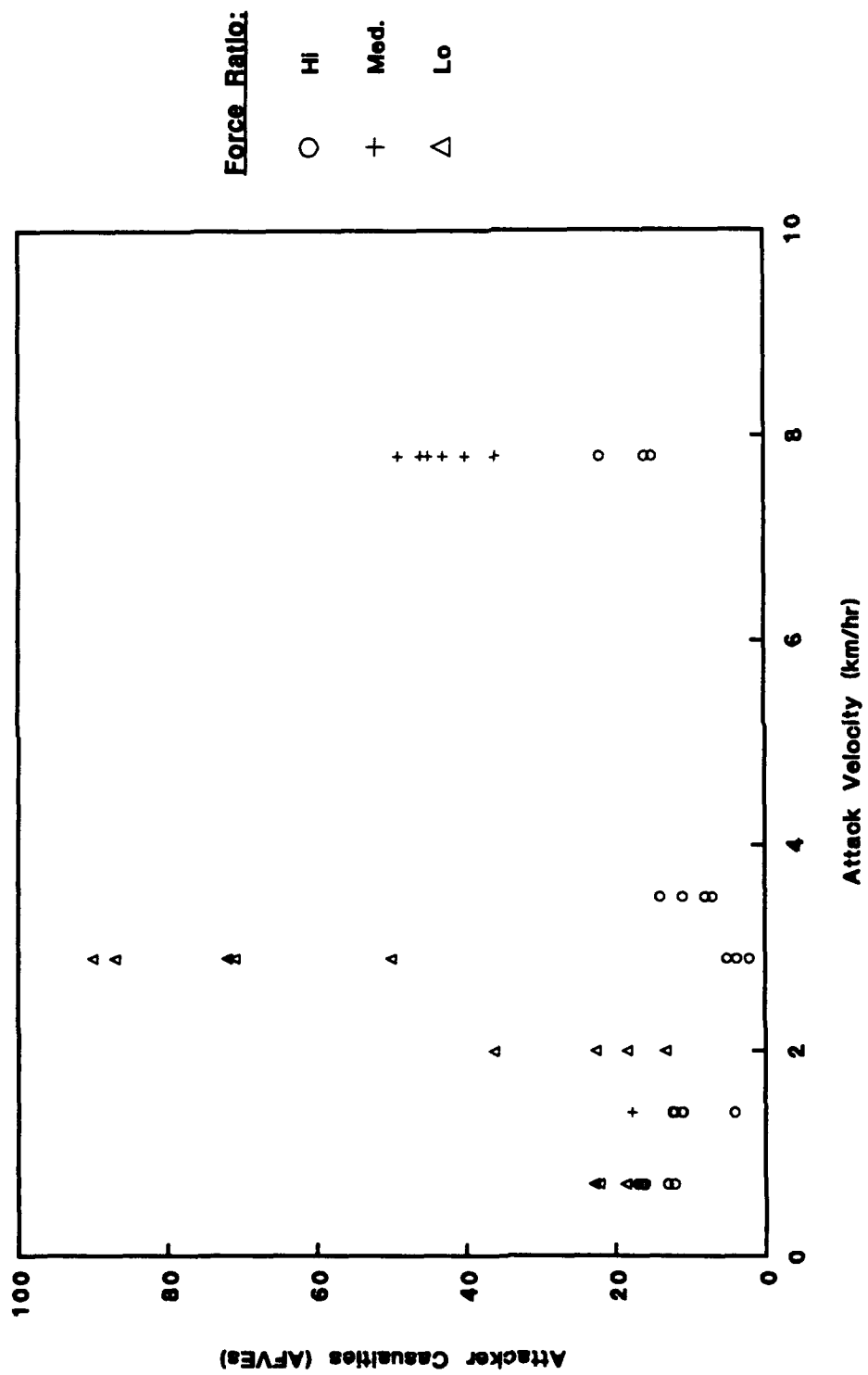


Figure IV-8. Force Ratio Effects, Southwest Asla

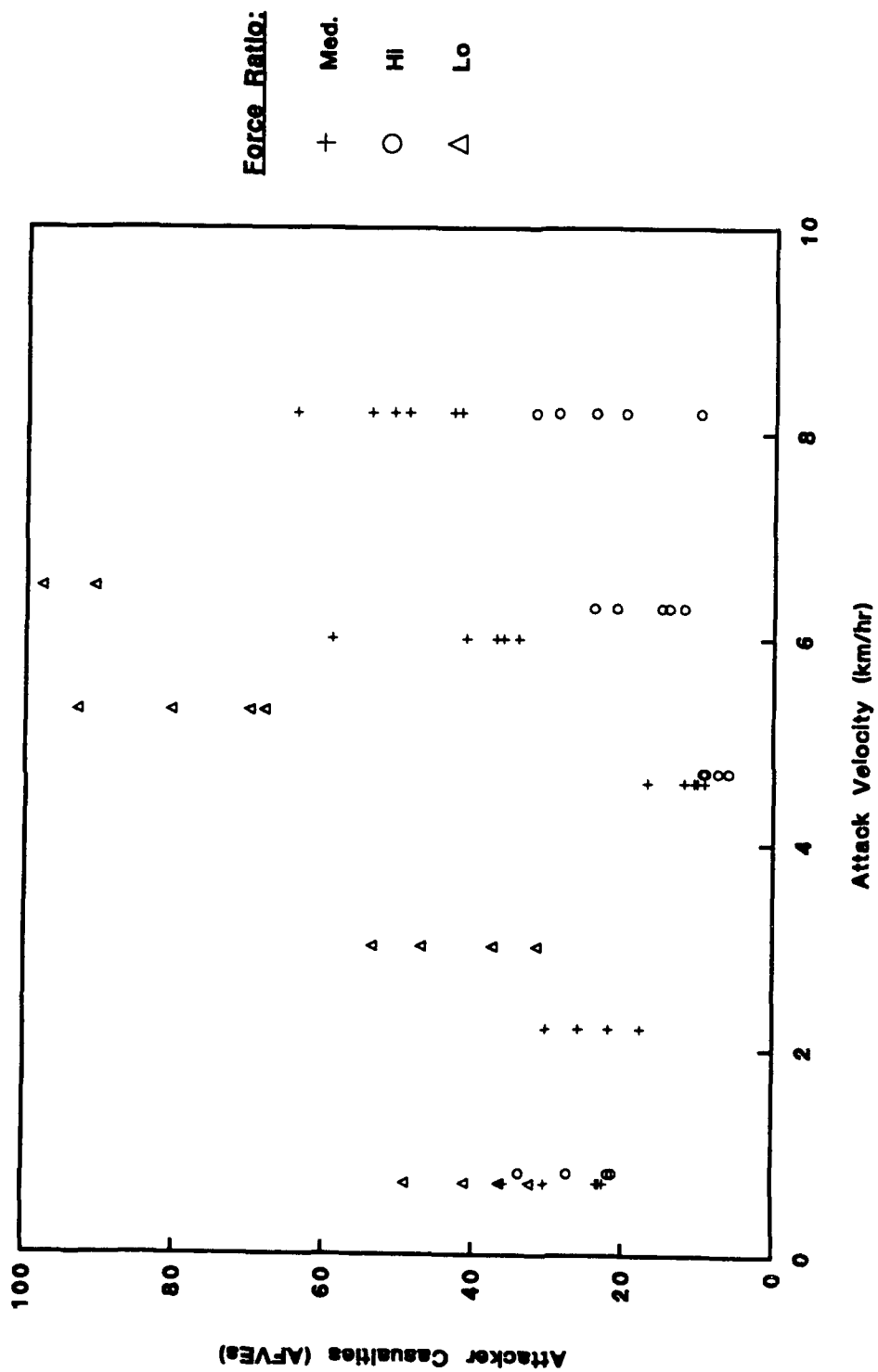


Figure IV-9. Force Ratio Effects, Korea

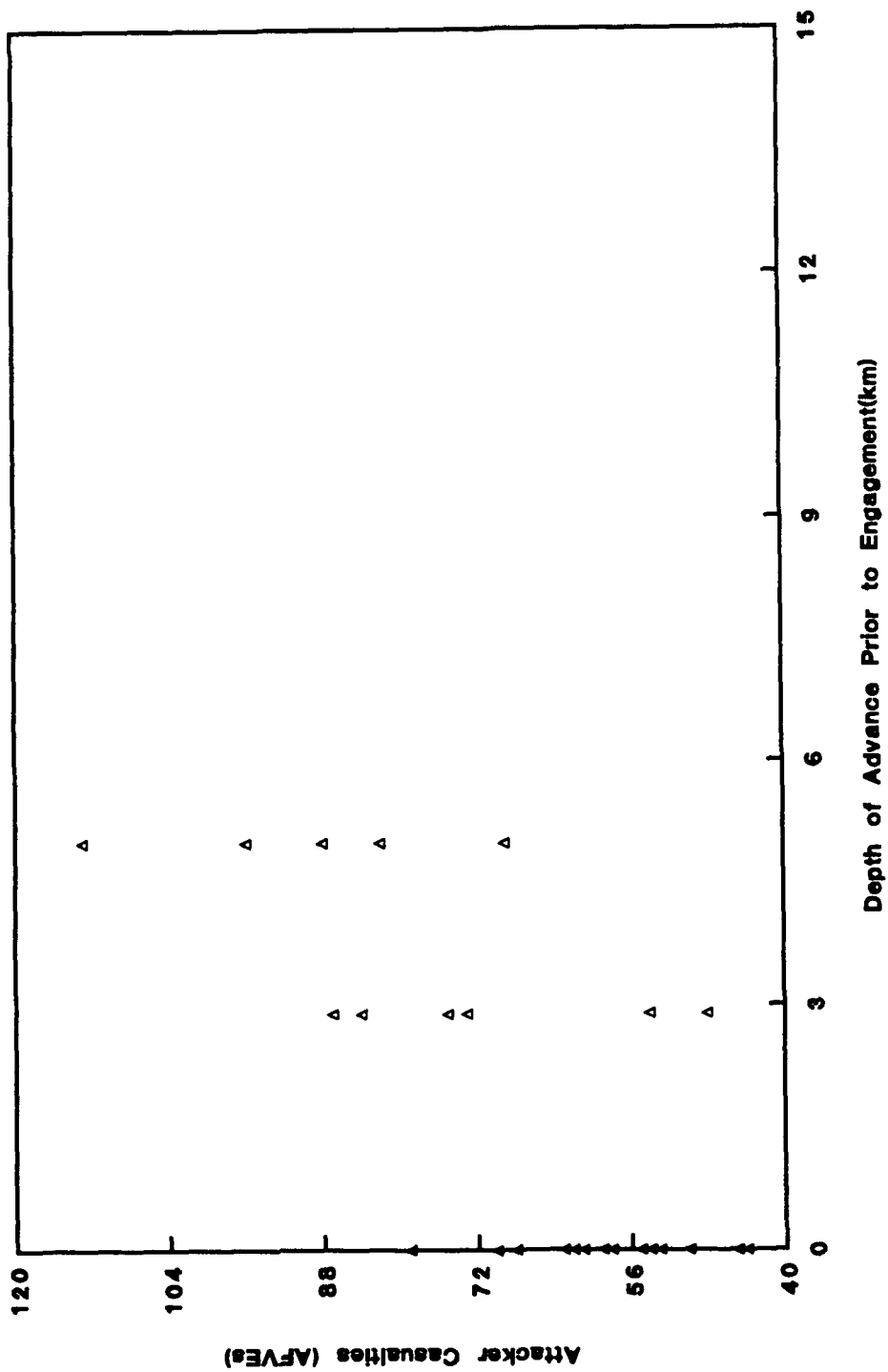


Figure IV-10. Assault upon Successive Lines, Central Europe

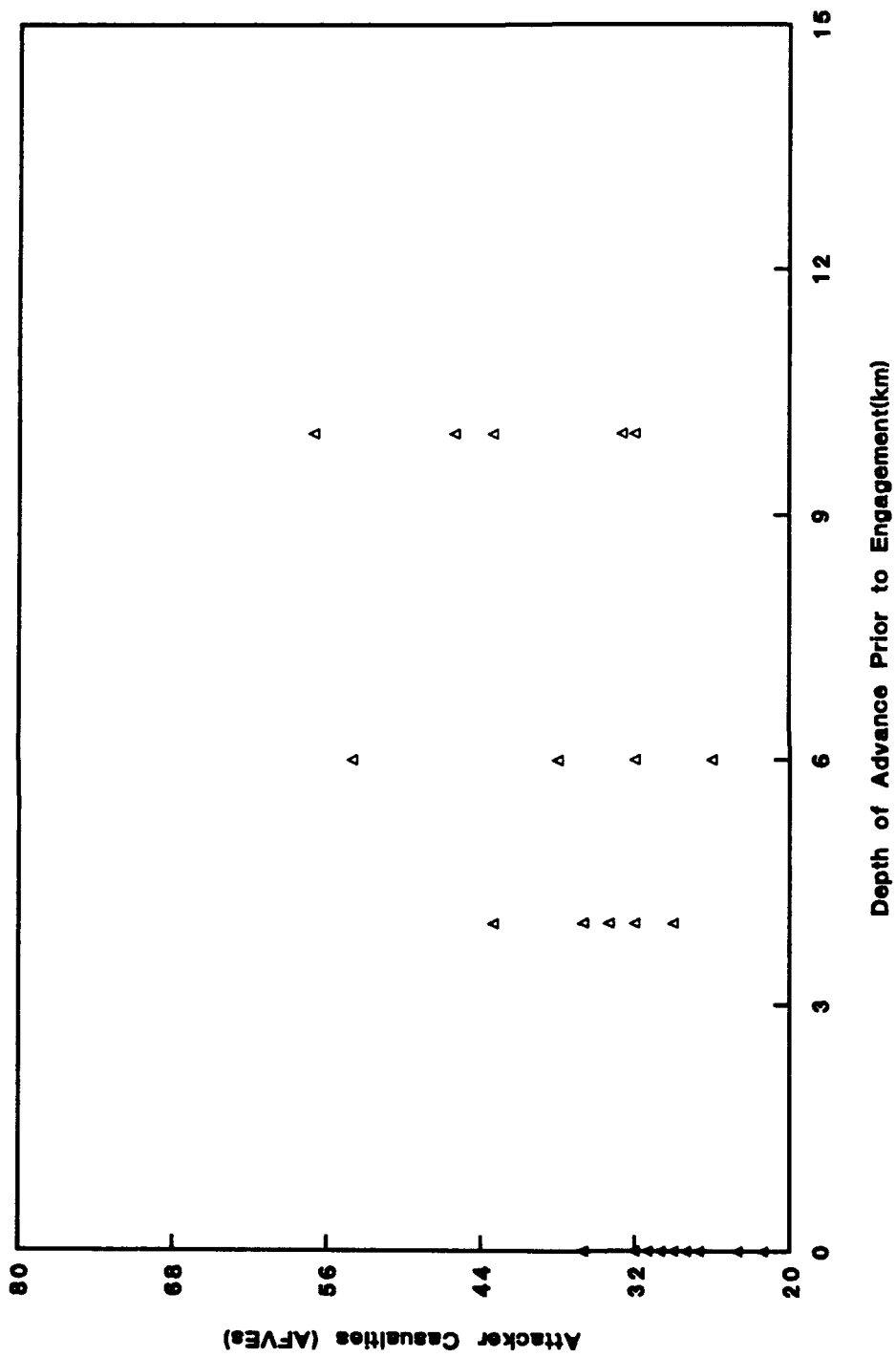


Figure IV-11. Assault upon Successive Lines, Southwest Asia

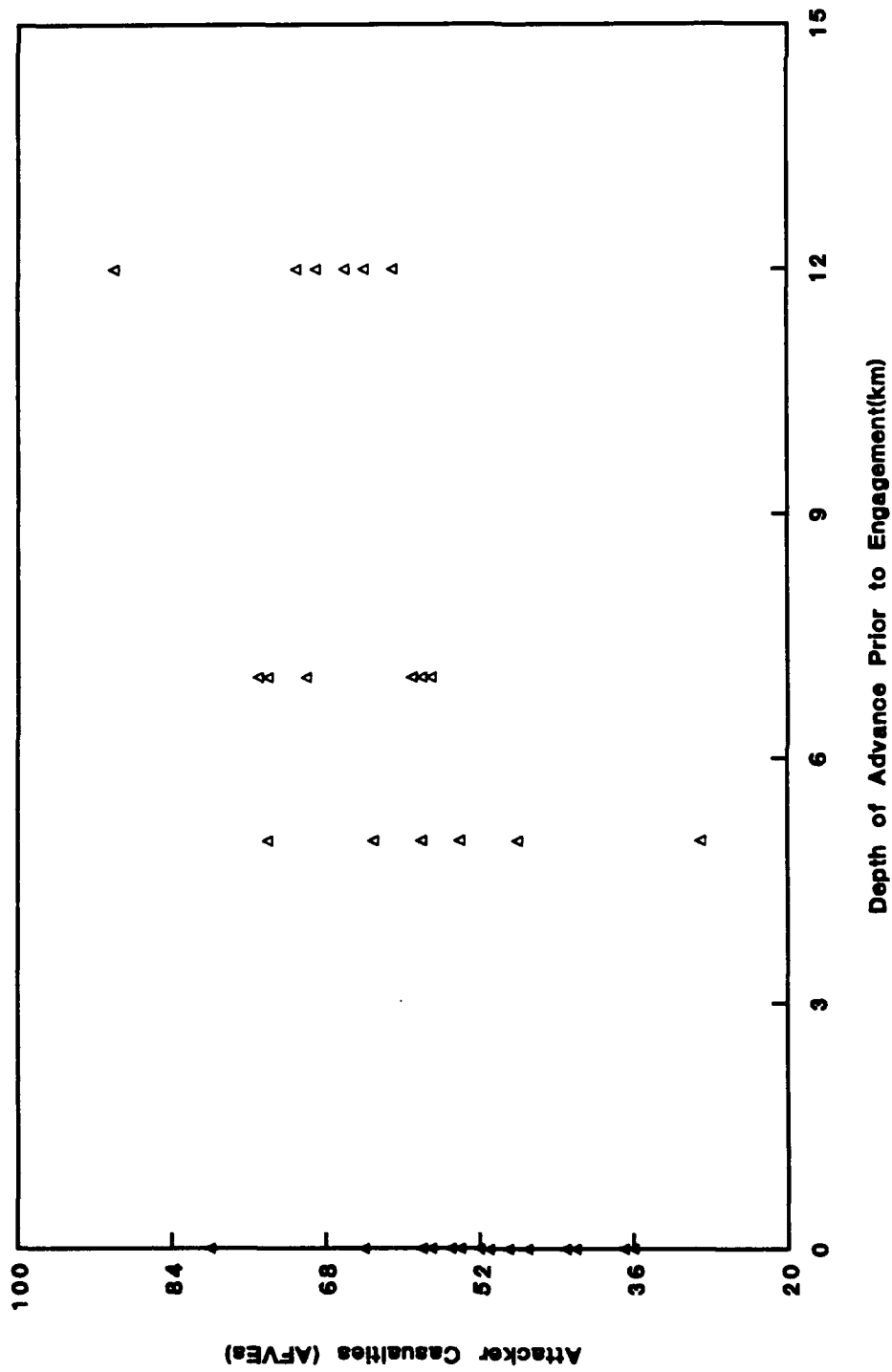


Figure IV-12. Assault upon Successive Lines, Korea

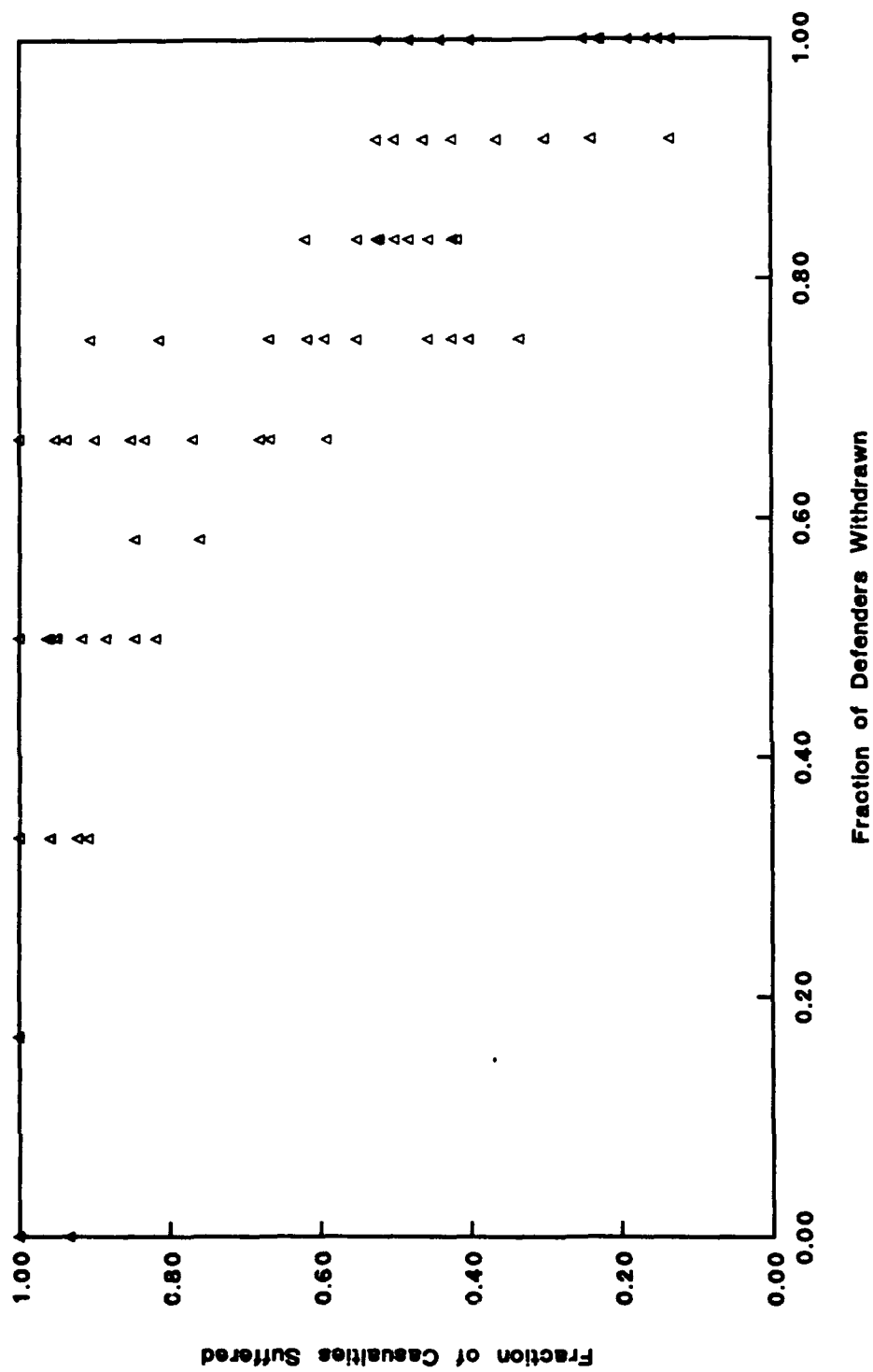


Figure IV-13. Withdrawal from Ground Engagements, Central Europe

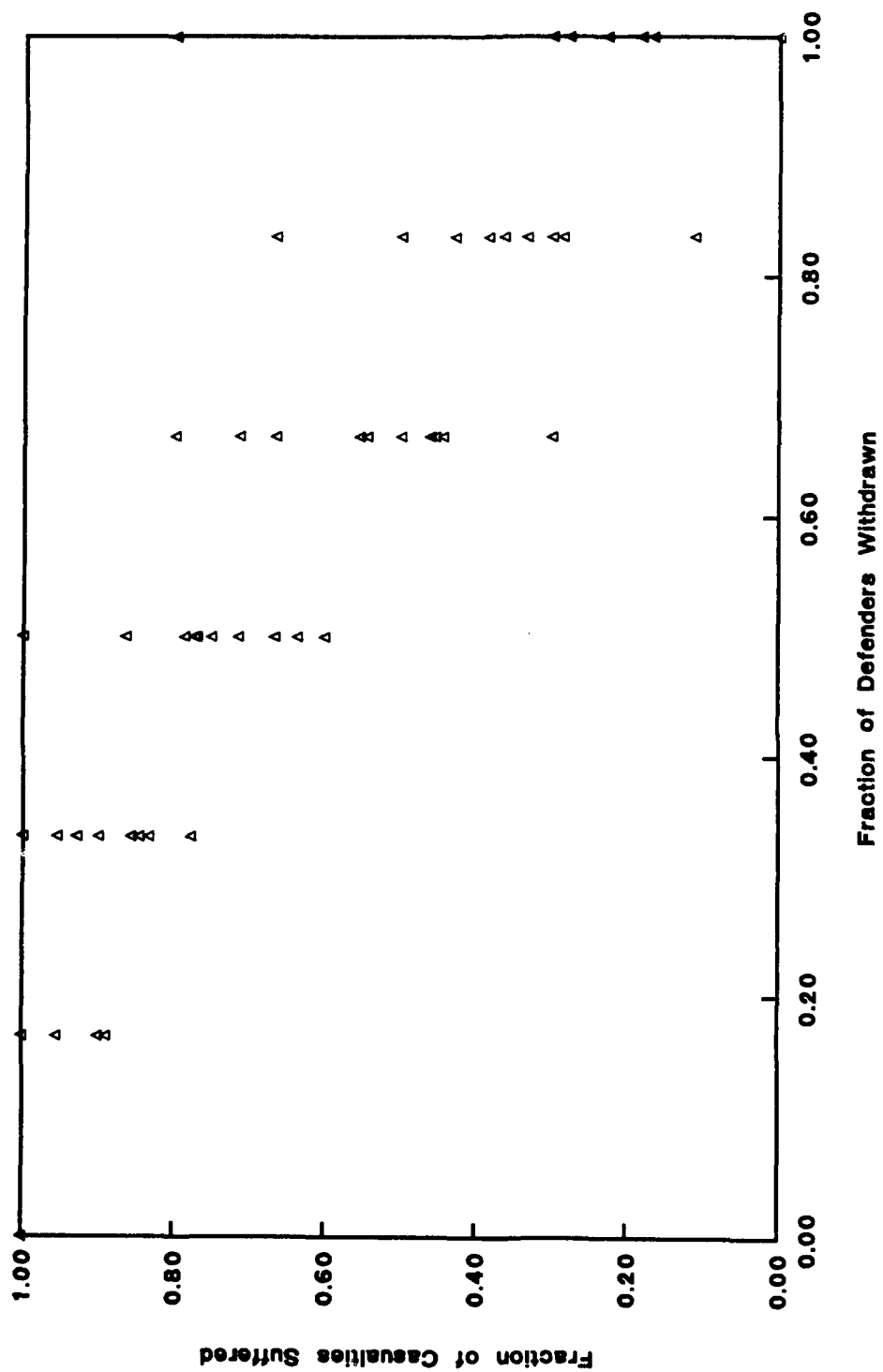


Figure IV-14. Withdrawal from Ground Engagements, Southwest Asia

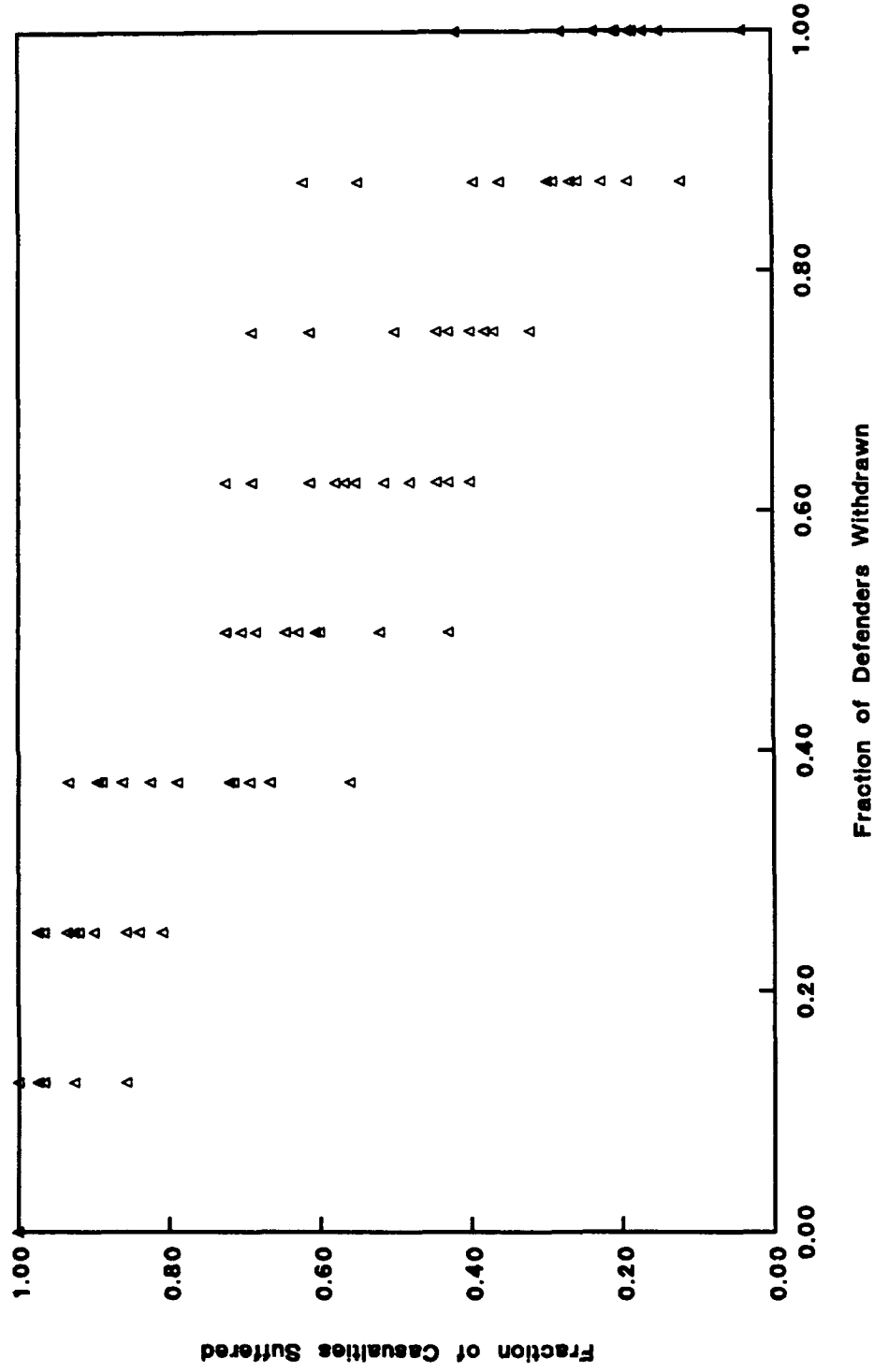


Figure IV-15. Withdrawal from Ground Engagements, Korea

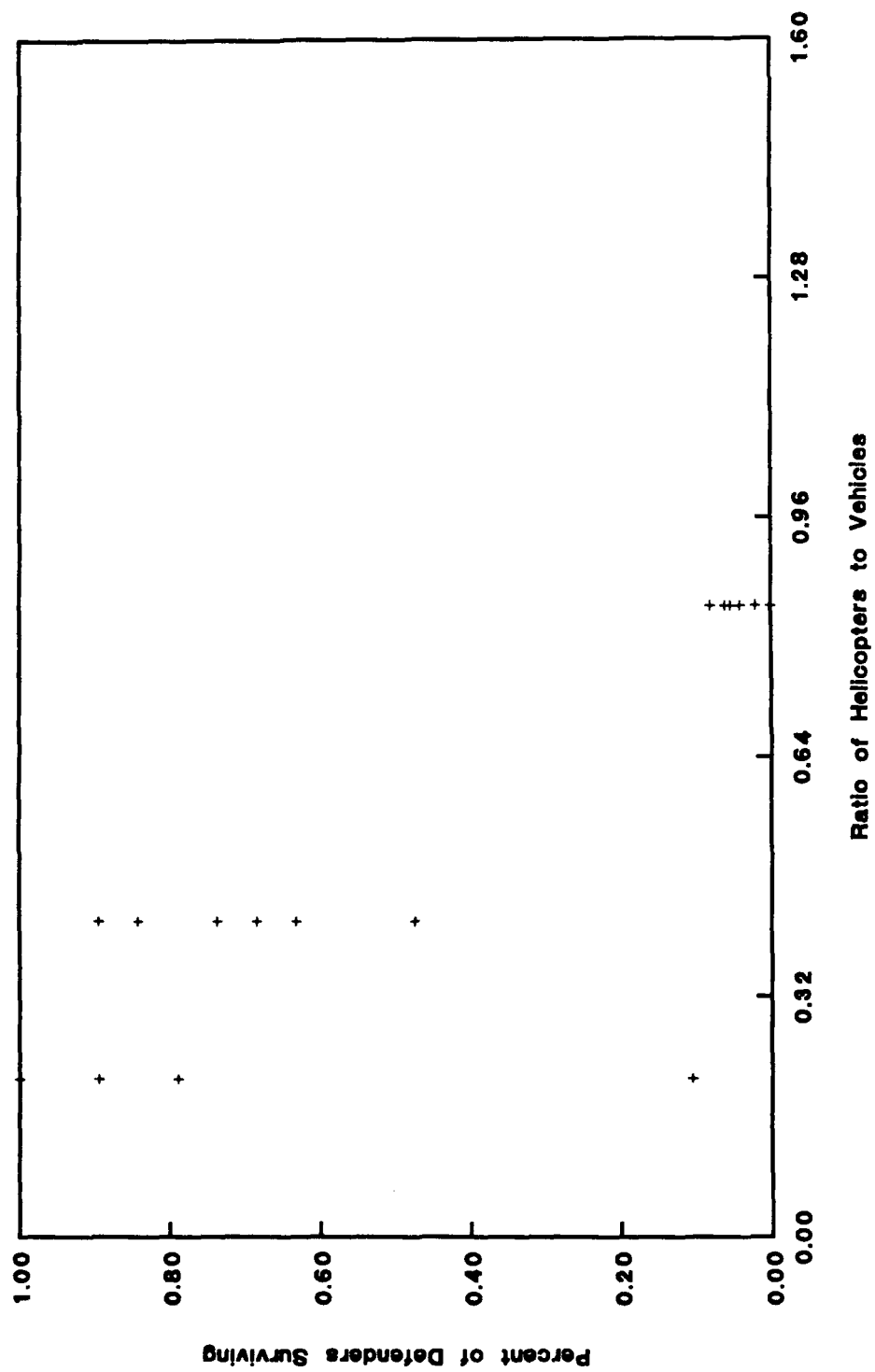


Figure IV-16. Helicopter Pursuit, Central Europe

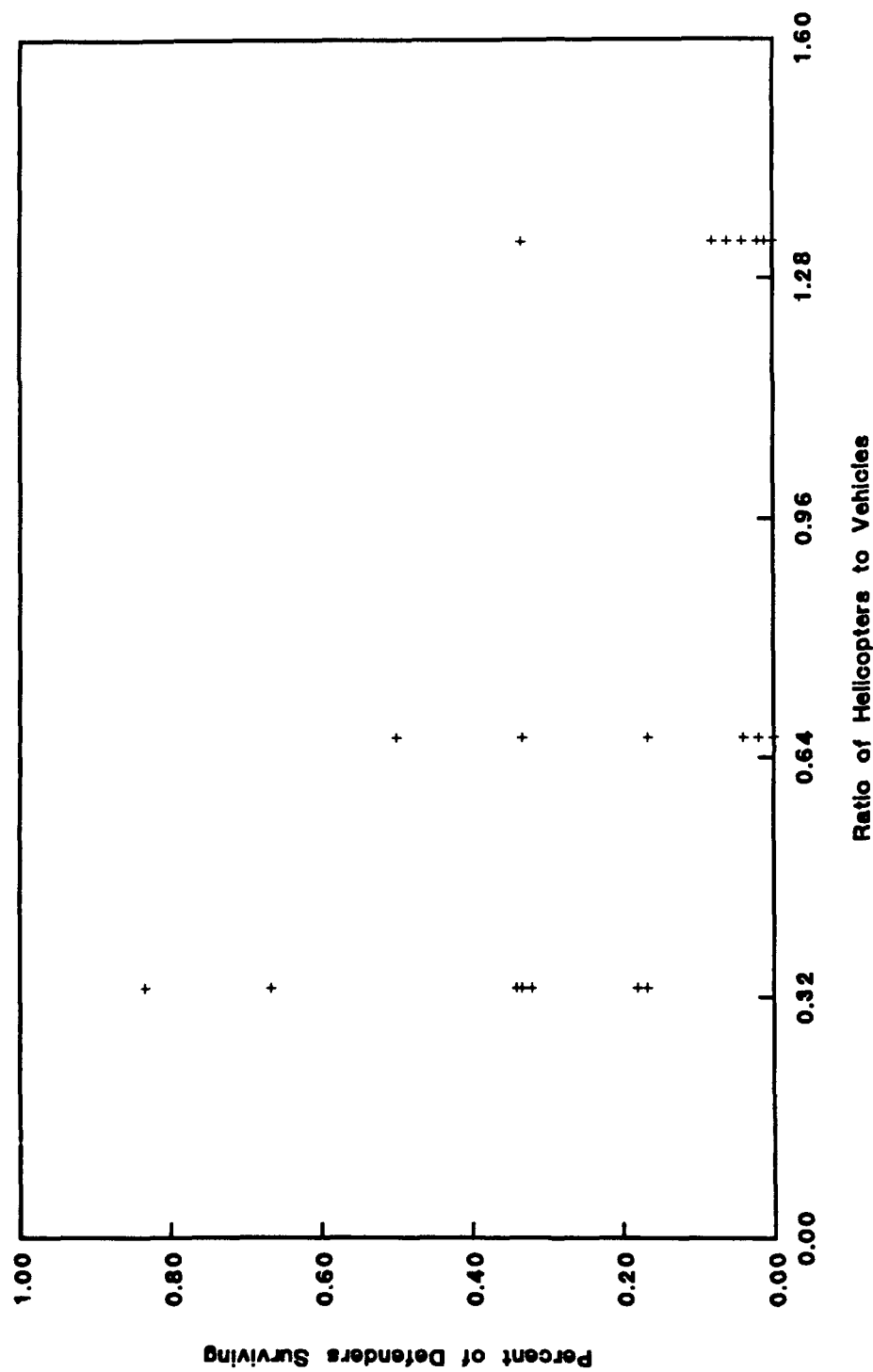


Figure IV-17. Helicopter Pursuit, Southwest Asia

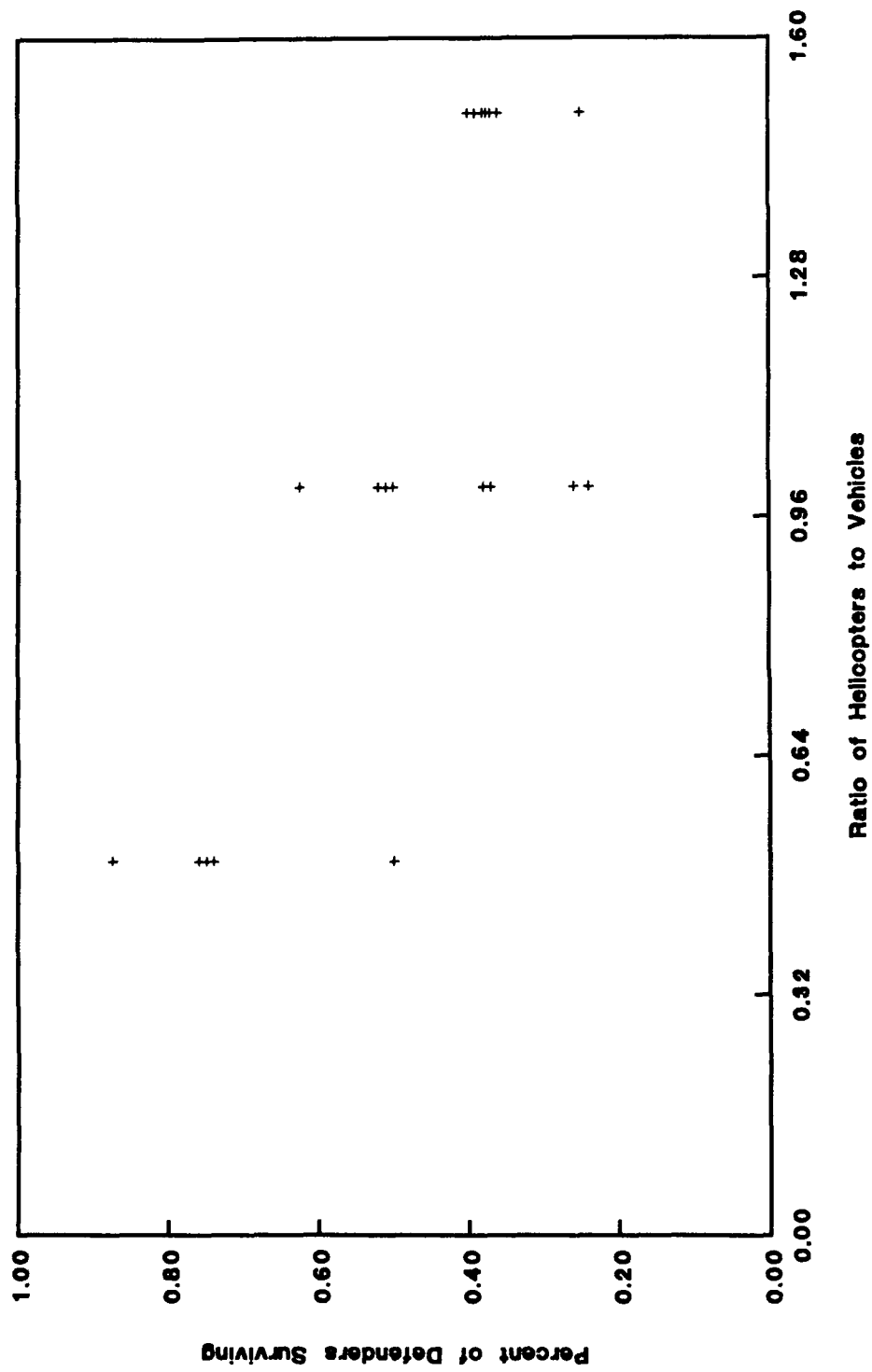


Figure IV-18. Helicopter Pursuit, Korea

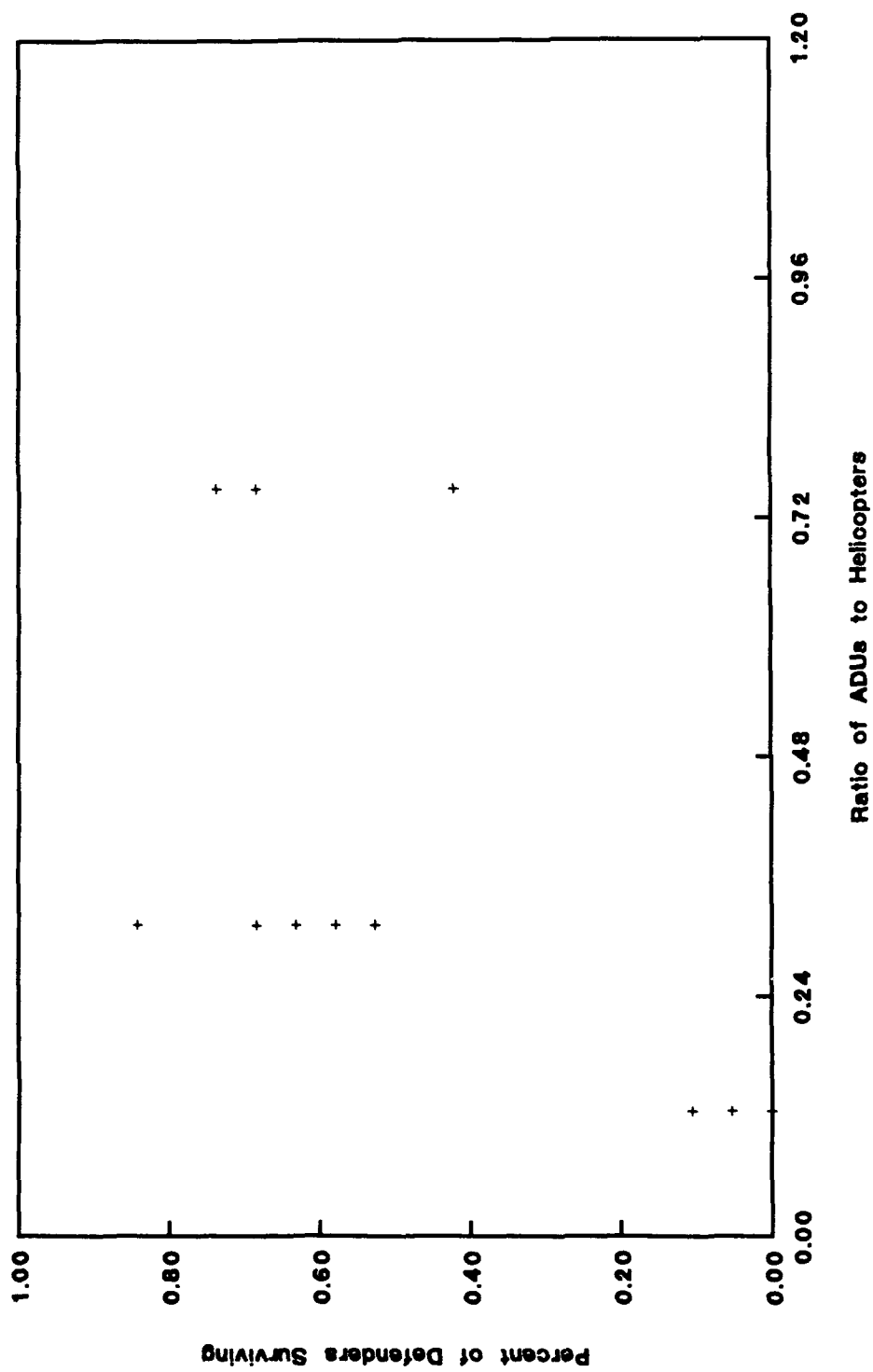


Figure IV-19. Withdrawal and Air Defense, Central Europe

Figure IV-20. Withdrawal and Air Defense, Southwest Asia

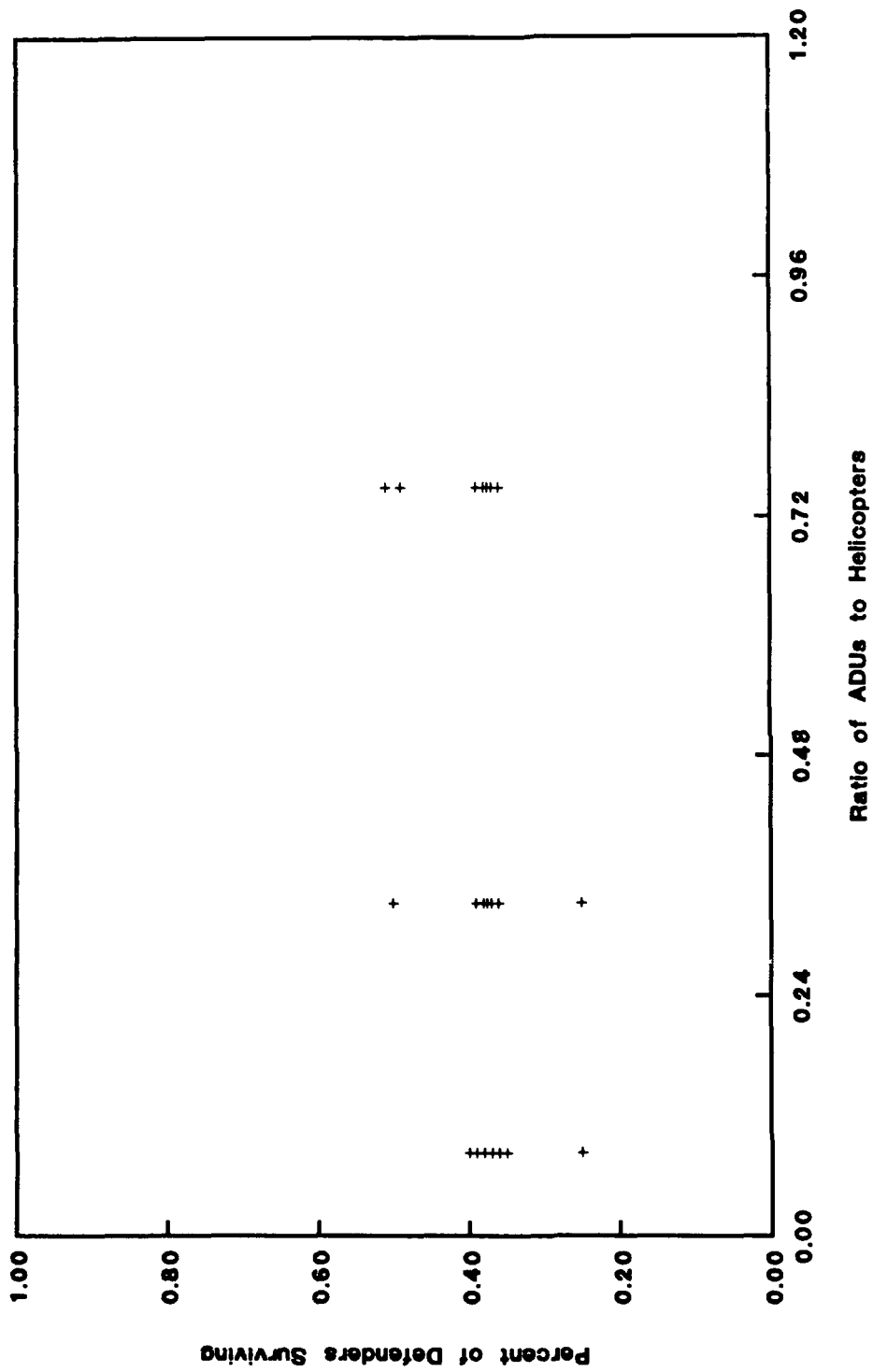


Figure IV-21. Withdrawal and Air Defense, Korea

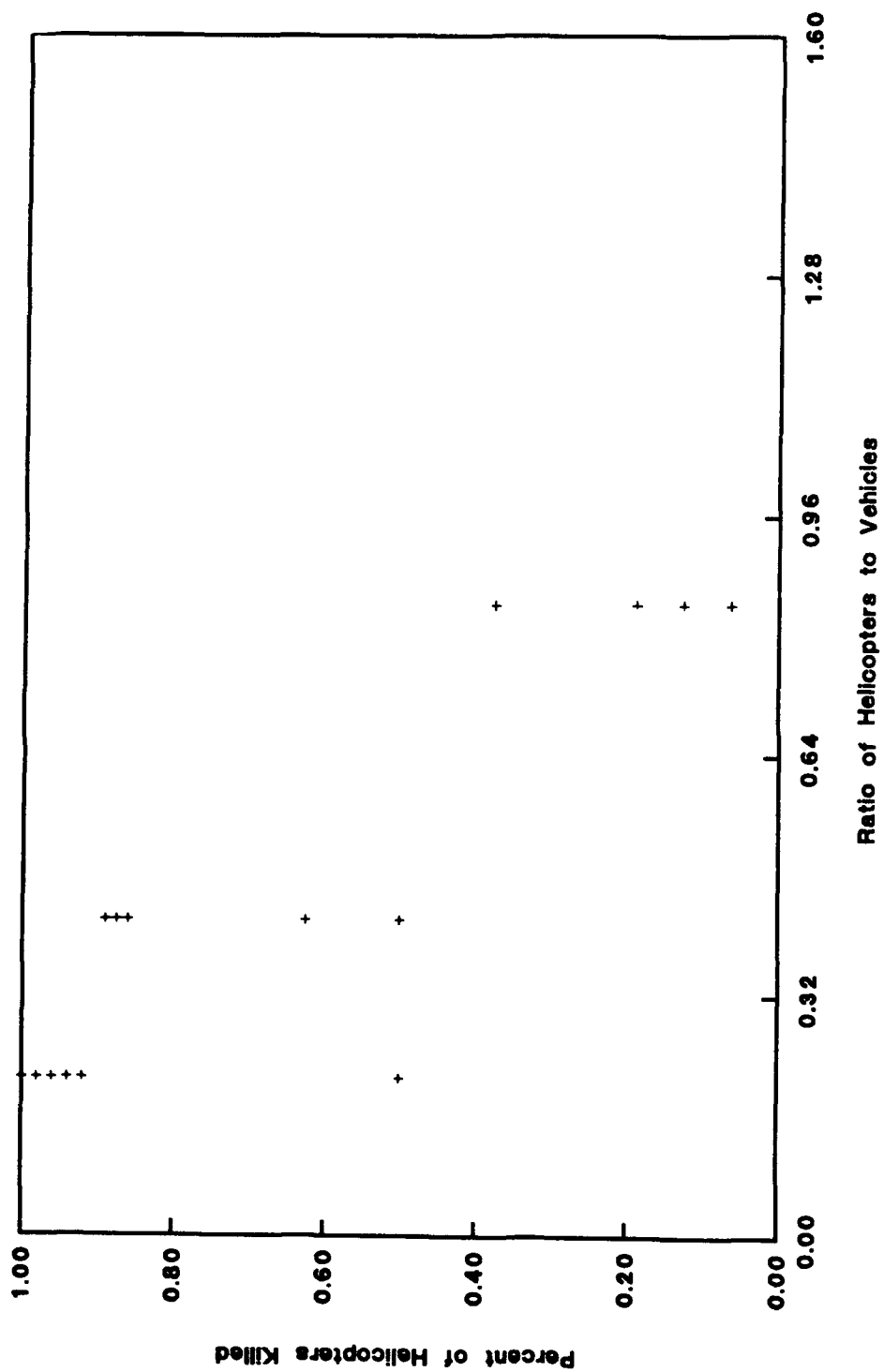


Figure IV-22. Pursuit and Helicopter Losses, Central Europe

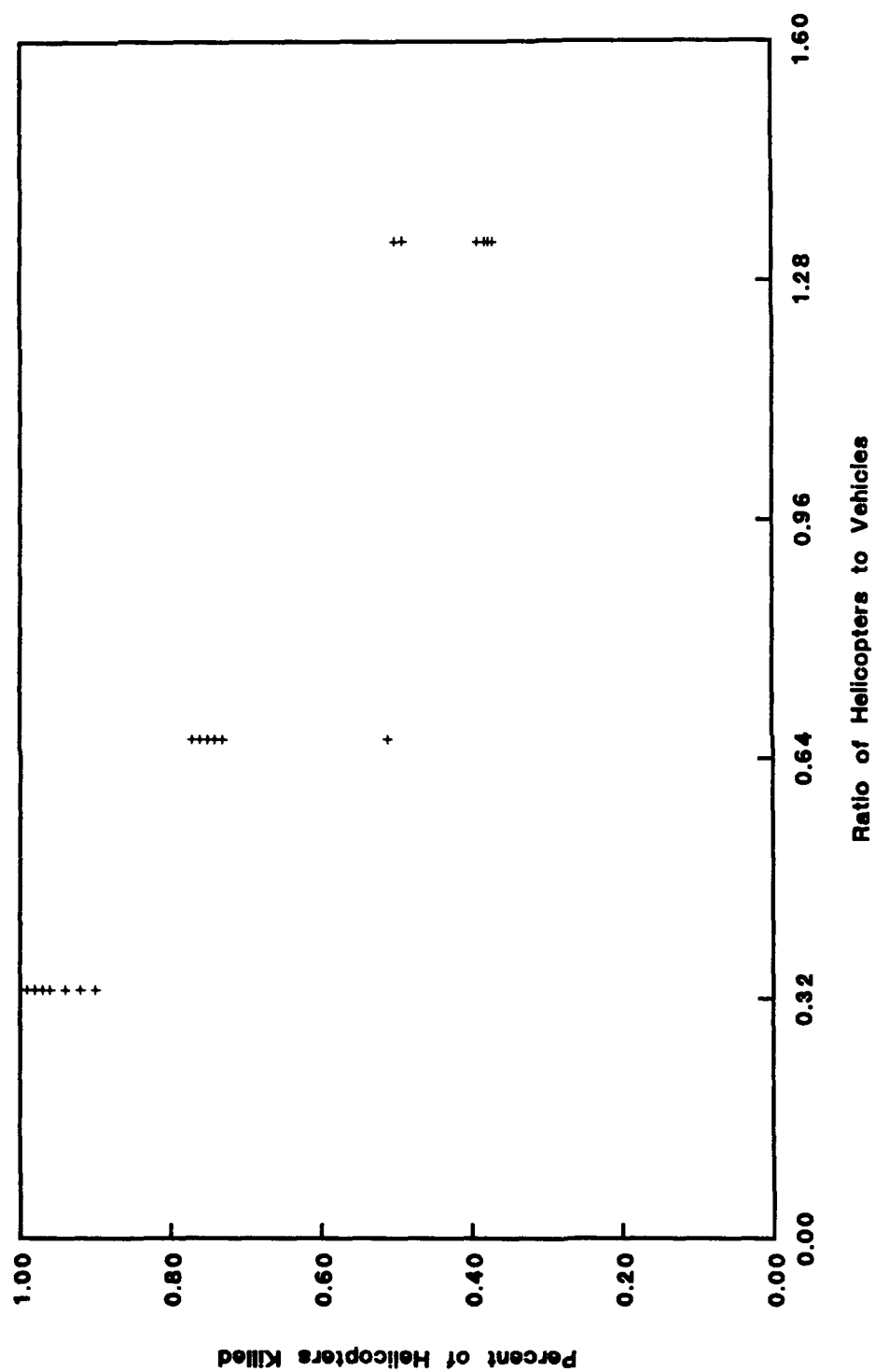


Figure IV-23. Pursuit and Helicopter Losses, Southwest Asia

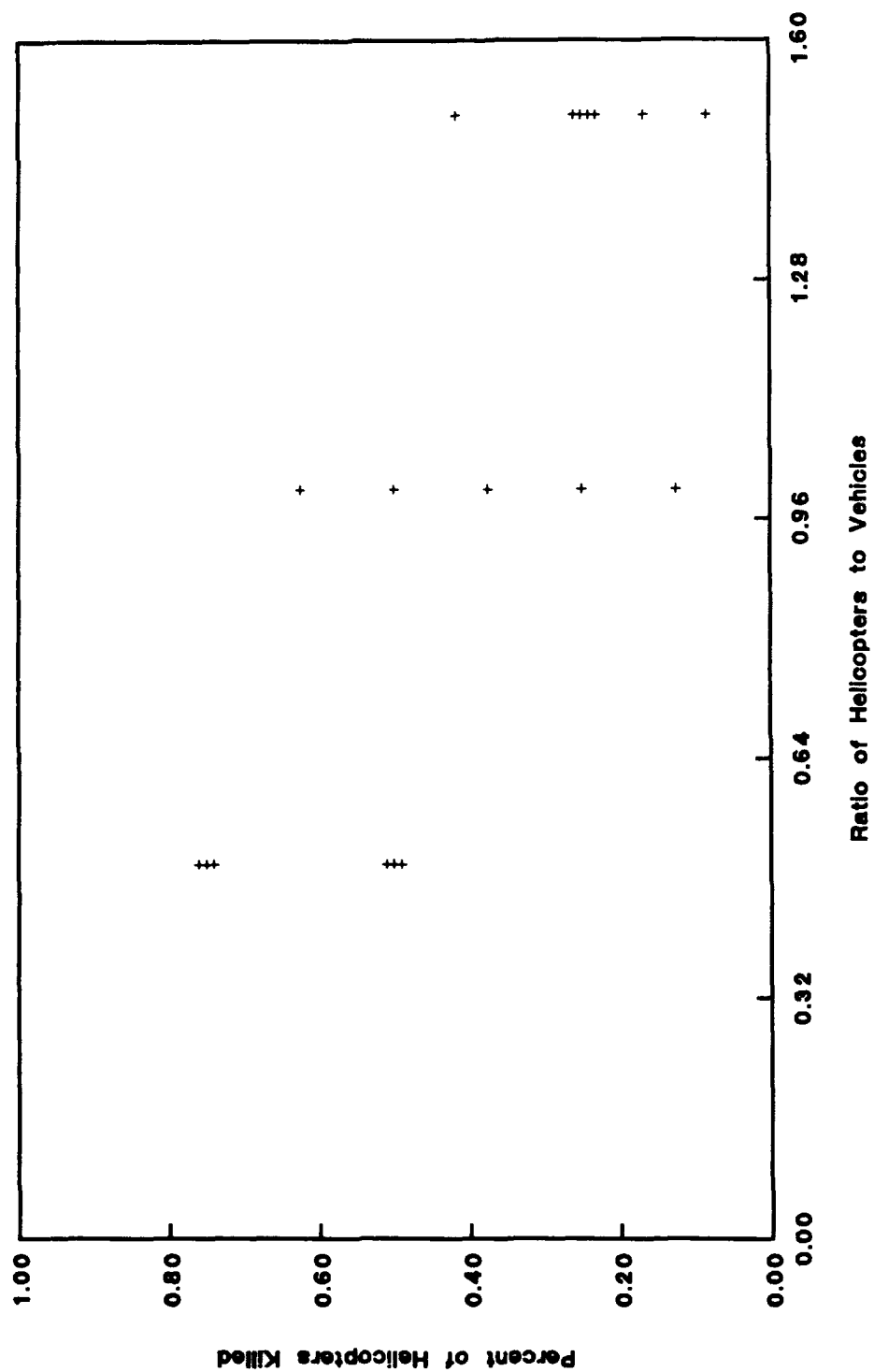


Figure IV-24. Pursuit and Helicopter Losses, Korea

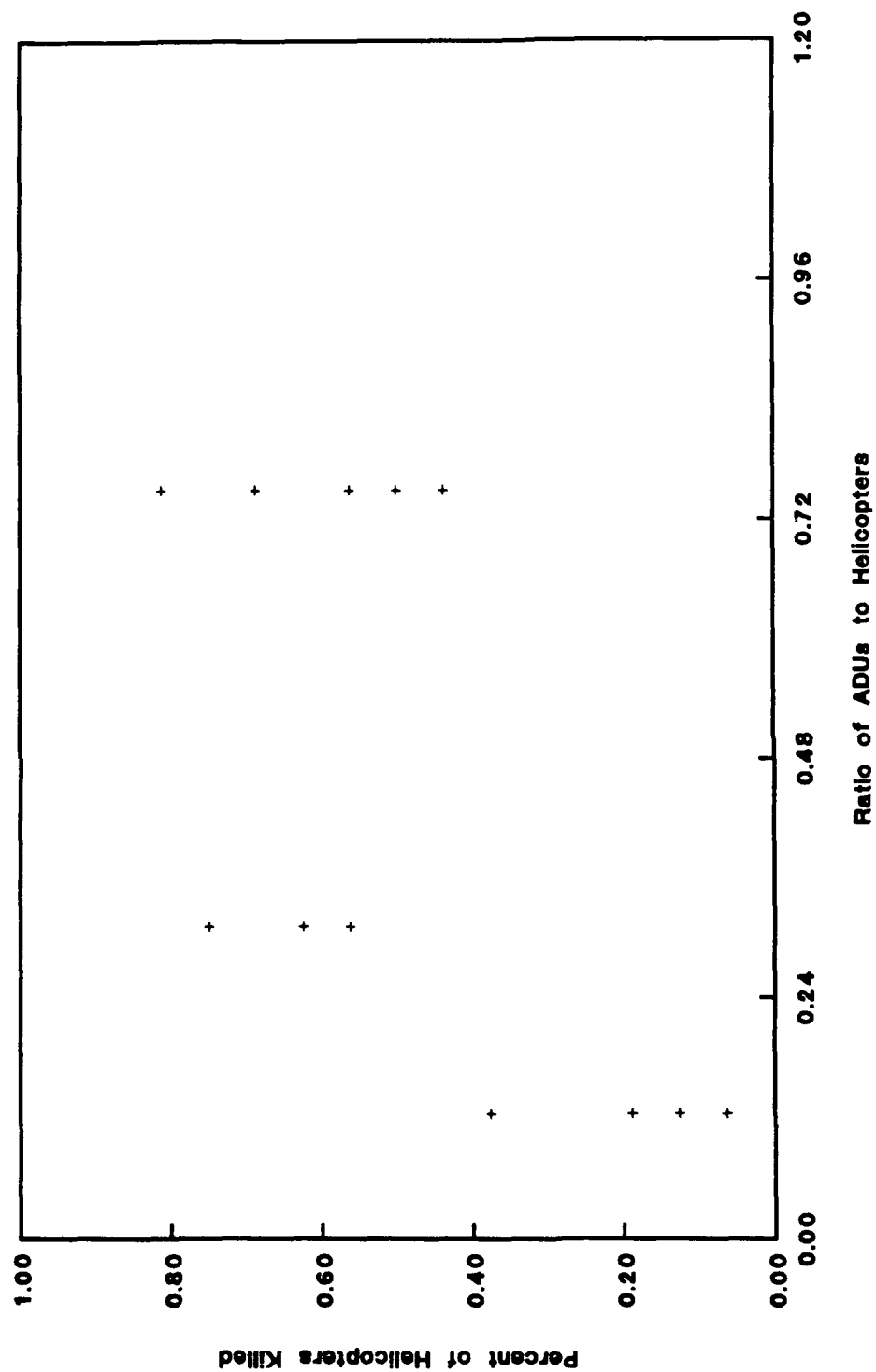


Figure IV-25. Air Defense and Helicopter Losses, Central Europe

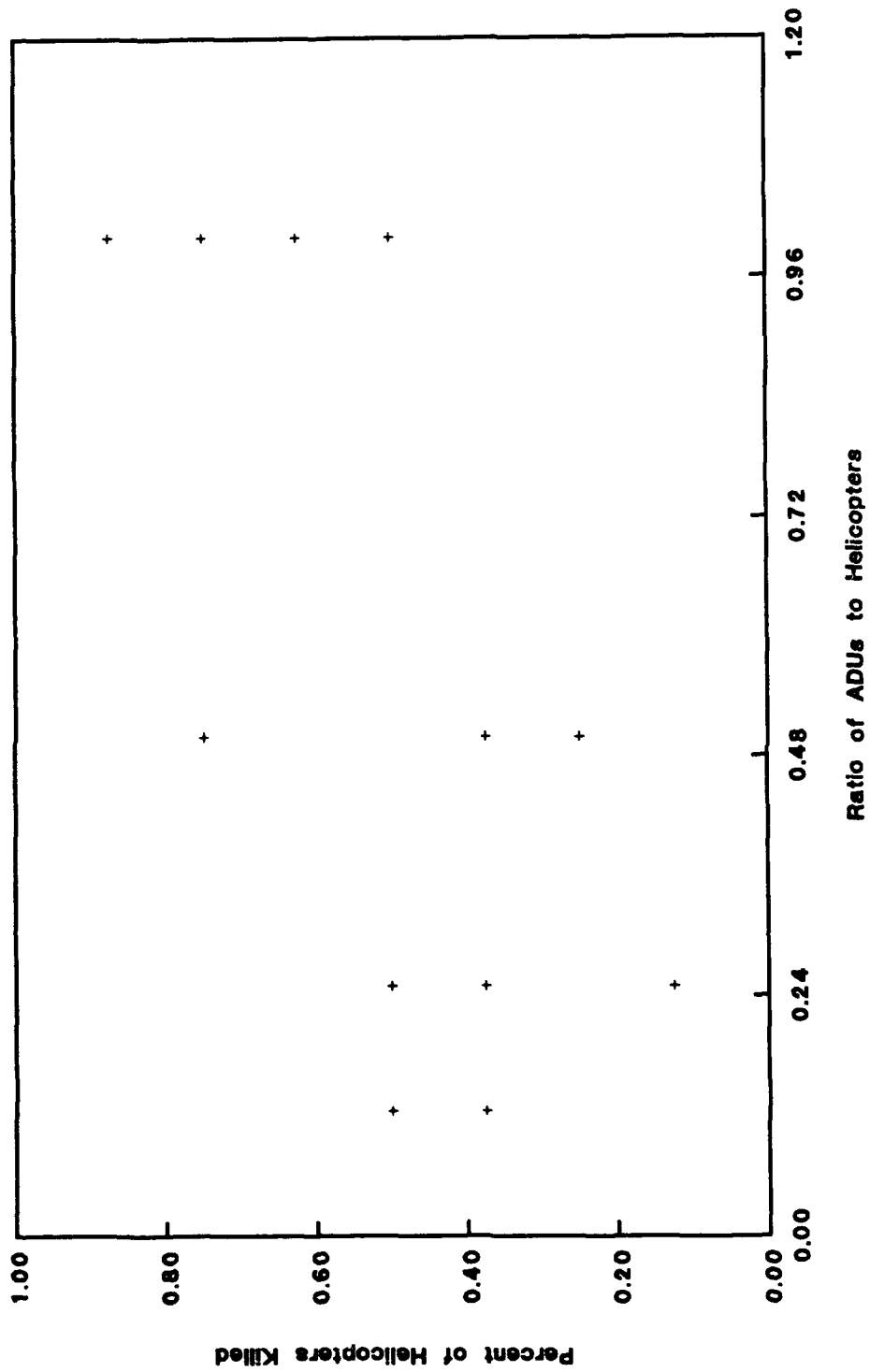


Figure IV-26. Air Defense and Helicopter Losses, Southwest Asia

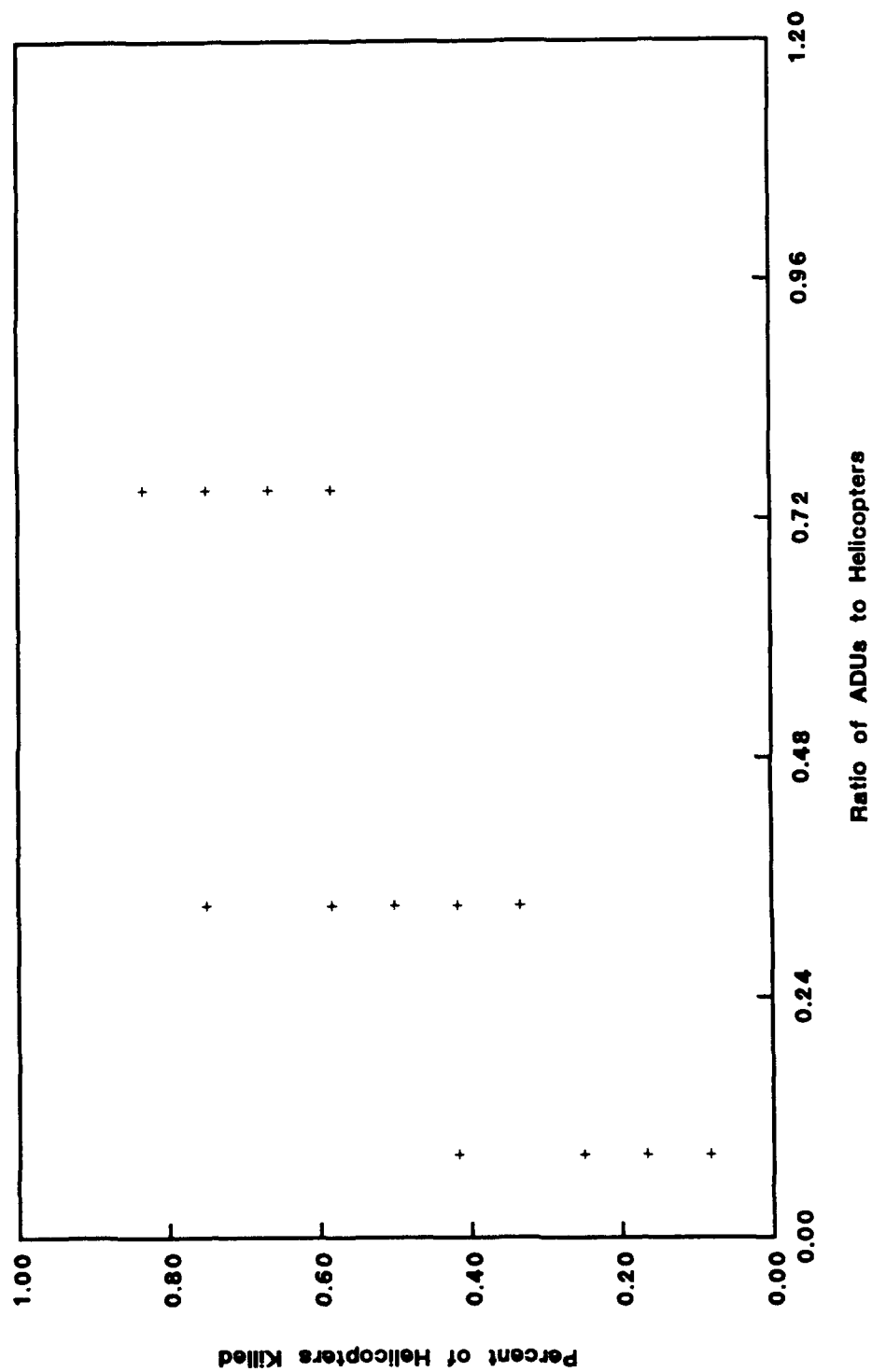


Figure IV-27. Air Defense and Helicopter Losses, Korea

B. EXPERIMENTAL LIMITATIONS AND ERROR

Over the course of this study the authors identified a number of potential limitations to the experimental approach and sources of experimental error. Section B.1. discusses the main potential sources of error or uncertainty in the Janus experiments: statistical error due to the stochastic nature of the model and the relatively small number of runs of each scenario, and systematic errors due to the uncertainty of some Janus inputs and algorithms. Section B.2. discusses the main potential sources of error or uncertainty in the coefficients derived for the tactical combat equations in the VFM model: weapons and munitions effects that were previously unknown or that could not be controlled due to the nature of the experiments, and the choices of equipment, tactics and direction of attack for the two sides in the Janus scenarios. Section B.3. discusses an excursion that the authors performed to assess the impact of weapon quality on the outcomes of the Janus scenarios.

1. Janus Experiments

Statistical error was introduced by the stochastic nature of the Janus simulation and the fact that, given time and resource limitations and the scope of the study (the authors ran 96 scenarios, involving 500 engagements), the authors could run each scenario only a few times. At the scale of the engagements simulated in the study (with less than 50 vehicles in combat at any one time), stochasticity can cause casualty results to vary dramatically. Stochasticity particularly affects artillery results—artillery effects in Janus are highly random—and high-velocity mounted assault results—through cascading effects of unlikely events. An illustration of cascading effects in an assault follows: the first few shots by defending vehicles kill significantly more attackers than usual, dramatically improving the immediate force ratio. The defenders destroy the remaining attackers in the first echelon more quickly, taking fewer losses. Subsequent echelons must kill the remaining defending vehicles before engaging the defending infantry, so the attacker takes even more losses, etc., leading to much higher attacking casualties than normally would occur. For the vast majority of the assault scenarios, it was possible to run only three engagements. For a small number of assault scenarios (in particular, those associated with the combination of a balanced force composition and attack velocity), and for all other scenarios, the authors ran more engagements (four to six). However, given that a variation of a factor of two in casualties suffered is not impossible, one can see where more runs would have been beneficial to reduce the impact of random fluctuations.

In addition to the difficulty of stochasticity, the second potential source of experimental error was the judgment of values for some of the Janus inputs. Janus is a very complicated model, with many pertinent inputs, and data for some of them is hard to find. For example, one important parameter is the distance at which one unit can detect another unit (vehicle or infantry) in full defilade. If this value is high, the defender loses a great advantage, as going to cover is not very effective. If this value is low, the defender can retreat under cover with impunity, even in engagements at short (and sometimes very short) range. It is not easy to find data of this type, nor is it easy to estimate. An effort was made to use reasonable estimates, but nevertheless scenario results are somewhat sensitive to these estimates.

These complications notwithstanding, IDA has been diligent and largely successful in its effort to eliminate idiosyncratic data. However, the problems of uncertain, indeed almost unknowable, data remain.

2. VFM Coefficients

Turning now to the coefficients derived from this work for the VFM combat equations, potential sources of limitations of the applicability of the VFM model were the authors' lack of a priori knowledge of the exact effectiveness of some weapons in the Janus scenarios, and the choice of equipment, tactics and direction of advance for the scenarios.

The first limitations to the applicability of VFM arises from the unexpected effectiveness of some of the weapon systems in Janus, as evidenced in scenarios in Southwest Asia, particularly in those exploring variations in amounts of artillery and numbers of attack helicopters. In deciding upon the range over which to explore each combat variable in the scenarios, the authors started with a base value representing a typical (according to existing units and military doctrine) force composition or force ratio and increased and decreased the base to create a range. Ranges were intended to include the values of each variable that could reasonably be expected in combat, and to provide enough variation in the variable to see the effects of changing it. For example, the blue attacking force in Southwest Asian assault scenarios consisted roughly of one tank company and one mechanized infantry company per echelon. The red attacking force in Korea consisted of two BMP companies and one tank company per echelon. Variations from this base were made in what seemed to be a reasonable fashion (sum of infantry fractions started with a base of roughly 1.0 and went from 0.5 to roughly 1.5).

In some instances, however, ranges may have been too small. In particular, this was true of U.S. (attacking) artillery variations in Southwest Asia. In the high velocity scenarios (mounted assaults employing a smoke screen and some artillery preparation), the base case artillery destroyed an average of 3.0 defending AFVEs. The smallest quantity of artillery (half the base) destroyed approximately 2.8 AFVEs, and the largest quantity of artillery (twice the base) destroyed an average of some 4.4 AFVEs. At a low attack velocity (the second fastest dismounted assault), the corresponding results were 8.1 AFVEs (base case), 6.3 AFVEs (half base), and 9.3 AFVEs (twice base). The marginal change in defending casualties with respect to attacking artillery support was quite small over the range explored; this is reflected in the combat equations in Appendix A. However, in each case artillery destroyed a significant fraction of the entire defensive force. Therefore one could conclude that this is a case of overkill, and that the real sensitivity of outcomes to changes in attacking artillery support was not properly represented by the data and was thus underestimated in the equations. For comparison with the case above the reader is referred to Korea, where in the fastest dismounted assaults, U.S. (defending) artillery destroyed on average 4.3 AFVEs (base case), 0.8 AFVEs (half base), and 10 AFVEs (twice base).

A similar problem occurred in the helicopter pursuit scenarios in Southwest Asia. Pursuing attack helicopters were found to be extremely effective, so much so that in some engagements two attack helicopters destroyed six withdrawing vehicles, even in the presence of defensive smoke screens and supporting ADUs. In the scenarios exploring the effectiveness of air defense, increasing the number of ADUs did very little to protect the withdrawing vehicles (although it did increase helicopter casualties). This happened for two reasons: the desert is very conducive to helicopter pursuit as it is very flat, and the AH-64 Apache is a very effective weapon system in this role. In the Central Europe scenarios, the Mi-24 Hind was used in pursuit. It was rather effective, but not as devastating as the Apache. The end result is that the combat equations derived in Appendix A for desert terrain may understate the sensitivity of the survival rate of withdrawing vehicles to the level of air defense.

With hindsight, there are obvious solutions to the foregoing artillery and helicopter problems. In the case of artillery, the scenarios could be repeated with a larger defending force (so the fraction destroyed by artillery is small) or fewer tubes supporting the attack. In the case of helicopters, the air defense scenarios could be repeated with fewer helicopters. However, the solutions and their underlying problems could not have been

discerned without the experimental results. As weapon system interactions in Janus are complex, merely examining values of probabilities of hitting and killing given a hit is not enough to alert one to the situation. Unfortunately, given time and resource limitations, the authors were unable to repeat any scenarios; however, they could be repeated in future Janus work at IDA.

The next limitations of the applicability of VFM arise from the choice of equipment, tactics and direction of attack in the Janus scenarios. As stated in Chapter III, the authors made those choices both to maintain consistency with the earlier, Central Europe Janus work, and to enable VFM to model combat involving U.S. forces under circumstances which they would most likely be found in the future.

To maintain consistency with the earlier work, both sides used equipment of the same generation, and, within the Janus model, some important parameters were set to be equal. Specifically, neither side was given a particular vision or sensor advantage over the other: both sides primarily used the optical sensors associated with their weapons, with a maximum possible range of sight of 6 km. However, U.S. and Soviet equipment performs differently in Janus and even when using the same equipment, the direction of attack across a given piece of terrain may influence Janus scenario outcomes. Different tactics affect scenario outcomes as well.

All of those factors affect conventional combat outcomes and the accuracy with which a model will simulate any given conflict. A case in point is the recent Persian Gulf War. Among other things, some have cited superior U.S. weapon systems, and particularly sensors, as major contributors to the crushing defeat of the Iraqi forces. If one were to simulate operation Desert Storm with the VFM model, using the combat equations derived in this study, the results could be different from the real outcome, as we currently assume that the effects of all factors not explicitly simulated and modeled cancel out for the two sides.⁹ Gaining a better understanding of issues like the impact of weapon technology and sensor performance would be a worthy goal of future work. However, such an investigation was beyond the scope of this study.

The above thus affects the applicability of the VFM model. One can be more confident about results the VFM model produces when it simulates the conditions that we did (e.g., Soviet forces attacking west in Europe against U.S. defenders) than about results

⁹ VFM would predict a substantial coalition victory in the Persian Gulf, but the predicted losses, particularly for U.S. forces, might not equal those actually suffered during the war.

it produces when it simulates conditions we did not (e.g., U.S. forces attacking north against North Korean defenders). In the same vein, one can be more confident about VFM results when the combat variables in VFM are within the ranges explored in the Janus scenarios. The curve fits may or may not be valid for extrapolation.

Lastly, all of the above may impose some limitations on the types of comparisons that can be made with the data from the different theaters. Comparisons of absolute data between Southwest Asia and Europe or Korea (e.g., the numbers of attacking casualties in mounted assaults) may be somewhat biased, but, as all conditions within each theater were completely consistent, comparisons of relative data (e.g., the relative effect on attacking casualties of doubling the attacker's artillery support in dismounted assaults) are not.

3. The Effects of Weapon Quality

The preceding aside, the authors recognized the potential impact of weapon quality, or technology, at the beginning of the study and performed an excursion in order to explore the magnitude of its effect. In the excursion, blue (U.S.) forces defended against a red (Iraqi) assault into Saudi territory. We performed the excursion using a different piece of terrain, some 20 kilometers southeast of the intersection of the Saudi, Kuwaiti and Iraqi international borders. Comparing the results of the excursion with the results of the scenario when roles were reversed allows one to draw some conclusions regarding the strength of the technological bias. At the highest combat velocity (a mounted assault with no smoke and little artillery preparation), the red attackers lost an average of 75.0 AFVEs. This compares with an average of 43.2 AFVEs lost by the blue attacking force employing similar tactics against a red defense, or, alternatively, with a predicted loss of 40.9 blue AFVEs as calculated using the casualty equation derived for Southwest Asia in Appendix A. At lower velocities, the technology bias disappears or is even reversed. Employing a dismounted assault under cover of smoke with minimal artillery preparation, the red attacker lost an average of 19.5 AFVEs, as opposed to predicted casualties for a blue attacker of 29.1 AFVEs (the authors did not run this scenario).

These differences can be attributed to four main factors. The first factor was that the blue defensive terrain was slightly better than was the red defensive terrain. On the terrain just north of the Iraqi-Saudi border blue forces were able to attack north, down a gentle slope, while on the terrain just south of the Kuwaiti-Saudi border the red forces had to attack south, up a gentle slope. The nature of the two pieces of terrain were such that

blue's lines of sight were somewhat better on the attack (extending in almost all cases out to the maximum possible line of sight in Janus, or 6 kilometers).

The second factor was that one blue weapon system, the AH-64 Apache attack helicopter, is far superior to its red counterpart, the Mi-24 Hind. Most importantly, the Apache is superior to the Hind in weapon load. On average, the Apache fired 12 to 14 Hellfire ATGMs (of 16 carried) at the red attackers, usually at long range (most destroyed their targets). In contrast, the Hind fired only, on average, two or three Swatter ATGMs (of four carried) at the blue attackers. As helicopters possess the longest ranged weapons on the battlefield, opening shots generally improved the ground force ratio more for blue than for red, allowing blue's vehicles to survive much longer than did red's.

The third factor was that blue artillery fired only improved conventional munitions (ICM), while red artillery fired a mixture of ICM and high explosive (HE) (roughly 1/3 ICM). As a consequence, red artillery destroyed, on average, 1 to 2 AFVEs of the blue attacker at the highest attack velocity, while blue artillery destroyed, on average, 5 AFVEs of the red attacker.

The last factor was that the blue attacking force was proportionally stronger in armor than the red attacking force (15 tanks out of 29 vehicles as opposed to 10 tanks out of 30 vehicles), and the adverse effect of this red force mixture is perhaps not adequately addressed in the equations. To characterize the runs, the attacking T-72s were eliminated early by long-ranged ATGM fire from Apaches or BFVs; the defending M1A1s were relatively invulnerable to fire from the BMPs; thus, the firepower of the M1A1s destroyed the first red echelon (this is similar to what happened in Europe when an infantry-heavy attacker attacked a tank-heavy defender at high velocity). Therefore, it was generally the case that more than one (and sometimes two) red echelons were required to kill all the blue vehicles, before the blue infantry were ever engaged. The blue attacking force, however, which was stronger in tanks, was not subject to this effect, as the Hinds carried little ammunition and the ATGM fire from the BMPs was relatively ineffective against M1A1s. Thus the the first blue echelon almost always destroyed the defending red vehicles and the second blue echelon could concentrate on red infantry.

The apparent reversal of the technological bias at low velocities could be caused by several factors. First, the combat equations, in general, tend to overestimate casualties at medium velocities (the fastest dismounted assaults) (see Appendix A); thus, true blue attacking losses could have been closer to the red losses. Since blue did not attack red under these conditions, no direct comparison is possible. Second, the higher fraction of

infantry that hurt red in the faster cases helps here, as each AFVE of infantry includes an IFV plus roughly 10 infantrymen, all of which have the ability to destroy a tank at close range; an AFVE of a tank, on the other hand, is only one tank.

In the end one may estimate the magnitude of the technological bias from the data. Red attackers suffered an average of 32 more casualties (75 compared with 43) in a high velocity assault than did blue attackers. Three or 4 of the 30 casualties were due to artillery (ICM over HE), 10 or so were due to attack helicopters (the AH-64 over the Mi-24), and the other, approximately 20, casualties were due to terrain, force composition (a blue fraction of tanks greater than the red), and the superior technology of blue ground weapons. Thus the technological effect at high velocity could be estimated, at most, to be worth about a 50 percent increase in casualties (20 compared with 43), plus the casualties that attack helicopters could be expected to cause (attacking casualties due to helicopters are directly proportional to the number of defending helicopters in the VFM combat equations in Appendix A). In reality, the effect is probably less than 50 percent since the lower number of red tanks (which were the only weapons that could engage the defending M1A1s effectively at any range) certainly reduced red's effectiveness in a mounted assault. The terrain may have made the Apaches somewhat more effective (by providing longer lines of sight), but the effect was probably small in comparison to the others. At lower velocities (dismounted assaults) it is difficult to discern the effect of technology because force composition and the inaccuracy of the casualty equations favor red. However, the reader should note that combat effectiveness of red and blue infantrymen in Janus is much more similar than that of red and blue vehicles.

The last identified limitation to the approach applies to almost all experimental work. The time and resources available did not allow the authors to explore all effects as thoroughly as they would have liked. This is especially true with respect to the matrix of equipment, tactics and direction of attack in the three theaters, levels of artillery support, and force composition at lower attacker:defender force ratios. Such efforts could be examined in the future.

C. DATA ANALYSIS

This section presents the results of the analysis of the experimental data to determine terrain effects upon the scenario outcomes. It explains the graphs in Section A in terms of the events that occurred in the Janus simulations and compares the results of similar scenarios in different theaters. Given an understanding of the events in the

simulations causing the results, one can deduce the effects of terrain. The analysis is presented in two parts: terrain effects upon attacker casualties, covering assaults of single defensive positions and assaults of successive defensive positions; and terrain effects upon defensive withdrawal, covering defensive withdrawal from ground engagements and defensive withdrawal and helicopter pursuit. The section concludes with a side note on how the advancement of technology has affected combat.

1. Terrain Effects upon Attacker Casualties

This section looks at the results of the variations of the values of the combat variables of which combinations were explored in the assault scenarios (single line and successive) and compares the results across the three theaters to determine the terrain effects. It examines the variable combinations of the sum of the fraction of infantry and attack velocity, number of supporting artillery tubes and combat velocity, and force ratio and combat velocity. Last it examines the disruption of attacking forces as they penetrate a defensive position.

Variation of the sum of the fraction of infantry and attack velocity. Looking first at the highest velocities (mounted assaults with no smoke screens and mounted assaults with smoke screens), one can see that in both cases casualties in Europe and Korea were roughly the same. In Southwest Asia the force ratio was lower than in Europe and Korea by a factor of two, so we must account for that by doubling the attacker's casualties before comparing them with the attacking casualties of the other theaters (we will demonstrate later in this section that attacking casualties are proportional to the force ratio). Even accounting for the difference in force ratio, one can see that casualties were about 30 percent lower. Casualties in all armor-heavy scenarios, again at both velocities, were about 30 percent lower than in the corresponding balanced scenarios. The reader should note that infantry-heavy attacks could not attain the highest velocity—too much time had elapsed by the time the attacking forces eliminated the defending force.

At higher velocities, force composition has a significant impact upon attacking casualties. An infantry-heavy attacker without smoke will suffer heavily even against an infantry-heavy defender. While closing, IFVs are vulnerable. When the attacker enters the defending infantry position, he suffers many more losses because the defender has more infantry, which fire more shots against more vulnerable targets. Artillery can mitigate the effect only slightly. In the armor-heavy scenarios the attacker does much better. Although there are more defending tanks, they are still highly outnumbered, they are not equal to the

more effective attacking weapons, and they do not survive long. Casualties from defending armor are therefore perhaps comparable to those suffered in the balanced case. However, casualties from defending infantry are lower because the smaller amount of infantry fires fewer shots at much less vulnerable targets. The net result is lower casualties.

In the Southwest Asian scenarios, stochastic effects or the technological bias described earlier (especially the advantage of the AH-64 over the Mi-24) could have caused the attacker's casualties to be lower than in Central Europe and Korea. One would normally expect attacking casualties to be higher in mounted assaults in the desert as the attacking vehicles are exposed for a long time within range of the defenders. An illustration of stochastic effects due to cascading events is provided by the outlier at high velocity in the armor-heavy scenarios (casualties near 40). This variation resulted because defending tanks got a succession of lucky shots; obviously it represents an extreme.

At lower velocities (dismounted assaults with smoke screens and increasingly long preparatory artillery barrages), casualties across the theaters began to even out. At the slowest velocities, casualties were almost equal in Southwest Asia and Korea, but they were much higher than the casualties in Europe, primarily because of the lack of defensive artillery in the Central European scenarios.¹⁰ Defensive bombardment of the attacker's staging area was found to be effective in the other two theaters in that an attacker could not wait with impunity for his artillery to pound a defensive position into nothingness. In fact, in Southwest Asia and Korea, at very low velocities attacking casualties actually increased as velocity decreased—the attacker gained little by waiting for his artillery to destroy the last few remaining vehicles of the defense, but the defender benefitted from his artillery continuing to wear down the large attacking formations.¹¹

One can also see at the slowest velocities that force composition makes little difference in the casualty totals. In armor-heavy scenarios, both sides have less infantry. Tanks are less vulnerable to the infantry; the net result is that relatively invulnerable vehicles fire at each other on both sides. In infantry-heavy scenarios, the increased vulnerability of attacking vehicles does not matter, as the first wave of attacking infantry

¹⁰ Defensive artillery was considered late in the first IDA study (S.D. Biddle et al., *Defense at Low Force Levels*, IDA Paper P-2380, August 1991) and was not present at all in the force composition scenarios.

¹¹ Defending artillery was somewhat less effective in Southwest Asia as the defenders were not assumed to fire 100 percent ICM.

generally sweeps the position of defending vehicles before the attacking IFVs are engaged. The attacker loses more infantry, but fewer vehicles—the effects tend to cancel out.

A few comments are necessary regarding infantry fraction combinations that were not included in the Southwest Asian and Korean scenarios (e.g., armor-heavy attack against an infantry-heavy defense, etc).¹² At low velocities, in the absence of artillery, attacking casualties really were found to be a function of the sum of the fractions of infantry. An armor-heavy attacker was found to suffer somewhat more casualties against an infantry-heavy defender than would a balanced attack against a balanced defense: the attacker did not have enough infantry to sweep the position of vehicles or defending infantry; therefore, the defenders typically destroyed all of the first attacking echelon's IFVs, plus some tanks. Thus an attacker generally required two echelons to take a position. An infantry-heavy attacker was found to suffer somewhat fewer casualties against an armor-heavy defender than would a balanced attack against a balanced defense: attacking infantry generally destroyed all defending infantry and IFVs and some tanks before the surviving defending tanks knocked out many attacking IFVs. In the end the differences between the three combinations were found to be small.

At higher velocities (mounted assaults), the sum of the fractions of infantry may be a less accurate indicator of casualties than the individual attacking or defending fractions. In high velocity scenarios, an infantry-heavy attacker suffered more—sometimes substantially more—casualties against an armor-heavy defender than would a balanced attack against a balanced defense (in fact, at low force ratios casualties were sometimes so high that the attacker could not achieve his desired velocity). An armor-heavy attacker against an infantry-heavy defender generally suffered somewhat fewer casualties than in the balanced case but not significantly fewer. Thus only in the instance of an infantry-heavy attack against an armor-heavy defender at high velocity is the assumption that casualties are governed by the sum of the fractions of infantry somewhat weak. However, expanding the matrix of scenarios to cover all combinations of attacking and defending infantry fractions would have increased the length and cost of the study considerably.

Variation of the number of supporting artillery tubes and attack velocity. To see effects of artillery variations, it is best to concentrate on the Southwest Asian and Korean

¹² In the first IDA study (Biddle et al., *Defense at Low Force Levels*), it was not known that attacking casualties are a function of the sum of the fractions of infantry, so multiple combinations of attacking and defending fractions of infantry that added up to the same sum were explored in those (Central Europe) scenarios.

scenarios rather than the Central European scenarios because the latter investigated artillery variations somewhat less extensively (see footnote 10, above). In the former two theaters, one can see, first of all, that in almost every case the effects of doubling the attacker's or halving the defender's artillery are the same, as are the effects of halving the attacker's or doubling the defender's artillery:¹³ the median values of attacking casualties are very similar. Furthermore, the difference between the two effects is also rather consistent across both theaters and a number of different attack velocities: attacking casualties were generally higher by a factor of 1.5 to 2.0 in scenarios with low attacking or high defending artillery support than they were in scenarios with high attacking or low defending artillery support.

It is interesting to observe that attacking casualties in the fastest dismounted scenarios in Southwest Asia were significantly higher than in the same scenarios in Korea (by roughly a factor of two). Since both scenarios used similar force compositions and force ratios, the differences must be due to terrain effects or stochasticity. A technology bias in favor of U.S. equipment would actually suggest the opposite result. It is further interesting to note that casualties in the slowest dismounted assaults in Korea were about 30 percent higher than in Southwest Asia. Since the difference between the two velocities is a longer artillery preparation time, and at very low velocities attacking artillery sometimes destroyed a significant portion of the defending force, the second observation would suggest that the superior U.S. artillery was driving the results of the slowest Southwest Asian scenarios.

The Central European scenarios show that increasing the defender's artillery causes more attacking casualties. They also provide a view of the balanced scenario data, showing the standard form of the VFM casualty equation in Appendix A. It is interesting to note that, in the absence of defending artillery, the slope of the casualty curve is very close to being monotonically positive.

Variation of the force ratio and attack velocity. The effects of changing the force ratio between the two sides were similar in all theaters. At moderately low to high velocities, the attacker's casualties were approximately inversely proportional to the attacker:defender ratio of ground AFVEs, or, since the number of attacking AFVEs was held constant while the number of defending AFVEs was changed, the attacker's casualties

¹³ No compensation is necessary for the Southwest Asian scenarios since the force ratios were approximately equal to those used in the Korean and Central European scenarios exploring artillery variations (roughly three to one).

were proportional to the number of defending AFVEs.¹⁴ At the lowest velocities, in scenarios in which the defender had a significant amount of artillery, the attacker's casualties were relatively insensitive to the force ratio.

These results are not surprising when one considers that the attacker's casualties at moderate to high velocities were caused primarily by defending AFVEs, while his casualties at low velocities were caused primarily by defending artillery (the amount of which was held constant over all scenarios investigating the effects of changing force ratios). In combat between armored vehicles, one would expect the attacker's losses to be proportional to the size of the defender's force and the size of the attacker's force if the probability of a shooter detecting a target was proportional to the number of available targets.¹⁵ In Janus this is the case, in that shooters scan their predetermined arcs of sight at a fixed rate and attempt to detect each potential target in the arc, and the probability of detecting any one target in the arc is unaffected by the number of other targets in the arc.¹⁶ Since we held the attacking force size constant in all force ratio scenarios, one would expect total attacking losses to be proportional to the defending force size. If combat was dominated by artillery fire, then one would expect the attacker's losses to be relatively independent of the size of the defender's force, given that the level of artillery support was held constant on both sides for all defending force sizes. In the extreme case, in which attacking artillery destroyed the entire defending force, the attacker's casualties would be totally independent of the size of the defending force as no ground combat would take place.

Disruption of attacking forces as they penetrate a defensive position. The results of the successive assault scenarios show clearly that attacking casualties increase, relative to scenarios in which the attacker does not have to penetrate a defensive position before the engagement, as an attacker penetrates a defensive position and becomes disordered due to enemy forces and terrain. Keeping in mind that, as was discussed in Chapter III, the results of these scenarios provide only a first estimate of the effect of disorder, we can see

¹⁴ The one exception was a dismounted scenario of moderate velocity in Southwest Asia at a 1.5:1 force ratio. Casualties were much higher than would be expected from the defender's force level and from other scenarios in Southwest Asia (note that the casualties in the 3:1 and 6:1 force ratio scenarios at low and high velocities are roughly proportional to the defender's force levels). The reason for this anomaly is unknown.

¹⁵ A. F. Karr, *Lanchester Attrition Processes and Theater-Level Combat Models*, IDA Paper P-1528, September 1981, pp. 10, 38-39.

¹⁶ D. R. Calloway et al., *The Janus Simulation Guide*, Version 4.05, M-278 Rev. 1, Lawrence Livermore National Laboratory, February 1990, p. 112.

the magnitude of the effect as the slope of a line drawn through the data points. One can see that the effect is more pronounced in Central Europe than it is in Southwest Asia. One would expect this as there was no terrain in Southwest Asia to hinder the movement of the attacking vehicles, but both forests and grades slowed some of them down in the other theaters. Thus, attacking echelons tended to stay in line better in Southwest Asia and maintained more mass at the point of attack. The slope of the line through the points was about 55 percent less in Southwest Asia than in Central Europe. Results of Korean scenarios were counterintuitive in that they indicated that the effect of disorder was less than that in Southwest Asia. This may have been due to the fact that the intermediate defensive positions in Korea were somewhat better than either the initial or the final positions. Thus, attackers tended to take more casualties in the middle positions regardless of having to pass through the previous position(s), and the quality of the defensive position, i.e., the effects of the local terrain, dominated the effects of disorder.

2. Terrain Effects upon Defensive Withdrawal

This section looks at the results of the variations of the values of the combat variables of which combinations were explored in the scenarios simulating withdrawal from ground engagements and withdrawal with helicopter pursuit and compares the results across the three theaters to determine the terrain effects. It examines terrain effects upon the defender's relative advantage accrued by withdrawing from combat after long-ranged exchanges of fire, while his fraction of force lost is lower than the attacker's fraction of force lost. It determines the terrain effects upon attack helicopter pursuit by examining, as functions of the ratio of pursuing helicopters to withdrawing vehicles and the ratio of helicopters to ADUs supporting the withdrawal, the fraction of withdrawing vehicles that survive withdrawal and the fraction of helicopters that are destroyed.

Defensive withdrawal from ground engagements. The effect of terrain on the effectiveness of early defensive withdrawal can be seen in the distance between the data points and an imaginary line drawn from (0,1) to (1,0) on the graphs (see the discussion in Section A.3.). The defender had the greatest advantage in Central Europe, followed by Southwest Asia and Korea. One would expect the advantage to be least in Korea, where the lines of sight are generally shorter and the defender therefore cannot take full advantage of long-ranged fire upon attacking vehicles. One would also expect the advantage to be greatest in Southwest Asia, where the defender can fire out to the maximum range of his weapons. Since blue (U.S.) vehicles were used on the attack in these scenarios, the

defender's advantage may have been counteracted by the superior accuracy of blue weapons at long range. Additionally, the force ratio was somewhat higher in Southwest Asia and Korea, and, typically, high force ratios obscure the effect as the attacker's firepower tends to overwhelm the defender. Based upon the coefficients derived from the curve fits to the data in Appendix A, the effect was about 50 percent more powerful in Europe than in Korea and about 40 percent more powerful than in Southwest Asia.

The effectiveness of helicopter pursuit of withdrawing vehicles. The effectiveness of helicopter pursuit is shown in terms of the sensitivity of the fraction of defending vehicles surviving withdrawal and the fraction of helicopters surviving pursuit to two ratios: pursuing helicopters:withdrawing vehicles and supporting ADUs:helicopters.

Terrain affects the survival of withdrawing vehicles significantly. The open spaces of Southwest Asia are much more favorable to pursuit than is the rolling terrain of Europe or the rugged terrain of Korea. From Figures IV-16 through IV-18 one can see that in Southwest Asia, even a relatively small number of helicopters could decimate a withdrawing force; in fact, in some scenarios with two-thirds as many helicopters as vehicles, all of the vehicles were destroyed. When the helicopters outnumbered the vehicles, the vehicles had little chance of surviving. With few helicopters, stochastic effects scattered the data as expected—an early loss of a helicopter or two (especially the highly effective AH-64) significantly increased the survival rate of the vehicles. As discussed in the limitations section, the superior performance of the AH-64 used in pursuit here over the Mi-24 used in the other two theaters influenced these results.

Contrast the results in Southwest Asia with those in Europe and Korea. Europe is sort of an intermediate case in that large numbers of helicopters did eliminate the withdrawing force, but smaller numbers were, with the exception of one engagement, less effective. Stochastic effects were less evident as lucky shots here did not remove as many potential kills from the pursuer here as in Southwest Asia. Korea, on the other hand, represents the other extreme. In that theater the helicopters were never able to eliminate the withdrawing force because some defenders always had hidden routes of withdrawal available to them. When the helicopters outnumbered the vehicles, they consistently eliminated only 60 to 70 percent of the withdrawing force. One might expect about 30 percent of a withdrawing force to survive in the face of any practical number of helicopters.

Figures IV-19 through IV-21, above, show the effects of increasing levels of air defense upon vehicle survival rates. One can see that the marginal effect of air defense was

greatest in Europe, where the fraction of vehicles surviving increased from near zero to 50 to 70 percent with significant air defense support (one ADU per three helicopters).

The marginal value of air defense was lower in Southwest Asia and Korea, but for different reasons. In a pursuit engagement, helicopters engage in a shooting match with ADUs and defending vehicles in overwatch. However, the helicopters almost always got the first shot—they detected the vehicles withdrawing in the open almost immediately and fired upon them. The helicopters detected the stationary, dug-in, and more distant ADUs and vehicles in overwatch more slowly (and vice versa), so they did not exchange fire until slightly later in the engagement. Thus, adding ADUs can never make withdrawal 100% successful. Nevertheless, more ADUs did eliminate the helicopters more quickly, and therefore more withdrawing vehicles survived. ADUs saved those vehicles that were hard to detect—those that would have been killed by the second, third, and fourth rounds of helicopter ATGM fire. In Korea, few vehicles were killed by the later rounds of fire. Those with exposed routes of withdrawal were killed early, and those with hidden routes were usually so well hidden that they were never killed. Thus the extra ADUs saved only those few vehicles with partially hidden routes of withdrawal. In Southwest Asia, helicopter pursuit was so effective because there were no hidden routes of withdrawal. Because they were so easy to detect, withdrawing vehicles were killed so early in the engagements that in almost every case the extra ADUs did not have time to save the vehicles by eliminating the helicopters (they did, however, destroy more helicopters). There were a few exceptions, however, where the ADUs quickly acquired and destroyed a number of helicopters, thus saving a significant fraction of the withdrawing force.

We should make a note here regarding the interactions between pursuing helicopters and defending ADUs. ADUs obviously fired upon pursuing helicopters frequently, but helicopters fired upon the ADUs infrequently. This was because the helicopters detected and then fired upon the withdrawing vehicles so much more easily and quickly and because in some cases the helicopters could not fire upon the ADUs. In Central Europe and Korea, the blue defenders employed man-portable Stinger missiles as ADUs. Helicopters in Janus cannot fire ATGMs at infantry units, so the red helicopters could not fire at the Stingers at the ranges of the pursuit engagements. In Southwest Asia the red defender employed a mix of SA-14 man-portable missiles, SA-13 self-propelled missiles, and ZSU-23 self propelled anti-aircraft guns. The blue helicopters could not fire at the SA-14s but could fire at the SA-13s and the ZSU-23s. The vulnerability of the red ADU mix could have reduced its effectiveness, but the data do not show that to have been the case. The SA-13s and ZSU-

23s were stationary, fewer in number, and farther away than the withdrawing vehicles; thus, the blue helicopters detected and fired upon them infrequently.

Figures IV-22 through IV-27, above, illustrate the effects of terrain upon helicopter casualties, first as a function of the ratio of helicopters to vehicles and then as a function of the ratio of ADUs to helicopters. In the first scenarios, which explored different ratios of helicopters to vehicles, the number of ADUs was characteristic of typical mechanized or armored units of the size of the withdrawing force. In the second scenarios, which explored different levels of air defense, the number of ADUs was increased until it nearly equalled the number of helicopters.

In all theaters, helicopter losses decreased as the ratio of helicopters to vehicles increased. Moreover helicopters suffered nearly 100 percent losses when they were heavily outnumbered by the withdrawing vehicles. However, losses were most sensitive to the ratio in the scenarios in Central Europe, followed by Korea and Southwest Asia. The median minimum fractions of helicopters lost in each theater, respectively, were (roughly): 15 percent, 20 percent, and 40 percent. In Central Europe the helicopters were able to acquire and fire upon most of the withdrawing vehicles fairly easily. Vehicles and ADUs were able to fire back as well, but the terrain did prohibit unengaged ADUs from taking long shots across the battlefield. Consequently, as the helicopters became more numerous, they could eliminate the vehicles more quickly and thus preserve themselves. In Korea, it was difficult for helicopters to acquire more than a few of the withdrawing vehicles, so they had to remain exposed over the battlefield for a relatively long time to complete their mission. During that time ADUs were able to fire upon them, even though the topography was more severe than in Europe. Thus helicopter losses were somewhat higher than in Europe; furthermore, they were less sensitive to the ratio of helicopters to vehicles. In Southwest Asia, it was very easy for the helicopters to acquire and fire upon the withdrawing vehicles. However, it was also very easy for the vehicles and the ADUs to fire back. Any vehicles in overwatch or ADUs within range could fire at a pursuing helicopter. As a result, helicopter losses were uniformly higher than in the other two theaters. Given that overwatching forces could fire effectively, increasing the ratio of helicopters to withdrawing vehicles would not reduce the total number of helicopters lost by very much.

Figures IV-25 through IV-27, above, illustrate terrain effects upon the sensitivity of fractional helicopter losses in pursuit to the ratio of ADUs to pursuing helicopters. At low levels of air defense, helicopter losses in Central Europe and Korea were rather sensitive to

the level of air defense: the fraction of helicopters lost increased nearly proportionally to the increase in the ratio of ADUs to helicopters. In Southwest Asia, helicopter losses at low levels of air defense were higher than in the other two theaters, but the increase in fraction lost was less than proportional to the increase in the ADU to helicopter ratio. At high levels of air defense, the three theaters were practically indistinguishable: at ADU-to-helicopter ratios over 0.75, helicopter losses ranged between 40 and 90 percent. Furthermore, after the initial sensitivity at low levels of air defense, helicopter losses in Europe and Korea exhibited the same relative insensitivity to the level of air defense as did helicopter losses in Southwest Asia.

These results have two causes. First, ADUs in Southwest Asia could engage helicopters from anywhere on the battlefield because of the flatness of the desert. Thus helicopter losses were higher at lower levels of air defense. It was only at higher levels of air defense that the defenders could cover the entire battlefield in Europe and Korea; it was only then that helicopter losses were equal to those in Southwest Asia. The relative insensitivity of losses to air defense at high levels arose because helicopter losses were approaching 100 percent, and the defender was getting diminishing marginal returns on the addition of more ADUs (the number of ADUs was approaching the number of helicopters); it became a target poor environment.

3. A Side Note on the Issue of Technology

As a side note on the issue of technology, the authors performed some excursion runs in Korea to briefly investigate the effects on combat of advancing technology on both sides. In those runs, the attacker and defender were armed with equipment that approximated that now owned by the North Koreans and South Koreans, respectively (T-62s and BTR-70s for the North and M-60A3s and M-113s for the South). Table IV-2 compares the attacker's casualties, for both the old technology (T-62s, BTR-70s, M-60s and M-113s) and the modern technology (T-72s, BMPs, M1s and BFVs), in an assault upon a single defensive position as a function of velocity. For both levels of technology force compositions were balanced; the force ratio was 30:8:

Table IV-2. Average Casualties in Assaults as a Function of Technology

Attack Velocity (km/hr)	Casualties (AFVEs)	
	Old Technology	Modern Technology
10	52.2	50.5
4	6.3	11.7
1	10.7	26.8

Note that, at higher attack velocities, changes in technology canceled out, as the results were approximately the same. Effective engagement (i.e., firing with a reasonable chance to hit and kill, given hit) began at shorter range in the low-technology case, but otherwise combat proceeded as before. At lower attack velocities, technology had a large impact. In particular, in the low-technology excursion neither side employed ICM with its artillery. Artillery caused many fewer casualties. For example, at the fastest dismounted speed, modern defending artillery (firing ICM) caused an average of 3.8 AFVEs of casualties, while the older defending artillery (firing HE) caused an average of 1 AFVE of casualties. These effects were even greater at slower velocities. These results suggest that artillery has become more dominant on the battlefield, but the reader should note that counterbattery fire was not simulated in any of the Janus scenarios, and it could counteract the artillery's increase in effectiveness against other targets.

V. CONCLUSIONS

Having presented and analyzed the data from the Janus simulations in the last chapter, we now state our conclusions and suggest how force planners might plan future U.S. force structure in light of the conclusions. This chapter contains two parts. The first part states the conclusions we drew from the analysis of the experimental data with respect to the effect of the terrain in the three theaters upon various aspects of combat. The second part discusses the implications of the study for the design of U.S. ground force structure in the future.

A. TERRAIN EFFECTS UPON TACTICAL COMBAT

The following major conclusions derived from the analysis of the Janus scenarios performed in Central Europe, Southwest Asia, and Korea. As the study did not explore the entire matrix of equipment, tactics and direction of advance in all three theaters (see Chapters III and IV), some of the conclusions are necessarily preliminary pending future Janus work.

- *Attack helicopters are more effective in Southwest Asia than in Europe or Korea.* The openness of the desert in Southwest Asia and the ruggedness of the hills in Korea directly affected the results of the withdrawal scenarios. Attack helicopters in Southwest Asia pursued and destroyed withdrawing forces up to three times their number in size. Helicopters in Europe generally destroyed a number of vehicles equal to their number, while helicopters in Korea destroyed somewhat fewer and never completely eliminated a withdrawing force. However, this conclusion is preliminary as scenario results were probably influenced by the difference in performance between Soviet and U.S. helicopters.
- *Individual air defense units are more effective in Southwest Asia than in Europe or Korea.* The theater topography significantly affected the performance of air defense units. At typical levels of air defense (1 ADU per 5 to 10 vehicles), helicopters suffered losses on pursuit missions of approximately 40 percent, 20 percent, and 15 percent in Southwest Asia, Europe and Korea. However, at higher levels of air defense, losses were roughly equivalent (50 to 90 percent) in all theaters. Moreover the marginal

return on additional air defense units decreased as the number of ADUs approached the number of helicopters.

- *Early defensive withdrawal from ground engagements is most effective in relatively open terrain, like that in Southwest Asia and even Central Europe, than in closer terrain, like that in Korea.* The measure of effectiveness of withdrawal was the attacker's cumulative casualties from the beginning of the scenario, normalized to the number he would take if the defender fought to the death compared with the fraction of the defending force surviving (and presumably withdrawing from combat) at any given time. In the experiments, withdrawal was most effective in Central Europe, followed by Southwest Asia and Korea. However, the results of the Southwest Asian scenarios were probably influenced by the use of effectively longer ranged U.S. weapon systems on the attack; Soviet weapon systems were used in the other theaters.
- *To first order, attacking forces suffer more from disorder as they penetrate defensive positions in terrain with obstacles, like that in Central Europe or Korea, than they do in terrain without, like that in Southwest Asia.* Attacking casualties were found to increase at a rate of roughly 8 percent per kilometer of penetration in Europe and a rate of 5 percent per kilometer in Southwest Asia. However, as Janus cannot simulate all of the phenomena that cause disorder among attacking forces, this conclusion is preliminary pending further study.
- *Changes in ground force composition affect combat outcomes similarly in all three theaters.* Changes in the fraction of infantry of both sides affected combat significantly at high velocities, but little at low velocities. Armor-heavy forces suffered about 30 percent fewer casualties in high velocity attacks than did balanced forces.
- *Changes in artillery support affect combat outcomes similarly in all three theaters.* Beginning with a typical level of artillery support for the attacker and the defender, halving the attacking artillery or doubling the defending artillery resulted in twice as many casualties for the attacker as did doubling the attacking artillery or halving the defending artillery. Moreover, at the lowest attack velocities, artillery caused more casualties on both sides than ground fire and attacking casualties actually increased as velocity decreased.
- *Changes in the attacker: defender force ratio affect combat outcomes similarly in all three theaters.* Above the lowest attack velocities, the attacker's casualties were found to be roughly proportional to the defender's force level, given an attacking force of constant initial size. At the lowest velocities, casualties were dominated by artillery and were relatively independent of the size of the defending force.

B. IMPLICATIONS FOR FUTURE U.S. FORCE STRUCTURE

As we stated in the introduction to this paper, in order to best design future doctrine and force structure for ground forces one must know as much as possible about the impact of the environment in which the forces will fight. Terrain is part of that environment. In the future, as the U.S. pulls forces back from overseas deployments, the force structure shrinks, and DoD emphasizes planning more for contingencies than for a global conflict with the Soviet Union, U.S. ground forces will have to be geared even more than now to deploy and fight in different environments. Thus, it is important to look at the impact of terrain in all of the major theaters where U.S. forces might be expected to fight. The reader should keep in mind, however, that this study only considered tactical combat results and did not consider other important issues like, for example, inter- or intratheater mobility—as Desert Shield and Storm clearly reminded us, forces have to deploy before they can fight; cost—given shrinking defense budgets the most *cost*-effective force may be more desirable than the most effective; or logistics—forces with high firepower may be difficult to supply in difficult terrain or remote theaters of operation.

First consider the areas of force structure most affected by terrain in the Janus scenarios: helicopters and air defense. The data indicated that helicopters are both more effective and more vulnerable in the open desert of Southwest Asia than they are in Europe or Korea. In Europe helicopters were also effective on defense and in pursuit, although not as effective as in Southwest Asia. In Korea helicopters were less effective in pursuit but still effective on defense. However, in both Europe and Korea helicopters were about half as vulnerable to typical levels of air defense as in Southwest Asia, although high levels of air defense inflicted heavy losses on the helicopters in all theaters. Helicopters were effective on the tactical defensive in all three theaters, so they should support ground forces wherever one could expect an armored or mechanized enemy attack. Whether or not to use helicopters in pursuit and how to do so is a question of doctrine rather than force structure, but doctrine should reflect the variation in effectiveness of helicopter pursuit across the theaters.

Regarding air defense, units attacking in all theaters should be provided with higher levels of air defense to protect themselves from highly effective attack helicopters. Units defending, and perhaps withdrawing, in the desert or in Europe should also be provided with higher levels of air defense than are now typical. Even a relatively small number of ADUs can inflict serious losses on a helicopter force in the desert. Those units may not be able to protect themselves from pursuing helicopters directly, but if the enemy knows he

will pay a high price in helicopters he may be deterred from pursuing. Defending units in Europe with higher levels of air defense, on the other hand, may be able to protect themselves. In Korea, however, pursuit was of limited effectiveness, so the provision of a high level of air defense to defending units is not as critical as in the other theaters. With the preceding in mind, it should be remembered that a defender begins to get diminishing marginal returns as the number of ADUs approaches the number of helicopters. The data indicate that this began to happen at a level of one ADU per three helicopters, which was roughly equivalent in these scenarios to one ADU per three ground AFVEs.

Next, consider the composition of the ground maneuver forces: infantry, IFVs, and tanks. The data indicated that in all theaters armor-heavy forces were more effective than balanced or infantry-heavy forces at performing mounted assaults and that armor-heavy forces were at least as effective as balanced or infantry-heavy forces at performing dismounted assaults in the face of significant amounts of defending artillery. Consequently, heavy ground forces should have a higher fraction of armor than infantry: the armor is more effective on the attack and on the defense one could still put a balanced force forward and maintain an armor-heavy reserve for counterattack. However, given that IFVs are more vulnerable to artillery than are tanks, an armor heavy defense may be desirable as well. Lastly, and most importantly from the perspective of this work, these results suggest that ground forces perform equally well in all three theaters. Thus future U.S. heavy forces would not have to be tailored or "earmarked" for potential major theaters of operation—any given unit could be sent to any given theater.¹ This flexibility would also allow the U.S. to maintain smaller ground forces—outside of consideration of simultaneous conflicts, forces with duplicate capabilities would not be needed for each theater. These recommendations hold for terrain in Central Europe Southwest Asia and Korea, although again the reader should note that this study did not consider extremely harsh or difficult terrain like alpine mountains, jungle or arctic environments.

Last, briefly consider artillery. In all theaters and at all but the highest attack velocities, where artillery bombardment times were very short, attacking casualties were sensitive to the levels of artillery support on both sides. At low attack velocities artillery caused more casualties on both sides than did ground fire. From these results it is obvious that maneuver forces should be supported by as much artillery as possible within the

¹ This pertains to equipment and troop combat training. Troops would still have to be trained to deal with particularly harsh environments like those of the desert or of high mountains.

constraints mentioned at the beginning of this section. Furthermore, given the effectiveness of artillery, and particularly ICM, against dismounted infantry, light (leg infantry) forces could be expected to suffer heavy casualties in the attack unless the defending artillery was heavily suppressed by counterbattery fire, air attack, or some other means. Lastly, like the results for ground forces, these results imply that U.S. artillery support for heavy forces would not have to be tailored to major potential theaters of operation.

This completes our recommendations regarding future U.S. force structures. They do not differ greatly from the conventional wisdom. Only the recommendations to procure all armor-heavy forces and to increase the amount of air defense provided to ground units conflict with the existing heavy force structure. Our results suggest that light forces would not fare well in combat against an enemy well supported with artillery, but we did not specifically simulate combat with light forces.

APPENDIX A

TACTICAL COMBAT COEFFICIENTS FOR THE VFM COMBAT MODEL

TACTICAL COMBAT COEFFICIENTS FOR THE VFM COMBAT MODEL

The second goal of this study, in addition to gaining a better understanding of the effects of terrain upon mechanized combat, was to provide tactical combat coefficients for the VFM theater-level combat model. Earlier Janus work provided combat coefficients for VFM for Central Europe.¹ Scenarios performed under this study provided coefficients for Southwest Asia and Korea. The first section of this appendix briefly describes the previous studies' derivation of the VFM combat equations and their coefficients, which this study repeated. The second section gives the coefficients for each theater and displays the products of the resulting combat equations with the experimental data presented earlier in Chapter IV of this paper.

A. STATISTICAL ANALYSIS

IDA studies P-2380 and P-2548 developed a theory of combat, in the form of a series of equations, that predicts tactical combat casualties as functions of the combat variables explored in this study. Those studies performed Janus experiments (using the same four scenario type that were used here) for Central Europe (whose data were presented in this work) and fit curves via multivariate regression analysis to the casualty data. The functional forms of the curves (terms in the equations) were derived from the theory of combat (see also Chapter II). The regression analysis produced values for coefficients to weight each of the terms in the combat equations. In this study casualty data from the Janus scenarios were fit to the existing functional forms of the combat equations using the statistical package Minitab. Terrain effects of each theater are reflected by the variation in the coefficients in the equations.

The multivariate regression analysis produced the following form for the casualty equation, where the casualties C are those that an attacker would be expected to suffer in an assault upon a defensive position of the same size that was simulated with Janus:

¹ S.D. Biddle et al., *Defense at Low Force Levels*, IDA Paper P-2380, August 1991, Appendix D, and Biddle et al., *Stabilizing and Destabilizing Weapons*, IDA Paper P-2548, September 1991, Appendix C.

$$C = \alpha \gamma \frac{D}{A} \left[k_3 \phi_i v + k_2 \hat{H}_d v + k_4 \phi_T + \frac{k_1 D_a}{v + 0.01} + \frac{k_6}{A_a (v + 1.0)} \right],$$

where:

- $\alpha =$ the reduction in attacking casualties due to early defensive disengagement
- $\gamma =$ the increase in attacking casualties due to disorder caused by penetrating a defensive position
- $\phi_i =$ $\phi_{ia} + \phi_{id}$
- $\phi_{ia} =$ fraction of attacker AFVEs that are infantry
- $\phi_{id} =$ fraction of defender AFVEs that are infantry
- $\phi_T =$ $(2 - \phi_i)$: the sum of the fractions of AFVEs that are tanks.
- $\hat{H}_d =$ number of defending attack helicopters
- $D =$ defending maneuver force strength (AFVEs)
- $A =$ attacking maneuver force strength (AFVEs)
- $v =$ attack velocity (kilometers per hour)
- $D_a =$ defending artillery strength (tubes)
- $A_a =$ attacking artillery strength (tubes).

Analysis produced the following functional form to describe the effects of an attacking force penetrating a defensive position and becoming disordered:

$$\gamma = 1 + k_8 P,$$

where γ is a scalar multiple representing the increase in attacker casualties in a given assault, relative to a perfectly coherent attack, caused by disorder, and P is the depth of penetration (kilometers) prior to the attack.

Statistical analysis produced the following functional form to describe the effects of early defensive withdrawal from a ground engagement:

$$\alpha = 1 - w k_{10},$$

where:

- $\alpha =$ fraction of fight-to-the-finish attacker casualties suffered when the defender withdraws a fraction of his strength, w
- $w =$ fraction of defending AFVE strength that a defender attempts to withdraw.

The following functional form describes the relationship between the number of defending vehicles that successfully withdraw from a position and the number that attempt to withdraw, as a function of the number of pursuing helicopters and the number of supporting ADUs:

$$w_{\text{SURV}} = 1.0 - \left(\frac{k_{20} H_p}{w} \right) - \left(\frac{k_{21} H_p}{N_{\text{AD}}} \right),$$

where:

w_{SURV} = fraction of withdrawn vehicles that successfully complete withdrawal
 H_p = number of attack helicopters in pursuit
 w = number of vehicles that attempt to withdraw
 N_{AD} = number of ADUs defending against pursuing attack helicopters.

The following functional form was developed to predict attack helicopter losses in each pursuit mission:

$$L_H = 1.0 - \exp \left[- \left(\frac{k_{22} w}{H_p} \right) - \left(\frac{k_{23} N_{\text{AD}}}{H_p} \right) \right],$$

where:

L_H = fraction of pursuing attack helicopters lost.

After the regression analyses the values of the coefficients in the equations were checked to ensure that the casualty trends were correct. The following criteria were applied, all other things being equal, to the coefficients:

$k_1 > 0$ (Attacking casualties due to defending artillery must increase as the amount of defending artillery increases.)

$k_2 > 0$ (The slope of the casualty curve must increase as the number of defending attack helicopters increases.)

$k_3 > 0$ (Casualties must increase with attack velocity.)

$k_6 > 0$ (Attacking casualties must decrease as the amount of supporting attacking artillery increases.)

$k_8 > 0$ (Attacking casualties per assault must increase as an attacking force penetrates deeper into a defensive position.)

$k_{10} > 1$ (The attacker's cumulative casualties at any time after the beginning of an assault, normalized to the number he would take if the defender fought to the death, must be greater than the fraction of the defending force surviving and withdrawing from combat.)

$k_{20} > 0$ (The fraction of defenders successfully withdrawing must decrease as the number of pursuing attack helicopters increases.)

$k_{21} > 0$ (The fraction of defenders successfully withdrawing must increase as the number of defending air defense teams increases.)

$k_{22} > 0$ (Losses of pursuing helicopters must increase with an increasing number of withdrawing vehicles.)

$k_{23} > 0$ (Losses of pursuing helicopters must increase as the number of ADUs supporting the withdrawal increases.)

B. COEFFICIENTS

This section presents the coefficients for the equations given above, with statistics indicating the goodness of fit (r^2 , standard error, and T-ratio).² It also plots the products of the equations against the experimental data from Chapter IV.³ The products of the equations resulted from setting the values of the combat variables in the equations equal to those in the scenarios. The theaters are presented in the order of Central Europe, Southwest Asia, and Korea.

1. Central Europe

VFM combat coefficients for Central Europe are given in Table A-1.⁴

² The meaning of the r^2 value is somewhat ambiguous for functional forms that have no constant term. The given r^2 is therefore illustrative, but not mathematically precise. The r^2 was calculated as $1 - (\text{error sum of squares} / \text{total sum of squares})$. The sum of squares has been corrected to account for the lack of a constant, and is identical to the true total sum of squares for the data. The T-ratio is approximate, calculated as $(\text{estimate} / \text{std.error})$.

³ As the earlier studies ran the European scenarios, performed the regression analyses and derived the VFM combat equations before this study, but this study used the existing equations, the curves fit the data from Central Europe better than the data from Southwest Asia and Korea. Furthermore, since the curves resulted from multivariate regression analyses, they are influenced by values of variables not shown on the graphs.

⁴ Statistical analyses were performed in Biddle et al., *Defense at Low Force Levels* and Biddle et al., *Stabilizing and Destabilizing Weapons*.

Table A-1. VFM Coefficients for Central Europe

Coefficient	Estimate	Std. error	T-ratio
K ₁	0.22	0.26	0.85
K ₂	1.45	0.35	4.14
K ₃	14.32	0.42	34.10
K ₄	11.80	2.23	5.29
K ₆	693.63	103.92	6.67
K ₈	0.09	---	---
K ₁₀	2.51	0.08	31.86
K ₂₀	0.188	0.032	5.95
K ₂₁	0.088	0.007	11.76
K ₂₂	0.52	0.031	16.82
K ₂₃	0.75	0.043	17.64

	Assaults	Successive Assaults	Disengagement
Sum of squares (corrected total)	206623.6	154.58	---
Error sum of squares	58378.1	62.71	---
Degrees of freedom	314	218	---
r ² (unadjusted)	0.71	0.59	---

* γ for Central Europe was determined by a linear fit to two data points representing mean casualties, thus r^2 was necessarily equal to unity and error was necessarily zero.

	Withdrawal Survival	Helicopter Losses
Sum of squares (corrected total)	3.26	282.01
Error sum of squares	0.8	20.16
Degrees of freedom	47	83
r ² (unadjusted)	0.76	0.93

Curve fits are shown in Figures A-1 through A-9

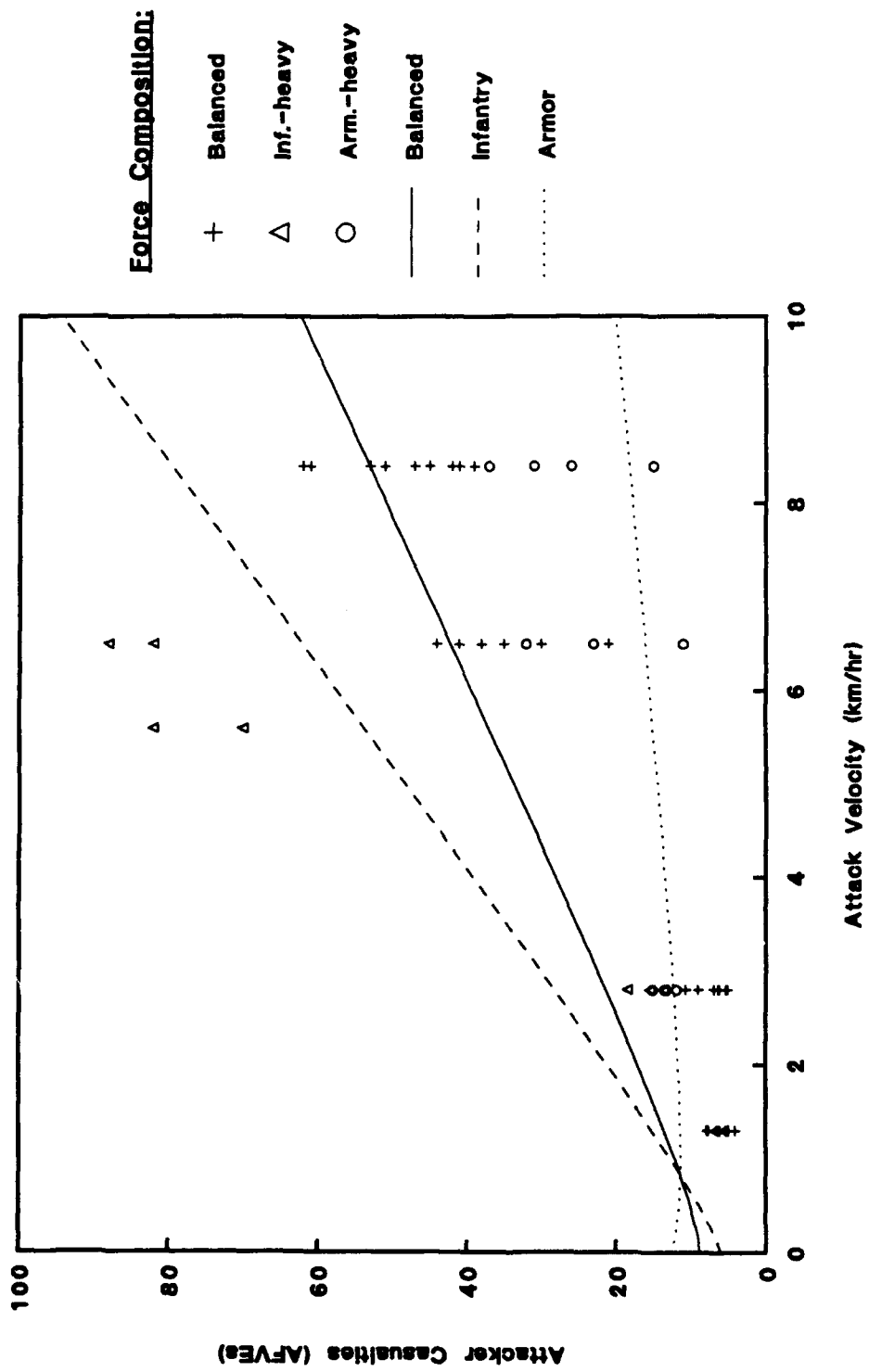


Figure A-1. Force Composition Effects, Central Europe

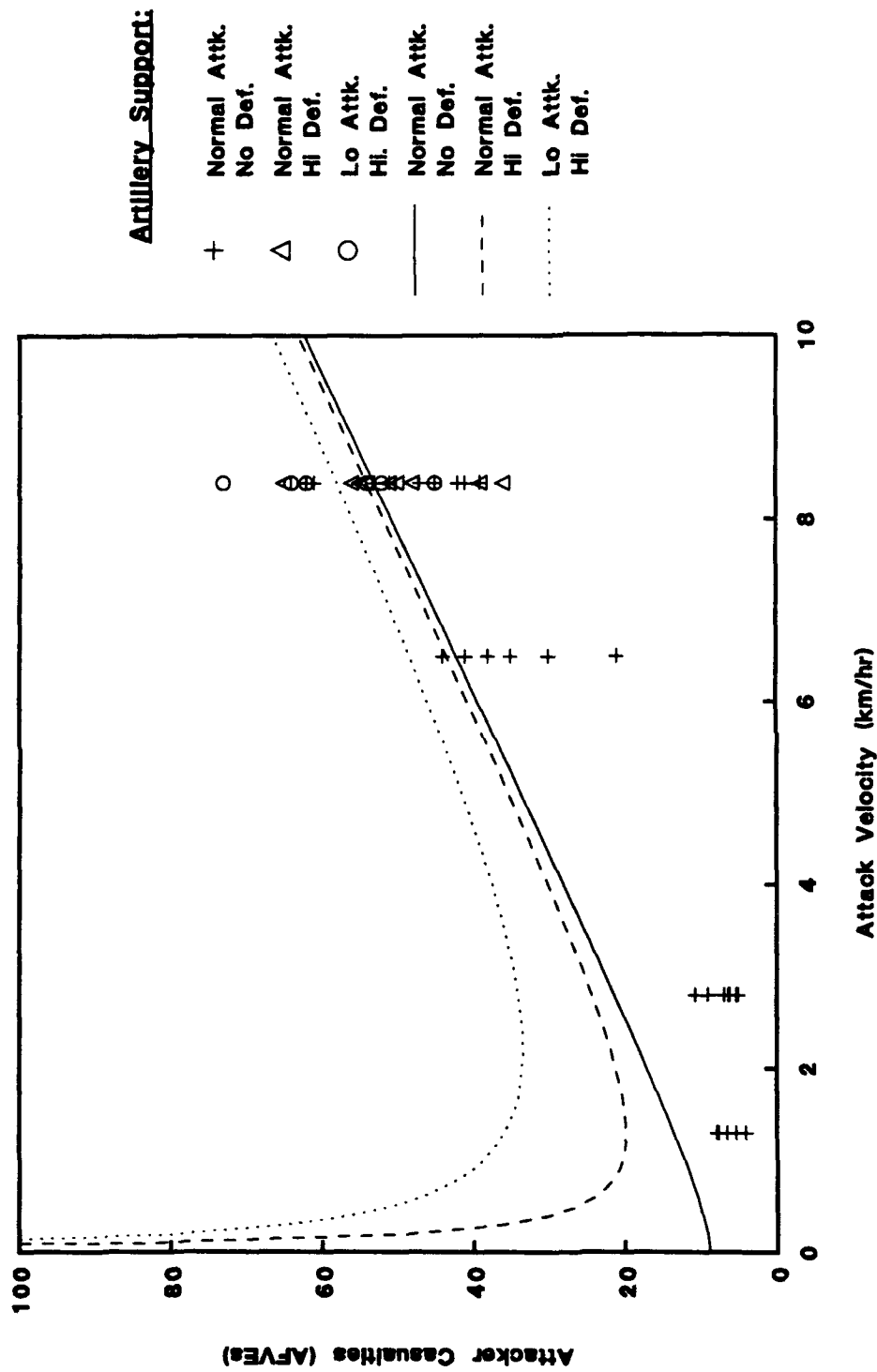


Figure A-2. Artillery Effect, Central Europe

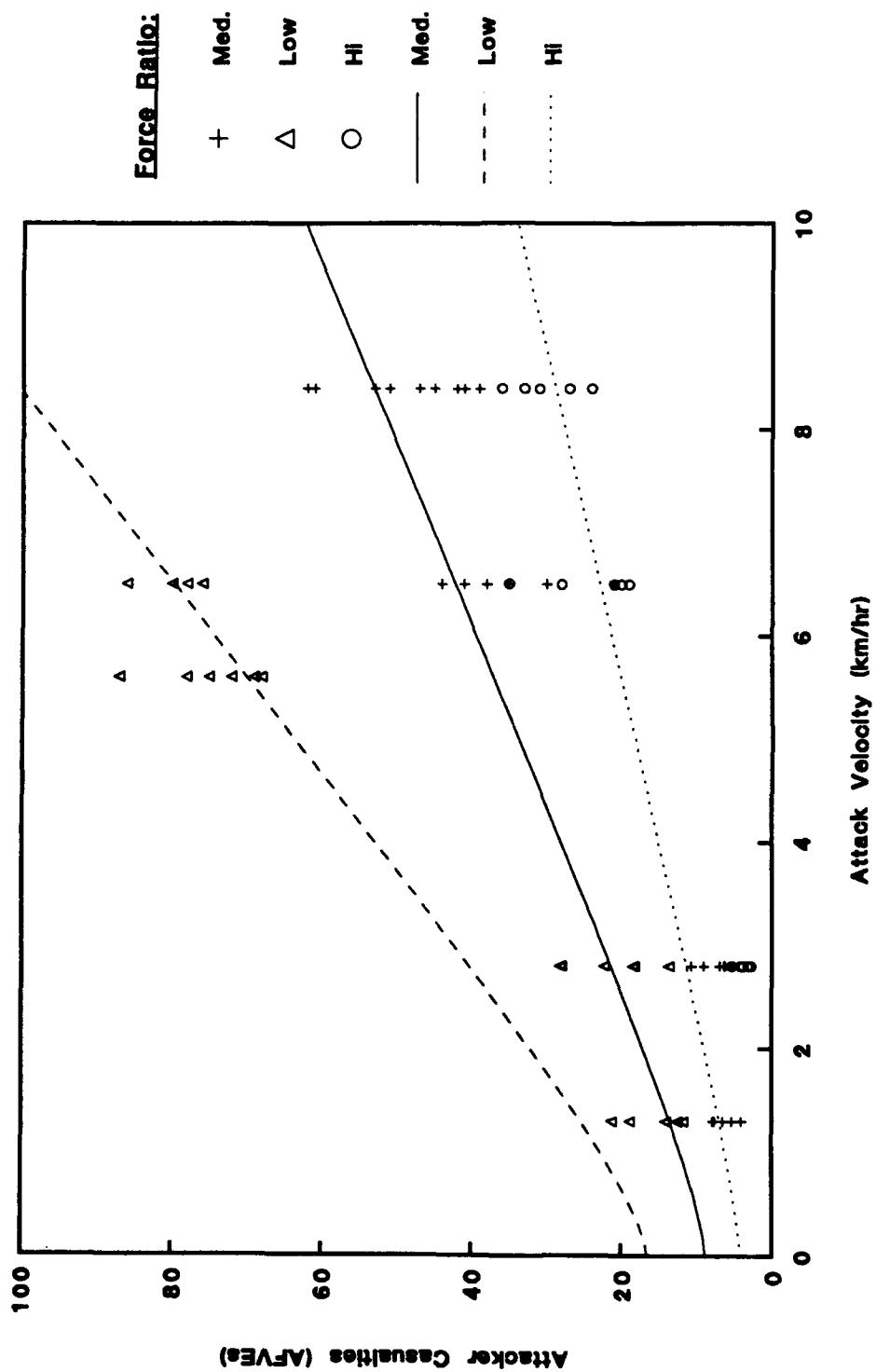


Figure A-3. Force Ratio Effects, Central Europe

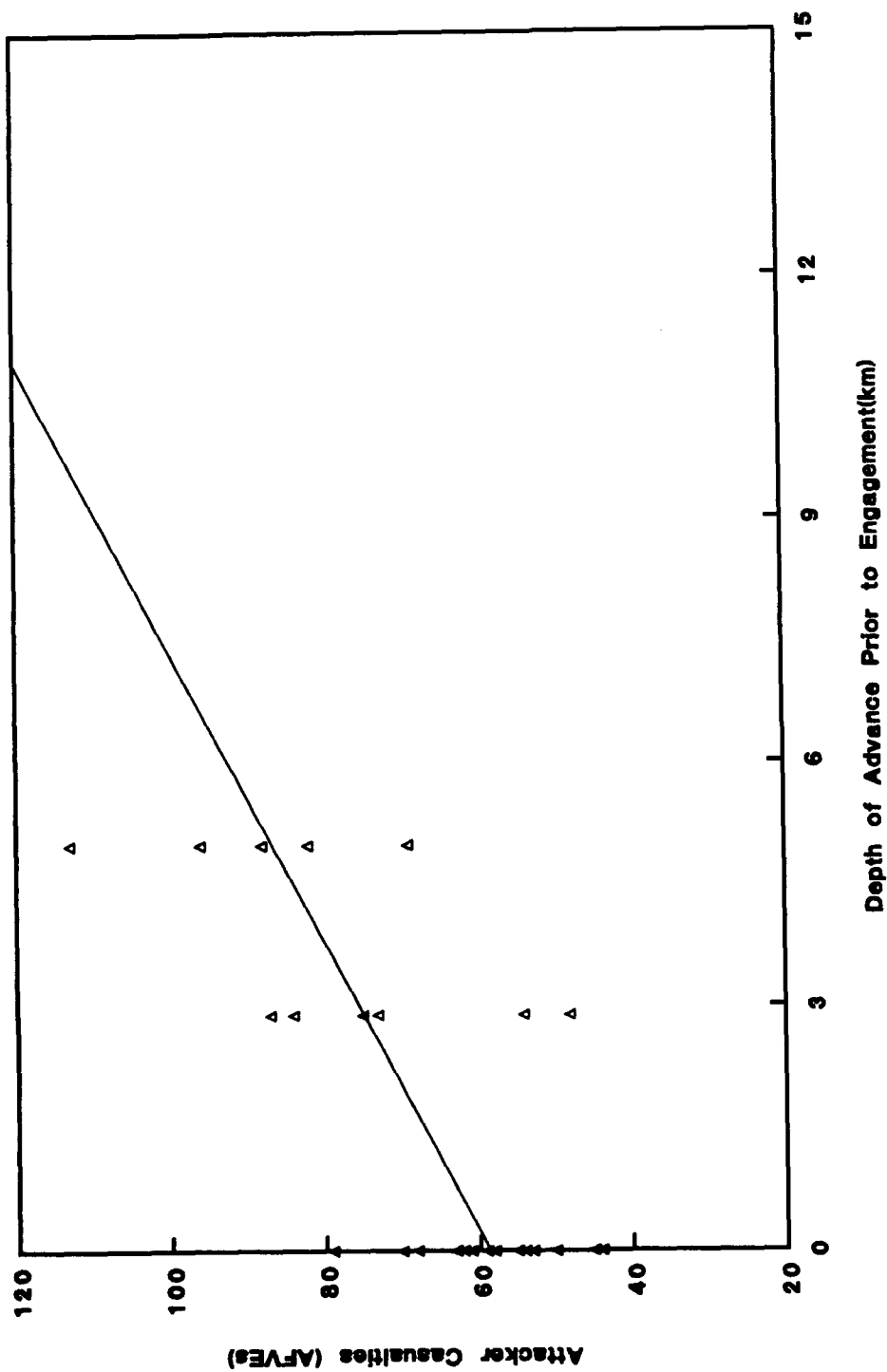


Figure A-4. Assault upon Successive Lines, Central Europe

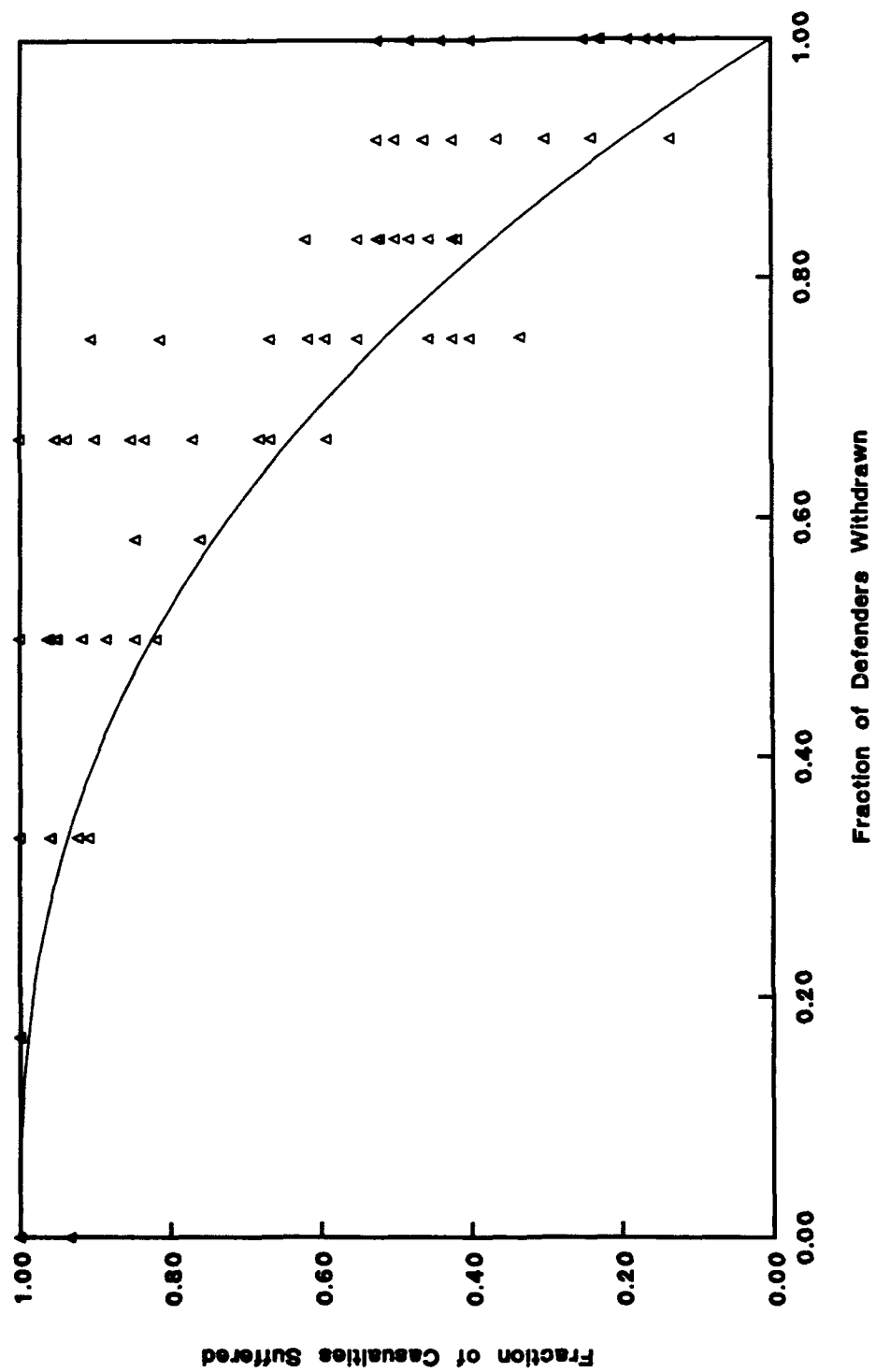


Figure A-5. Withdrawal from Ground Engagements, Central Europe

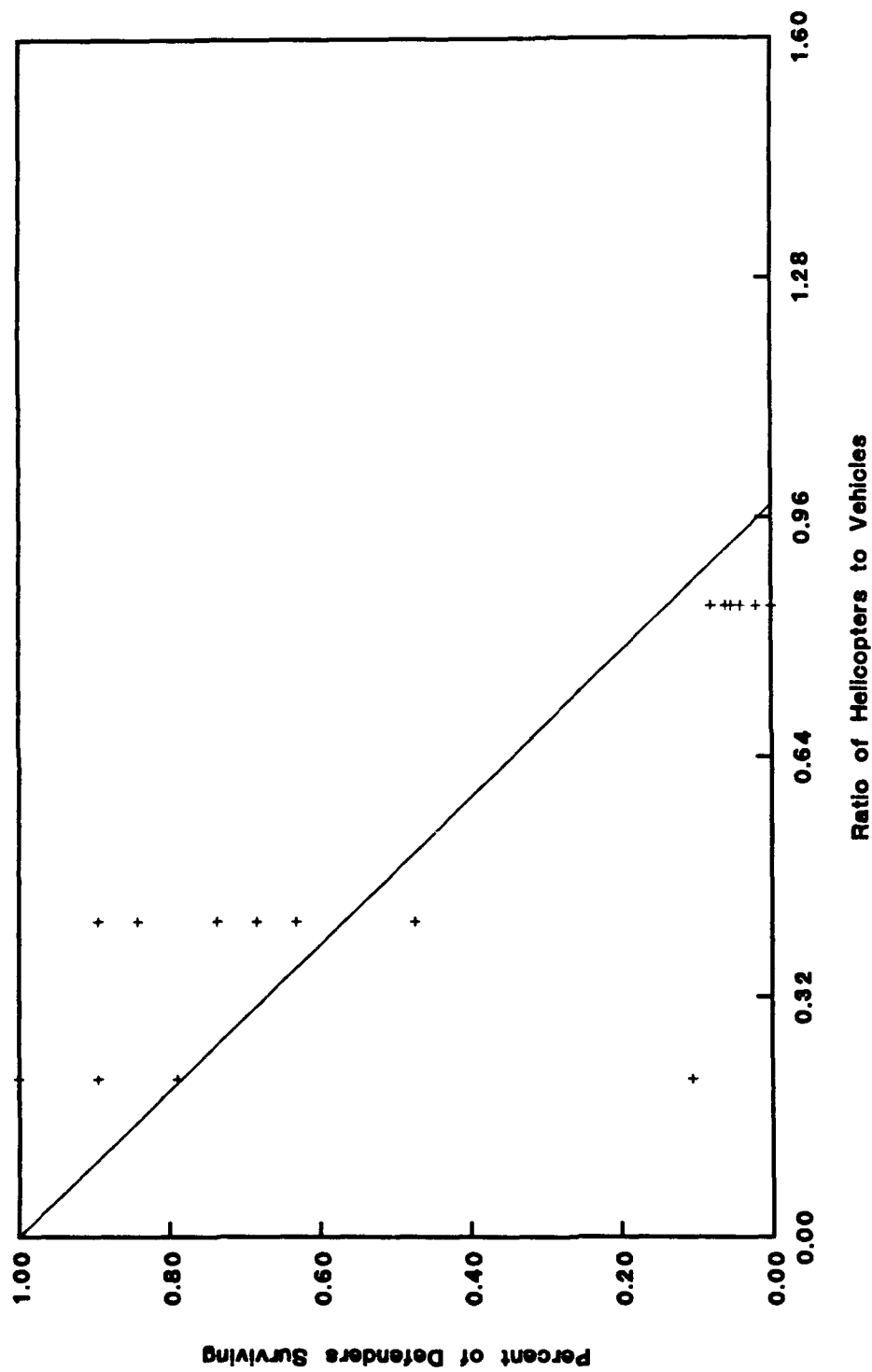


Figure A-6. Helicopter Pursuit, Central Europe

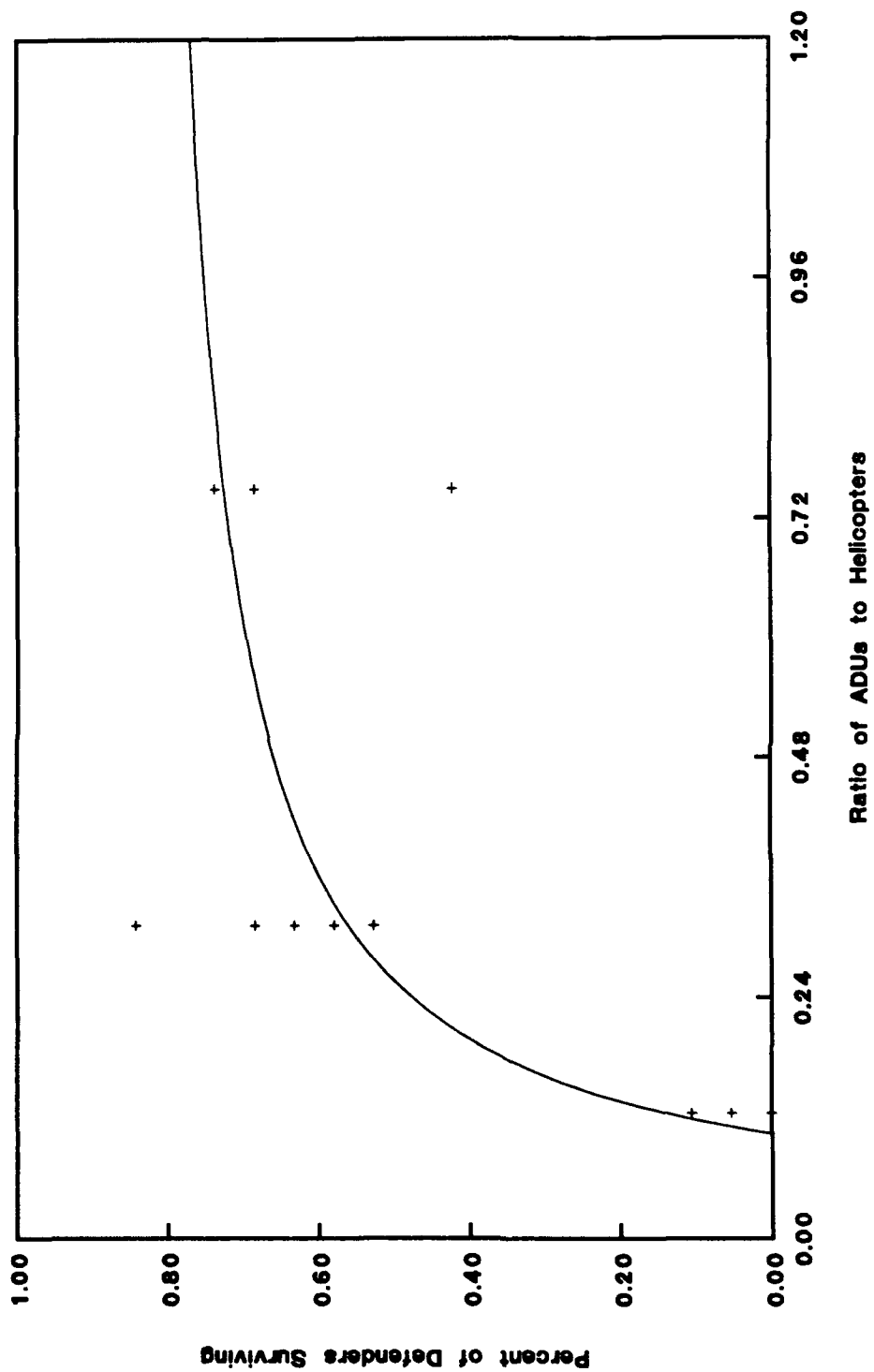


Figure A-7. Withdrawal and Air Defense, Central Europe

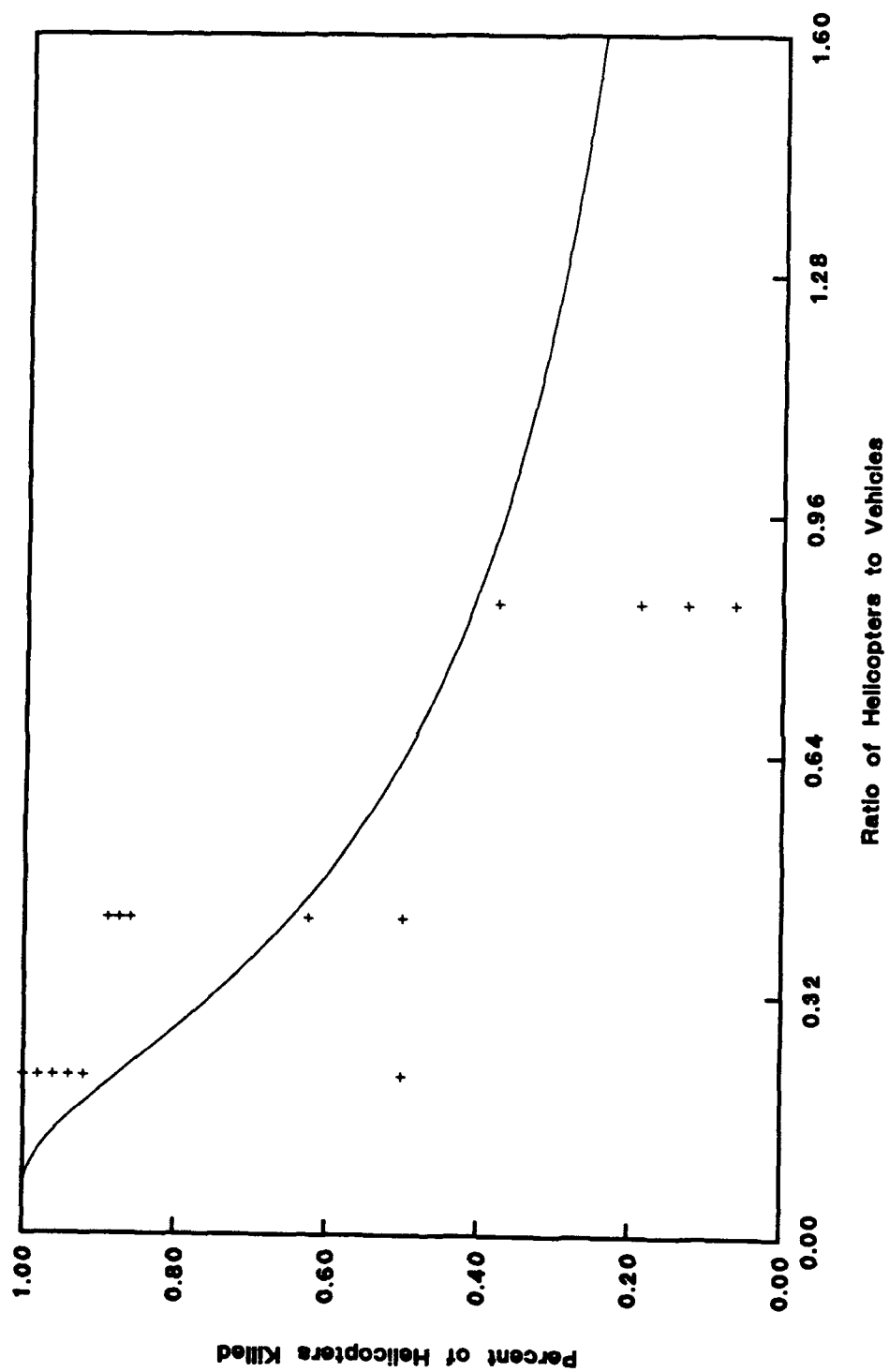


Figure A-8. Pursuit and Helicopter Losses, Central Europe

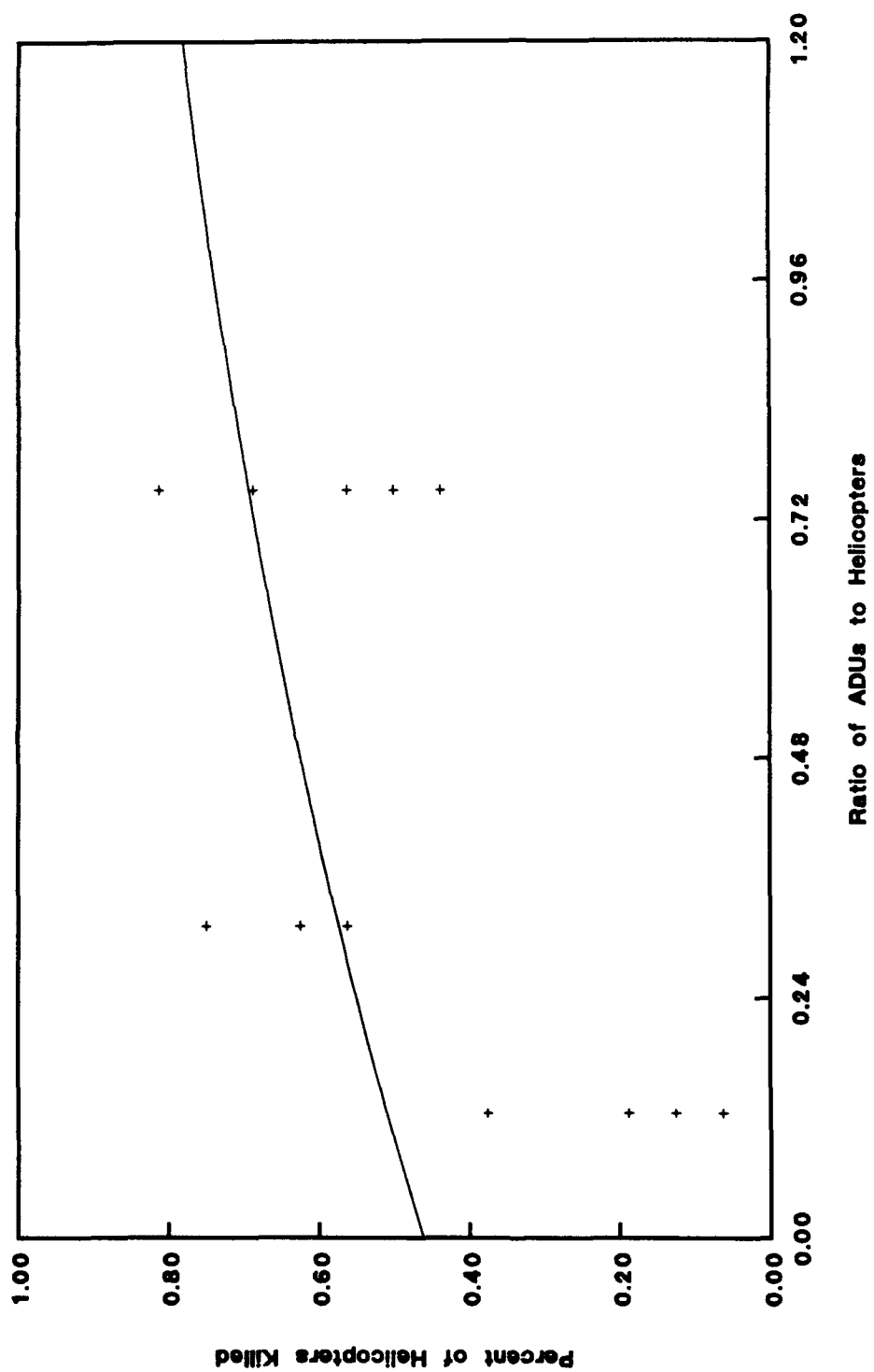


Figure A-9. Air Defense and Helicopter Losses, Central Europe

2. Southwest Asia

VFM combat coefficients for Southwest Asia are given in Table A-2.

Table A-2. VFM Coefficients for Southwest Asia

Coefficient	Estimate	Std. error	T-ratio
K ₁	0.16	0.15	1.07
K ₂	0.32	0.80	0.39
K ₃	15.0	1.42	10.6
K ₄	23.81	6.55	3.63
K ₆	233.0	1113.0	0.21
K ₈	0.052	0.012	4.23
K ₁₀	1.74	0.087	19.93
K ₂₀	0.66	0.058	11.47
K ₂₁	0.031	0.016	1.99
K ₂₂	0.67	0.04	15.27
K ₂₃	0.61	0.12	4.88

	Assaults	Successive Assaults	Disengagement
Sum of squares (corrected total)	43014.9	1982.0	29.31
Error sum of squares	15742	1155.92	10.63
Degrees of freedom	148	26	52
r ² (unadjusted)	0.63	0.42	0.64

	Withdrawal Survival	Helicopter Losses
Sum of squares (corrected total)	1.85	19.75
Error sum of squares	2.32	3.70
Degrees of freedom	42	42
r ² (unadjusted)	-0.25	0.81

Curve fits are shown in Figures A-10 through A-18

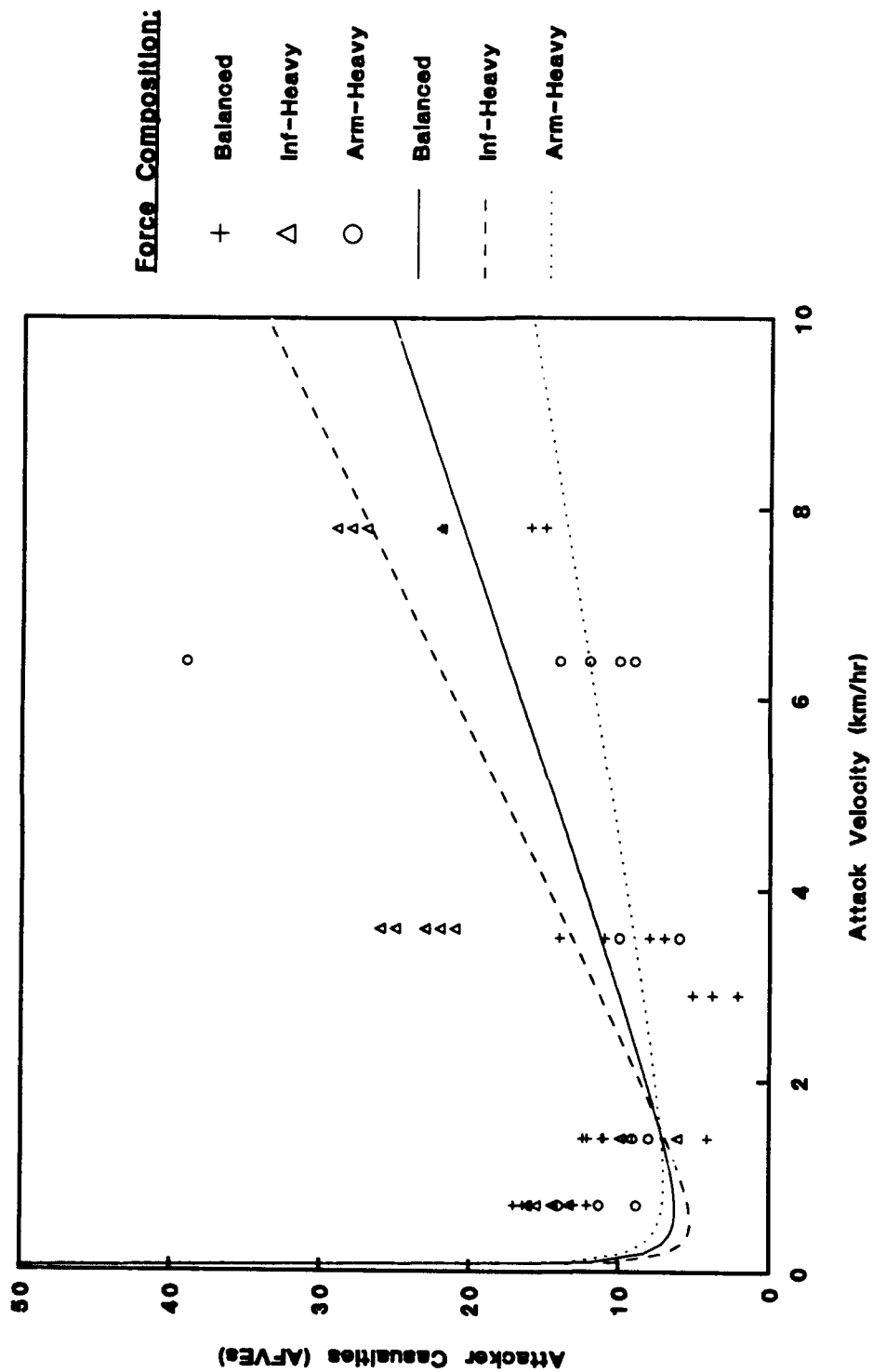


Figure A-10. Force Composition Effects, Southwest Asia

Artillery Support:

- + Hi Attk.
- △ Hi Def.
- + Lo Def.
- Lo Attk.
- Hi Attk.
- - - Hi Def.
- - - Lo Def.
- Lo Attk.

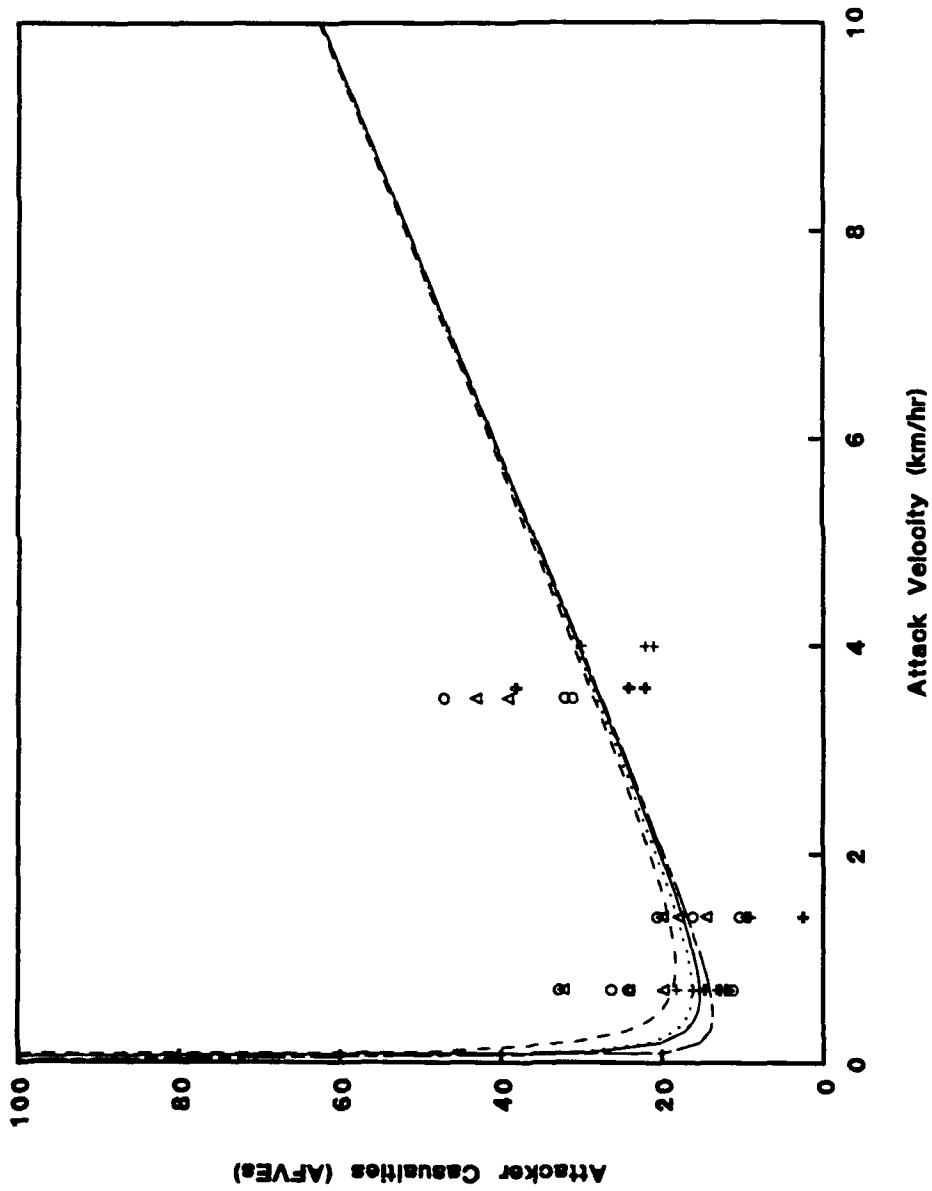


Figure A-11. Artillery Effect, Southwest Asla

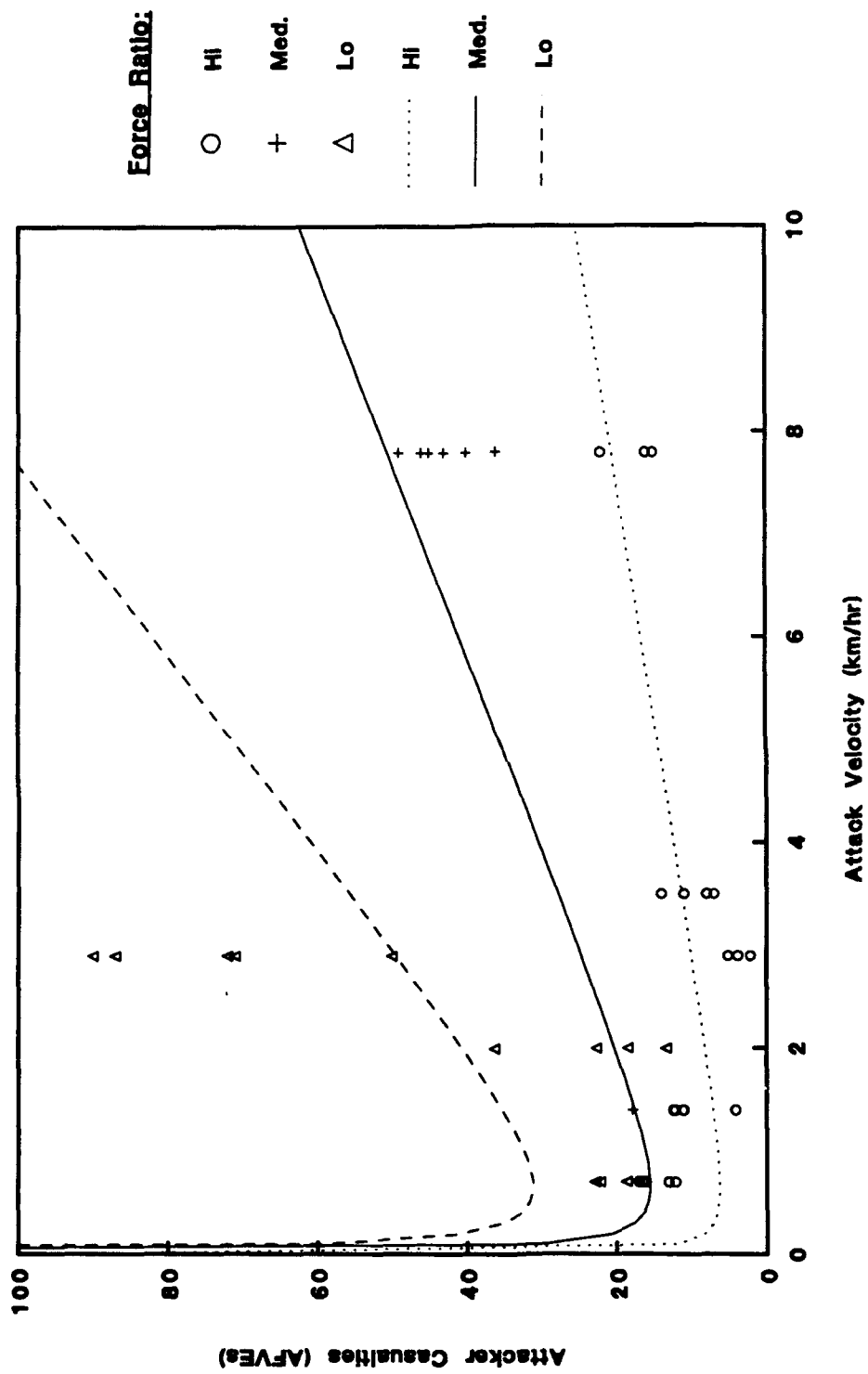


Figure A-12. Force Ratio Effects, Southwest Asia

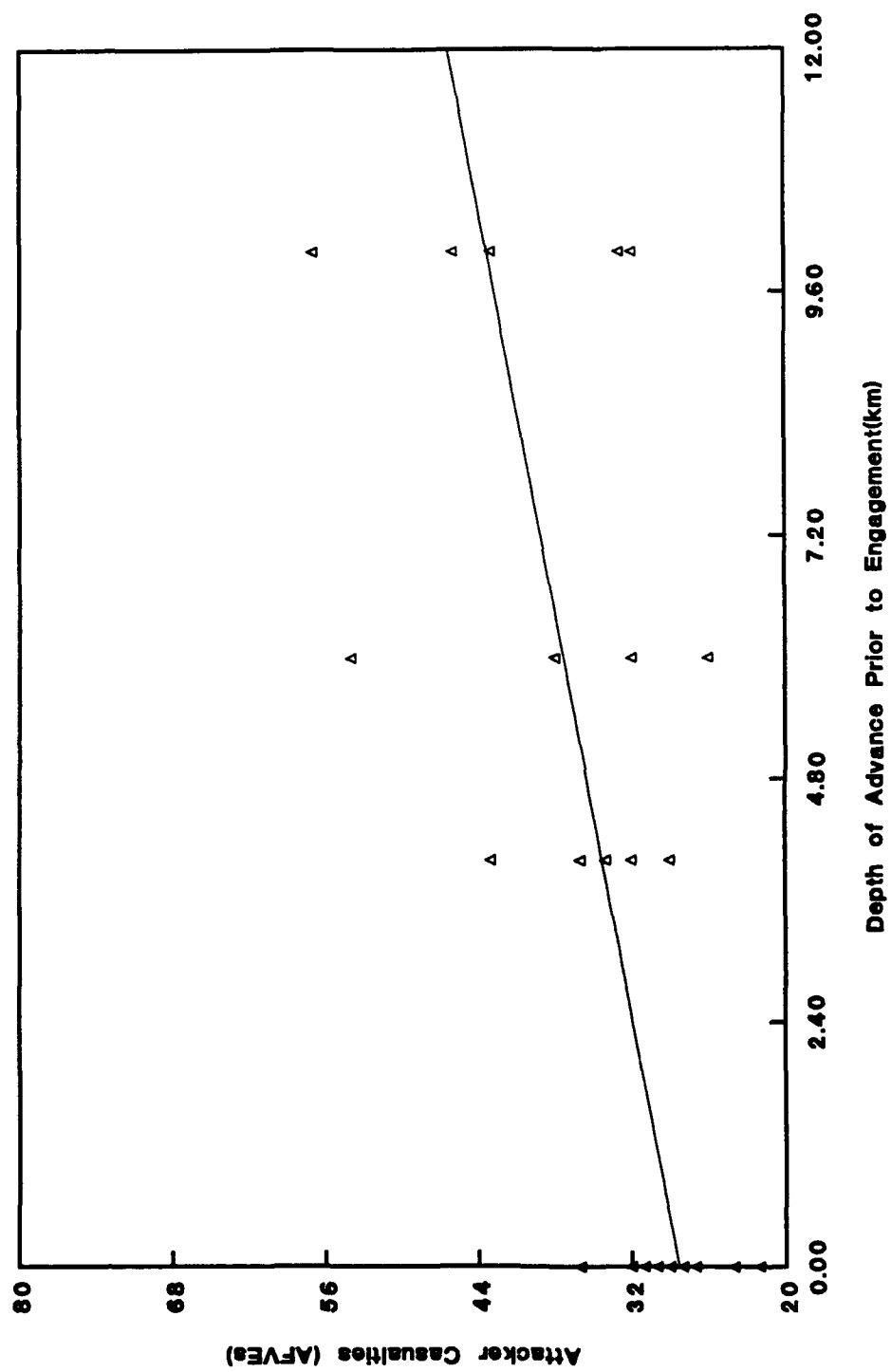


Figure A-13. Assault upon Successive Lines, Southwest Asia

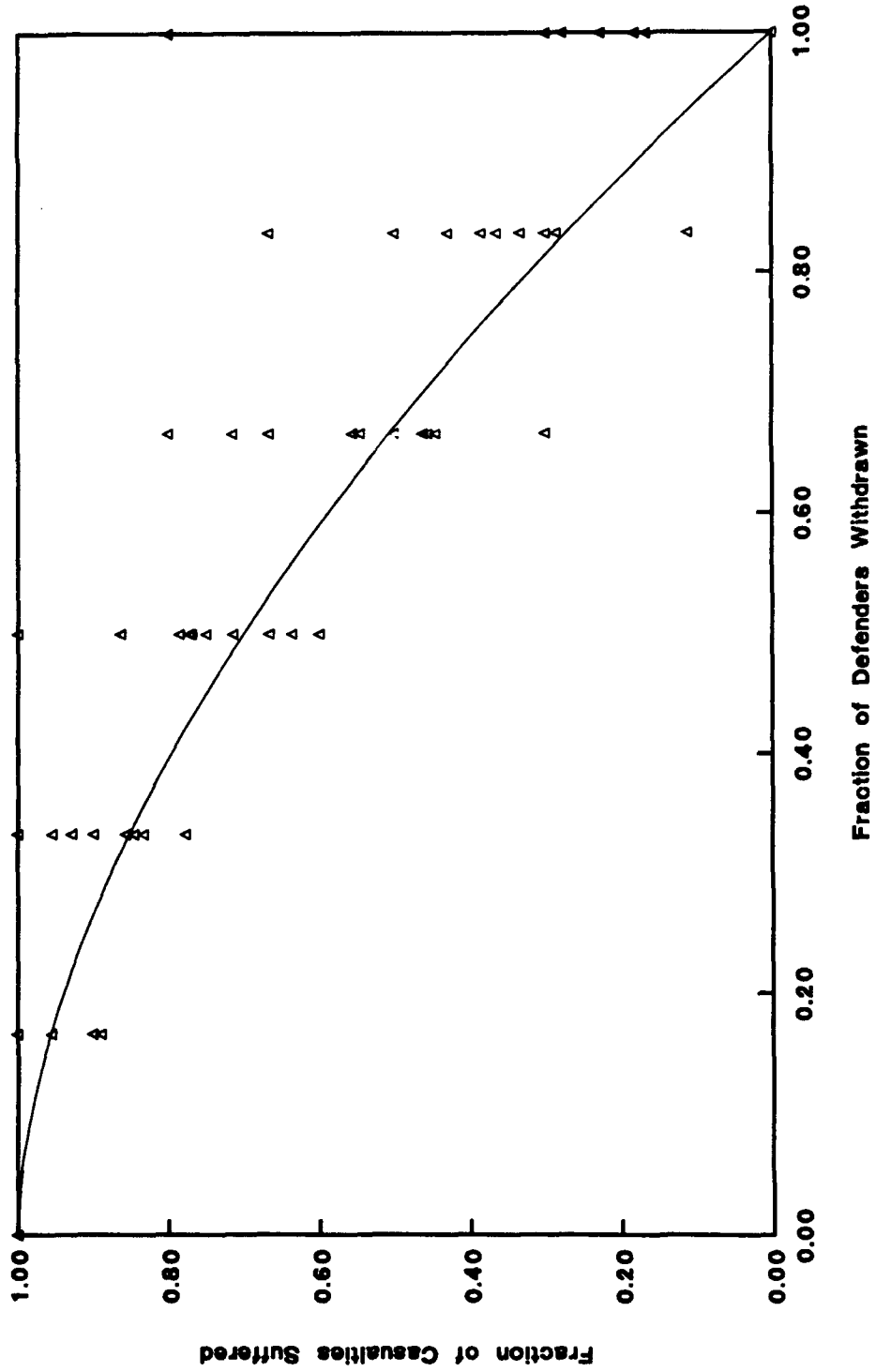


Figure A-14. Withdrawal from Ground Engagements, Southwest Asia

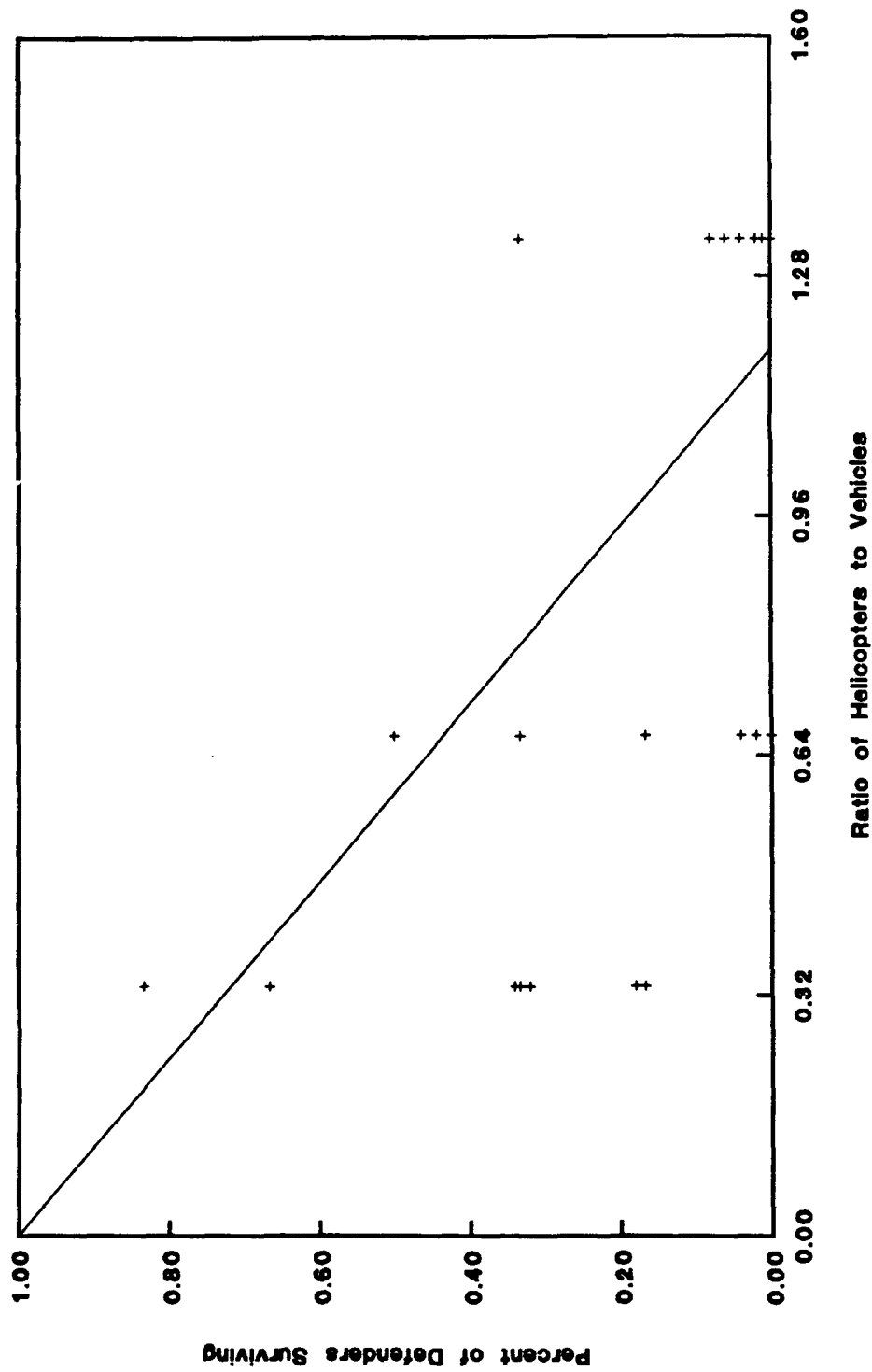


Figure A-15. Helicopter Pursuit, Southwest Asia

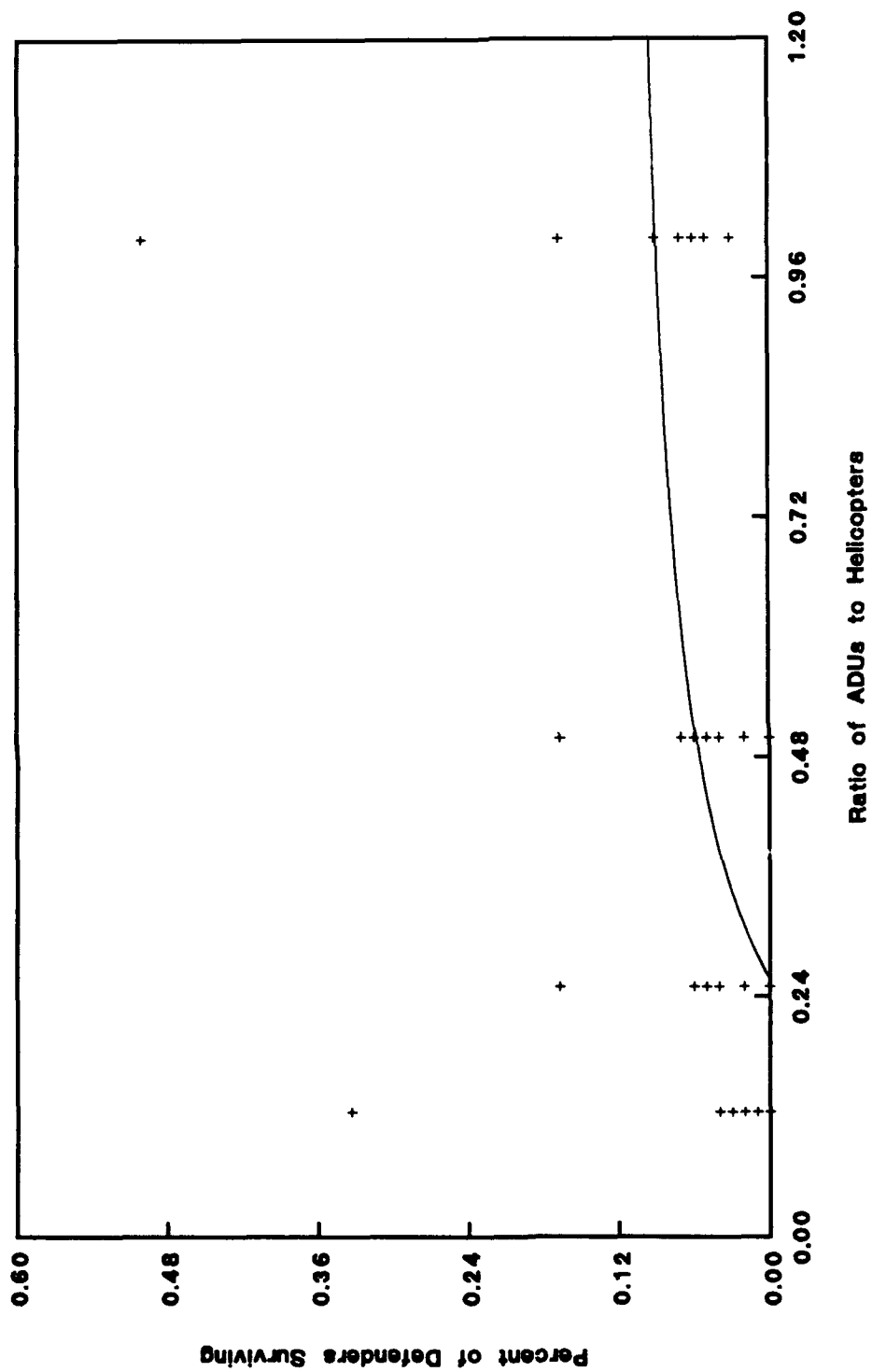


Figure A-16. Withdrawal and Air Defense, Southwest Asia

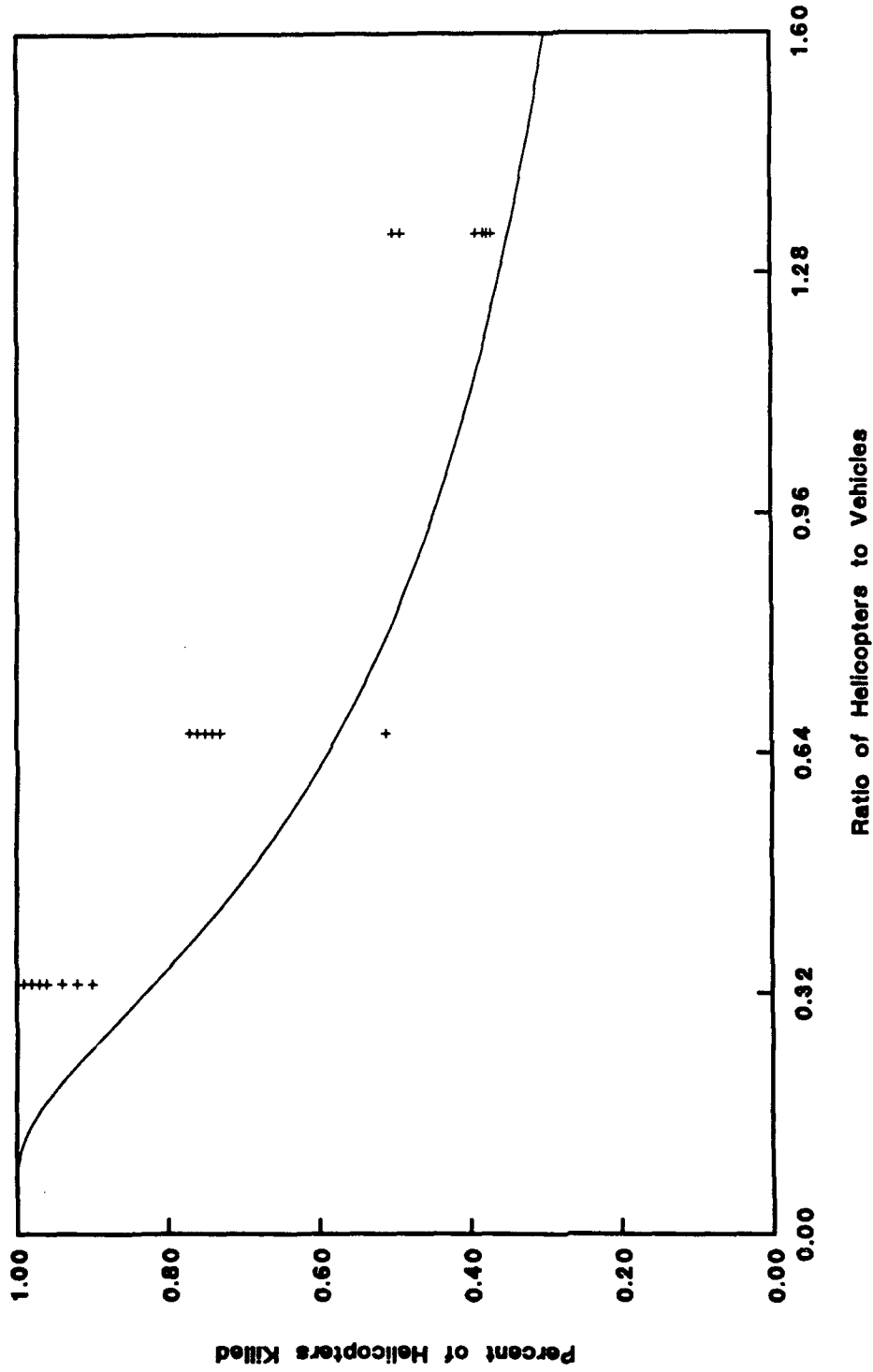


Figure A-17. Pursuit and Helicopter Losses, Southwest Asia

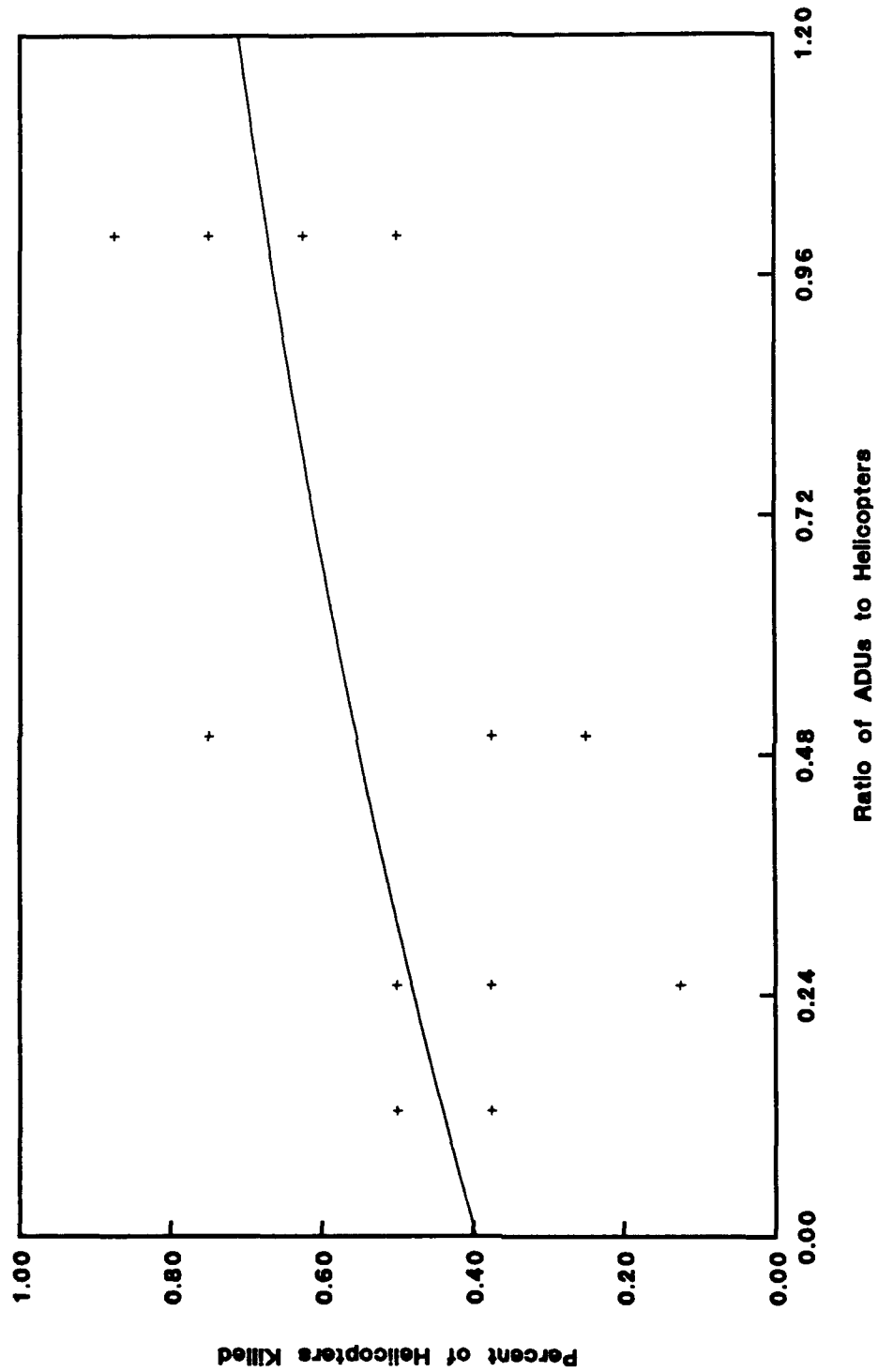


Figure A-18. Air Defense and Helicopter Losses, Southwest Asia

3. Korea

VFM combat coefficients for Korea are given in Table A-3.

Table A-3. VFM Coefficients for Korea

Coefficient	Estimate	Std. error	T-ratio
K ₁	0.80	0.31	2.52
K ₂	3.80	0.97	3.94
K ₃	17.41	1.36	12.81
K ₄	0	—	—
K ₆	3295.0	2214.0	1.49
K ₈	0.037	0.008	4.50
K ₁₀	1.68	0.06	28.36
K ₂₀	0.38	0.03	13.89
K ₂₁	0.014	0.005	2.71
K ₂₂	0.27	0.058	4.68
K ₂₃	1.75	0.18	9.46

	Assaults	Successive Assaults	Disengagement
Sum of squares (corrected total)	95007	6877.7	192.60
Error sum of squares	46485	4355.5	17.42
Degrees of freedom	185	36	81
r ² (unadjusted)	0.51	0.37	0.91

	Withdrawal Survival	Helicopter Losses
Sum of squares (corrected total)	0.76	7.79
Error sum of squares	0.52	2.88
Degrees of freedom	36	36
r ² (unadjusted)	0.32	0.63

Curve fits are shown in Figures A-19 through A-27

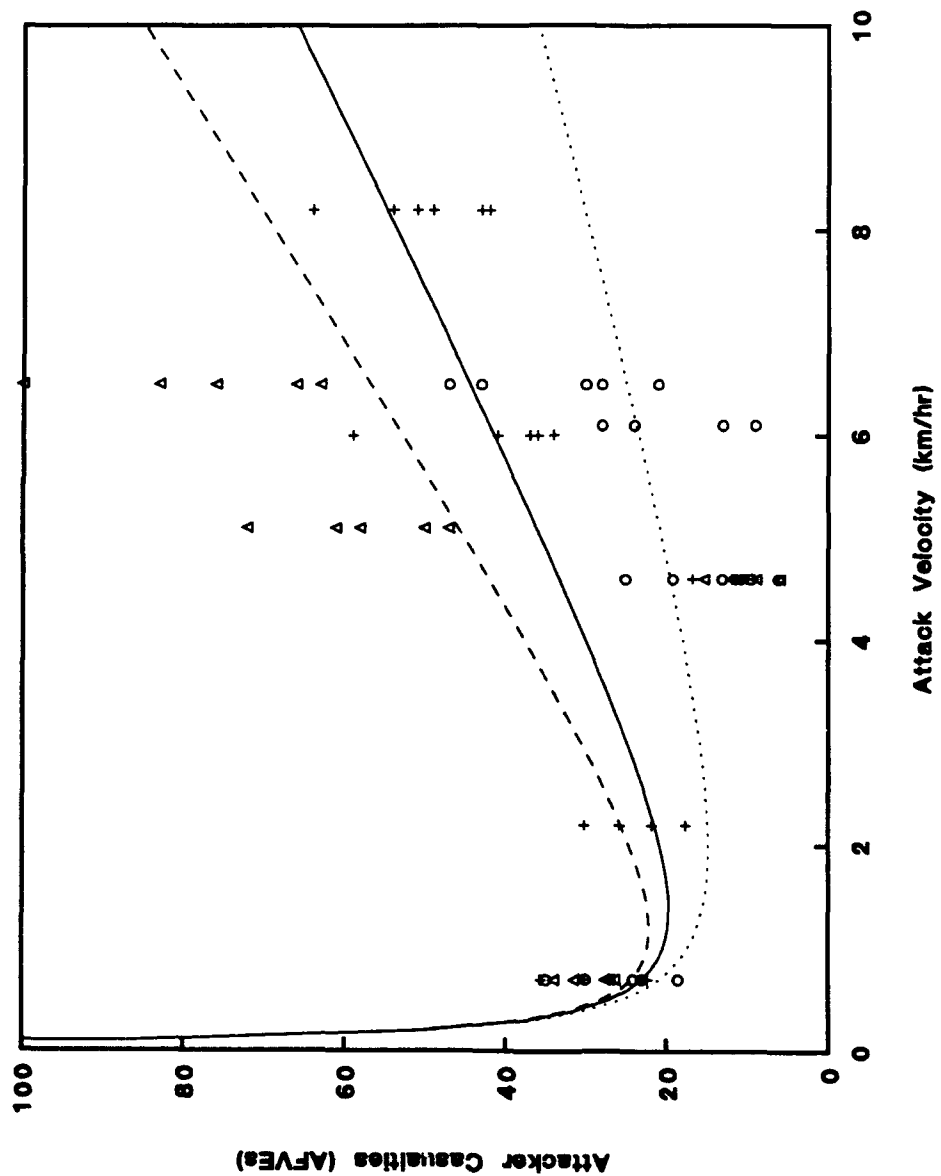


Figure A-19. Force Composition Effects, Korea

Artillery Support:

+ Hi Attk

△ Hi Def.

○ Lo Attk.

+ Lo Def.

— Hi Attk.

- - - Hi Def.

... Lo Attk.

- - - Lo Def.

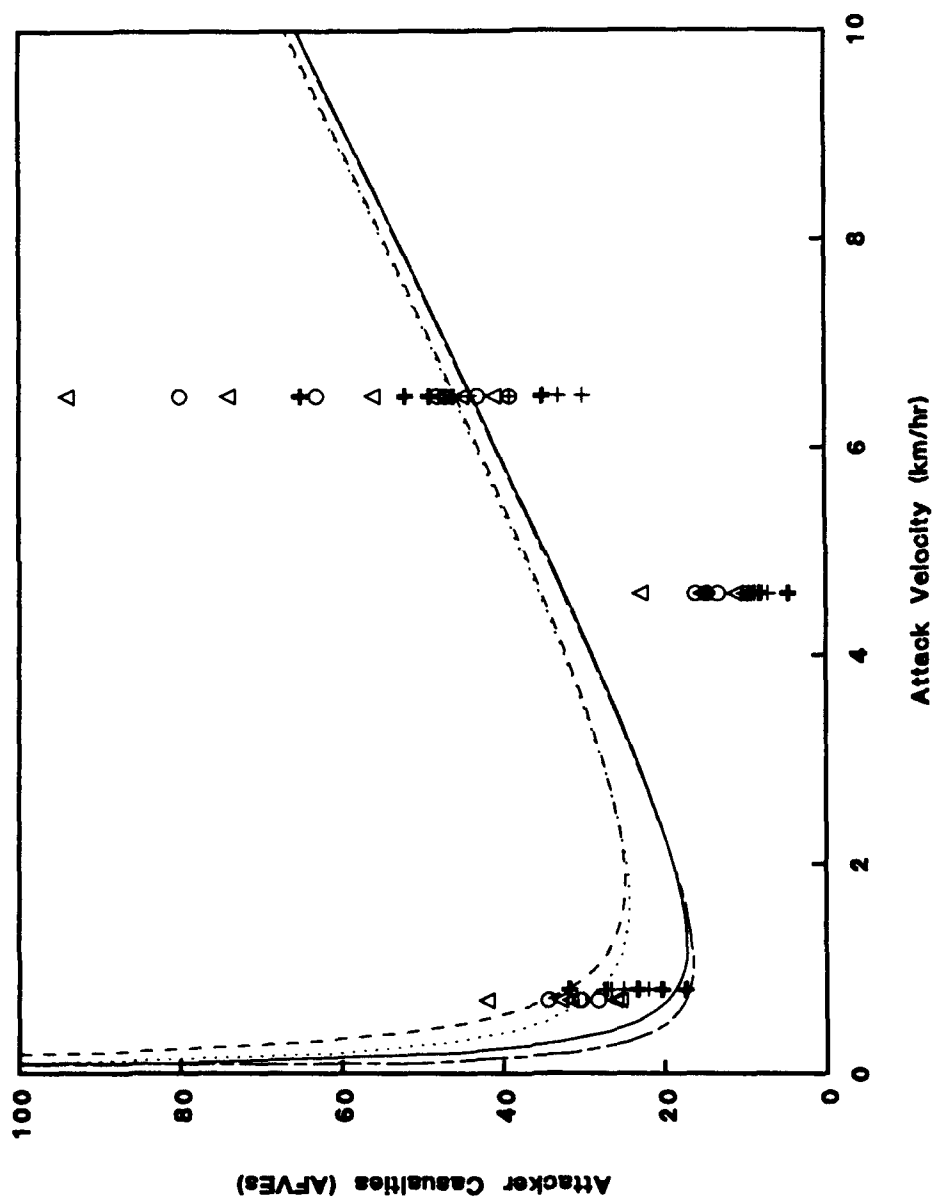


Figure A-20. Artillery Effect, Korea

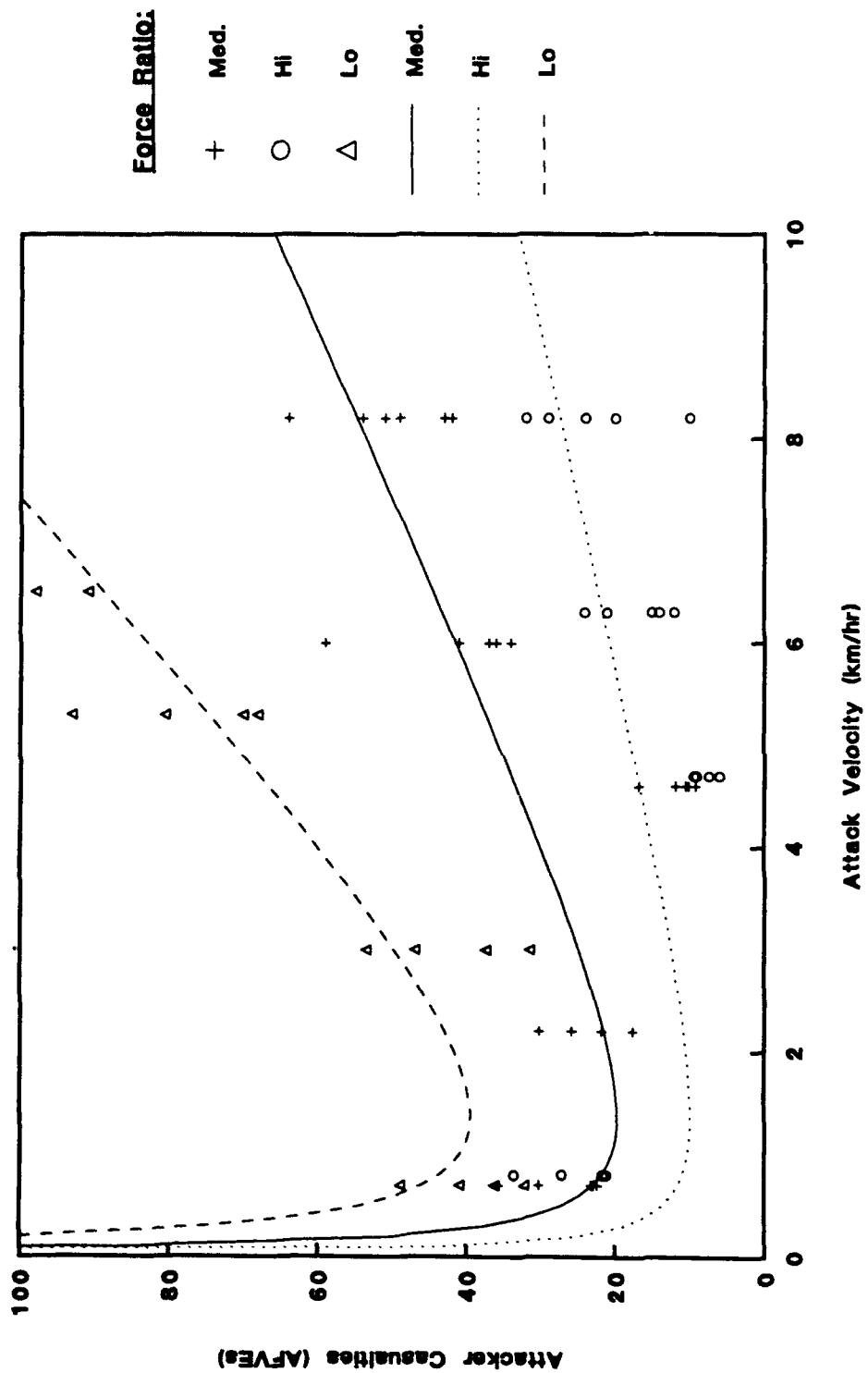


Figure A-21. Force Ratio Effects, Korea

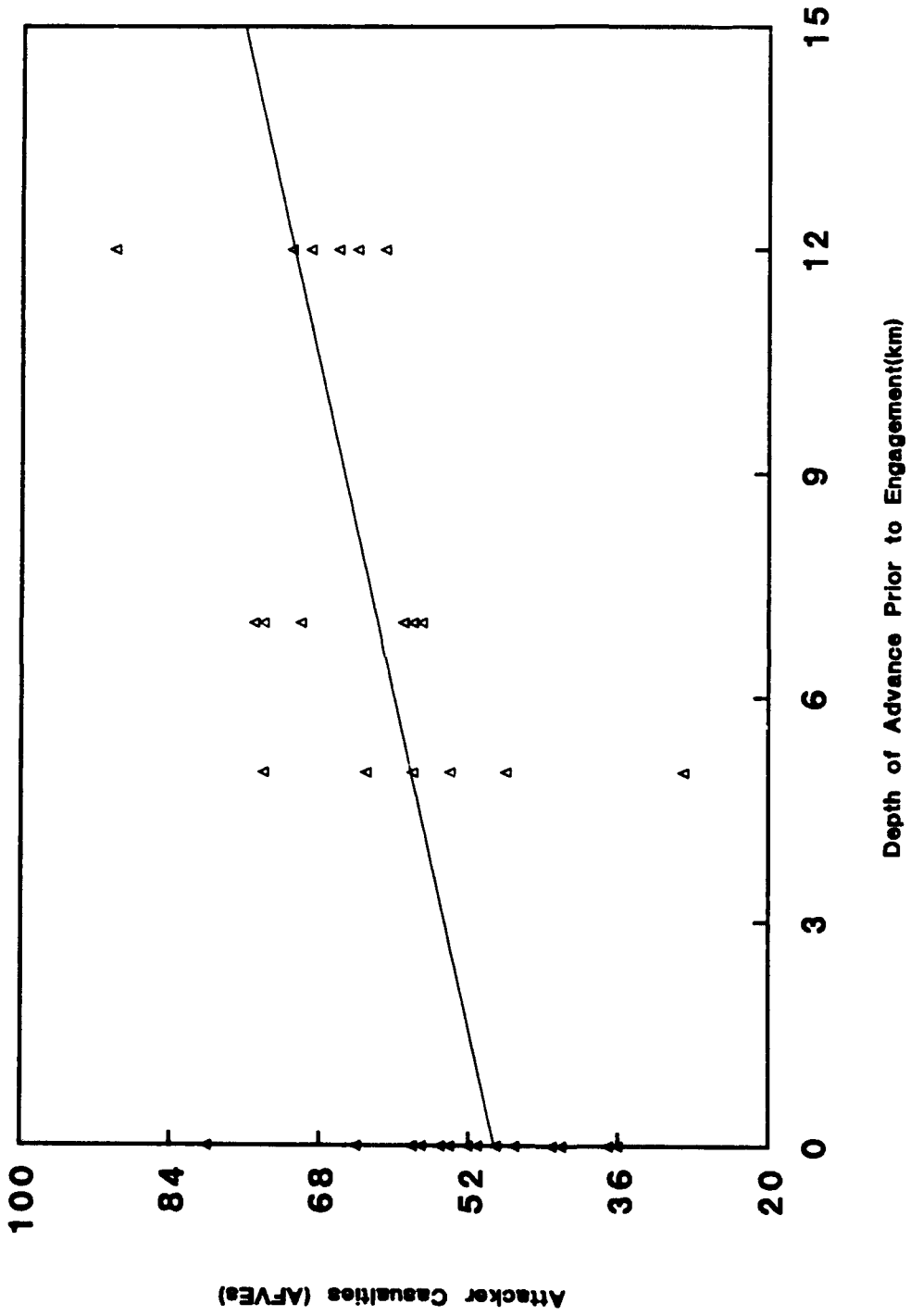


Figure A-22. Assault upon Successive Lines, Korea

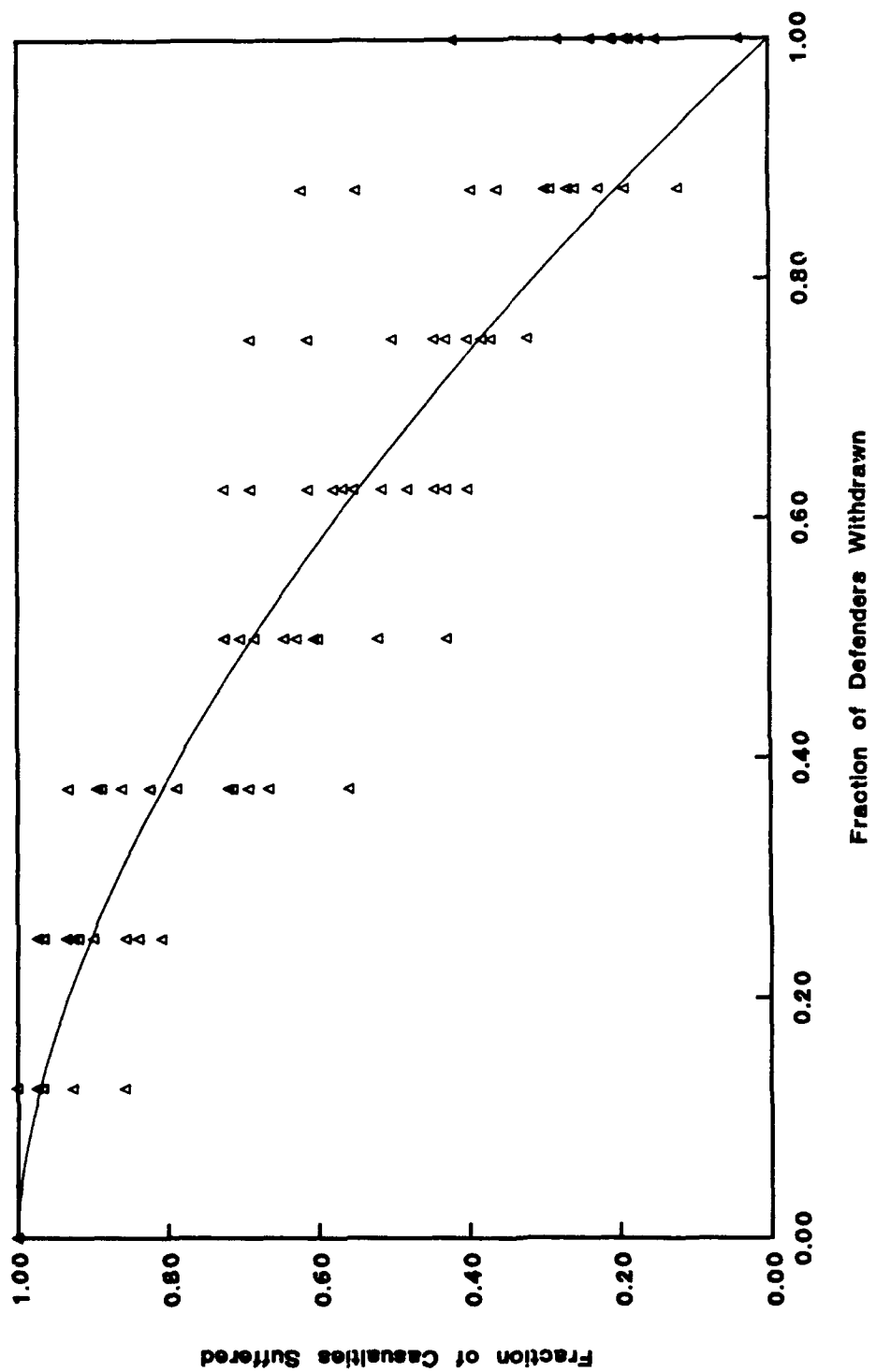


Figure A-23. Withdrawal from Ground Engagements, Korea

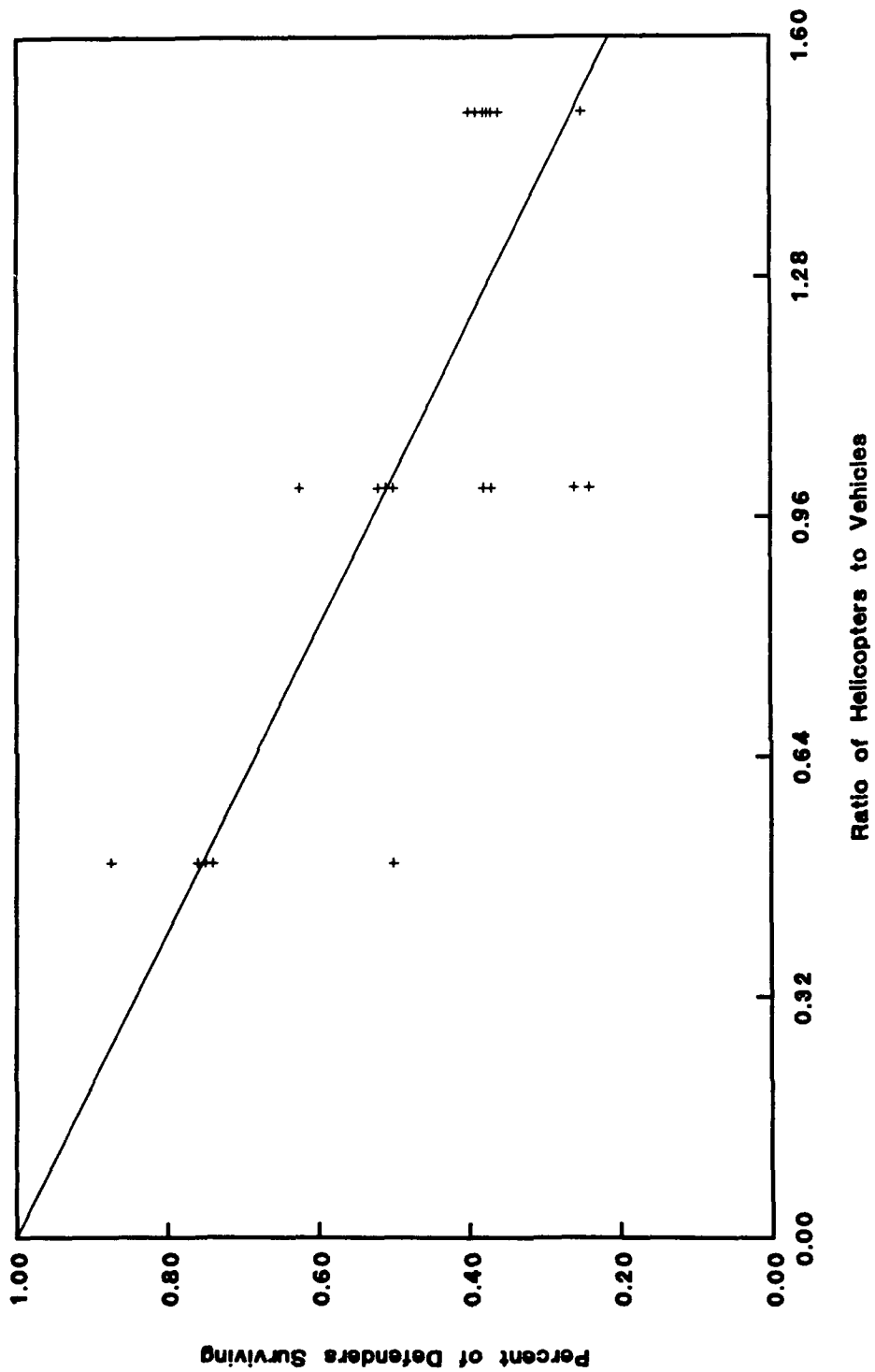


Figure A-24. Helicopter Pursuit, Korea

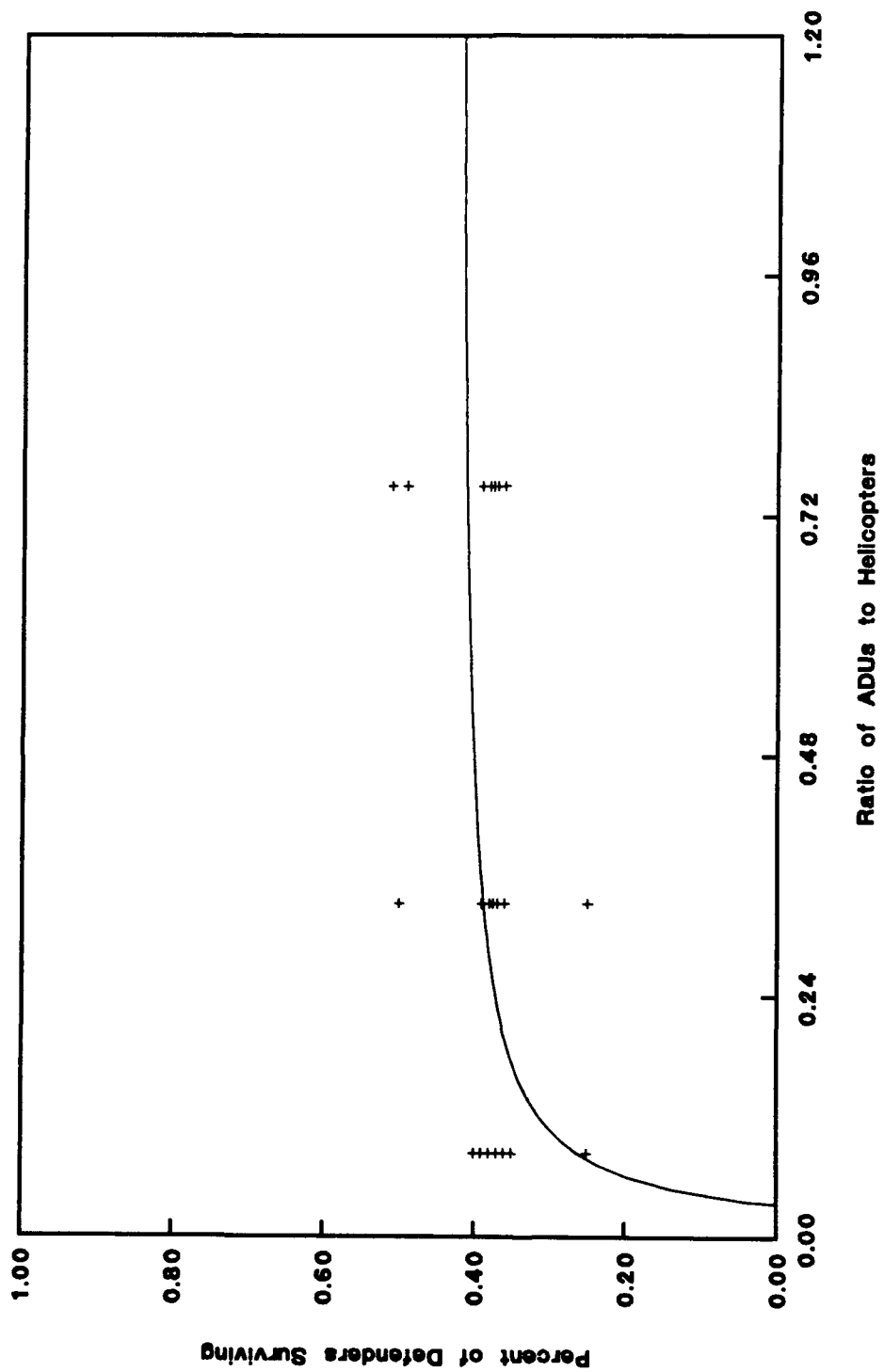


Figure A-25. Withdrawal and Air Defense, Korea

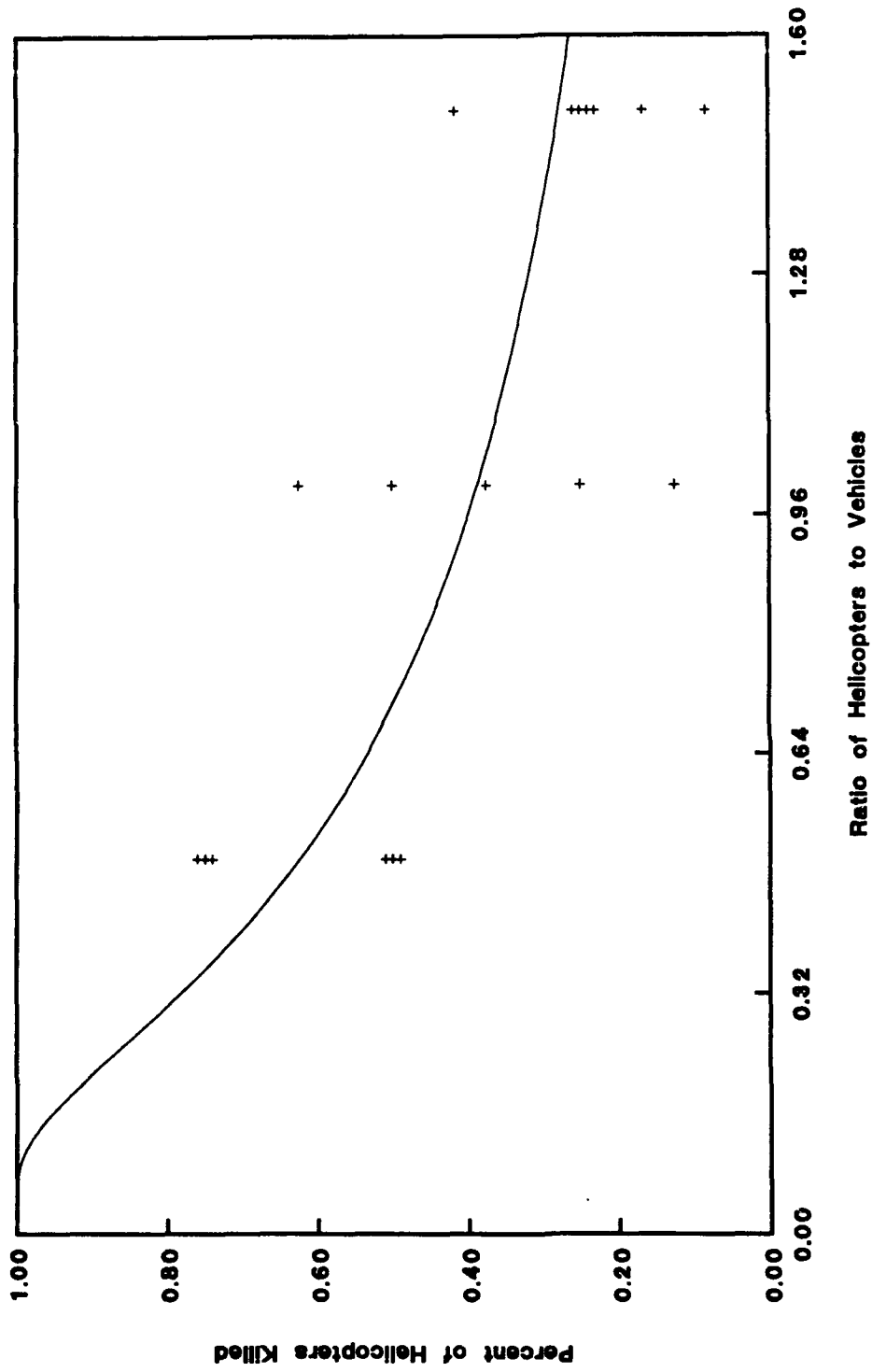


Figure A-26. Pursuit and Helicopter Losses, Korea

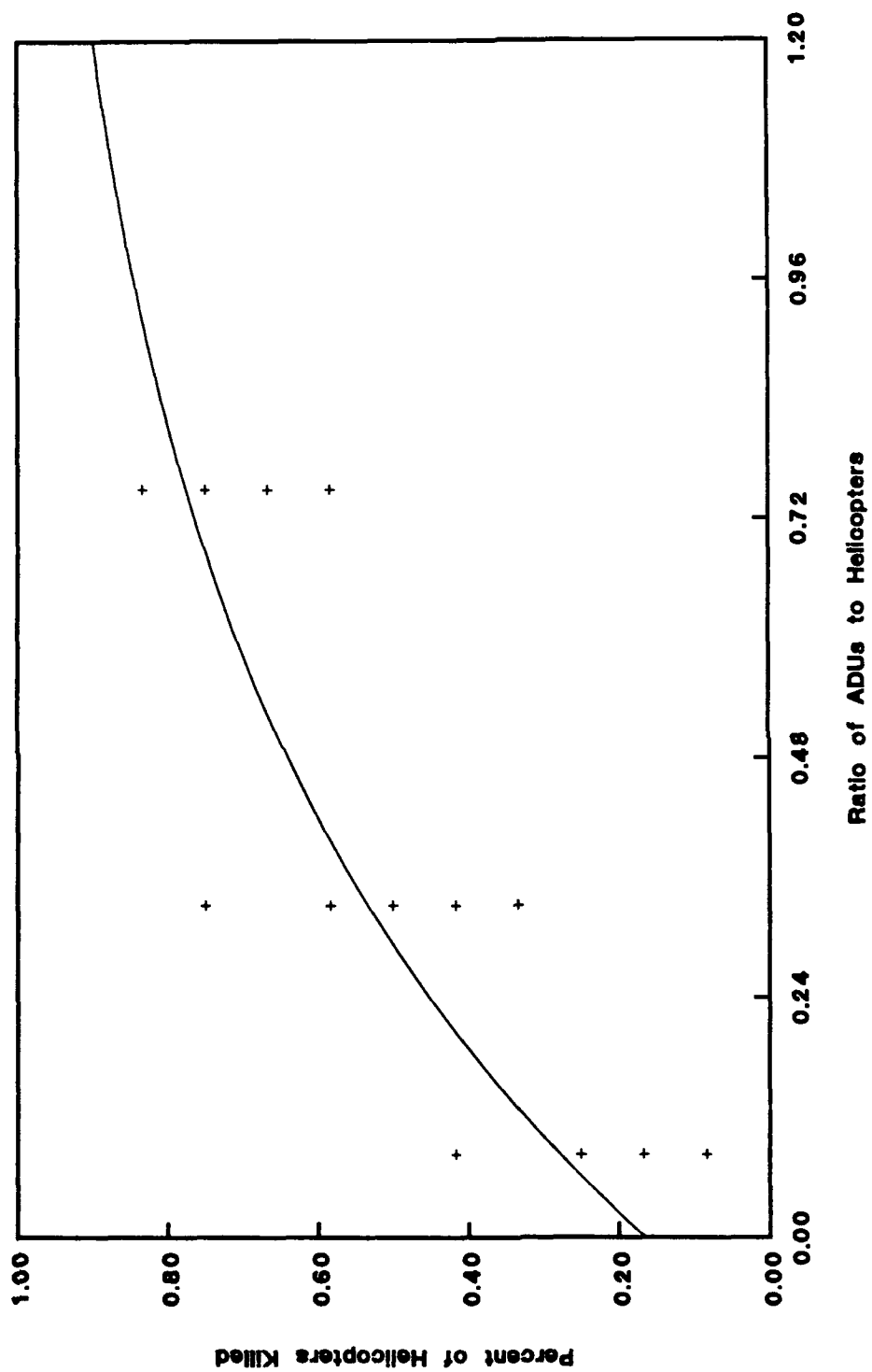


Figure A-27. Air Defense and Helicopter Losses, Korea

APPENDIX B

JANUS SCENARIO DATA

JANUS SCENARIO DATA

This appendix contains all of the JANUS scenario casualty data and combat variables.

Tables B-1—B-3 contain the data from the single assault scenarios for Central Europe, Southwest Asia and Korea, respectively. Casualties are denoted by C ; combat variables are denoted as in Equation 1 in Appendix A.

Tables B-4—B-6 contain the data from the successive assault scenarios for Central Europe, Southwest Asia and Korea, respectively. Casualties are denoted by C ; depth of penetration prior to engagement is denoted by P .

Tables B-7—B-9 contain the data used to assess withdrawal from engagement from scenarios in Central Europe, Southwest Asia and Korea, respectively. Cumulative attacking and defending casualties at times t are denoted by $C_A(t)$ and $C_D(t)$, respectively; total attacking casualties are denoted by C .

Tables B-10—B-12 contain the data from the helicopter pursuit scenarios for Central Europe, Southwest Asia and Korea, respectively. Helicopter and withdrawing vehicle casualties are denoted by C_H and C_W , respectively; the initial numbers of helicopters, withdrawing vehicles and air defense units are denoted by H_p , w and N_{AD} , respectively.

(This page is intentionally left blank.)

Table B-1. Assault Scenarios, Central Europe

C	V	ϕ_{ia}	ϕ_{id}	A_a	D_a	A	D
9.00	2.80	0.73	0.38	52.00	1.00	22.00	8.00
5.30	2.80	0.73	0.38	52.00	1.00	22.00	8.00
6.30	2.80	0.73	0.38	52.00	1.00	22.00	8.00
6.20	2.80	0.73	0.38	52.00	1.00	22.00	8.00
6.90	2.80	0.73	0.38	52.00	1.00	22.00	8.00
10.70	2.80	0.73	0.38	52.00	1.00	22.00	8.00
5.10	2.80	0.73	0.38	52.00	1.00	22.00	8.00
4.00	1.30	0.73	0.38	52.00	1.00	22.00	8.00
6.50	1.30	0.73	0.38	52.00	1.00	22.00	8.00
5.30	1.30	0.73	0.38	52.00	1.00	22.00	8.00
7.60	1.30	0.73	0.38	52.00	1.00	22.00	8.00
7.80	1.30	0.73	0.38	52.00	1.00	22.00	8.00
30.00	6.50	0.73	0.38	48.00	1.00	22.00	8.00
21.00	6.50	0.73	0.38	48.00	1.00	22.00	8.00
41.00	6.50	0.73	0.38	48.00	1.00	22.00	8.00
44.00	6.50	0.73	0.38	48.00	1.00	22.00	8.00
38.00	6.50	0.73	0.38	48.00	1.00	22.00	8.00
35.00	6.50	0.73	0.38	48.00	1.00	22.00	8.00
47.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
51.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
53.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
62.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
47.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
41.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
41.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
61.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
39.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
42.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
45.00	8.40	0.73	0.38	48.00	1.00	22.00	8.00
9.30	2.80	0.90	0.38	52.00	1.00	22.00	8.00
4.40	2.80	0.90	0.38	52.00	1.00	22.00	8.00
8.90	2.80	0.90	0.38	52.00	1.00	22.00	8.00
10.60	2.80	0.90	0.38	52.00	1.00	22.00	8.00
7.20	2.80	0.90	0.38	52.00	1.00	22.00	8.00
7.80	2.80	0.90	0.38	52.00	1.00	22.00	8.00
49.00	6.50	0.90	0.38	48.00	1.00	22.00	8.00
33.00	6.50	0.90	0.38	48.00	1.00	22.00	8.00
43.00	6.50	0.90	0.38	48.00	1.00	22.00	8.00
51.00	6.50	0.90	0.38	48.00	1.00	22.00	8.00
60.00	6.50	0.90	0.38	48.00	1.00	22.00	8.00

Table B-1. Continued

C	V	ϕ_{ia}	ϕ_{id}	A_a	D_a	A	D
85.00	8.40	0.90	0.38	48.00	1.00	22.00	8.00
62.00	8.40	0.90	0.38	48.00	1.00	22.00	8.00
69.00	8.40	0.90	0.38	48.00	1.00	22.00	8.00
73.00	8.40	0.90	0.38	48.00	1.00	22.00	8.00
55.00	8.40	0.90	0.38	48.00	1.00	22.00	8.00
12.10	2.80	0.10	0.38	52.00	1.00	22.00	8.00
14.80	2.80	0.10	0.38	52.00	1.00	22.00	8.00
19.10	2.80	0.10	0.38	52.00	1.00	22.00	8.00
15.80	2.80	0.10	0.38	52.00	1.00	22.00	8.00
7.90	2.80	0.10	0.38	52.00	1.00	22.00	8.00
34.00	6.50	0.10	0.38	48.00	1.00	22.00	8.00
34.00	6.50	0.10	0.38	48.00	1.00	22.00	8.00
20.00	6.50	0.10	0.38	48.00	1.00	22.00	8.00
19.00	6.50	0.10	0.38	48.00	1.00	22.00	8.00
45.00	6.50	0.10	0.38	48.00	1.00	22.00	8.00
32.00	8.40	0.10	0.38	48.00	1.00	22.00	8.00
36.00	8.40	0.10	0.38	48.00	1.00	22.00	8.00
52.00	8.40	0.10	0.38	48.00	1.00	22.00	8.00
35.00	8.40	0.10	0.38	48.00	1.00	22.00	8.00
38.00	8.40	0.10	0.38	48.00	1.00	22.00	8.00
27.60	2.80	0.73	0.88	52.00	1.00	22.00	8.00
21.60	2.80	0.73	0.88	52.00	1.00	22.00	8.00
16.10	2.80	0.73	0.88	52.00	1.00	22.00	8.00
12.20	2.80	0.73	0.88	52.00	1.00	22.00	8.00
2.30	1.30	0.73	0.88	52.00	1.00	22.00	8.00
10.10	1.30	0.73	0.88	52.00	1.00	22.00	8.00
7.40	1.30	0.73	0.88	52.00	1.00	22.00	8.00
4.30	1.30	0.73	0.88	52.00	1.00	22.00	8.00
73.00	5.60	0.73	0.88	48.00	1.00	22.00	8.00
78.00	5.60	0.73	0.88	48.00	1.00	22.00	8.00
66.00	5.60	0.73	0.88	48.00	1.00	22.00	8.00
64.00	5.60	0.73	0.88	48.00	1.00	22.00	8.00
82.00	6.50	0.73	0.88	48.00	1.00	22.00	8.00
78.00	6.50	0.73	0.88	48.00	1.00	22.00	8.00
6.60	2.80	0.73	0.12	52.00	1.00	22.00	8.00
7.70	2.80	0.73	0.12	52.00	1.00	22.00	8.00
7.90	2.80	0.73	0.12	52.00	1.00	22.00	8.00
7.10	2.80	0.73	0.12	52.00	1.00	22.00	8.00
9.00	2.80	0.73	0.12	52.00	1.00	22.00	8.00
4.90	2.80	0.73	0.12	52.00	1.00	22.00	8.00
31.00	6.50	0.73	0.12	48.00	1.00	22.00	8.00
10.00	6.50	0.73	0.12	48.00	1.00	22.00	8.00

Table B-1. Continued

C	V	ϕ_{ia}	ϕ_{id}	A_a	D_a	A	D
29.00	6.50	0.73	0.12	48.00	1.00	22.00	8.00
20.00	6.50	0.73	0.12	48.00	1.00	22.00	8.00
26.00	6.50	0.73	0.12	48.00	1.00	22.00	8.00
25.00	8.40	0.73	0.12	48.00	1.00	22.00	8.00
33.00	8.40	0.73	0.12	48.00	1.00	22.00	8.00
17.00	8.40	0.73	0.12	48.00	1.00	22.00	8.00
52.00	8.40	0.73	0.12	48.00	1.00	22.00	8.00
32.00	8.40	0.73	0.12	48.00	1.00	22.00	8.00
18.40	2.80	0.90	0.88	52.00	1.00	22.00	8.00
15.40	2.80	0.90	0.88	52.00	1.00	22.00	8.00
13.50	2.80	0.90	0.88	52.00	1.00	22.00	8.00
5.50	1.30	0.90	0.88	52.00	1.00	22.00	8.00
6.70	1.30	0.90	0.88	52.00	1.00	22.00	8.00
5.50	1.30	0.90	0.88	52.00	1.00	22.00	8.00
70.00	5.60	0.90	0.88	48.00	1.00	22.00	8.00
82.00	5.60	0.90	0.88	48.00	1.00	22.00	8.00
82.00	6.50	0.90	0.88	48.00	1.00	22.00	8.00
88.00	6.50	0.90	0.88	48.00	1.00	22.00	8.00
20.80	2.80	0.10	0.88	52.00	1.00	22.00	8.00
19.50	2.80	0.10	0.88	52.00	1.00	22.00	8.00
26.90	2.80	0.10	0.88	52.00	1.00	22.00	8.00
12.60	1.30	0.10	0.88	52.00	1.00	22.00	8.00
7.20	1.30	0.10	0.88	52.00	1.00	22.00	8.00
8.60	1.30	0.10	0.88	52.00	1.00	22.00	8.00
63.00	5.60	0.10	0.88	48.00	1.00	22.00	8.00
76.00	5.60	0.10	0.88	48.00	1.00	22.00	8.00
72.00	5.60	0.10	0.88	48.00	1.00	22.00	8.00
75.00	5.60	0.10	0.88	48.00	1.00	22.00	8.00
79.00	6.50	0.10	0.88	48.00	1.00	22.00	8.00
71.00	6.50	0.10	0.88	48.00	1.00	22.00	8.00
78.00	6.50	0.10	0.88	48.00	1.00	22.00	8.00
82.00	6.50	0.10	0.88	48.00	1.00	22.00	8.00
7.40	2.80	0.90	0.12	52.00	1.00	22.00	8.00
10.30	2.80	0.90	0.12	52.00	1.00	22.00	8.00
5.70	2.80	0.90	0.12	52.00	1.00	22.00	8.00
7.90	2.80	0.90	0.12	52.00	1.00	22.00	8.00
41.00	5.60	0.90	0.12	48.00	1.00	22.00	8.00
29.00	5.60	0.90	0.12	48.00	1.00	22.00	8.00
33.00	5.60	0.90	0.12	48.00	1.00	22.00	8.00
31.00	5.60	0.90	0.12	48.00	1.00	22.00	8.00
59.00	6.50	0.90	0.12	48.00	1.00	22.00	8.00
42.00	6.50	0.90	0.12	48.00	1.00	22.00	8.00

Table B-1. Continued

C	V	ϕ_{ia}	ϕ_{id}	A_a	D_a	A	D
73.00	6.50	0.90	0.12	48.00	1.00	22.00	8.00
78.00	6.50	0.90	0.12	48.00	1.00	22.00	8.00
15.10	2.80	0.10	0.12	52.00	1.00	22.00	8.00
13.50	2.80	0.10	0.12	52.00	1.00	22.00	8.00
11.90	2.80	0.10	0.12	52.00	1.00	22.00	8.00
13.30	2.80	0.10	0.12	52.00	1.00	22.00	8.00
23.00	6.50	0.10	0.12	48.00	1.00	22.00	8.00
11.00	6.50	0.10	0.12	48.00	1.00	22.00	8.00
23.00	6.50	0.10	0.12	48.00	1.00	22.00	8.00
32.00	6.50	0.10	0.12	48.00	1.00	22.00	8.00
26.00	8.40	0.10	0.88	48.00	1.00	22.00	8.00
37.00	8.40	0.10	0.88	48.00	1.00	22.00	8.00
15.00	8.40	0.10	0.88	48.00	1.00	22.00	8.00
31.00	8.40	0.10	0.88	48.00	1.00	22.00	8.00
18.20	2.80	0.73	0.40	52.00	1.00	22.00	15.00
18.40	2.80	0.73	0.40	52.00	1.00	22.00	15.00
13.60	2.80	0.73	0.40	52.00	1.00	22.00	15.00
13.60	2.80	0.73	0.40	52.00	1.00	22.00	15.00
28.10	2.80	0.73	0.40	52.00	1.00	22.00	15.00
22.20	2.80	0.73	0.40	52.00	1.00	22.00	15.00
27.90	2.80	0.73	0.40	52.00	1.00	22.00	15.00
18.80	1.30	0.73	0.40	52.00	1.00	22.00	15.00
12.50	1.30	0.73	0.40	52.00	1.00	22.00	15.00
11.70	1.30	0.73	0.40	52.00	1.00	22.00	15.00
14.00	1.30	0.73	0.40	52.00	1.00	22.00	15.00
21.20	1.30	0.73	0.40	52.00	1.00	22.00	15.00
87.00	5.60	0.73	0.40	48.00	1.00	22.00	15.00
68.00	5.60	0.73	0.40	48.00	1.00	22.00	15.00
78.00	5.60	0.73	0.40	48.00	1.00	22.00	15.00
75.00	5.60	0.73	0.40	48.00	1.00	22.00	15.00
72.00	5.60	0.73	0.40	48.00	1.00	22.00	15.00
69.00	5.60	0.73	0.40	48.00	1.00	22.00	15.00
68.00	5.60	0.73	0.40	48.00	1.00	22.00	15.00
76.00	6.50	0.73	0.40	48.00	1.00	22.00	15.00
86.00	6.50	0.73	0.40	48.00	1.00	22.00	15.00
78.00	6.50	0.73	0.40	48.00	1.00	22.00	15.00
80.00	6.50	0.73	0.40	48.00	1.00	22.00	15.00
88.00	6.50	0.73	0.13	48.00	1.00	22.00	15.00
71.00	6.50	0.73	0.13	48.00	1.00	22.00	15.00
55.00	5.60	0.73	0.13	48.00	1.00	22.00	15.00
55.00	5.60	0.73	0.13	48.00	1.00	22.00	15.00
60.00	5.60	0.73	0.13	48.00	1.00	22.00	15.00

Table B-1. Continued

C	V	ϕ_{ia}	ϕ_{id}	A_a	D_a	A	D
66.00	5.60	0.73	0.13	48.00	1.00	22.00	15.00
82.00	5.60	0.73	0.13	48.00	1.00	22.00	15.00
78.00	5.60	0.90	0.40	48.00	1.00	22.00	15.00
80.00	5.60	0.90	0.40	48.00	1.00	22.00	15.00
70.00	5.60	0.90	0.40	48.00	1.00	22.00	15.00
58.00	5.60	0.90	0.40	48.00	1.00	22.00	15.00
62.00	5.60	0.90	0.40	48.00	1.00	22.00	15.00
24.00	5.60	0.10	0.13	48.00	1.00	22.00	15.00
25.00	5.60	0.10	0.13	48.00	1.00	22.00	15.00
29.00	5.60	0.10	0.13	48.00	1.00	22.00	15.00
44.00	5.60	0.10	0.13	48.00	1.00	22.00	15.00
32.00	5.60	0.10	0.13	48.00	1.00	22.00	15.00
50.00	6.50	0.10	0.13	48.00	1.00	22.00	15.00
52.00	6.50	0.10	0.13	48.00	1.00	22.00	15.00
34.00	6.50	0.10	0.13	48.00	1.00	22.00	15.00
61.00	6.50	0.10	0.13	48.00	1.00	22.00	15.00
58.00	6.50	0.10	0.13	48.00	1.00	22.00	15.00
34.80	2.80	0.10	0.13	52.00	1.00	22.00	15.00
11.50	2.80	0.10	0.13	52.00	1.00	22.00	15.00
19.50	2.80	0.10	0.13	52.00	1.00	22.00	15.00
5.30	2.80	0.73	0.50	52.00	1.00	22.00	4.00
4.10	2.80	0.73	0.50	52.00	1.00	22.00	4.00
3.10	2.80	0.73	0.50	52.00	1.00	22.00	4.00
3.80	2.80	0.73	0.50	52.00	1.00	22.00	4.00
2.80	2.80	0.73	0.50	52.00	1.00	22.00	4.00
2.70	2.80	0.73	0.50	52.00	1.00	22.00	4.00
33.00	8.40	0.73	0.50	48.00	1.00	22.00	4.00
36.00	8.40	0.73	0.50	48.00	1.00	22.00	4.00
31.00	8.40	0.73	0.50	48.00	1.00	22.00	4.00
24.00	8.40	0.73	0.50	48.00	1.00	22.00	4.00
33.00	8.40	0.73	0.50	48.00	1.00	22.00	4.00
27.00	8.40	0.73	0.50	48.00	1.00	22.00	4.00
21.00	6.50	0.73	0.50	48.00	1.00	22.00	4.00
20.00	6.50	0.73	0.50	48.00	1.00	22.00	4.00
19.00	6.50	0.73	0.50	48.00	1.00	22.00	4.00
28.00	6.50	0.73	0.50	48.00	1.00	22.00	4.00
35.00	6.50	0.73	0.50	48.00	1.00	22.00	4.00
20.00	6.50	0.73	0.50	48.00	1.00	22.00	4.00
62.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00
54.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00
61.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00
44.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00

Table B-1. Continued

C	V	ϕ_{ia}	ϕ_{id}	A _a	D _a	A	D
70.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00
50.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00
63.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00
45.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00
55.00	6.20	0.67	0.38	1.00	1.00	30.00	8.00
58.00	7.90	0.67	0.38	1.00	1.00	30.00	8.00
68.00	7.90	0.67	0.38	1.00	1.00	30.00	8.00
79.00	7.90	0.67	0.38	1.00	1.00	30.00	8.00
59.00	7.90	0.67	0.38	1.00	1.00	30.00	8.00
58.00	7.90	0.67	0.38	1.00	1.00	30.00	8.00
53.00	7.90	0.67	0.38	1.00	1.00	30.00	8.00
88.00	19.80	0.64	0.37	1.00	1.00	59.00	17.50
94.00	19.80	0.64	0.37	1.00	1.00	59.00	17.50
87.00	19.80	0.64	0.37	1.00	1.00	59.00	17.50
83.00	19.80	0.64	0.37	1.00	1.00	59.00	17.50
105.00	19.80	0.64	0.37	1.00	1.00	59.00	17.50
104.00	19.80	0.64	0.37	1.00	1.00	59.00	17.50
92.00	19.80	0.64	0.37	1.00	1.00	59.00	17.50
87.00	20.40	0.64	0.36	1.00	1.00	59.00	12.50
70.00	20.40	0.64	0.36	1.00	1.00	59.00	12.50
73.00	20.40	0.64	0.36	1.00	1.00	59.00	12.50
76.00	20.40	0.64	0.36	1.00	1.00	59.00	12.50
83.00	20.40	0.64	0.36	1.00	1.00	59.00	12.50
21.00	23.30	0.61	0.33	1.00	1.00	59.00	6.00
22.00	23.30	0.61	0.33	1.00	1.00	59.00	6.00
24.00	23.30	0.61	0.33	1.00	1.00	59.00	6.00
22.00	23.30	0.61	0.33	1.00	1.00	59.00	6.00
31.00	23.30	0.61	0.33	1.00	1.00	59.00	6.00
30.00	23.30	0.61	0.33	1.00	1.00	59.00	6.00
19.80	1.30	0.60	0.40	52.00	10.00	17.50	15.00
30.90	1.30	0.60	0.40	52.00	10.00	17.50	15.00
27.10	1.30	0.60	0.40	52.00	10.00	17.50	15.00
24.50	1.30	0.60	0.40	52.00	10.00	17.50	15.00
26.80	1.30	0.60	0.40	52.00	10.00	17.50	15.00
19.30	1.30	0.60	0.40	52.00	10.00	17.50	15.00
38.60	1.30	0.60	0.40	52.00	10.00	17.50	15.00
26.80	1.30	0.60	0.40	52.00	10.00	17.50	15.00
53.30	1.10	0.60	0.40	26.00	26.00	17.50	15.00
52.30	1.10	0.60	0.40	26.00	26.00	17.50	15.00
38.20	1.10	0.60	0.40	26.00	26.00	17.50	15.00
47.30	1.10	0.60	0.40	26.00	26.00	17.50	15.00
37.10	1.10	0.60	0.40	26.00	26.00	17.50	15.00

Table B-1. Continued

C	V	ϕ_{ia}	ϕ_{id}	A_a	D_a	A	D
51.00	1.10	0.60	0.40	26.00	26.00	17.50	15.00
35.80	1.20	0.60	0.40	26.00	10.00	17.50	15.00
19.90	1.20	0.60	0.40	26.00	10.00	17.50	15.00
13.30	1.30	0.60	0.38	52.00	10.00	17.50	8.00
15.30	1.30	0.60	0.38	52.00	10.00	17.50	8.00
14.80	1.30	0.60	0.38	52.00	10.00	17.50	8.00
14.20	1.30	0.60	0.38	52.00	10.00	17.50	8.00
15.20	1.30	0.60	0.38	52.00	10.00	17.50	8.00
65.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
39.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
56.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
36.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
55.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
54.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
36.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
50.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
55.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
48.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
51.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
54.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
56.00	8.40	0.73	0.38	48.00	104.00	22.00	8.00
45.00	8.40	0.73	0.38	6.00	104.00	22.00	8.00
54.00	8.40	0.73	0.38	6.00	104.00	22.00	8.00
62.00	8.40	0.73	0.38	6.00	104.00	22.00	8.00
52.00	8.40	0.73	0.38	6.00	104.00	22.00	8.00
64.00	8.40	0.73	0.38	6.00	104.00	22.00	8.00
73.00	8.40	0.73	0.38	6.00	104.00	22.00	8.00

Table B-2. Assault Scenarios, Southwest Asia

C	V	ϕ_i	A_a	D_a	$\hat{H}$	A	D
16.00	7.80	1.02	72.00	40.00	1.00	29.00	4.00
16.00	7.80	1.02	72.00	40.00	1.00	29.00	4.00
15.00	7.80	1.02	72.00	40.00	1.00	29.00	4.00
22.00	7.80	1.02	72.00	40.00	1.00	29.00	4.00
14.00	3.50	1.02	72.00	40.00	1.00	29.00	4.00
8.00	3.50	1.02	72.00	40.00	1.00	29.00	4.00
11.00	3.50	1.02	72.00	40.00	1.00	29.00	4.00
7.00	3.50	1.02	72.00	40.00	1.00	29.00	4.00
2.10	2.90	1.02	72.00	40.00	1.00	29.00	4.00
5.10	2.90	1.02	72.00	40.00	1.00	29.00	4.00
3.80	2.90	1.02	72.00	40.00	1.00	29.00	4.00
11.10	1.40	1.02	72.00	40.00	1.00	29.00	4.00
4.10	1.40	1.02	72.00	40.00	1.00	29.00	4.00
11.00	1.40	1.02	72.00	40.00	1.00	29.00	4.00
12.40	1.40	1.02	72.00	40.00	1.00	29.00	4.00
12.10	1.40	1.02	72.00	40.00	1.00	29.00	4.00
13.00	0.70	1.02	72.00	40.00	1.00	29.00	4.00
16.40	0.70	1.02	72.00	40.00	1.00	29.00	4.00
17.00	0.70	1.02	72.00	40.00	1.00	29.00	4.00
12.10	0.70	1.02	72.00	40.00	1.00	29.00	4.00
16.00	0.70	1.02	72.00	40.00	1.00	29.00	4.00
29.00	7.80	1.51	72.00	40.00	1.00	29.00	4.00
28.00	7.80	1.51	72.00	40.00	1.00	29.00	4.00
22.00	7.80	1.51	72.00	40.00	1.00	29.00	4.00
27.00	7.80	1.51	72.00	40.00	1.00	29.00	4.00
21.00	3.60	1.51	72.00	40.00	1.00	29.00	4.00
23.00	3.60	1.51	72.00	40.00	1.00	29.00	4.00
26.00	3.60	1.51	72.00	40.00	1.00	29.00	4.00
22.00	3.60	1.51	72.00	40.00	1.00	29.00	4.00
25.00	3.60	1.51	72.00	40.00	1.00	29.00	4.00
9.90	1.40	1.51	72.00	40.00	1.00	29.00	4.00
9.40	1.40	1.51	72.00	40.00	1.00	29.00	4.00
6.10	1.40	1.51	72.00	40.00	1.00	29.00	4.00
16.10	0.70	1.51	72.00	40.00	1.00	29.00	4.00
15.50	0.70	1.51	72.00	40.00	1.00	29.00	4.00
13.30	0.70	1.51	72.00	40.00	1.00	29.00	4.00
14.40	0.70	1.51	72.00	40.00	1.00	29.00	4.00
14.00	6.40	0.53	72.00	40.00	1.00	29.00	4.00
9.00	6.40	0.53	72.00	40.00	1.00	29.00	4.00
39.00	6.40	0.53	72.00	40.00	1.00	29.00	4.00
12.00	6.40	0.53	72.00	40.00	1.00	29.00	4.00
10.00	6.40	0.53	72.00	40.00	1.00	29.00	4.00

Table B-2. Continued

C	V	ϕ_i	A_a	D_a	$\hat{H}$	A	D
6.00	3.50	0.53	72.00	40.00	1.00	29.00	4.00
10.00	3.50	0.53	72.00	40.00	1.00	29.00	4.00
6.00	3.50	0.53	72.00	40.00	1.00	29.00	4.00
8.00	1.40	0.53	72.00	40.00	1.00	29.00	4.00
9.10	1.40	0.53	72.00	40.00	1.00	29.00	4.00
8.00	1.40	0.53	72.00	40.00	1.00	29.00	4.00
14.00	0.70	0.53	72.00	40.00	1.00	29.00	4.00
11.30	0.70	0.53	72.00	40.00	1.00	29.00	4.00
8.80	0.70	0.53	72.00	40.00	1.00	29.00	4.00
17.80	1.40	1.02	72.00	40.00	1.00	29.00	10.00
36.00	7.80	1.02	72.00	40.00	1.00	29.00	10.00
46.00	7.80	1.02	72.00	40.00	1.00	29.00	10.00
43.00	7.80	1.02	72.00	40.00	1.00	29.00	10.00
45.00	7.80	1.02	72.00	40.00	1.00	29.00	10.00
40.00	7.80	1.02	72.00	40.00	1.00	29.00	10.00
49.00	7.80	1.02	72.00	40.00	1.00	29.00	10.00
21.00	4.00	1.02	144.00	40.00	1.00	29.00	10.00
22.00	4.00	1.02	144.00	40.00	1.00	29.00	10.00
30.00	4.00	1.02	144.00	40.00	1.00	29.00	10.00
9.60	1.40	1.02	144.00	40.00	1.00	29.00	10.00
9.40	1.40	1.02	144.00	40.00	1.00	29.00	10.00
8.90	1.40	1.02	144.00	40.00	1.00	29.00	10.00
16.10	0.70	1.02	144.00	40.00	1.00	29.00	10.00
18.10	0.70	1.02	144.00	40.00	1.00	29.00	10.00
13.10	0.70	1.02	144.00	40.00	1.00	29.00	10.00
16.10	0.70	1.02	144.00	40.00	1.00	29.00	10.00
43.00	3.50	1.02	72.00	80.00	1.00	29.00	10.00
39.00	3.50	1.02	72.00	80.00	1.00	29.00	10.00
43.00	3.50	1.02	72.00	80.00	1.00	29.00	10.00
19.80	1.40	1.02	72.00	80.00	1.00	29.00	10.00
19.90	1.40	1.02	72.00	80.00	1.00	29.00	10.00
14.40	1.40	1.02	72.00	80.00	1.00	29.00	10.00
17.80	1.40	1.02	72.00	80.00	1.00	29.00	10.00
19.70	0.70	1.02	72.00	80.00	1.00	29.00	10.00
24.00	0.70	1.02	72.00	80.00	1.00	29.00	10.00
24.10	0.70	1.02	72.00	80.00	1.00	29.00	10.00
32.10	0.70	1.02	72.00	80.00	1.00	29.00	10.00
38.00	3.60	1.02	72.00	20.00	1.00	29.00	10.00
22.00	3.60	1.02	72.00	20.00	1.00	29.00	10.00
24.00	3.60	1.02	72.00	20.00	1.00	29.00	10.00
9.20	1.40	1.02	72.00	20.00	1.00	29.00	10.00
2.40	1.40	1.02	72.00	20.00	1.00	29.00	10.00

Table B-2. Continued

C	V	ϕ_i	A_a	D_a	$\hat{H}$	A	D
11.60	0.70	1.02	72.00	20.00	1.00	29.00	10.00
12.70	0.70	1.02	72.00	20.00	1.00	29.00	10.00
12.00	0.70	1.02	72.00	20.00	1.00	29.00	10.00
14.60	0.70	1.02	72.00	20.00	1.00	29.00	10.00
47.00	3.50	1.02	36.00	40.00	1.00	29.00	10.00
31.00	3.50	1.02	36.00	40.00	1.00	29.00	10.00
32.00	3.50	1.02	36.00	40.00	1.00	29.00	10.00
20.50	1.40	1.02	36.00	40.00	1.00	29.00	10.00
16.10	1.40	1.02	36.00	40.00	1.00	29.00	10.00
10.30	1.40	1.02	36.00	40.00	1.00	29.00	10.00
26.20	0.70	1.02	36.00	40.00	1.00	29.00	10.00
24.10	0.70	1.02	36.00	40.00	1.00	29.00	10.00
32.70	0.70	1.02	36.00	40.00	1.00	29.00	10.00
11.10	0.70	1.02	36.00	40.00	1.00	29.00	10.00
69.00	6.80	1.51	72.00	40.00	1.00	29.00	10.00
61.00	6.80	1.51	72.00	40.00	1.00	29.00	10.00
53.00	6.80	1.51	72.00	40.00	1.00	29.00	10.00
55.00	6.80	1.51	72.00	40.00	1.00	29.00	10.00
8.60	2.90	1.51	72.00	40.00	1.00	29.00	10.00
6.90	2.90	1.51	72.00	40.00	1.00	29.00	10.00
8.40	2.90	1.51	72.00	40.00	1.00	29.00	10.00
12.80	2.90	1.51	72.00	40.00	1.00	29.00	10.00
17.30	0.70	1.51	72.00	40.00	1.00	29.00	10.00
15.80	0.70	1.51	72.00	40.00	1.00	29.00	10.00
14.90	0.70	1.51	72.00	40.00	1.00	29.00	10.00
14.20	0.70	1.51	72.00	40.00	1.00	29.00	10.00
56.00	7.80	0.53	72.00	40.00	1.00	29.00	10.00
49.00	7.80	0.53	72.00	40.00	1.00	29.00	10.00
56.00	7.80	0.53	72.00	40.00	1.00	29.00	10.00
34.00	7.80	0.53	72.00	40.00	1.00	29.00	10.00
10.60	2.90	0.53	72.00	40.00	1.00	29.00	10.00
4.70	2.90	0.53	72.00	40.00	1.00	29.00	10.00
13.10	2.90	0.53	72.00	40.00	1.00	29.00	10.00
5.10	2.90	0.53	72.00	40.00	1.00	29.00	10.00
7.20	0.70	0.53	72.00	40.00	1.00	29.00	10.00
15.30	0.70	0.53	72.00	40.00	1.00	29.00	10.00
14.30	0.70	0.53	72.00	40.00	1.00	29.00	10.00
18.50	0.70	0.53	72.00	40.00	1.00	29.00	10.00
37.00	7.80	1.02	72.00	40.00	3.00	29.00	10.00
42.00	7.80	1.02	72.00	40.00	3.00	29.00	10.00
51.00	7.80	1.02	72.00	40.00	3.00	29.00	10.00
54.00	7.80	1.02	72.00	40.00	3.00	29.00	10.00

Table B-2. Continued

C	V	ϕ_i	A_a	D_a	$\hat{H}$	A	D
56.00	7.80	1.02	72.00	40.00	3.00	29.00	10.00
87.00	2.90	1.02	72.00	40.00	1.00	29.00	20.00
50.00	2.90	1.02	72.00	40.00	1.00	29.00	20.00
72.00	2.90	1.02	72.00	40.00	1.00	29.00	20.00
71.00	2.90	1.02	72.00	40.00	1.00	29.00	20.00
90.00	2.90	1.02	72.00	40.00	1.00	29.00	20.00
13.30	2.00	1.02	72.00	40.00	1.00	29.00	20.00
18.40	2.00	1.02	72.00	40.00	1.00	29.00	20.00
22.60	2.00	1.02	72.00	40.00	1.00	29.00	20.00
36.20	2.00	1.02	72.00	40.00	1.00	29.00	20.00
16.60	0.70	1.02	72.00	40.00	1.00	29.00	20.00
18.60	0.70	1.02	72.00	40.00	1.00	29.00	20.00
22.80	0.70	1.02	72.00	40.00	1.00	29.00	20.00
22.10	0.70	1.02	72.00	40.00	1.00	29.00	20.00
30.00	7.80	1.02	72.00	40.00	4.00	29.00	4.00
19.00	7.80	1.02	72.00	40.00	4.00	29.00	4.00
23.00	7.80	1.02	72.00	40.00	4.00	29.00	4.00
21.00	7.80	1.02	72.00	40.00	4.00	29.00	4.00
12.70	1.50	1.02	72.00	40.00	4.00	29.00	4.00
12.30	1.50	1.02	72.00	40.00	4.00	29.00	4.00
17.70	1.50	1.02	72.00	40.00	4.00	29.00	4.00
10.30	1.50	1.02	72.00	40.00	4.00	29.00	4.00

Table B-3. Assault Scenarios, Korea

C	V	ϕ_i	A_a	D_a	$\hat{H}$	A	D
49.00	8.20	1.17	76.00	39.00	1.00	30.00	8.00
42.00	8.20	1.17	76.00	39.00	1.00	30.00	8.00
51.00	8.20	1.17	76.00	39.00	1.00	30.00	8.00
64.00	8.20	1.17	76.00	39.00	1.00	30.00	8.00
43.00	8.20	1.17	76.00	39.00	1.00	30.00	8.00
54.00	8.20	1.17	76.00	39.00	1.00	30.00	8.00
59.00	6.00	1.17	76.00	39.00	1.00	30.00	8.00
41.00	6.00	1.17	76.00	39.00	1.00	30.00	8.00
36.00	6.00	1.17	76.00	39.00	1.00	30.00	8.00
37.00	6.00	1.17	76.00	39.00	1.00	30.00	8.00
34.00	6.00	1.17	76.00	39.00	1.00	30.00	8.00
10.50	4.60	1.17	76.00	39.00	1.00	30.00	8.00
9.20	4.60	1.17	76.00	39.00	1.00	30.00	8.00
10.10	4.60	1.17	76.00	39.00	1.00	30.00	8.00
11.90	4.60	1.17	76.00	39.00	1.00	30.00	8.00
16.80	4.60	1.17	76.00	39.00	1.00	30.00	8.00
21.80	2.20	1.17	76.00	39.00	1.00	30.00	8.00
17.60	2.20	1.17	76.00	39.00	1.00	30.00	8.00
30.20	2.20	1.17	76.00	39.00	1.00	30.00	8.00
25.80	2.20	1.17	76.00	39.00	1.00	30.00	8.00
22.30	0.70	1.17	76.00	39.00	1.00	30.00	8.00
23.10	0.70	1.17	76.00	39.00	1.00	30.00	8.00
35.60	0.70	1.17	76.00	39.00	1.00	30.00	8.00
30.20	0.70	1.17	76.00	39.00	1.00	30.00	8.00
22.80	0.70	1.17	76.00	39.00	1.00	30.00	8.00
43.00	6.50	0.52	76.00	39.00	1.00	30.00	8.00
28.00	6.50	0.52	76.00	39.00	1.00	30.00	8.00
30.00	6.50	0.52	76.00	39.00	1.00	30.00	8.00
47.00	6.50	0.52	76.00	39.00	1.00	30.00	8.00
21.00	6.50	0.52	76.00	39.00	1.00	30.00	8.00
24.00	6.10	0.52	76.00	39.00	1.00	30.00	8.00
24.00	6.10	0.52	76.00	39.00	1.00	30.00	8.00
13.00	6.10	0.52	76.00	39.00	1.00	30.00	8.00
9.00	6.10	0.52	76.00	39.00	1.00	30.00	8.00
28.00	6.10	0.52	76.00	39.00	1.00	30.00	8.00
9.50	4.60	0.52	76.00	39.00	1.00	30.00	8.00
19.20	4.60	0.52	76.00	39.00	1.00	30.00	8.00
6.10	4.60	0.52	76.00	39.00	1.00	30.00	8.00

Table B-3. Continued

C	V	ϕ_i	A_a	D_a	$\hat{H}$	A	D
25.10	4.60	0.52	76.00	39.00	1.00	30.00	8.00
13.10	4.60	0.52	76.00	39.00	1.00	30.00	8.00
18.50	0.70	0.52	76.00	39.00	1.00	30.00	8.00
24.10	0.70	0.52	76.00	39.00	1.00	30.00	8.00
23.00	0.70	0.52	76.00	39.00	1.00	30.00	8.00
30.00	0.70	0.52	76.00	39.00	1.00	30.00	8.00
34.90	0.70	0.52	76.00	39.00	1.00	30.00	8.00
100.00	6.50	1.58	76.00	39.00	1.00	30.00	8.00
76.00	6.50	1.58	76.00	39.00	1.00	30.00	8.00
63.00	6.50	1.58	76.00	39.00	1.00	30.00	8.00
66.00	6.50	1.58	76.00	39.00	1.00	30.00	8.00
83.00	6.50	1.58	76.00	39.00	1.00	30.00	8.00
58.00	5.10	1.58	76.00	39.00	1.00	30.00	8.00
72.00	5.10	1.58	76.00	39.00	1.00	30.00	8.00
61.00	5.10	1.58	76.00	39.00	1.00	30.00	8.00
50.00	5.10	1.58	76.00	39.00	1.00	30.00	8.00
47.00	5.10	1.58	76.00	39.00	1.00	30.00	8.00
11.90	4.60	1.58	76.00	39.00	1.00	30.00	8.00
15.30	4.60	1.58	76.00	39.00	1.00	30.00	8.00
11.30	4.60	1.58	76.00	39.00	1.00	30.00	8.00
8.80	4.60	1.58	76.00	39.00	1.00	30.00	8.00
5.90	4.60	1.58	76.00	39.00	1.00	30.00	8.00
31.40	0.70	1.58	76.00	39.00	1.00	30.00	8.00
27.00	0.70	1.58	76.00	39.00	1.00	30.00	8.00
27.50	0.70	1.58	76.00	39.00	1.00	30.00	8.00
33.90	0.70	1.58	76.00	39.00	1.00	30.00	8.00
26.30	0.70	1.58	76.00	39.00	1.00	30.00	8.00
30.00	6.50	1.17	152.00	39.00	1.00	30.00	8.00
33.00	6.50	1.17	152.00	39.00	1.00	30.00	8.00
44.00	6.50	1.17	152.00	39.00	1.00	30.00	8.00
35.00	6.50	1.17	152.00	39.00	1.00	30.00	8.00
39.00	6.50	1.17	152.00	39.00	1.00	30.00	8.00
7.80	4.60	1.17	152.00	39.00	1.00	30.00	8.00
8.00	4.60	1.17	152.00	39.00	1.00	30.00	8.00
10.10	4.60	1.17	152.00	39.00	1.00	30.00	8.00
7.10	4.60	1.17	152.00	39.00	1.00	30.00	8.00
25.10	0.80	1.17	152.00	39.00	1.00	30.00	8.00
22.00	0.80	1.17	152.00	39.00	1.00	30.00	8.00
27.10	0.80	1.17	152.00	39.00	1.00	30.00	8.00
27.50	0.80	1.17	152.00	39.00	1.00	30.00	8.00
26.60	0.80	1.17	152.00	39.00	1.00	30.00	8.00
94.00	6.50	1.17	76.00	78.00	1.00	30.00	8.00

Table B-3. Continued

C	V	ϕ_i	A _a	D _a	$\hat{H}$	A	D
41.00	6.50	1.17	76.00	78.00	1.00	30.00	8.00
74.00	6.50	1.17	76.00	78.00	1.00	30.00	8.00
45.00	6.50	1.17	76.00	78.00	1.00	30.00	8.00
47.00	6.50	1.17	76.00	78.00	1.00	30.00	8.00
56.00	6.50	1.17	76.00	78.00	1.00	30.00	8.00
22.80	4.60	1.17	76.00	78.00	1.00	30.00	8.00
9.60	4.60	1.17	76.00	78.00	1.00	30.00	8.00
15.30	4.60	1.17	76.00	78.00	1.00	30.00	8.00
11.10	4.60	1.17	76.00	78.00	1.00	30.00	8.00
25.50	0.70	1.17	76.00	78.00	1.00	30.00	8.00
32.90	0.70	1.17	76.00	78.00	1.00	30.00	8.00
31.60	0.70	1.17	76.00	78.00	1.00	30.00	9.00
42.00	0.70	1.17	76.00	78.00	1.00	30.00	8.00
26.10	0.70	1.17	76.00	78.00	1.00	30.00	8.00
48.00	6.50	1.17	38.00	39.00	1.00	30.00	8.00
63.00	6.50	1.17	38.00	39.00	1.00	30.00	8.00
39.00	6.50	1.17	38.00	39.00	1.00	30.00	8.00
80.00	6.50	1.17	38.00	39.00	1.00	30.00	8.00
47.00	6.50	1.17	38.00	39.00	1.00	30.00	8.00
43.00	6.50	1.17	38.00	39.00	1.00	30.00	8.00
9.60	4.60	1.17	38.00	39.00	1.00	30.00	8.00
14.70	4.60	1.17	38.00	39.00	1.00	30.00	8.00
13.30	4.60	1.17	38.00	39.00	1.00	30.00	8.00
16.10	4.60	1.17	38.00	39.00	1.00	30.00	8.00
30.30	0.70	1.17	38.00	39.00	1.00	30.00	8.00
28.20	0.70	1.17	38.00	39.00	1.00	30.00	8.00
30.50	0.70	1.17	38.00	39.00	1.00	30.00	8.00
34.40	0.70	1.17	38.00	39.00	1.00	30.00	8.00
52.00	6.50	1.17	76.00	20.00	1.00	30.00	8.00
35.00	6.50	1.17	76.00	20.00	1.00	30.00	8.00
65.00	6.50	1.17	76.00	20.00	1.00	30.00	8.00
52.00	6.50	1.17	76.00	20.00	1.00	30.00	8.00
46.00	6.50	1.17	76.00	20.00	1.00	30.00	8.00
49.00	6.50	1.17	76.00	20.00	1.00	30.00	8.00
4.60	4.60	1.17	76.00	20.00	1.00	30.00	8.00
8.10	4.60	1.17	76.00	20.00	1.00	30.00	8.00
14.60	4.60	1.17	76.00	20.00	1.00	30.00	8.00
9.40	4.60	1.17	76.00	20.00	1.00	30.00	8.00
31.80	0.80	1.17	76.00	20.00	1.00	30.00	8.00
20.30	0.80	1.17	76.00	20.00	1.00	30.00	8.00
17.40	0.80	1.17	76.00	20.00	1.00	30.00	8.00
23.30	0.80	1.17	76.00	20.00	1.00	30.00	8.00

Table B-3. Continued

C	V	ϕ_i	A_a	D_a	$\hat{H}$	A	D
101.00	3.60	1.58	76.00	39.00	1.00	30.00	16.00
111.00	3.60	1.58	76.00	39.00	1.00	30.00	16.00
102.00	3.60	1.58	76.00	39.00	1.00	30.00	16.00
135.00	3.60	1.58	76.00	39.00	1.00	30.00	16.00
49.60	3.00	1.58	76.00	39.00	1.00	30.00	16.00
56.10	3.00	1.58	76.00	39.00	1.00	30.00	16.00
48.90	3.00	1.58	76.00	39.00	1.00	30.00	16.00
41.30	3.00	1.58	76.00	39.00	1.00	30.00	16.00
40.80	0.70	1.58	76.00	39.00	1.00	30.00	16.00
40.10	0.70	1.58	76.00	39.00	1.00	30.00	16.00
59.20	0.70	1.58	76.00	39.00	1.00	30.00	16.00
44.10	0.70	1.58	76.00	39.00	1.00	30.00	16.00
59.00	6.50	0.52	76.00	39.00	1.00	30.00	16.00
52.00	6.50	0.52	76.00	39.00	1.00	30.00	16.00
68.00	6.50	0.52	76.00	39.00	1.00	30.00	16.00
71.00	6.50	0.52	76.00	39.00	1.00	30.00	16.00
52.00	6.50	0.52	76.00	39.00	1.00	30.00	16.00
51.00	6.00	0.52	76.00	39.00	1.00	30.00	16.00
48.00	6.00	0.52	76.00	39.00	1.00	30.00	16.00
38.00	6.00	0.52	76.00	39.00	1.00	30.00	16.00
35.00	6.00	0.52	76.00	39.00	1.00	30.00	16.00
50.00	6.00	0.52	76.00	39.00	1.00	30.00	16.00
21.40	3.00	0.52	76.00	39.00	1.00	30.00	16.00
25.60	3.00	0.52	76.00	39.00	1.00	30.00	16.00
43.90	3.00	0.52	76.00	39.00	1.00	30.00	16.00
50.70	3.00	0.52	76.00	39.00	1.00	30.00	16.00
38.30	0.70	0.52	76.00	39.00	1.00	30.00	16.00
37.50	0.70	0.52	76.00	39.00	1.00	30.00	16.00
31.40	0.70	0.52	76.00	39.00	1.00	30.00	16.00
24.00	0.70	0.52	76.00	39.00	1.00	30.00	16.00
10.00	8.20	1.17	76.00	39.00	1.00	30.00	4.00
24.00	8.20	1.17	76.00	39.00	1.00	30.00	4.00
32.00	8.20	1.17	76.00	39.00	1.00	30.00	4.00
20.00	8.20	1.17	76.00	39.00	1.00	30.00	4.00
29.00	8.20	1.17	76.00	39.00	1.00	30.00	4.00
12.00	6.30	1.17	76.00	39.00	1.00	30.00	4.00
15.00	6.30	1.17	76.00	39.00	1.00	30.00	4.00
21.00	6.30	1.17	76.00	39.00	1.00	30.00	4.00
14.00	6.30	1.17	76.00	39.00	1.00	30.00	4.00
24.00	6.30	1.17	76.00	39.00	1.00	30.00	4.00
7.40	4.70	1.17	76.00	39.00	1.00	30.00	4.00
9.40	4.70	1.17	76.00	39.00	1.00	30.00	4.00

Table B-3. Continued

C	V	ϕ_i	A_a	D_a	$\hat{H}$	A	D
6.00	4.70	1.17	76.00	39.00	1.00	30.00	4.00
9.10	4.70	1.17	76.00	39.00	1.00	30.00	4.00
21.10	0.80	1.17	76.00	39.00	1.00	30.00	4.00
33.50	0.80	1.17	76.00	39.00	1.00	30.00	4.00
21.60	0.80	1.17	76.00	39.00	1.00	30.00	4.00
27.10	0.80	1.17	76.00	39.00	1.00	30.00	4.00
92.00	5.40	1.17	76.00	39.00	5.00	30.00	8.00
55.00	5.40	1.17	76.00	39.00	5.00	30.00	8.00
81.00	5.40	1.17	76.00	39.00	5.00	30.00	8.00
46.00	5.40	1.17	76.00	39.00	5.00	30.00	8.00
79.00	5.40	1.17	76.00	39.00	5.00	30.00	8.00
17.20	3.00	1.17	76.00	39.00	5.00	30.00	8.00
23.10	3.00	1.17	76.00	39.00	5.00	30.00	8.00
31.00	3.00	1.17	76.00	39.00	5.00	30.00	8.00
22.90	3.00	1.17	76.00	39.00	5.00	30.00	8.00
27.50	3.00	1.17	76.00	39.00	5.00	30.00	8.00
20.00	8.20	1.17	76.00	39.00	3.00	30.00	4.00
19.00	8.20	1.17	76.00	39.00	3.00	30.00	4.00
43.00	8.20	1.17	76.00	39.00	3.00	30.00	4.00
25.00	8.20	1.17	76.00	39.00	3.00	30.00	4.00
37.00	8.20	1.17	76.00	39.00	3.00	30.00	4.00

Table B-4. Successive Assault Scenarios, Central Europe

C	P
54.00	2.90
75.00	2.90
48.00	2.90
84.00	2.90
73.00	2.90
87.00	2.90
88.00	5.00
69.00	5.00
113.00	5.00
96.00	5.00
82.00	5.00
62.00	0.00
54.00	0.00
61.00	0.00
44.00	0.00
70.00	0.00
50.00	0.00
63.00	0.00
45.00	0.00
55.00	0.00
58.00	0.00
68.00	0.00
79.00	0.00
59.00	0.00
58.00	0.00
53.00	0.00

Table B-5. Successive Assault Scenarios, Southwest Asia

C	P
24.00	0.00
24.00	0.00
31.00	0.00
29.00	0.00
28.00	0.00
24.00	0.00
32.00	0.00
36.00	0.00
27.00	0.00
29.00	0.00
30.00	0.00
22.00	0.00
29.00	4.00
43.00	4.00
36.00	4.00
34.00	4.00
32.00	4.00
54.00	6.00
26.00	6.00
32.00	6.00
38.00	6.00
38.00	6.00
33.00	10.00
32.00	10.00
57.00	10.00
43.00	10.00
46.00	10.00

Table B-6. Successive Assault Scenarios, Korea

C	P
49.00	0.00
42.00	0.00
51.00	0.00
64.00	0.00
43.00	0.00
54.00	0.00
52.00	0.00
47.00	0.00
55.00	0.00
36.00	0.00
58.00	0.00
80.00	0.00
37.00	0.00
43.00	0.00
47.00	0.00
37.00	0.00
37.00	0.00
57.00	0.00
57.00	7.00
58.00	7.00
75.00	7.00
70.00	7.00
74.00	7.00
59.00	7.00
64.00	12.00
69.00	12.00
71.00	12.00
66.00	12.00
69.00	12.00
61.00	12.00
90.00	12.00
74.00	5.00
48.00	5.00
63.00	5.00
54.00	5.00
58.00	5.00
29.00	5.00

Table B-7. Withdrawal Scenarios, Central Europe

$C_D(t)$	$C_A(t)$	C
0.00	1.00	20.00
0.00	2.00	20.00
0.00	3.00	20.00
0.50	3.00	20.00
0.50	5.00	20.00
0.50	6.00	20.00
1.50	6.00	20.00
1.50	8.00	20.00
2.00	8.00	20.00
2.00	9.00	20.00
2.00	11.00	20.00
2.00	12.00	20.00
2.00	15.00	20.00
2.00	16.00	20.00
2.00	17.00	20.00
2.00	18.00	20.00
2.00	20.00	20.00
3.00	20.00	20.00
4.00	20.00	20.00
5.00	20.00	20.00
6.00	20.00	20.00
0.00	1.00	22.00
0.00	2.00	22.00
0.00	4.00	22.00
0.00	5.00	22.00
0.50	5.00	22.00
0.50	6.00	22.00
0.50	8.00	22.00
1.00	8.00	22.00
1.00	10.00	22.00
1.50	10.00	22.00
2.00	10.00	22.00
2.00	13.00	22.00
3.00	13.00	22.00
3.00	15.00	22.00
3.00	16.00	22.00
3.00	17.00	22.00
3.00	18.00	22.00
4.00	18.00	22.00
4.00	20.00	22.00
5.00	20.00	22.00

Table B-7. Continued

$C_D(t)$	$C_A(t)$	C
5.00	21.00	22.00
5.00	22.00	22.00
6.00	22.00	22.00
0.00	1.00	24.00
0.00	2.00	24.00
0.00	4.00	24.00
1.00	4.00	24.00
1.00	5.00	24.00
1.00	6.00	24.00
1.00	7.00	24.00
1.00	10.00	24.00
1.50	10.00	24.00
1.50	11.00	24.00
1.50	12.00	24.00
1.50	13.00	24.00
1.50	16.00	24.00
2.00	16.00	24.00
2.00	17.00	24.00
2.00	18.00	24.00
2.00	19.00	24.00
2.00	20.00	24.00
3.00	22.00	24.00
4.00	22.00	24.00
4.00	23.00	24.00
5.00	24.00	24.00
5.00	24.00	24.00
6.00	24.00	24.00
0.00	1.00	25.00
0.00	3.00	25.00
0.00	5.00	25.00
0.00	6.00	25.00
0.00	9.00	25.00
0.00	11.00	25.00
1.00	11.00	25.00
1.00	12.00	25.00
1.00	13.00	25.00
2.00	13.00	25.00
2.00	16.00	25.00
2.00	17.00	25.00
2.50	17.00	25.00
2.50	18.00	25.00
2.50	19.00	25.00

Table B-7. Continued

$C_D(l)$	$C_A(l)$	C
3.00	19.00	25.00
3.00	20.00	25.00
3.00	21.00	25.00
3.00	23.00	25.00
3.00	24.00	25.00
4.00	24.00	25.00
5.00	25.00	25.00
6.00	25.00	25.00
0.00	1.00	20.00
0.00	3.00	20.00
0.00	4.00	20.00
0.00	6.00	20.00
0.00	8.00	20.00
1.00	9.00	20.00
1.00	10.00	20.00
1.00	11.00	20.00
1.50	11.00	20.00
2.00	11.00	20.00
2.00	12.00	20.00
2.00	13.00	20.00
2.00	14.00	20.00
2.00	15.00	20.00
2.00	17.00	20.00
2.00	18.00	20.00
3.00	18.00	20.00
3.00	19.00	20.00
5.00	19.00	20.00
5.00	20.00	20.00
6.00	20.00	20.00
0.00	1.00	16.00
0.00	2.00	16.00
0.00	3.00	16.00
0.00	4.00	16.00
0.50	5.00	16.00
0.50	6.00	16.00
0.50	7.00	16.00
0.50	8.00	16.00
1.00	8.00	16.00
1.50	8.00	16.00
1.50	11.00	16.00
1.50	12.00	16.00
1.50	13.00	16.00

Table B-7. Continued

$C_D(t)$	$C_A(t)$	C
2.00	13.00	16.00
2.00	14.00	16.00
2.00	15.00	16.00
3.00	16.00	16.00
5.00	16.00	16.00
6.00	16.00	16.00
0.00	1.00	13.00
0.00	2.00	13.00
0.00	3.00	13.00
0.50	3.00	13.00
0.50	4.00	13.00
0.50	5.00	13.00
0.50	6.00	13.00
1.50	6.00	13.00
1.50	8.00	13.00
2.50	8.00	13.00
2.50	9.00	13.00
2.50	10.00	13.00
2.50	11.00	13.00
3.00	11.00	13.00
4.00	12.00	13.00
5.00	13.00	13.00
6.00	13.00	13.00
0.00	1.00	21.00
0.00	2.00	21.00
0.00	4.00	21.00
0.50	5.00	21.00
1.00	5.00	21.00
1.00	6.00	21.00
1.00	8.00	21.00
1.00	9.00	21.00
1.00	10.00	21.00
1.00	13.00	21.00
1.50	13.00	21.00
1.50	14.00	21.00
2.00	14.00	21.00
3.00	14.00	21.00
3.00	15.00	21.00
3.00	18.00	21.00
3.00	20.00	21.00
4.00	20.00	21.00
4.00	21.00	21.00

Table B-7. Continued

$C_D(t)$	$C_A(t)$	C
6.00	21.00	21.00
0.00	1.00	27.00
0.00	2.00	27.00
0.00	3.00	27.00
0.00	4.00	27.00
0.00	5.00	27.00
0.00	6.00	27.00
0.00	7.00	27.00
0.00	10.00	27.00
0.00	11.00	27.00
0.00	13.00	27.00
1.00	13.00	27.00
1.50	13.00	27.00
1.50	14.00	27.00
1.50	16.00	27.00
2.00	16.00	27.00
2.00	19.00	27.00
2.00	20.00	27.00
2.00	21.00	27.00
2.00	23.00	27.00
3.00	25.00	27.00
3.00	26.00	27.00
4.00	27.00	27.00
5.00	27.00	27.00
6.00	27.00	27.00
0.00	1.00	15.00
0.00	2.00	15.00
0.50	2.00	15.00
1.50	2.00	15.00
1.50	3.00	15.00
1.50	5.00	15.00
2.00	5.00	15.00
2.00	6.00	15.00
2.00	7.00	15.00
2.00	10.00	15.00
2.00	11.00	15.00
2.00	12.00	15.00
2.00	14.00	15.00
2.00	15.00	15.00
3.00	15.00	15.00
4.00	15.00	15.00
6.00	14.00	15.00

Table B-7. Continued

$C_D(t)$	$C_A(t)$	C
0.00	1.00	26.00
0.00	2.00	26.00
0.00	4.00	26.00
0.00	5.00	26.00
0.00	6.00	26.00
0.50	7.00	26.00
0.50	8.00	26.00
0.50	9.00	26.00
0.50	11.00	26.00
1.00	11.00	26.00
1.50	11.00	26.00
2.00	11.00	26.00
2.00	12.00	26.00
2.00	15.00	26.00
2.00	16.00	26.00
2.00	17.00	26.00
2.00	20.00	26.00
3.00	23.00	26.00
4.00	24.00	26.00
5.00	25.00	26.00
5.00	26.00	26.00
6.00	26.00	26.00
0.00	1.00	21.00
0.00	2.00	21.00
0.00	4.00	21.00
0.00	6.00	21.00
0.00	7.00	21.00
0.00	9.00	21.00
0.00	11.00	21.00
0.50	11.00	21.00
1.00	11.00	21.00
1.50	11.00	21.00
1.50	14.00	21.00
1.50	15.00	21.00
1.50	16.00	21.00
1.50	17.00	21.00
1.50	19.00	21.00

Table B-7. Continued

$C_D(l)$	$C_A(l)$	C
2.00	20.00	21.00
3.00	20.00	21.00
3.00	21.00	21.00
4.00	21.00	21.00
5.00	21.00	21.00
6.00	21.00	21.00

Table B-8. Withdrawal Scenarios, Southwest Asia

$C_D(t)$	$C_A(t)$	C
0.00	1.00	6.00
1.00	2.00	6.00
2.00	4.00	6.00
3.00	4.00	6.00
4.00	5.00	6.00
5.00	6.00	6.00
6.00	6.00	6.00
0.00	4.00	5.00
2.00	4.00	5.00
4.00	5.00	5.00
6.00	5.00	5.00
1.00	3.00	9.00
2.00	4.00	9.00
3.00	6.00	9.00
4.00	7.00	9.00
5.00	9.00	9.00
6.00	9.00	9.00
0.00	3.00	10.00
1.00	3.00	10.00
2.00	3.00	10.00
3.00	6.00	10.00
4.00	9.00	10.00
5.00	9.00	10.00
6.00	10.00	10.00
3.00	6.00	8.00
5.00	8.00	8.00
6.00	8.00	8.00
1.00	1.00	9.00
2.00	5.00	9.00
3.00	6.00	9.00
4.00	7.00	9.00
5.00	9.00	9.00
6.00	9.00	9.00
0.00	5.00	18.00
1.00	12.00	18.00
2.00	12.00	18.00
3.00	18.00	18.00
4.00	18.00	18.00
5.00	18.00	18.00
6.00	18.00	18.00
3.00	6.00	9.00

Table B-8. Continued

$C_D(t)$	$C_A(t)$	C
5.00	8.00	9.00
6.00	9.00	9.00
0.00	5.00	22.00
1.00	11.00	22.00
2.00	12.00	22.00
3.00	19.00	22.00
5.00	21.00	22.00
6.00	22.00	22.00
0.00	0.00	11.00
1.00	4.00	11.00
2.00	5.00	11.00
3.00	7.00	11.00
4.00	11.00	11.00
5.00	11.00	11.00
6.00	11.00	11.00
0.00	4.00	22.00
1.00	11.00	22.00
3.00	17.00	22.00
4.00	21.00	22.00
6.00	22.00	22.00
1.00	5.00	13.00
2.00	6.00	13.00
3.00	10.00	13.00
4.00	11.00	13.00
5.00	13.00	13.00
6.00	13.00	13.00
1.00	2.00	7.00
2.00	5.00	7.00
3.00	5.00	7.00
4.00	6.00	7.00
5.00	7.00	7.00
6.00	7.00	7.00
1.00	6.00	14.00
2.00	7.00	14.00
3.00	11.00	14.00
4.00	13.00	14.00
5.00	14.00	14.00
6.00	14.00	14.00

Table B-9. Withdrawal Scenarios, Korea

$C_D(t)$	$C_A(t)$	C
0.00	7.00	25.00
1.00	9.00	25.00
2.00	10.00	25.00
3.00	12.00	25.00
4.00	15.00	25.00
5.00	18.00	25.00
6.00	23.00	25.00
7.00	25.00	25.00
7.00	25.00	25.00
0.00	1.00	25.00
1.00	3.00	25.00
2.00	8.00	25.00
3.00	10.00	25.00
4.00	13.00	25.00
5.00	14.00	25.00
6.00	21.00	25.00
7.00	25.00	25.00
8.00	25.00	25.00
0.00	6.00	40.00
1.00	9.00	40.00
2.00	16.00	40.00
3.00	29.00	40.00
4.00	29.00	40.00
5.00	33.00	40.00
6.00	36.00	40.00
7.00	40.00	40.00
8.00	40.00	40.00
0.00	6.00	35.00
1.00	9.00	35.00
2.00	15.00	35.00
3.00	18.00	35.00
4.00	22.00	35.00
5.00	25.00	35.00
6.00	30.00	35.00
7.00	35.00	35.00
8.00	35.00	35.00
0.00	26.00	62.00
1.00	34.00	62.00
2.00	38.00	62.00
3.00	38.00	62.00
4.00	40.00	62.00

Table B-9. Continued

$C_D(t)$	$C_A(t)$	C
5.00	43.00	62.00
6.00	58.00	62.00
7.00	62.00	62.00
8.00	62.00	62.00
0.00	4.00	21.00
1.00	4.00	21.00
2.00	8.00	21.00
3.00	9.00	21.00
4.00	9.00	21.00
5.00	14.00	21.00
6.00	17.00	21.00
7.00	18.00	21.00
8.00	21.00	21.00
0.00	5.00	27.00
1.00	8.00	27.00
2.00	12.00	27.00
3.00	12.00	27.00
4.00	19.00	27.00
5.00	24.00	27.00
6.00	25.00	27.00
7.00	25.00	27.00
8.00	27.00	27.00
0.00	9.00	38.00
1.00	15.00	38.00
2.00	19.00	38.00
3.00	21.00	38.00
4.00	26.00	38.00
5.00	34.00	38.00
6.00	37.00	38.00
7.00	38.00	38.00
8.00	38.00	38.00
1.00	8.00	30.00
2.00	12.00	30.00
3.00	17.00	30.00
4.00	18.00	30.00
5.00	28.00	30.00
6.00	29.00	30.00
7.00	29.00	30.00
8.00	30.00	30.00
0.00	8.00	38.00
1.00	11.00	38.00
2.00	14.00	38.00

Table B-9. Continued

$C_D(t)$	$C_A(t)$	C
3.00	22.00	38.00
4.00	23.00	38.00
5.00	30.00	38.00
6.00	37.00	38.00
7.00	37.00	38.00
8.00	38.00	38.00
0.00	6.00	29.00
1.00	18.00	29.00
2.00	20.00	29.00
3.00	20.00	29.00
4.00	21.00	29.00
5.00	25.00	29.00
6.00	28.00	29.00
7.00	28.00	29.00
8.00	29.00	29.00

Table B-10. Helicopter Pursuit Scenarios, Central Europe

H_p	N_{AD}	w	C_w	C_H
8.00	2.00	19.00	2.00	7.00
8.00	2.00	19.00	7.00	4.00
8.00	2.00	19.00	10.00	4.00
8.00	2.00	19.00	5.00	7.00
8.00	2.00	19.00	3.00	7.00
8.00	2.00	19.00	6.00	5.00
16.00	2.00	19.00	18.00	6.00
16.00	2.00	19.00	19.00	6.00
16.00	2.00	19.00	19.00	3.00
16.00	2.00	19.00	19.00	2.00
16.00	2.00	19.00	19.00	1.00
16.00	2.00	19.00	17.00	3.00
4.00	2.00	19.00	2.00	4.00
4.00	2.00	19.00	0.00	4.00
4.00	2.00	19.00	2.00	4.0
4.00	2.00	19.00	0.00	4.00
4.00	2.00	19.00	4.00	4.00
4.00	2.00	19.00	2.00	2.00
16.00	24.00	19.00	5.00	10.00
16.00	24.00	19.00	4.00	10.00
16.00	24.00	19.00	4.00	13.00
16.00	24.00	19.00	4.00	15.00
16.00	24.00	19.00	6.00	9.00
16.00	24.00	19.00	7.00	11.00
16.00	12.00	19.00	6.00	11.00
16.00	12.00	19.00	11.00	8.00
16.00	12.00	19.00	5.00	11.00
16.00	12.00	19.00	6.00	9.00
16.00	12.00	19.00	5.00	13.00
16.00	12.00	19.00	5.00	7.00
16.00	6.00	19.00	9.00	9.00
16.00	6.00	19.00	8.00	9.00
16.00	6.00	19.00	9.00	12.00
16.00	6.00	19.00	7.00	10.00
16.00	6.00	19.00	3.00	12.00
16.00	6.00	19.00	6.00	10.00
16.00	12.00	11.00	2.00	7.00
16.00	12.00	11.00	6.00	6.00
16.00	12.00	11.00	4.00	6.00
16.00	12.00	11.00	3.00	13.00
16.00	12.00	11.00	4.00	10.00

Table B-10. Continued

H_p	N_{AD}	w	C_w	C_H
16.00	12.00	19.00	7.00	13.00
16.00	12.00	19.00	6.00	13.00
16.00	12.00	19.00	2.00	12.00
16.00	12.00	19.00	6.00	6.00
16.00	6.00	19.00	5.00	8.00
16.00	6.00	19.00	7.00	11.00

Table B-11. Helicopter Pursuit Scenarios, Southwest Asia

H_p	N_{AD}	w	C_w	C_H
8.00	1.00	6.00	6.00	3.00
8.00	1.00	6.00	6.00	4.00
8.00	1.00	6.00	6.00	4.00
8.00	1.00	6.00	6.00	3.00
8.00	1.00	6.00	6.00	3.00
8.00	1.00	6.00	6.00	3.00
8.00	1.00	6.00	4.00	4.00
4.00	1.00	6.00	6.00	3.00
4.00	1.00	6.00	3.00	3.00
4.00	1.00	6.00	5.00	2.00
4.00	1.00	6.00	6.00	3.00
4.00	1.00	6.00	6.00	3.00
4.00	1.00	6.00	3.00	3.00
4.00	1.00	6.00	4.00	3.00
2.00	1.00	6.00	5.00	2.00
2.00	1.00	6.00	4.00	2.00
2.00	1.00	6.00	2.00	2.00
2.00	1.00	6.00	4.00	2.00
2.00	1.00	6.00	4.00	2.00
2.00	1.00	6.00	5.00	2.00
2.00	1.00	6.00	1.00	2.00
8.00	2.00	6.00	6.00	4.00
8.00	2.00	6.00	5.00	3.00
8.00	2.00	6.00	6.00	3.00
8.00	2.00	6.00	6.00	3.00
8.00	2.00	6.00	6.00	4.00
8.00	2.00	6.00	6.00	4.00
8.00	2.00	6.00	6.00	1.00
8.00	4.00	6.00	6.00	2.00
8.00	4.00	6.00	6.00	3.00
8.00	4.00	6.00	6.00	3.00
8.00	4.00	6.00	5.00	3.00
8.00	4.00	6.00	6.00	3.00
8.00	4.00	6.00	6.00	3.00
8.00	4.00	6.00	6.00	6.00

Table B-11. Continued

H_p	N_{AD}	w	C_w	C_H
8.00	8.00	6.00	6.00	6.00
8.00	8.00	6.00	6.00	6.00
8.00	8.00	6.00	6.00	7.00
8.00	8.00	6.00	3.00	5.00
8.00	8.00	6.00	6.00	4.00
8.00	8.00	6.00	6.00	4.00
8.00	8.00	6.00	5.00	6.00

Table B-12. Helicopter Pursuit Scenarios, Korea

H_p	N_{AD}	w	C_w	C_H
8.00	1.00	8.00	5.00	2.00
8.00	1.00	8.00	5.00	3.00
8.00	1.00	8.00	3.00	5.00
8.00	1.00	8.00	6.00	2.00
8.00	1.00	8.00	6.00	1.00
8.00	1.00	8.00	4.00	4.00
8.00	1.00	8.00	4.00	4.00
8.00	1.00	8.00	4.00	3.00
12.00	1.00	8.00	6.00	2.00
12.00	1.00	8.00	5.00	5.00
12.00	1.00	8.00	5.00	3.00
12.00	1.00	8.00	5.00	3.00
12.00	1.00	8.00	5.00	3.00
12.00	1.00	8.00	5.00	3.00
12.00	1.00	8.00	5.00	1.00
4.00	1.00	8.00	4.00	3.00
4.00	1.00	8.00	1.00	3.00
4.00	1.00	8.00	2.00	2.00
4.00	1.00	8.00	2.00	2.00
4.00	1.00	8.00	4.00	3.00
4.00	1.00	8.00	2.00	2.00
4.00	1.00	8.00	4.00	2.00
12.00	4.00	8.00	5.00	7.00
12.00	4.00	8.00	6.00	9.00
12.00	4.00	8.00	5.00	5.00
12.00	4.00	8.00	5.00	7.00
12.00	4.00	8.00	4.00	4.00
12.00	4.00	8.00	5.00	5.00
12.00	4.00	8.00	5.00	6.00
12.00	8.00	8.00	5.00	8.00
12.00	8.00	8.00	4.00	10.00
12.00	8.00	8.00	4.00	9.00
12.00	8.00	8.00	5.00	8.00
12.00	8.00	8.00	5.00	7.00
12.00	8.00	8.00	5.00	9.00
12.00	8.00	8.00	5.00	10.00