EDITOR'S NOTES

This issue highlights the work our departments do for our parent services, DoD, and the rest of the government. It is a source of great pride to me to see how our dedicated faculties find the time "out of hide" to do this work. In an era of declining resources, we are truly doing more with less.

The 1998 SASMC was a great success, thanks to the efforts of MAJ **Tasha "Robbie" Williams** at USMA and to the faculty advisors at all three participating academies. I hope you enjoy the article about the SASMC in this issue.

This issue is my last as editor. I have been associated with *Mathematica Militaris* for 6 years now, three as managing editor and three as editor. I know that the articles don't write themselves, and how important is the work of the associate and managing editors. I'd like to salute Major **Bernd Schliemann**, our managing editor, for his hard work over the last few years. A hard charger and self-starter, Bernd has made my job as editor very simple! Bernd is departing USMA to go to Fort Bragg, NC, and our loss is definitely Fort Bragg's gain. I'd also like to thank our associate editors at USNA, MAJ **Mike Shehan**, USAFA, Dr. **Brad Kline**, and USCGA, Dr. **Joseph Wolcin**. They have done great work soliciting and assembling the articles for our issues.

As this is my last issue, allow me to mount the soapbox one final time. I'd like to see even more cross-fertilization of ideas between our departments. While our cultures are different, our missions are very similar: to produce quantitatively proficient leaders for our services. We do have much to share with each other. To that end, I'd like to see even more faculty participation in the SASMCs, perhaps including a faculty round table each year to discuss one or two common items of interest.

I'll be on the faculty of the Operations Research Department at the Naval PostGraduate School in Monterey for the next few years. Please say "hi" if you are in the neighborhood.

In closing, the Association of Graduates, USMA, deserves a special mention for funding this newsletter. Their generosity has made possible the many informative and frank exchanges recorded on these pages. They have our sincere thanks.

Best wishes from West Point,

LTC Dave Olwell
Now Editor Emeritus

CONTENTS

SUBSCRIPTIONS TO *MATHEMATICA MILITARIS*:

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Editor, *Mathematica Militaris*

Department of Mathematical Sciences
United States Military Academy
ATTN: MADN-MATH
West Point, New York 10996

Overview

This issue begins with a summary of research conducted this past summer by USAFA's Lt Col **Carl D. Bodenschatz** and Maj **James R. Simpson** for the Armament Directorate at Eglin AFB. Their account details the consulting work performed during a period of six weeks. The authors conclude that the work not only provided a needed service for the Armament Directorate, but had a positive impact on the faculty and their current students.

LTC **Dave Olwell** presents a broad overview of the type of outreach and research currently being conducted at USMA. Although he does not discuss every bit of on going research, his article gives a flavor of the type of research and consulting effort being embarked at West Point and identifies some of the customers.

With the goal of providing the best and most purposeful education to their cadets, USAFA Professors **Mark Parker** and **Jim Lowe** provide an interesting approach to teaching Operations Research (OR). Their capstone OR course seeks to find realistic problems for local government and civilian organizations and lets the cadets solve them. The result is satisfied customers and cadets who can tackle tough problems.

USNA is also committed to a strong research and outreach program. Professor **Pete McCoy** highlights the work of two colleagues who are using research efforts and interests to improve classroom instruction. In an effort to provide midshipmen with an application oriented approach to learning, USNA's Mathematics Department focuses on Fleet applications to facilitate cadet understanding.

Maj **Marie Revak**, Lt Col **Steve Hadfield**, and Lt Col **Raymond Yelle** have successfully employed a "Testbank" database for readiness testing of crew members at Cheyenne Mountain Operations Center located in the mountains overlooking Colorado Springs. The database that was initially developed to aid in evaluating USAFA cadets, now serves to train the crew members at this critical facility.

The USMA Mathematical Sciences Center of Excellence provides a valuable service to both the Army Research Laboratory (ARL) and USMA cadets and faculty. It provides many research opportunities for cadets and faculty and provides valuable insight and answers to ARL. The article's author, LTC **Don Engen**, presents some of the many research and outreach efforts that the center has conducted in its relatively short existence.

USAFA provides a 3-day "short" course to government agencies interested in basic statistics and Statistical Process Control. Maj **Jim Rutledge** and Capt **Tim Webb** outline the course, its objectives, and its benefits in this informative article.

Finally, LTC **Dave Olwell** summarizes the recent events surrounding the Service Academy Student Mathematics Conference conducted here at West Point. Included are a few of the insightful topics discussed by the cadets/midshipmen during this annual program.

Analytical and Statistical Consulting for the Armament Directorate

Lt Col Carl D. Bodenschatz
Maj James R. Simpson
US Air Force Academy

Last summer, Maj Jim Simpson and I took advantage of a somewhat unique opportunity to consult extensively with the Armament Directorate of the Wright Laboratories at Eglin AFB, FL. During the spring semester, Mr. Hunt of the Technology Assessment Branch contacted me to inquire about the possibility of extended consulting. Mr. Hunt and others in the branch had attended a short course in the Design of Experiments I had conducted at Eglin AFB a couple of years earlier. During that course, I helped develop a model that aided them in their job. They were aware of the power of statistics but were unsure how to continue to apply it effectively in their jobs.

We discussed the type and length of consulting possible. We agreed on a total of six weeks during the summer and arranged our calendars accordingly. Maj Simpson covered the first three-week period and I covered the second. We scheduled a one-day overlap to help bring me up to speed on his progress. The Armament Directorate funded our travel. Our contributions were primarily in five of their projects. We will briefly summarize these and then provide an evaluation of our involvement.

Modular Effectiveness Vulnerability Assessments (MEVA) Code Designed Experiments

Program Description

The MEVA code is a multi-process computer program, which provides a computational environment and algorithms for assessing the survivability/vulnerability of fixed targets subjected to conventional weapon attack.

The MEVA simulation is an enhancement to the Effectiveness/Vulnerability Assessments in Three Dimensions (EVA-3D) program. EVA-3D was designed to assess the survivability/vulnerability of fixed underground hardened targets subjected to conventional weapon attack. The assessment was accomplished by modeling the attack or delivery conditions, the penetration event, weapon fuzing, and detonation effects using Monte-Carlo type calculations. MEVA enhances EVA-3D by restructuring the code into a modular framework allowing existing and emerging technologies to be integrated easily into the system. MEVA also includes improved airblast and fragmentation models, a target model generator, and aboveground target modeling capability.

The Air Force is planning to perform verification and validation (V&V) tests on the MEVA model. They plan to test each of the simulation modules as well as the entire system. The V&V tests will include actual tests for comparison as well as simulation comparisons using previously validated software programs.

USAFA Involvement

We were asked to assist the AF program manager for MEVA Verification and Validation in designing a series of tests to evaluate fully the new MEVA program. The evaluation consists of individual module assessments as well as an overall system or network assessment. The tests will include extensive software experimentation for verification along with actual testing on the range to validate the model.

Work has begun on verification tests for the penetration module. Once the results are analyzed for the penetration module, we can begin verification planning for the other hard and soft target network modules.

The hard and soft target network verification will be performed by using the significant factors from the individual module verifications. Perhaps there will be a common set of significant input factors that can be used in the network verification. Finally, these designs will be brought into the MEVA configuration management plan. They will be exercised when a code change has been made to ensure that the improvement was accomplished successfully and that other modules weren't adversely impacted.

Agent Release Model (ARM) Phenomenology Experiments

Program Description

The Agent Release Model (ARM) is part of a series of models designed to assess the defeat of weapons of mass destruction (WMD) targets while quantifying the amount of viable agent released into the atmosphere from attacks by conventional weapons. Information from this tool can be used by weapon designers, military planners, field commanders, and other decision makers to select the best method and to determine the most favorable conditions to attack WMD targets with the least collateral hazard potential. The proposed modeling effort leverages existing algorithms developed by the Air Force rather than developing new models from scratch. The ARM determines whether or not chemical or biological agent is released from its containment vessel, and, if so, the amount, physical form, and timing of the agent release due to conventional blast and fragmentation weapon effects.

USAFA Involvement

The Armament Directorate is interested in increasing the fidelity of certain aspects of the code. To model the phenomenology correctly, they want to perform a series of experiments on containers with fluid and another series of tests on containers with powder. Some of these tests are designed to validate phenomenology already modeled. Each of the experiments has a number of input and output parameters. Testing is costly and the number of input combinations for each experiment is extensive.

We developed templates in Microsoft Excel to identify, for each of the six tests, the control (experimental) factors, the response variables of interest, factors to hold constant, and nuisance (uncontrollable) factors. As the programmer from Kaman Sciences determined the correct factors and appropriate levels for these factors, we completed

the spreadsheets and prepared a statistical software program for data entry and analysis. The spreadsheets for the six fluid tests are complete. As the tests are conducted, we can input the data, conduct analyses, and build a predictive model for each response variable using the statistically significant input variables.

Component Vulnerability (COVUL) Tests

Program Description

The Component Vulnerability program consists of evaluations of hundreds of units that may be present at target facilities. The program was initiated to improve vulnerability predictions of mission critical components (MCC's) contained within hardened structures. The goal of the program is to determine the vulnerability of each component to various threats (blast, fragments, etc.) and to develop fragility functions for them. Components vary considerably in size, shape and criticality. Examples include power units, computers, generators, batteries, pumps, pipes and valves, and blast doors. The purpose of fragment testing is to determine the effects of fragment impact on the probability of kill for each type of component. Probability of kill is obtained by gathering data on various fragment shotlines using fragments of different size representing different intensity levels. Shotlines are selected at random from the possible combinations of impact locations, orientation angles, and obliquity angles.

USAFA Involvement

We were asked to study the shotline selection process. Because there are millions of location/angle combinations, and because actual shot tests are expensive, it is important to efficiently sample shotlines. The defense contractor, Southwest Research Institute, was tasked with developing the shotline selection process, as well as the approach for using the resulting data to calculate kill probabilities.

We performed a geometric analysis of possible shotlines, given the location of the fragment impact. Based on this analysis, we proposed an improvement to the angle selection process using a four-parameter beta distribution. We investigated various parameter values to better represent the probability of certain shotlines. Wanting to keep the process simple, we restricted the scope to only three distributions, one for each of three zones of fragment impact.

In this project, we were also able to help mentor a high school student who was assigned to the program manager for the summer as part of an apprentice program. The apprentice program at Eglin AFB is a very competitive and selective program where exceptional and promising high school students are paired up with working engineers at Eglin AFB to see how science and engineering are applied in the workplace. The program manager had the student work on developing a computer program to select an impact location and then select an impact angle (using one of the three distributions we proposed), given the impact location.

Soft Target Vulnerability Assessment Tests

Program Description

The Soft Target Vulnerability Assessment program is designed to evaluate conventional weapon effectiveness against soft targets. Most of the previous studies evaluated the effectiveness of conventional munitions against hard targets—often underground bunkers made of reinforced concrete. The soft target vulnerability assessment will look at fragmentation effects on five other wall materials.

Testing the fragmentation effects partially consists of firing steel cubes (representing bomb fragments) from a 30mm gun at different velocities at target materials. The cubes are initially enclosed in a plastic sabot, which aerodynamically separates from the cube after exiting the barrel of the gun. A small number of full-scale tests will also be done using live Mk-82 500 pound general-purpose bombs.

USAFA Involvement

We were asked to evaluate the proposed test design matrix. We were able to suggest a 33% reduction in required tests with potentially no loss in information gained. We recommended initially modeling the response variables with linear functions of the input variables. We can estimate the accuracy of this linear approximation during confirmation runs at the center values.

A larger issue was determining the representative test conditions. We analyzed the results of previous arena tests on six Mk-82 bombs.

In an arena test, a munition is exploded in an arena of panels constructed to collect a statistically significant sampling of fragments in a region from nose to tail. We used graphical and numerical descriptive statistics to help characterize the distribution of fragments from the Mk-82 bomb. This analysis confirmed the selection of velocities planned for the soft target tests but altered the size of the steel cubes to be more representative of actual bomb fragments.

Shaped Charge Design and Testing

Program Description

A shaped charge is an explosive designed to create a crater into which another explosive can be inserted before detonation. Shaped charges have been used in mining operations to create holes in large rocks where another explosive charge can be inserted. They have also been used to penetrate the armor plate of tanks, destroy a concrete runway, or create foxholes. Shaped charges can be used as part of a dual-stage warhead to achieve better effectiveness against hardened targets.

Many previous tests of shaped charges had been conducted. A partial database of these tests had been developed in Microsoft Access. A number of the test reports were on file in the Armament Directorate. While there was a lot of previous information available, it wasn't in a very useful form. There was a risk of reinventing the wheel or repeating a test that had already been conducted.

A limited evaluation of shaped charge effectiveness against hardened targets was being considered. A goal of the current effort was to identify the best and most promising factors for shaped charge design to penetrate concrete or reinforced concrete, creating a crater large enough for a follow-through warhead.

USAFA Involvement

We conducted a literature review of previous tests of shaped charges, identifying input factors, test conditions, and results. Only some of the previous tests were applicable since many of the charges were fired against soil, sand, clay, rock, or steel targets. We identified previous test efforts with potentially useful information for the development of an effective shaped charge design for hardened targets.

Unless complete and precise engineering models of shaped charge designs are available, a thorough and systematic design and testing program is necessary to achieve the optimal design. Depending on the importance of shaped charges to future weapons development efforts and the potential increase in weapon effectiveness possible with an optimal shaped charge design, we recommended considering such a program. However, it is also possible that previous testing has suggested values for the factors that will produce acceptable (though not optimal) results for weapons employment against hardened targets.

Summary

We consider our involvement at Eglin AFB a win-win-win situation for everyone concerned. The Armament Directorate gains some statistical and analytical expertise to improve the efficiency and effectiveness of their design and testing. Our short course in Design of Experiments is even more effective when we help apply it to specific projects. Follow-on consulting help is also possible to take advantage of the knowledge and perspective we gained during our TDY. The Air Force Academy benefits because we can bring current Air Force projects, engineering challenges, and applications of statistical analysis back to share with cadets. Interested cadets could possibly get involved in follow-on research projects. Finally, we personally benefit because trips like these help USAFA instructors "stay blue" and add to our professional development.

Outreach and Service in the USMA Math Department

LTC Dave Olwell
US Military Academy

The Department of Mathematical Sciences at USMA has an increasingly aggressive program of outreach and consulting to Army activities. We provide unbiased quantitative analysis to the Army and other DoD activities, using the unique talents of our faculty. During a department research briefing in January, Major General **Mark Hamilton**, Commander, US Army Recruiting Command, described the faculty at West Point as a "national treasure" and the "strategic intellectual reserve of the Army."

Our department sees that our primary mission is to develop cadets, of course. We also have a secondary mission to develop our faculty, especially those rotating faculty members whose future assignments will include tours as analysts and decision-makers.

Our research program supports both missions. Unlike other Centers of Excellence at USMA, the Mathematical Sciences Center of Excellence does not have any full time analysts assigned to it. As a result, we focus on projects that contribute to our educational missions. We have been very fortunate, as almost all of our outreach activities have reached back into the classroom. These projects reach back by providing concrete examples of the military use of the mathematical sciences and by providing contexts for student research projects.

We have also seen our faculty members move on to key analytical positions in the Army, following initial contacts made during outreach activities. We have tried to work on important problems for the Army leadership. Our hope is that promotion boards will value this work above and beyond teaching duties.

Our research breaks down into two areas: that done for the Army Research Laboratories (ARL), and other research. ARL is our primary research client. The work done for ARL is discussed by LTC **Don Engen** in a separate article, and tends to be concerned with either developing algorithms or complex mathematical models of physical phenomena. I will discuss the other research we do for the Army.

We have committed to a second major client, the Army Digitization Office (ADO), for a multi-year study of the effects of information and digitization on combat outcomes. LTC **Gary Krahn**, our new deputy department head, is the project leader. A strong team of faculty in the department supports him. This project was just begun this spring, and has already generated intense national interest, including an article in *Defense Daily*. We anticipate this project will take the majority of our non-ARL research efforts for the next two years. This project is funded by the ADO through a block grant, to cover TDY and research costs.

We have helped other Army activities recently. MAJ **Jim Matheson** and CPT **Jim Glackin** conducted research for the Benet Labs at Watervliet Arsenal last summer. They developed a mathematical model and computer simulation to describe the behavior of sputtered atoms traveling through neutral gasses.

MAJ **Joe Maier** analyzed snow records to predict snow density throughout the world for the planning of mobility and other operational constraints in cold weather operations. He did this work for the Cold Regions Research and Engineering laboratory, which funded the travel and overhead.

LTC **Kevin Pilgrim** worked with the Training and Doctrine Command Analysis Center (TRAC) at White Sands Missile Range to do a comparative analysis of former Soviet information theory. TRAC funded this research.

COL **Chris Arney** participated as an invited panelist at the 65th Military Operations Research Society Symposium, discussing "Analysis for Complex, Uncertain Times: Applying the New Sciences of Chaos and Complexity." COL Arney also participates in a number of technical review boards for the Army, such as the steering committee for the mathematics division of the Army Research Office.

Prior to changing affiliations last summer to the Naval Academy, Dr. **Erik Bollt** was doing exciting work on chaotic control of communications. His work was sponsored by several agencies, including the National Science Foundation, the Army Research Laboratories, and the Dean's Fund here at USMA. His work resulted in 9 refereed papers and presentations.

The department won a grant from the National Reconnaissance Office for algorithms to map terrain using remote sensors. Drs. **Jim Rolf** and **Dave Anderson** are doing this exciting work.

The department has also had statistical outreach activities. Clients have included the Senior Review Panel on Sexual Harassment for the Army, the DoD Safety Office, the Patriot Project Office, the Deputy Under Secretary of the Army for Operations Research, the Naval Recruiting Command, the 1st Armored Division, the New York Police Department, and other agencies. Much of the work was funded by the clients and by a grant from the Dean's Fund for Faculty Development and Research at USMA. There is current work on an initiative to devise

sampling plans and analysis strategies for the Ethical Climate Assessment Survey developed by the Department of Behavioral Sciences and Leadership at USMA for the Army.

Much of the statistical work has found its way into the classroom as projects in the Applied Statistics or Theoretical Statistics electives.

The Department has captured some of its consulting experiences (and many of the models resulting from our outreach) as projects in its new book, Military Mathematical Modeling, edited by COL Arney. We expect to publish the book this summer through the Government Printing Office, and use it in our classes throughout the curriculum.

The department has its fingers in many pies. The common theme of our work is that we provide honest answers, with a unique blend of Army perspective and technical expertise. We try to provide value for the Army, while also collecting great examples of the mathematical sciences in action for our classrooms. We feel our research work is making a difference for the Army, for our faculty development, and for our students.

Cadets as Consultants - Operations Research at USAFA

Prof Mark Parker, Dept of Mathematical Sciences
Prof Jim Lowe, Department of Management
US Air Force Academy

In order to adequately prepare cadets for the scientific analyst career field, the Operations Research (OR) curriculum at USAFA requires cadets to perform a major consultation project for a real client (military or civilian) to graduate with the OR degree. This requirement is fulfilled via a capstone course, Ops Rsch 420 – Case Studies in Operations Research, which is taken during a cadet's final semester.

The Operations Research major at USAFA is a multidisciplinary program jointly administered by the departments of Computer Science, Economics, Management, and Mathematical Sciences. Faculty members from participating departments solicit potential projects from Air Force organizations and the Colorado Springs community. A list of these potential projects is distributed to the cadets during the first week of classes. Cadets organize themselves into groups based upon mutual interests, and the clients for these potential projects are invited into the classroom during the first two weeks of the term to brief the cadets on their projects. Cadet teams have an opportunity to talk with the clients and then provide their instructor a rank ordering of their top three preferred projects. Similarly, clients submit a list of cadets they would like to "hire". Both cadet and client preferences are considered in the assignment process, although client preferences are more heavily weighted. Once the final list of projects and assignments has been made, OR faculty are encouraged to pick a project related to their area of expertise and mentor the cadets in their efforts on the project.

The cadets next prepare a formal project proposal that includes their interpretation of the problem, background information on the problem, and a final product description. In order to help cadets with their first consulting assignment, a series of three milestone reports are required prior to the final presentation and report. The first report emphasizes the end product and helps to shape the study:

1. What will be the output of the study?
2. What is the utility of the study?
3. How will the results be used?

We attempt to focus the cadets on the utility of and the politics of the decision they will be supporting. One measure of the success of a project is its implementation and impact on the client. The second report focuses on the data that they are collecting and answering such questions as:

1. What data need to be collected to complete the study?
2. Is the client cooperating in the data collection effort?
3. Do the data exist?

The third and final milestone is an "in-house" pre-brief of the results. This gives cadets an opportunity to present their results to the faculty prior to their client briefing. At the end of the semester, the clients are invited back for a final formal presentation. Comments are solicited from the client, including input to the group's grade. This input accounts for 10% of the group's grade.

Most of the projects have been very successful and have led to increased efficiency for the clients. Past DOD-related projects have included a Joint

Service Airborne Warfare Simulation supporting the US Space Command at Peterson AFB. The cadet analysis studied the operational effects of various weather conditions. The project concluded with a rank ordering of effects and recommendations on which should be included in the larger simulation. Another cadet team conducted a design of experiments project for Sandia Labs to determine the design parameters for a handheld laser gun.

A study performed for the USAFA Commissary evaluated current usage and recommended alternatives to increase usage. Shopping cart comparisons determined that the Commissary provided significant savings over local stores. Customer surveys were used to determine why utilization was not higher. The study concluded that, by extending hours, advertising hours of operation, and offering base taxi service, utilization would be increased.

Civilian projects have been run with both local government and local commercial businesses. Within the past year, cadets developed, tested, validated, and implemented a customer service survey of the Colorado Springs Airport operations. This led directly to changes in security check procedures and the installation of a new metal detector to increase throughput at airport bottlenecks.

This spring, twenty projects are being sponsored. One group this term is performing a regression analysis to aid in forecasting natural gas usage. This is critical for bases that work with local utilities to provide usage estimates in return for price breaks. Previous models have not used seasonal information to make predictions, and when forecasts are not within some percentage of actual usage, a penalty is paid.

Another cadet project this term is developing a forecasting model to help food services with the problem of serving 4000 cadets a sit-down breakfast. They are gathering and analyzing data on “no shows” and plate waste in order to evaluate serving options, such as “full buffet” or “partial buffet,” which could reduce costs.

The Ops Rsch 420 course provides a service to both clients and cadets. The success of this capstone course has led to a number of base organizations coming to the faculty asking for help (rather than faculty having to “beat the bushes” for clients). The cadets are provided with an opportunity to experience life as a consultant in a controlled environment. The course is frequently mentioned in exit interviews as a highlight of the academic career at USAFA.

Math Connections

Professor Pete McCoy
US Naval Academy

Mathematics developed from a need to describe and predict real world phenomena. The first problems, while simple by today's standards, were difficult to handle relative to the base of knowledge that existed in society at the time they were proposed. Perhaps they arose in connection with "surveying", the need to define and measure boundaries of properties, or from the need to predict dates for crop planting. Thus, geometry and astronomy began. New, but interrelated, areas of mathematics arise and grow in response to problems that may be scientific or economic. One finds this "cause and effect" woven into history in a way that it forms the bedrock of our culture. The Mathematics Department at the USNA emphasizes this philosophy by looking at Fleet applications in its standard course work, through honors papers, and by specially designed courses and long term research projects for Midshipmen.

New faculty members, Dr. **Ted Stanford** and Dr. **Erik Bollt**, highlight their teaching with applications. The purpose is to connect classroom with science in order to engender a greater appreciation and understanding of scientific principles on which complex systems are based. This emphasis sharpens the Midshipmen's critical thinking skills and gives them a better ability to make decisions based on an understanding of the connections between the theory, design, and applications that mathematics provides.

Dr. Stanford recently visited the USNA's Department of Seamanship and Navigation in order to identify mathematical issues that exist in modern navigation. Dr. Stanford's interest is in how electronic navigation systems work. He is also interested in map making. In particular, how different projections from the sphere to the plane are actually used in describing a curved surface on a flat plane. He borrowed several navigational texts and is looking for examples to tie in with his calculus classes. Dr. Stanford is the author of

"Knots and Surfaces" (with D.W. Farmer) American Mathematical Society, Math World, vol. 6, 1996.

Dr. Erik Bollt's interest is in the study of "Chaos" and time-series analysis. Chaos is in some way the opposite of the regularity that characterizes geometry and the deductions in geometry that follow from the regularity. One can consider cardiac arrhythmia and the fluctuations of complex economic systems as examples of chaotic time-series based models. Dr. Bollt is involved in a three-semester research project with a Midshipman Trident Scholar. Their objective is to study these systems and to develop software for making predictions and analyzing errors. The benchmarks are drawn from computer-generated and real world data. The intention is to develop a tool that can be used in the study of chaotic data sets.

While many of their colleagues continue to be involved in such projects, it is encouraging to see the newest members of the department perpetuate the tradition of application-based teaching and research intent on solving pertinent problems.

Academic Testing Meets Operational Readiness

Maj Marie Revak
Lt Col Steve Hadfield
US Air Force Academy

Lt Col Raymond Yelle
Cheyenne Mountain Operations Center

Several years ago, the Department of Mathematical Sciences at the Air Force Academy developed a "Testbank" database. The purpose of the Testbank database is to enhance the reliability and efficiency of test development through the automation process and preserve the statistical item analysis of test items. The Testbank allows us to re-use test items and compare student achievement across semesters (we refer to this as "anchoring"). It also allows us to continually refine and improve upon our multiple-choice test items. Once our Testbank software was adopted by several departments here at USAFA, we wondered about other possible Air Force applications.

We are currently adapting the Testbank software for use by NORAD/USSPACECOM's Cheyenne Mountain Operations Center (CMOC). Operational crew members at CMOC are assigned to 26 different positions across five centers. Crew members must pass a comprehensive 50 item multiple-choice exam and a performance evaluation before they are declared "mission-ready crew certified." The Standardization/Evaluation Division has asked us to help automate their testing procedures and computerize their associated trend analysis effort. In addition, we have provided instruction on improving the effectiveness of their multiple-choice test items and conducting statistical item analysis.

Our contribution will bolster CMOC's sustainment of combat readiness by improving the efficiency, validity, and reliability of their written evaluation program.

USMA's Mathematical Sciences Center of Excellence (MSCE)

LTC Don Engen
US Military Academy

The Mathematical Sciences Center of Excellence (MSCE) was established by a Memorandum of Agreement between the U.S. Army Research Laboratory (ARL) and the Department of Mathematical Sciences, United States Military Academy (USMA) at West Point, NY, in February of 1993. ARL continues to generously support the MSCE by providing the funds necessary to sustain its operation; these funds primarily support civilian faculty salaries, travel, and equipment. The MSCE serves a multidimensional purpose whose emphasis is to unite the unique capabilities of these organizations in a manner that benefits ARL, USMA faculty and cadets, and ultimately, the United States Army. Current MSCE staffing includes LTC **Dave Olwell**, LTC **Don Engen**, and MAJ **Jim Gigrich**.

There are two major functions the MSCE oversees: (1) the ARL/USMA Cadet and Faculty Research Program, and (2) the Davies Postdoctoral Fellowship Program.

(1) **The ARL/USMA Cadet and Faculty Research Program** culminates each fall with the conduct of the ARL/USMA Technical Symposium (AUTS), which provides a forum for USMA faculty, both military and civilian, to present and discuss various aspects of their collaborative research conducted over the previous year. The first two AUTS (1993 and 1994) were held at Aberdeen Proving Ground, Maryland, under the direction of

the following former members of the MSCE: MAJ Edward Healy, MAJ Keith Matthews, Dr. Peter Plostins, and COL John Edwards. The 3rd AUTS was held in 1995 at both Adelphi, Maryland and West Point, in order to accommodate the widest possible attendance. The 4th and 5th AUTS were held at both Aberdeen Proving Ground, Maryland, and West Point. The 6th AUTS is scheduled for 4-6 November 1998 (4 and 5 November at Aberdeen Proving Ground and 6 November at West Point). Please let us know if you are interested in attending either or both sessions.

Proceedings are published for each annual AUTS. These Proceedings present results from the research presentations by USMA faculty members given over the two day period. The range of topics addressed in the various papers convey the diversity of current research interests of the program participants, and are representative of the potential for future expansion of the ARL/USMA Cadet and Faculty Research Program coordinated by the MSCE. Additionally, these papers clearly convey the degree of problem sophistication the Army encounters as it continues to pursue the technological advancements envisioned for Force XXI.

In the appendix to this article is a listing of presentations made during the 5th AUTS (1997) by USMA faculty and ARL scientists. Copies of the Proceedings from each of the past three AUTS are available upon request from:

United States Military Academy
Department of Mathematical Sciences
Mathematical Sciences Center of Excellence
ATTN: MATH-MSCE
West Point, NY 10997-1786

Requests for copies of these Proceedings may also be faxed to:

(914) 938-7690, ATTN: MSCE

The "Cadet portion" of the ARL/USMA Cadet and Faculty Research program consists primarily of coordinating Cadet Academic Individual Advanced Development (AIAD) summer assignments to ARL. For a complete listing of the options available to cadets for their AIADs, see *http://giants.airmics.gatech.edu/iad.html*. Cadets participating in a research experience AIAD with ARL may continue their research during a senior research course (for Mathematics and Operations Research Majors), MA491: Research Seminar in Applied Mathematics.

(2) **The Davies Postdoctoral Fellowship Program** was established and is sponsored by the National Research Council (NRC) and co-funded by ARL and USMA. It is a unique part of the NRC Associateship Program that provides an opportunity for recently graduated Ph..D.'s to serve a three-year term as Davies Fellows in an academic department at USMA and in a research laboratory at ARL. At USMA, they gain teaching experience under the guidance of senior faculty members. At ARL, they gain valuable research experience by working on problems of interest to the US Army with a senior ARL scientist. The Program was initiated in the summer of 1996 with four Davies Fellows in the Department of Mathematical Sciences. There are currently six Fellows in the Department of Mathematical Sciences and one in the Department of Civil and Mechanical Engineering. Two Fellows are expected to join this summer - one in the Department of Civil and Mechanical Engineering and one in the Department of Physics.

The following is a list of the current Davies Fellows who have made significant contributions while participating in the Davies Postdoctoral Fellowship Program:

Dr. David B. Anderson, Rutgers Univ
Dr. Ethan Berkove, Univ of Wisconsin
Dr. Mary Jane Graham, SUNY Stony Brook
Dr. David J. Haroldsen, California Tech
Dr. Richard J. Marchand, Univ of Virginia
Dr. Diana M. Thomas, Georgia Tech
Dr. Darrell C. Rapp, Penn State

Since its inception, the number of participants in various MSCE programs has continued to grow, as knowledge of this cooperative agreement disseminates throughout the ARL, USMA, and the Army research community. To date, over 50 USMA faculty members, and over 50 individual ARL scientists have conducted formal collaborative research under the auspices of the MSCE. Many of these faculty and scientists have been involved for several years conducting research together on multi-year projects.

Appendix: Contents of the 5th Annual ARL/ USMA Technical Symposium (1997) Proceedings

1. **"Optical Turbulence Mitigation Through Wide Baseline Stereo Imaging and Multi-Resolution Analysis"**
Dr. David B. Anderson, Math, USMA
Wendell Watkins, ARL

2. **"Modeling the Effect of Intense Sound on the Ear"**
Dr. Ethan J. Berkove, Math, USMA
Dr. G. Richard Price, ARL

3. **"Alkane Cracking Reactions in Zeolites with Coadsorbed Metal Halides"**
Dr. Andrew I. Biaglow, Chemistry, USMA
Mr. Gary L. Hagnauer, ARL

4. **"Channel Capacity of a Noise Resistant Chaotic Communication Device"**
Dr. Erik M. Bollt, Math, USNA
C. Retter, ARL

5. **"Calculation of Power Spectral Density Functions of a Modulated Sinusoidal Wave for Two Classical Cases of Noise: Stationary and Nonstationary"**
Dr. George D. Catalano, C&ME, USMA
Mr. James A. Boehm III, ARL

6. **"Dynamics and Control of Guided Projectiles: 1997 Research"**
Dr. Mark F. Costello, C&ME, USMA
Dr. Peter Plostins, ARL

7. **"Natural Frequency and Mode Shape Evaluation for the Study of Aeroelastic Phenomena in Extended Range Field Artillery Projectiles"**
Dr. Christopher J. Earls, C&ME, USMA
Dr. Drew Wilkerson, ARL

8. **"The Decrement in Auditory Performance Decrement Due to Heavy Breathing While Wearing an M40 Mask with Hood"**
LTC Jose A. Picart, BS&L, USMA
Dr. Sehchang Hah, BS&L, USMA
Dr. Jock O. Grynovicky, ARL

9. **"Development of Navier-Stokes Predictive Capability for Lateral Jet Flow Dynamics"**
Dr. Mary J. Graham, Math, USMA
Dr. Paul Weinacht, ARL

10. **"An Information Retrieval Application for Simulated Annealing"**
MAJ Bernard J. Jansen, EE&CS, USMA
COL Mark R. Kindl, ARL

11. **"Blast Evaluation Methodology for Production Vulnerability Analyses"**
Dr. J. Terrence Klopcic, ARL

12. **"Using the Cambridge Materials Selector in Survivability and Decontamination Evaluations"**
Dr. Edward M. Lenoe, C&ME, USMA
John D. Majeski, ARL

13. **"Hydrogen Detection in Metals Using a Coincidence Detector Configuration to Perform Nuclear Reaction Analysis"**
Dr. Daniel K. Marble , Physics, USMA
Dr. James K. Hirvonen, ARL

14. **"Development of Control Algorithms for Precision Guided Munitions Using Microelectromechanical (MEM) Technology"**
Dr. Richard J. Marchand, Math, USMA
Dr. William P. D'Amico, Jr., ARL

15. **"Statistical Process Control of Low Frequency Events"**
LTC David H. Olwell, Math, USMA
Dr. Barry A Bodt, ARL

16. **"Software Tools for Modeling Beam Propagation in Thick Nonlinear Media with Application to Thermal Lensing"**
Dr. Tim Pritchett, Physics, USMA
Gary L. Wood, ARL

17. **"Voting Techniques for Combining Multiple Classifiers"**
Dr. Diana M. Thomas, Math, USMA
Dr. Nasser M. Nasrabadi, ARL

18. **"The Impact of Technology on Tactical Decision Making: A Cognitive Evaluation"**
LTC Lawrence Shattuck, BS&L, USMA
Dr. Jock O. Grynovicky, ARL

19. **"Wearable Computers: Military Application Areas and Cadet/Faculty Projects"**
Dr. Charles C. Tappert, EE&CS, USMA
Mr. Richard C. Kaste, ARL

20. **"Characterization of Comb-Burst Dendrimers Using Static and Dynamic Light Scattering"**
Dr. Gary Washington, Chemistry, USMA
Nora Beck Tan, ARL

Reach Out and Teach Someone

Maj Jim Rutledge
Capt Tim Webb
US Air Force Academy

The Department of Mathematical Sciences has developed a 3-day short course on Basic Statistics and Statistical Process Control. The purpose of the course is to promote quantitative tools that can be used to improve processes throughout the Department of Defense (DoD). The course is available to any government agency for minimal cost. This article will briefly discuss the course content, course philosophy, and some of the pros and cons of teaching such a course.

The short course covers much of the same material that is offered in USAFA's core basic statistics course. As a result, many faculty members are qualified to teach the 3-day short course. Currently, eight instructors have volunteered to be on the team that teaches the course. The course content appears in the appendix at the end of this article.

Most of the course materials are obtained from a local consulting firm, which saves the instructors a great deal of material-preparation time. For a modest fee, the students receive a participants guide and the text Basic Statistics: Tools for Continuous Improvement, by Kiemele, Schmidt, and Berdine. This is the same text that we use in our core basic statistics course. In addition, the students also receive the software package *SPC Kiss*. While *SPC Kiss* is not a full-featured statistical package, it has the advantage of being Excel-based and easily implemented and understood by the students. A course requirement is that computers must be available to students, with a student-to-computer ratio no greater than 3-to-1. Experience shows that most students bring their own laptops.

The philosophy of the course is to keep statistics simple. Anybody who possesses basic high school math skills should be able to complete the course successfully. The "active learning" approach to education is used throughout. Every key concept is reinforced with "hands-on" exercises—the key to success in the course. A workbook with solutions has been created to facilitate the application of newly learned statistical methods. The course also makes extensive use of the statapult (see figure). The statapult is an excellent "hands-on" tool for teaching process flow, cause and effect diagrams, run charts, regression, SPC, and process capability. For example, it is easy to build a regression model for launch distance as a function of pull-back angle. This model can then be used to determine the pull-back angle needed to hit a target for a given distance. Specification limits can be put on the launch distance and multiple shots can then be taken to determine process control and capability. The students really enjoy the activities that surround the statapult.

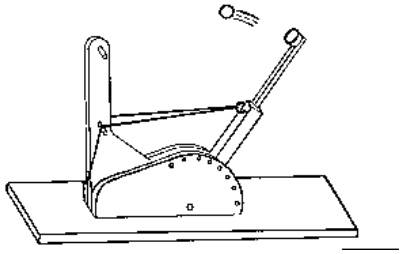

Figure: Statapult

Typically, two USAFA instructors teach the course. Two instructors coupled with the "hands-on" exercises provides the impetus for excellent one-on-one instruction. The students really appreciate the individual attention they receive.

As you can imagine, the biggest downside of this course is that it takes time and energy away from an instructor's usual teaching duties. Teaching the short course during the winter, spring, or summer breaks can minimize this. The advantages of teaching the course, on the other hand, are several. First and foremost, the course helps people in the government improve their processes and reduce costs. It teaches the participants how to use data to make decisions instead of their "gut feel." Running a close second, it is fun and rewarding to teach the course. Third, it helps keep instructors up to speed on current issues facing the military. Students often come to class with some sort of problem that they have been working on. These problems often make great "military applications" that can be shared with USAFA cadets. Fourth, instructors develop contacts for future jobs and research projects. The short course has assisted us in promoting our Cadet Summer Research Program.

The short course is very affordable. Currently, the host unit pays $155 to cover the costs of a

book, software, and the rights to reproduce the participants' guide. In addition, the hosting unit must pay for the temporary duty assignment of the instructors. When compared to similar courses (which cost anywhere from $1000 to $3000 per student), the price is very affordable. Our last short course, taught to 16 people at Air Mobility Command (AMC), cost $250 per student.

In short, the course is a win-win situation. The host unit gets a quality course geared to helping their people improve their processes. The instructors gain experience, which makes them better USAFA instructors.

Appendix: Syllabus for Basic Statistics and Statistical Process Control

Day 1

- *The role of statistics in process improvement*
  - Process flow
  - Cause and effect diagrams
- *Making sense out of data using graphical and measurement tools*
  - Histogram
  - Measures of location and dispersion
  - Run chart
  - Scatter diagram
  - Correlation
  - Pareto chart
- *Probability distributions*
  - Binomial
  - Poisson
  - Normal

Day 2

- *Sampling distributions and confidence intervals*
  - Sample size calculations
  - Hypothesis testing

Day 3

- *Simple linear regression*
- *Statistical process control* (SPC)
  - X-bar and R chart
  - Individuals and moving range chart
  - P-chart
  - C-chart

8th Annual SASMC

LTC Dave Olwell
US Military Academy

West Point hosted the 8th annual Service Academy Student Mathematics Conference (SASMC) 16- 19 April 1998. Papers summarizing current research projects in the mathematical sciences were presented by five midshipmen from Annapolis, eleven Air Force cadets, and nineteen cadets from USMA.

Topics covered a wide range, from the "La Salle's Conjecture" by CDT **Hyeong-jin Yoon**, USMA, to "Detecting a Patrolling Submarine" by MIDN **A. N. McGowan**, USNA, to "Gender in the Workplace", by C1C **Jason Vinson**, USAFA.

Several underclassmen participated, including sophomore C3C **Steve Ramsey**, USAFA, who presented a paper on "Newton's method as a Chaotic Dynamical System," a topic familiar to those in the USMA audience who recalled MA103, Discrete Dynamical Systems.

USMA CDT **Rich Johnson**, '99, company E3, coordinated the billeting of the midshipmen and cadets in the barracks. The midshipmen and USAFA cadets enjoyed seeing how "the other half lives", and commented on the differences in privileges, barracks life and messing arrangements.

Lieutenant **Mark Lucas**, who had participated in the original conference in 1991 as a midshipman, led the Navy contingent. Lieutenant Lucas, a nuclear submariner, is now on the mathematics faculty at Annapolis. Professor **Charles Mylander** also attended. The Air Force faculty representatives were Lt Col **Eric Bussian** (last year's host), Lt Col **Carl Bodenschatz**, Major **Jim Rutledge**, and Professor **Mark Parker**. The faculty members enjoyed lively conversation at dinner Thursday and Friday nights.

MAJ **Tasha "Robbie" Williams** coordinated the USMA activities, with some suggestions from LTC Dave Olwell. Following social activities in New York City and the local area, the participants departed Sunday for the return trip to USNA and USAFA.

USNA will host next year's conference in April of 1999.
A list of presentations follows:

La Salle's Conjecture
CDT Hyeong-jin Yoon, USMA

Lanchester Equation in Combat Modeling
CDT Eric Heinle and CDT Troy Smith, USMA
abstract follows

Detecting a Patrolling Submarine
MIDN A.N. McGowan, USNA

Number Game as a partitioning problem
CDT Steve Lott, USMA

Gender in the Workplace
C1C Jason Vinson, USAFA

Save Money for King Hall
MIDN Paul Detar, USNA

Ranking Teams: A Mathematical Approach
CDT Banaise Blake, USMA

Newton's Method as a Chaotic Dynamical System
C3C Steve Ramsey, USAFA

Modeling Information Gain In Tactical Situations
CDT Stephen E. Douglas, USMA

Studying Cadet Attitudes Toward Math
CDT Adam Radicic and CDT Corbett McCallum, USMA

Studying Cadets Grades in Math-Based Course
CDT Eddy Lee and CDT Samuel Wilson, USMA

What the Numbers Really Mean: Trends and Predictors of Mathematics Grades
CDT Michael Avey and CDT Katharine Miller, USMA

Economics and the Nobel Prize
CDT Robert Ruckman, USMA

Reassigning Marine Corps Reservists to Improve Readiness
MIDN Jeremy L. Leiby, USNA
abstract follows

Who is Number 1?
CDT Matthew Benigni, USMA

Modeling the Effectiveness of Information-based Operations
CDT Ann Bonney and CDT Mark Wanish, USMA

Structuring the Teaching of the USAF Academy's Soaring Program
C1C Scott McKeever, USAFA

Mathematical Analysis of Physical Fitness Testing
CDT Dennis Pintor and CDT Anthony DeSimone, USMA

Shift-and-Add Pairs of Maximum Length Linear Sequences
CDT Steve Haley, USMA

Dynamic Markov Compression as a Tool for Comparing DNA Sequences
MIDN J. Michael Montgomery, USNA
**abstract follows*

Predicting Cadet Debt Levels
C2C Christopher D. Barth, USAFA

Estimating Shipyard Employment Levels using Structural Modeling
MIDN 1/c Titus Fortner, USNA

Modeling the Distribution of Chaotic Orbits
C1C Paul Emslie and C1C Joel Hetzer, USAFA
**abstract follows*

Geodesic
MIDN 1/c Michael Conrady, USNA

Lanchester Equation In Combat Modeling

Cadets Eric Heinle and Troy Smith
US Military Academy

The purpose of our capstone design project is to analyze the similarities and differences between a differential equation based model and a discrete dynamical system based model. In particular, we are examining the differences between Lanchester's Square Law and the JANUS combat modeling software. Using a specific engagement from the Battle of 73 Eastings, we are going to compare the output from both JANUS and Lanchester's Equations. Using specific measures of effectiveness (MOE's) such as loss exchange ratio (LER), and number of soldiers remaining after time (t), we are able to compare the differences between our two models. JANUS is a combat modeling software that will run a simulated battle under time and condition constraints that our design group specifies and return the output from the confrontation in terms of the MOE's mentioned above. Lanchester's Square Law is a differential equations based model that allows us to predict who should be the victor in a given confrontation given the initial force sizes and a calculated attrition coefficient. Comparing the output from these two models will allow us to compare and contrast the

differences between the two simulations, one being differential equations based and the other being discrete dynamical systems based.

Advisor: LTC William Fox, USMA

Reassigning Marine Corps Reservists To Improve Readiness

MIDN Jeremy L. Leiby
US Naval Academy

A linear programming (transportation) model has been constructed using an assignment approach to help the Marine Corps Reserves better assign reservists to units in a geographical area. The area used in the pilot model given is Southern California. The Marine Corps has over 40 reserve units in this area. Some units are over manned while others are undermanned. If a unit is too drastically undermanned it can not perform its mission and can not be deployed operationally. The problem addressed is how to reassign and/or retrain the current population of reservists in Southern California to achieve a minimum of 90% manning in as many units as possible. Reservists are recruited and receive Marine Occupational Specialty (MOS) training for specific billets at specific reserve units. Before being accepted for training in a particular MOS a Marine must score above a certain level on a standardized test. Reassignment/retraining decisions are based upon such factors as billet vacancies that a Marine is qualified to fill based upon his test scores, rank, proximity to the units where vacancies exist, and the cost of retraining the Marine for a different MOS.

The "sources" used for the transportation model are sets of Marines, based on current unit, current rank, primary MOS, and standardized test score. The "destinations" for the model are sets of billets, based on the unit, rank, billets, MOS, and required score. The objective function is a utility function based on the distance between the location of the unit to which a Marine is currently assigned and the location of the unit to which the Marine is reassigned. A penalty for retraining is also included. For example, suppose a choice is to be made between reassigning a Marine to a billet with the same MOS at another unit and retraining the Marine to fill a billet at the same location but with a different MOS. If the distance between the units is less than 100 miles, then reassignment is favored by the utility function. If the distance between units is greater than 100 miles, then retaining is favored. There are two reasons for these choices. First, retraining results in monetary cost to the Marine Corps while reassignment does not. Second, assignment to a unit more than 100 miles from a Marine's place of residence requires a waiver and the Marine must be willing to accept the assignment. The objective function to be minimized is then a sum of the retraining penalty and a weighted distance between the units. Computational results will be provided.

Dynamic Markov Compression As A Tool For Comparing DNA Sequences

MIDN J. Michael Montgomery
US Naval Academy

My goal is to apply the technique of Dynamic Markov Compression to the problem of locating dissimilarities between DNA sequences. DNA sequences can be considered as strings of characters (A, C, G, T) Dynamic Markov Compression is a compression technique which dynamically constructs a finite state machine describing frequently-observed patterns in a string to be compressed. The efficacy of compression can be used as a measure of the state machine's success in predicting patterns in the string. I modified a C program (written by Tong Lai Yu of the Department of Computer Science at California State University, San Bernadino) to fit the needs of this project. This program uses Dynamic Markov Compression to compress large binary files. I made several changes to the program to fit the task of comparing DNA sequences: adding the capability to save the state machine derived from a given string, to read a pre-existing state machine and compress statically, and to report on compression efficacy for portions of a string. This report will show the results of the testing done on both simple artificial strings, as well as naturally-occurring DNA sequences.

Modeling The Distribution Of Chaotic Orbits

C1C Paul Emslie and C1C Joel Hetzer
US Air Force Academy

The study of chaos is a relatively new mathematical concept. One characteristic of chaos is sensitive dependence on initial conditions. Sensitive dependence might roughly be defined as magnification of error when the function or system is iterated several times. This property, however, is not fully descriptive of chaos, because some systems may magnify error without being chaotic. Therefore, another property we might add is that the system will exhibit mixing or blending.

An inherently chaotic system is vastly different from simply a random system in that for a given input x, the system will always return the same y. In contrast, a purely random system will generate multiple and unpredictable outputs for a single input if it is tried multiple times.

For our study, we have concentrated on three parameterized families of chaotic functions, the members of which map the unit interval back into itself. These three are the shift map f(x):=ax Mod 1, the tent map f(x):=a(2 Abs(x-1/2) +1), and the logistic map f(x):=ax(1-x). Our goal is to find out where the orbits of these functions spend most of their time in the interval [0,1], and then to construct a probability density function (pdf). Certain points are of interest in our analysis of a mapping. These points are the fixed points (where $f(x) = x$), the periodic points (where $f^n(x) = x$), and the critical points (where the first derivative is 0 or undefined). We note that the function f(x)=2x Mod1 has a uniform pdf, while the pdf for the function f(x)=4x(1-x) is decidedly non-uniform. Nearby parameters give rise to much more complicated pdf's.

Advisor: Dr. Brad Kline, USAFA

Calculus Enhanced with Computer Algebra and Graphing Using the TI-92

WHAT: A reform calculus short course sponsored by the United States Military Academy and The Ohio State University, and partially funded by Texas Instruments.

WHO: University, college and high school calculus instructors.

WHEN: July 27 - 31, 1998

BY: Mary Ann Connors, USMA and guest lecturer Frank Demana, The Ohio State University.

- Each participant will have loan of a TI-92 for the week. Computer Based Laboratory instruments will also be available for data collection. Real world applications and other calculus reform pedagogy will be featured.

- Continental breakfast, snacks, lunch and instructional materials will be provided. One afternoon or evening meal will be during a cruise on the Hudson River.

- Texas Instruments will have reduced prices on the TI-92 ($100), CBL ($110), Graph Link Software ($30), and other TI products. Purchases are limited to one calculator and one other item. (Prices and items are subject to change.)

- Air-conditioned hotel rooms are available at conference rates of $53 single occupancy and $83 double. Please indicate Booking #2948 when making reservations at the Hotel Thayer (914) 446-4731.

- There are a limited number of spaces available. Applicants will be accepted on a first come - first serve basis upon receipt of the $130.00 registration fee (payable to MACC).

REGISTRATION / QUESTIONS? CONTACT:
LTC Kathleen Snook
Department of Mathematical Sciences
West Point, New York 10996
Phone: (914) 938-4544 fax: (914) 938-2409
e-mail: ak7056@exmail.usma.edu