Proceedings of the 2004 Winter Simulation Conference
R .G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters, eds.

MEDIUM CALIBER CANNON LETHALITY STUDY FOR FUTURE AND CURRENT INFANTRY FIGHTING VEHICLES

Russell Schott
Patrick Downes
Rocky Gay
Nate Whitten
James Paine
Michael Goddard
Michael Rybacki
William Klimack

Department of Systems Engineering
United States Military Academy
West Point, NY 10996, U.S.A.

ABSTRACT

According to the Army Chief of Staff, the Army's infantry fighting vehicle, the Bradley Fighting Vehicle, will be in service until 2032. The Bradley Fighting Vehicle needs an improved medium caliber cannon to defeat the growing threats from improved light armored vehicles and hand held rocket propelled grenades. The Army can continue to keep the Bradley Fighting Vehicle in service by increasing the lethality of its weapon systems. We examine six medium caliber cannons and their impact on the battlefield. We also examine the use of new medium caliber air burst munitions. Combat modeling and simulation using the Joint Conflict and Tactical Simulation (JCATS) is used to predict the contributions of these new technologies to the infantry soldier. Multiple mission scenarios in different environments to include Baghdad urban combat are examined. The medium caliber cannon selected will be the final lethality enhancement for the Bradley.

1 INTRODUCTION

The purpose of this paper is to describe our use of combat modeling and simulation to analyze the effectiveness of alternative upgrades to the Bradley Fighting Vehicle's current main weapon system, the 25 millimeter (mm) M242 Bushmaster I cannon. We designed three unique simulation environments to analyze the capabilities of the six candidate cannons under consideration. We will discuss how this simulation project, which focuses on measuring the Bradley Fighting Vehicle's lethality and in turn, its survivability, fits in with a higher order study that includes an analysis of the Bradley Fighting Vehicle's logistical footprint, turret and system modifications, and lifecycle costs. We will also discuss measures of effectiveness developed to measure the performance of the candidate cannons and discuss some general results and conclusions from our simulation output.

1.1 The Bradley Fighting Vehicle

The Army first fielded the Bradley Fighting Vehicle, or simply the Bradley, in 1983. United Defense Corporation constructed over 6,385 Bradleys for the Army and halted production in 1995 (Foss 2000). The Bradley's four primary missions are to:

- Provide mobile protected transport of sufficient infantry to the critical point on the battlefield
- Provide fires to support dismounted infantry
- Provide fires to suppress or destroy enemy IFV's and light armor vehicles
- Provide anti-armor fires to destroy enemy armor (United States Army Infantry Center 2003).

The Bradley provides the much needed battlefield mobility, armor protection and lethal firepower required by the infantry to accomplish their mission of closing with and destroying the enemy. The Bradley has successfully demonstrated its combat effectiveness in Operation Desert Storm and in the latest Gulf War.

1.1.1 System Characteristics

The Bradley's primary weapon system is the 25mm M242 Bushmaster I. This cannon is capable of firing two types of ammunition. The first type of ammunition is armor piercing and is intended to defeat enemy armored targets, such as armored personnel carriers. The second type of ammunition is a high explosive round. This type of ammunition is designed to defeat enemy light skinned vehicles, such as trucks, cargo vehicles, and enemy infantry. The Bradley is capable of carrying a total of 300 rounds in the turret that are configured to fire.

The Bradley is also equipped with an anti-tank capability, the Tube Launched, Optically Tracked, Wire-Guided (TOW) Missile. This tank killing capability gives the Bradley a long range, lethal weapon and greatly enhances the Bradley's survivability versus tanks. A third weapon system on the Bradley is the 7.62mm coaxial machine gun. This machine gun is designed to destroy dismounted infantry targets. It provides a close range capability versus enemy soldiers and even light skinned vehicles. The Bradley is equipped with both day and limited visibility optics systems. A thermal imaging system allows the crew to identify and recognize all types of threats and to use all of its powerful weapons systems in limited visibility (FM 23-1).

1.1.2 System Shortcomings

Just as our nation's military forces have continued to improve its capabilities, so have our nation's foes. There are two primary threat improvements that directly affect the Bradley's combat effectiveness. The first is the increased capability of enemy armored personnel carriers. Improved armor technologies have increased threat vehicle survivability and decreased the Bradley's lethality. The second emerging threat versus the Bradley is the proliferation of rocket propelled grenades (RPG's). These are an inexpensive weapon system that are very easy to use. The Army's recent experiences in Iraq clearly illustrate the RPG's effectiveness.

In order for the Bradley to be a viable threat to enemy forces for the remainder of its lifecycle, the Bradley must evolve quickly and ahead of our threat forces. The Army has developed two methods of evolving to stay ahead of the enemy's progress. The first is increasing the caliber of the main cannon on the Bradley. By increasing the caliber of the cannon, the Army can use larger munitions that are more lethal and kill at a greater range than today's 25mm munitions. The Army's second improvement is in developing high explosive rounds with an air burst capability. This air burst capability is being designed to destroy protected targets such as troops taking cover behind a berm. This new round would be similar to a mortar round. After being fired, the round would explode above its intended target raining down shrapnel to kill the target. This air burst round is an improvement over the current capability, the high explosive round, and is specifically designed to defeat enemy infantry forces, countering their ability to launch RPG's.

1.1.3 Future System Requirements (Stakeholder Analysis)

This study was commissioned by the Program Manager of Ground Combat Systems, Warren, Michigan, who has set clear goals and objectives for future improvements for the Bradley's weapon systems. The Bradley's main cannon must be able to destroy targets at 2,000 meters. The Bradley must also have increased lethality in order to defeat improved armored personnel carriers. However, in obtaining these objectives, the Army must be able to insert the new cannon into the current Bradley with minimal changes to the current turret and weapons control systems. Fortunately, there are many medium caliber weapon systems that can be configured into the Bradley turret without major modifications.

1.1.4 Candidate Weapon Systems

Our study will look at the performance of a total of six different medium caliber cannons. One of the weapon systems is the Bradley's current cannon, the 25mm M242 Bushmaster I. Four of the other candidates are modifications to the Bushmaster cannon with larger munitions. Larger munitions are capable of traveling further and are more lethal. However, larger munitions also take up more space in the tight confines of the Bradley turret. For example, the Bradley can carry 300 rounds of 25mm ammunition but only 93 rounds of 50mm ammunition. The sixth candidate is the CT2000 40mm cannon. This system provides improved lethality compared to the 25mm cannon, but requires more turret modifications to the current system to implement. The six candidates will be identified by their caliber throughout the remainder of the report: 25mm, 30mm, 35mm, 40mm, 50mm, 40mm CTAI.

2 SIMULATIONS

We designed three unique mission profiles to test the performance of our candidate weapon systems. We will discuss the simulation environment itself and then discuss each of our mission profiles.

2.1 Joint Conflict and Tactical Simulation (JCATS)

"JCATS provides an interactive, high-resolution, entity-level, conflict simulation that models joint, multi-sided air, ground and sea combat on a high/low resolution digitized polygonal terrain" (United States Joint Forces Command 2004). JCATS provided us with a simulation environment in which we could model the performance of the candidate cannons in multiple scenarios. JCATS provides analysts and military personnel dual capabilities. It can be used either to conduct analytical experiments or to conduct simulated training exercises. JCATS can integrate actual terrain databases so the simulations can occur on real terrain. This allowed us to test the candidate weapon systems in current Army environments. We utilized terrain files of the National Training Center at Fort Irwin, California, and also of Baghdad, Iraq.

In all of our simulation scenarios, we focused only on the performance of the candidate cannons. Hence, we modeled the Bradley with only the main cannon. We did not model the Bradley's TOW system or the 7.62mm machine gun. We also limited the modeling in our simulations to direct fire engagements only. This allowed us to focus directly on the performance of the candidate weapon systems and not on the interactions of other combat multipliers, such as indirect fire.

2.1.1 Simulation Inputs

The VISTA Scenario Editor is the software medium used to design and build simulations in JCATS. Through VISTA, we built the organizational structures of our friendly forces (Blue Force) and our enemy forces (Red Force). We assigned combat power to the two opposing sides, specifying the number and characteristics of the different types of vehicles and personnel on each side. In order to accommodate each of the six candidate cannons being analyzed, we specifically designed our system of interest, the Bradley, to be easily modified from scenario to scenario.

Building a vehicular weapon system in JCATS consists of three primary inputs: the system, the station, and the munition. First we built the system, the Bradley itself. We then built "stations" on the Bradley. Six different weapon stations were built representing each of the six candidate cannons being evaluated in our simulations. Finally, we built the ammunition to be fired from each station and linked the respective stations and ammunition together.

Each station was designed to fire both armor piercing ammunition (AP) and air burst ammunition (AB). Each type of ammunition has a Probability of Hit (PH) curve and a Probability of Kill (PK) curve associated with it. Since each station can fire both munitions, each station is linked to two sets of distinct curves. The capability of each station was therefore defined by the probability curves associated with both its AP ammunition and its AB ammunition. These curves also establish the basis of the simulation results. When a Blue Force Bradley engages a Red Force element, or vice-versa, an adjudication of the direct fire engagement is primarily based on the respective PH and PK curves. Classified input for PH and PK curves was provided by the U.S. Army Material Systems Analysis Activity. Additionally, we were able to easily vary the specific amount of ammunition a Bradley carried, basing inputs on the bullet size and turret stowage volume for each of the six stations.

2.2 Design of Experiments

Utilizing three scenarios, we designed a series of experiments to test the effectiveness of the six cannon candidates. We varied the cannon as well as varying the type of ammo load each Bradley carried into combat. There were two variations of ammo load and they describe the ratio of the two types of ammunition the Bradley can fire. The first case was a 3:1 ratio of AP rounds to AB rounds. This type of ratio is more favorable when the enemy is primarily a mounted, armored threat. The second case was a 1:3 ratio of AP rounds to AB rounds. This type of ratio is more favorable when the threat is dismounted. It is also a favorable ratio to defeat enemy RPG's and the soldiers who fire them. We conducted 30 runs for each of the six candidates, in each of our three scenarios, with the two variations of ammunition load. We chose 30 runs as being both a manageable number of iterations as well as a sufficient number for the Central Limit Theorem (CLT) to apply. The CLT states that the distribution of the means of each of our different performance measures for our thirty runs should be approximately normally distributed and in turn allow us to calculate confidence intervals. This is important in our output analysis in which we calculate confidence intervals to compare significant differences in cannons. Overall, we conducted a total of 1,080 simulations.

2.2.1 Scenario One: Blue Attack

The first scenario we designed was a battalion task force attack in an open desert environment. Figure 1 shows the friendly and enemy forces arrayed. Both the attacking and the defending force have large fields of fire and excellent observation. The Blue Forces are equipped with 58 Bradleys. The defending Red Force consists of one mechanized infantry company. The Red Force has 12 armored personnel carriers, a machine gun platoon, and a total of nine grenadiers. The grenadiers carry RPG's and pose a great threat to the attacking Bradleys. The attacking Blue Forces have a slightly greater than 3:1 force ratio.

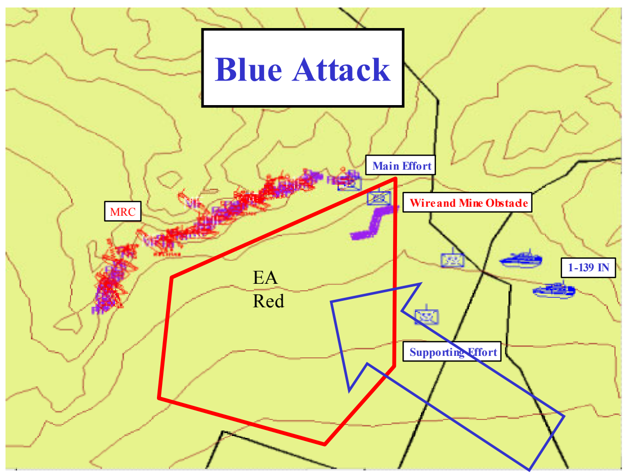

Figure 1: Blue Attack

The Red Force is deployed to defend a mountain pass that provides Blue Forces the ability to quickly move combat power and combat supplies forward to sustain their attack. The Blue Forces attack to destroy the Red Force in order to seize this key terrain. Two of the Blue Force companies (approximately one half of its Bradley force) will establish a base of fire to support the attack of the other two maneuver companies, The two maneuver companies will attack to attempt to complete the destruction of the Red Forces.

2.2.2 Scenario Two: Blue Defend

In our second scenario, the Blue Forces are now defending. We also greatly increased the size of both the attacking and defending forces. This increased combat power would give us a larger data sample of direct fire engagements. Forces are arrayed in JCATS as in Figure 2.

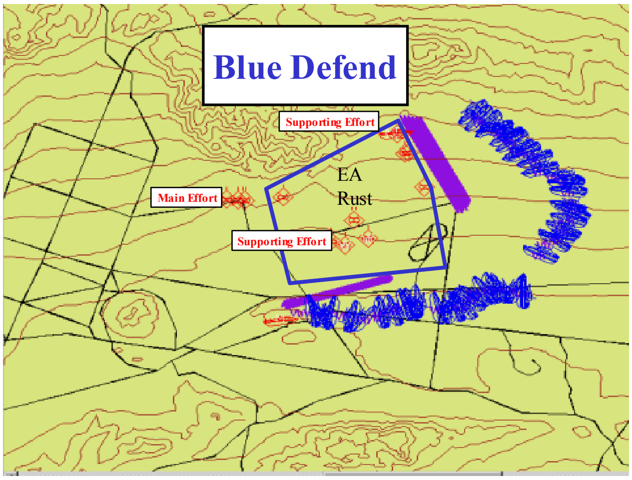

Figure 2: Blue Defend

The defending Blue Force was again a battalion sized element and consisted of 44 Bradleys. The Blue Forces are arrayed so that they can mass direct fires in one large battalion sized engagement area. Blue Force wire obstacles and anti-tank minefields direct the movement of the attacking Red Force into the Blue Force engagement area.

The Red Force is a motorized rifle regiment and consists of over 90 armored personnel carriers. The Red Force's greatest strength is their mass. They have the ability to bring to bear an overwhelming amount of direct fire. The motorized rifle regiment is divided into three battalions. Two lead battalions will attack to suppress and fix the Blue Forces, preventing them the ability to maneuver. The third battalion will attempt to create a penetration in the Blue Force defensive lines and exploit this penetration by moving as much combat power as possible through it.

2.2.3 Scenario Three: Blue Attack – Urban Environment

The third scenario tests the Bradley in an urban environment, specifically the streets of Baghdad. The Blue Force consists of two Bradley companies, 28 combat vehicles in all. The Red Force is a diverse organization, with elements that resemble traditional regular army foes and elements that represent the asymmetric warfare utilized by the Fedayeen, Sadaam loyalists, and terrorists in the Baghdad area. Forces are arrayed as in Figure 3 below.

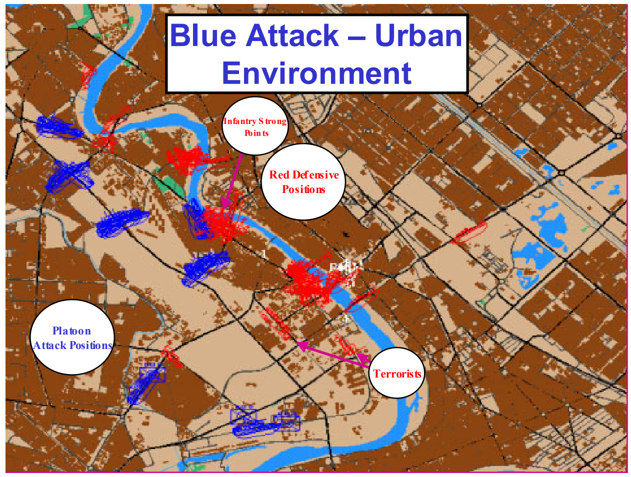

Figure 3: Blue Attack—Urban Environment

The Red Forces are positioned to defend six bridges. Each bridge has an armored personnel carrier and an infantry squad defending it. Each of the infantry squads is equipped with RPG's. In addition to the Red Force infantry squads, the Red Force has RPG teams arrayed through out the city streets. Some of these terrorist forces are mobile, and some are in buildings, on the rooftops of buildings, or on the streets themselves. These terrorists attempt to destroy the Blue Forces before they maneuver to the crossing sites.

The Blue Force has a considerable combat vehicle force ratio advantage, almost 4 to 1. But the Red Forces have enough dismounted infantry to have a two to one advantage over the Blue Force Bradleys. The Blue Forces conduct six separate, but simultaneous attacks to seize the bridges and create maneuver space for follow on forces.

3 SIMULATION OUTPUT

The JCATS Analyst Workstation (AWS) provides the user an ability to create reports and graphs for individual completed simulation runs, and allows a simulation to be replayed for analysis. However, utilizing individual reports from the over 1,000 iterations we conducted would clearly not be efficient. We designed and utilized a tool called the JCATS Evaluator Toolset (JETS) that helped us to analyze output results collectively. Particularly, we wanted to analyze the results of each of our 12 different design points (six calibers x two ammo ratios) for each of our three scenarios. For each design point in each scenario we ran batch runs of 30 simulations. The JCATS AWS capability does not support this kind of analysis easily.

JCATS produces a *.DAT* output file for each run that captures a plethora of direct fire engagement data pertinent to our analysis. JETS, a Microsoft Access database application, allowed us to integrate the batch run of 30 JCATS output files by design point into a common database. This integration helped produce reports and graphs from the JCATS batch files and allowed us to analyze the performance of our candidate systems. We queried the database for specific measures of effectiveness data and then transferred those specific queries into a Microsoft Excel spreadsheet. Finally, we utilized Minitab, a statistical software package, and a One-way Analysis of Variance (ANOVA) to determine whether or not our varying cannons had significant differences in regards to our measures of effectiveness. We validated our output procedures by comparing our outputs from JETS with the outputs of individual runs using the actual JCATS AWS.

We were primarily interested in analyzing the lethality of the candidate weapon systems and how well the two ammunition ratios performed. Accordingly, we developed a set of 23 measures of effectiveness that indicated how lethal the candidate cannons were. We focused on how well the Bradleys destroy enemy armored personnel carriers and enemy dismounted infantry and how efficiently they perform these missions. We were also interested in how survivable the Bradleys were. The longer the Bradleys can survive on the battlefield, the more likely they are to destroy enemy forces. We will further examine our six main measures of effectiveness.

We used two natural measures of the Bradley's lethality to analyze our alternatives. The first measure was the number of enemy infantry killed by the Bradleys. The second was the number of enemy armored personnel carriers killed by the Bradleys.

We chose to use survivability measures as well to measure the Bradley's lethality. Specifically, we were interested in measuring the percentage of Bradleys that survived each battle. A lethal system should survive longer on the battlefield because it is able to kills its threats prior to being killed. We also looked at the Loss Exchange Ratio. This is a measure of the ratio of the number of enemy armored personnel carriers destroyed to the number of Bradleys destroyed. A larger ratio indicates the Bradleys are both more lethal and survivable than their armored threats.

We used two other measures to analyze the candidate systems. These measures were measures of lethality but also of sustainability. We were interested in looking at the total number of rounds the Bradley would carry and the average number of rounds that had to be expended by a Bradley to destroy a target. The following ratio helped us to calculate the Stowed Kills, the expected number of kills a Bradley would get with a full load of ammunition. We calculated this for both AP rounds and AB rounds:

$$\text{AP Stowed Klls} = \frac{\text{Rnds Stowed per Bradley}}{\text{AVG \# of Rnds per APC Destroyed}}$$

We used a similar equation to calculate the total number of AB Stowed Kills. These two measures gave us a measure of how lethal our candidate cannons were. Essentially, the stowed kills measure is the average number of kills we can expect from a fully loaded Bradley. We can assume that the more rounds the Bradley can carry based on the size of the munition, the more kills we would expect.

4 RESULTS

Ultimately, we analyzed the output from 12 design points each with 30 different simulation runs for each of our three scenarios. We focused our analysis on whether or not we could determine statistically significant differences in our measures of effectiveness among the six candidate cannons. We utilized a One-way ANOVA and Tukey's Multiple Comparison Test.

4.1 One-Way ANOVA and Tukey's Multiple Comparison Test

A One-way ANOVA tests the equality of two or more means categorized by a single factor (Neter et al. 1996). In our case, the six cannons represent the single factor. Although we altered the ammunition ratio of AP:AB between 3x1 (a favorable ratio against a mounted, armored threat) and 1x3 (a favorable ratio against a dismounted threat), we analyzed these results separately.

For our six measures of effectiveness, we conducted a One-way ANOVA and Tukey's Multiple Comparison Test. In analyzing each measure of effectiveness the Minitab output displays the 95% confidence intervals for each cannons performance. This gives a relative picture of the performances of the six cannons amongst one another. Overlapping confidence intervals indicates no significant different in performance. However, Tukey's Multiple Comparison Test provides the statistical significance to identify whether cannons perform better or worse for a specific measure of effectiveness. Tukey's Test compares the means of each cannons performance with every other cannon while maintaining our desired 95% confidence level. Tukey's compares the performance of two cannons by looking at the difference in their means and calculating confidence intervals on that difference. If the interval does not include zero, the difference in the means is considered significant. Therefore the performance of the cannons is significantly different. Finally, we verified the statistical assumptions associated with our analysis by looking at normal probability plots (to detect nonnormality), histograms of the residuals (to detect multiple peaks, outliers, and non-normality), residuals versus the fitted values (to detect non-constant variance and outliers), and residuals versus order (to detect time dependence of residuals). In all cases, our assumptions held.

To display our results, we graphed the six cannon's mean results for each measure of effectiveness utilizing a line graph. To indicate if there was actually a significant difference in those means, we included a chart indicating significance as seen below in Figure 4.

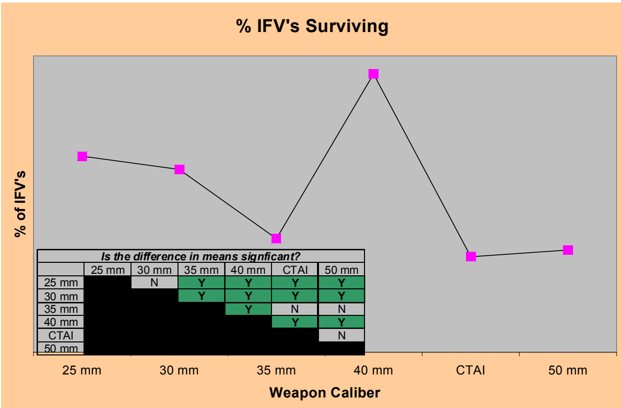

Figure 4: Example Output Results

5 CONCLUSIONS

Throughout this study, the primary tradeoff involved among our six candidate cannons is the tradeoff between lethality and stowage volume in the Bradley turret. Bigger calibers, or bullets, provide increased lethality. However, the tradeoff is that fewer bullets can be carried. Though, the results varied among the three scenarios, we are able to draw the following conclusions:

- The 25mm is still an effective system and our troops today are in good hands. This is primarily based on the ability to carry 300 ready rounds, which is 120 more rounds than any of the other cannon candidates.
- 40mm appears to provide the greatest increase in lethality versus the loss of rounds because it can still carry a *good* number of rounds (180 rounds).
- The CTAI candidate exhibited limited increased capability, possibly due to limited round capacity (only 93 rounds).

5.1 Future Work

We are continuing to refine and analyze our simulation output results. Additionally, we are incorporating our simulation results into a larger study that considers several other factors including:

- life cycle cost assessment
- turret integration
- risk
- reliability
- growth potential
- doctrine, training, logistics, operations and maintenance.

We will continue to conduct sensitivity analysis on our results as well as expand our output analysis to a Two-way ANOVA that considers not only the cannons under consideration as a factor, but also the ammunition ratio as a factor.

ACKNOWLEDGMENTS

Special thanks goes out to Mr. John Melendez in the Department of Systems Engineering who was instrumental in this analysis. John developed JETS for this analysis, as well as consistently trouble shot many JCATS and technology hiccups. We would also like to thank MAJ Tom Rippert for coordinating with the 7th ATC in Germany and acquiring the Baghdad terrain files utilized in this study.

REFERENCES

Department of the Army. 1996. *Field Manual 23-1: Bradley Gunnery*. Washington, D.C.

Foss, C. F. 2000. *Jane's Armour and Artillery*. 21st Edition. Alexandria, Virginia. Jane's Information Group.

Neter, J., M. H. Kutner, C. J. Nachtsheim, and W. Wasserman. 1996. *Applied Linear Statistical Models*. 4th ed. Boston, Massachusetts: McGraw-Hill.

United States Army Infantry Center. 2003. "The A3 Bradley Fighting Vehicle". Available online via `http://www.infantry.army.mil/tsm-b/m2a3desc.htm` [Accessed November 15, 2004].

United States Joint Forces Command. 2004. "Joint Conflict and Tactical Simulation (JCATS)". Available online via `<http://www.jwfc.jfcom.mil/about/fact_jcats.htm>` [Accessed February 18, 2004].

AUTHOR BIOGRAPHIES

MAJ RUSSELL J. SCHOTT is an Assistant Professor in the Department of Systems Engineering at West Point. He graduated with a B.S. in Systems Engineering from the United States Military Academy at West Point in 1991 and was commissioned as an Infantry Officer. He has served with the 7th Infantry Division at both Fort Ord, CA, and Fort Lewis, WA, and then with the 1st Infantry Division in Schweinfurt, Germany. He earned a M.S. in Industrial Engineering from Georgia Tech in 2001. His email is `<russ.schott@us.army.mil>`.

MAJ PATRICK M. DOWNES is an Assistant Professor in the Department of Systems Engineering at West Point. He graduated with a B.S. in Systems Engineering from the United States Military Academy at West Point in 1993 and was commissioned as an Infantry Officer. He has served with the 25th Infantry Division at Schofield Barracks, Hawaii and the 1st Armored Division, Fort Riley, Kansas.

MAJ Downes earned a M.S. in Systems Engineering from the University of Virginia in 2000. His email is `<patrick.downes@usma.edu>`.

LTC ROCKY GAY is an Assistant Professor in the Department of Systems Engineering at West Point. He graduated with a B.S. from the United States Military Academy at West Point in 1982 and was commissioned as an Armor Officer. He has served in Armor units in Desert Storm, Germany, Bosnia and the U.S. He earned a M.S. and a Ph.D. in Industrial Engineering from Texas A&M University. His email is `<ralph.gay@us.army.mil>`.

CADET NATE WHITTEN is a Systems Engineering major at West Point. He will be commissioned a 2LT in the Armor. He is Captain of the Army Gymnastics team.

CADET JAMES PAINE is a Systems Engineering major at West Point. He will be commissioned a 2LT in the Infantry. His first assignment will be with the 82d Airborne Division in Fort Bragg, North Carolina.

CADET MICHAEL GODDARD is a Systems Engineering major at West Point. He will be commissioned a 2LT in the Corps of Engineers. His first assignment will be with the 2d Infantry Division in Korea.

CADET MICHAEL RYBACKI is a Systems Engineering major at West Point. He will be commissioned a 2LT in the Infantry. His first assignment will be with the 82d Airborne Division in Fort Bragg, North Carolina.

COL WILLIAM KLIMACK is an Academy Professor in the Department of Systems Engineering at West Point. He graduated from Lehigh in 1979 and has been an Infantry officer for over 25 years. He has served in numerous Infantry units stateside and overseas, to include serving as the Chief of Staff of UN forces in Haiti. He received his Ph.D. in Operations Research from the Air Force Institute of Technology. His email address is `<william.klimack@usma.edu>`.