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Optimal Mix of Army Aviation Assets

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The Army plan for future heavy division attack helicopter battalion organization calls for a similar organization to that which exits today: three attack companies consisting of three scout helicopters and five attack helicopters each, for a total of nine scouts and 15 attack helicopters per battalion. The scout to attack helicopter ratio has been fairly consistent over the last thirty years. With the current fielding of AH-64D Longbow Apache and development of RAH-66 Comanche helicopters, it seems worthwhile to evaluate the number and types of helicopters that should be assigned to the attack helicopter battalion.

This project investigated the predicted combat effectiveness of a variety of attack helicopter battalion force structures. Both the AH-64D and theRAH-66 were investigated in scout attack roles at three or five helicopters per platoon, with a focus on survivability, lethality and detection capabilities.

The analysis contained in this technical report uses experimental design, multiple scenarios, multiple replications and confidence intervals to robustly investigate various battalion designs in an attempt to determine the best attack helicopter battalion force structure to meet the demands of the Force XXI and Army After Next.

This project required analysis of each of 16 design points in three high resolutions scenarios. These scenarios were developed in Janus 6.0 and an associated database was edited and refined to create advanced vehicles and aircraft which might be expected for a 2010 combat engagement. A full 2^4 factorial design of experiments, plus a base case, resulted in seventeen design points requiring evaluation. Ten replications of each design point in each scenario, along with a more detailed refinement of two missions, required over 600 combat simulation runs.

Analysis of output data revealed that Army development plans for future attack helicopter battalion force structures seem to be on track.

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Preface

This report provides the results of a study conducted at the United States Military Academy's Operations Research Center (ORCEN) which investigated various design proposals for an attack helicopter battalion. This unclassified research was conducted to enhance and support cadet education in the study of systems engineering at the United States Military Academy (USMA). A team of six cadets and one instructor from the Department of Systems Engineering assisted by performing combat simulation runs and preliminary analysis. Special thanks to Major Dave Briggs, and his SE402/403 Systems Design team of Cadets Ben Ambrose, Josh Glendening, Michael J. Hahn, Paul Schaffer, Jacob W. Shaver, and Abelardo Terpin.

The enclosed technical report is a product of the USMA Operations Research Center and does not represent official US Army data, results, policy positions or recommendations.

The Operations Research Center

The United States Military Academy's Operations Research Center provides a small, full-time analytical capability in support of the Academy's purpose and mission, the goals of the academic program and the disciplines of systems engineering, operations research and engineering management. The ORCEN is organized under the Office of the Dean as an Academy Center of Excellence. It typically employs about five full-time Army analysts; at any point in time, about a half-dozen Department of Systems Engineering and Department of Mathematical Sciences military and civilian faculty, together with students of the Military Academy, are working on a part-time basis on ORCEN projects. The ORCEN is co-located with the Department of Systems Engineering in Mahan Hall, West Point, NY and is sponsored by the Assistant Secretary of the Army (Financial Management).

The goals of the Operations Research Center include: enrich cadet education; enhance the professional development opportunities of Academy faculty by providing opportunities to engage in current issues and areas of importance to the Army; establish and maintain strong ties between the Academy and the Army; and remain abreast of and integrate new technologies into academic programs. Fully staffed and funded since Academic Year 1991, the ORCEN has made significant contributions to the Army's analytical efforts.

Contents

Executive Summary

The Army plan for future heavy division attack helicopter battalion organization calls for a similar organization to that which exists today: three attack companies consisting of three scout helicopters and five attack helicopters each, for a total of nine scouts and 15 attack helicopters per battalion. The scout to attack helicopter ratio has been fairly consistent over the last thirty years. With the current fielding of AH-64D Longbow Apache and development of RAH-66 Comanche helicopters, it seems worthwhile to evaluate the number and types of helicopters that should be assigned to the attack helicopter battalion.

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Analysis of output data revealed that Army development plans for future attack helicopter battalion force structures seem to be on track.

Chapter 1: Introduction

1-1. Purpose

This unclassified study explores the operational performance of several different heavy division attack helicopter battalion force structures in three scenarios. The goal of this study is to attempt to identify an optimal design by: (1) evaluating the relative effectiveness of alternative *types* of scout and attack helicopters, and (2) investigating relative performance differences by varying the *number* of a company's scout and attack helicopters.

1-2. Problem Statement

a. Army plans for the future heavy divisional attack helicopter battalion force structure (circa 2010) call for it to be similar to that used today; three attack helicopter companies, consisting of one scout platoon and one attack platoon each. Historically, we can see that the ratio of scout to attack helicopters has been fairly consistent (companies made up of approximately 36-40% scouts). As the Army is currently investigating some major changes in divisional force structure for Force XXI and Army After Next, in addition to incorporating advanced technology and capabilities, it seems like now is a good time to evaluate whether the historical ratio makes sense.

Reference	Scout	Attack	Systems
FM 1-100 Army Aviation (April 1959)	*No mention of attack helicopters. Helicopters used mainly for command, control, and logistic support.*		H-13, H-23, HU-1, etc.
FM 1-15 Aviation Battalion Infantry, Airborne, Mechanized, and Armored Divisions (December 1961)	*No mention of attack helicopters. Capabilities include airlift, aerial surveillance, reconnaissance, and target acquisition.*		Airmobile company, Aviation General Support Company
FM 1-110 Armed Helicopter Employment (July 1966)	UH-1B: "The principles of employing armed helicopters are still in the formative stage." "The number of armed helicopters used on a particular mission will depend upon the airmobile capability allocated to the ground commander and the responsive fire support required."		7.62 mm (750m max. eff. rg.) 2.75 inch FFAR (2500m) AGM-22B (3500m) 40mm (1200m)
FM 1-100 Army Aviation Utilization (October 1971)	Offensive missions include: tactical escort, reconnaissance, fire support, economy of force, security missions, collecting information, engaging counterattacking forces, penetration, exploitation, counterattack, and pursuit.		2.75 inch FFAR 40mm grenade launcher ATGM 7.62mm 20-/30-mm
ARCSA III: FM 1-15 Aviation Reference Data (September 1977)	4x OH-58C	7x AH-1S	TOW 2.75 inch FFAR 20mm
AOE	4x OH-58C	6x AH-64A	SAL Hellfire 2.75 inch FFAR 30mm Stinger
ARI: Aviation Attack Battalion Study Final Report (October 1993)	3x AH-64A	5x AH-64A	SAL Hellfire 2.75 inch FFAR 30mm
ARI Interim: Aviation Force Structure (January 1997)	3x AH-64D	5x AH-64D	RF Hellfire 2.75 inch FFAR 30mm Stinger
ARI Objective: Force XXI Heavy Division Conservative Heavy Design (FY2010 Objective as of 14 May 1997)	3x RAH66	5x AH-64D	RF Hellfire 2.75 inch FFAR 20mm 30mm Stinger

Table 1-1: Evolution of the Attack Helicopter Company

b. Comanche's role as "quarterback of the digital battlefield" is still up in the air. The Army Times reported in its April 13, 1998 issue that the 1997 Quadrennial Defense Review recommended that the Army cannot afford to develop all of its advanced technology programs ("Comanche faces cloudy future", page 28). A review of Comanche's added value to the attack helicopter battalion mission could help decision makers determine whether to continue to allocate resources towards this project.

1-3. Related Study

Technical Report TRAC-TR-0993, "Aviation Attack Battalion Study Final Report," October 1993, TRADOC Analysis Center – Operations Analysis Center, Production Analysis Directorate, Fort Leavenworth, Kansas. This study identifies, as part of the Aviation Restructuring Initiative (ARI), the benefits and liabilities involved in replacing the OH-58C (Kiowa) with the AH-64A (Apache) as the scout helicopter in the heavy division attack helicopter battalion.

1-4. Assumptions

a. The scenarios used in the study are representative of likely situations for employment of attack helicopter battalions.

b. Threat doctrine and equipment projections are representative of future enemies.

c. Projected capabilities of advanced aircraft being studied can be modeled by making appropriate database changes relative to current aircraft. Surrogate data substituted for identified data deficiencies sufficiently represent the systems involved.

d. Future attack helicopter battalion organization (three attack companies, one each scout and attack platoon per company) and roles will not change from current organization and roles.

1-5. Scope

a. Limitations

(1) This was an unclassified study. As such, it allowed cadets at the United States Military Academy to participate in this project without regard to classification restrictions. Much effort was placed in accurately replicating these scenarios without using classified data. While the system databases used were not classified, we believe they closely replicated the combat systems specifications.

(2) The effectiveness analysis focused on evaluating the attack helicopter battalion in its primary role -- attack. The study did not attempt to measure the value of reconnaissance or any other roles planned for the AH-64D Longbow Apache or RAH-66 Comanche.

(3) The focus of the study was limited to performance and effectiveness analysis, and did not attempt to identify sustainment or personnel issues associated with the alternative force structures. Furthermore, many aspects of the technology found in the advanced aircraft cannot be modeled with current software packages. This fact limits the study to the named measures of effectiveness, and does not allow investigation of such improvements as information sharing, target hand-off, and situational awareness.

b. Constraints

(1) The basis for performance and effectiveness comparison is the current heavy division attack helicopter battalion. The force structure for this unit consists of a pure AH-64A Apache battalion, composed of three scouts and five attack helicopters in each of three companies.

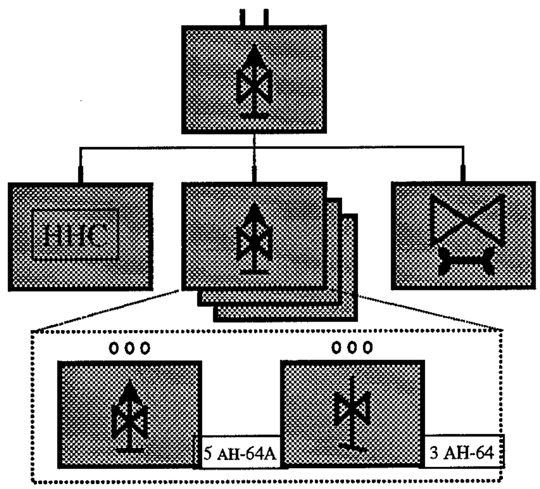


Figure 1-1: Base case

(2) This study considers only AH-64D Longbow Apache and RAH-66 Comanche helicopters as possible candidates for inclusion in future attack helicopter battalions. The direction of Army Aviation is towards advanced aircraft which will rely heavily upon digitization. This rules out consideration in this study of older technology, such as AH-64A (other than for comparison purposes), OH-58D(I) Kiowa Warrior, and AH-1 Cobra.

(3) Only attack helicopter battalions for heavy (i.e., armor or mechanized infantry) divisions are evaluated. This narrows the focus of the study which does not consider other types of attack helicopter units, such as light or airborne division attack helicopter battalions or cavalry units.

(4) The high-resolution scenarios (HRS) are derived from the TRADOC Analysis Center's Gist Book. Because of the unclassified nature of the study, we used the gist book's basic approach and war game summary, along with sketches provided by the Air Maneuver Battle Lab at Ft. Rucker to create the scenarios on representative terrain in Janus 6.0 software. We used HRS 59.0 (Army Aviation Artillery Air Force Attack (SWA)) and HRS 37.0 (Mechanized Brigade Attack (EUR)) to represent a range of potential missions that a heavy division attack helicopter battalion may be called upon to perform. These scenarios are further described in section 3-2.

Chapter 2: Methodology

2-1. Study Methodology

The analytical tools used to compare the various alternatives included static comparisons, combat modeling, experimental design, and statistical significance. Each analytical tool focused on providing measures of performance and effectiveness which could provided insights into the effectiveness of the base case and alternative designs.

a. Study plan: The following figure shows the systems design process used during the study:

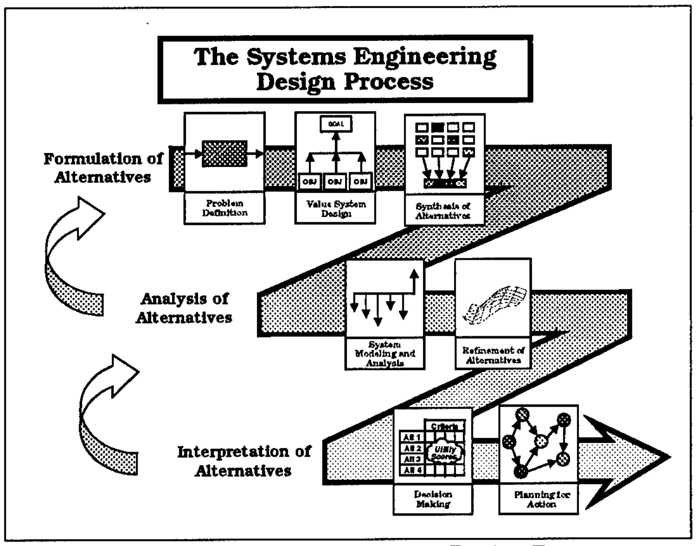


Figure 2-1: Systems Engineering Design Process

This process is the basis for the study of systems engineering at the United States Military Academy, West Point, New York. It serves as a guide to show students studying systems engineering the many factors that must be taken into account when designing large, complex systems. The top line of the chart, "Formulation of Alternatives," was applied during our development of the experimental design which covered a large range of possible attack helicopter battalion force structures. The next step, "Analysis of Alternatives," was represented in this study by the application of each alternative to appropriate scenarios. Finally, this report represents the culmination of the "Interpretation of Alternatives" phase.

The Army's doctrinal manual for attack helicopter operations (FM 1-112) states that employment options for attack helicopter battalions include attacking massed armored forces, attacking in depth, dominating avenues of approach, reinforcing ground forces by fire, defeating enemy penetrations, and protecting flanks. In order to ensure that our analysis covered a range of possible attack helicopter battalion missions, we evaluated performance for multiple battalion designs in three scenarios – Corps Artillery Group (CAG) attack, 2nd Echelon attack, and Close Battle / Hasty Attack. These scenarios are discussed in detail in Section 3-2 (Effectiveness Analysis). This mix of scenarios permits insight into the best overall battalion force structure, and does not rely on the results from just one scenario.

b. Analytic tools: We used static comparisons, combat modeling with multiple replications, experimental design, and measured statistical significance to help gain insights into the strengths and weaknesses of the battalion designs.

(1) Static comparison allows a side-by-side look at the major equipment and performance characteristics for the helicopter types under consideration.

(2) Multiple replications of stochastic combat simulation software (Janus 6.0) output allows analysis of a range of results. By performing a number of replications of the software run, we can gain insights about the mean and variance of our measures of effectiveness, rather than relying on only one replication. Controlling random number seeds used during the replications reduces a source of external variability.

(3) Experimental design allows comparison of output response when purposeful changes are made to the input variables [Montgomery]. In our case, there are four input changes (described later) which we desired to investigate over a variety of measures of performance and effectiveness (also described later). Analysis of all possible combinations of the factors leads to more complete interpretation of the results.

(4) Statistical significance. In order to compare the results from multiple replications, we want to investigate more than just the average results of multiple replications. Statistical significance allows us to state whether there is a difference in the observations based on the number of runs and the standard deviation of the results. This procedure allows us to create confidence intervals around the sample average where we would expect to find the mean value for a very large number of replications. Overlapping confidence intervals implies that we cannot definitively state that there is a difference between the mean values we observed during the experiment.

c. Performance analysis: Performance analysis focused on looking at specific characteristics of the helicopters. These capabilities were evaluated through static comparisons. The mission equipment, weapons loads, aircraft survivability equipment (ASE), average age, cruise speed, weight capacity, and observability characteristics of the aircraft were examined.

d. Effectiveness analysis: This area of analysis used simulation output to measure the lethality and survivability for the various battalion designs in each scenario. Because the nature of computer simulation relies heavily on the input database assumptions, one should keep in mind when interpreting the output that the analysis is representative of differences between systems. Simulation results help identify whether one system is better than the next, but only for specific areas of interest. By its character, simulation "is not an emulation tool with which the modeler attempts to create an exact replica of a system. Even if a computer were available which could handle every possible detail affecting every element of the system under study, the time and cost required to build the model would not justify the results." [Harrell]

2-2. Alternatives

a. Base case. The base case consisted of a battalion of 24 AH-64A helicopters formed into three identical companies of three scout and five attack helicopters each. This formed a basis for comparison to evaluate the modeling and effectiveness of the advanced aircraft types described below.

b. Aircraft types. Two types of advanced helicopters (AH-64D Longbow Apache, and RAH-66 Comanche) were evaluated for performance in both the scout and attack roles. Since there were two aircraft types and two roles, this led to an evaluation of the following battalion designs:

Scout platoon	Attack platoon
AH-64D	AH-64D
RAH-66	AH-64D
AH-64D	RAH-66
RAH-66	RAH-66

Table 2-1: Aircraft Types

It may be argued that the AH-64D scout / RAH-66 attack combination is not a logical force structure. The low-observable capabilities of RAH-66 seem best suited to the scout role; however, the AH-64D scout / RAH-66 attack combination is included in order to best evaluate all possible combinations in an experimental design. Helicopter role effectiveness is discussed in paragraph 3-2.

c. Platoon force levels. Two force levels (3 or 5 helicopters) were studied for each platoon. This allowed us to evaluate four combinations of helicopter types per company, and presented the opportunity to look at the effects of alternative ratios of scout to attack helicopters.

Scout platoon	Attack platoon	Note
3	3	*a*
3	5	*b*
5	3	*c*
5	5	*d*

Table 2-2: Platoon force levels

Notes
a: Fewer aircraft per company than current design
b: Current force level design
c: Reversed scout / attack force levels
d: More aircraft per company than current design

d. Experimental Design. The combinations of two aircraft types and two force levels per platoon led to the following experimental design. Base case runs were conducted separately (for comparison purposes only) and not included in the experimental design.

Scout platoon	Attack platoon	
3 AH-64D	3 AH-64D	
3 RAH-66	3 AH-64D	
3 AH-64D	3 RAH-66	
3 RAH-66	3 RAH-66	
3 AH-64D	5 AH-64D	ARI Interim design
3 RAH-66	5 AH-64D	ARI Objective design
3 AH-64D	5 RAH-66	
3 RAH-66	5 RAH-66	RAH-66 pure design (current force levels)
5 AH-64D	3 AH-64D	
5 RAH-66	3 AH-64D	
5 AH-64D	3 RAH-66	
5 RAH-66	3 RAH-66	
5 AH-64D	5 AH-64D	
5 RAH-66	5 AH-64D	
5 AH-64D	5 RAH-66	
5 RAH-66	5 RAH-66	

Table 2-3: Experimental Design

This is a full 2^4 factorial design which offers the benefits of experimental design described in paragraph 2-1b(3). Analysis of this design can be found in Appendix C.

2-3. Measures of Effectiveness

Measures of effectiveness (MOE) and performance used during this study are listed below. A discussion of the performance and effectiveness of the force structures is in Chapter 3, and more detailed discussions of confidence intervals and analysis of variance associated with each MOE are found in Appendices A through C. Instead of combining and weighting measures of effectiveness to determine the best force structure, each MOE is examined individually.

a. How do alternatives differ in the scout helicopter's ability to detect and acquire the enemy?

(1) Helicopter system capabilities; navigation, pilotage, and target acquisition capabilities.

(2) Detections over time; indicates the number of detections by helicopters during specific time intervals. The slope of the plotted results indicates the detection rate at which red vehicles are being discovered. Higher peaks on the graph indicate more detections taking place during a time interval.

(3) Number of detections made; indicates the total number of detections of red vehicles by helicopters during the scenario.

(4) Average and maximum distance from helicopters at which threat units are detected.

(5) Detections per blue helicopter loss; calculated by dividing the number of detections by helicopters divided by the number of helicopters killed, measuring cost of information gain. A larger number indicates that more enemy vehicles were detected for each helicopter killed.

b. How do the alternatives differ in firepower and ability to destroy enemy vehicles?

(1) Helicopter system capabilities; weapon types, maximum loads.

(2) Blue helicopter kills of threat systems over time; the number of kills of red vehicles made during a specific time interval. The slope of the plotted results indicates the rate at which red vehicles are being destroyed. Higher peaks on the graph indicate more enemy vehicles being killed during a time interval.

(3) Total blue helicopter kills of threat systems. The total number of kills of red vehicle types.

c. What are the differences in contributions of each alternative to survivability?

(1) Helicopter system capabilities; aircraft survivability equipment (ASE), radar cross section, infrared signature.

(2) Blue helicopter status over time; indicates the number of helicopters destroyed during a specific time interval. The slope of the graph indicates the casualty rate at which blue helicopters are being lost; a steeper slope indicates that helicopters are dying faster.

(3) Loss exchange ratio (LER). The number of red systems killed by helicopters divided by the number of helicopters dead at the end of the scenario. A larger number indicates that more enemy vehicles are destroyed for each blue helicopter lost.

$$LER = \frac{\#\, red\ vehicles\, killed\ by\, blue\ helicopters}{\#\, blue\ helicopters\, killed\ by\, red\ systems} x100\%$$

2-4. Janus 6.0 Model

The Janus model is an interactive, high-resolution, force-on-force, brigade-level, stochastic combat simulation. The principal focus of Janus is on ground maneuver and artillery units, but Janus also models rotary and fixed wing aircraft, engineer support, minefield employment and breaching, resupply, weather and its effects, and day and night visibility. The following list contains important capabilities and assumptions that allowed us to conduct the study:

a. Random number starting seeds were controlled to allow direct comparison of simulation runs with different configurations.

b. Automatic replication capability (using AutoJan) allowed scenario replication with events such as movement orders and artillery firing taking place at exactly the same time. AutoJan is a feature of Janus 6.0 which records controller commands and allows a "replay" feature following changes, for example, in random numbers or force definition. This reduced one source of variation by removing human interaction after the first replication, causing output differences based only on changed factors.

c. Janus allows programming of target priorities, so that if more than one type of enemy vehicle is detected, the simulated helicopter will engage the highest priority target first.

d. Assumptions. As mentioned in paragraph 2-1d, no simulation can cover all aspects of a system (especially a battle!), so the following assumptions helped overcome database limitations and model the future battlefield in Janus:

(1) Anti-helicopter threat is extremely high. This assumption allowed us to identify differences between advanced force structures because current anti-helicopter threat sometimes resulted in no losses for some design points in some scenarios.

(2) All scout and no attack helicopters have FCR. This assumption let us ignore the current fielding plan for FCR which calls for only 1/3 of each type aircraft to have FCR. In some design points, there were more scouts than attack aircraft, and it would have been difficult to model which aircraft had this capability.

(3) 20 km detection capability of FCR. Since unclassified FCR data was not available, it seemed reasonable to assume that FCR would have a significant advantage over current target detection systems. A sensor was created in the Janus database that has a high probability of detection at 20 km, assuming that the sensor has line-of-sight to the target.

(4) Same FCR used on AH-64D and RAH-66. Although the RAH-66 is supposed to have a miniaturized version of the AH-64D FCR, we assumed that its capabilities would be exactly the same.

(5) Increased sensor height for attack helicopters simulates info sharing. Since Janus does not simulate the passing of digital information, we compensated for this by increasing the sensor height on the attack helicopters. This increased height made it possible for the attack helicopters to fire from a masked position, simulating the relay of battlefield data from scout helicopters.

(6) Comanche IR detectability is 4 times smaller than Apache; cross section of Comanche-scout is 1/600 of Apache's. A big advantage of the RAH-66 is its low observability. We reduced the radar cross section of RAH-66 by reducing its physical dimensions in Janus to approximately $1/600^{th}$ of Apache's physical cross section. IR detection was changed by altering the thermal contrast field in Janus. These changes affected enemy probability of detection of Comanche.

e. Runs. Janus runs used to create data for the helicopter role analysis were made separately from the data used in the scout/attack force level analysis and the experimental design. This was done to derive more fidelity for the helicopter role analysis. Longer runs allowed better routes and movement techniques, resulting in more robust analysis of how specific helicopters performed in the scout and attack roles. Time and resource constraints prevented running long scenarios for all replications of each design point. However, the observed characteristics adequately represent the true performance differences between the alternatives.

f. Scenarios. Two high-resolution scenarios from TRADOC's Gist Book were used to examine three missions: deep attack against stationary targets, deep attack against moving targets, and close battle. These scenarios took place on vastly different terrain against a variety of target types.

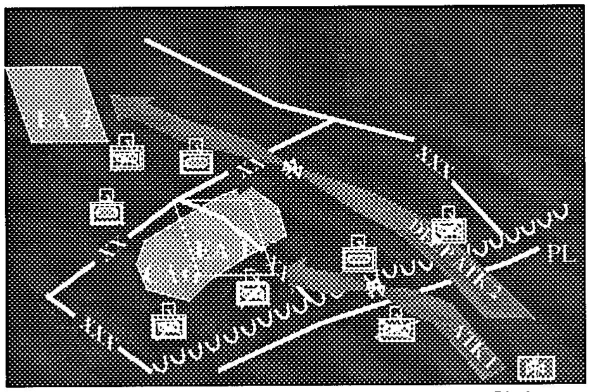


Figure 2-2: High Resolution Scenario 59.0

(1) HRS 59.0 Southwest Asia Corps Artillery Group (CAG) Destruction and 2nd Echelon Attack: A prepositioned brigade combat team conducts a delay against a Red corps (minus). Army aviation conducts cross-FLOT operations approximately 12 km deep on long-range fire support systems positions with the enemy artillery group. A second deep attack mission engages a moving second echelon division approximately 20 km deep into red territory. Environmental factors key to this scenario: Southwest Asia summer, rolling terrain, 0200 hours local time. The CAG attack and 2nd echelon attack missions were evaluated as separate scenarios and were not run simultaneously. The size of the Janus terrain database was approximately 1600 square kilometers.

(a) CAG Destruction mission target priorities – ADA, FA, other vehicles.

(b) Second Echelon Attack mission target priorities – ADA, tanks, other vehicles.

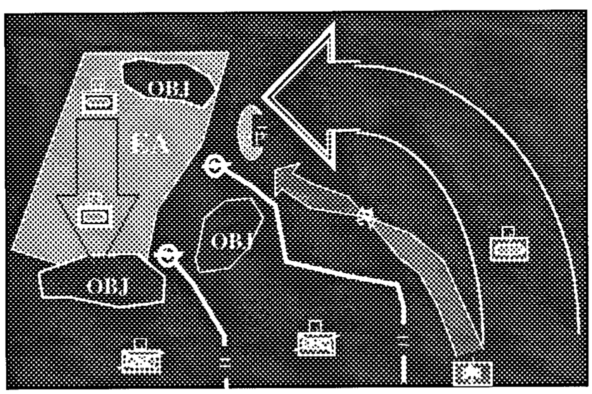


Figure 2-3: High Resolution Scenario 37.0

(2) HRS 37.0 Europe Hasty Attack / Close Battle mission: Red first echelon division penetrates Blue brigade combat team defensive positions. Red calls forward second echelon tank division to continue attack. Blue commander orders counterattack against first and second echelons. Attack helicopters engage Red first and second echelons in the close battle. Environmental factors key to this scenario: European winter, mountainous terrain, 0100 hours local time. The size of the Janus terrain database was approximately 100 square kilometers.

(3) Tactical events: We began each Janus replication with 100% operational readiness for each attack helicopter battalion. Suppression of enemy air defense (SEAD) missions by Blue artillery targeted known and suspected air defense locations along all routes. Artillery was also used to prepare the battle position (BP). Target priorities – ADA, tanks, personnel carriers, other vehicles.

Scenarios based in HRS 59.0 (i.e., CAG Destruction and 2nd Echelon Attack) begin with the attack helicopter battalion on the friendly side of the forward line of own troops (FLOT), with the scout platoon leading the attack platoon and one minute separation between companies. Routes are flown at 15 meters altitude and 130 knots airspeed. Scouts engage air defense threats along the route. Upon arrival at holding area (HA) approximately 5 km from BP, aircraft transition to 5 meters altitude and 70 knots. The attack helicopters stop at the HA while the scouts reconnoiter the BP. Scouts take positions forward in the BP and call forward attack helicopters until they are within Hellfire range of the targets. Hover altitude is 3 meters. After servicing the targets, attack platoons follow the scouts on a different route back to friendly territory. The scenario ends when all surviving aircraft cross the FLOT, for a total game time run length of approximately 35 minutes.

The Hasty Attack / Close Battle mission likewise had the attack platoons following the scouts, but pre-planned SEAD did not take place due to the nature of the mission. In this scenario, the Blue brigade has set up a hasty defense after encountering a Red tank division in a meeting engagement. Three Blue battalion task forces go online along the two natural avenues of approach from the north. The attack helicopter battalion is called upon to directly reinforce the western task force into a battle position adjacent to, and approximately 1 km behind the FLOT. Engagements are very heavy from both sides for the first 20 minutes after the lead regiments are destroyed. One attack company moves north adjacent to the western avenue of approach and engages the 2d echelon regiment. The scenario takes approximately 25 minutes of game time.

Chapter 3: Analysis

3-1. Performance Analysis

a. Helicopter characteristics. This table represents some of the significant differences in the navigation, pilotage, target acquisition, survivability, age, speed and weight of the aircraft considered in this study. Refer to Appendix E for a discussion of specific techniques used to model AH-64D and RAH-66 in the Janus database for this study.

	AH-64A	AH-64D	RAH-66
Navigation	Doppler radar Global positioning system	Dual global positioning system and inertial nav Tactical situation display	Moving digital map
Pilotage	FLIR Image intensification	Glass cockpit Enhanced fault isolation Improved sensors Multifunction displays	Wide-field of view helmet-mounted display Triple redundant fly-by-wire flight control system
Target Acquisition	FLIR/DTV/DVO	FLIR/DTV/DVO FCR	2nd gen. FLIR Low-light TV FCR
Aircraft Survivability Equipment	Radar warning Radar jammer Infrared jammer Chaff dispenser	Laser warning Radar frequency interferometer	Low observables
Year, First Unit	1985	1997	2007?
Cruise Speed	155 kt	139 kt	161 kt
Max Weight	17,650 lb	23,000 lb	17,174 lb

Table 3-1: Mission Equipment

b. Weapons load. This table represents the respective weapons load used in the scenarios for each type helicopter in the scout and attack roles:

	AH-64A	AH-64D	RAH-66
Scout	38x FFAR 8x SAL Hellfire 4x Stinger 1200x 30mm	38x FFAR 8x RF Hellfire 4x Stinger 1200x 30mm	6x RF Hellfire on fully retractable internal missile armament system. 500x 20mm
Attack	16x SAL Hellfire 4x Stinger 1200x 30mm	16x RF Hellfire 4x Stinger 1200x 30mm	14x RF Hellfire (6 internal, 8 external) 500x 20mm

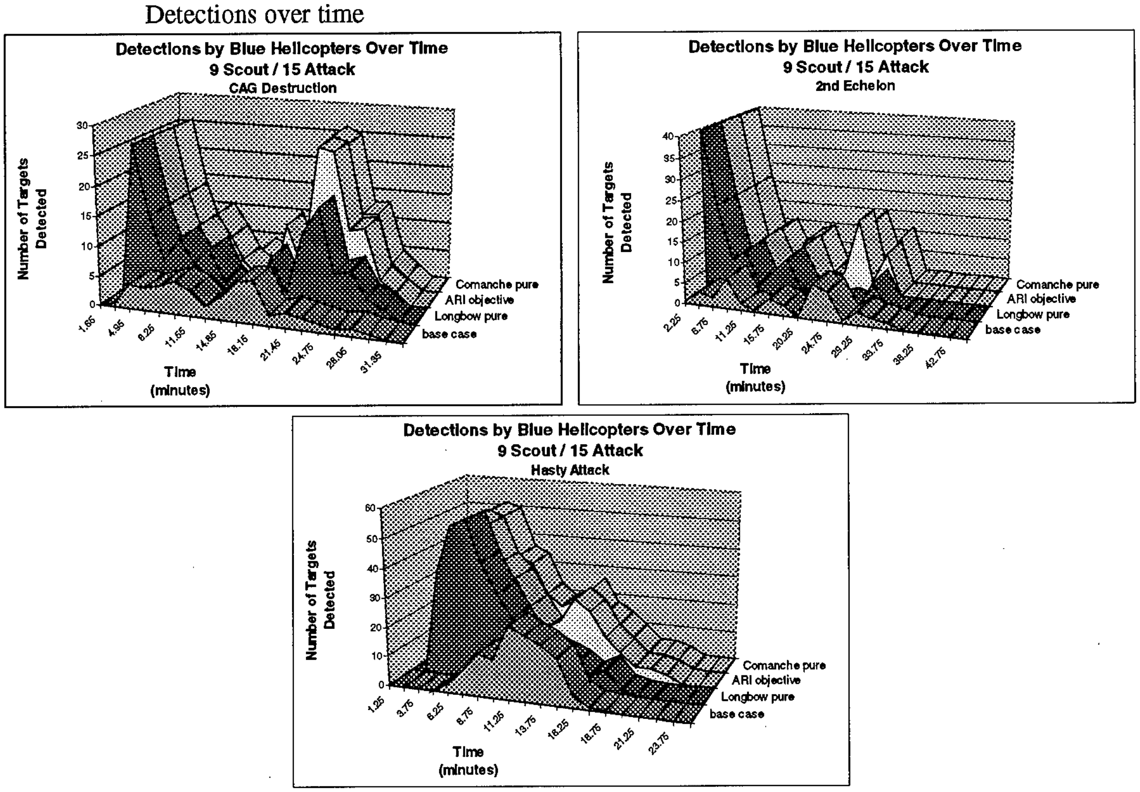
Table 3-2: Weapon configuration

3-2. Helicopter Role Analysis

The performance of AH-64D pure, RAH-66 scout / AH-64D attack (i.e., the ARI objective), and RAH-66 pure force structures, each with 9 scouts and 15 attack helicopters, are compared with the ARI base case. The following charts represent confidence intervals based on ten simulation replications. Additional graphs associated with these results are found in Appendix A.

a. Detections. Our assumption that only scouts have FCR allows us to limit our analysis of detections. For the base case, we used detections by all scout and attack helicopters; for all other cases only detections by scouts were used. This is a result of the increased sensor range and performance of FCR, as well as a means of reducing "artificial" detections by the attack helicopters; recall that it was necessary to place FCR sensors on attack helicopters in order to model information sharing. Any detections made by attack helicopter sensors were removed from the analysis.

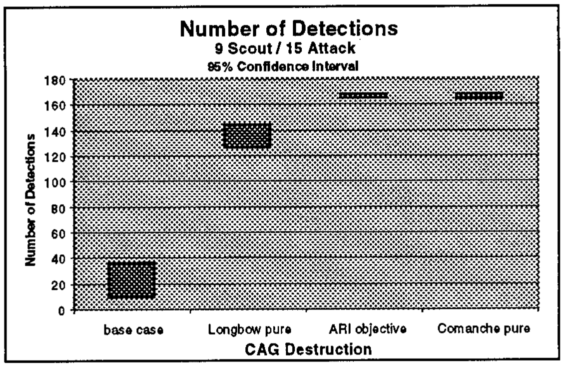
Detections over time

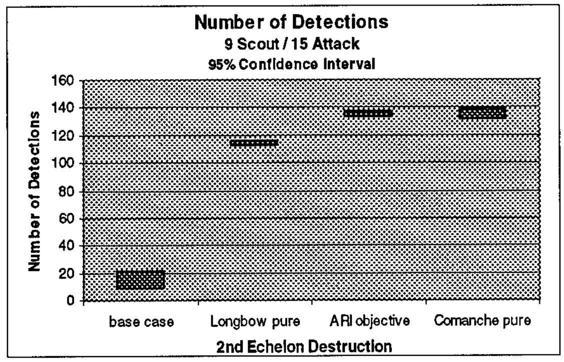


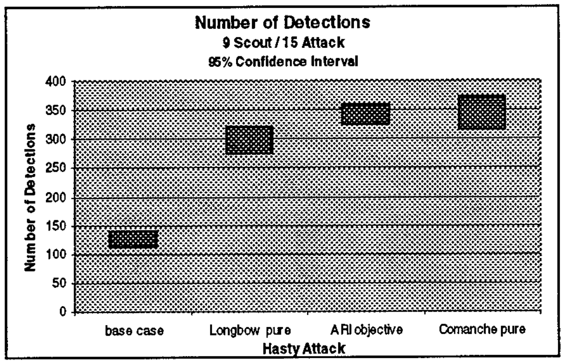
We notice a large spike of detections at the beginning of each scenario for the three proposed battalion types. This is due to the excellent performance of the fire control radar on the scout helicopters. The number of detections generally decreases over time as targets are destroyed. Since the radar performance is considered identical for AH-64D and RAH-66, the differences in the graphs are mainly due to helicopter survivability; as scouts are killed, the number of detections decreases.

*****

Number of detections made







These charts represent the total number of detections by scouts. All three scenarios show the same trend; addition of fire control radar greatly increases the number of detections, and the best performing units are those with Comanche scouts. Analysis of the confidence intervals shows that we do not expect a statistical difference for this MOE between the ARI objective and Comanche pure designs.

*****

Distance at which threat units are detected

CAG Destruction		
Force Structure	**Avg. Range**	**Max Range**
Base case	7.07	11.93
Longbow pure	12.64	19.98
ARI Objective	12.30	19.98
Comanche pure	12.34	19.98

2nd Echelon		
Force Structure	**Avg. Range**	**Max Range**
Base case	7.19	12.74
Longbow pure	14.38	19.90
ARI Objective	13.15	19.96
Comanche pure	13.16	19.96

Hasty Attack		
Force Structure	**Avg. Range**	**Max Range**
Base case	3.15	6.29
Longbow pure	5.22	10.56
ARI Objective	4.82	10.61
Comanche pure	4.84	10.65

The maximum detection range was limited to 20 km, and this is represented in the first two scenarios (southeast Asia, generally flat terrain, good visibility). The max range of the FCR is consistent among the proposed battalions, and appreciably better than the sensors on AH-64A.

In two of the scenarios, the Longbow pure battalion makes significantly fewer but longer range detections, and there is no significant difference between ARI objective and Comanche pure ranges. This may be a result of the timing of Blue helicopter deaths in the scenarios. Initially, detections are made at longer ranges since the helicopters begin the scenarios on the friendly side of the FLOT. As the scenarios progress, the two designs with the best survivability make more short-range detections as they conduct the battle and engage enemy vehicles. The Longbow pure design loses significantly more helicopters enroute to the battle position, resulting in fewer short-range detections, but also resulting in raising its average detection range.

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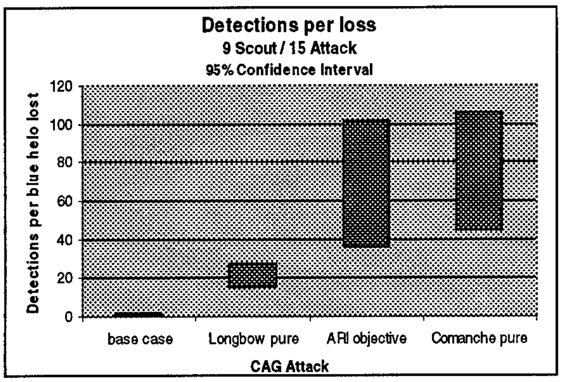
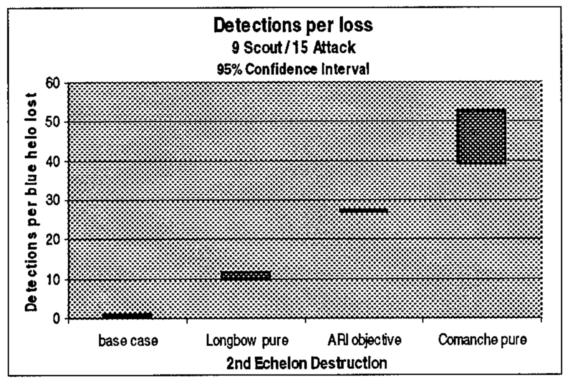
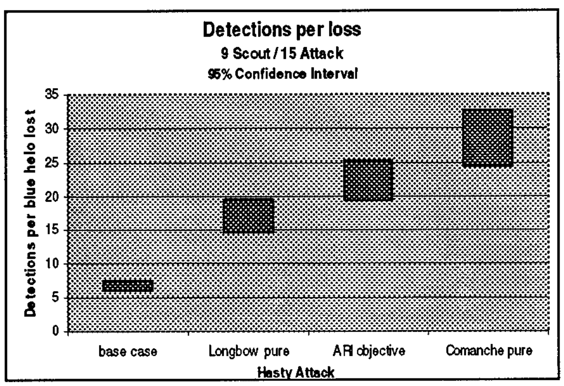
Detections per loss



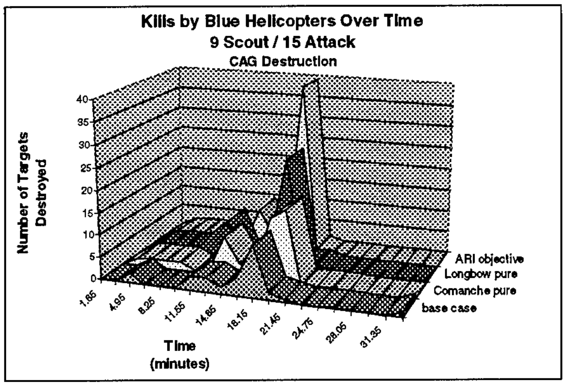


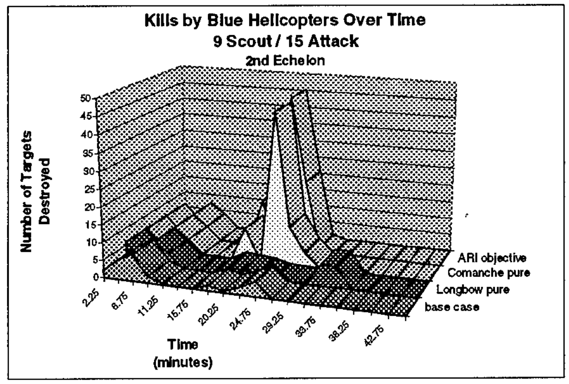


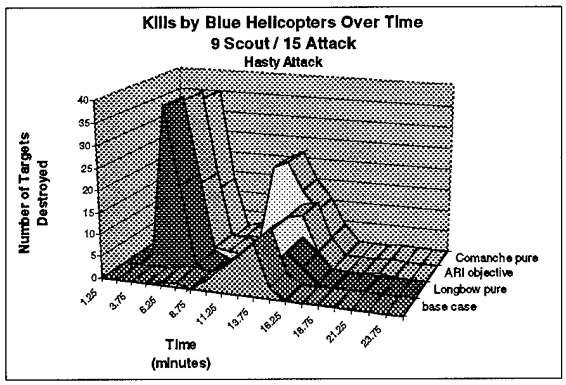
We notice a generalized pattern for each scenario: increasing detection-to-loss ratio as we move progressively through the base case, Longbow pure, ARI objective, and Comanche pure designs. This can be mainly attributed to survivability, since loss of fewer aircraft increases the ratio. Analysis of confidence intervals suggests that the Comanche pure design always has a better ratio than the Longbow pure design. The ARI objective confidence interval sometimes overlaps the intervals from the pure designs, implying that there is no statistical difference between the mean values for some missions.

b. Kills

Kills over time







In these charts, higher peaks corresponds to killing targets more quickly. The largest peaks in the first two scenarios represent the main engagement shots fired by the attack platoon. The smaller peaks just prior to the large peaks represent target engagements by the scout platoons in their attempt to clear the battle position while the attack platoons are moving forward from the holding area. Any kills prior to, or after, these two main peaks represent engagements along the routes, mostly against air defense units. This is especially noticeable in the second scenario, where there are many target engagements on the way to the battle position, and only a few on the way back to the friendly side.

Engagements in the hasty attack mission are represented by a spike early in the scenario. As seen in the analysis of detections, there are many enemy targets immediately observed. When the helicopters are within range, shots are immediately fired and vehicles are destroyed. The second main peak in this scenario represents the short-range cross FLOT engagements from one of the attack companies.

Performance in this MOE correlates to detections and survivability; undetected targets cannot be engaged, and lost helicopters cannot destroy enemy vehicles.

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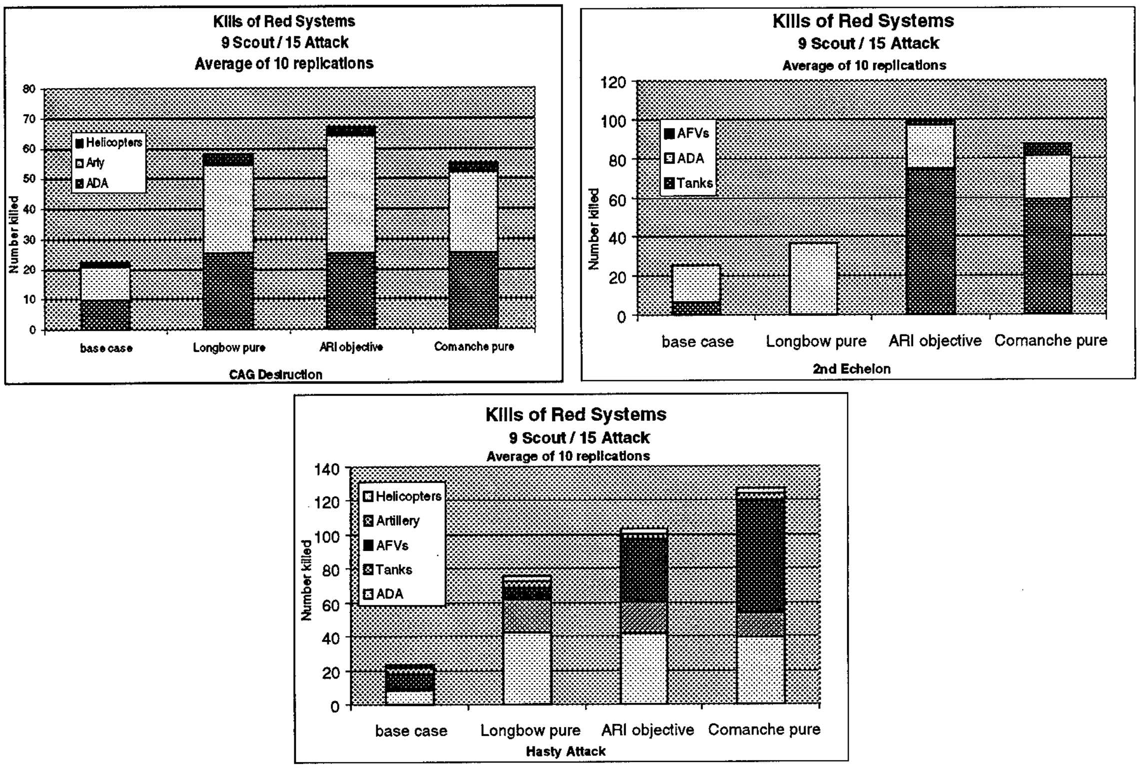
Total Kills



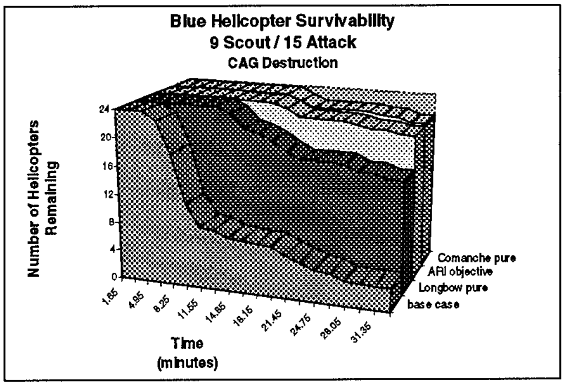
For the first two scenarios, the ARI objective force structure kills the most targets; the third scenario has the best performance by the Comanche pure design. For the CAG Destruction mission, the Longbow pure and Comanche pure force structures performed almost equally as well. In the 2[nd] Echelon mission, the Comanche pure design greatly outperformed the Longbow pure design; analysis of target types that were destroyed implies a problem with target priorities. In this scenario, the Longbow pure design killed ADA exclusivley. (This was noticed during preliminary analyis, and the design point was re-run with the same outcome. This result is surprising since it used the same database as the other scenarios, and this problem is not evident in those. We would expect that the kills would be similar to those for the Comanche pure design, as in the CAG Destruction mission.)

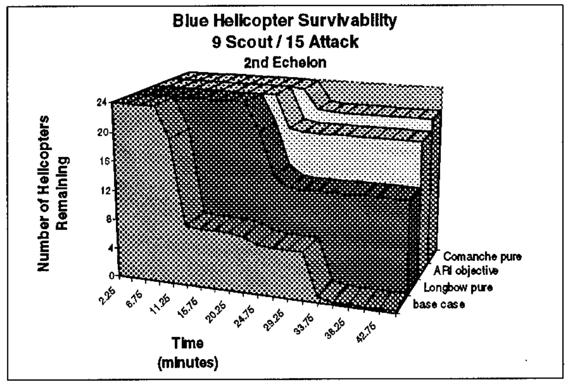
Another non-intuitive result concerns the base case in the first scenario. For this design point, the number of detections is greater than the number of kills. Recall that the detections shown in the graphs correspond only to those made by the scouts. Due to comparatively limited sensor performance, AH-64A base case attack helicopters may have a tendency to fire more autonomously-designated missiles than the FCR-equipped force structures.

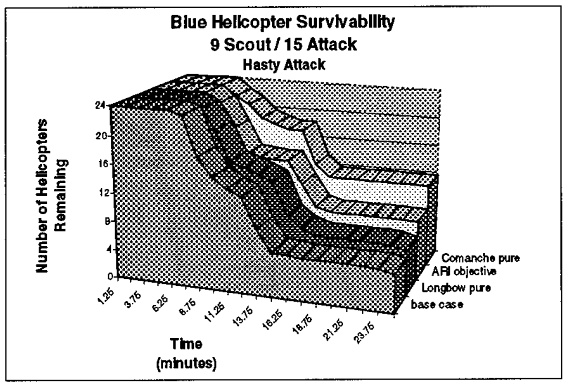
Kills of enemy weapon systems appear to be correlated to survivability and weapons load. The largest weapons loads are carried by the base case and Longbow pure designs; the smallest number of missiles is carried by the Comanche pure design.

c. Survivability

Losses over time







In these graphs, we observe that the Comanche pure design is the most survivable during all phases of the battle, followed by ARI objective, Longbow pure, and the base case. The steepest declines in the graphs show the most deadly portions of the missions; generally these occur as the unit approaches its battle position. For the base case, movement along the routes is especially deadly. For the first two scenarios, the ARI objective design performs almost as well as the Comanche pure design.

Statistically, the Comanche pure design always survives better than the Longbow pure design. In two of three missions (both deep attacks), there is not a statistical difference between the survivability of ARI objective and Comanche pure designs. In the hasty attack mission, the Comanche pure design stands alone as the most survivable.

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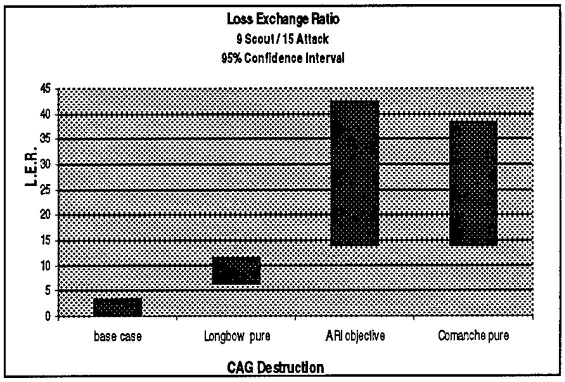
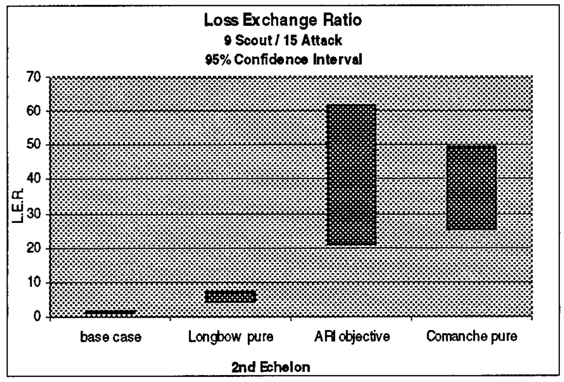
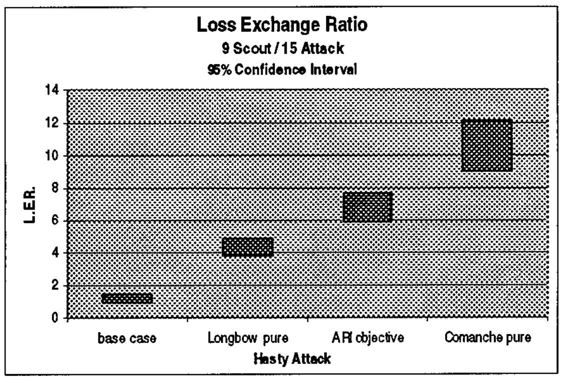
LER







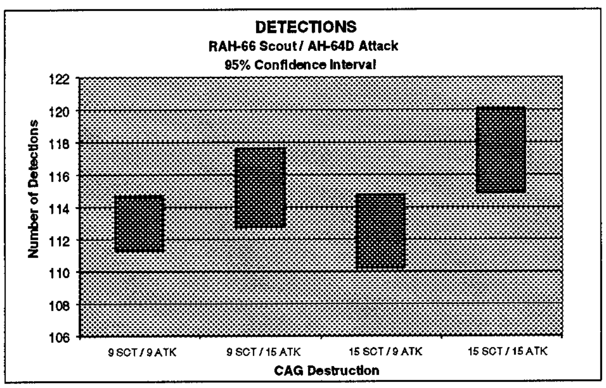
Again, there is no statistical difference between the results for the ARI objective and Comanche pure designs for the deep attack missions, and again, both have better results than the Longbow pure design. The differences between the average results in the hasty attack mission are all statistically significant.

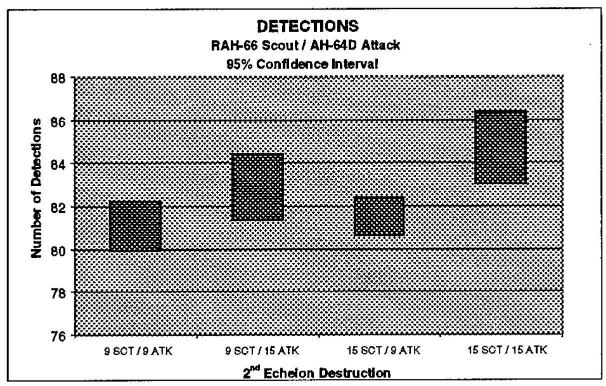
3-3. Scout/Attack Force Level Analysis

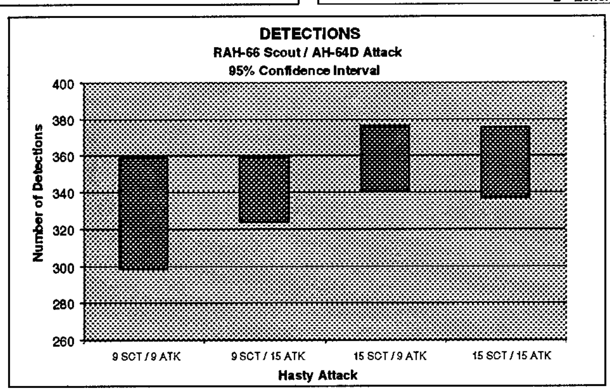
A review of the results found in section 3-2 implies that the ARI objective design performed as well or better than the Longbow pure and Comanche pure designs for most of the measures of effectiveness in the three scenarios. Therefore, all battalion designs in this section of the analysis use RAH-66 scout and AH-64D attack helicopters. (Section 3-4 contains analysis of the full factorial experimental design.) The following discussions compare the relative performance differences observed when altering the total number of scout and attack helicopters between 9 and 15 for the battalion: 9 scouts / 9 attack (9/9), 9 scouts / 15 attack (9/15), 15 scouts / 9 attack (15/9), or 15 scouts / 15 attack (15/15). Recall from section 2-4 that a different set of Janus runs was used to create this data, so some of the results presented in this section will differ from those shown in Section 3-2 (helicopter role analysis). However, we would expect a similar amount of *difference* in performance if the replications had been run for the same length as those in the helicopter role analysis. Additional graphs associated with these results are found in Appendix B.

a. Detections.

Number of detections made.



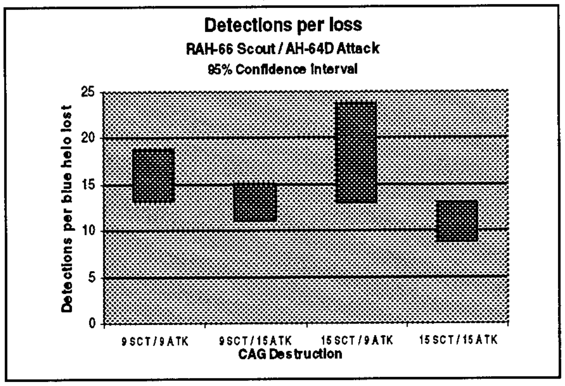


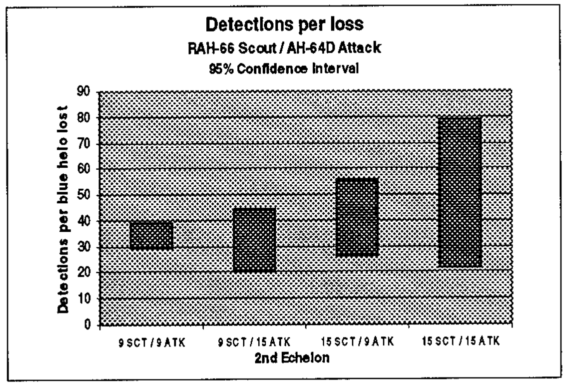


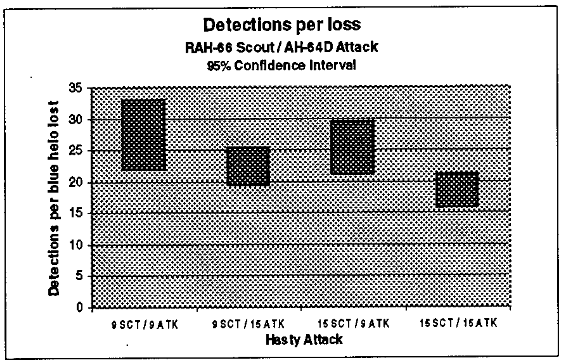
There are no large significant differences in the number of detections observed during any of the three scenarios when altering the number of helicopters in the platoons. In the first two scenarios, it seems as if the designs with 9 attack helicopters make fewer detections than the 15 / 15 design. This fact seems correlated to: (1) the lower quantity of point target weapon systems (Hellfire missiles) carried by the 9 / 9 and 9 / 15 designs, and (2) lower scout survivability because fewer threat weapons are destroyed as a result.

* * * * *

Detections per helicopter loss



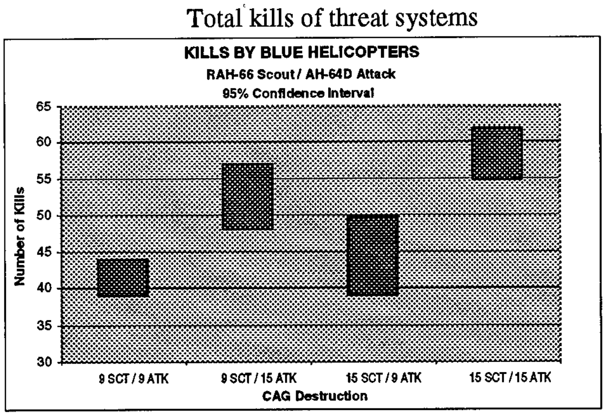


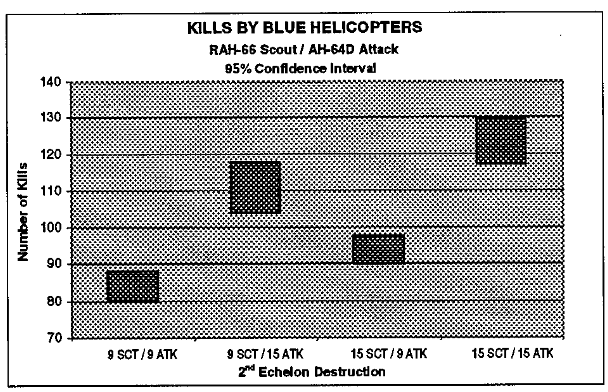


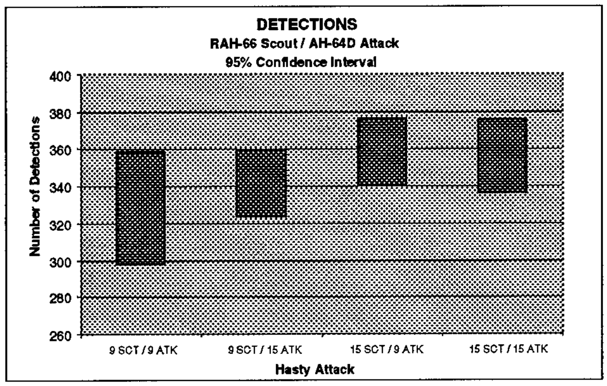
In two of three scenarios, the 15/15 design performed significantly worse than both the 9/9 and 15/9 designs. This phenomenon may be attributed to the lower survivability of AH-64D compared with RAH-66; more Longbow Apaches on the battlefield increases the chances that more helicopters will be lost, increasing the denominator and lowering the ratio. In the other scenario, there were no statistical differences.

b. Kills

Total kills of threat systems







The general trend shows that more attack helicopters allows the battalion to kill a larger number of enemy vehicles; this is especially true for the two deep attack scenarios. Also, in general, a larger number of scouts tends to increase the number of kills, but not as significantly as the increase due to a similar number of attack helicopters. This is an intuititve result—attack helicopters carry more missles than scouts. It follows that the battalion which kills the most enemy vehicles is the 15/15 design.

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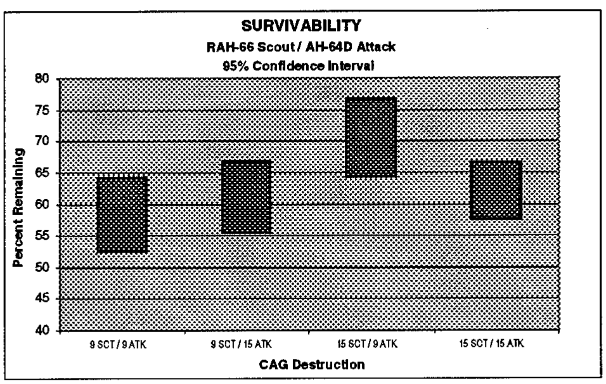
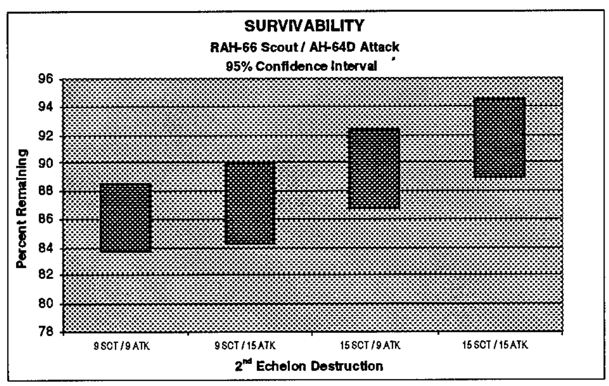
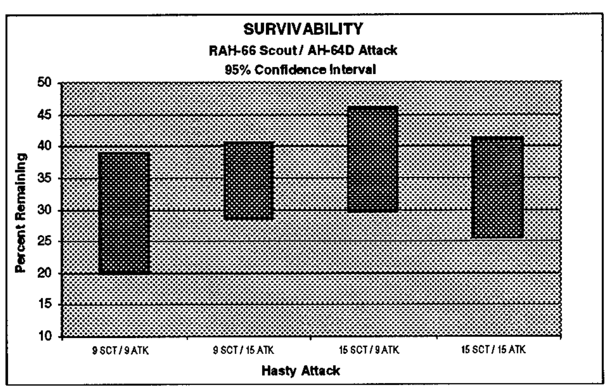
c. Survivability

Percent surviving



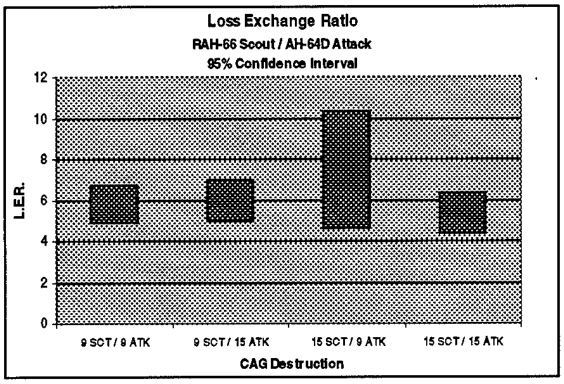


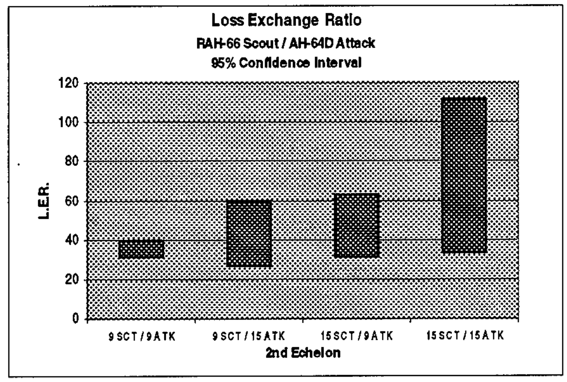


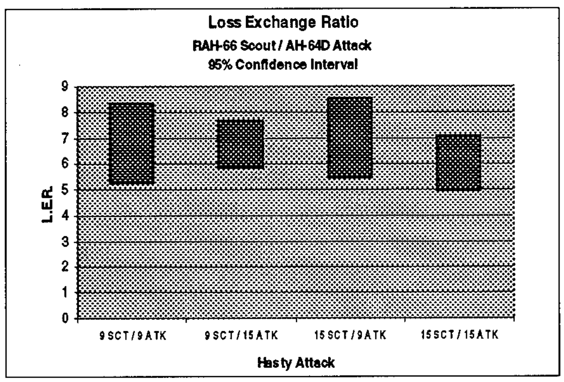
There are no large significant differences in the percentage of helicopters that survive during any of the three scenarios when altering the number of helicopters in the battalion.

*****

LER







There are no significant differences in the loss exchange ratio for any of the three scenarios when altering the number of helicopters in the battalion.

3-4. DOE Analysis

All combinations of AH-64D and RAH-66 force structures, each with 9 or 15 scouts, and 9 or 15 attack helicopters were analyzed using standard experimental design techniques. Pareto charts, estimated effects, and analysis of variance tables associated with these results are found in Appendix C. Summarized below are the major observations from an analysis of the experimental design:

a. Detections. Increasing the number of scouts generally leads to more detections. This is due to the fact that having more scouts means that there is a better chance for more detections to take place after a scout loss has occurred. Also, in the two deep attack missions, an increase in the number of attack helicopters also significantly increased the number of detections, perhaps because the increased missile carrying capacity resulted in more lethality to enemy threat systems.

b. Average detection range. In all three missions, we observe that AH-64D scouts make significantly longer-range detections. The cause for this phenomenon seems to lie in the combination of survivability and timing of detections, as mentioned in section 3-2. Further findings concerning average detection range are mixed and inconclusive.

c. Detections per loss. A common factor for increasing the detections per loss ratio during the three missions is scout type; RAH-66 in the scout role significantly increases the ratio. Furthermore, Comanche in the attack role was a significant factor for two of three missions.

d. Kills. Having more attack helicopters allows the battalion to kill more enemy vehicles. AH-64D was the better attack helicopter for two of the missions. The type of scout that gave the best performance for this MOE varied: Longbow Apache was better for one mission, Comanche was a better scout for another mission, and scout type was not significant in the third mission.

e. Survivability. Comanche survives best in either the scout or attack role. However, the number of attack helicopters also was significant for all three missions—it seems that having a higher proportion of attack-to-scout helicopters may tend to increase the percentage of helicopters that survive a given mission. [This result was not reflected in the analysis in section 3-3.] This suggests that the current and proposed designs with 3 scouts and 5 attack helicopters may be the most survivable. However, helicopter type is a much more significant factor than the number of helicopters in a platoon.

f. Loss exchange ratio. Scout type is significant in all three missions; Comanche in the scout role leads to increased LER. For two missions, Comanche in the attack role also had a significant impact.

Chapter 4: Findings and Conclusions

4-1. Findings. The purpose of this study was to explore the operational performance of different heavy division attack helicopter battalion force structures in three scenarios. The goal of this study was to attempt to identify an optimal design by: (1) evaluating the relative effectiveness of alternative *types* of scout and attack helicopters, and (2) investigating relative performance differences by varying the *number* of a company's scout and attack helicopters. The following findings review the insights gained during the analysis of the performance and effectiveness of the designs.

a. The following chart lists the best battalion design for each mission type. When more than one type of force structure is listed, then there was no significant difference in performance for that mission. The designs listed in this chart are all based on 9 scouts and 15 attack helicopters per battalion.

Mission	Number of Detections	Detections per loss	Kills	Survivability	LER
CAG Attack	ARI objective Comanche pure	ARI objective Comanche pure	ARI objective	ARI objective Comanche pure	ARI objective Comanche pure
2nd Echelon	ARI objective Comanche pure	Comanche pure	ARI objective	ARI objective Comanche pure	ARI objective Comanche pure
Hasty Attack	Longbow pure ARI objective Comanche pure	ARI objective Comanche pure	Comanche pure	Comanche pure	Comanche pure

Figure 4-1: Combined results

b. Changing the size of an attack helicopter battalion does not affect the number of detections of enemy vehicles by the helicopters. Scout helicopters with FCR were very good at identifying targets, and having more scouts did not necessarily increase the number of enemy vehicles found.

c. The number of enemy vehicles killed during a battle was directly related to the number of missiles engaging them. Attack helicopters carry more missiles than scouts, so attack helicopter type (AH-64D attack helicopters carried 16 missiles each; RAH-66 attack helicopters carried 14 missiles each) and platoon size were the biggest factors for killing targets.

d. Comanche helicopters were much more survivable on a high threat battlefield than Apaches. This is reflected in the survival rate for RAH-66 overall, and especially by the Comanche pure design during the hasty attack mission. The attack helicopter battalion's overall survival rate increased significantly when there were more helicopters in the attack platoons than in the scout platoons.

d. A synergistic effect took place when combining AH-64D attack platoons and RAH-66 scout platoons for deep attack missions. It seems that the Comanche scouts were very effective at surviving the anti-helicopter threat, and were successful in destroying that threat before it was able to engage the Apache helicopters. The AH-64D attack helicopters survived better, thus causing more missiles to be available for battle position operations.

e. Survivability of Comanche is the most important factor for high-threat missions, such as in the close battle / hasty attack scenario. The low-observable characteristics of RAH-66 seem to make it well suited for this type of mission. Survivability in a helicopter-hostile environment ultimately makes an impact on mission success (i.e., enemy destruction) and the ability to fight the next battle.

4-2. Conclusion

While the results in this study may not be identical to those done in a classified environment, we are confident that the differences between the alternatives are truly indicative of actual performance differences.

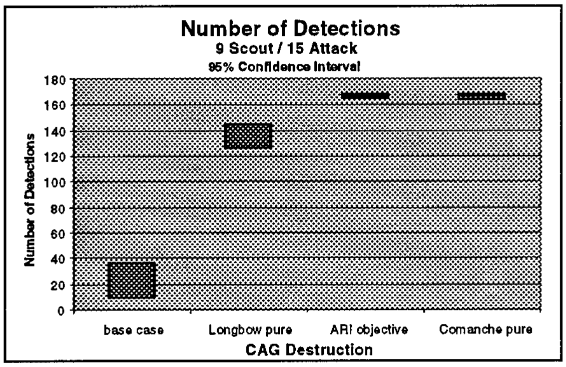
It seems as if the Army is on the right track in force structure development for the heavy division attack helicopter battalion. The transition from the current AH-64A pure battalion to a Longbow pure design represents a great leap in mission effectiveness for the attack helicopter battalion.

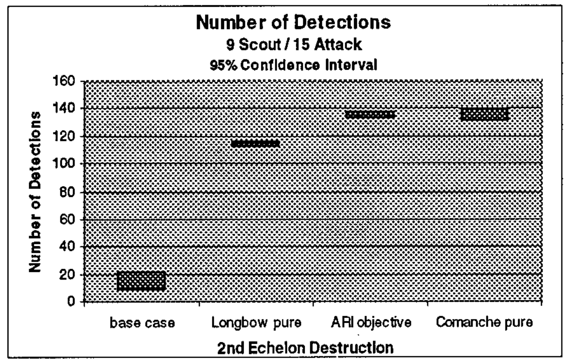
The ARI objective combination of nine Comanche scouts and fifteen Longbow Apache attack helicopters should cause another leap in mission effectiveness. Depending upon the scenario, the performance of a Comanche pure battalion could closely match or exceed the performance of the ARI objective battalion.

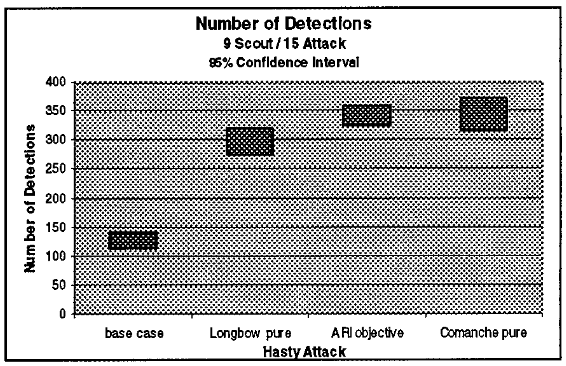
Appendix A. Aircraft Role Analysis

a. Detections: total detections by all helicopters for base case; only detections by scouts for all other cases.

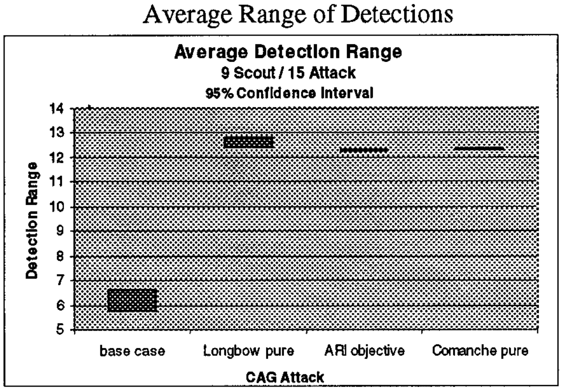
Number of Detections [CI]

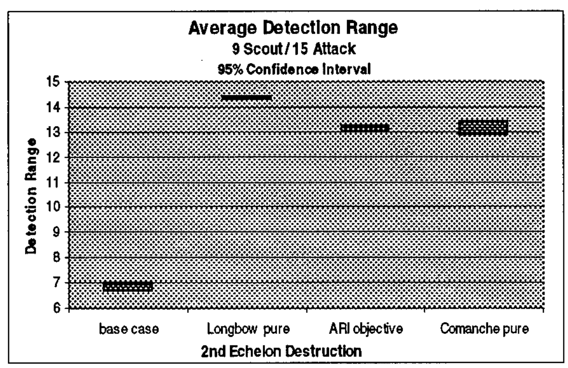


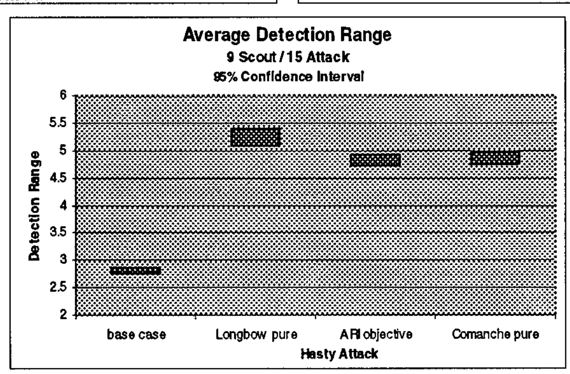




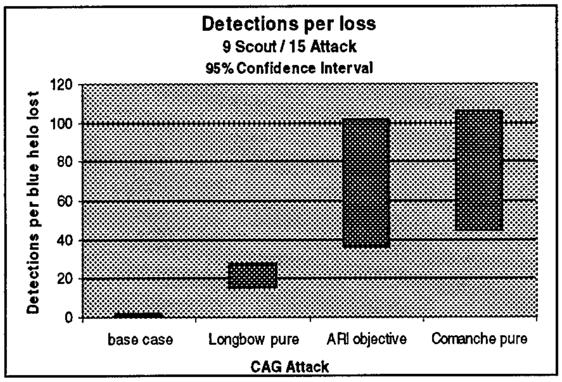
Average Range of Detections

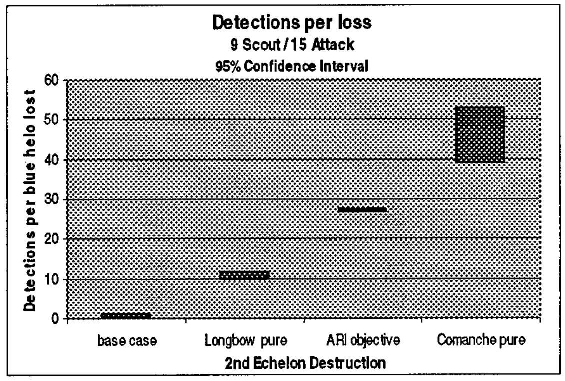


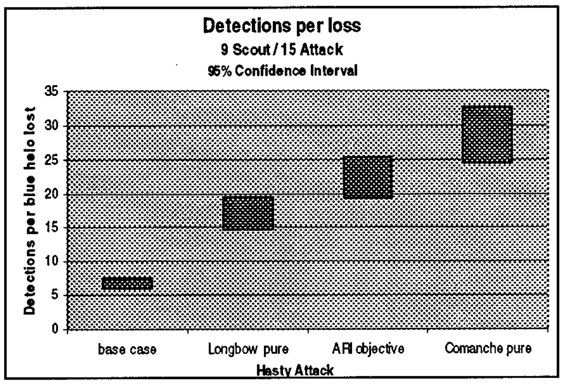




Detections per lost blue helicopter

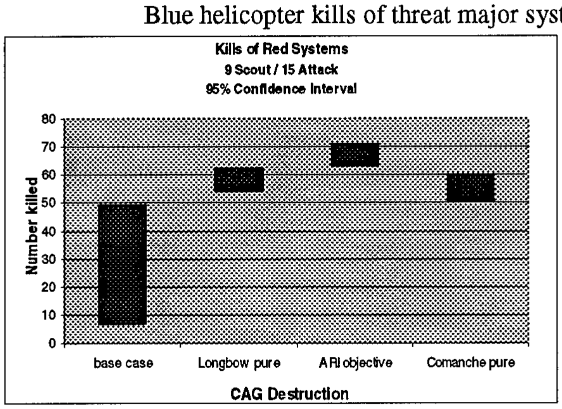


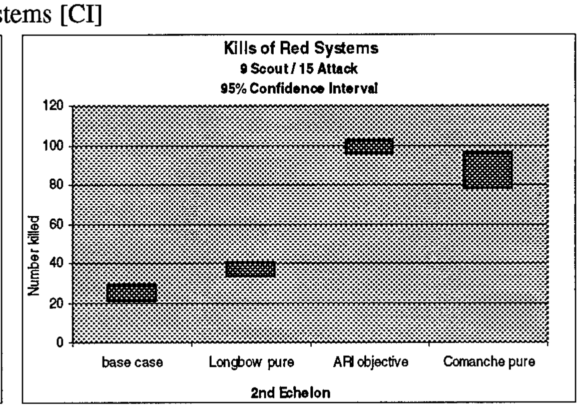


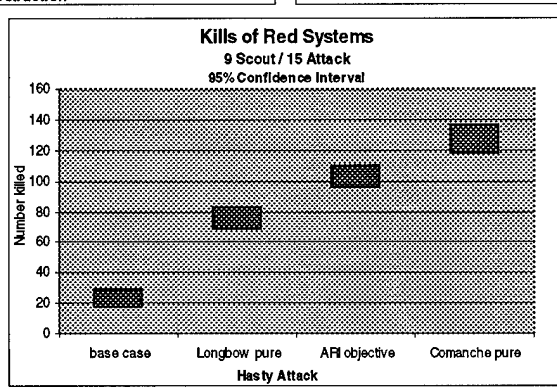


b. Kills

Blue helicopter kills of threat major systems [CI]

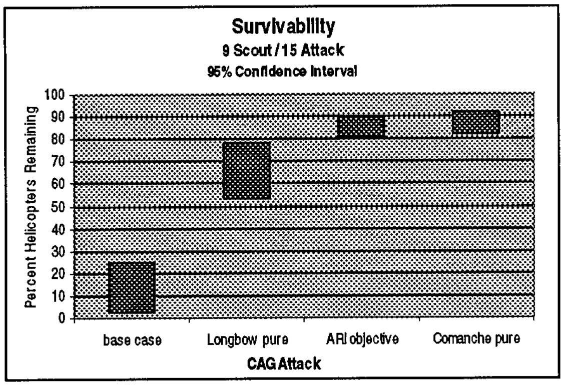


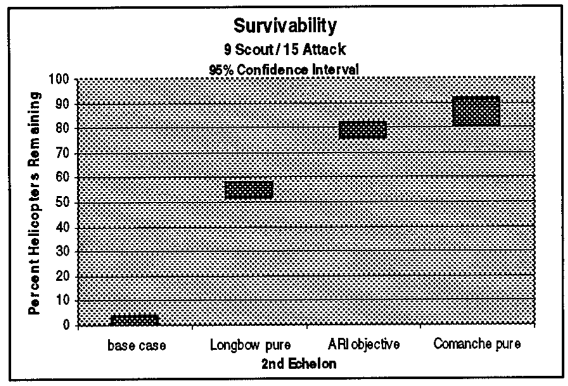


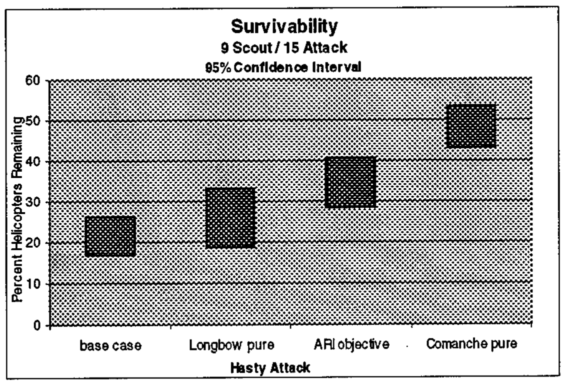


c. Survivability

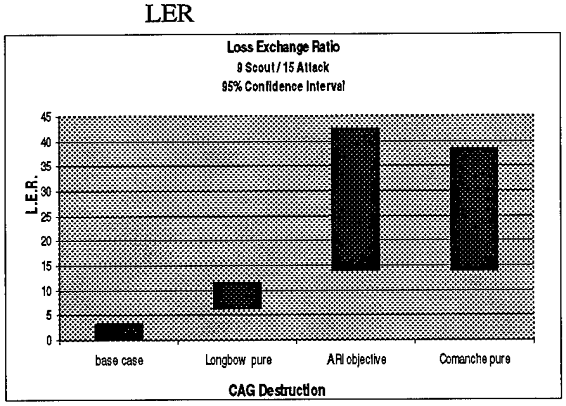
Blue helicopter losses [CI]

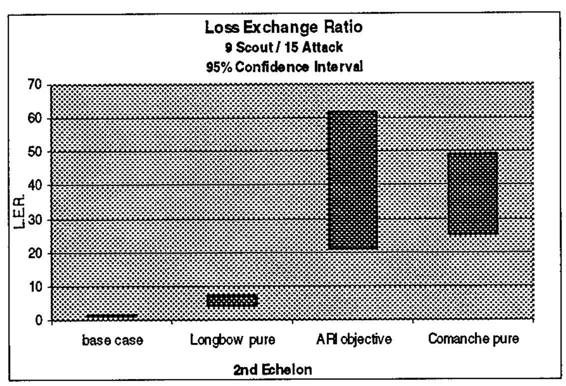


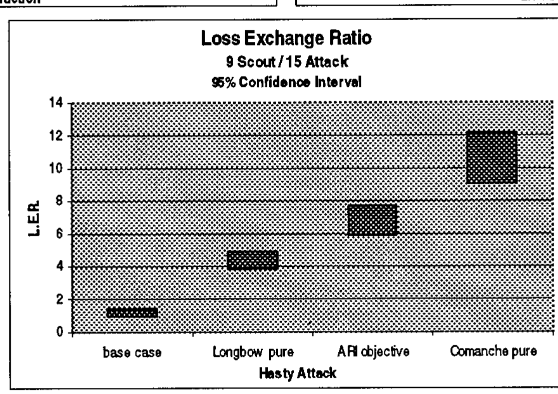




LER



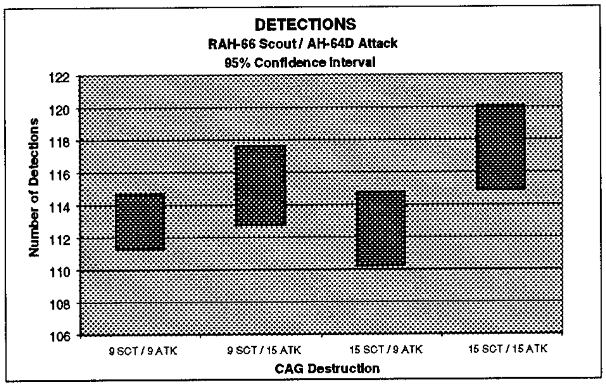


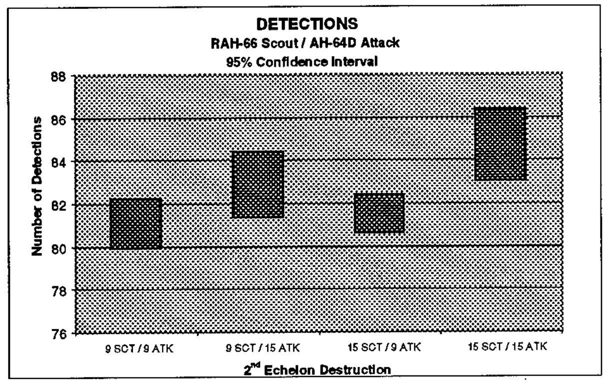


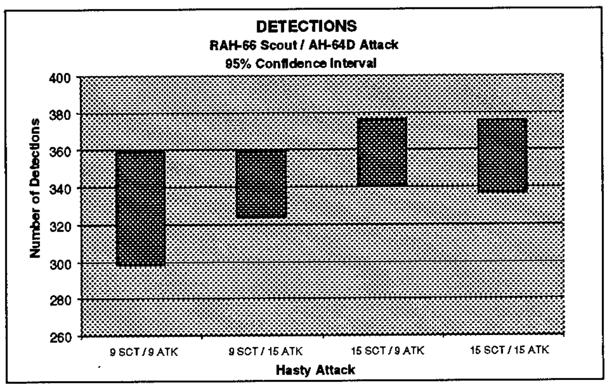
Appendix B. Force Level Analysis

a. Detections by scouts.

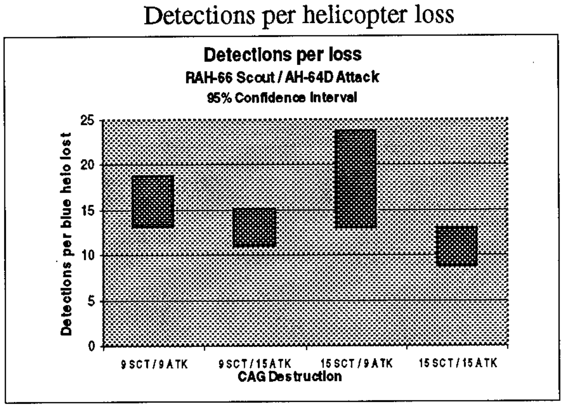
Number of Detections

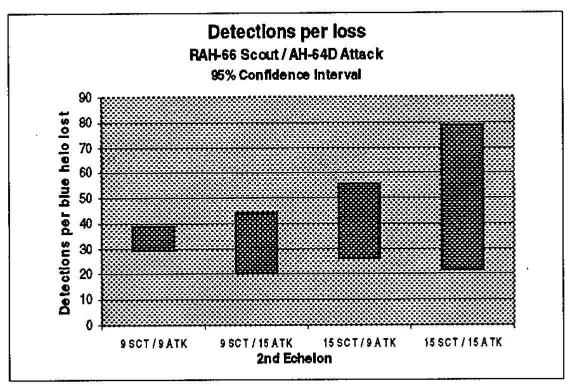


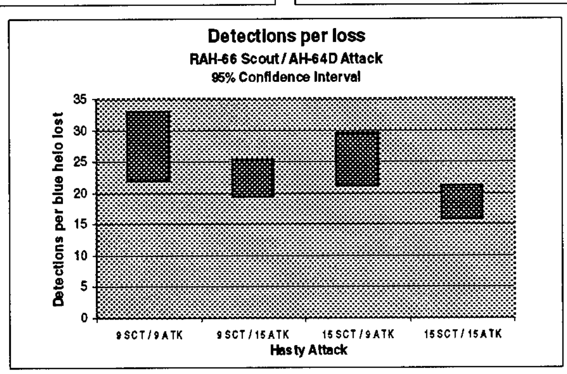




Detections per helicopter loss

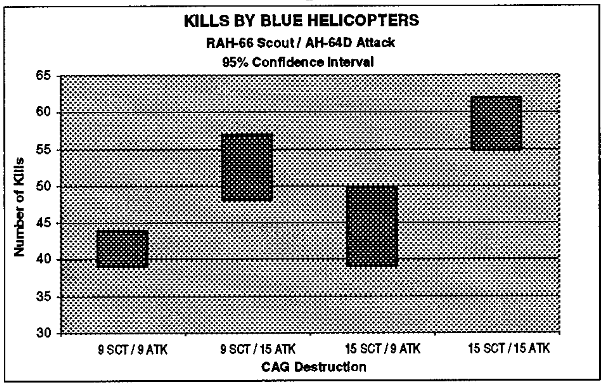


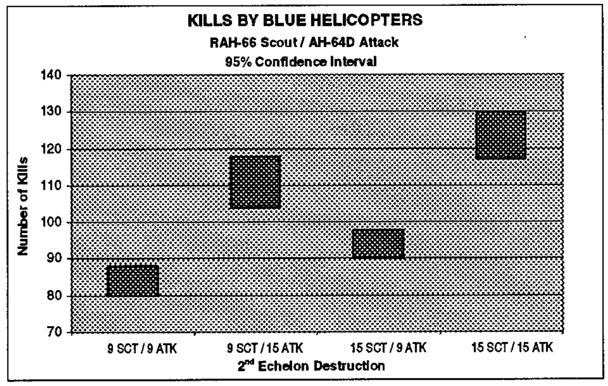


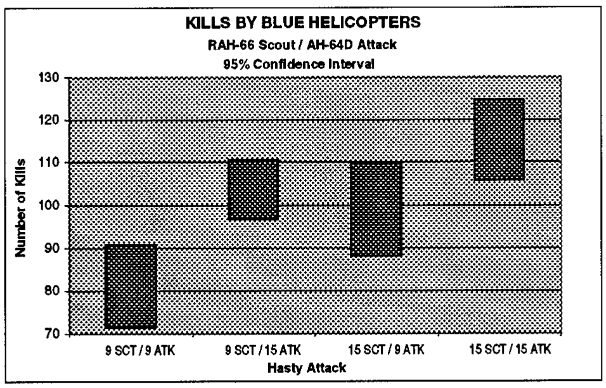


b. Kills

Blue helicopter kills of threat major systems

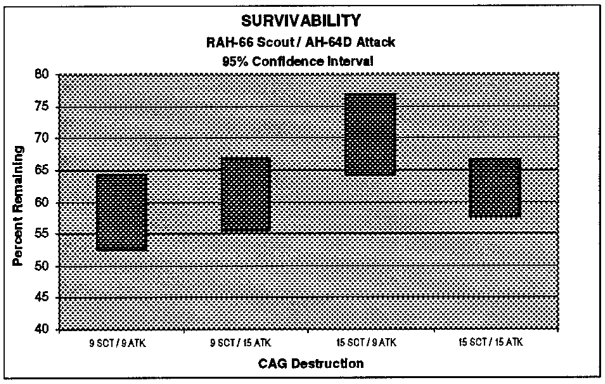


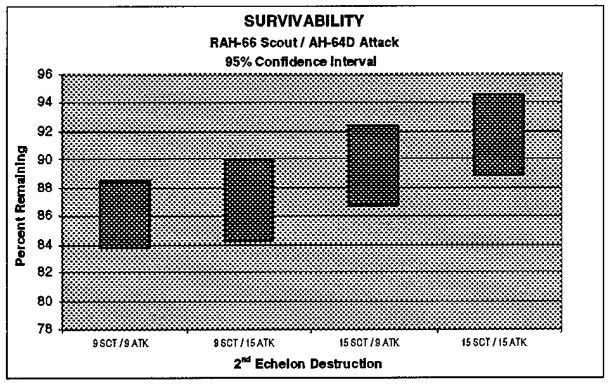


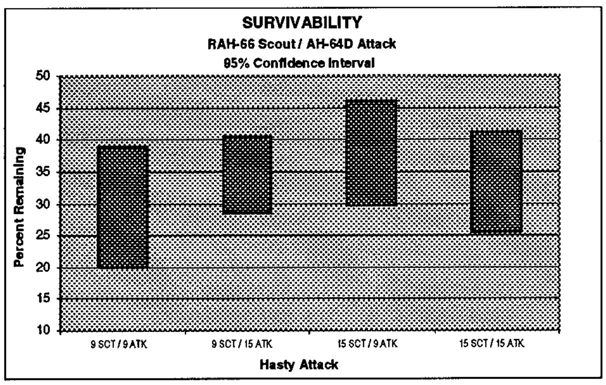


c. Survivability

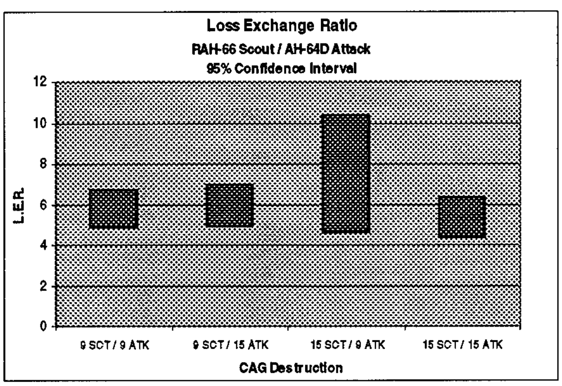
Threat kills of blue helicopters [CI]

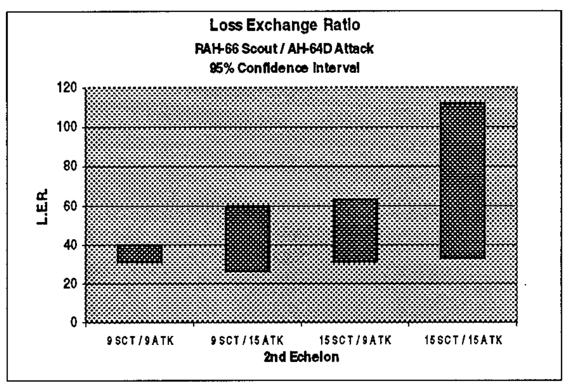


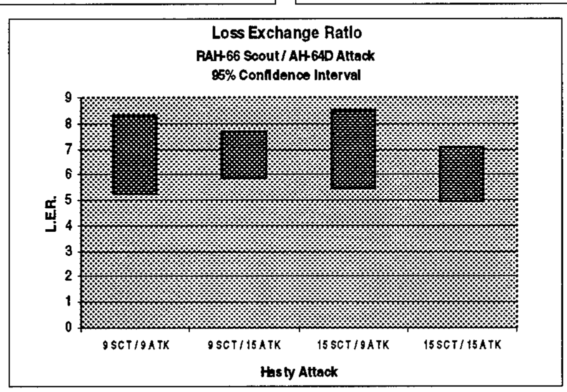




LER







Appendix C. Experimental Design Analysis

Minitab results:

Pareto charts, Estimated effects and coefficients, ANOVA tables.

100=CAG Destruction, 200=2nd Echelon, 300=Hasty Attack.

Term	Low	High
AtkType	AH64D	RAH66
SctType	AH64D	RAH66
NumAtk	9	15
NumSct	9	15

(1) Number of detections.

(2) Average detection distance.

(3) Detections per Blue helicopter loss.

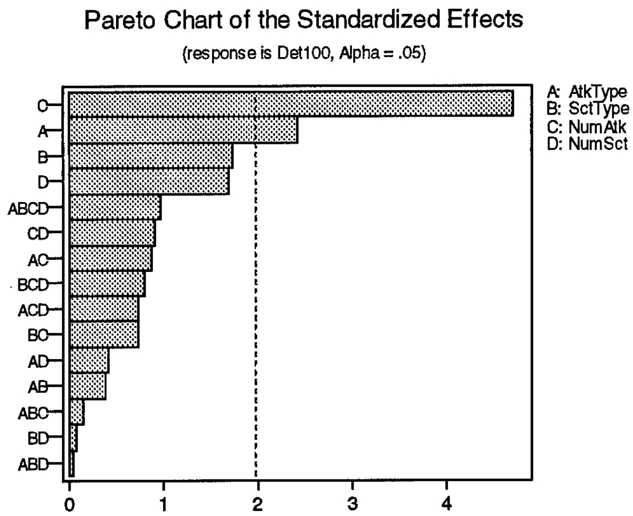
(4) Total Blue helicopter kills of threat systems.

(5) Scout / Attack lethality range

(6) Blue helicopter survivability percentage.

(7) Loss exchange ratio.

Fractional Factorial Fit: CAG Destruction



Estimated Effects and Coefficients for Det100

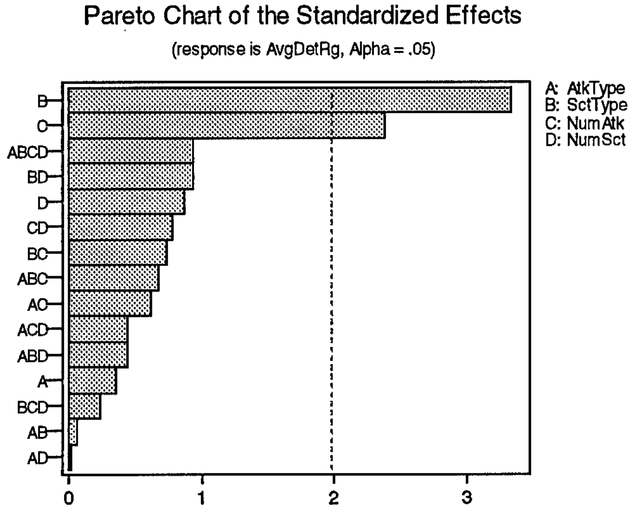
Term	Effect	Coef	StDev Coef	T	P
Constant		113.188	0.3606	313.86	0.000
AtkType	-1.750	-0.875	0.3606	-2.43	0.016
SctType	1.250	0.625	0.3606	1.73	0.085
NumAtk	3.400	1.700	0.3606	4.71	0.000
NumSct	1.225	0.612	0.3606	1.70	0.092
AtkType*SctType	0.275	0.137	0.3606	0.38	0.704
AtkType*NumAtk	-0.625	-0.312	0.3606	-0.87	0.388
AtkType*NumSct	0.300	0.150	0.3606	0.42	0.678
SctType*NumAtk	-0.525	-0.262	0.3606	-0.73	0.468
SctType*NumSct	-0.050	-0.025	0.3606	-0.07	0.945
NumAtk*NumSct	0.650	0.325	0.3606	0.90	0.369
AtkType*SctType*NumAtk	-0.100	-0.050	0.3606	-0.14	0.890
AtkType*SctType*NumSct	-0.025	-0.013	0.3606	-0.03	0.972
AtkType*NumAtk*NumSct	0.525	0.263	0.3606	0.73	0.468
SctType*NumAtk*NumSct	0.575	0.288	0.3606	0.80	0.427
AtkType*SctType*NumAtk*NumSct	-0.700	-0.350	0.3606	-0.97	0.333

Analysis of Variance for Det100

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	707.43	707.43	176.856	8.50	0.000
2-Way Interactions	6	50.28	50.28	8.379	0.40	0.876
3-Way Interactions	4	24.68	24.68	6.169	0.30	0.880
4-Way Interactions	1	19.60	19.60	19.600	0.94	0.333
Residual Error	144	2996.40	2996.40	20.808		
Pure Error	144	2996.40	2996.40	20.808		
Total	159	3798.38				

Unusual Observations for Det100

Obs	Det100	Fit	StDev Fit	Residual	St Resid
6	121.000	111.800	1.443	9.200	2.13R
21	126.000	115.900	1.443	10.100	2.33R
30	126.000	114.700	1.443	11.300	2.61R
66	120.000	109.700	1.443	10.300	2.38R
117	102.000	115.900	1.443	-13.900	-3.21R
125	105.000	115.700	1.443	-10.700	-2.47R
126	105.000	114.700	1.443	-9.700	-2.24R



Estimated Effects and Coefficients for AvgDetRg

Term	Effect	Coef	StDev Coef	T	P
Constant		6.56637	0.006304	1041.68	0.000
AtkType	-0.00450	-0.00225	0.006304	-0.36	0.722
SctType	-0.04200	-0.02100	0.006304	-3.33	0.001
NumAtk	0.03000	0.01500	0.006304	2.38	0.019
NumSct	0.01100	0.00550	0.006304	0.87	0.384
AtkType*SctType	-0.00075	-0.00037	0.006304	-0.06	0.953
AtkType*NumAtk	0.00775	0.00387	0.006304	0.61	0.540
AtkType*NumSct	0.00025	0.00012	0.006304	0.02	0.984
SctType*NumAtk	0.00925	0.00462	0.006304	0.73	0.464
SctType*NumSct	0.01175	0.00587	0.006304	0.93	0.353
NumAtk*NumSct	-0.00975	-0.00488	0.006304	-0.77	0.441
AtkType*SctType*NumAtk	-0.00850	-0.00425	0.006304	-0.67	0.501
AtkType*SctType*NumSct	0.00550	0.00275	0.006304	0.44	0.663
AtkType*NumAtk*NumSct	-0.00550	-0.00275	0.006304	-0.44	0.663
SctType*NumAtk*NumSct	-0.00300	-0.00150	0.006304	-0.24	0.812
AtkType*SctType*NumAtk*NumSct	0.01175	0.00587	0.006304	0.93	0.353

Analysis of Variance for AvgDetRg

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	0.11221	0.112210	0.028053	4.41	0.002
2-Way Interactions	6	0.01517	0.015175	0.002529	0.40	0.879
3-Way Interactions	4	0.00567	0.005670	0.001418	0.22	0.925
4-Way Interactions	1	0.00552	0.005522	0.005522	0.87	0.353
Residual Error	144	0.91552	0.915520	0.006358		
Pure Error	144	0.91552	0.915520	0.006358		
Total	159	1.05410				

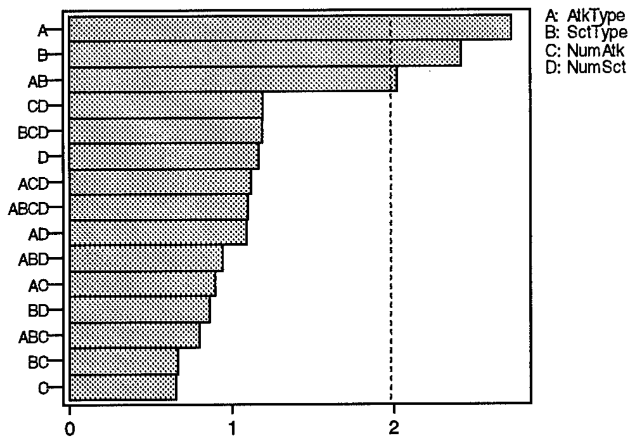
Unusual Observations for AvgDetRg

Obs	AvgDetRg	Fit	StDev Fit	Residual	St Resid
21	6.41000	6.58400	0.02521	-0.17400	-2.30R
38	6.79000	6.61900	0.02521	0.17100	2.26R
65	6.75000	6.59000	0.02521	0.16000	2.12R
66	6.36000	6.55800	0.02521	-0.19800	-2.62R
73	6.75000	6.58400	0.02521	0.16600	2.19R
113	6.77000	6.59000	0.02521	0.18000	2.38R
114	6.77000	6.55800	0.02521	0.21200	2.80R
121	6.31000	6.58400	0.02521	-0.27400	-3.62R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is Det/Loss, Alpha = .05)



Estimated Effects and Coefficients for Det/Loss

Term	Effect	Coef	StDev Coef	T	P
Constant		30.716	6.907	4.45	0.000
AtkType	37.679	18.839	6.907	2.73	0.007
SctType	33.344	16.672	6.907	2.41	0.017
NumAtk	9.088	4.544	6.907	0.66	0.512
NumSct	-16.092	-8.046	6.907	-1.16	0.246
AtkType*SctType	27.953	13.977	6.907	2.02	0.045
AtkType*NumAtk	12.391	6.195	6.907	0.90	0.371
AtkType*NumSct	-15.105	-7.552	6.907	-1.09	0.276
SctType*NumAtk	9.210	4.605	6.907	0.67	0.506
SctType*NumSct	-11.967	-5.984	6.907	-0.87	0.388
NumAtk*NumSct	-16.540	-8.270	6.907	-1.20	0.233
AtkType*SctType*NumAtk	11.094	5.547	6.907	0.80	0.423
AtkType*SctType*NumSct	-13.044	-6.522	6.907	-0.94	0.347
AtkType*NumAtk*NumSct	-15.401	-7.701	6.907	-1.11	0.267
SctType*NumAtk*NumSct	-16.367	-8.183	6.907	-1.18	0.238
AtkType*SctType*NumAtk*NumSct	-15.192	-7.596	6.907	-1.10	0.273

Analysis of Variance for Det/Loss

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	114923	114923	28731	3.76	0.006
2-Way Interactions	6	66587	66587	11098	1.45	0.198
3-Way Interactions	4	31932	31932	7983	1.05	0.386
4-Way Interactions	1	9232	9232	9232	1.21	0.273
Residual Error	144	1099301	1099301	7634		
Pure Error	144	1099301	1099301	7634		
Total	159	1321975				

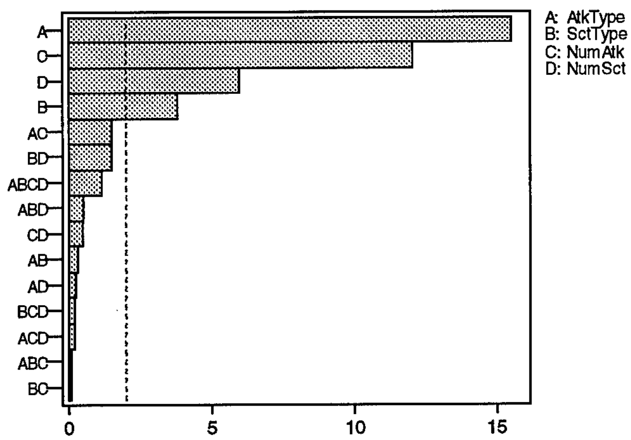
Unusual Observations for Det/Loss

Obs	Det/Loss	Fit	StDev Fit	Residual	St Resid
8	1140.00	160.95	27.63	979.05	11.81R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is TotalKil, Alpha = .05)



Estimated Effects and Coefficients for TotalKil

Term	Effect	Coef	StDev Coef	T	P
Constant		57.925	0.4579	126.49	0.000
AtkType	14.200	7.100	0.4579	15.50	0.000
SctType	-3.500	-1.750	0.4579	-3.82	0.000
NumAtk	11.025	5.513	0.4579	12.04	0.000
NumSct	5.450	2.725	0.4579	5.95	0.000
AtkType*SctType	-0.300	-0.150	0.4579	-0.33	0.744
AtkType*NumAtk	-1.375	-0.687	0.4579	-1.50	0.135
AtkType*NumSct	0.200	0.100	0.4579	0.22	0.827
SctType*NumAtk	0.075	0.037	0.4579	0.08	0.935
SctType*NumSct	-1.350	-0.675	0.4579	-1.47	0.143
NumAtk*NumSct	0.425	0.213	0.4579	0.46	0.643
AtkType*SctType*NumAtk	-0.075	-0.038	0.4579	-0.08	0.935
AtkType*SctType*NumSct	-0.450	-0.225	0.4579	-0.49	0.624
AtkType*NumAtk*NumSct	-0.175	-0.087	0.4579	-0.19	0.849
SctType*NumAtk*NumSct	-0.175	-0.088	0.4579	-0.19	0.849
AtkType*SctType*NumAtk* NumSct	-1.025	-0.513	0.4579	-1.12	0.265

Analysis of Variance for TotalKil

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	14605.7	14605.7	3651.43	108.83	0.000
2-Way Interactions	6	161.2	161.2	26.86	0.80	0.571
3-Way Interactions	4	10.8	10.8	2.69	0.08	0.988
4-Way Interactions	1	42.0	42.0	42.03	1.25	0.265
Residual Error	144	4831.4	4831.4	33.55		
Pure Error	144	4831.4	4831.4	33.55		
Total	159	19651.1				

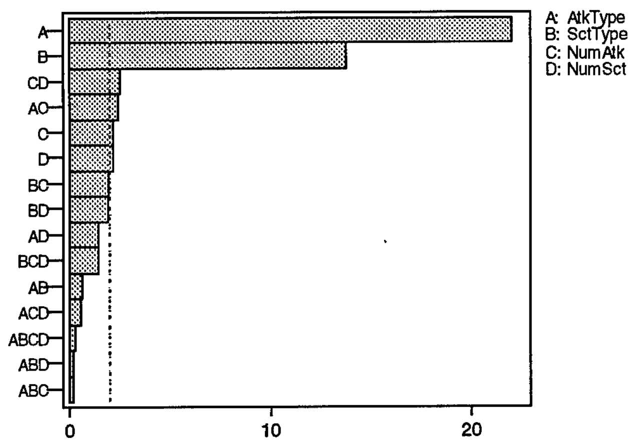
Unusual Observations for TotalKil

Obs	TotalKil	Fit	StDev Fit	Residual	St Resid
1	27.0000	43.1000	1.8317	-16.1000	-2.93R
49	30.0000	43.1000	1.8317	-13.1000	-2.38R
59	26.0000	44.4000	1.8317	-18.4000	-3.35R
60	49.0000	60.7000	1.8317	-11.7000	-2.13R
103	67.0000	52.6000	1.8317	14.4000	2.62R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is Surv100, Alpha = .05)



Estimated Effects and Coefficients for Surv100

Term	Effect	Coef	StDev Coef	T	P
Constant		67.566	0.5967	113.24	0.000
AtkType	26.271	13.135	0.5967	22.01	0.000
SctType	16.410	8.205	0.5967	13.75	0.000
NumAtk	2.597	1.299	0.5967	2.18	0.031
NumSct	2.597	1.298	0.5967	2.18	0.031
AtkType*SctType	-0.729	-0.365	0.5967	-0.61	0.542
AtkType*NumAtk	2.833	1.417	0.5967	2.37	0.019
AtkType*NumSct	-1.750	-0.875	0.5967	-1.47	0.145
SctType*NumAtk	-2.305	-1.153	0.5967	-1.93	0.055
SctType*NumSct	2.278	1.139	0.5967	1.91	0.058
NumAtk*NumSct	-2.993	-1.497	0.5967	-2.51	0.013
AtkType*SctType*NumAtk	0.209	0.104	0.5967	0.17	0.861
AtkType*SctType*NumSct	0.209	0.104	0.5967	0.18	0.861
AtkType*NumAtk*NumSct	0.646	0.323	0.5967	0.54	0.589
SctType*NumAtk*NumSct	-1.715	-0.857	0.5967	-1.44	0.153
AtkType*SctType*NumAtk* NumSct	0.312	0.156	0.5967	0.26	0.794

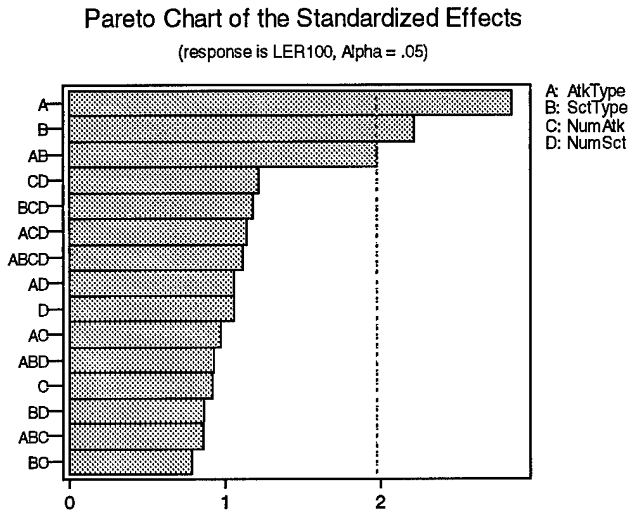
Analysis of Variance for Surv100

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	38916.4	38916.4	9729.10	170.80	0.000
2-Way Interactions	6	1243.4	1243.4	207.23	3.64	0.002
3-Way Interactions	4	137.8	137.8	34.44	0.60	0.660
4-Way Interactions	1	3.9	3.9	3.90	0.07	0.794
Residual Error	144	8202.5	8202.5	56.96		
Pure Error	144	8202.5	8202.5	56.96		
Total	159	48503.9				

Unusual Observations for Surv100

Obs	Surv100	Fit	StDev Fit	Residual	St Resid
31	80.000	62.000	2.387	18.000	2.51R
37	66.670	46.667	2.387	20.003	2.79R
81	27.780	42.777	2.387	-14.997	-2.09R
85	62.500	46.667	2.387	15.833	2.21R
132	66.670	83.333	2.387	-16.663	-2.33R
139	87.500	70.416	2.387	17.084	2.39R
157	63.330	47.333	2.387	15.997	2.23R

R denotes an observation with a large standardized residual



Estimated Effects and Coefficients for LER100

Term	Effect	Coef	StDev Coef	T	P
Constant		16.712	4.051	4.13	0.000
AtkType	23.066	11.533	4.051	2.85	0.005
SctType	18.006	9.003	4.051	2.22	0.028
NumAtk	7.447	3.723	4.051	0.92	0.360
NumSct	-8.594	-4.297	4.051	-1.06	0.291
AtkType*SctType	16.028	8.014	4.051	1.98	0.050
AtkType*NumAtk	7.865	3.932	4.051	0.97	0.333
AtkType*NumSct	-8.602	-4.301	4.051	-1.06	0.290
SctType*NumAtk	6.382	3.191	4.051	0.79	0.432
SctType*NumSct	-6.992	-3.496	4.051	-0.86	0.390
NumAtk*NumSct	-9.857	-4.928	4.051	-1.22	0.226
AtkType*SctType*NumAtk	6.949	3.475	4.051	0.86	0.392
AtkType*SctType*NumSct	-7.528	-3.764	4.051	-0.93	0.354
AtkType*NumAtk*NumSct	-9.246	-4.623	4.051	-1.14	0.256
SctType*NumAtk*NumSct	-9.566	-4.783	4.051	-1.18	0.240
AtkType*SctType*NumAtk*NumSct	-9.048	-4.524	4.051	-1.12	0.266

Analysis of Variance for LER100

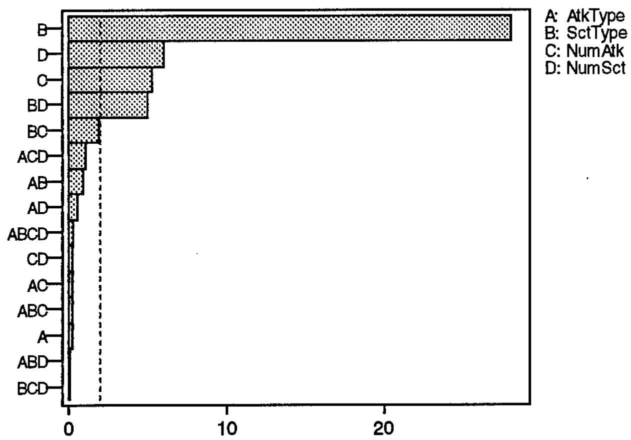
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	39422	39422	9856	3.75	0.006
2-Way Interactions	6	23181	23181	3864	1.47	0.192
3-Way Interactions	4	11278	11278	2820	1.07	0.372
4-Way Interactions	1	3274	3274	3274	1.25	0.266
Residual Error	144	378024	378024	2625		
Pure Error	144	378024	378024	2625		
Total	159	455181				

Unusual Observations for LER100

Obs	LER100	Fit	StDev Fit	Residual	St Resid
8	670.000	94.300	16.202	575.700	11.84R

R denotes an observation with a large standardized residual

Fractional Factorial Fit: 2nd Echelon



Estimated Effects and Coefficients for Det200

Term	Effect	Coef	StDev Coef	T	P
Constant		72.912	0.3350	217.67	0.000
AtkType	0.125	0.063	0.3350	0.19	0.852
SctType	18.800	9.400	0.3350	28.06	0.000
NumAtk	3.500	1.750	0.3350	5.22	0.000
NumSct	4.025	2.012	0.3350	6.01	0.000
AtkType*SctType	-0.600	-0.300	0.3350	-0.90	0.372
AtkType*NumAtk	-0.150	-0.075	0.3350	-0.22	0.823
AtkType*NumSct	-0.375	-0.188	0.3350	-0.56	0.577
SctType*NumAtk	-1.275	-0.637	0.3350	-1.90	0.059
SctType*NumSct	-3.350	-1.675	0.3350	-5.00	0.000
NumAtk*NumSct	0.150	0.075	0.3350	0.22	0.823
AtkType*SctType*NumAtk	-0.125	-0.062	0.3350	-0.19	0.852
AtkType*SctType*NumSct	-0.050	-0.025	0.3350	-0.07	0.941
AtkType*NumAtk*NumSct	-0.700	-0.350	0.3350	-1.04	0.298
SctType*NumAtk*NumSct	0.025	0.013	0.3350	0.04	0.970
AtkType*SctType*NumAtk*NumSct	0.175	0.088	0.3350	0.26	0.794

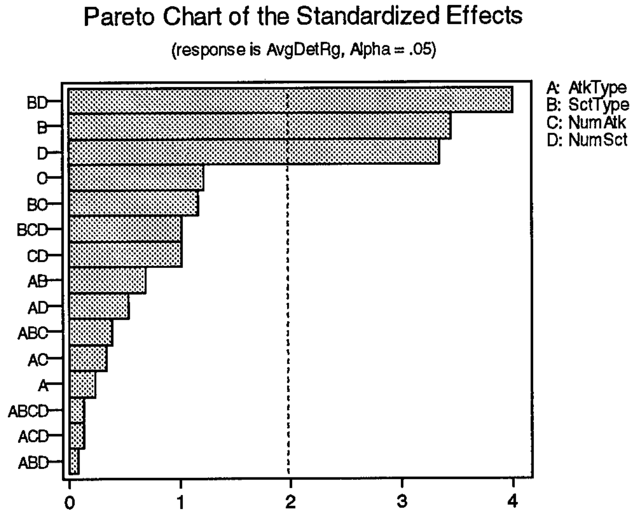
Analysis of Variance for Det200

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	15276.3	15276.3	3819.06	212.73	0.000
2-Way Interactions	6	535.7	535.7	89.29	4.97	0.000
3-Way Interactions	4	20.4	20.4	5.09	0.28	0.888
4-Way Interactions	1	1.2	1.2	1.23	0.07	0.794
Residual Error	144	2585.2	2585.2	17.95		
Pure Error	144	2585.2	2585.2	17.95		
Total	159	18418.8				

Unusual Observations for Det200

Obs	Det200	Fit	StDev Fit	Residual	St Resid
29	61.0000	69.9000	1.3399	-8.9000	-2.21R
30	61.0000	69.4000	1.3399	-8.4000	-2.09R
37	73.0000	61.2000	1.3399	11.8000	2.94R
41	74.0000	64.1000	1.3399	9.9000	2.46R
42	75.0000	65.4000	1.3399	9.6000	2.39R
53	51.0000	61.2000	1.3399	-10.2000	-2.54R
54	54.0000	63.1000	1.3399	-9.1000	-2.26R
101	53.0000	61.2000	1.3399	-8.2000	-2.04R
106	55.0000	65.4000	1.3399	-10.4000	-2.59R
117	73.0000	61.2000	1.3399	11.8000	2.94R
118	72.0000	63.1000	1.3399	8.9000	2.21R
134	78.0000	63.1000	1.3399	14.9000	3.71R

R denotes an observation with a large standardized residual



Estimated Effects and Coefficients for AvgDetRg

Term	Effect	Coef	StDev Coef	T	P
Constant		5.21400	0.004928	1058.05	0.000
AtkType	-0.00225	-0.00113	0.004928	-0.23	0.820
SctType	-0.03400	-0.01700	0.004928	-3.45	0.001
NumAtk	-0.01200	-0.00600	0.004928	-1.22	0.225
NumSct	-0.03300	-0.01650	0.004928	-3.35	0.001
AtkType*SctType	0.00675	0.00338	0.004928	0.68	0.495
AtkType*NumAtk	0.00325	0.00162	0.004928	0.33	0.742
AtkType*NumSct	-0.00525	-0.00263	0.004928	-0.53	0.595
SctType*NumAtk	0.01150	0.00575	0.004928	1.17	0.245
SctType*NumSct	0.03950	0.01975	0.004928	4.01	0.000
NumAtk*NumSct	0.01000	0.00500	0.004928	1.01	0.312
AtkType*SctType*NumAtk	0.00375	0.00187	0.004928	0.38	0.704
AtkType*SctType*NumSct	-0.00075	-0.00038	0.004928	-0.08	0.939
AtkType*NumAtk*NumSct	0.00125	0.00063	0.004928	0.13	0.899
SctType*NumAtk*NumSct	-0.01000	-0.00500	0.004928	-1.01	0.312
AtkType*SctType*NumAtk* NumSct	0.00125	0.00062	0.004928	0.13	0.899

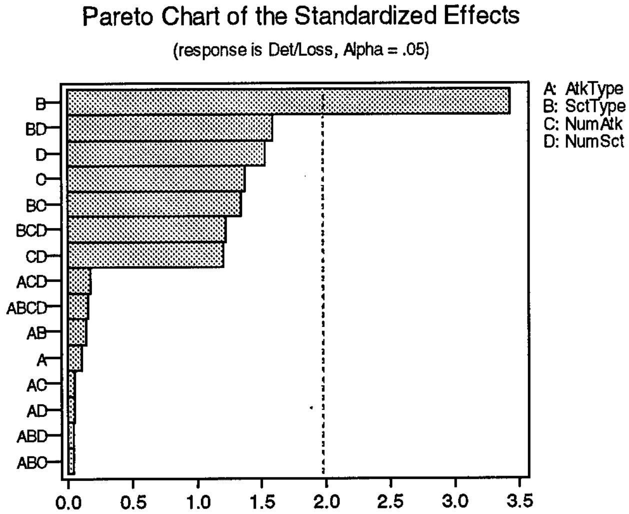
Analysis of Variance for AvgDetRg

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	0.095763	0.095763	0.0239406	6.16	0.000
2-Way Interactions	6	0.075047	0.075047	0.0125079	3.22	0.005
3-Way Interactions	4	0.004647	0.004647	0.0011619	0.30	0.878
4-Way Interactions	1	0.000062	0.000062	0.0000625	0.02	0.899
Residual Error	144	0.559520	0.559520	0.0038856		
Pure Error	144	0.559520	0.559520	0.0038856		
Total	159	0.735040				

Unusual Observations for AvgDetRg

Obs	AvgDetRg	Fit	StDev Fit	Residual	St Resid
2	5.41000	5.28700	0.01971	0.12300	2.08R
21	5.12000	5.24800	0.01971	-0.12800	-2.16R
53	5.39000	5.24800	0.01971	0.14200	2.40R
54	5.37000	5.24300	0.01971	0.12700	2.15R
61	5.06000	5.20000	0.01971	-0.14000	-2.37R
106	5.33000	5.19000	0.01971	0.14000	2.37R
121	5.33000	5.20300	0.01971	0.12700	2.15R
122	5.31000	5.19000	0.01971	0.12000	2.03R
125	5.32000	5.20000	0.01971	0.12000	2.03R
150	5.10000	5.24300	0.01971	-0.14300	-2.42R

R denotes an observation with a large standardized residual



Estimated Effects and Coefficients for Det/Loss

Term	Effect	Coef	StDev Coef	T	P
Constant		30.092	7.192	4.18	0.000
AtkType	-1.503	-0.752	7.192	-0.10	0.917
SctType	49.306	24.653	7.192	3.43	0.001
NumAtk	19.733	9.866	7.192	1.37	0.172
NumSct	21.915	10.957	7.192	1.52	0.130
AtkType*SctType	-1.990	-0.995	7.192	-0.14	0.890
AtkType*NumAtk	0.808	0.404	7.192	0.06	0.955
AtkType*NumSct	-0.769	-0.384	7.192	-0.05	0.957
SctType*NumAtk	19.345	9.672	7.192	1.34	0.181
SctType*NumSct	22.809	11.404	7.192	1.59	0.115
NumAtk*NumSct	17.339	8.669	7.192	1.21	0.230
AtkType*SctType*NumAtk	0.595	0.298	7.192	0.04	0.967
AtkType*SctType*NumSct	-0.650	-0.325	7.192	-0.05	0.964
AtkType*NumAtk*NumSct	-2.464	-1.232	7.192	-0.17	0.864
SctType*NumAtk*NumSct	17.554	8.777	7.192	1.22	0.224
AtkType*SctType*NumAtk*NumSct	-2.225	-1.113	7.192	-0.15	0.877

Analysis of Variance for Det/Loss

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	132118	132118	33029.4	3.99	0.004
2-Way Interactions	6	48011	48011	8001.9	0.97	0.450
3-Way Interactions	4	12599	12599	3149.8	0.38	0.822
4-Way Interactions	1	198	198	198.1	0.02	0.877
Residual Error	144	1191793	1191793	8276.3		
Pure Error	144	1191793	1191793	8276.3		
Total	159	1384719				

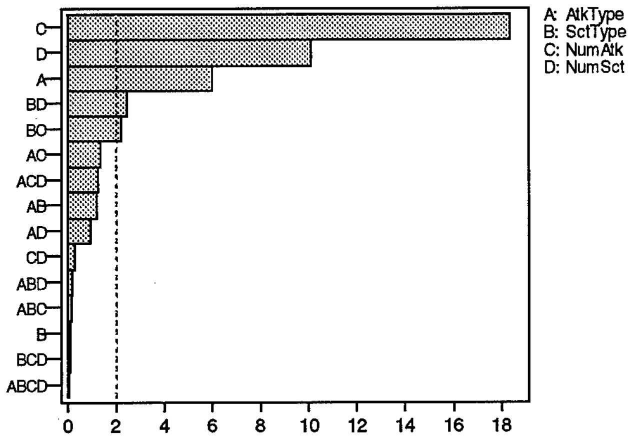
Unusual Observations for Det/Loss

Obs	Det/Loss	Fit	StDev Fit	Residual	St Resid
32	830.000	109.992	28.769	720.008	8.34R
95	850.000	118.191	28.769	731.809	8.48R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is TotalKil, Alpha = .05)



Estimated Effects and Coefficients for TotalKil

Term	Effect	Coef	StDev Coef	T	P
Constant		98.300	0.6446	152.49	0.000
AtkType	-7.725	-3.863	0.6446	-5.99	0.000
SctType	0.125	0.063	0.6446	0.10	0.923
NumAtk	23.675	11.838	0.6446	18.36	0.000
NumSct	13.000	6.500	0.6446	10.08	0.000
AtkType*SctType	-1.550	-0.775	0.6446	-1.20	0.231
AtkType*NumAtk	-1.750	-0.875	0.6446	-1.36	0.177
AtkType*NumSct	-1.225	-0.613	0.6446	-0.95	0.344
SctType*NumAtk	2.850	1.425	0.6446	2.21	0.029
SctType*NumSct	-3.175	-1.587	0.6446	-2.46	0.015
NumAtk*NumSct	-0.375	-0.188	0.6446	-0.29	0.772
AtkType*SctType*NumAtk	0.175	0.088	0.6446	0.14	0.892
AtkType*SctType*NumSct	-0.250	-0.125	0.6446	-0.19	0.847
AtkType*NumAtk*NumSct	-1.600	-0.800	0.6446	-1.24	0.217
SctType*NumAtk*NumSct	0.100	0.050	0.6446	0.08	0.938
AtkType*SctType*NumAtk*NumSct	-0.075	-0.038	0.6446	-0.06	0.954

Analysis of Variance for TotalKil

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	31567.9	31567.9	7891.97	118.69	0.000
2-Way Interactions	6	1012.4	1012.4	168.73	2.54	0.023
3-Way Interactions	4	106.5	106.5	26.63	0.40	0.808
4-Way Interactions	1	0.2	0.2	0.23	0.00	0.954
Residual Error	144	9574.6	9574.6	66.49		
Pure Error	144	9574.6	9574.6	66.49		
Total	159	42261.6				

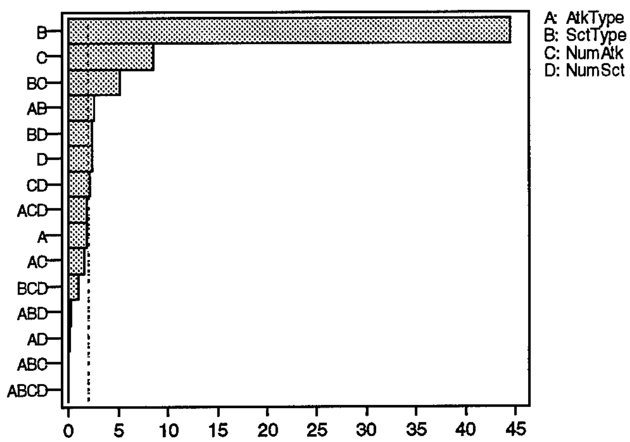
Unusual Observations for TotalKil

Obs	TotalKil	Fit	StDev Fit	Residual	St Resid
31	140.000	123.400	2.579	16.600	2.15R
40	120.000	103.000	2.579	17.000	2.20R
48	128.000	109.400	2.579	18.600	2.40R
55	90.000	110.700	2.579	-20.700	-2.68R
71	93.000	110.700	2.579	-17.700	-2.29R
78	95.000	111.200	2.579	-16.200	-2.09R
111	106.000	123.400	2.579	-17.400	-2.25R
112	89.000	109.400	2.579	-20.400	-2.64R
149	121.000	103.600	2.579	17.400	2.25R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is Surv200, Alpha = .05)



Estimated Effects and Coefficients for Surv200

Term	Effect	Coef	StDev Coef	T	P
Constant		68.645	0.4410	155.66	0.000
AtkType	1.549	0.774	0.4410	1.76	0.081
SctType	39.208	19.604	0.4410	44.45	0.000
NumAtk	7.501	3.750	0.4410	8.50	0.000
NumSct	2.084	1.042	0.4410	2.36	0.019
AtkType*SctType	-2.271	-1.135	0.4410	-2.57	0.011
AtkType*NumAtk	1.410	0.705	0.4410	1.60	0.112
AtkType*NumSct	-0.049	-0.024	0.4410	-0.06	0.956
SctType*NumAtk	-4.542	-2.271	0.4410	-5.15	0.000
SctType*NumSct	2.125	1.062	0.4410	2.41	0.017
NumAtk*NumSct	-1.876	-0.938	0.4410	-2.13	0.035
AtkType*SctType*NumAtk	0.021	0.011	0.4410	0.02	0.981
AtkType*SctType*NumSct	0.229	0.115	0.4410	0.26	0.795
AtkType*NumAtk*NumSct	-1.577	-0.788	0.4410	-1.79	0.076
SctType*NumAtk*NumSct	0.876	0.438	0.4410	0.99	0.322
AtkType*SctType*NumAtk* NumSct	0.020	0.010	0.4410	0.02	0.981

Analysis of Variance for Surv200

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	64011.6	64011.6	16002.9	514.28	0.000
2-Way Interactions	6	1432.4	1432.4	238.7	7.67	0.000
3-Way Interactions	4	132.2	132.2	33.1	1.06	0.377
4-Way Interactions	1	0.0	0.0	0.0	0.00	0.981
Residual Error	144	4480.9	4480.9	31.1		
Pure Error	144	4480.9	4480.9	31.1		
Total	159	70057.1				

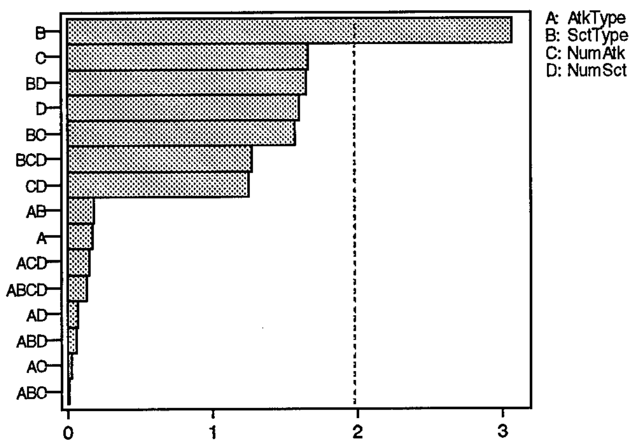
Unusual Observations for Surv200

Obs	Surv200	Fit	StDev Fit	Residual	St Resid
2	55.560	42.221	1.764	13.339	2.52R
49	27.780	41.109	1.764	-13.329	-2.52R
82	27.780	42.221	1.764	-14.441	-2.73R
85	37.500	52.917	1.764	-15.417	-2.91R
89	29.170	42.500	1.764	-13.330	-2.52R
133	70.830	52.917	1.764	17.913	3.38R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is LER200, Alpha = .05)



Estimated Effects and Coefficients for LER200

Term	Effect	Coef	StDev Coef	T	P
Constant		38.879	9.952	3.91	0.000
AtkType	-3.377	-1.689	9.952	-0.17	0.866
SctType	61.034	30.517	9.952	3.07	0.003
NumAtk	32.993	16.497	9.952	1.66	0.100
NumSct	31.797	15.899	9.952	1.60	0.112
AtkType*SctType	-3.548	-1.774	9.952	-0.18	0.859
AtkType*NumAtk	0.433	0.217	9.952	0.02	0.983
AtkType*NumSct	-1.428	-0.714	9.952	-0.07	0.943
SctType*NumAtk	31.265	15.632	9.952	1.57	0.118
SctType*NumSct	32.757	16.379	9.952	1.65	0.102
NumAtk*NumSct	24.880	12.440	9.952	1.25	0.213
AtkType*SctType*NumAtk	0.200	0.100	9.952	0.01	0.992
AtkType*SctType*NumSct	-1.267	-0.634	9.952	-0.06	0.949
AtkType*NumAtk*NumSct	-2.915	-1.457	9.952	-0.15	0.884
SctType*NumAtk*NumSct	25.391	12.696	9.952	1.28	0.204
AtkType*SctType*NumAtk*NumSct	-2.556	-1.278	9.952	-0.13	0.898

Analysis of Variance for LER200

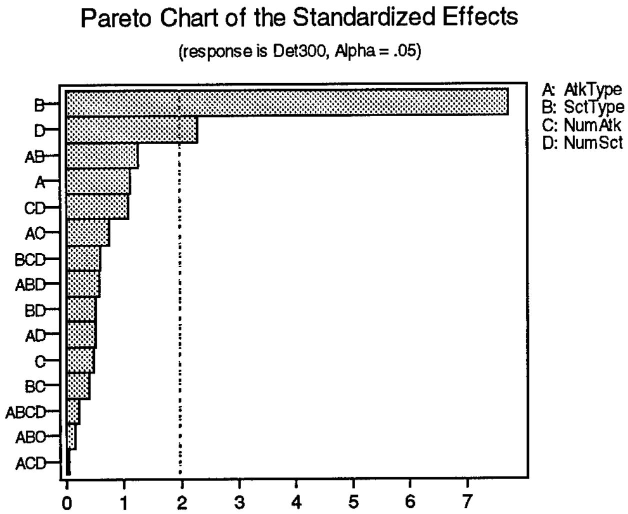
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	233449	233449	58362.2	3.68	0.007
2-Way Interactions	6	107373	107373	17895.5	1.13	0.348
3-Way Interactions	4	26194	26194	6548.5	0.41	0.799
4-Way Interactions	1	261	261	261.3	0.02	0.898
Residual Error	144	2282079	2282079	15847.8		
Pure Error	144	2282079	2282079	15847.8		
Total	159	2649356				

Unusual Observations for LER200

Obs	LER200	Fit	StDev Fit	Residual	St Resid
32	1160.00	151.71	39.81	1008.29	8.44R
95	1170.00	166.17	39.81	1003.83	8.41R

R denotes an observation with a large standardized residual

Fractional Factorial Fit: Hasty Attack



Estimated Effects and Coefficients for Det300

Term	Effect	Coef	StDev Coef	T	P
Constant		324.212	2.824	114.80	0.000
AtkType	6.350	3.175	2.824	1.12	0.263
SctType	43.650	21.825	2.824	7.73	0.000
NumAtk	2.675	1.338	2.824	0.47	0.636
NumSct	12.950	6.475	2.824	2.29	0.023
AtkType*SctType	-7.025	-3.512	2.824	-1.24	0.216
AtkType*NumAtk	-4.150	-2.075	2.824	-0.73	0.464
AtkType*NumSct	-2.875	-1.438	2.824	-0.51	0.612
SctType*NumAtk	-2.250	-1.125	2.824	-0.40	0.691
SctType*NumSct	2.875	1.438	2.824	0.51	0.612
NumAtk*NumSct	-6.050	-3.025	2.824	-1.07	0.286
AtkType*SctType*NumAtk	-0.875	-0.438	2.824	-0.15	0.877
AtkType*SctType*NumSct	-3.150	-1.575	2.824	-0.56	0.578
AtkType*NumAtk*NumSct	-0.225	-0.113	2.824	-0.04	0.968
SctType*NumAtk*NumSct	-3.275	-1.638	2.824	-0.58	0.563
AtkType*SctType*NumAtk*NumSct	-1.250	-0.625	2.824	-0.22	0.825

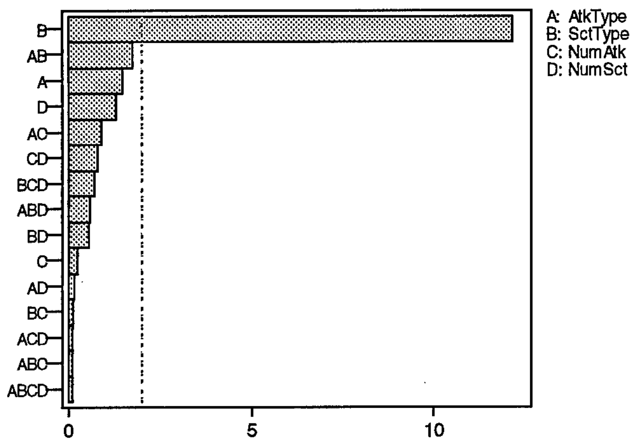
Analysis of Variance for Det300

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	84820	84820	21205.0	16.62	0.000
2-Way Interactions	6	4991	4991	831.8	0.65	0.689
3-Way Interactions	4	859	859	214.6	0.17	0.954
4-Way Interactions	1	63	63	62.5	0.05	0.825
Residual Error	144	183751	183751	1276.0		
Pure Error	144	183751	183751	1276.0		
Total	159	274483				

Unusual Observations for Det300

Obs	Det300	Fit	StDev Fit	Residual	St Resid
4	247.000	337.700	11.296	-90.700	-2.68R
8	256.000	343.900	11.296	-87.900	-2.59R
15	284.000	356.100	11.296	-72.100	-2.13R
16	254.000	342.900	11.296	-88.900	-2.62R
70	388.000	305.600	11.296	82.400	2.43R
115	415.000	328.800	11.296	86.200	2.54R
125	380.000	302.800	11.296	77.200	2.28R

R denotes an observation with a large standardized residual



Estimated Effects and Coefficients for AvgDetRg

Term	Effect	Coef	StDev Coef	T	P
Constant		5.0284	0.01527	329.28	0.000
AtkType	-0.0455	-0.0227	0.01527	-1.49	0.138
SctType	-0.3712	-0.1856	0.01527	-12.16	0.000
NumAtk	-0.0073	-0.0036	0.01527	-0.24	0.813
NumSct	-0.0393	-0.0196	0.01527	-1.29	0.201
AtkType*SctType	0.0535	0.0267	0.01527	1.75	0.082
AtkType*NumAtk	0.0270	0.0135	0.01527	0.88	0.378
AtkType*NumSct	-0.0045	-0.0023	0.01527	-0.15	0.883
SctType*NumAtk	0.0038	0.0019	0.01527	0.12	0.902
SctType*NumSct	-0.0168	-0.0084	0.01527	-0.55	0.584
NumAtk*NumSct	0.0247	0.0124	0.01527	0.81	0.419
AtkType*SctType*NumAtk	0.0030	0.0015	0.01527	0.10	0.922
AtkType*SctType*NumSct	0.0180	0.0090	0.01527	0.59	0.557
AtkType*NumAtk*NumSct	-0.0030	-0.0015	0.01527	-0.10	0.922
SctType*NumAtk*NumSct	0.0213	0.0106	0.01527	0.70	0.488
AtkType*SctType*NumAtk*NumSct	-0.0025	-0.0012	0.01527	-0.08	0.935

Analysis of Variance for AvgDetRg

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	5.6596	5.65960	1.41490	37.92	0.000
2-Way Interactions	6	0.1807	0.18075	0.03012	0.81	0.566
3-Way Interactions	4	0.0317	0.03174	0.00794	0.21	0.931
4-Way Interactions	1	0.0002	0.00025	0.00025	0.01	0.935
Residual Error	144	5.3730	5.37304	0.03731		
Pure Error	144	5.3730	5.37304	0.03731		
Total	159	11.2454				

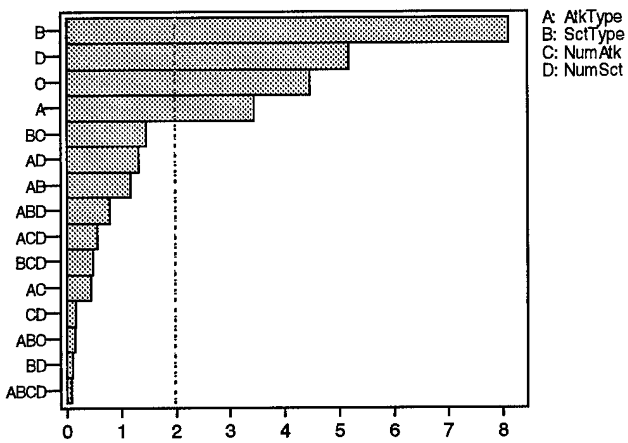
Unusual Observations for AvgDetRg

Obs	AvgDetRg	Fit	StDev Fit	Residual	St Resid
4	5.30000	4.87500	0.06108	0.42500	2.32R
8	5.24000	4.86100	0.06108	0.37900	2.07R
37	4.87000	5.24400	0.06108	-0.37400	-2.04R
53	5.62000	5.24400	0.06108	0.37600	2.05R
69	4.85000	5.24400	0.06108	-0.39400	-2.15R
70	4.68000	5.19200	0.06108	-0.51200	-2.79R
115	4.52000	4.91600	0.06108	-0.39600	-2.16R
125	4.78000	5.24800	0.06108	-0.46800	-2.55R
131	4.54000	4.91600	0.06108	-0.37600	-2.05R
149	5.67000	5.24400	0.06108	0.42600	2.32R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is Det/Loss, Alpha = .05)



Estimated Effects and Coefficients for Det/Loss

Term	Effect	Coef	StDev Coef	T	P
Constant		21.737	0.4839	44.92	0.000
AtkType	3.318	1.659	0.4839	3.43	0.001
SctType	7.849	3.925	0.4839	8.11	0.000
NumAtk	-4.310	-2.155	0.4839	-4.45	0.000
NumSct	-5.000	-2.500	0.4839	-5.17	0.000
AtkType*SctType	1.135	0.567	0.4839	1.17	0.243
AtkType*NumAtk	0.416	0.208	0.4839	0.43	0.668
AtkType*NumSct	-1.281	-0.641	0.4839	-1.32	0.188
SctType*NumAtk	-1.417	-0.709	0.4839	-1.46	0.145
SctType*NumSct	-0.098	-0.049	0.4839	-0.10	0.919
NumAtk*NumSct	0.165	0.083	0.4839	0.17	0.865
AtkType*SctType*NumAtk	-0.148	-0.074	0.4839	-0.15	0.878
AtkType*SctType*NumSct	-0.755	-0.378	0.4839	-0.78	0.436
AtkType*NumAtk*NumSct	0.527	0.264	0.4839	0.55	0.587
SctType*NumAtk*NumSct	-0.449	-0.224	0.4839	-0.46	0.644
AtkType*SctType*NumAtk*NumSct	0.082	0.041	0.4839	0.08	0.933

Analysis of Variance for Det/Loss

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	4648.0	4647.98	1161.99	31.02	0.000
2-Way Interactions	6	205.9	205.95	34.32	0.92	0.485
3-Way Interactions	4	42.9	42.88	10.72	0.29	0.887
4-Way Interactions	1	0.3	0.27	0.27	0.01	0.933
Residual Error	144	5394.8	5394.83	37.46		
Pure Error	144	5394.8	5394.83	37.46		
Total	159	10291.9				

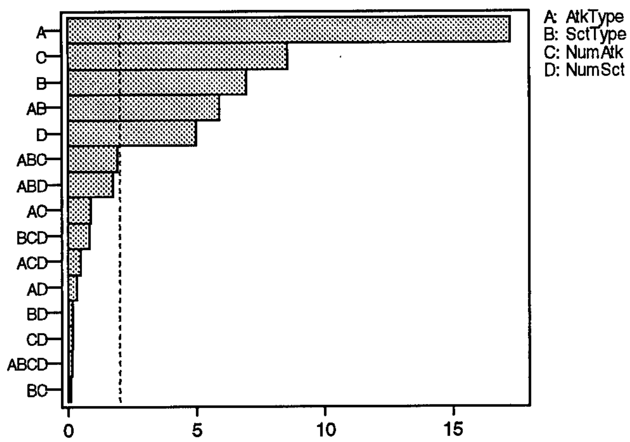
Unusual Observations for Det/Loss

Obs	Det/Loss	Fit	StDev Fit	Residual	St Resid
4	19.0000	34.3480	1.9356	-15.3480	-2.64R
49	38.5000	20.7210	1.9356	17.7790	3.06R
115	41.5000	27.5170	1.9356	13.9830	2.41R
124	49.2500	26.8880	1.9356	22.3620	3.85R
131	39.4000	27.5170	1.9356	11.8830	2.05R
132	48.0000	34.3480	1.9356	13.6520	2.35R
160	39.3000	21.7540	1.9356	17.5460	3.02R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is TotalKil, Alpha = .05)



Estimated Effects and Coefficients for TotalKil

Term	Effect	Coef	StDev Coef	T	P
Constant		104.219	1.014	102.76	0.000
AtkType	34.988	17.494	1.014	17.25	0.000
SctType	14.112	7.056	1.014	6.96	0.000
NumAtk	17.338	8.669	1.014	8.55	0.000
NumSct	10.113	5.056	1.014	4.99	0.000
AtkType*SctType	-11.987	-5.994	1.014	-5.91	0.000
AtkType*NumAtk	1.737	0.869	1.014	0.86	0.393
AtkType*NumSct	-0.688	-0.344	1.014	-0.34	0.735
SctType*NumAtk	-0.188	-0.094	1.014	-0.09	0.926
SctType*NumSct	0.387	0.194	1.014	0.19	0.849
NumAtk*NumSct	-0.338	-0.169	1.014	-0.17	0.868
AtkType*SctType*NumAtk	-3.937	-1.969	1.014	-1.94	0.054
AtkType*SctType*NumSct	-3.563	-1.781	1.014	-1.76	0.081
AtkType*NumAtk*NumSct	1.012	0.506	1.014	0.50	0.618
SctType*NumAtk*NumSct	-1.662	-0.831	1.014	-0.82	0.414
AtkType*SctType*NumAtk* NumSct	0.237	0.119	1.014	0.12	0.907

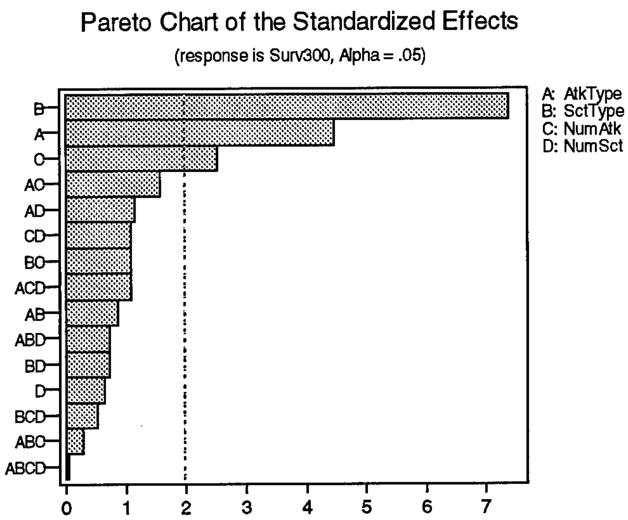
Analysis of Variance for TotalKil

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	73046	73045.6	18261.4	110.97	0.000
2-Way Interactions	6	5900	5899.6	983.3	5.98	0.000
3-Way Interactions	4	1279	1279.4	319.8	1.94	0.106
4-Way Interactions	1	2	2.3	2.3	0.01	0.907
Residual Error	144	23697	23696.5	164.6		
Pure Error	144	23696	23696.5	164.6		
Total	159	103923				

Unusual Observations for TotalKil

Obs	TotalKil	Fit	StDev Fit	Residual	St Resid
6	99.000	124.900	4.057	-25.900	-2.13R
8	102.000	127.500	4.057	-25.500	-2.10R
15	82.000	115.200	4.057	-33.200	-2.73R
35	55.000	81.100	4.057	-26.100	-2.14R
55	79.000	103.700	4.057	-24.700	-2.03R
75	128.000	99.100	4.057	28.900	2.37R
82	130.000	103.800	4.057	26.200	2.15R
91	67.000	99.100	4.057	-32.100	-2.64R
115	111.000	81.100	4.057	29.900	2.46R
130	75.000	103.800	4.057	-28.800	-2.37R
142	115.000	139.600	4.057	-24.600	-2.02R

R denotes an observation with a large standardized residual



Estimated Effects and Coefficients for Surv300

Term	Effect	Coef	StDev Coef	T	P
Constant		31.917	0.9241	34.54	0.000
AtkType	8.235	4.118	0.9241	4.46	0.000
SctType	13.624	6.812	0.9241	7.37	0.000
NumAtk	4.667	2.333	0.9241	2.53	0.013
NumSct	-1.166	-0.583	0.9241	-0.63	0.529
AtkType*SctType	1.584	0.792	0.9241	0.86	0.393
AtkType*NumAtk	2.889	1.444	0.9241	1.56	0.120
AtkType*NumSct	-2.112	-1.056	0.9241	-1.14	0.255
SctType*NumAtk	-1.999	-0.999	0.9241	-1.08	0.281
SctType*NumSct	1.333	0.667	0.9241	0.72	0.472
NumAtk*NumSct	-2.000	-1.000	0.9241	-1.08	0.281
AtkType*SctType*NumAtk	-0.500	-0.250	0.9241	-0.27	0.787
AtkType*SctType*NumSct	-1.334	-0.667	0.9241	-0.72	0.472
AtkType*NumAtk*NumSct	1.986	0.993	0.9241	1.07	0.284
SctType*NumAtk*NumSct	-0.959	-0.479	0.9241	-0.52	0.605
AtkType*SctType*NumAtk*NumSct	-0.083	-0.042	0.9241	-0.05	0.964

Analysis of Variance for Surv300

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	11063.1	11063.1	2765.78	20.24	0.000
2-Way Interactions	6	1003.3	1003.3	167.22	1.22	0.297
3-Way Interactions	4	275.6	275.6	68.90	0.50	0.733
4-Way Interactions	1	0.3	0.3	0.28	0.00	0.964
Residual Error	144	19673.2	19673.2	136.62		
Pure Error	144	19673.2	19673.2	136.62		
Total	159	32015.5				

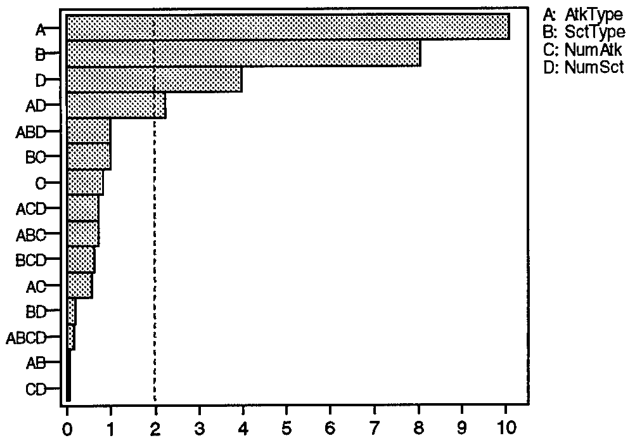
Unusual Observations for Surv300

Obs	Surv300	Fit	StDev Fit	Residual	St Resid
18	0.0000	25.5560	3.6962	-25.5560	-2.30R
35	5.5600	29.4440	3.6962	-23.8840	-2.15R
49	55.5600	19.4460	3.6962	36.1140	3.26R
83	5.5600	29.4440	3.6962	-23.8840	-2.15R
124	66.6700	39.9990	3.6962	26.6710	2.41R
160	66.6700	44.0000	3.6962	22.6700	2.04R

R denotes an observation with a large standardized residual

Pareto Chart of the Standardized Effects

(response is LER300, Alpha = .05)



Estimated Effects and Coefficients for LER300

Term	Effect	Coef	StDev Coef	T	P
Constant		6.9683	0.1562	44.62	0.000
AtkType	3.1496	1.5748	0.1562	10.08	0.000
SctType	2.5216	1.2608	0.1562	8.07	0.000
NumAtk	-0.2524	-0.1262	0.1562	-0.81	0.420
NumSct	-1.2454	-0.6227	0.1562	-3.99	0.000
AtkType*SctType	-0.0179	-0.0089	0.1562	-0.06	0.954
AtkType*NumAtk	0.1736	0.0868	0.1562	0.56	0.579
AtkType*NumSct	-0.7049	-0.3524	0.1562	-2.26	0.026
SctType*NumAtk	-0.3084	-0.1542	0.1562	-0.99	0.325
SctType*NumSct	-0.0554	-0.0277	0.1562	-0.18	0.860
NumAtk*NumSct	-0.0149	-0.0074	0.1562	-0.05	0.962
AtkType*SctType*NumAtk	-0.2219	-0.1109	0.1562	-0.71	0.479
AtkType*SctType*NumSct	-0.3124	-0.1562	0.1562	-1.00	0.319
AtkType*NumAtk*NumSct	0.2256	0.1128	0.1562	0.72	0.471
SctType*NumAtk*NumSct	-0.1909	-0.0954	0.1562	-0.61	0.542
AtkType*SctType*NumAtk*NumSct	0.0491	0.0246	0.1562	0.16	0.875

Analysis of Variance for LER300

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	715.74	715.735	178.934	45.85	0.000
2-Way Interactions	6	25.03	25.028	4.171	1.07	0.384
3-Way Interactions	4	9.37	9.366	2.341	0.60	0.663
4-Way Interactions	1	0.10	0.097	0.097	0.02	0.875
Residual Error	144	562.02	562.021	3.903		
Pure Error	144	562.02	562.021	3.903		
Total	159	1312.25				

Unusual Observations for LER300

Obs	LER300	Fit	StDev Fit	Residual	St Resid
75	11.6400	7.0180	0.6247	4.6220	2.47R
82	11.8200	8.0330	0.6247	3.7870	2.02R
115	11.1000	6.8210	0.6247	4.2790	2.28R
123	11.1800	7.0180	0.6247	4.1620	2.22R
124	16.5000	8.9060	0.6247	7.5940	4.05R
132	16.4300	11.2930	0.6247	5.1370	2.74R
160	15.1000	8.3660	0.6247	6.7340	3.59R

R denotes an observation with a large standardized residual

Appendix D. Scenario Force Structures

SIDE 1 FORCE DESCRIPTION

Unit Num	System Name	System Type	Total Elements
1	(scout helicopter)		3 or 5
2	(scout helicopter)		"
3	(scout helicopter)		"
4	(attack helicopter)		3 or 5
5	(attack helicopter)		"
6	(attack helicopter)		"
7	JAV DE	206	4
8	FSCV	143	9
9	M1A2	107	14
10	FSCV	143	2
11	B120MM	16	6
12	M1A2	107	14
13	M1A2	107	14
14	JAV DE	206	5
15	JAV DE	206	9
16	BRAD M	127	14
17	FSCV	143	6
18	B120MM	16	6
19	BRADFI	130	1
20	BRADFI	130	1
21	BRADFI	130	1
22	JAV DE	206	5
23	BRAD M	127	2
24	FSCV	143	6
25	JAV DE	206	9
26	BRAD M	127	14
27	JAV DE	206	9
28	BRAD M	127	14
29	M1A2	107	14
30	B120MM	16	6
31	BRADFI	130	1
32	BRADFI	130	1
33	BRADFI	130	1
34	JAV DE	206	5
35	BRAD M	127	2
36	FSCV	143	6
37	JAV DE	206	9
38	BRAD M	127	14
39	JAV DE	206	9
40	BRAD M	127	14
41	M1A2	107	14
42	B120MM	16	6
43	BRADFI	130	1
44	BRADFI	130	1
45	BRADFI	130	1
46	MLRS	9	9
47	AVENGE	154	2
48	AVENGE	154	2
49	AVENGE	154	2
50	BUAV	179	1
51	BUAV	179	1
52	BUAV	179	1
53	BUAV	179	1
54	BUAV	179	1
55	BUAV	179	1
56	A-10	217	2
57	A-10	217	2
58	A-10	217	2
59	Linebk	124	2
60	Linebk	124	2
61	Linebk	124	2
62	Linebk	124	2
63	M109A6	3	6
64	M109A6	3	6
65	M109A6	3	6

SIDE 2 FORCE DESCRIPTION

Unit Num	System Name	System Type	Total Elements
1	BTR-80	367	3
2	BTR-80	367	17
3	BTR-80	367	11
4	BTR-80	367	11
5	BTR-80	367	11
6	BTR-80	367	17
7	BMP-3	379	1
8	T-80U	385	11
9	T-80U	385	10
10	T-80U	385	10
11	2S1	100	6
12	2S1	100	6
13	2S1	100	6
14	2S6	358	2
15	2S6	358	2
16	2S6	358	2
17	BMP-3	379	6
18	BRDM-2	375	3
19	BMP-3	379	2
20	BRDM-2	375	4
21	BTR-80	367	17
22	BTR-80	367	11
23	BTR-80	367	11
24	BTR-80	367	11
25	BTR-80	367	17
26	BTR-80	367	11
27	BTR-80	367	11
28	BTR-80	367	11
29	BRDM-S	363	9
30	SA-13	354	6
31	SA-13	354	6
32	SA-13	354	6
33	SA-13	354	6
34	MT-12	309	2
35	MT-12	309	2
36	MT-12	309	2
37	BTR-80	367	3
38	BTR-80	367	17
39	BTR-80	367	11
40	BTR-80	367	11
41	BTR-80	367	11
42	BTR-80	367	17
43	BMP-3	379	1
44	T-80U	385	11
45	T-80U	385	10
46	T-80U	385	10
47	2S1	100	6
48	2S1	100	6
49	2S1	100	6
50	2S6	358	2
51	2S6	358	2
52	2S6	358	2
53	BMP-3	379	6
54	BRDM-2	375	3
55	BMP-3	379	2
56	BRDM-2	375	4
57	BTR-80	367	17
58	BTR-80	367	11
59	BTR-80	367	11
60	BTR-80	367	11
61	BTR-80	367	17
62	BTR-80	367	11
63	BTR-80	367	11
64	BTR-80	367	11
65	BRDM-S	363	9

SIDE 2 FORCE DESCRIPTION

Unit Num	System Name	System Type	Total Elements
66	SA-13	354	6
67	SA-13	354	6
68	SA-13	354	6
69	SA-13	354	6
70	MT-12	309	2
71	MT-12	309	2
72	MT-12	309	2
73	BMP-3	379	1
74	BTR-80	367	2
75	BMP-3	379	13
76	BTR-80	367	2
77	BMP-3	379	10
78	BMP-3	379	10
79	BMP-3	379	10
80	BMP-3	379	13
81	BTR-80	367	2
82	BMP-3	379	10
83	BMP-3	379	10
84	BMP-3	379	10
85	BMP-3	379	13
86	BTR-80	367	2
87	BMP-3	379	10
88	BMP-3	379	10
89	BMP-3	379	10
90	T-80U	385	11
91	T-80U	385	10
92	T-80U	385	10
93	2S1	100	6
94	2S1	100	6
95	2S1	100	6
96	2S6	358	2
97	2S6	358	2
98	2S6	358	2
99	BMP-3	379	6
100	BRDM-2	375	3
101	BMP-3	379	2
102	BRDM-2	375	4
103	BRDM-S	363	9
104	SA-13	354	6
105	SA-13	354	6
106	SA-13	354	6
107	SA-13	354	6
108	MT-12	309	2
109	MT-12	309	2
110	MT-12	309	2
111	T-80U	385	1
112	BTR-80	367	2
113	BMP-3	379	1
114	BMP-3	379	1
115	T-80U	385	11
116	T-80U	385	10
117	T-80U	385	10
118	BMP-3	379	1
119	T-80U	385	11
120	T-80U	385	10
121	T-80U	385	10
122	BMP-3	379	1
123	T-80U	385	11
124	T-80U	385	10
125	T-80U	385	10

Unit Num	System Name	System Type	Total Elements
126	2S1	100	6
127	2S1	100	6
128	2S1	100	6
129	2S6	358	2
130	2S6	358	2
131	2S6	358	2
132	BMP-3	379	6
133	BMP-3	379	2
134	BRDM-2	375	4
135	BRDM-2	375	3
136	SA-13	354	2
137	SA-13	354	2
138	SA-13	354	2
139	BTR-80	367	3
140	2S3	99	18
141	2S3	99	18
142	2S3	99	18
143	HOPLIT	70	1
144	HOPLIT	70	1
145	HOPLIT	70	1
146	HOPLIT	70	1
147	HOPLIT	70	1
148	HOPLIT	70	1
149	HIP E	75	1
150	HIP E	75	1
151	HIP E	75	1
152	HIP E	75	1
153	HIP	71	1
154	HIP	71	1
155	HIND	77	1
156	HIND	77	1
157	HIND	77	1
158	HIND	77	1
159	HIND	77	1
160	HIND	77	1
161	RUAV	304	1
162	RUAV	304	1
163	RUAV	304	1
164	RUAV	304	1
165	RUAV	304	1
166	RUAV	304	1
167	SA-13	354	2
168	SA-8B	356	2
169	2S6	358	2
170	2S6	358	6
171	SA-8B	356	7
172	SA-13	354	7
173	BRDM-S	363	4
174	BRDM-S	363	4
175	BRDM-S	363	4
176	MT-12	309	4
177	MT-12	309	4
178	MT-12	309	4
179	BMP-3	379	5
180	BMP-3	379	5
181	BMP-3	379	5
182	BRDM-2	375	2
183	BRDM-2	375	2
184	BRDM-2	375	2
185	BTR-80	367	2
186	BTR-80	367	2
187	BTR-80	367	2
188	BM-21	84	6
189	BM-21	84	6
190	BM-21	84	6

Appendix E. Janus Modeling of AH-64D and RAH-66

Following is a list of some of the major changes made to the JANUS database used by the Department of Systems Engineering at the United States Military Academy, West Point, NY. Minor changes to the database are not shown.

1. Create FCR: Sensor 43. FCR is modeled as a highly sensitive (sensor type 4) thermal seeker. Change FOV to N-90, W-360, N→W-0.25.
2. Create DTV: Sensor 25. Change FOV to N-0.9, W-4.00, N→W-0.225, sensor type 2.
3. Create FLIR: Sensor 37. Change FOV to N-3.10, W-50.0, N→W-0.062, sensor type 4.
4. Change sensors on Apache to 37-25-37. Element Spacing 200 meters.
5. Change Fly Type 32 to Nap1-60, Nap2-120.
6. Create Longbow Apache by copying Apache. Element Spacing 100 meters. Fly type 32. Change sensors to 43-37-43.
7. Create Comanche by copying Longbow Apache. Change dimensions to L-0.60, W-0.20, H-0.17 meters. Change weight, fuel capacity, and fuel burn rates to half of Apache's. Chemical X factor to zero. Change 30mm gun to 20mm HEIT (weapon 12).
8. Create RF Hellfire by increasing PK and PH tables for Hellfire on Longbow / Comanche by 0.04 for each target type.
9. Increase mast height to 10m for attack helicopters (simulate target h/o info from scouts).
10. Change weapons loads to scout/attack parameters.
11. Comanche-atk dimensions = Comanche-sct plus:
    W = 4 x msl width (4 x 0.178 = 0.712)
    H = 2 x msl height (2 x 0.178 = 0.356)
    L = msl length (1.727)
    ⇨ L = 1.85, W = 0.91, H = 0.52
12. HF trigger pulls / reload = 16
13. Other changes to weapon selection / changeover range
14. Target priorities based on scenario

Appendix F. 66th MORS Presentation

Optimal Mix of Army Aviation Assets

Operations Research Center
US Military Academy
West Point, NY

CPT JON SHUPENUS
USMA Department of Mathematical Sciences

MAJ DAVID BRIGGS
USMA Department of Systems Engineering

Six USMA cadets
SE402 / 403 Systems Design Course

Study Team

- CPT Jon Shupenus
  - Former AH-64 company commander
  - MS Applied mathematics, MS OR&S (RPI '97)
- MAJ David Briggs
  - USMA systems engineering instructor
  - MS OR, MS Simulation Modeling and Analysis (UCF '95)
- SE402 / 403
  - Design of real-world, large scale and complex systems; reinforces iterative nature of formulation, analysis, and interpretation of designs. Topics include needs analysis, quality function deployment, modeling, trade-off analysis, compatibility analysis and systems architecture.

Outline

- History of attack helicopter battalions
- Project description
- Modeling AH-64D Longbow Apache and RAH-66 Comanche in Janus
- Analysis of battalion designs

History

- Early 1960's: Logistics, C^2 (H-13, H-23, HU-1)
- Mid 1960's: Armed helicopters still in the formative stage
  - UH-1B: 7.62mm, 2.75" FFAR, AGM-22B, 40mm
- Early 1970's: Offensive missions (Tactical escort, reconnaissance, fire support, security, penetration, exploitation, counterattack, pursuit)
  - AH-1: 2.75" FFAR, 40mm, ATGM, 7.62mm, 20/30mm
- Mid 1970's: scout platoon 4x OH-58C, attack platoon 7x AH-1S
- 1985: 4x OH-58C, 6x AH-64A
- 1993: 3x AH-64A, 5x AH-64A (ARI)
- 1997: 3x AH-64D, 5x AH-64D
- 2010? 3x RAH-66, 5x AH-64D

Purpose

- Explore operational performance of heavy division attack helicopter battalion force structures in various scenarios
  - Investigate effects of combinations of *different types* of scout and attack helicopters
  - Investigate effects of alternative *force levels* of scout and attack helicopters

Related Study

- Technical report TRAC-TR-0993, "Aviation Attack Battalion Study Final Report," October 1993, TRADOC Analysis Center -- Operations Analysis Center, Production Analysis Directorate, Fort Leavenworth, KS
  - Identifies the benefits and liabilities involved in replacing the OH-58C (Kiowa) with the AH-64A (Apache) as the scout helicopter in the heavy division attack helicopter battalion

Scope

- Limitations
  - Unclassified: aircraft, vehicle and weapon databases; Enemy force structure
  - Attack mission: not reconnaissance
  - Performance / effectiveness analysis: not sustainment, personnel levels, etc.
- Constraints
  - Base case: current ARI configuration
  - Consider only AH64D and RAH66
  - Heavy division attack helicopter battalion

Methodology

- Analytic tools
  - Replications of stochastic simulation
  - Experimental design
  - Statistical significance
- Performance comparison
  - Helicopter system capabilities
- Effectiveness analysis
  - Survivability, lethality, detections

Alternatives

- Base case (current ARI)
- Aircraft types
  - AH-64D Longbow Apache
  - RAH-66 Comanche
- Force levels
  - 3 or 5 scouts per platoon
  - 3 or 5 attack helicopters per platoon
  - 18, 24, or 30 total aircraft per battalion

Janus 6.0

- High-resolution interactive combat computer simulation model
- Stochastic; random number seeds
- Auto script capability for replications
- Janus Evaluator's Tool Set (JETS) post-processor
  - Detections, fires, kills, artillery, statistics ...
  - ... by killer, coalition, side, task force, system, weapon, round type, sensor
  - *Demo*

Modeling in Janus

- Most important items for simulating aircraft differences *in this study*:
  - Signature characteristics
  - Sensor characteristics
  - Weapons loads
  - High threat
  - Same TTP

Assumptions

Assumption	*Effect*
One each attack and scout platoon per company	Allows aggregation in JANUS
All scout and no attack helicopters have FCR	Ignore distribution plan which calls for 1/3 of aircraft to have FCR
Same FCR on AH64D & RAH66; digitization works	Unclassified comparison of Apache and Comanche FCR not available
Friendly and enemy units have advanced equipment	Study 2010 scenarios
Anti-helicopter threat is extremely high	Allows the study to evaluate differences between design points
20 km detection capability of FCR	Unclassified detection capability not available; 20 km range assumed from discussion with pilots

Assumptions (cont.)

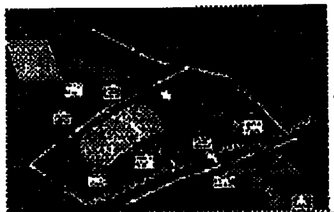
Assumption	*Effect*
Comanche IR detectability is 4 sigma smaller than Apache	Reduce thermal contrast to 1/4 Apache's
Cross section of Comanche-scout is 1/600 of Apache	Reduce length, width, height to reduce P(detection)
Attack hel. cross section increases by dimensions of external missiles	Increases radar cross section to approx. 1/42, not 1/600
Comanche-scout carries only internal loads to minimize radar signature	Takes advantage of stealthy characteristics, but reduces kill capability
Increased sensor height for attack helicopters simulates info sharing	Needed to model digital target handoff capability

Weapon Loads

	AH-64A	AH-64D	RAH-66
Scout	38x FFAR 8x SAL Hellfire 4x Stinger 1200x 30mm	38x FFAR 8x RF Hellfire 4x Stinger 1200x 30mm	6x RF Hellfire on fully retractable internal missile armament system 500x 20mm
Attack	16x SAL Hellfire 4x Stinger 1200x 30mm	16x RF Hellfire 4x Stinger 1200x 30mm	14x RF Hellfire (6 internal, 8 external) 500x 20mm

HRS 59.0 Deep Attacks

- SWA scenario: Propositional brigade combat team conducts a delay. Army aviation conducts cross-FLOT operations on long-range fire support systems positions with the enemy artillery group. A second deep attack mission engages moving second echelon division.



Environmental factors --
- SWA summer
- 0200 hours
- Rolling terrain
- 1600 km² terrain

Target priorities --
- CAG:
  - ADA
  - FA
- 2nd Echelon:
  - ADA
  - tanks

HRS 37.0 Hasty Attack

- EUR scenario: Red first echelon penetrates Blue defensive positions. Red calls forward second echelon tank division to continue attack. Blue commander orders counterattack against first and second echelons. Attack helicopters engage Red first and second echelons in the close battle.

Environmental factors --
- EUR winter
- 0100 hours
- Mountainous terrain
- 100 km² terrain

Target priorities --
- ADA
- tanks
- personnel carriers

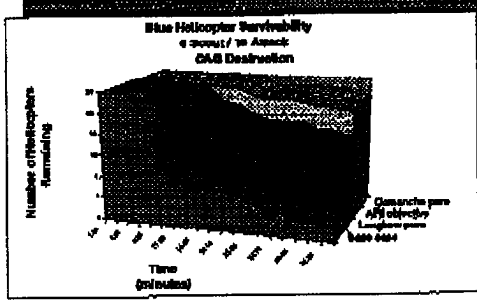
Effectiveness analysis

- Based on over 500 JANUS replications
  - 17 design points, 10 replications per design point, 3 scenarios
- Statistics
  - Average values vs. Confidence intervals
- Survivability: Over time, LER
- Detections: Total, Over time, Range, Detects per loss
- Kills: Against enemy systems, Over time
- Results shown in this briefing are for CAG attack mission in HRS 59.0

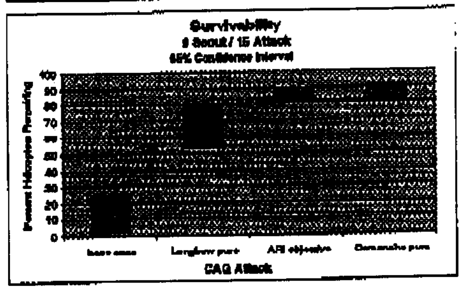
Helicopter Type Analysis

- 9 Scout / 15 Attack
  - Base case
  - Longbow pure
  - ARI Objective (Comanche scout, Longbow attack)
  - Comanche pure

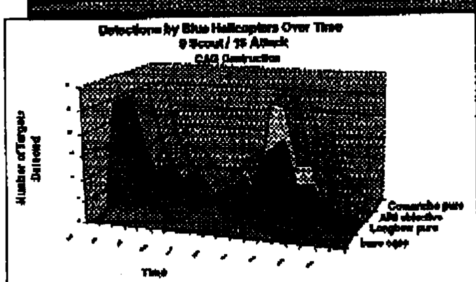
Survivability



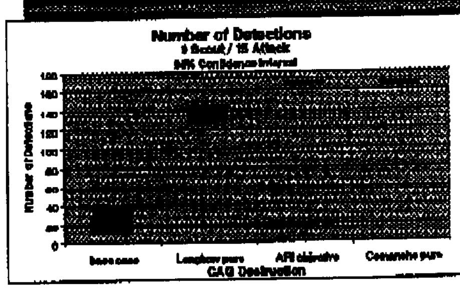
Survivability



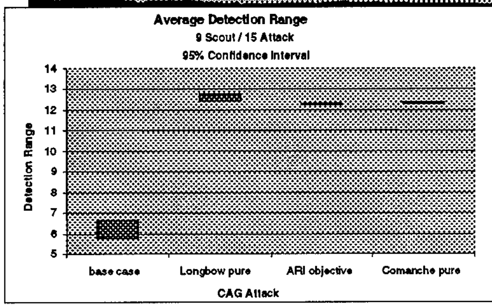
Detections



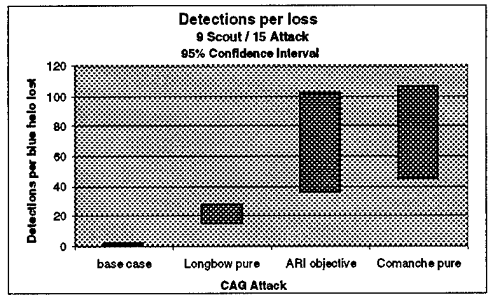
Detections



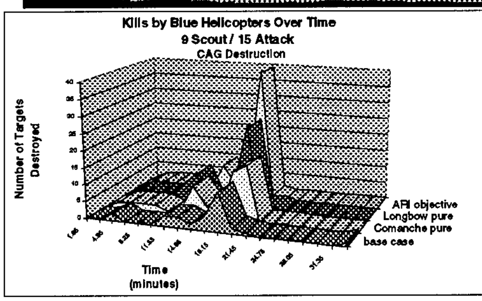
Detections



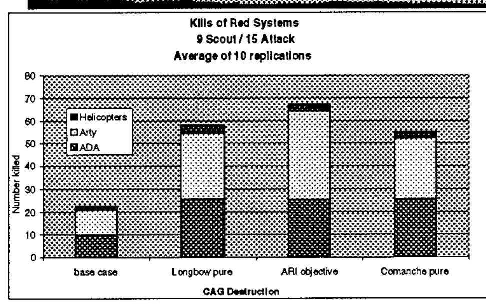
Detections per loss



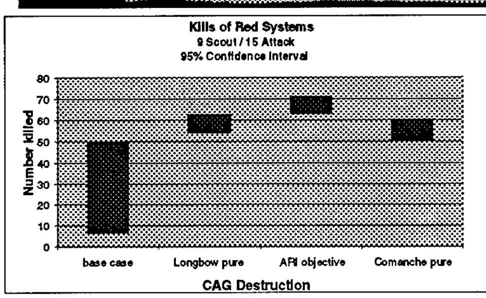
Kills



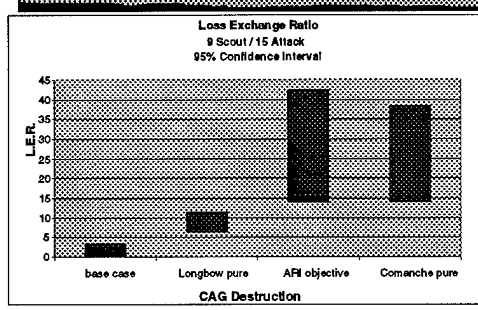
Kills



Kills



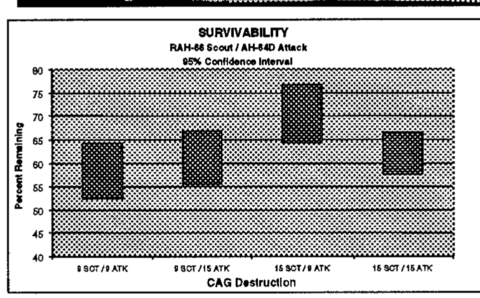
Loss Exchange Ratio



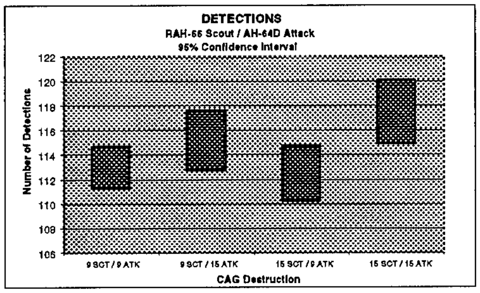
Force Level Analysis

- RAH-66 scout / AH-64D attack
  - 9 Scout / 9 Attack
  - 9 Scout / 15 Attack
  - 15 Scout / 9 Attack
  - 15 Scout / 15 Attack

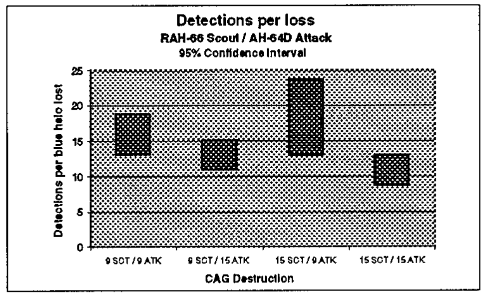
Survivability



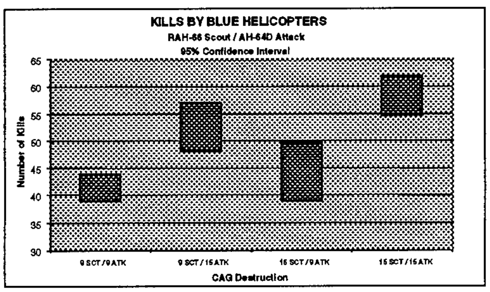
Detections



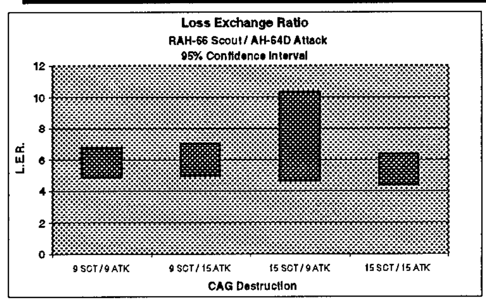
Detections per loss



Kills



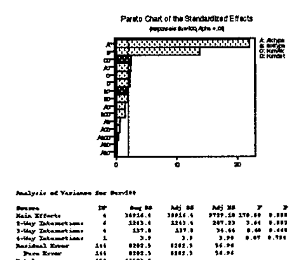
Loss Exchange Ratio



DOE Analysis

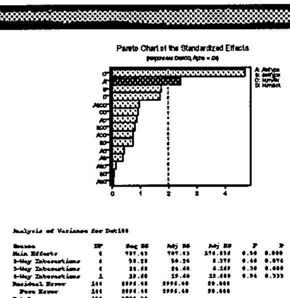
- 2^4 factorial design
- 10 replications
- alpha = .05

Survivability



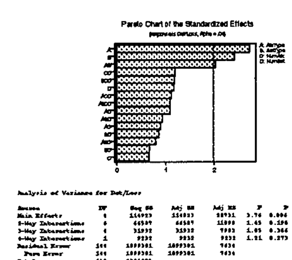
Comanche survives best due to low observables (RCS, IR signature)

Detections



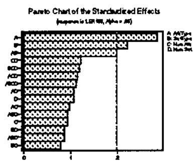
More AH-64Ds in the attack platoon increases the number of detections (Enhances scout survivability)

Detections per loss



Losing fewer Comanches increases the Det/loss ratio

Loss Exchange Ratio



Killing fewer enemy but losing fewer Comanches increases the LER more than the increased kills but lower survival of Longbow

Analysis of Variance for LER100

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Main Effects	4	39422	39422	9856	3.75	0.006
2-Way Interactions	6	23181	23181	3864	1.47	0.192
3-Way Interactions	4	11278	11278	2820	1.07	0.372
4-Way Interactions	1	3274	3274	3274	1.25	0.266
Residual Error	144	378824	378824	2625		
Pure Error	144	378824	378824	2625		
Total	159	455981				

Findings

In general...

- ARI Objective force structure (9x RAH-66, 15x AH-64D) performs best for planned deep attacks
- Comanche-pure design (24x RAH-66) performs best during hasty attack / close battle
- Aircraft type is more important for survival than number of aircraft per company (Comanche survives best)
- Battalion size does not affect survival percentage or LER
- Synergistic effect of RAH-66 / AH-64D mix greatly increases performance over Longbow-pure design
- Comanche-pure design kills fewer vehicles than ARI Objective

Conclusion

- Army seems to be on the right track in force structure development for the heavy division attack helicopter battalion
- Older simulation models are still useful

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