ANALYSIS OF ALTERNATIVES: MULTIVARIATE CONSIDERATIONS

THESIS

John J. Siegner, Lieutenant Colonel
AFIT/GOA/ENS/98M-07

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GOA/ENS/98M-07

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John J. Siegner, B.S., M.S.

Lieutenant Colonel, USAF

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John J. Siegner, B.S., M.S.
Lieutenant Colonel, USAF

Approved:

Chairman — 11 Mar 98 (date)

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Table of Contents

Page

List of Figures

List of Tables

Table Page

Abstract

The Aeronautical System Center (ASC) is developing a Simulation and Analysis Facility (SIMAF) that will link models, simulations, hardware-in-the-loop, and system-in-the-loop resources to create a robust virtual environment supporting assessment of alternate systems in the defense acquisition process. ENS is assisting ASC with scenario development, experimental design, and battleroom visualization efforts for a SIMAF capability demonstration.

This thesis uses multivariate analysis and visualization tools to develop an approach for reducing the dimensionality of multiple campaign level measures of effectiveness for a notional Analysis of Alternatives (AoA) study. Additionally, the thesis advances an AoA visualization paradigm for the SIMAF capability demonstration.

The results of this study suggest that multivariate data reduction techniques and user interactive visualization of multivariate analysis results can be employed to combine multiple MOEs into a reduced set of interpretable factors capturing the operational effectiveness performance of competing acquisition alternatives. The thesis research also successfully demonstrated a visual data mining approach applied to the visualization of campaign level analysis results and the cost/effectiveness integration of an AoA effort.

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1. Introduction

1.1 Background

Modeling and simulation (M&S) is increasingly chosen as a tool to aid in defense acquisition decisions. The M&S Master Plan, DoD 5000.59-P, describes the DoD vision of "synthetic environments" representing every potential opponent in any region of the world with realistic interactions for research, development, and test and evaluation activities in defense acquisition (DoD 5000.59-P, 1995:2-2). These "synthetic environments" would potentially link several types of M&S including operations with real equipment in the field (live); war games, models, and analytical tools (constructive); and systems and troops in simulators fighting on simulated battlefields (virtual) (Schoen and Starr, 1993: 845). M&S resources augmenting these environments would be collocated or distributed geographically and linked through high-speed data networks. The 1996 Quadrennial Defense Review (QDR) accentuated the need for improved analytical tools to capture the key variables in force-on-force assessments across the spectrum of military engagements, from minor contingencies to major regional conflicts (Holzer, 1997: 28).

The Air Force's Aeronautical Systems Center (ASC) is currently developing a capability to link models, simulations, hardware-in-the-loop, operator-in-the-loop, and system-in-the-loop resources to create a robust virtual environment that will support the assessment of alternative systems in the acquisition process. ASC's Simulation & Analysis Facility (SIMAF) will use the Distributed Interactive Simulation (DIS) protocol to link extensive resources indigenous to Wright Patterson Air Force Base's Wright Laboratory. Additionally, DIS will facilitate linkage to assets remote from the base providing a scaleable virtual environment capability. The SIMAF will leverage off the extensive analytical expertise organic to ASC for planning and post processing. The facility will function both as a virtual integrator of models, simulations, and hardware via communications and networking nodes and as a physical gateway for ASC modeling, simulation, and analysis to the synthetic battlespace (Smith, 1997: 4).

1.2 Problem Statement

The program management office for the SIMAF, ASC/SM, plans a capability demonstration in the Spring of 1998. The demonstration will showcase the capability SIMAF provides to improve analysis underlying the Air Force acquisition decision process. The event will be attended by acquisition decision makers - senior leaders from the Air Force Material Command (AFMC) and ASC, and prospective SIMAF users - representatives from ASC's System Project Offices (SPO) and from the Center's analytical teams. AFIT/ENS is supporting the demonstration with scenario development, experimental design, and battleroom visualization efforts (ASC, 1997: 1).

1.3 Scope

This thesis focuses on the campaign analysis and Analysis of Alternatives (AoA) portion of the SIMAF tasking including the data visualization. ASC/XRE routinely conducts and oversees modeling and simulation efforts to support AoA efforts (Logan, 1997). The AoA study's comparison of the relative advantages and disadvantages of possible acquisition alternatives assists the decision maker in selecting the alternative solution providing the maximum value of military worth. AoA analyses includes modeling and simulation at differing analysis levels, few-on-few, campaign, etc., gauged to appropriately address the mission effectiveness requirements of the potential acquisition.

The final product of an AoA study is a report that displays a comparison of alternatives in terms of cost and effectiveness. Literature review and personal interviews indicate there is not a widely accepted approach in the acquisition community to combine multiple measures of mission effectiveness into a single effectiveness measure for AoA reporting. This document describes and demonstrates one strategy to address the multivariate nature of effectiveness measures via multivariate and visualization tools.

ASC/SM has directed an end-to-end scenario for the capability demonstration that highlights SIMAF's potential to integrate data flow between simulations at various levels of the modeling hierarchy (engineering, engagement, mission, and/or campaign) in virtual and constructive environments for use in analysis to support acquisition decisions (Smith, 1997: 9). High fidelity visualizations of the simulations and analytical results at each stage of the scenario are required to present demonstration observers with a coherent visual rendering of SIMAF operation and output abilities. The visualizations must be robust enough to support the information requirements of both viewers with limited formal analytical backgrounds and experienced analysts.

The notional acquisition of a new air superiority fighter, the F-XX, was chosen for the SIMAF demonstration. The THUNDER 6.4.2 campaign model with an unclassified Southwest Asia (SWA) based database developed by ASC/XRE was selected for the simulation. In view of the notional nature of the F-XX and the fact that much of the data on the actual aircraft and equipment provided in the ASC database has been notionalized for classification purposes, the utility of the output of the simulation is limited to qualitative information for contrasting acquisition alternatives rather than generating hard quantitative performance measures.

1.4 Thesis Overview

The next four chapters provide a detailed description of the thesis effort. Chapter two summarizes a review of literature published on topics impacting the thesis area of interest including the AoA process, military M&S, information visualization, design of experiments, and multivariate analysis. The specifics of the methodology applied in the thesis are discussed in chapter three. Chapter four provides results and an analysis of the data. Finally, conclusions and recommendations for areas of future research are presented in chapter five.

The appendices supplement the material in the text. Appendix A depicts the suggested format of an AoA Report Format. The Air and Space Power Validation Group's (ASPVG) listing of the measures THUNDER can assess at the campaign level is at Appendix B. Appendix C lists the output metrics and their abbreviations. THUNDER data files modified for the thesis effort are documented in Appendix D. The output responses from the THUNDER runs, calculations used in the analysis of the results, intermediate data sets and schema used for the visualization data set are included in the remaining appendices.

2. Literature Review

2.1 Analysis of Alternatives (AoA)

An AoA is a detailed analysis of the advantages and disadvantages of the potential alternative solutions to address an established mission need (Draft OASP 97-1, 1997:6). The DoD regulation outlining the mandatory procedures for Major Defense Acquisition Programs (MDAP) and Major Information System Acquisition Programs (MAISAP), DoDR 5000.2-R, requires preparation of an AoA for all Acquisition Category (ACAT) I and IA programs (DoDR 5000.2-R, 1996:3). ACAT I and IA are MDAP and MAISAP programs, respectively. Selection criteria for the ACAT designation of a program is listed in several documents including DODR 5000.2-R. AoA study efforts are performed on other ACAT programs as required.

AoAs provide analytical justification for selected courses of action (Diaz, 1992: 79). Alternative solutions considered in an AoA must be comprehensive to include current systems, modifications to current systems, commercial off-the-shelf/government off-the-shelf (COTS/GOTS) possibilities, systems in development, non-developmental systems, conceptual systems (if they can be fielded within the time constraints imposed by the requirements), and systems of other services and allies (Draft OASP 97-1, 1997:16).

The AoA process results in a report discussing the analytical rationale for the selection of the best solution in terms of cost and operational effectiveness to support a program decision. An outline of the suggested format for the AoA report is attached at

Appendix A. This document facilitates the acquisition process by providing a linkage between system requirements and specific measures of operational effectiveness (AoA Course, 1997:10). It provides an audit trail that weaves all procurement justifications together (Diaz, 1992: 81). The analysis helps the decision maker judge whether or not any of the proposed alternatives to an existing system offer sufficient military and/or economic advantage to be worth the cost. In addition to providing a quantitative assessment of each alternative, the AoA should assess sensitivities of each potential solution to uncertainty in key assumptions (e.g. threat) and/or system variables (e.g. user specified performance capabilities - airspeed, range, payload, etc.). Guidelines provided by AFMC's Office of Aerospace Studies (OAS), the Air Force's AoA center of expertise, and completed studies assist the study team in operational effectiveness and cost analysis during the AoA effort.

2.1.1 Operational Effectiveness Methodology. Combat effectiveness analysis is a measure of an alternative's ability to meet established mission requirements in an operational environment (Diaz, 1992: 87). The assessment of operational effectiveness via M&S should include the use of existing, validated models to evaluate the quantitative impact on mission accomplishment of competing system alternatives (Draft OASP 97-1, 1997: 19). The ability of the solutions to meet mission requirements is delineated in several ways. High level mission tasks (MT) are determined that describe the tasks a system will be expected to perform. Alternative system performance is then measured by the degree the specified tasks are accomplished. Task performance is gauged by Measures of Effectiveness (MOEs), qualitative measures of a system's performance or a characteristic that indicates the degree to which it performs a task or meets a requirement under specified conditions. Subordinate to MOEs, Measures of Performance (MOP) provide the lowest quantitative measure of the systems' physical performance - range, velocity, etc., or physical characteristic - height, weight, volume, etc. (AoA course,

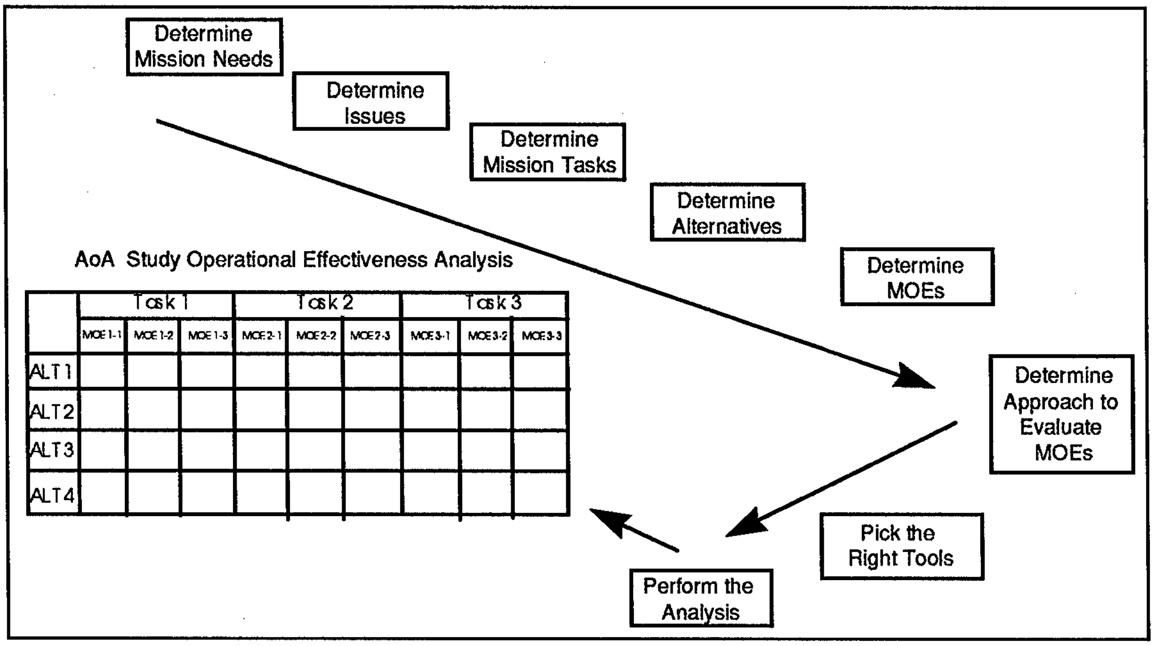

Figure 1, General Approach to Effectiveness Analysis (AoA Executive Brief, 1997:21)

1997:58). The general approach to an effectiveness analysis is depicted in Figure 1.

An example of an air superiority mission task might be the number of days to achieve air superiority. The solutions proposed in an AoA are assessed on how well they satisfy the mission tasks. Once alternative solutions have been scoped, the next step is to identify MOEs and MOPs to evaluate the ability of the solutions to support the mission tasks. MOEs should be chosen that directly relate to a systems mission tasks and overall mission accomplishment. These measures should be selected to reflect the contribution of a particular system to the outcome of battle, not just how far it can shoot or how fast it can fly (Draft OASP 97-1, 1997:23). The cost/effectiveness assessment stage of an AoA uses a single effectiveness measure for each alternative solution.

2.1.2 Combining Effectiveness Measures. While there are processes to quantify MOEs, there is not a universally accepted method to combine several MOEs into a single effectiveness measure (Pinker, Samuel, and Batcher, 1995:8). Past AoA study efforts have predominantly taken two approaches to deriving a single overarching effectiveness measure for alternate solutions. One approach is to derive a single measure from the user at the outset of the study that encapsulates the operational effectiveness of the system, e.g. number or percentage of targets killed. Another method used for arriving at a single effectiveness measure has been to evaluate several MOEs in the course of the AoA study, then selecting one of the measures as best representing the system's ability to accomplish its mission for use in the cost/effectiveness analysis.

Strategies have been proposed to combine measures of effectiveness into a single measure. One method proposed for combining MOEs is to use a linear combination of the various measures of crucial importance to the decision maker to form a single index for each alternative (Pinker, Samuel, and Batcher, 1995:9). The measures are weighted to reflect their criticality to the decision maker. The difference in units between the factors in this approach is addressed by normalizing the data to a baseline alternative. A shortcoming of this method is that the choice of the baseline for normalization could possibly change the rankings. Another strategy to reduce MOE dimensionality proposes a similar approach, but normalizes the data across alternatives using the best value as the baseline for each factor. This approach to normalizing the factors ensures a consistent ranking insensitive to the addition of new alternatives (Melese and Bonsper, 1996:17).

Air Force AoA guidance generally discourages combining MOEs into a single weighted measure. However, the guidance acknowledges that weighting schemes can be useful to the analysis if the weighting methodology is clearly explained to facilitate an accurate interpretation of the results (Draft OASP 97-1, 1997:77). In addition to operational effectiveness, AoAs also include cost analysis.

2.1.3 Cost Analysis. The AoA process views cost as an independent variable (CAIV). CAIV is a concept emphasizing cost or unit price as a constant. Cost and operational effectiveness are considered equals necessitating trade-offs throughout the acquisition process. An affordable price for a system is established, then either performance or schedule is adjusted to meet that price (Draft OASP 97-1, 1997:18). A Life Cycle Cost (LCC) estimate is completed on all alternatives in the AoA. Costs included in the LCC are development, installation, procurement, operations and support (O&S), and disposal costs of the system. The final stage of the AoA effort is the integration of the cost analysis with the effectiveness measures.

2.1.4 Cost/Effectiveness Analysis. There are several approaches to cost effectiveness analysis of alternatives; 1) a direct comparison of cost versus effectiveness, 2) a comparison on equal cost basis, and 3) a comparison on an equal effectiveness basis. A direct comparison fuses together the equal cost basis and effectiveness approaches by the addition of a cost ceiling provided by the SPO and an effectiveness ceiling provided by the user to filter out unacceptable alternatives (Draft OASP 97-1, 1997: 92). A comparison on an equal cost basis would be how many targets could be neutralized for XX dollars with the use of each alternative in a scenario. An equal effectiveness basis might be the cost of each alternative to neutralize XX targets. Figure 2 depicts an AoA cost/effectiveness comparison. A graph of this type is typically the summary of an AoA effort. The figure would seem to clearly indicate alternative 7 as the preferred choice.

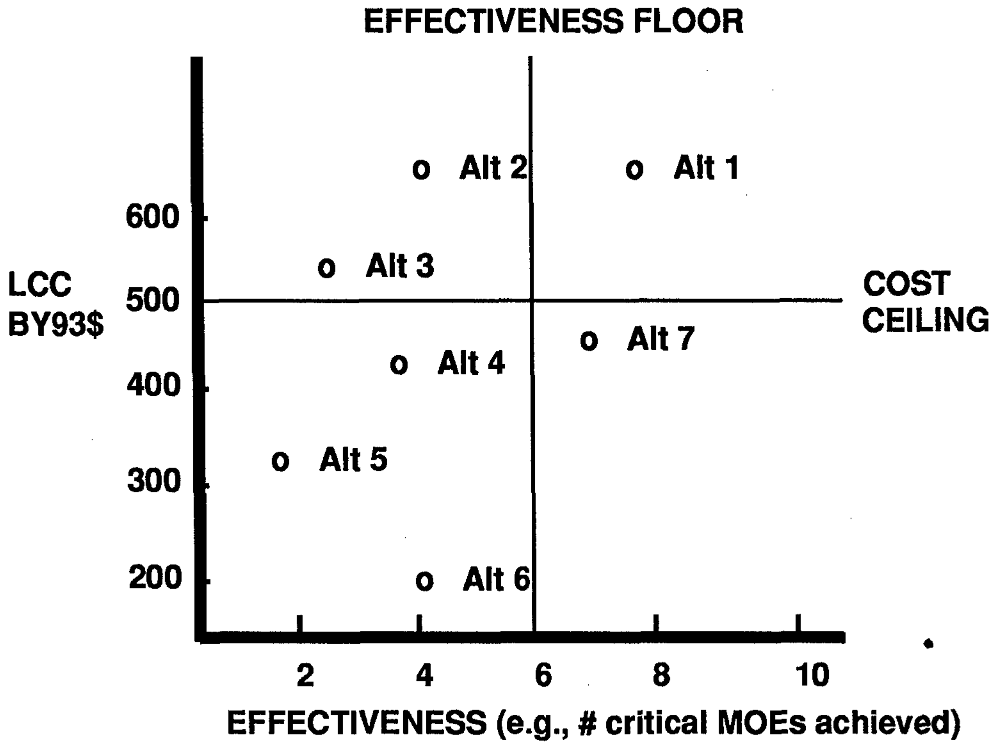

Figure 2, Cost/Effectiveness Comparison (Draft OASP 97-1, 1997:92)

However, other factors come into play in the determination of the best solution that are not considered in the AoA, - politics, force structure, schedule, etc.

2.2 Military M&S

Models are mathematical representations of a real-world system. A simulation is the operation of a real-world system or process over time. The behavior of a system as it evolves over time is studied by developing a simulation model (Banks, Carson, and Nelson, 1996:3). Dimensions of DoD M&S are depicted in Figure 3. As depicted in the figure, military M&S employed in training, acquisition, and analysis includes subsystem (engineering level) through campaign/ theater level types.

> Models for defense analysis range from engineering models of specific systems (an airborne radar system for example) to engagement models (surface-to-air (SAM) systems engaging aircraft) to mission models (a model of a flight of

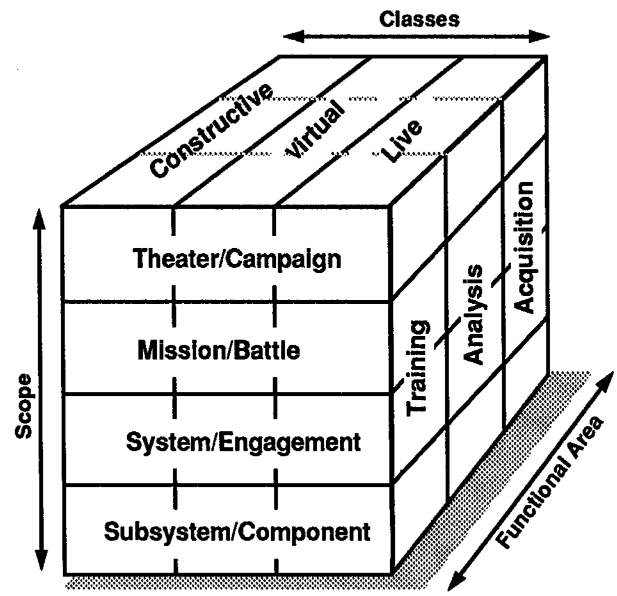

Figure 3, DoD M&S Dimensions (DoD 5000.59-P, 1995:2-

aircraft from takeoff to target engagement and return) to the campaign model representing a set of missions, operations, or battles in a military campaign (Hillestad, Bennett, and Moore, 1996:4).

Classes of modeling and simulation cover the spectrum from live or operator-in-the-loop M&S, to virtual M&S encompassing a confederation of live, hardware/operator-in-the-loop, and analytical resources operating in real-time, to constructive M&S composed of analytical resources.

2.2.1 Campaign Modeling. Campaign modeling is characterized as the highest level in the DoD modeling hierarchy as depicted in Figure 4. As the figure depicts, resolution is lowest and aggregation is highest at the top of the modeling hierarchy. The subsystem/component model at the bottom of the pyramid must render the system at a high degree of granularity for engineering level analysis. The level of detail within a particular system must be aggregated to included many systems within a campaign level simulation and still run at a reasonable speed.

An aggregated combat model groups individual combatants into larger 'units', typically using the real world hierarchical command organizations of the force to determine natural groupings in the model. Thus the entities in an aggregated model might be company, battalion, or division size units. Aggregated models do not contain detailed information about individuals making up a unit or about individual engagements making up a battle. Thus they can model larger forces in theater and campaign scenarios (Hartman, 1996:1-3).

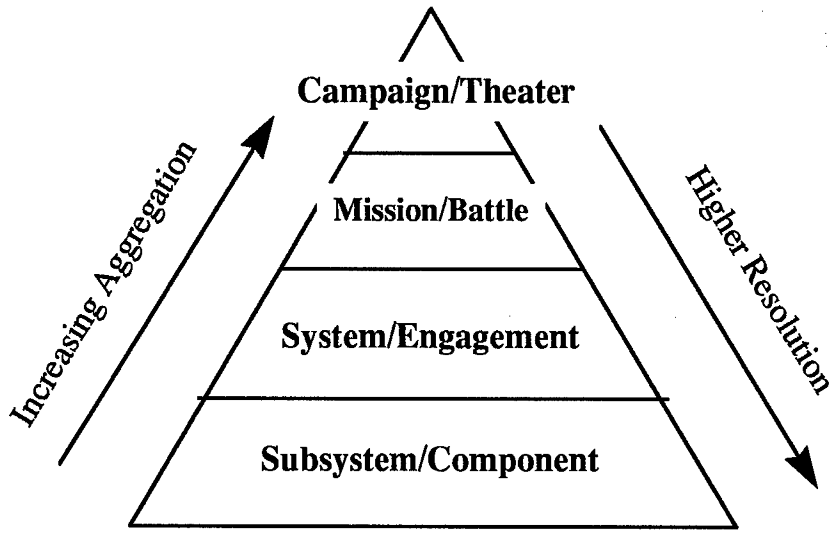

Figure 4, DoD M&S Hierarchy (THUNDER Analyst Manual, 1995:3)

The source of much of the data to populate a campaign model is computations of other, higher-resolution models, e.g. outputs of mission, engagement, and engineering level models. The process of calibrating a campaign model with data from a higher resolution model requires a knowledgeable analyst to determine how to aggregate the data, when the approximation is good enough, what cases to use, and what parameters to adjust to achieve a good approximation (Hillestad, Bennett, and Moore, 1996: 16).

Analysis of objectives is the best approach to understanding military campaigns. Objectives guide decisions at every level of DoD from the National Command Authority to junior officers engaged in combat (Prinie and Gardiner, 1996:3). Modeling output is used to assess Measures of Outcome (MOO) of a campaign. MOOs are a level above the

MTs as described in the discussion of operational effectiveness methodology. MOEs support the assessment of MTs. MTs, in turn, are used to evaluate the accomplishment of MOOs. A commander achieves operational objectives, the MOO, within the concept of operations or the campaign plan to accomplish his mission, e.g. dominate opposing operations in the air (Prinie and Gardiner, 1996:16). Analysis at the campaign level is concerned with the cumulative long term effects of kills and losses on the outcome of theater level conflict of campaign duration. Determination of the relative values of all targets killed and losses is the exclusive domain of Theater/Campaign Level analysis (ASC/XR Levels of Analysis, 1997:3).

Analysis of Alternatives (AoA) generally involve campaign level modeling to support the assessment of potential solutions (Starr, 1997:254). Campaign level modeling is too coarse grained to be used to for determining marginal value or the impact of small force increments (AFMCP 800-66, 1993:17). The value of campaign analysis in military applications is its utility in capturing the interactions among the total forces involved: air, ground, naval, and coalition forces. Campaign models are often referred to as theater models because one theater of operation is involved, although several campaigns may be included in the theater (Hillstead, Bennett, and Moore, 1996:4). Theater level models involve complex interactions among many different players and organizations making it difficult to assess the effect a single variable (e.g. introduction of a new fighter aircraft) has on the outcome of the conflict. The challenge of the military analyst is to develop modeling techniques to use high resolution insights within a campaign (Friel, 1992:129). The appropriate choice of performance measures is pivotal to relevant campaign insights. A campaign analysis is the analytical equivalent of a military campaign executed under an operations plan that defines a series of operations by integrated forces (Friel, 1992:130).

2.2.2 THUNDER. THUNDER is a data driven, force-on-force theater level model. The data files (80+) in THUNDER create the simulation scenario by defining, terrain, forces, equipment, and weapon systems. The model stochastically simulates the air war providing outputs for theater analyses supporting force structure evaluations, tactics development, war-gaming, and analysis of alternatives efforts (THUNDER Analyst Manual, 1995:1).

M&S credibility is measured by verification and validation and formally approved as adequate for use in a particular application by accreditation (VV&A) (DMSO, 1996:1-3). THUNDER is a legacy simulation.

> A good legacy simulation is characterized by a long history of consistent use and development by an active (usually large) user group, good configuration management and documentation, and widely recognized community acceptance of its results (DMSO, 1996:1-7).

The user is responsible for the VV&A of legacy M&S. Thorough and well maintained documentation makes verification fairly straightforward. THUNDER has not received a formal results validation using the thesis scenario data files to compare simulation output with the actual performance/ employment of the aircraft represented. This validation would be accomplished by the user. The user can also perform a conceptual model validation by comparing THUNDER's assumptions, limitations, and design elements to their specific requirements. After completing the V&V, the accreditation agent, the legacy M&S user, formally accredits that a specific simulation can be used for a specific application, based on objective evidence of suitability for the application (DMSO, 1996:1-9).

Air Force AoA guidance underscores the use of existing, validated models to evaluate the quantitative impact competing system solutions have on mission accomplishment (Draft OASP 97-1, 1997:19). The prohibitive cost and time to develop a large scale model is a strong argument for the use of existing, widely accepted models.

In addition to analyses supporting defense acquisitions and force structure assessments, THUNDER has been used as a campaign level analysis tool in several recent theses. Grier developed a THUNDER based quick turn evaluation tool that links cost and capabilities of alternative force structures (Grier, 1996:4). A Response Surface Methodology (RSM) based approach to develop a tool for force structure assessments utilizing THUNDER output was advanced by Farmer in his thesis work (Farmer, 1996:6-1). Forsythe's thesis focused on THUNDER's air apportionment process. He employed an RSM technique to provide insights on aircraft apportionment and campaign outcome relationships that facilitate the evaluation of non-material solutions in acquisition decisions (Forsythe, 1994:1-1). Webb performed a sensitivity analysis on selected THUNDER 5.9 outputs to inputs specified by ASC/XR (Webb, 1994:1.6).

2.3 Information Visualization

The purpose of information visualization is to assist the analyst and the decisionmaker through a visual rendering of analytical results. Although closely related to scientific visualization, information visualization provides a geometric structure to abstract, symbolic, and numeric information (Talbert, 1997:21). Scientific visualization is mainly employed to visually present the numerical output of a simulation, e.g. the simulated airflow around an aircraft (Edwards, 1992:1).

Leveraging on a human's natural ability to recognize patterns and structures of images versus tables of numbers, a properly implemented information visualization allows the presentation of large volumes of data in a format that can be easily assimilated by the viewer (Wright, 1995:19). However, it is incumbent for the analyst to format the visualization into the context of the decisionmaker (Jones, 1996:29). The visualization should adhere to basic principles of graphic design to achieve the maximum impact on the viewer. Sound graphic design dictates that displays of data focus on structure, maximizing the ink (pixel) to data ratio for high data densities (e.g. representing many numbers in a small area). Additionally, the data should be presented in various levels of granularity, from aggregate to fine resolution (Tufte, 1983:14). The image presented must enable users to quickly extract the information they need, understand its import, and make decisions (Gershon, Eick, 1997:29).

A non-interactive example of information visualization used in a military simulation application is the viewer. The viewer allows the user insight into the simulation by displaying the values of simulation parameters or representations of the simulation and any connected databases (Molitoris and Taylor, 1995:1173). A stealth viewer provides a non-interactive view of the air war from various perspectives (cockpit, ground, "God's eye") and temporal (live or recorded) regimes (Zyda, et. al, 1993:251). Stealth viewing gives the opportunity for the analyst and decision maker to better evaluate the performance of an aircraft model by viewing the visual rendering of the simulation from different aspects.

Information visualizations provided via graphics such as scatterplots, histograms, and 3D spin plots can reveal the structure of data overlooked by the application of automated, pattern detected algorithms (Elder and Pregibon, 1997:103). Two visualization techniques that assist both the decisionmaker's understanding and the researcher's analysis of the large data sets are animation and data mining.

2.3.1 Animation. Interactive visualization environments have the potential to provide practical solutions to real world problems involving complex data more rapidly than either a human or computer operating independently (Uthurusamy, 1996:564). Animation promotes a greater understanding of the information visualization by allowing the user to interact with a scene by rotating the graphic to view the image from different angles, moving through the scene to zoom into an area of interest, and selectively choosing higher/lower detail of specific objects to filter the data and potentially reveal patterns/anomalies in the numbers displayed.

Often it is difficult to target a single point or a bounded subset of points of statistical interest to an analysis out of a large data set. Interactive visualization allows the analyst to view numerous predictor/response combinations revealing a wide range of patterns without having to choose these pattern parameters as goals in advance (Elder and Pregibon, 1997:103).

2.3.2 Data Mining. Data Mining via visualization allows the identification and cataloguing of trends in large databases by applying pattern recognition, statistical, and mathematical techniques (Berry, 1997:96). Data mining specific statistical packages are weighted more heavily in analytical tools to address non-linearity, outliers, and non-numerical data than many high-end statistical packages (Pass, 1997:26). The goals of data mining are descriptive and prescriptive. Predictive from the aspect of forecasting future outputs. Descriptive from the aspect of plumbing understandable patterns that describe the data.

Selecting the appropriate data mining technique(s) for a data set involves two steps; 1) translate the problem at hand into a series of data mining tasks and 2) understand the data in terms of the fields, contents, and structure of relationships between the records (Berry, 1997:413). Data mining techniques (algorithms) target six high level tasks to achieve these goals - classification, regression, clustering, summarization, dependency modeling, or change and deviation detection (Fayyad, Pietetsky-Shapiro, and Smyth, 1996:13). Classification bins data into predefined classes. Regression pairs data items with prediction variables. Clustering segments a diverse population into subsets/clusters of more homogeneous subgroups (Berry, 1997:55). Summarization characterizes the data via a compact description, e.g. mean and standard deviation. Dependency modeling develops a model describing the dependencies between variables (Fayyad, Pietetsky-Shapiro, and Smyth, 1996:15). Change variation and deviation detection focuses on significant changes in the data from previously measured values.

The algorithms for data mining are proliferate, but can generally can be described in terms of three unifying characteristics; model representation, model evaluation, and search (Fayyad, Pietetsky-Shapiro, and Smyth, 1996:16). Model representation describes the patterns found in the data. Model evaluation is validation of the model with actual data. The search characteristic is self explanatory. Users can interact with aggregate data while having the capability to drill-down to perform a detailed analysis of the performance of a specific aircraft or weapons type over the campaign (Wright, 1997:68). Detailed analysis via data mining helps identify patterns/anomalies for the analyst/decisionmaker. It augments visualization of the data by providing a focus and preventing the data from overloading the viewer. Knowledge discovery from databases (KDD) takes the process a step further by using personal expertise and interpretative skills to derive useful knowledge from the data (Fayyad, Pietetsky-Shapiro, and Smyth. 1996:4). Figure 5 encapsulates the KDD process.

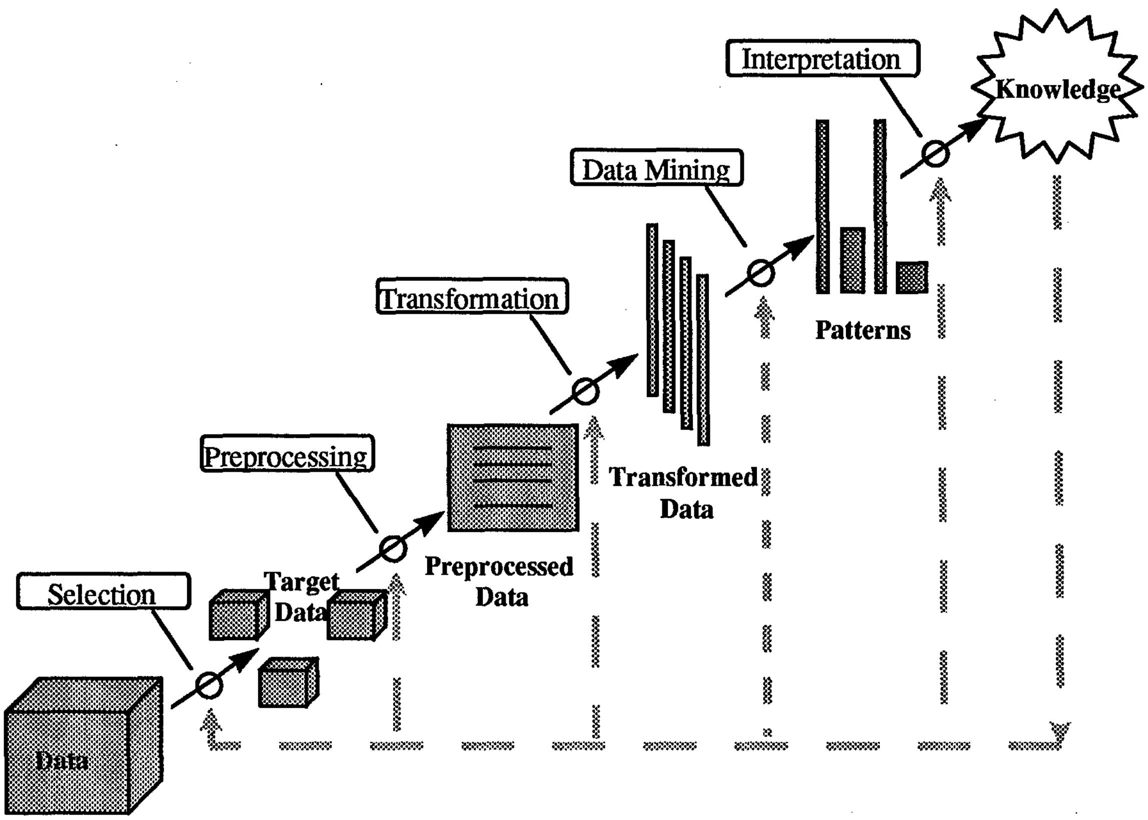

Figure 5, Overview of Knowledge Discovery from Databases Process (Fayyad, Piatetsky-Shapiro, and Smyth, 1996: 10)

2.4 Design of Experiment (DOE)

M&S to support acquisition should include experimental design to facilitate the investigation of how sensitive the results of the analysis are to changes in the input parameters (Starr, 1997:253). DOE provides a planning tool for determining the configurations of the input parameters to simulate that will provide the most information.

The efficiency of carefully designed experiments is much higher than an arbitrary sequence of runs to see what happens (Law and Kelton, 1991:657).

Input parameters to the experiment such as the decision variables, the structural assumptions, and the parameters of the random variables, are called factors (Banks, Carson, and Nelson, 1996, 500). The simulation is run at various values, or levels of the factors to provide output performance responses over the desired range of interest. A combination of factors at a specified level is called a treatment or a design point. The experimental design is the collection of design points to be investigated in an experiment. Experimental responses are used by the researcher in determining if there are any differences between the levels of the factors.

The factors can be either quantitative or qualitative. A quantitative factor is one whose levels can be associated with a numerical scale, e.g. temperature, pressure, or time. Qualitative factors are factors whose levels cannot be arranged in order of magnitude, e.g. batches of raw material, work shifts, etc. (Montgomery, 1976:55). The levels of the factors can be specifically chosen or picked at random from all possible factor levels.

Randomness and replication are applied to derive realism and statistical inferences, respectively, from simulation output. Randomness of events in simulation imitates real life to portray uncertainty (Banks, Carson, and Nelson, 1996:25). Replications are repetitions of the experiments at a specific design point.

2.4.1 Replications. Simulations are classified as either terminating or non-terminating. Terminating simulations run for a specific duration, whereas non-terminating/steady state simulations continue for a very long time. The determination of the simulation type depends on the study objectives and the nature of the system (Banks, Carson, and Nelson, 1996:436). The experimental design for terminating simulations calls for multiple replications with the length of each replication determined by prespecified initial and final conditions (Nelson, 1992:127).

The number of replications can be determined to give a user specified precision within a confidence interval by first making an initial sample size of n_0 replications. Four to five replications is recommended for n_0 (Banks, Carson, and Nelson, 1996:449). The number of replications can be determined to provide an estimate of the output mean, μ, to a user specified degree of precision by a sequential procedure, adding new replications one at a time (Law and Kelton, 1991:538). The procedure does not require normality of the random variables, only that the variables are independent and identically distributed (i.i.d.). This method ensures only the number of replications are accomplished that need be in order to achieve a prespecified absolute error level. To ensure the half-length(h.l.) of the 100(1-α)% confidence interval is met, a sample of n must be chosen such that $n > n_0$ and

$$\text{h.l.} = \frac{t_{\alpha/2,n-1} s_0}{n^{1/2}} \leq \varepsilon \qquad (2.1)$$

where t is the 100*(1-$\alpha/2$) percentage point of the t distribution with $n - 1$ degrees of freedom, s_0 is an initial estimate of the population standard deviation, n is the sample size, and ε is the user defined error criterion. Solving equation (2.1) gives n is the smallest integer satisfying $n > n_0$ and

$$\text{n} \geq \left(\frac{t_{\alpha/2,n-1} s_0}{\varepsilon} \right)^2 . \qquad (2.2)$$

Since $t_{\alpha/2,n-1} \geq z_{\alpha/2}$, an initial estimate for is n

$$n \geq \left(\frac{z_{\alpha/2} s_0}{\varepsilon} \right)^2 \qquad (2.3)$$

where z is the 100*($1-\alpha/2$) percentage point of the normal distribution (Banks, Carson, and Nelson, 1996:448).

2.4.2 Randomness. Randomness in a simulation experiment is achieved by using pseudorandom numbers that are controlled via a random number seed or stream. The assignment of a different random seed or stream to the start of each replication is normally not necessary since most simulation languages begin subsequent replications using random numbers from where the previous replication finished (Nelson, 1992:128). This is the case with the random number allocation of THUNDER. The simulation's SIMSCRIPT II.5 language employs a random number generator with a period of approximately ten billion numbers (THUNDER Analyst Manual, 1995:96).

2.5 Multivariate Analysis

Multivariate analysis focuses on the correlation/covariance relationships between three or more variables (Dillon and Goldstein, 1984:2). Both covariance and correlation describe the dependencies between variables. The variance-covariance matrix, $\underset{\sim}{C}$, is formulated as follows:

$$\underset{\sim}{S} = \underset{\sim}{X}^T \underset{\sim}{X} - (1/n)(\underset{\sim}{X}^T \underset{\sim}{1})(\underset{\sim}{1}^T \underset{\sim}{X}) \qquad (2.4)$$

$$\underset{\sim}{C} = (1/(n-1))\,\underset{\sim}{S} \qquad (2.5)$$

where $\underset{\sim}{S}$ is the mean corrected sum of squares and cross products matrix, $\underset{\sim}{X}$ is the data matrix, n is the number of observations, and $\underset{\sim}{1}$ is an (n x 1) vector of 1's. It is difficult to employ covariance as an absolute measure of dependence because its value depends on scale of measurement (Wackerly, Mendenhall, and Schaeffer, 1996:224). The correlation matrix, $\underset{\sim}{R}$, is used when there are differences in scale. The correlation matrix is related to covariance as depicted in its formulation.

$$\underset{\sim}{R} = \underset{\sim}{D}\,\underset{\sim}{S}\,\underset{\sim}{D} \tag{2.6}$$

D is a diagonal matrix with diagonal elements $1/S_{jj}^{1/2}$ where j is variables (columns) of the input data .

Multivariate analysis techniques are applied to facilitate data reduction, sorting and grouping, investigating dependence, prediction, or hypothesis testing. The choice of the techniques is based on the objective of the analysis. Three multivariate techniques commonly used for data reduction are Principal Component Analysis, Factor Analysis, and Cluster Analysis.

2.5.1 Principal Component Analysis (PCA). The objective of PCA is to reduce the variable data dimensionality to a set of linear combinations that explains as much of the variability of the original data as possible. Choice of the use of the variance-covariance or the correlation matrices in PCA depends on the homogeneity of the data. The correlation matrix is used in conjunction with standardized data (adjust each variable for its variability) when the data has different units and scales (Dillon and Goldstein, 1984:38).

The principal components loadings matrix describes how the variances load on the variables. The matrix is extracted from either the variance-covariance or correlation matrix. Extraction of the loadings from the variance-covariance matrix is formulated as follows:

$$\underset{\sim}{D}^{-1/2}\,\underset{\sim}{A}_c\,\underset{\sim}{\Lambda}^{1/2} \tag{2.7}$$

where $\underset{\sim}{A}_c$ is the matrix of eigenvalues for $\underset{\sim}{C}$, and $\underset{\sim}{\Lambda}$ is a diagonal matrix of the square roots of the eigenvalues of $\underset{\sim}{C}$ (Bauer, 1997:50). The eigenvalues of $\underset{\sim}{C}$ form the top row of the loadings matrix. The correlation matrix using standardized data is the basis of loading extraction when variables have grossly different variances or are measured in significantly different units. The formulation of the extraction of loadings from $\underset{\sim}{R}$ is the same approach as for the $\underset{\sim}{C}$ loadings extraction depicted in (2.7) above. The eigenvalues of $\underset{\sim}{R}$ form the top row of the loadings matrix.

The dimensionality of the data can be estimated from the eigenvalues extracted from the variance-covariance matrix. A threshold on percentage variance (e.g. 85%) can be applied to the variance-covariance extracted matrix. The number of successive components required to extract the threshold cumulative variance is the dimensionality of the data.

Likewise, dimensionality of correlation matrix extracted data can be estimated in several ways. One method, attributed to Kaiser, is based on the size of the eigenvalues extracted from $\underset{\sim}{R}$. Since the variance each standardized variable contributes to a principal component extraction is one, components with eigenvalues less than 1 are less important from a variance standpoint than the observed value (Tabachnick and Fidell, 1989:634). Subsequently, the number of components with eigenvalues ≥ 1 is the dimensionality of the data. A graphical approach to dimensionality estimation is the scree test. The test requires the eigenvalues to be plotted in sequential order of their extraction. The number of eigenvalues immediately above the point where the values become a straight line plot is the dimensionality of the data (Dillon and Goldstein, 1984:48). Dimensionality assessment is one reason PCA is recommended as the first step in Factor Analysis. PCA reveals a great deal of information about the probable structure and nature of factors (Tabachnick and Fidell, 1989:626).

2.5.2 Factor Analysis (FA). Where PCA emphasizes the differences in the variances between the variables, FA targets the communalities or common variability. PCA has the most utility in determining a small set of linear combinations characterizing the variance in the data. FA best describes the qualitative and quantitative nature of the underlying data structure (Dillon and Goldstein, 1984:55). FA is applied either as an exploratory or confirmatory method. The exploratory application is to search for a common structure to the data. The confirmatory utility of FA is to test a hypothesis. The factor loading matrix is used to interpret the variables. The factor loading matrix, $\underset{\sim}{A}$, can be determined directly by the formulation:

$$\underset{\sim}{A} = \underset{\sim}{V}\,\underset{\sim}{L}^{1/2} \tag{2.8}$$

where $\underset{\sim}{V}$ are the eigenvectors extracted from the correlation matrix of standardized data and $\underset{\sim}{L}$ is a diagonal matrix with the eigenvalues of $\underset{\sim}{R}$ on the diagonal. A factor is interpreted from the variables that are highly correlated with it.

Extraction techniques do not generally provide an interpretable solution without rotation (Tabachnick and Fidell, 1989:623). Rotation is usually performed after factor extraction to maximize high correlations and minimize low ones. One problem with extracted FA and PCA units is there are an infinite number of rotations available, all accounting for the same variance but with factors defined slightly differently. The final choice among alternatives depends on the researcher's assessment of its interpretability and scientific utility (Tabachnick and Fidell, 1989:598).

There are two methods of factor rotation; orthogonal and oblique. The distinction between the two methods is that orthogonal preserves the original orientation between factors so they are still perpendicular after rotation. Factor orientation is not preserved in oblique rotation (Dillon and Goldstein, 1984:55). Varimax is a orthogonal rotation technique that employs maximization of variances to accentuate high factor loadings and reduce low ones.

A procedure to verify that the appropriate number of factors have been extracted is via an assessment of the difference between the correlation matrix produced by observed variables and the correlation matrix from factors (reproduced matrix);

$$\underset{\sim}{R}_{res} = \underset{\sim}{R} - \underset{\sim}{\bar{R}} \qquad (2.9)$$

where $\underset{\sim}{R}_{RES}$ is the matrix of differences called the residual correlation matrix, $\underset{\sim}{R}$ is the original correlation matrix with communalities on the diagonal, and $\underset{\sim}{\bar{R}}$ is the correlation matrix of factors. In a good FA, correlations in the residual matrix are small indicating a good fit between observed and reproduced matrices (Tabachnick & Fidell, 1989:599).

Factor scores give the projection of an observation on the common factors, in other words, its location in common factor space. This information can provide additional insight into the structure of the data by highlighting patterns of common variation (Dillon and Goldstein, 1984:96). Factor scores cannot be calculated directly but rather estimated. One approach for factor score determination is a regression type technique. First, a factor score coefficients matrix, $\underset{\sim}{B}$, is determined using a formulation similar to multiple regression,

$$\underset{\sim}{B} = \underset{\sim}{R}^{-1}\underset{\sim}{A} \qquad (2.10)$$

where $\underset{\sim}{R}^{-1}$ is the inverse matrix of correlations between factors and variables, and $\underset{\sim}{A}$ is the factor loadings matrix. The factor score matrix, $\underset{\sim}{F}$, is determined as the product between the standardized data matrix, $\underset{\sim}{Z}$, and the factor score coefficient matrix, $\underset{\sim}{B}$, using the formulation:

$$\underset{\sim}{F} = \underset{\sim}{Z}\,\underset{\sim}{B} \qquad (2.11)$$

Plots of factor scores facilitate the understanding of different patterns of common variance in the data (Dillon and Goldstein, 1984:98).

2.5.3 Cluster Analysis. Clustering is a method to discover structure within a complex data set for the purpose of reducing the dimensionality of the data. In clustering, data or variables are organized into relatively distinct clusters each with elements having a high degree of "natural association" (Anderberg, 1973:17). The analysis focuses on rows or individual objects of the data matrix reducing the number of distinct entities by grouping them into clusters. Grouping is accomplished via some similarity measure or distance measurement such as the Euclidean distance between respective objects. The Euclidean distance, $\| \; \|$, between two vectors, $\underset{\sim}{X}$ and $\underset{\sim}{Y}$, is formulated as follows:

$$\left\| \underset{\sim}{X}^T - \underset{\sim}{Y}^T \right\| = \left[\left(\underset{\sim}{X} - \underset{\sim}{Y} \right)^T \left(\underset{\sim}{X} - \underset{\sim}{Y} \right) \right]^{1/2} \qquad (2.12)$$

The scale invariance of Euclidean distance measurement necessitates the input data be standardized (each variable divided by its standard deviation) (Dillon & Goldstein, 1984:162). The hierarchical clustering technique performs successive groupings of data or divisions of data. Additive or agglomerative hierarchical clustering methods continue until all the data is grouped into a single cluster.

Cluster analysis is a tool for suggestion and discovery that can illuminate relationships and principles previously unnoticed. The results of the analysis may be a hypothesis to be tested or be compelling enough to be immediately adopted (Anderberg, 1973:19).

3. Methodology

3.1 Introduction/Overview

Chapter three includes a brief discussion of the overall objectives of the research, then sequentially recounts the analytical methods applied in the thesis effort to reduce the dimensionality of measures of effectiveness for AoA.

3.2 Objectives

The goal of the research was twofold, 1) development of an approach to reduce the dimensionality of multiple campaign level measures of effectiveness for an AOA, and 2) development of an AoA visualization paradigm for the capability demonstration of the ASC SIMAF. The two objectives overlapped by design.

The thesis objectives were the culmination of several subobjectives:

1) Determine an AoA scenario

2) Determine measures of effectivness and THUNDER output to support the analysis

3) Modify THUNDER data files/report output to support analysis

4) Determine a design of experiments for the simulation

5) Perform the simulation

6) Use multivariate and visualization tools to reduce effectiveness measure dimensionality

7) Use visualization tools to display AoA results

3.3 Scenario

The scenario for the analysis was based on a notional established mission need for a new air superiority fighter. The author is assuming the role of an analyst performing the campaign level analysis for the notional using command's AoA study director. If this was an actual AoA study effort for an air superiority fighter acquisition, the study director would be from the Air Combat Command (ACC). This document describes the campaign level modeling and analysis in support of the AOA study . The results of the campaign level modeling in an AOA analysis are generally documented in section four of the AoA final report. A suggested AoA report format is attached at Appendix 1. THUNDER version 6.4.2 was used for the campaign level modeling. The three alternative solutions considered in the AOA study include the current system, modifications to the current system, and systems in development.

The Air Force's current air superiority fighter and the baseline in the experiment is the F-15C. Acquisition of the Air Force's next generation air superiority fighter, the F-22, was not considered in the study. The modification to the current system is an improved radar. This type of avionics improvement could be part of a programmed upgrade for the aircraft. The system in development is the notional F-XX. The three alternatives were examined employing two air-to-air armament configurations: 1) a standard F-15C load including four AIM-9 missiles, four Advanced Medium Range Air-to-Air Missile (AMRAAM) missiles, and a 20 mm cannon and 2) the replacement of the four AMRAAM missiles in the standard load with a new radar missile variant, the AIM-X. Subsequently, the resulting test matrix includes six combinations of aircraft and armament. Experimental design is described in detail in a later section.

The mission need specified that the new fighter perform effectively in an air superiority role when employed in a Southwest Asia (SWA) scenario. Hence, the database used in the analysis was an unclassified SWA THUNDER scenario provided by ASC/XR. The campaign scenario was a modified version of the Middle East (ME) scenario included in the THUNDER 6.4.2 model distribution. Table 1 depicts a breakout

Table 1, Listing of Aircraft With Air Superiority Taskings in Scenario

Side	Type Aircraft	Number
Blue	F-15C	124
Blue	F-14	100
Red	MIG-29	147
Red	MIG-21	147

of Blue and Red air-to-air players flying air superiority as their primary mission in the experiment scenario. The Blue air-to-air players and their beddown locations in the databases are based on information in The Conduct of the Persian War - Final Report to Congress (Department of Defense, 1992:142). The source for the information on Red air-to-air players is the book Storm Over Iraq (Hallion, 1992:146). Red air-to-air players in the THUNDER scenario used in the experiment included 750 fighter aircraft that were arbitrarily positioned among 20 deployment bases. The F-15C represented 55% of the Blue aircraft in the scenario solely tasked with an air superiority mission.

3.4 THUNDER Output

The output selected for the simulation was based on issues measurable at the campaign level. The overall campaign objective for the notional fighter was to gain and maintain air superiority. The Air and Space Power Validation Group (ASPVG) assessed THUNDER version 6.3 for its capability to measure campaign objectives. The output of the assessment was a listing of campaign objectives broken down into two subordinate levels; operational objectives and operational tasks. Additionally, the validation group assigned a qualitative measure to THUNDER ability to assess each campaign objective, operational objective, and operational task. The list of ASVPG operational objectives THUNDER measures for the air superiority campaign objective are as follows:

Defeat Air Attacks
Suppress Generation of Air Sorties
Suppress Surface-Based Air Defenses
Defeat Attacking Ballistic Missiles
Suppress the Generation of Ballistic Missile Launches
(ASVPG, 1995:4)

Operations objectives are related in that the progress toward one objective assists in attaining another objective or objectives (Pirnie and Gardiner, 1996:20). While the F-XX would only directly impact the first operational objective listed, it would indirectly impact the remaining issues due the increase of strikers reaching their targets on account of a more effective air superiority fighter. Operation tasks are tactical-level objectives that must be attained to accomplish operational objectives (Pirnie and Gardiner, 1996:19). The operation tasks for each of the operational objectives in the air superiority campaign objective that THUNDER can measure are listed in Appendix B (ASPVG, 1995:4). The unclassified THUNDER data base can measure the following metrics to assess operational tasks:

Red aircraft lost due to Blue air
Total number of Blue aircraft destroyed on the ground
Number of Red aircraft destroyed in the open
Number of Transportable Erector/Launchers (TEL) killed
Number of Acquisition (ACQ) radars killed
Number of Fire Control (FC) radars killed
Number of Blue Aircraft lost to enemy surface-to-air (SAM) missile threats (Grier, 1996: 109)

The Blue sorties generated for the 30 day war changes significantly for each alternative solution. Subsequently, the Blue aircraft lost to SAMs was measured as a ratio of aircraft lost/sortie.

Three operational task metrics were added to those listed above; Red sortie generation capability on day 30, days to reach air supremacy, and Blue air-to-air losses/ sortie. Red sortie generation capability on day 30 is the ratio of Red sorties generated on day 30 to the sorties generated on day 1. For this experiment, days to air supremacy was measured as the point Red sorties generation rate decreased to 10% of the initial total sortie rate. Air Force doctrine characterizes air supremacy as the absolute control of air or space that is only possible when the enemy does not possess adequate aerospace forces capable of effective interference (AFM 1-1, Vol I, 1992:10). For example, during Desert Storm the United States commander in chief of the Central Command (USCINCCENT) claimed air superiority from the outset of the conflict but waited until D+10 to declare air supremacy when he judged the Iraq air forces had lost the capability to pose a serious threat (Pirnie and Gardiner, 1996:16). The Blue air losses/sortie measure of effectiveness was measured as the ratio of Blue air-to-air losses to the total Blue sorties for the 30 day war. An overview of the operational task metrics to campaign objective hierarchy addressed in this investigation is depicted in Figure 6. Mappings of operational task metrics to operational tasks is in Appendix B. Appendix C lists the abbreviations for all output variables used in the simulation.

Campaign Objective
Gain and Maintain Air Superiority
↓
Operational Objectives

Defeat Air Attacks	Suppress Generation of Air Sorties	Suppress Surface-Based Air Defenses	Defeat Attacking Ballistic Missiles	Suppress Generation of Ballistic Missile Launches
↓	↓	↓	↓	↓

Operational Task Metrics

RedLoss BlueGrnd BLossSort	RedOpen RedSort AirSup	BlueSA RedTEL RedACQ RedFC	No metrics measureable at unclassified level	No metrics measureable at unclassified level

Figure 6, Campaign Objective to Operational Task Metric Hierarchy

3.5 THUNDER File Modifications

The following section describes the modifications to THUNDER data files in the experiment. THUNDER file names are in *italics*. Copies of the modified data files for the experiment are depicted in the order discussed in the text at Appendix D.

This effort was not a sensitivity analysis or trade-off study to optimize an actual aircraft design. Quick-look, single repetition runs of a 30 day war in THUNDER with various RCSs, missile P_ks, radar designs, and detection capabilities for the F-XX and system improvements to the F-15C were performed. The exploratory runs were made solely to implement data file changes that provided a notional aircraft/system modifications with a significant capability improvement to attrit red air at a level measurable in a campaign level analysis. The *control.dat* file was configured to run a 30 day war. A 30 day war was chosen because it was adequate for a drawdown of Red sortie generation capability to assess the air supremacy output discussed in section 3.4. A compendium of the these quick look studies is not included in this document.

Air-to-air engagement P_ks used in the *airairpk.dat* file would normally be derived using Joint Munitions Effectiveness Methodology (JMEM) data and results of engagement level models such as TAC BRAWLER. The SIMAF environment will allow the user to make TAC BRAWLER (or other engagement level and/or mission level model) analysis to determine missile P_ks for different weapon/aircraft/tactics combinations. These P_ks will be used to calibrate the aggregate weapons platform P_ks used in THUNDER simulations, either in advance of running the simulation or on-the-fly as "requested" by the simulation. The notional P_k values input by the user represent those resulting from the aggregation of inputs coming from TAC BRAWLER or a similar model. The actual P_k values used in the simulation were chosen primarily to show a delta with the addition of the AIM-X missile.

Prior to the initiation of experimental runs the *airairpk.dat* file in the THUNDER scenario provided by ASC/XR were modified. The original file yielded a Red air-to-air 2:1 kill ratio advantage (~ 400 Red kills : ~ 200 Blue kills) for a 30 day war. Weapon/aircraft P_ks in the *airairpk.dat* file were changed to provide approximately equal air-to-air kill ratios (~200 kills/each) for Red and Blue in the baseline, F-15C, case. More detailed discussion of the experimental design is included in section 3.6.

Ease of file modification was facilitated by changing parameters in existing aircraft entities rather creating new entities from scratch. The existing THUNDER F-15C files were changed to F-XX or F-15C with updated avionics files. AIM-7 files were changed to AIM-X files and AMRAAM references were deleted from F-15C and F-XX data files as required for the alternative solution under consideration. Changing from one alternative to another usually involved only a name change, e.g. "F-15C" to "F-XX", and the modification of one two parameters in the existing file for the previous aircraft or missile system. Table 2 lists the THUNDER data files modified for each alternative. The specific changes to THUNDER data files are described in the following sections.

Table 2, Data Files Modified by Alternative Solution

F-15C w/Missile	F-15C w/Radar	F-15C w/Radar and Missile	F-XX	F-XX w/Missile
airairpk.dat *airmunit.dat* *critres.dat* *relrngadvn.dat* *typeac.dat*	*detect.dat* *typeac.dat* *typejam.dat* *typerdr.dat*	*airairpk.dat* *airmunit.dat* *critres.dat* *detect.dat* *relrngadvn.dat* *typeac.dat* *typejam.dat* *typerdr.dat*	*acserv.dat* *detect.dat* *squadron.dat* *typeac.dat* *typejam.dat* *typerdr.dat*	*acserv.dat* *airairpk.dat* *airmunit.dat* *critres.dat* *detect.dat* *relrngadvn.dat* *squadron.dat* *typeac.dat* *typejam.dat* *typerdr.dat*

3.5.1F-XX RCS and Radar Modifications. The new air superiority fighter, the F-XX, was modeled as an F-15C with a very low RCS and an improved radar. The reduced RCS impacts detection range of ground and early warning assets in THUNDER when the F-XX is the only type aircraft in the flight group. Otherwise, THUNDER uses the RCS of the aircraft with the highest RCS in the flight group. One of the air-to-air missions captured in THUNDER is Barrier Combat Air Patrol (BARCAP). BARCAP aircraft patrol a designated area on their side of the Forward Line of Troops (FLOT) to intercept any aircraft that attempt to pass through the area (THUINDER Analyst Manual, 1995:21). The increased radar sweep width of the F-XX's radar impacts BARCAP detection probabilities.

Six data files were modified to implement the RCS and radar improvements that differentiated the F-XX from the F-15C; *typeac.dat*, *typerdr.dat*, *typejam.dat*, *detect.dat*, *acserv.dat*, and *squadron.dat*. Modifications to *acserv.dat* and *squadron.dat* were limited to global replacement of F-15C nomenclature with F-XX.

Typeac.dat required the addition of a new radar cross section (RCS) object for the F-XX and a relabeling of the F-15C references. An RCS of 0.05, approximately two orders of magnitude below the baseline F-15C in the scenario, was chosen for F-XX RCS. The RCS value was set based on a series of quick look analyses of the effect of RCS of Red air-to-air losses.

The F-XX's radar was implemented by adding a new aircraft radar object in the *typerdr.dat* file for the aircraft that doubled the one square meter detection range and maximum range of the radar over the F-15C system. Additionally, *typerdr.dat* was modified to increase the sweep width of the original F-15C radar in the file from 90 to 120 degrees for the F-XX. The *typejam.dat* file required similar changes as those to the *typerdr.dat* file, the creation of a detect object. Although the scenario did not require electronic jamming, the *typejam.dat* file change was required for the simulation to run. The jamming and burn-through profiles for the F-XX radar were left at the same as values as those for the F-15C radar.

Engagement probability (input in *detect.dat*) as used in THUNDER, is the probability that a type of aircraft will be able to engage an enemy type aircraft given a detection. This probability is an aggregate representation of the factors affecting the outcome of an aerial engagement once initiated, i.e. sensor suite, cockpit visibility, ability to reposition aircraft, etc. Detection probabilities are a function of airborne early warning (AEW) state. The possible states represented by THUNDER are no AEW, Blue AEW only, Red AEW only, and both Blue and Red AEW available (Analyst Manual, 1995:43).

The F-XX RCS and radar modifications required modifying the *detect.dat* file to reflect both a decreased RCS and an increased onboard radar capability. The probability of RED detecting the F-XX in each of the four AEW scenarios discussed above was set to probabilities comparable to low observable (LO) platforms, the Tomahawk and F-117, already included in the database. The probability of the F-XX radar detecting Red aircraft was increased by 0.2 for all AEW scenarios to characterize the improved detection capability of the new radar.

3.5.2 F-15C Radar Modifications. Radar modifications to the F-15C required the changes to the same data files as the F-XX radar implementation; *typeac.dat, typerdr.dat, typejam.dat, and detect.dat. Typeac.dat* was updated for the new radar identification number. The same changes were made for the *typerdr.dat* and *typejam.dat* as described for the F-XX in the previous section. The *detect.dat* only required the modification of the probabilities for the F-15C detecting Red aircraft in each of the four AEW cases. Hence, detection probabilities were increased by 0.2 for all AEW scenarios against all Red aircraft types.

3.5.3 F-XX/F-15C Air-to-Air Missile Modifications. As noted in the introduction to this section, probability of kills in the data files provided by ASC/XR were initially reduced to provide a relative parity (~ 200 air-to-air kills/side) for a 30 day war. The reduction in P_k's also allowed some margin to implement a P_k improvement for the introduction of a new missile. The new missile, the AIM-X, required modification of six data files *airairpk.dat*, *airmunit.dat*, *critres.dat*, *relrngadvn.dat*, and *typeac.dat.* All AIM-7 instances in the *airmunt.dat* and *critres.dat* files were changed to AIM-X. Occurrences of the AMRAAM for the F-15C/F-XX in the *acserv.dat* and *typeac.dat* files were changed to the weapons code for the AIM-X.

A new code for the AIM-X was added to the *airairpk.dat* file. The new missile was included in the configuration for the F-15C/F-XX. P_ks for the AIM-X were increased 0.3 above AMRAAM P_ks against all Red targets. THUNDER converts the raw P_ks for each weapon into an aggregated weapon P_k for each type of engaged aircraft (Analyst Manual, 1995:38). The aggregate P_ks are used to determine the attrition rates for defenders and attackers in aerial engagements.

The advantage gained by the use of longer range weapons is represented by the concept of relative range advantage (Analyst Manual, 1995: 40). This advantage impacts the probability that an attacking aircraft will launch a weapon successfully at a defending aircraft. A new killer identification number was added to the *relrngadvn.dat* file for the new AIM-X missile. The file was modified to reflect a AIM-X range advantage over all Red ordnance.

3.6 Experimental Design

The experiment was designed as a two way analysis of variance fixed effects model. The first treatment was the F-15C configuration. As previously noted, the F-XX mirrors the F-15C performance with a reduced RCS and an improved radar. This treatment was fixed at three levels for the baseline F-15C and the two alternative modifications. The other treatment was the armament configuration. Two levels of configurations were considered, the standard F-15C load and the standard load with the AIM-X missiles replacing the AMRAAMs. The design yielded six treatment combinations. The experimental design for the simulation is depicted in Table 3.

Table 3, Experimental Design

Aircraft/ Ordnance	F-15C	F-15C w/Radar	F-15 w/RCS & Radar **(F-XX)**
4 AMRAAM, 4 AIM-9, Gun			
4 AIM-X, 4AIM-9, Gun			

The number of replications at each design point was determined via the 2-stage method discussed in section 2.4.1.

Common random numbers (CRN) or correlated sampling is often applied as a variance reduction technique (VRT) for the comparison of two or more alternate system configurations (Law and Kelton, 1991:613). The CRN approach permits the comparison of alternate systems subjected to identical or nearly identical experimental conditions in hopes of differentiating which system is best even though the respective estimates are subject to sampling error (Goldsman, 1992:101). Application of the techniques requires that the same random numbers are used to simulate the systems of interest for each replication of an experiment (Banks, Carson, and Nelson, 1996:481). Employment of CRN in the AoA study implies that replication 12 of the THUNDER simulation for the F-XX scenario would use the same random number stream as replication 12 of the F-15C scenario, the F-15C w/AIM-X scenario, etc. Synchronization of the random numbers, or forcing the same random numbers to be used for the same purpose at each of the design point, can enhance the effect of CRN (Nelson, 1992:131).

The ten distinct random number generators in THUNDER can be assigned to different event categories, e.g. air defense events, air-to-air events, etc., in an attempt to maintain positive correlation through isolating processes within the simulation (THUNDER Analyst Manual, 1995:97). However, the complexity of the multitude of interactions in the model contributes to the uncertainty of the variance reduction achieved through the synchronization scheme. The THUNDER simulations in this effort used an unsynchronized CRN VRT approach. The same random number seed was used at the initiation of the runs for each design point, with no further efforts taken to synchronize random number use.

3.7 Simulation

The VV&A of THUNDER for use in this experiment began with the modification of data files for alternative scenarios discussed in section 2.1.3. The simulation was verified through debugging the changes to the data files on short, one to two replication, trial simulation runs. Additional verification of the scenario included reviewing the simulation's situation map (invoked by command **ttsm**) animation, output graphs (invoked by command **ttgraph**), and output reports for anomalies. The textual description of file inconsistencies and errors in the *debug.out* file generated by

THUNDER facilitated the verification process. The verification of the simulation included an active dialogue with experienced THUNDER analysts at ASC/XR and simulation runs under a variety of input settings for reasonable output during the RCS exploration discussed in section 2.2.

A conceptual model validation of the scenario for this experiment was performed by comparing THUNDER's assumptions, limitations, and design elements against the specific requirements. Validation of the simulation's capability to provide output to meet our requirements was performed in parallel with the verification. The experiment's focus on modifying scenario data to provide significant differences in the performance of alternative solutions made the validation and accreditation less stringent than if there was a requirement for high fidelity representations of each player in the simulation to evaluate actual design sensitivities. The author accredited the model for the thesis effort based on literature reviews of THUNDER application to similar efforts and personal involvement in the validation and verification discussed in the paragraphs above.

The air war was simulated in THUNDER's high resolution mode. This setting provides a higher granularity representation of the aircraft combat attrition than the binomial distributed flight attritions in the low resolution mode.

> In the high resolution mode, flights are tracked individually. Stochastic determinations are made as to whether defender and flight groups enter an engagement. Outcomes of the engagements are determined based on escort tactics, relative range advantages, and survival and kill probability data for the one-on-one air battles between the various engaging threat and defender aircraft types. These values, the number of aircraft in a flight, and a computed probability of such an engagement occurring between flights give an attrition rate for the flight (THUNDER Analyst Manual, 1995: 33).

3.8 Multivariate Analysis

The initial analysis of output responses for the F-15C, F-15C w/Missile, F-15C w/Radar, and F-15C w/Radar & Missile alternatives suggested a lack of statistical significance between the alternate solutions. Consequently, Bonferroni confidence intervals were calculated to make multiple simultaneous comparisons. When it is desired to make statements about several variables simultaneously, the Bonferroni approach is used to provide the analyst with a fairly high confidence all statements are true simultaneously. A simultaneous confidence coefficient of at least $(1-\alpha)$ can be assured by choosing the confidence intervals I_j, for $j = 1,2, \ldots m$ comparisons, so that $\sum_{j=1}^{m} \alpha_j = \alpha$. One way to achieve this objective is if each interval is constructed to have confidence coefficient $1-(\alpha/m)$ (Wackerly, Mendenhall, and Schaeffer, 606:1996).

The smaller the value of α_j, the wider the j th confidence interval. The major advantage of the Bonferroni approach is it holds whether the models for the alternative designs are run with independent sampling, or with common random numbers (Banks, Carson, and Nelson, 1996:493). The primary disadvantage is that as the number of comparisons increases, the widths of the individual intervals increase. The Bonferroni technique is ordinarily most useful when the number of simultaneous estimates is not too large (Neter, Kutner, Nachtsheim, and Wasserman, 1996:155). Ten comparisons is generally recommended as the limit .

The confidence intervals, $\theta_1 - \theta_i$, with an overall confidence coefficient at least $(1-\alpha)$ are given by:

$$\bar{D}_{.i} - t_{\alpha_i/2,R-1} s.e.(\bar{D}_{.i}) \le \theta_1 - \theta_i \le \bar{D}_{.i} + t_{\alpha_i/2,R-1} s.e.(\bar{D}_{.i}), \quad i = 1,2,\ldots m \qquad (3.1)$$

where $\bar{D}_i$ is the sample mean difference averaged over all replications (R), $t_{\alpha_i/2,R-1}$ is the $100^*(1-\alpha_i/2)$ percentage point of the t distribution with $R-1$ degrees of freedom, $s.e.(\bar{D}_i)$ is standard error of $\bar{D}_i$, and m is the total number of comparisons (Banks, Carson, and Nelson, 1996:494). Confidence intervals completely to the right of zero indicate $\theta_1 > \theta_i$. Intervals completely to the left of zero indicate there is strong evidence that $\theta_1 < \theta_i$. Those intervals that include zero offer no strong evidence that one alternative is better than the other.

The SAS.JMP statistics software package was used to perform statistical analysis of the output metrics data. The distribution of each case's data was assessed. Since the output data violated normality, a statistical procedure was required that did not require stringent distributional assumptions, such as non-parametric, or distribution free, methods. Non-parametric methods are inference procedures having test statistics whose distribution under H_0 remains the same, regardless of how the population sampled may change (Larson and Marx, 510:1981). The Wilcoxon signed rank test is a non-parametric technique.

> In performing the Wilcoxon signed rank test, the signed differences between the pairs of observations are rank ordered in terms of their absolute size, and the sign of each difference is attached to the rank associated with that difference is attached to the rank associated with that difference. The test statistic is then W, the sum of the ranks with the less-frequently-occurring sign. For large n, the sampling distribution of W is approximately normal (Winkler and Hays, 856:1975).

The signed rank test requires equal samples sizes. No assumptions are made concerning the underlying population distributions. A large-sample ($n > 25$) Wilcoxon signed rank test was used on the matched paired observations of the F-15C and the F-XX w/missile (the extremes of the design points) in the investigation to test the hypothesis that the outputs for the two alternatives have the same distributions (Wackerly, Mendenhall, and Schaeffer, 1996:656). Failure to reject the hypothesis for the two-tailed test was used as a basis to discard an output as statistically insignificant. The variance-covariance and correlation matrices of the six scenarios were calculated to determine the variances and correlations in the remaining data for each case.

The data was then standardized. For the univariate case, standardized scores in excess of $\pm$ 3.0 were considered outliers (Tabachnick & Fidell, 1989: 68). Those runs with standardized scores in excess of $\pm$ 1.9 for more than one response were considered multivariate outliers. The outlier analysis was not to eliminate data points. The outlier information was used primarily for insights on the data structure.

A Principal Component Analysis (PCA) was performed on the data to determine the dimensionality. Component loadings were determined. The different units represented by the outputs necessitated the use of the correlation matrix and standardized data for PCA extraction. Two graphical dimensionality tests were performed - magnitude of the eigenvalues (Kaiser's test) and the scree test. The dimensionality insights from the PCA were used to determine a starting point for the rotations of factors in the factor analysis.

A cluster analysis was performed on the standardized data as a discovery tool for the potential groupings of the data. Agglomerative clustering methods were applied to the standardized data. Data was grouped via the squared Euclidean distance between the means of the clusters. The grouping of the clusters provided additional insight into the dimensionality and structure of the data.

An exploratory Factor Analysis (FA), using the dimensionality information gleaned from the PCA and cluster analyses, was performed to determine a common structure underlying the data. As with the PCA, different units represented by the THUNDER measured outputs necessitated use of the correlation matrix for FA extraction. The dimensionality data furnished insights on the starting point for performing iterative rotations of the components via the varimax rotation method.

Successive rotations of the factors yielded an interpretable loading matrix. A residual matrix of the final loadings was calculated to assess the fit of the factor model. The factors were then interpreted based on the final loadings. The final factor loading matrix was used to estimate the factor coefficients score matrix for additional insights on the data structure via visualization of the scores.

3.9 Visualization

The visualization effort had two purposes, 1) employ a visual paradigm for reducing MOE dimensionality, and 2) develop an AoA visualization approach for the SIMAF capability demonstration. Notional LCCs were used for all alternatives in developing the graphical representation of cost/effectiveness integration step of the AoA study effort discussed in section 2.1.4.

Visualization of the data was via MineSet 3.0, a data mining and visualization tool produced by Silicon Graphics Incorporated (SGI). The visualization tool used required development of a data file consisting of rows of tab-separated fields ("save as" option in EXCEL) and a configuration file (data schema) describing the format of the input data (MineSet User's Guide, 1997). The principal MineSet tool used in the analysis for the discovery of data patterns and trends was the "Scatter Visualizer" depicted in

Figure 7. The tool was used to display the data via a three dimensional scatter plot paradigm . Additional dimensionality was added to the rendering of the data via the use

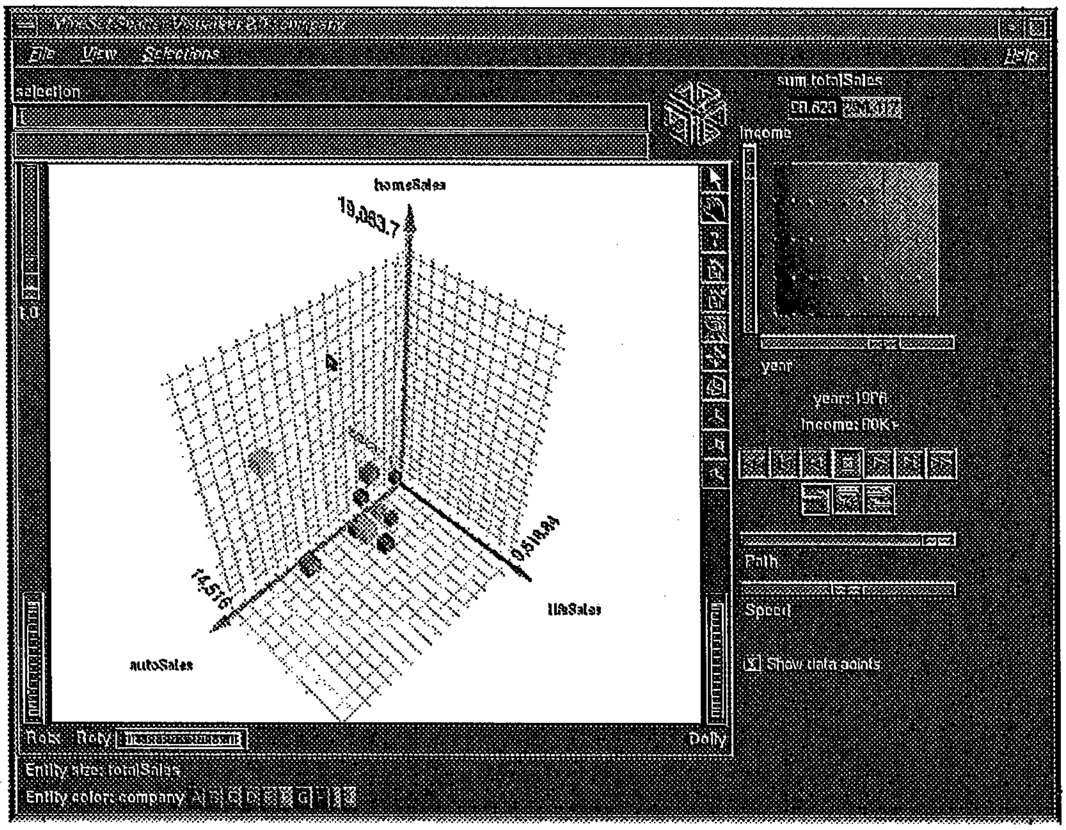

Figure 7, MineSet Scatter Visualizer (MineSet User's Manual, 1997)

of color, size, and entity labeling. Filtering, rotation of the data, and focus on individual data points were used to drill down into the data and visually data-mine for structural insights. The KDD process outlined in Figure 5 was used as a guideline in visualization development and data mining application for the thesis effort.

Since the goal of the end-user was to gain insights on the AoA from a multivariate perspective, the visual data mining effort targeted two areas: the output responses of the simulation and the factor scores from the multivariate analysis of the output responses discussed in this chapter. The simulation output data was complete and clean (no spurious symbols, illegal operations, etc.). Consequently, data cleaning and preprocessing was not required. As noted previously in the chapter, tests of statistical significance were applied to reduce the number of dependent variables under consideration. Additionally, estimates of the centroids for each of the for the alternative output responses and factor scores was included in the data set to facilitate filtering. Data mining algorithms were not applied to the data using the tools organic to the MineSet application. Rather FA data reduction algorithms were performed off-line and the resulting factor scores imported to MineSet for viewing. The data mining effort focused on patterns of data for the respective alternatives clustering at specific output response and factor score levels and the dispersion (variability) of those clusters. Finally, iterative interactions with the data utilizing the steps described above yielded discovered knowledge on output response structure, factor score/data dimensionality, and AoA cost/effectiveness integration that is documented in the results and conclusions sections of this report, chapters four and five.

Once the analyst completed the visual data-mining and analysis. The decision maker, autonomously and assisted by the analyst, interacted with the data using the same or a subset of the visualization tools employed by the analyst. The MineSet software permitted the decision maker to customize the depth of data mining and KDD to their personal comfort/interest level, supporting either a high level panning and zooming through the data focusing on specific points of interest, or a detailed "what if" investigation of the data set utilizing real-time filtering or other data mining tools. Based on the presentation of the analytical results and the KDD gained by the visualization, the decision maker was equipped to make an acquisition decision or to scope additional data gathering efforts to facilitate a decision.

4. Results

This chapter discusses the analysis of the experimental design, the multivariate analysis and the visualization results. Symmetric matrices in this section are displayed as a diagonal and lower matrix elements.

4.1 Experimental Design Analysis

Ten simulation output responses were measured. The output responses and the abbreviations for the responses in this document are listed in Table 4.

Table 4, Description of Output Response Measures

AirSup	Days to air supremacy (10% of initial Red sortie rate)
BLossSort	Blue air-to-air losses per blue sortie flown
BlueGrnd	Total number of Blue aircraft destroyed on the ground
BlueSA	Blue aircraft losses to enemy SAMs per Blue sortie flown
RedACQ	Number of Red acquisition radars destroyed
RedFC	Number of Red fire control radars destroyed
RedLoss	Red aircraft lost to Blue air
RedOpen	Number of Red aircraft destroyed at their home airfields in the open (not sheltered)
RedSort30	Red sortie generation capability on day 30 (ratio to initial sortie generation rate)
RedTEL	Number of Red transportable erector/launchers destroyed

Initially, four independent replications were made at each design point. These initial sample sizes of four were used to determine the final sample size (and the remaining number of replications) required to give a user specified precision with a 90% confidence level. Based on anticipated absolute error thresholds to discriminate between the alternatives for each output response and simulation time required for each replication (~ 0.5 hours), thirty one replications were performed at each design point. The estimated 90% confidence interval half-lengths for each response and design point based on thirty one replications of the experiment and the standard deviations of the initial samples are listed in Appendix E. The output responses are at Appendix F.

Relative frequency histograms of the response data for each of the design points was plotted for a graphical description of the data. The histograms for the responses are in Appendix G. The rectangles on the histograms indicate the fraction of total output measurements falling within each range indicated on the x-axis.

The mean output responses and confidence intervals for each design point are listed in Table 5. Discussion of statistical significance in this chapter refers to

Table 5, Means of Output Responses w/90% Confidence Intervals

MOEs	Aircraft/ Weapons	F-15C	F-15C w/Radar	F-15C w/RCS & Radar **(F-XX)**
RedLoss	Standard Load	203 ± 5	214 ± 6	317 ± 5
RedSort30		0.0404±0.0036	0.0316±0.0039	0.0093±0.0012
BLossSort		0.0028±0.0001	0.0026±0.0001	0.0017±0.0001
AirSup		24.2 ± 0.5	22.9 ± 0.5	19.1 ± 0.3
BlueSA		0.0050±0.0001	0.0048±0.0001	0.0046±0.0001
BlueGrnd		99 ± 4	91 ± 5	81 ± 4
RedOpen		242 ± 5	242 ± 6	181 ± 5
RedTEL		6184 ± 155	6309 ± 129	6259 ± 165
RedACQ		44 ± 21	39 ± 13	51 ± 23
RedFC		5010 ± 137	5153 ± 119	5295 ± 144
RedLoss	New Missile	227 ± 8	253 ± 7	359 ± 6
RedSort30		0.0324±0.0039	0.0252±0.0031	0.0015±0.0005
BLossSort		0.0025±0.0001	0.0025±0.0001	0.0014±0.0001
AirSup		22.9 ± 0.5	21.7 ± 0.5	16.7 ± 0.3
BlueSA		0.0049±0.0001	0.0049±0.0001	0.0043±0.0001
BlueGrnd		90 ± 4	87 ± 5	73 ± 3
RedOpen		231 ± 7	216 ± 4	161 ± 5
RedTEL		6517 ± 158	6334 ± 156	6418 ± 125
RedACQ		30 ± 12	33 ± 10	45 ± 23
RedFC		5352 ± 144	5172 ± 141	5491 ± 110

overlapping output response 90% confidence interval half lengths between alternatives as indicating a lack of statistical significance. The mean of the RedLoss response increases with both modifications to the current air superiority fighter (radar and reduced RCS) and the new missile indicating these changes increase the air-to-air lethality of the fighter. The radar improvements appear to cause a small increase in RedLoss (~10 - 25), the new missile causes a moderate change (~20 - 40), and the RCS reduction causes a large change(~100). The F-15C and F-15C w/Radar, and F-15C w/Radar and F-15C w/Missile are not statistically different for RedLoss responses. RedSort30, BLossSort, AirSup, BlueSA, BlueGrnd, and RedOpen responses decreased as the modifications to the F-15C were implemented. For all six of these measures, the most pronounced changes occur at the reduced RCS design points. RedSort30 and AirSup have the same interpretation as the RedLoss. As the air-to-air lethality of the alternative increases the rollback of Red sortie generation occurs more rapidly. F-15C w/Missile and F-15C w/Radar are not statistically different for either RedSort30 or AirSup. F-15C w/Radar and F-15C w/Radar and Missile are not statistically different for RedSort30. BLossSort and BlueGrnd responses indicate with less Red fighters airborne, there are less shooters to attrit Blue either in the air or on the ground. BLossSort and BlueGrnd responses for F-15C w/Radar, F-15C w/Missile, and F-15C w/Radar and Missile are not statistically different. Decreasing RedOpen responses corresponding to F-15C improvements indicate that as more Red aircraft are attrited, the Offensive Counterair missions targeting fighters in the open have less targets to choose from. There is no difference between the F-15C and the F-15C w/Radar for RedOpen responses. There was not as great a difference in the BlueSA output between design points as for the other responses. BlueSA responses were not statistically different for a comparison between the F-15C, the F-15C w/Missile, the F-15C w/Radar, or between the F-15C w/Radar and Missile design points, or between the F-15C w/Radar and the F-XX. The increase of RedFC responses, albeit small, indicated the fighter modifications improved the effectiveness of suppressing enemy air defenses. There was no statistical difference between the F-15C, the F-15C w/Radar, and the F-15C w/Radar and Missile, or between the F-15C w/Missile, the F-15C w/Radar, the F-15C w/Radar and Missile, and the F-XX, or between the F-XX, the F-XX w/Missile, and the F-15C w/Missile.

The number of cases for which the output responses were the same between the different F-15C alternatives (radar, new missile, both) indicates the performances of the platforms at the campaign level of analysis are very similar. The Bonferroni confidence intervals described in chapter three were calculated to simultaneously compare the F-15C, F-15C w/Missile, F-15C w/Radar, and F-15C w/Radar & Missile alternatives for each output response. Appendix H depicts the Bonferroni 90% confidence intervals for F-15C, F-15C w/Missile, F-15C w/Radar and F-15C w/Radar & Missile output response comparisons. RedLoss, RedSort30, BLossSort, AirSup, BlueGrnd, RedOpen, RedFC, and RedTEL output responses indicate at least one comparison with a statistically significant finding.

The RedLoss confidence intervals for the F-15C vs. F-15C w/Missile and F-15C w/Radar & Missile are left of zero indicating the F-15C performance in attriting red aircraft improves with the addition of the new missile and the improved radar/new missile combination. F-15C w/Missile vs. F-15C w/Radar & Missile is also left of zero suggesting higher red aircraft attrition for the Blue forces with the improved radar/new missile pairing versus the new missile alone. F-15 w/Radar output response performance is less than F-15C w/Radar & Missile. F-15C vs F-15C w/Radar and F-15C w/Missile vs. F-15C w/Radar do not offer strong evidence that one alternative is better than the other.

The RedSort30 confidence intervals for the F-15C vs. F-15C w/Missile, F-15C w/Radar, and F-15C w/Radar & Missile are all right of zero indicating the improvements to the current air superiority fighter improve Blue force's capability to draw down Red sortie generation. F-15C w/Missile vs F-15C w/Radar and F-15C w/Radar & Missile, and F-15C w/Radar vs. F-15C w/Radar & Missile do not offer strong evidence that one alternative is better than the other.

The BLossSort confidence intervals for the F-15C vs. F-15C w/Missile and F-15 w/Radar & Missile are right of zero indicating the new missile and the improved radar/new missile combination improve the F-15C's capability to reduce Blue air-to-air losses per sortie. F-15C vs F-15C w/Radar, F-15C w/Missile vs. F-15C w/Radar, and F-15C w/Radar vs. F-15C w/Radar & Missile do not offer strong evidence that one alternative is better than the other.

The AirSup confidence intervals for the F-15C vs. F-15C w/Missile, F-15C w/Radar, and F-15C w/Radar & Missile are right of zero indicating the improvements to the F-15C reduces the number of the days for Blue forces to reach air supremacy. Additionally, F-15C w/Missile vs. F-15C w/Radar & Missile suggest the improved radar/new missile combination has a greater effect on Blue forces acheiving air supremacy than the new missile alone. F-15C w/Radar vs. F-15C w/Radar & Missile is also right of zero suggesting the pairing of the improved radar with the new missile is an improvement over the radar alone for reducing the days to air supremacy. Only the

F-15C w/Missile vs. the F-15C w/Radar does not seem to provide statistical evidence that one alternative is better than the other.

Only the BlueGrnd confidence interval for the F-15C vs. F-15C w/Radar & Missile is right of zero indicating the radar improvement and new missile combination has a greater effect reducing Blue losses on the ground than the current F-15C. The remainder of the BlueGrnd confidence intervals suggest no strong statistical evidence that one alternative is better than the other.

The RedOpen confidence intervals for the F-15C vs. F-15C w/Radar & Missile is right of zero indicating the radar improvement and the new missile pairing reduces the Red aircraft destroyed in the open. Also, F-15C w/Missile vs. F-15C w/Radar & Missile is right of zero indicating the radar improvement and new missile configuration has a greater effect on reducing Red aircraft destroyed in the open than the new missile alone. Additionally, the F-15C w/Radar vs. F-15C w/Radar & Missile indicates the radar/missile combination results in less Red aircraft destroyed in the open than the radar alone. This tracks with the original interpretation of the information in Table 4 - increased RedLoss performance leaves less Red targets in the open. F-15C vs. the F-15C w/Radar and Missile, F-15C w/Missile vs. F-15C w/Radar & Missile, and F-15C w/Radar vs. F-15C w/Radar & Missile do not seem to provide statistical evidence that one alternative is better than the other.

The RedFC confidence intervals for the F-15C vs. F-15C w/Missile is the only interval to the left of zero suggesting the new missile increases the number of Red fire control radars destroyed. The remainder of the RedFC confidence intervals suggest no strong statistical evidence that one alternative is better than the other.

The RedTEL confidence interval for the F-15C vs. F-15C w/Missile is the only interval to the left of zero indicating the new missile makes Blue forces more effective at destroying Red TELs than the current air superiority aircraft. The remainder of the RedTEL confidence intervals suggest no strong statistical evidence that one alternative is better than the other.

Both the BlueSA and the RedACQ families of confidence intervals include zero for all alternatives suggesting there is no strong statistical evidence that one system design is better than another for those output response categories.

Table 6 summarizes the information from the Bonferroni confidence intervals. The cells are shaded for the comparisons where the confidence intervals suggest strong statistical evidence that the first alternative listed is better than the second. The empty cells depict those cases where the confidence intervals indicate strong statistical evidence the first alternative listed is inferior to the second. In the case where the confidence intervals included zero, a "?" is listed in the table cell. Trends in the table indicate the F-15C w/Missile alternative is better than the F-15C alternative (six of ten output responses), the F-15C w/Radar alternative is better than the F-15C alternative (two of ten output responses), the F-15C w/Radar & Missile alternative is better than the F-15C alternative(six of ten responses), the F-15C w/Radar & Missile alternative is better than the F-15C w/Missile alternative (three of ten responses), and the F-15C w/Radar & Missile alternative is better than the F-15C w/Radar (two of ten responses).

Table 6, Summary of Bonferroni Family of Confidence Intervals

Output Responses/ Comparisons	RedLoss	RedSort30	BLossSort	AirSup	BlueSA	BlueGrnd	RedOpen	RedACQ	RedFC	RedTEL
F-15C vs F-15C w/Missile					?	?	?	?		
F-15C vs. F-15C w/Radar	?		?		?	?	?	?	?	?
F-15C vs. F-15C w/Radar & Missile					?			?	?	?
F-15C w/Missile vs. F-15C					?	?	?	?		
F-15C w/Missile vs. F-15C w/Radar	?	?	?	?	?	?	?	?	?	?
F-15C w/Missile vs. F-15C w/Radar & Missile		?	?		?	?		?	?	?
F-15C w/Radar vs. F-15C	?		?		?	?	?	?	?	?
F-15C w/Radar vs. F-15C w/Missile	?	?	?	?	?	?	?	?	?	?
F-15C w/Radar vs. F-15C w/Radar & Missile		?	?		?	?		?	?	?
F-15C w/Radar & Missile vs.F-15C					?			?	?	?
F-15C w/Radar & Missile vs. F-15C w/Missile		?	?		?	?		?	?	?
F-15C w/Radar & Missile vs. F-15C w/Radar		?	?		?	?		?	?	?

A Wilcoxon Signed-Rank Test was performed between the F-15C and the F-XX with the new missile design points. The test was performed to evaluate the hypothesis that the medians of the output responses were equal. Failure to reject the null hypothesis indicates the output responses for a particular measure may not be significant. The results of the signed-rank test are in Table 7.

The high signed-rank p-values for the RedTEL and RedACQ output responses indicate the distributions of the two fields are the same for the F-15C and F-XX w/Missile alternatives. This suggests that at a 90% confidence interval, the

Table 7, Wilcoxon Signed-Rank Test for F-15C and F-XX w/New Missile

	RedLoss	RedSort30	BLossSort	AirSup	BlueSA	BlueGrnd	RedOpen	RedTEL	RedACQ	RedFC
Two-tailed p value	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.094	0.860	0.000
Wilcoxon Z value	-4.860	-4.860	-4.860	-4.860	-4.223	-4.782	-4.860	-1.685	-0.176	-3.645

employment of the F-XX w/Missile does not increase the number of Red acquisition radars or TELs destroyed by Blue forces. The Air-to-Air Escort (AIRESC) and Fighter Sweep (FSWP) air superiority taskings of the alternatives in the study have a negligible effect on the outcome of the air-to-ground interdiction sorties that target Red acquisition radars and TELs. AIRESC missions accompany missions to provide air-to-air protection. FSWP missions attack enemy aircraft that are operating on their side of the FLOT during a period when friendly ground attack aircraft are operating in the vicinity (THUNDER Analyst Manual, 20:1995). Since F-15C and F-XX w/Missile were used in the signed-rank test to bound the alternative output responses, eliminating RedTEL and RedACQ output responses from the multivariate analysis should not effect the results. Table 8 lists a variance-covariance matrix, $\underset{\sim}{C}$, of the remaining eight output responses.

Table 8, Variance-Covariance Matrix of Output Responses

Variables	RedLoss	RedSort30	BLossSort	AirSup	BlueSA	BlueGrnd	RedOpen	RedFC
RedLoss	3625							
RedSort30	-0.838	2.83E-04						
BLossSort	-0.03	7.99E-06	3.305E-07					
AirSup	-151.783	0.044	0.001	8.66				
BlueSA	-0.015	4.57E-06	1.533E-07	7.98E-04	1.953E-07			
BlueGrnd	-427.029	0.137	0.005	24.115	0.003	248.326		
RedOpen	-1961	0.382	0.015	73.074	0.006	210.499	1241	
RedFC	7093	-2.599	-0.092	-438.849	-0.105	-2128	-3028	209400

The variances are along the diagonal of the matrix. The wide range of variances and diverse units of the output data indicates the correlation matrix, $\underset{\sim}{R}$, is the best choice for extracting the PCA and FA. $\underset{\sim}{R}$ for the eight output responses is depicted in Table 9.

Table 9, Correlation Matrix of Output Responses

Variable	RedLoss	RedSort30	BLossSort	AirSup	BlueSA	BlueGrnd	RedOpen	RedFC
RedLoss	1							
RedSort30	-0.8269	1						
BLossSort	-0.8679	0.8264	1					
AirSup	-0.8567	0.8837	0.878	1				
BlueSA	-0.551	0.6149	0.6035	0.6139	1			
BlueGrnd	-0.4501	0.5182	0.5349	0.52	0.413	1		
RedOpen	-0.9245	0.6441	0.7514	0.705	0.3981	0.3792	1	
RedFC	0.2574	-0.3375	-0.3504	-0.3258	-0.5192	-0.2951	-0.1878	1

The correlation matrix indicates a significant negative correlation (> .5) between RedLoss and RedSort30, BLossSort, AirSup, BlueSA, and RedOpen. All these correlations seem intuitive except the negative loading on BlueSA.

The description of high resolution air defense site engagements in the THUNDER analyst manual offers an explanation of the BlueSA correlations.

> In HIGH resolution, the distance at which an air defense site will detect the group is based upon the site's acquisition and fire control capabilities, the flight group's radar cross section, ingress and terminal altitudes, jamming ability, and the terrain. Once the site is encountered, THUNDER uses the acquisition distance and weapon range to determine the number of rounds the site can fire. These factors, along with the P_k, determine the flight group's losses (THUNDER Analyst Manual, 55:1995).

Air defense site P_k's were not modified for the different alternatives in this investigation. In the HIGH resolution mode of THUNDER, the reduced RCS of the F-XX should increase red aircraft losses and reduce blue surface-to-air losses/sortie. The BlueSA output responses for the F-15C, F-15C w/Missile, F-15C w/Radar, and F-15C w/Radar & Missile should not change significantly. This conjecture is supported by the family of

Bonferroni confidence intervals for BlueSA in Table 6 that all include zero and the results of the Wilcoxon signed-rank test for F-15C and the F-XX w/Missile BlueSA output responses in Table 7.

RedSort30 has significant correlations with RedLoss, BLossSort, AirSup, BlueSA, BlueGrnd, and RedOpen. All correlations are fairly intuitive except for the BlueSA just discussed. BLossSort has significant correlations with RedLoss, RedSort30, AirSup, BlueSA, BlueGrnd, and RedOpen. AirSup has significant correlations with RedLoss, RedSort30, BLossSort, BlueSA, BlueGrnd, and RedOpen. BlueSA has significant correlations with RedLoss, RedSort30, BLossSort, AirSup, and RedFC. Again the correlations are fairly intuitive. BlueGrnd has significant correlations with RedSort30, BLossSort and AirSup. RedOpen has significant correlations with RedLoss, RedSort30, BLossSort, and AirSup. RedFC has significant correlations with BlueSA.

Multivariate analysis was performed on the eight MOE responses; RedLoss, RedSort30, BLossSort, AirSup, BlueSA, BlueGrnd, RedOpen, and RedFC.

4.2 Multivariate Analysis

4.2.1 Outliers. Prior to any applications of multivariate data reduction tools, the data was standardized and an analysis of outliers (≥ 1.9) was performed. The significant outliers by case and replication are listed in Table 10. The alternatives averaged about three replications with potential outliers. The F-15C w/Radar had the least replications with potential outliers (two) and the F-XX had the most (six). Outliers were generally limited to one or two variables for each affected replication. No outliers were excessive - there were no replications with multiple responses >>2 (Tabachnick & Fidell, 1989:68).

Table 10, Standardized Outliers by Alternative and Replication

Scenario	Rep	Red A-A Losses	Red Percent Sortie	Blue Loss /Sortie	Air Supremacy (.10)	Blue S-A Losses /Sortie	Total Blue Destroyed on Ground	Total Red Destroyed in the Open	Total Red FC Radars Killed
F-15C	4		3.0	2.4	3.7				
F-15C	19	-2.2							2.2
F-15C	23			2.1				-2.3	
F-15C Msl	3	2.1						-2.2	
F-15C Msl	10		3.2	2.4	3.0		1.9		
F-15C Msl	25					2.2			-2.0
F-15C Rdr	26					2.0	2.0	-2.1	
F-15C Rdr	27			-2.2	-2.3	-2.1			
F-15C Rdr/Msl	12		2.2		2.0				
F-15C Rdr/Msl	24	-2.2						2.0	
F-XX	3				2.8			-2.1	
F-XX	12		3.1						
F-XX	9	2.4							2.1
F-XX	19				-2.0	2.2			
F-XX	21		1.9				2.1		-2.1
F-XX	25							-3.1	
F-XX Msl	1			2.5		2.0			-2.2
F-XX Msl	14		4.2						
F-XX Msl	18	1.9						-2.1	
F-XX Msl	19	-2.4					-2.2		

Based on the outlier analysis, the output responses of all replications were retained for the remaining analysis.

4.2.2 PCA. PCA loadings, depicted in Table 11, were extracted from the correlation matrix. The eigenvalues of each component are in the top row of the matrix.

Table 11, PCA Loading and Variance Reduction of Output Responses

EigenValue:	5.1929	1.0811	0.6631	0.4566	0.323	0.1547	0.0998	0.0288
Percent:	64.9	13.5	8.3	5.7	4.0	1.9	1.2	0.4
CumPercent:	64.9	78.4	86.7	92.4	96.5	98.4	99.6	100.0
Eigenvectors:								
RedLoss	-0.4083	-0.2698	0.1546	0.1494	-0.1392	0.1636	0.0331	0.8168
RedSort30	0.3980	0.0450	0.0068	0.2728	-0.4764	-0.5615	-0.4223	0.2110
BLossSort	0.4092	0.0912	-0.0174	0.0126	-0.1582	0.7832	-0.4250	0.0690
AirSup	0.4084	0.0905	-0.0140	0.1934	-0.3584	0.1258	0.7977	0.0828
BlueSA	0.3159	-0.4223	-0.1804	0.5829	0.5890	-0.0128	0.0033	0.0488
BlueGrnd	0.2732	-0.1909	0.9128	-0.1627	0.1587	-0.0518	0.0201	-0.0329
RedOpen	0.3567	0.3668	-0.1799	-0.4679	0.4327	-0.1565	0.0510	0.5221
RedFC	-0.1974	0.7479	0.2784	0.5296	0.2020	0.0384	-0.0254	0.0266

The individual variance reduction provided by each component and the cumulative variance reduction are listed in the next two rows, respectively. The component loadings are listed below their respective eigenvalue/variance assessment.

Applying Kaiser's approach (retain eignevalues > 1) to the data in Table 11 indicates the dimensionality of the data is two. After the second component, all eignevalues are less than one. The first component provides the bulk of reduction in variance. Figure 8 graphically depicts Kaiser's criteria for dimensionality and the

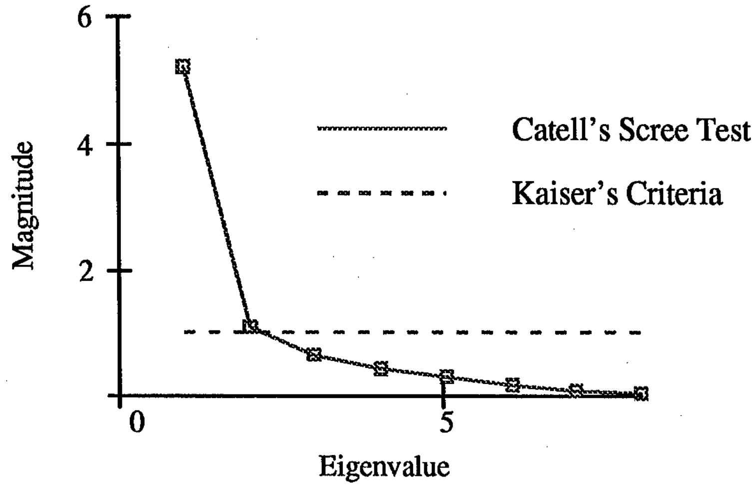

Figure 8, Data Dimensionality By Scree Test and Kaiser Criteria

Catell's scree test for the data. There is a distinct elbow in the scree test plot at the second eigenvalue suggesting a data dimensionality of two. Retaining the two components would explain over 78 percent of the variance in the data.

4.2.3 Cluster Analysis. Cluster analysis was applied as a tool of discovery for insights on the dimensionality of the response data. Hierarchical clustering techniques were applied to all the responses for the six alternatives via the centroid linkage method. The centroid method is an agglomerative approach that clusters based on the squared Euclidean distance between the means of two clusters. The centroid method was applied because of its robustness to outliers (JMP Manual, 330:1995). The method yielded 37 clusters for the responses for 186 replications (31 replications of six alternatives). There were five clusters in the JMP output that had ten or more clusters assigned. Although the majority (greater than 50% of the replications) of the F-15C with the new missile, the F-XX, and the F-XX with the new missile were binned in three separate clusters, the clustering did not yield any trends.

The JMP clustering output was then constrained to identify six clusters. The threshold of six was chosen commensurate with the number of alternatives under consideration. The number of replications binned in each cluster is depicted in Table 12. The data in Table 12 indicates the replications primarily grouped in two clusters. This clustering pattern seems to support the dimensionality insights from PCA. Clustering data is in Appendix I. The data indicated two clusters.

Table 12, Cluster Output Constrained to Six Clusters

Cluster	Members
1	116
2	62
3	2
4	1
5	4
6	1

4.2.4 FA. Factors were extracted from the correlation matrix. Varimax rotation was begun on two factors based on the dimensionality insights from the PCA and clustering. Rotations were also accomplished for three and four factors. The results of the two and four factor rotations are in Appendix J. The loadings after three factor rotation presented the clearest interpretation of the factors. The structure of the loadings for the three factor rotation was fairly simple. No rows had more than one high correlation, reducing the complexity and ambiguity of the interpretation. The loadings from the three factor varimax rotation are depicted in Table 13. The significant loadings (> 0.5) are listed in

Table 13, Rotated Factor Loadings

RedLoss	**0.9545**	0.1617	0.1510
RedSort30	**-0.7955**	-0.3116	-0.3081
BLossSort	**-0.8442**	-0.2866	-0.2897
AirSup	**-0.8418**	-0.2856	-0.2918
BlueSA	-0.4413	**-0.7069**	-0.1955
BlueGrnd	-0.2729	-0.1738	**-0.9352**
RedOpen	**-0.9061**	-0.0356	-0.0727
RedFC	0.0693	**0.9192**	0.0931

bold type. RedLoss loaded positively on Factor 1. Factor 1's remaining significant loadings (RedSort30, BLossSort, AirSup, RedOpen) all loaded negatively. Factor 2 had a significant negative loading by BlueSA and a positive loading by RedFC. The third factor had a significant negative loading by BlueGrnd. Factor interpretation of the three factors is shown in Table 14. The strong positive loading of RedLoss on Factor1 and the

Table 14, Factor Interpretations

Factor	Significant Loadings	Interpretation
1	RedLoss -RedSort30 -BLossSort -AirSup -RedOpen	Air-toAir Lethality
2	-BlueSA RedFC	SEAD Effectiveness
3	-BlueGrnd	IADS Effectiveness

negative loads of RedSort30, BLossSort, AirSup, and RedOpen on the same factor give rise to the factor interpretation of Air-to-Air Lethality. This captures the impact of the alternatives on Blue's overall air-to-air lethality. The strong positive loading by RedFC and moderately high negative loading of BlueSA support the interpretation of Factor 2 as describing Suppression of Enemy Defense (SEAD) Effectiveness. The factor measures the effect of the alternatives on Blue's ability to negate the Red SAM threat. The high negative loading on the third factor leads to an interpretation of Integrated Air Defense System (IADS) effectiveness. This factor measures the impact of the alternatives on the effectiveness of Blue IADS assets (C^2, air-to-air defensive assets, SAMs) to protect Blue airbases.

The residual matrix, $\underset{\sim}{R}_{RES}$, provides a measure of the fit of the FA to the data. The $\underset{\sim}{R}_{RES}$ for the varimax rotated factor loadings described above is depicted in Table 15. All

Table 15, Residual Matrix

Variables	RedLoss	RedSort30	BLossSort	AirSup	BlueSA	BlueGrnd	RedOpen	RedFC
RedLoss	4.28E-06							
RedSort30	0.029	3.55E-07						
BLossSort	0.028	-0.024	4.84E-06					
AirSup	0.037	0.035	9.70E-04	2.88E-06				
BlueSA	0.014	-0.017	-0.028	-0.017	2.51E-06			
BlueGrnd	-0.02	-0.041	-0.016	-0.032	-0.013	-2.72E-06		
RedOpen	-0.043	-0.11	-0.045	-0.089	-0.041	0.058	3.34E-07	
RedFC	0.029	0.033	-1.53E-03	0.022	0.179	-0.029	-0.086	-1.96E-06

cells in the matrix were less than one indicating the rotated factors fit the data well. The factor scores were determined from the factor loadings and the coefficients. Factor scores summarize the correlations between output variables.

Appendix K lists the scores for the alternatives. The means of the factor scores for each alternative are listed in Table 16. The graphical rendering of the factor scores provides additional insight into the underlying structure of the data. The scores were plotted in the visualizations depicting output responses in common factor space discussed in the next section.

Table 16, Means w/90% Confidence Intervals of Factor Scores

Alternatives	Air-to-Air Lethality	SEAD Effectiveness	IADS Effectiveness
F-15C	-0.8655 ± 0.0850	-0.3393 ± 0.3166	-0.4750 ± 0.2692
F-15C Msl	-0.6579 ± 0.1399	0.1890 ± 0.3240	0.3240 ± -0.1016
F-15C Rdr	-0.7729 ± 0.1541	0.0046 ± 0.2769	0.0085 ± 0.3742
F-15C Rdr & Msl	-0.1746 ± 0.1475	-0.2832 ± 0.3207	0.0504 ± 0.3220
F-XX	0.9654 ± 0.0904	0.0270 ± 0.3142	0.1075 ± 0.2813
F-XX Msl	1.5055 ± 0.1094	0.4019 ± 0.2315	0.4102 ± 0.2138

4.3 Visualization

Scatter visualizations were used to visually data mine the responses for patterns and anomalies in the data. The scatter visualization tool used is described in detail in Chapter 6 of the <u>MineSet User's Manual</u> at www.sgi.com (MineSet User's Manual, 1997). Buttons on the panels used to configure the visualizer tool discussed in this section are in **bold type**. The schema used for the visualization in the thesis effort are at Appendix L. The data files used in the visualization were Excel spreadsheets saved in a tab delimited format. The means for each alternative were labeled with a run number of "M" in the data files. The following narrative briefly explains the configuration of the scatter visualization to support this investigation.

Figure 9 depicts a Data Destination Panel setup for a scatter visualizer session. The button on the data destination panel at the top left labeled **scatter visualizer** indicates the MineSet visualization tool selected. The user specifies the data fields to be visualized in the area labeled **visual elements**. Only those selections <u>without</u> an asterisk "*" are required entries to launch the scatter visualizer tool using the **invoke tool** button at the lower right corner of the panel. The three output responses mapped to the axes in the figure are BLossSort, BlueSA, and RedFC. The size of the entities is scaled to the

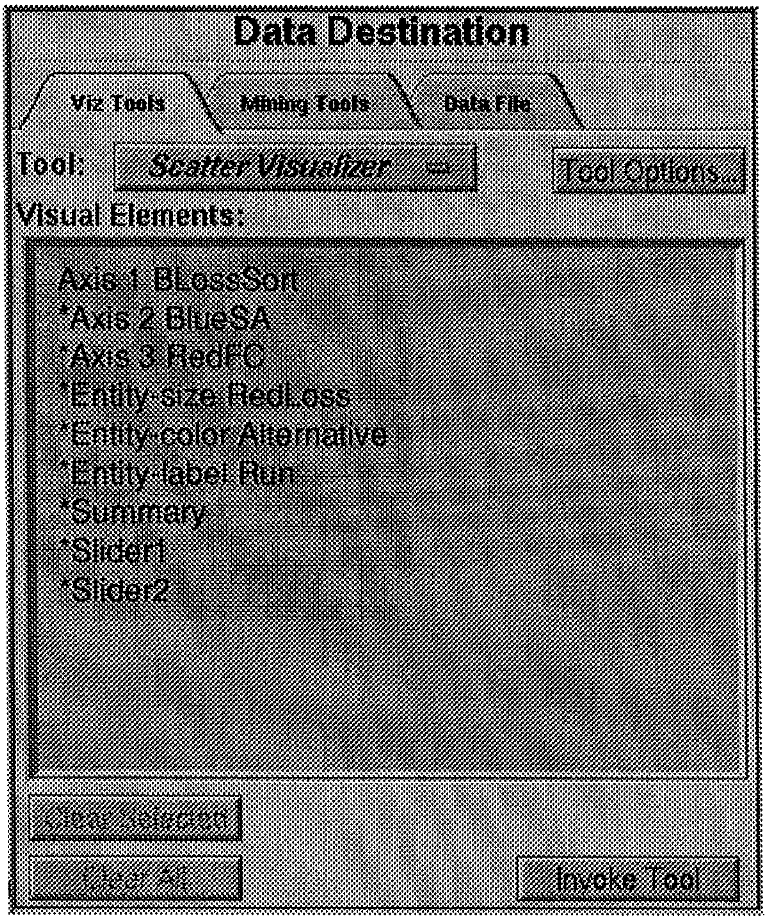

Figure 9, Scatter Visualizer Data Destination Panel (MineSet User's Manual, 1997)

RedLoss response. The color coding of the data entities is mapped to the alternative solutions. The separate data entities are labeled by run number.

The scatter visualizer's Options Dialog Box activated by the **tool options** button in the upper right corner of the panel, allows the user to label axes and specify entity color mapping. The options dialog box is depicted in Figure 10. The axes are labeled,

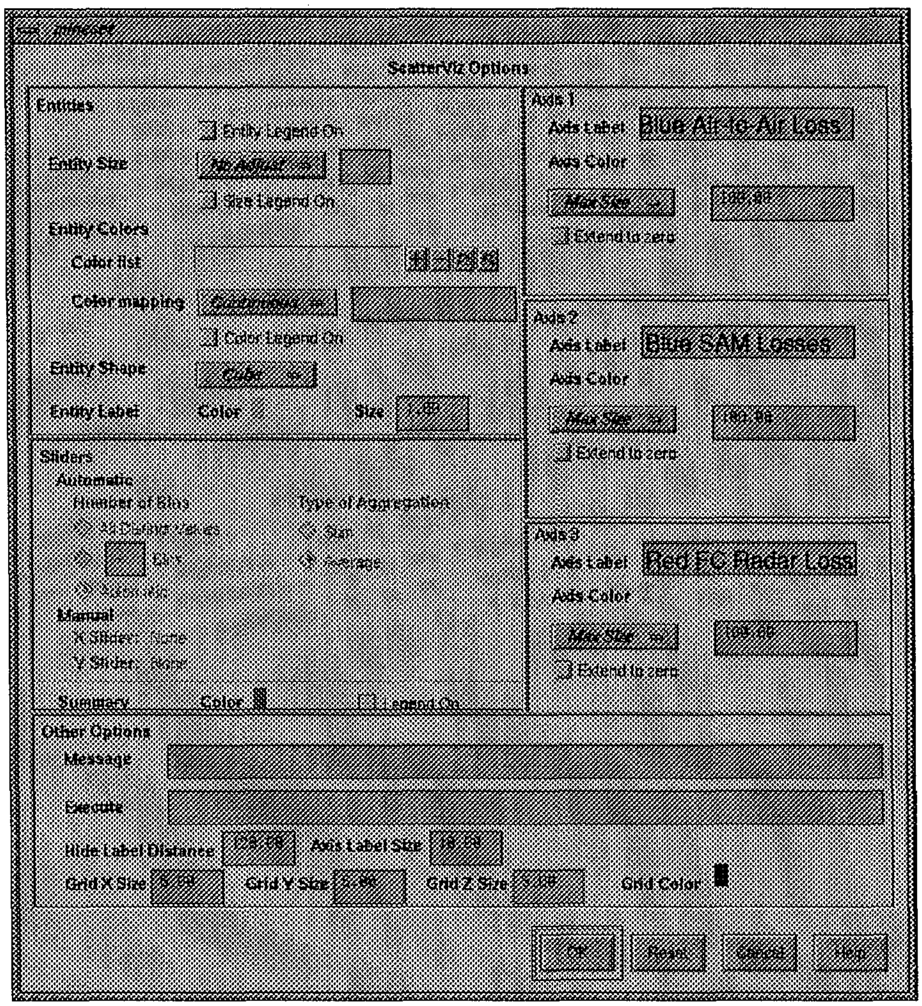

Figure 10, Scatter Visualizer Options Dialog Box (MineSet Users' Manual, 1997)

mapped to a color, and sized (as required) using the axes input areas on the right side of the dialog box . The labels listed for the axis labels were used with the data destination setup just described in Figure 10. The output response names are truncated in the figure. The upper left corner of options dialog box has spaces for the user to map entities to colors, shapes, and labels. The remaining functions in the box were not used in this investigation.

4.3.1 Output Response Visualization. The visualization of the output responses focused on three areas for the identification of patterns and/or anomalies: output response correlations, outliers, and variability. The analyst began with the aggregate data view

(186 data points for six alternatives) generated by the scatter visualizer. The view of the data was rotated and panned to provide the best analyst viewing perspectives for the data structure. The analyst drilled down into the detail of the data at the aggregate level by selecting the display of summary data for data points of interest.

The Filter Panel depicted in Figure 11 was used to drill down to the next level of output data by selecting specific classes of data points for display, e.g. the F-XX replications with RedLoss greater than 300 and BLossSort less than 0.0016. The filter was also used to drill back out of the data by selecting the means for the alternatives. Filter choices were selected by highlighting the fields of interest listed in the three windows at the top of the figure and via queries using the buttons and input boxes in the bottom half of the panel. Means of the output responses for each alternative were labeled with an "M" in the run field of the data. The analyst drilled out of the aggregate data and back in by entering "M" in the input box adjacent to the run label. The entry removes all the data from the view except the means. Filtered displays were rendered with the **scale to filter** button in the lower right corner of the panel in the "off" position. This setting retained the scale of the view when shifting between the aggregate and filtered viewing paradigms to facilitate side-by-side comparisons.

The scatter visualization of the output responses for BlueSA, RedFC, and BlueGrnd was noteworthy as the one case of all displayed where the improved performance of the F-XX and F-XX w/Missile over the other alternatives was not

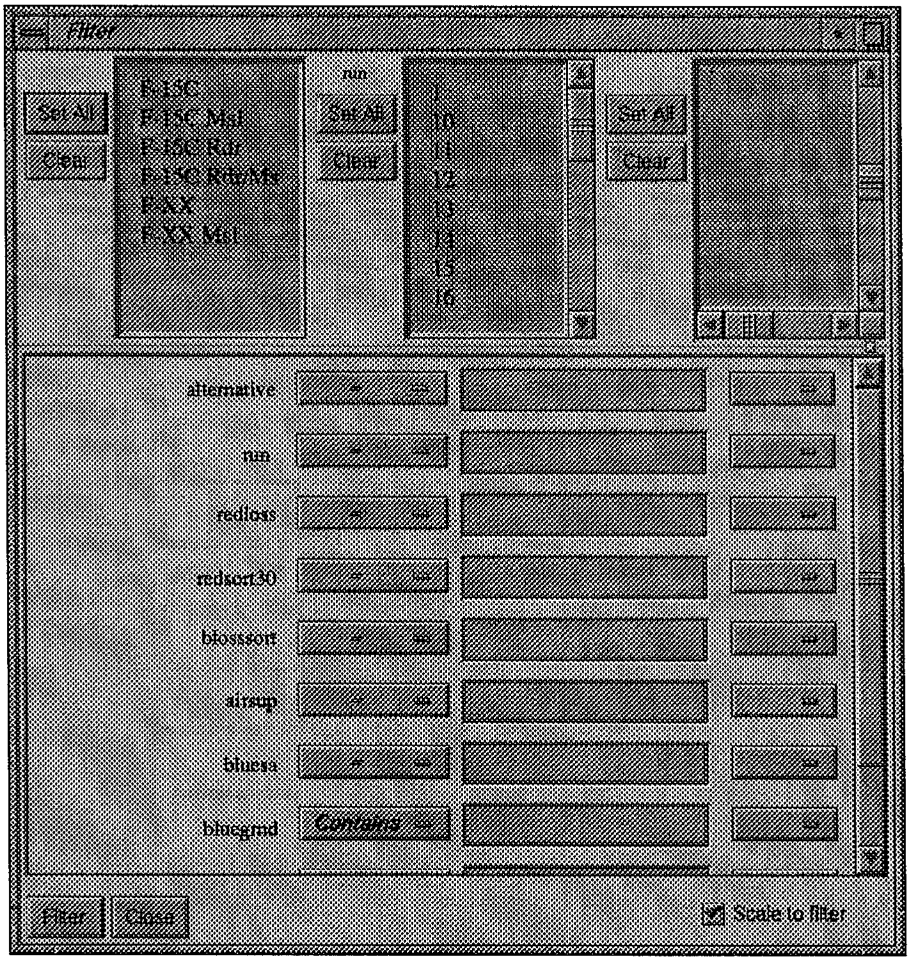

Figure 11, Scatter Visualizer Filter Panel (MineSet User's Manual, 1997)

apparent from the aggregate data display. The underlying structure was not apparent until the data was filtered to display only the means. The difficulty in discriminating the performance of the alternatives is explained in the discussion of the experimental design analysis. There is a lack of statistical significance between the BlueSA and RedFC output responses for several alternatives.

Outliers in the data were detected by noting those points appearing to have a significant separation from the center of mass for each alternative's data. The analyst zoomed in on potential outliers. Display of the summary screen provided output response information for the point of interest. The aggregate display was then filtered to depict the separation between the point and the mean of its alternative grouping for additional insights. The twenty replications with outliers listed in standardized matrix of Table 10 were displayed and visually data mined. This allowed the analyst to confirm the textual interpretation that there are no patterns in the outliers. The analyst derived insights on the variability of the data from aggregate views and views of the output response means. Using the output response variances on the diagonal of the variance/covariance matrix in Table 8 enabled the analyst to focus on output responses with extremes of variability. RedFC, RedLoss, and RedOpen were visualized for insight into the output responses with the highest variability. The MineSet visual display for RedFC, RedLoss, and RedOpen is depicted in Figure 12. Although the MineSet screen display does not lend itself well to a black and white 2D rendering in the figure, the dispersion of the data points for RedFC, RedLoss, and RedOpen output responses depicted in Figure 12 confirms the significant variability of the group, particularly the RedFC. BlueSA, BLossSort, and RedSort30 were visualized for insight into the responses with the lowest variability. The MineSet visual display for BlueSA, BLossSort, and RedSort30 is depicted in Figure 13. The compact grouping of BlueSA, BLossSort, and RedSort30 in Figure 13 provides insight small variability of the group.

Overall, the response output visualization did not yield additional insights on the structure of the data beyond the previous data analysis. However, the capability to target interest areas and drill down into the data through visualization allowed the analyst to come to qualitative insights on the correlations, outliers, and variability of the data more quickly than if presented a table of simulation output to assimilate. The visualization confirmed analyst conclusions that the modifications of the F-15C radar, replacement of the AMRAAM with a new missile, and RCS reduction to implement the F-XX yielded

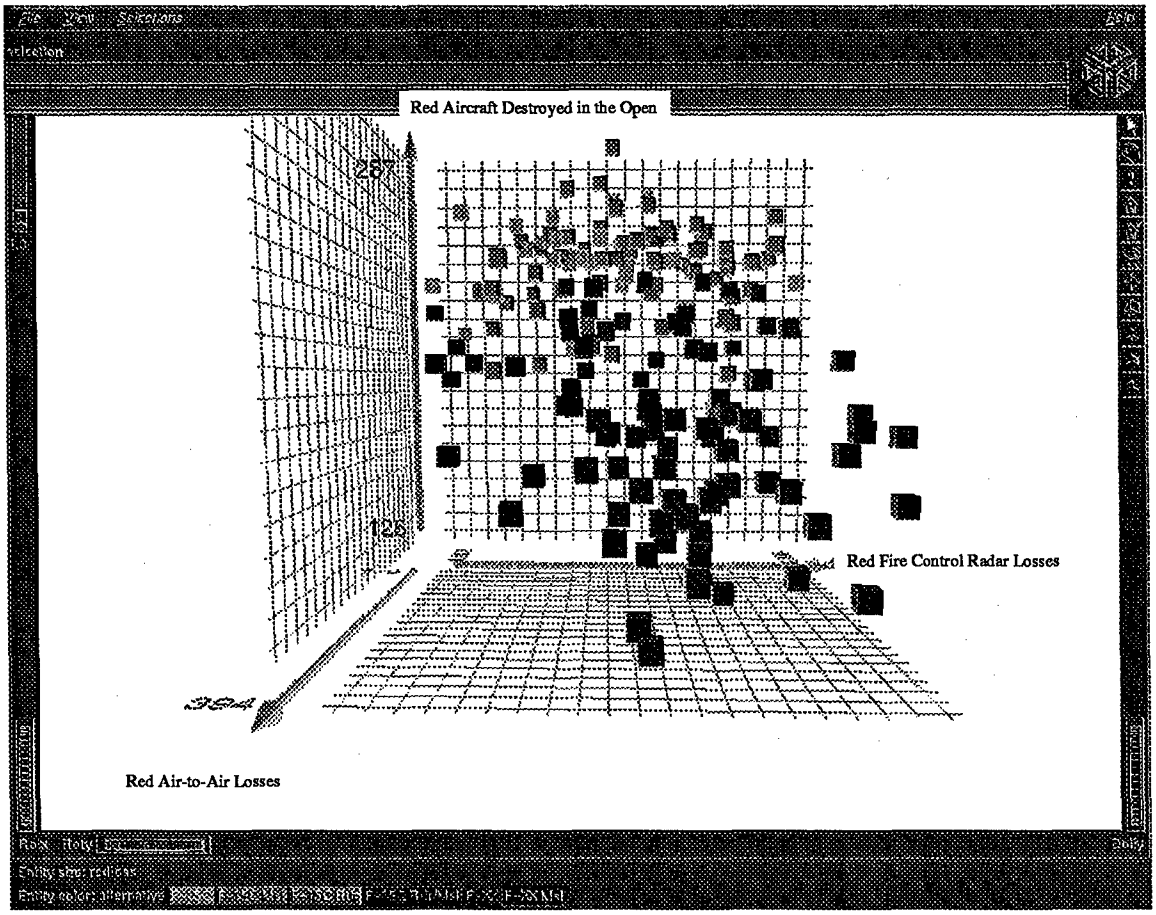

Figure 12, Scatter Visualization of RedFC, RedLoss, and RedOpen Output Responses

progressively improved output responses. The radar improvements and addition of the new missile generally yielded the same performance. The exceptions in the performance between of the F-15C with radar improvements and the alternative with the new missile were highlighted by the visualization. Otherwise, the F-15 configured with the new missile or the new radar yielded the same performance in the campaign level analysis. The F-15C configured with both the new missile and radar outperformed either modification (new missile or radar) alone in all measures except BlueSA and RedFC. However, the difference in the performance in these two cases does not exceed the 90% confidence level half lengths for the response outputs.

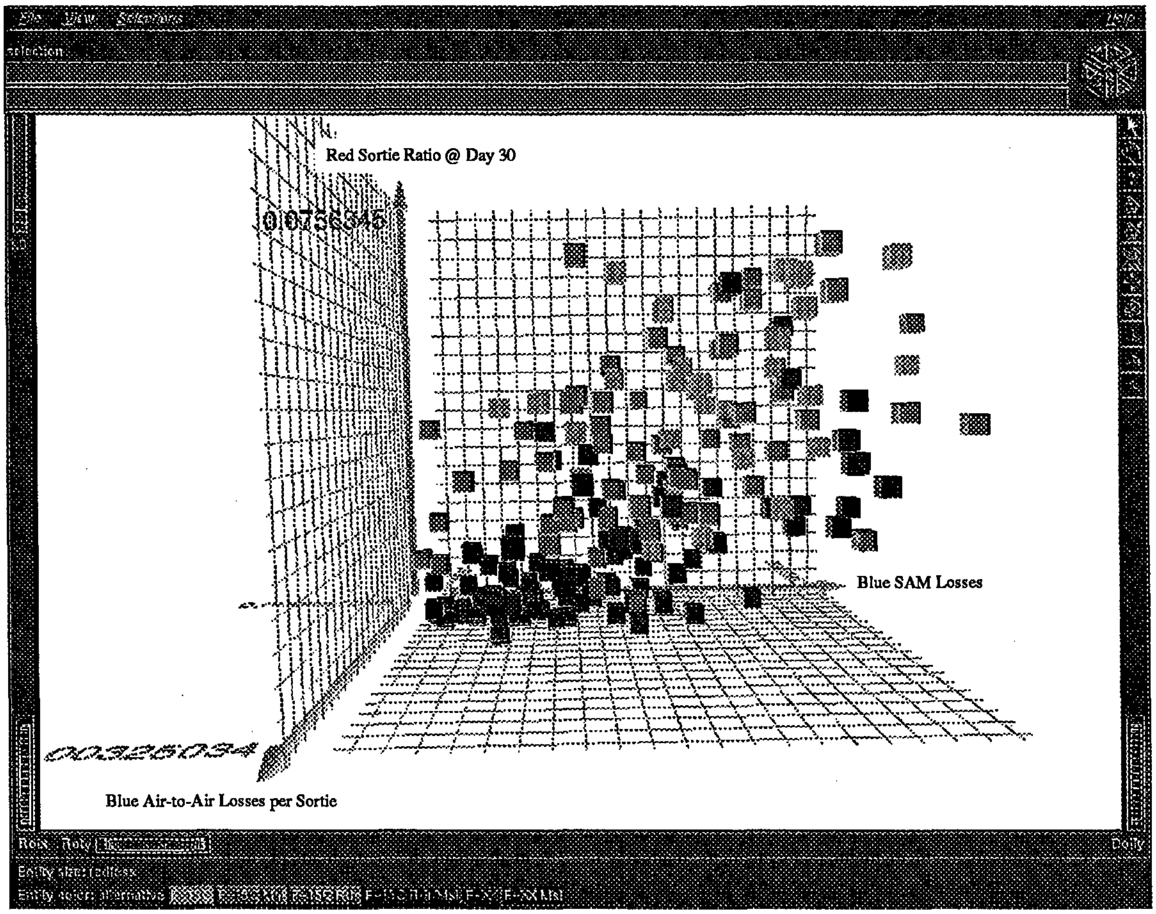

Figure 13, Scatter Visualization of BlueSA, BLossSort, and RedSort30 Output Responses

4.3.2 Factor Score Visualization. After exploring the responses, the factors were visualized. The three axes of the scatter visualization were labeled Air-to-Air Lethality, SEAD Effectiveness, and IADS Effectiveness. The size of the entities and entity labels were based on notional LCC as follows:

F-15C	$29M
F-15C with new missile	$33M
F-15C with new radar	$35M
F-15C with new radar and missile	$40M
F-XX	$70M
F-XX with new missile	$77M

Entity colors were mapped to the same fields as in the output response visualizations. A measure of the adequacy of factor rotation is the orientation of clusters of factor scores relative to the axes. The visualization of the aggregate data indicated clustering of the data points around the air-to-air lethality axis. However, the clustering is not definitive enough to make an assessment of the adequacy of the rotation.

The aggregate factor scores are fairly widely dispersed in the MineSet 3D visualization of the data. The variability in the factor scores of the F-15C alternatives (radar improvement, new missile, both) is apparent from the visualization. It is difficult from the aggregate data to quantify one of the F-15C options (radar, new missile, both) as better than another except that all show improvement over the current air superiority fighter. The data points for the F-XX and F-XX w/new missile are more tightly grouped indicating less variability. The F-XX and F-XX w/new missile factor scores are clearly separated from the F-15C alternatives. Additionally, the center of mass for F-XX w/new missile factor scores is clearly to the right of the F-XX suggesting a synergistic effect between the new missile and the reduced RCS that did not exist with the radar improvement alone. The visual display of the aggregate factor scores show the center of mass for each alternative (F-15C, F-15C w/missile, F-15C w/radar, F-15C w/radar and missile, F-XX, F-XX w/missile) progressively transiting the graphic to a quadrant of positive loading in air-to-air lethality, DCA effectiveness, and SEAD effectiveness factor scores.

Filtering the factors scores to display the means for each alternative indicates the F-15C w/missile shows greater improvement over the F-15C than the radar improvement. The area of greatest improvement over the base cases for all alternatives is in the air-to-air lethality factor. This finding tracks with the large amount of variability in the data explained by the first component in the PCA. IADS and SEAD effectiveness show moderate to low improvement between the F-15C and the modifications (new missile, radar, both). Additionally, the F-15C modifications and the F-XX vary little in DCA effectiveness. The F-XX w/new missile shows significant increase over the other alternatives in DCA effectiveness. Likewise, the F-15Cs and the F-XX had approximately the same level of improvement for SEAD effectiveness except a decreasing effectiveness by the F-15C w/new missile and radar. This anomaly may be due to the statistical significance issues for BlueSA and RedFC discussed previously in this section. The F-XX and F-XX w/new missile show improvements in all areas. The visualization of the mean factor scores in Figure 14 depicts a side view of the cost/effectiveness integration plot for the campaign analysis. Figure 15 depicts the top view of the plot. The operational effectiveness of the six alternatives are their air-to-air lethality, SEAD effectiveness, and IADS effectiveness mean factor scores represented in three space. The notional LCCs, in millions of dollars, is represented by the size and labels on the entities. Both figures underscore that the average improvement in the air-to-air lethality performance of the F-15C w/Radar & Missile, F-XX, and F-XX w/Missile is greater than the average improvement for said alternatives in the SEAD or IADS labels on the entities. Both figures underscore that the average improvement in the air-to-air lethality performance of the F-15C w/Radar & Missile, F-XX, and F-XX w/Missile is greater than the average improvement for said alternatives in the SEAD or IADS effectiveness performance. The two plots also graphically display the average overall

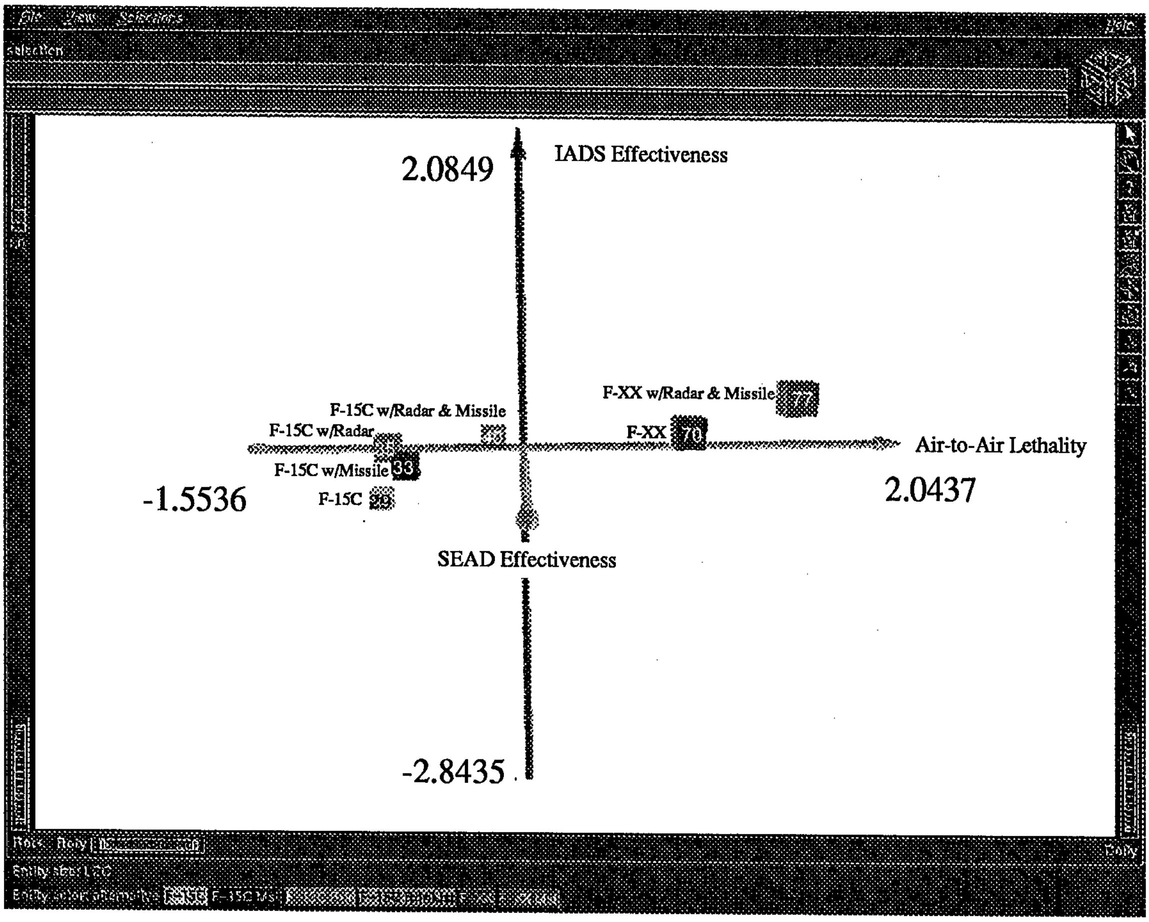

Figure 14, Scatter Visualization of Mean Factor Scores - Side View

operational effectiveness (air-to-air lethality, SEAD effectiveness, IADS effectiveness) of the F-XX w/Missile is greater than the other alternative solutions

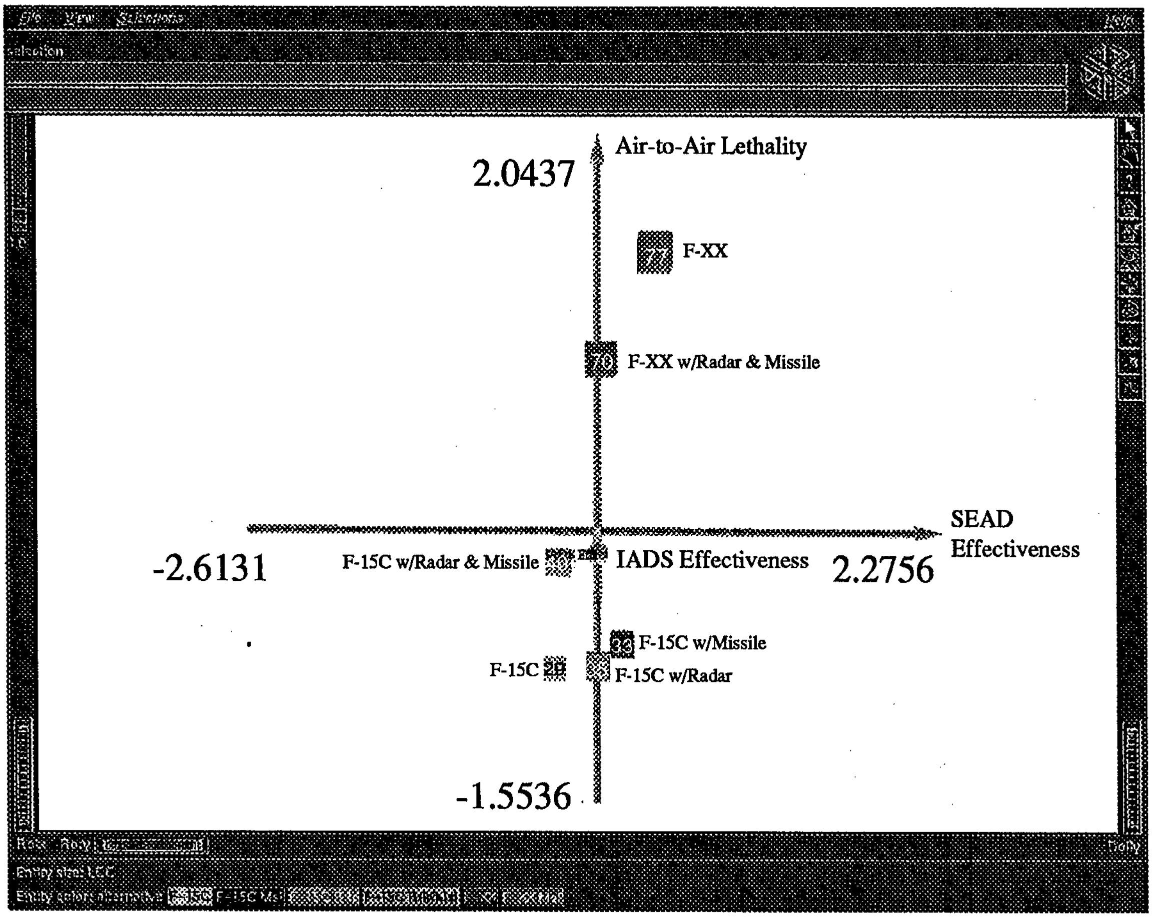

Figure 15, Scatter Visualization of Mean Factor Scores - Top View

5. Conclusions and Recommendations

This chapter discusses the conclusions and recommendations drawn from the analysis.

5.1 Summary

This thesis effort developed an approach to reduce the dimensionality of multiple campaign level measures of effectiveness for an AoA. Additionally, an AoA visualization paradigm was developed for the capability demonstration of ASC's SIMAF.

The campaign level analysis and AoA results discussed in the thesis were based on a notional acquisition of a new air superiority fighter, the F-XX. The on-going acquisition and fielding of the F-22 fighter was not addressed in the study. An experimental design with two treatments, one with three levels of F-15C and one with two levels of weapons configuration, was the basis of the campaign level simulation performed. The F-XX is characterized as the level of F-15C with an improved radar and reduced RCS. The DOE yielded six design points; the F-15C, the F-15C w/Missile, the F-15C w/Radar, the F-15C w/Radar & Missile, the F-XX, and the F-XX w/Missile.

AFSAA's THUNDER 6.4.2 campaign level model was used in the simulation. Unclassified THUNDER data files for a SWA scenario provided by ASC/XR were used in the model. Each alternative was assessed for its contribution to the campaign objective of gaining and maintaining air superiority. The ten simulation output responses collected to measure the accomplishment of the campaign objective were chosen based on recommendations in an ASPVG report discussing THUNDER use in campaign analysis. Thirty one replications of a 30 day war were performed at each design point. Output responses for the F-15C, F-15C w/Missile, F-15C w/Radar, and F-15C w/Radar & Missile alternatives necessitated the use of Bonferroni confidence intervals to make simultaneous comparisons. The comparisons indicated the F-15C w/Missile design is generally better than F-15C (improved performance in six out of ten output responses), the F-15C w/Radar design is generally better than the F-15C (improved performance in two out of ten output responses), the F-15C w/Radar & Missile design is generally better than the F-15C (improved performance in six out of ten output responses), the F-15C w/Radar & Missile design is generally better both the F-15C w/Missile and F-15C w/Radar (improved performance in three out of ten output responses for each alternative).

A Wilcoxon signed rank test was used to compare the distributions of the output responses for the F-15C and the F-XX w/ Missile. Two output response fields with identical distributions for the two alternatives were not included in the multivariate analysis.

Multivariate and visualization tools were used to reduce the dimensionality of the AoA operational effectiveness measures - the simulations output responses. Three multivariate data reduction techniques were used to assess the structure of the data; PCA, cluster analysis, and FA. Although PCA and clustering suggested an underlying data structure with a dimensionality of two, the FA yielded the clearest interpretation after an orthogonal (varimax) rotation of three factors. The loadings of the rotated variables indicated an interpretation of the three factors as Air-to-Air Lethality, SEAD Effectiveness, and IADS Effectiveness.

The results of an AoA are presented in terms of a comparison of the LCC versus the operational effectiveness of the alternatives. One approach to presenting an AoA cost/effectiveness assessment for the six alternatives is the 3D bar chart depicted in Figure 16. The mean factor scores, representing a three dimensional assessment of each

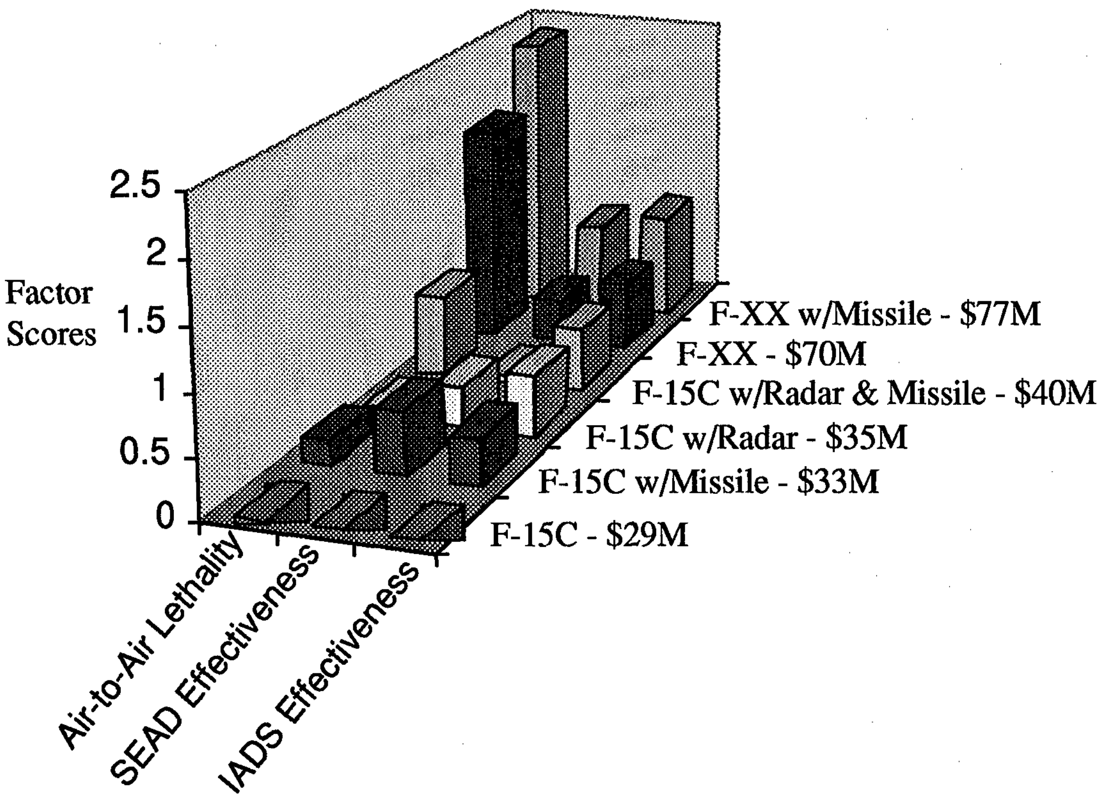

Figure 16, Cost/Effectiveness Comparison Bar Chart

alternative's operational effectiveness, are indicated by the bars in the figure. The scores have been transformed to the positive axes. Notional LCCs of the alternatives in millions of dollars are immediately to the right of the alternative labels. The factor interpretations are at the bottom of the figure. The figure indicates that the greatest area of improvement in operational effectiveness of the F-15C w/Radar & Missile, F-XX, and F-XX w/Missile over the current air superiority fighter is average air-to-air lethality performance. The alternatives generally show improvement in average SEAD and IADS Effectiveness performance over the F-15C. However, average SEAD and IADS effectiveness between alternatives is not significantly different except for the F-XX w/Missile. Figure 16 alone does not provide a definitive answer to the question of F-XX acquisition. In acquisition deliberations, the decision maker would consider the cost/effectiveness information provided by the figure in light of budget, force structure, schedule, etc.

Visualization of the data via high-end visualization software and a workstation for high resolution graphics and animations provided additional insights on the underlying structure of the data. The simulation output responses and multivariate analysis results were preprocessed using JMP data mining algorithms. Subsequently, the JMP output was visually data mined by rendering a graphic of the data and interacting with the 3D visualization. User/visualization interface was through use of the mouse to select entities of interest and user developed queries.

The output responses and factors scores were displayed using the SGI's MineSet visualization tool. The visualization confirmed the relationships between the output responses and highlighted the variability differences between F-15C alternatives with and without the reduced RCS. The factor analysis visualization provided the similar insights into the effects of RCS on variability.

The differences in variability between the reduced RCS and the other alternatives is due to the effect of RCS on ground controlled intercept (GCI)/AEW detection ranges and the probability of detection by threat aircraft. The reduced RCS was implemented via an RCS value in the *typeac.dat* file and reduced detection probabilities in the *detect.dat* file for the F-XX. Consequently, it will be less likely that there will be detections/ engagements of the F-XX by adversary interceptor aircraft. The reduction of stochastic engagement events by adversary aircraft reduces the variability of the output responses for the F-XX scenarios.

The factor scores displayed in three space accentuated the significant improvements between the alternatives in air-to-air lethality and the marginal improvements in SEAD effectiveness and IADS effectiveness. The F-XX w/Missile indicated an improved SEAD and IADS effectiveness performance over other alternatives.

The value added by data mining via visualization of the data was the faster information assimilation through user interaction with the data.

5.2 Findings

This investigation yielded the following findings from the simulation responses for the notional F-XX AoA study scenario used in this thesis effort:

1) The F-15C w/Missile showed improved RedLoss, RedSort30, BLossSort, AirSup, RedFC, and RedTEL performance over the F-15C.

1) The F-15C w/Radar showed improved RedSort30 and AirSup performance over the F-15C.

3) The F-15 w/Radar & Missile showed improved RedLoss, RedSort30, BLossSort, AirSup, BlueGrnd, and RedOpen performance over the F-15C.

4) The F-15C w/Radar & Missile showed improved RedLoss, AirSup, and RedOpen performance over the F-15C.

5) The F-15C w/Radar & Missile showed improved RedLoss, AirSup, and RedOpen performance over the F-15C.

6) RedAQ and RedTEL output responses were not statistically significant for a comparison of the F-15C and F-XX w/Missile.

7) The eight measures of effectiveness for the AoA can be represented by three interpretable factors through the application of FA - Air-to-Air Lethality, SEAD Effectiveness, and IADS Effectiveness.

8) 3D visualization of the mean factor scores for the six alternatives indicated the greatest improvement for the three factors was in the average air-to-air lethality factor scores for the F-15C w/Radar & Missile, F-XX, and F-XX w/Missile.

5.3 Lessons Learned

The THUNDER basic course presented by the model's vender, S3I Inc., significantly improved the user's learning curve in running the simulation. The course covered fundamentals of data file manipulation and air war planning. Students who undertake future THUNDER-based theses should consider taking the THUNDER basic course as funds and time permit. Other excellent THUNDER resources used in this effort were the on-line THUNDER Analyst Manual and advanced THUNDER analyst course material available at the C3I website, www.c3I.com. The documentation was particularly useful for the analysis of the simulation output.

Access to a CD disk writer was useful. The THUNDER output (graphics and textual files) for this investigation exceeded 400M for each 31 replication run of the 30 day war. The CD writer allowed the user to archive the data from each run on a CD (650M capacity). This capability also helped manage limited hard disk storage space on the workstation dedicated to the investigation.

Analysis of the simulation output was greatly streamlined through the use of the UNIX script *ttgraph.nawk* and the use of EXCEL macros. The UNIX script allowed the user to convert the THUNDER's *ttgraph.rpt* files to comma delimited files that could be imported into EXCEL. The use and coding of the *ttgraph.nawk* script is described in Grier's thesis (Grier, 1997:107). The EXCEL macros were used to populate spreadsheets for each alternative from the comma delimited files, extract data from the data set of each replication's output data, and build tables consolidating the data from all the replications for each alternative.

Once the visualization tool for the effort was chosen, the MineSet operators' manual on the SGI website was a great learning aid to utilize the software. The manual presented examples of the schema required to configure MineSet visualizer tools and discussed the use of input screens to customize and interact with the visualizations. The MineSet team at SGI provided quick and detailed feedback to my e-mailed questions. While there are other commercially available visualization and data mining packages, MineSet's ease of use for an analyst with limited UNIX and database knowledge was noteworthy.

The only drawback I found with the use of the MineSet tool was in converting screen graphic images to black and white images for publication in this thesis. MineSet allows the user to save screen images in an .rgb format. The .rgb format files can be saved to .gif files using an IRIX utility called *togif* available at the SGI website. Microsoft's Photo Shop utility can be used to reverse the black background in the MineSet scatter visualization images and enhance the rendering of the entities, but the publication quality is still limited.

This effort required the use of several software packages for visualization design (MineSet) and presentation (Hummingbird EXCEED Multiplatform and 3D). Although funding was available to purchase the software, often the government acquisition procedures delayed delivery. Fortunately, the software used in this effort was available in fully operational demo copies at websites and through sale representatives. ENS's host administrator for the modeling and simulation department was pivotal in assisting with the procurement, installation, and operation of the software.

Each set of an alternative's thirty one replications of the 30 day war on THUNDER for this effort took over sixteen and a half hours to complete using the simulation's **ttrep** script. Thesis research by Davies during the same timeframe of this effort utilized a script to run multiple THUNDER replications on numerous central processing units (CPU) at ASC's Major Shared Resource Center (MSRC) simultaneously. Davies' approach drastically reduced the time to make multiple THUNDER replications (Davies, 1998). He was able to complete thirty one replications of a 34 day war in less than two hours. Future THUNDER theses efforts should consider using said script on MSRC or AFIT UNIX network assets.

5.4 Recommendations for Future Study

Data mining has significant applications to operations research. Patterns and classifications of large sets of data, such as simulation output, that can be revealed/made through data mining are clearly of benefit to the military analyst. There are numerous data mining tools available commercially including statistic packages such as JMP. The MineSet data mining software utilized in this investigation was exclusively used for its visualization capability. The extensive capability of the software to apply data mining algorithms to large data sets through the use of the client/server module was not investigated.

Future investigations could use MineSet's data mining capabilities to drill into large data sets for pattern recognition and classification. Additionally, thesis efforts could investigate dependencies within simulation data sets via MineSet's decision tree functions.

Appendix A

The following outline is the Suggested Analysis of Alternatives (AoA) Report format provided by the Air Force Center of Expertise for AoAs, the Office of Aerospace Studies (Draft OASP 97-1, 1997:30). In an actual AoA study, the campaign level analysis discussed in the thesis would be documented in section 4 of the suggested format below.

TITLE
EXECUTIVE SUMMARY
1. INTRODUCTION
    1.1. Background
    1.2. Purpose
    1.3. Scope
2. ACQUISITION ISSUES
    2.1. Mission Need
    2.2. Threat(s)
    2.3. Scenarios
    2.4. Environment
    2.5. Constraints and Assumptions
    2.6. Operations Concept
3. ALTERNATIVES
    3.1. Description of Alternatives
    3.2. Nonviable Alternatives
4. ANALYSIS OF ALTERNATIVES
    4.1. Methodology
        4.1.1. Effectiveness Methodology
        4.1.2. Cost Methodology
        4.1.3. Cost-Effectiveness Methodology
    4.2. Models and Data
        4.2.1. Effectiveness Models and Data
        4.2.2. Cost Models and Data
        4.2.3. Cost-Effectiveness Models and Data
    4.3. Effectiveness Analysis
        4.3.1. Mission Tasks (MTs)
        4.3.2. Measures of Effectiveness (MOEs)
        4.3.3. Measures of Performance (MOPs)
        4.3.4. Effectiveness Sensitivity Analysis
        4.3.5. TEMP/ORD/AoA Linkage
    4.4. Life Cycle Cost Analysis
        4.4.1. Research and Development (R&D) Cost
        4.4.2. Investment Cost
        4.4.3. Operations and Support (O&S) Cost
        4.4.4. Disposal Cost
        4.4.5. Cost Sensitivity Analysis
    4.5. Cost-Effectiveness Analysis
    4.6. Tradeoff Analysis

Appendix B

This table lists the operational objectives and operational tasks under the Gain and Maintain Air Superiority campaign objective that can be measured by THUNDER (ASPVG, 1995:4). Additionally, the mapping of the output identifiers for the metrics measured in the unclassified data base to the operational tasks are listed.

Operational Objectives	Operational Tasks	Metric
Defeat air attacks	Destroy/disrupt aircraft and helicopters in flight.	RedLoss BLossSort
	Destroy/disrupt cruise missiles in flight	N/A
	Disrupt sensors on aircraft and weapons	N/A
	Execute passive defense measures in threatened areas	BlueGrnd
Suppress generation of air sorties	Crater/mine/damage airfield runways and taxiways	RedSort30 AirSup
	Destroy/damage aircraft in the open or in revetments	RedOpen RedSort30 AirSup
	Destroy/damage aircraft in hardened shelters	RedSort30 AirSup
	Destroy/damage airbase support facilities	RedSort30 AirSup
	Deny attack helicopter forward area refuel/replenishment points (FARRP)	N/A
Suppress surface-based air defenses	Destroy/damage fixed surface-to-air missile (SAM) launchers	RedTEL RedACQ RedFC BlueSA
	Destroy/damage SAM launchers and anti-aircraft artillery (AAA)	RedTEL RedACQ RedFC BlueSA
	Destroy/disrupt tracking and engagement radars	N/A
Defeat attacking ballistic missiles	Destroy ballistic missiles in flight (active defense)	N/A
	Execute passive defense measures in threatened areas	N/A

Operational Objectives	Operational Tasks	Metric
Suppress the generation of ballistic missile launches	Damage/destroy transportable erector launchers (TELs) in the field and disrupt operations	N/A
	Damage/destroy TELs in garrisons and assembly areas	N/A
	Damage/destroy fixed TBM launchers	N/A

Appendix C

This appendix alphabetically lists the abbreviations used for the THUNDER output metrics.

AirSup	Days to air supremacy (defined as 10% of initial Red sortie generation rate)
BLossSort	Blue air-to-air loss per blue sortie flown
BlueGrnd	Total number of Blue aircraft destroyed on the ground
BlueSA	Number of Blue aircraft lost to enemy surface-to-air missile threats per sortie
RedACQ	Number of acquisition radars killed
RedFC	Number of fire control radars killed
RedLoss	Red aircraft lost due to Blue air
RedOpen	Number of Red aircraft destroyed in the open
RedSort30	Red sortie generation capability on day 30
RedTEL	Number of transportable erector/launchers killed

Appendix D

This appendix contains excerpts of the modified THUNDER data files for each AoA alternative solution. The files are listed in the order they are discussed in the text. Some files are included in their entirety.
The changes to the files from the original data files provided by ASC/XR are shaded and italicized ***with notations in bold type.***

`control.dat` - All scenarios

```
CONTROLS.020

  REPORT.TITLE          "UNCLASSIFIED  THUNDERSTORM "

  BASIC.SIMULATION.CONTROLS
    NUMBER.OF.DAYS.OF.WAR(INT.DAYS)                30  All scenarios
    BEGIN.DAYLIGHT(DEC.HOURS)                    12.00
    END.DAYLIGHT(DEC.HOURS)                      24.00
    ADX.PROVIDE.TERM.AD.FOR.FIXED.TGTS            YES
    IGNORE.RANGE.CONSTRAINTS                      NO
    COUNT.ALERT.MSN.AS.COMPLETE                   NO
  END.BASIC.SIMULATION.CONTROLS

  GAME.CONTROLS
    GAME.FILE.MOD.FLAG                            YES
    GAME.ENABLE                                   NO
    GAME.CYCLE                                    24
    FIRST.GAME.STOP(DAYS)                         1.1
  END.GAME.CONTROLS

  ADF.CALIBRATION.CONTROLS
    ADF.CALIBRATION.MODE.ENABLE                   NO
@     if enabled
@       only preplanned ATOs fly
@       all ADvsAC Pks = 0.0
@       unlimited AD ammo reloads
@       lethal SEAD disabled
@       air-to-ground disabled
@       special ADF calibration transactions enabled
@       ADF results averaged over multiple reps:
    REPLICATIONS.PER.ADF.CALCULATION                3
    USE.MANUAL.IADS.IADS.VALUES(YES,NO)           NO
    MANUAL.IADS.INTEGRATION.LEVEL(0.0-1.0)        0.7
    MANUAL.IADS.SECONDS.DELAY                    15.0
    MANUAL.IADS.INTIMIDATE                        0.0
  END.ADF.CALIBRATION.CONTROLS

  COMPUTATIONAL.RESOLUTION.LEVELS(LOW,HIGH)
    BLUE.AIR.DEFENSE                              HIGH
    RED.AIR.DEFENSE                               HIGH
    AIR.WAR                                       HIGH
    BLUE.RECONNAISSANCE                           HIGH
    RED.RECONNAISSANCE                            HIGH
    WEATHER                                       LOW
    GROUND.MOVEMENT                               HIGH
```

```
  CRITICAL.RESOURCES                                  LOW
END.COMPUTATIONAL.RESOLUTION.LEVELS

GRAPHIC.OUTPUT.CONTROLS
  WRITE.GRAPHIC.TO.TRANS                               NO
  POST.PROCESS.GRAPHICS(BOTH,CHART,MAP,NONE)           BOTH
  AD.COMPLEX.STATUS.UPDATE.CYCLE(HOURS)                12
  AIRBASE.STATUS.UPDATE.CYCLE(HOURS)                   12
  CHOKE.POINT.STATUS.UPDATE.CYCLE(HOURS)               12
  COMMAND.STATUS.UPDATE.CYCLE(HOURS)                   12
  LOG.FAC.STATUS.UPDATE.CYCLE(HOURS)                   12
  STRATEGIC.TARGET.STATUS.UPDATE.CYCLE(HOURS)          12
  SUPPLY.TRAIN.STATUS.UPDATE.CYCLE(HOURS)              12
  TBM.UNIT.STATUS.UPDATE.CYCLE(HOURS)                  12
  UNIT.STATUS.UPDATE.CYCLE(HOURS)                      12
  PERCEPT.STATUS.UPDATE.CYCLE(HOURS)                   12
  AIR.REPORT.CYCLE(DAY,GAME,BLUE,RED)                  DAY
END.OUTPUT.CONTROLS

OVERALL.REPORT.CONTROLS
  REPORT.MODE(STANDARD,METRIC,BOTH)              STANDARD
END.OVERALL.REPORT.CONTROLS

DATA.REPORT.CONTROLS
  NUMBER.OF.DATA.REPORTS                               73
  CONTROL.FILE                        DR-2             NO
  RANDOM.SEEDS                        DR-3             NO
  STANDARD.TARGETS                    DR-5             NO
  TYPE.RADAR                          DR-10            NO
  TYPE.JAMMER                         DR-11            NO
  AIR.DEFENSE.DATA.REPORTS            ****
    TYPE.AIR.DEFENSE                  DR-12            NO
    POSTURES.&.CLASSES                DR-13            NO
    INTEGRATED.AD.SYSTEM              DR-14            NO
    ADA.ENGAGEMENT.PROBS              DR-15            NO
    AD.VS.AIRCRAFT.PKS                DR-27            NO
    AD.COMPLEXES                      DR-66            NO
  PLANNING.DATA.REPORTS               ****
    AIR.RULES                         DR-20            NO
    AIR.ALLOCATION                    DR-21            NO
    AIR.PLANNING.FACTORS              DR-67            NO
    OCA.TARGETS                       DR-23            NO
    PREPLANNED.ATOS                   DR-29            NO
    ZONE.SECTOR.TGT.PRIORITY          DR-65            NO
    INT.DEPTH.FACTOR.CURVES           DR-68            NO
    STI.TARGETS                       DR-70            NO
  AIR.TO.AIR.DATA.REPORTS             ****
    AIR.TO.AIR.PKS                    DR-24            NO
    RELEASE.RANGE.ADVANTAGE           DR-25            NO
    CONFIG.DETECT.PROBS               DR-26            NO
  AIR.TO.GROUND.PKS                   DR-28            NO
  HARM.PKS                            DR-40            NO
  MINE.PKS                            DR-41            NO
  TAKEOFF.LANDING.PKS                 DR-42            NO
  TYPE.AIR.MUNITIONS                  DR-31            NO
  TYPE.AIRCRAFT                       DR-32            NO
  AIRCRAFT.MAINTENANCE                DR-39            NO
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  TBM.UNITS                          DR-75         NO
  TBM.DETECTION                      DR-76         NO
  AIRBASE                            DR-33         NO
  CARRIER.BATTLE.GROUP               DR-30         NO
  SUPPLY.KIT                         DR-34         NO
  SQUADRON                           DR-35         NO
  AIR.TO.GRD.MIN.CEIL.VIS            DR-36         NO
  SUPPLY.URGENCY.CURVES              DR-37         NO
  CRITICAL.RESOURCES                 DR-38         NO
  NODES                              DR-45         NO
  TRANS.SHIPMENT.POINTS              DR-46         NO
  ARCS                               DR-47         NO
  CHOKE.POINTS                       DR-48         NO
  MINE.DELAY.CURVES                  DR-49         NO
  BATTLEFIELD                        DR-50         NO
  AIR.NETWORK                        DR-73         NO
  GROUND.TARGET.ACQUISITION          DR-51         NO
  TERRAIN                            DR-52         NO
  INTERVISIBILITY.CURVES             DR-53         NO
  TYPE.C3.FACILITY                   DR-55         NO
  COMMAND                            DR-56         NO
  GROUND.RULES                       DR-57         NO
  SUPPLY.TRAIN.TARGETS               DR-54         NO
  LOGISTIC.FACILITY                  DR-58         NO
  TYPE.UNIT                          DR-59         NO
  TYPE.EQUIPMENT                     DR-60         NO
  EQUIPMENT.SIZE.CATEGORY            DR-61         NO
  WEAPON.VS.EQUIPMENT.EFFECTS        DR-62         NO
  UNIT                               DR-63         NO
  UNIT.SUPPLY.CURVES                 DR-81         NO
  LIFT.EVENTS                        DR-82         NO
  PERCEPTIONS                        DR-64         NO
  STRATEGIC.TARGETS                  DR-69         NO
  AIRCRAFT.FACTORS                   DR-71         NO
  SREC.MAX.EFFECT.MULTIPLIER         DR-72         NO
  BOOST.PHASE.INTERCEPT              DR-77         NO
  WEATHER.STATIONS                   DR-80         NO
  ISR.DATA.REPORTS                   ****
    ISR.SATELLITES                   DR-83         NO
    ISR.PLANNING                     DR-84         NO
    ISR.TARGETS                      DR-85         NO
    ISR.SENSORS                      DR-86         NO
    ISR.EFFECTS                      DR-87         NO
    ISR.INITIALIZATION               DR-88         NO
    ISR.EVENTS                       DR-89         NO
END.DATA.REPORT.CONTROLS

OUTPUT.REPORT.CONTROLS
  COMPLETED.MISSION.INFO           AW-1   NO     BOTH    0.00   300.00
  DAILY.AIR.WAR.RESULTS.SUMMARIES         ****
    MISSION.&.SORTIE.SUMMARY       AW-2   NO    BOTH    0.00   300.00
    AIRCRAFT.LOSS.SUMMARY          AW-3   NO    BOTH    0.00   300.00
    AIRBASE.ACTIVITY               AW-4   NO    BOTH    0.00   300.00
    SORTIE.GENERATION              AW-5   NO    BOTH    0.00   300.00
  CANCELLED.MISSION.INFO           AW-6   NO    BOTH    0.00   300.00
  INDIVIDUAL.MISSION.KILL.RESULTS         ****
    DCA.MISSION.KILLS              AW-7   YES    BOTH    0.00   300.00
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    ODCA.MISSION.KILLS            AW-8  YES    BOTH    0.00   300.00
    HVAA.MISSION.KILLS            AW-9  YES    BOTH    0.00   300.00
    BARCAP.MISSION.KILLS          AW-10 YES    BOTH    0.00   300.00
    FSWP.MISSION.KILLS            AW-11 YES    BOTH    0.00   300.00
    DTBM.MISSION.KILLS            AW-12 NO     BOTH    0.00   300.00
    STI.MISSION.KILLS             AW-13 NO     BOTH    0.00   300.00
    CAS.MISSION.KILLS             AW-14 NO     BOTH    0.00   300.00
    BAI.MISSION.KILLS             AW-15 NO     BOTH    0.00   300.00
    INT.MISSION.KILLS             AW-16 NO     BOTH    0.00   300.00
    OCA.MISSION.KILLS             AW-17 NO     BOTH    0.00   300.00
    DSEAD.MISSION.KILLS           AW-18 NO     BOTH    0.00   300.00
    SUPPRESSION.MISSION.KILLS     AW-19 NO     BOTH    0.00   300.00
    OTBM.MISSION.KILLS            AW-20 NO     BOTH    0.00   300.00
    AIR.ESCORT.MISSION.KILLS      AW-21 YES    BOTH    0.00   300.00
    HIGH.VALUE.ASSET.ACTIVITY     AW-22 NO     BOTH    0.00   300.00
    DEFENDING.AIRCRAFT.KILLS      AW-23 YES    BOTH    0.00   300.00
  AIRCRAFT.MAINTENANCE                  ****
    TYPE.AIRCRAFT.MX.ACTIVITY     MX-1  NO     BOTH    0.00   300.00
    CONSUM.RESOURCE.ACTIVITY      MX-2  NO     BOTH    0.00   300.00
    NON.CONSUM.RES.ACTIVITY       MX-3  NO     BOTH    0.00   300.00
  GROUND.COMBAT.CYCLE.REPORTS           ****
    UNIT.STATUS                   CC-1  NO     BOTH    0.00   300.00
    C3.FACILITY.STATUS            CC-2  NO     BOTH    0.00   300.00
    CHOKE.POINT.STATUS            CC-3  NO     BOTH    0.00   300.00
    FLOT.MOVEMENT                 CC-4  NO     BOTH    0.00   300.00
    ZONE.SECTOR.AD.STATUS         CC-5  NO     BOTH    0.00   300.00
    TYPE.AD.SITE.STATUS           CC-6  NO     BOTH    0.00   300.00
    STRATEGIC.TARGET.STATUS       CC-7  NO     BOTH    0.00   300.00
    IADS.STATUS                   CC-8  NO     BOTH    0.00   300.00
  AIR.MISSION.PLANNING.REPORTS          ****
    APPORTIONMENT.ALLOCATION      MP-1  NO     BOTH    0.00   300.00
    AIR.TASKING.ORDERS            MP-2  NO     BOTH    0.00   300.00
    SORTIES.SCHEDULED.SUMMARY     MP-3  NO     BOTH    0.00   300.00
    TARGET.PRIORITIES             MP-4  NO     BOTH    0.00   300.00
    AIR.REFUELING.ALLOCATION      MP-5  NO     BOTH    0.00   300.00
  GROUND.SUPPLY.CYCLE.REPORTS           ****
    LOGISTIC.FACILITY.STATUS      SC-1  NO     BOTH    0.00   300.00
    SUPPLY.TRAIN.STATUS           SC-2  NO     BOTH    0.00   300.00
    CRITICAL.RESOURCE.STATUS      SC-3  NO     BOTH    0.00   300.00
END.OUTPUT.REPORT.CONTROLS

GAME.REPORT.SELECTION
  GC-1  NO BOTH "AIR COMMAND MISSION ALLOCATION REPORT"
  GC-2  NO BOTH "AIR COMMAND RESOURCE ALLOCATION REPORT"
  GC-3  NO BOTH "TARGET PRIORITY REPORT"
  GC-4  NO BOTH "GROUND COMMAND STRUCTURE WITH SUPPORTING AIR
COMMANDS"
  GC-5  NO BOTH "AIR COMMAND STRUCTURE WITH SUPPORTED GROUND
COMMANDS"
  GC-6  NO BOTH "AIR BASE ASSETS REPORT"
  GC-7  NO BOTH "LOGISTICS FACILITY ASSETS REPORT"
  GC-8  NO BOTH "AIRCRAFT CHARACTERISTICS REPORT"
  GC-9  NO BOTH "ZONE SECTOR PERCEPTION HISTORY"
  GC-10 NO BOTH "FLOT MOVEMENT REPORT"
  GC-11 NO BOTH "MISSION ALLOCATION PROJECTION"
  GC-12 NO BOTH "PROJECTED AIR TASKING ORDERS"
  GC-13 NO BOTH "PROJECTED SORTIES SCHEDULED"
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  GC-14 NO BOTH "AIRCRAFT PLANNING FACTORS"
  GC-15 NO BOTH "PREPLANNED ATO REPORT"
  GC-16 NO BOTH "ZONE SECTOR AIR DEFENSE SITE STATUS"
  GC-17 NO BOTH "AIR COMBAT RULES"
  GC-18 NO BOTH "AIR PLANNING RULES"
END.GAME.REPORT.SELECTION

TRANSACTION.CONTROLS
@DEBUG.TRANSACTIONS
  ADFL  0   0.000  300.00
  ADFH  0   0.000  300.00
  AIRA  0   0.000  300.00
  AIRF  0   0.000  300.00
  AIRG  0   0.000  300.00
  ANTC  0   0.000  300.00
  ANTI  0   0.000  300.00
  ANTP  0   0.000  300.00
  BSEL  0   0.000  300.00
  BSEM  0   0.000  300.00
  BSEO  0   0.000  300.00
  CONA  0   0.000  300.00
  GRDC  0   0.000  300.00
  GRDM  0   0.000  300.00
  GRDO  0   0.000  300.00
  ISRE  0   0.000  300.00
  ISRP  0   0.000  300.00
  ISRS  0   0.000  300.00
  ISRT  0   0.000  300.00
  LOGS  0   0.000  300.00
  LOGE  0   0.000  300.00
  NETM  0   0.000  300.00
  NETP  0   0.000  300.00
  PLAA  0   0.000  300.00
  PLAT  0   0.000  300.00
  RECT  0   0.000  300.00
  RULP  0   0.000  300.00
  STAA  0   0.000  300.00
  UTLA  0   0.000  300.00
  UTLG  0   0.000  300.00
  UTLF  0   0.000  300.00
  WTHH  0   0.000  300.00
@GRAPHIC.TRANSACTIONS
  GRAA  3   0.000  300.00
  GRAG  4   0.000  300.00
  GRAI  0   0.000  300.00
@ANALYSIS.TRANSACTIONS
  EQ.KILLS  0   0.000  300.000
  AA.KILLS  3   0.000  300.000
  SA.KILLS  3   0.000  300.000
  MUNT.EXP  3   0.000  300.000
  STR.TGT   0   0.000  300.000
  AA.ENC    0   0.000  300.000
@DATABASE.TRANSACTIONS
  DB.PLAN   0   0.000  300.000
  DB.EXEC   0   0.000  300.000
  DB.STATE  0   0.000  300.000
@RMS.TRANSACTIONS
```

```
  RMSPP       0    0.000   300.000
@MP.TRANSACTIONS
  MPPP        0    0.000   300.000
@AIR.LIFT.TRANSACTIONS
  ALFT        0    0.000   300.000
@ISR.TRANSACTIONS
  ISRPP       0    0.000   300.000
END.TRANSACTION.CONTROLS

RANDOM.NUMBER.STREAM.DATA
  READ.RANDOM.SEEDS                        YES
  WRITE.RANDOM.SEEDS                       YES
  SINGLE.SEED.ALL.NUMBERS                  NO
  SINGLE.SEED.IS(INT)                      1

  RN.STREAMS
  ADF100.1    1
  ADF100.2    1
  ADF105.1    1
  ADF120.1    1
  ADF120.2    1
  ADF120.3    1
  ADF140.1    1
  ADF150.1    1
  ADF150.2    1
  ADF150.3    1
  ADF150.4    1
  ADF150.5    1
  ADF160.1    1
  ADF161.1    1
  ADF161.2    1
  ADF161.3    1
  ADF161.4    1
  ADF161.5    1
  ADF200.1    1
  ADF300.1    1
  ADF300.2    1
  ADF500.1    1
  AIR007.1    1
  AIR017.1    1
  AIR041.1    1
  AIR041.2    1
  AIR050.1    1
  AIR050.2    1
  AIR060.1    1
  AIR060.2    1
  AIR070.1    1
  AIR070.2    1
  AIR021.1    1
  AIR101.1    1
  AIR101.2    1
  AIR110.1    1
  AIR120.1    1
  AIR150.1    1
  AIR150.2    1
  AIR241.1    1
  AIR526.1    1
```

AIR528.1	1
AIR540.1	1
AIR550.1	1
AIR561.1	1
AIR561.2	1
AIR564.1	1
AIR567.1	1
AIR567.2	1
AIR800.1	1
AIR800.2	1
AIR810.1	1
AIR810.2	1
AIR830.1	1
AIR830.2	1
AIR830.3	1
AIR830.4	1
AIR840.1	1
AIR840.2	1
AIR840.3	1
AIR911.1	1
AIR911.2	1
AIR920.1	1
BSE002.1	1
BSE003.1	1
BSE003.2	1
BSE050.1	1
BSE050.2	1
BSE200.1	1
BSE200.2	1
BSE200.3	1
BSE200.4	1
BSE200.5	1
BSE201.1	1
BSE201.2	1
BSE251.1	1
BSE260.1	1
BSE260.2	1
BSE270.1	1
BSE800.1	1
GRD100.1	1
GRD300.1	1
GRD302.1	1
GRD309.1	1
GRD871.1	1
GRD871.2	1
ISR000.1	1
ISR000.2	1
ISR000.3	1
ISR001.1	1
ISR115.1	1
ISR115.2	1
ISR250.1	1
ISR250.2	1
ISR251.1	1
ISR251.2	1
ISR251.3	1
ISR251.4	1

ISR360.1	1
ISR365.1	1
ISR400.1	1
ISR500.1	1
ISR500.2	1
ISR500.3	1
PLA443.1	1
REC011.1	1
REC011.2	1
REC011.3	1
REC012.1	1
REC012.2	1
REC012.3	1
REC012.4	1
REC012.5	1
REC012.6	1
REC013.1	1
REC013.2	1
REC013.3	1
REC013.4	1
REC013.5	1
REC013.6	1
REC014.1	1
REC014.2	1
REC014.3	1
REC014.4	1
REC014.5	1
REC014.6	1
REC014.7	1
REC014.8	1
REC014.9	1
REC015.1	1
REC015.2	1
REC015.3	1
REC015.4	1
REC015.5	1
REC015.6	1
REC015.7	1
REC015.8	1
REC016.1	1
REC016.2	1
REC016.3	1
REC016.4	1
REC016.5	1
REC016.6	1
REC016.7	1
REC016.8	1
REC016.9	1
REC016.10	1
REC016.11	1
REC017.1	1
REC017.2	1
REC017.3	1
REC017.4	1
REC017.5	1
REC017.6	1
REC017.7	1

```
    REC017.8   1
    REC017.9   1
    REC017.10  1
    REC018.1   1
    REC018.2   1
    REC018.3   1
    REC018.4   1
    REC310.1   1
    REC310.2   1
    REC320.1   1
    REC320.2   1
    REC320.3   1
    REC330.1   1
    REC330.2   1
    REC330.3   1
    REC330.4   1
    REC330.5   1
    REC330.6   1
    REC330.7   1
    REC330.8   1
    REC341.1   1
    REC341.2   1
    REC900.1   1
    UTL305.1   1
    UTL520.1   1
    UTL520.2   1
    UTL550.1   1
    UTL550.2   1
    UTL750.1   1
    UTL920.1   1
    END.RN.STREAMS
  END.RANDOM.NUMBER.STREAM.DATA

END.CONTROL
```

airairpk.dat - F-15C, F-15C w/Radar, F-XX Scenarios

```
AIR.AIR.PKS.202
  BLUE.PK.MULTIPLIER(DEC) 1.00      RED.PK.MULTIPLIER(DEC)    1.00
  KILLERS
    BLUE
@  KILL_ID    MUNT   ----AIRCRAFT---------------------
        10    102                   1014  1015  1215  1016  1018  END
        11    103   1004 1026 1010 1014  1015  1215  1016  1018  END
        12    104   1004 1026       1014                    1018  END

    RED
@  KILL_ID    MUNT --- AIRCRAFT-----------
        20    201   2001  2021  2023  2029  END
        21    202   2001  2021  2023  2029  END
        22    203   2001  2021        2029  END
        23    208   2001  2021  2023  2029  END
  END.KILLERS
 PKS
    BLUE
                   210  220  230
        10          3    4    5        Pk's of all Blue and Red aircraft
        11          3    4    7        in scenario provided by ASC/XR
        12          4    5    8        reduced to Pk's in bold for all
                                       scenarios
    RED
              100  110  120  130
        20     1    2    2    2        Same notation as above
        21     2    2    2    2
        22     2    2    2    2
        23     2    2    2    2
  END.PKS
  LOW.RES.AIR.TO.AIR.PKS
    BLUE
        210
           1.000  25
           END.SET
        220
           1.000  25
           END.SET
        230
           1.000  25
           END.SET
    RED
        100
           1.000  2
           END.SET
        110
           1.000  5
           END.SET
        120
           1.000  5
           END.SET
        130
```

```
          1.000  5
          END.SET
  END.LOW.RES.PKS
END.AIR.AIR.PKS
```

airairpk.dat – All w/AIM-X Scenarios

```
AIR.AIR.PKS.202
  BLUE.PK.MULTIPLIER(DEC) 1.00       RED.PK.MULTIPLIER(DEC)    1.00
  KILLERS
    BLUE
@  KILL_ID    MUNT   ----AIRCRAFT--------------------
        10    101                           1015                    END
New killer ID added for all w/AIM-X scenarios
        11    102                     1014        1215  1016  1018  END
        12    103   1004 1026 1010 1014    1015   1215  1016  1018  END
        13    104   1004 1026           1014                    1018  END

    RED
@  KILL_ID    MUNT --- AIRCRAFT-----------
        20    201   2001   2021   2023   2029   END
        21    202   2001   2021   2023   2029   END
        22    203   2001   2021          2029   END
        23    208   2001   2021   2023   2029   END
  END.KILLERS
 PKS
    BLUE
                   210  220  230
        10          6    7    8
New AIM-X Pks added for all AIM-X scenarios
        11          3    4     5
        12          3    4     7
        13          4    5     8

    RED
             100  110  120  130
        20     1    2    2   2
        21     2    2    2   2
        22     2    2    2   2
        23     2    2    2   2
  END.PKS
  LOW.RES.AIR.TO.AIR.PKS
    BLUE
        210
           1.000  25
           END.SET
        220
           1.000  25
           END.SET
        230
           1.000  25
           END.SET
    RED
        100
           1.000  2
           END.SET
        110
           1.000  5
           END.SET
        120
```

```
                1.000  5
                END.SET
             130
                1.000  5
                END.SET
      END.LOW.RES.PKS
    END.AIR.AIR.PKS
```

acserv.dat - F-XX, F-15C w/AIM-X, F-15C w/Radar and AIM-x, F-XX w/AIM-X

```
SERVICE.KITS.304

.
.
.

1015 "F-15C KIT"            Change "F-15C" to "F-XX" for F-XX scenarios
  SIDE..NUM.AC
    1      24
  MUNITIONS..ID..NUM
     1102    5000           Change "1102" to "1101" for AIM-X in all w/AIM-X scenarios
     1103    5000
     1104    5000
  REPAIR.RESOURCES..ID..NUM
        1      50
        2      25
        3      25
  INT.LEVEL.MAINTENANCE.FACS
  END.KIT

.
.
.

END.SERVICE.KITS
```

```
SQUADRONS.305
.
.
.

1015 "F-15C"          Change "F-15C" to "F-XX" for all F-XX scenarios
  DAY.IN.THEATER..AUTH.QTY.SORT/DAY..AC.MAX.SORT/DAY
       1.00                3.34                3.50
       6.00                2.75                3.34
  END.PROFILE
.
.
.
@ INCIRLIK
11601  "F-16_INCIRLIK"
  SIDE..SUP.CMD.ID..TYPE.AC.ID..AUTH.QTY..AR.PRIORITY...RECCE.PRIORITY
    1       1200          1016        37          1             0
  MOB.ID..DISP.AB.ID..SERV.KIT.ID..SORT.PROF.ID..MISSION.CLASS
    1003       1007          1016          1016         INCIRLIK.MULTI.ROLE

..DCA..ODCA..HVAA..BARC..FSWP..EAIR...STI...CAS...BAI...INT...OCA..OTBM
..DTBM
      0     70     70     70     70     70     50     70     70     70     90
90     0

.DSED..SSUP..CSUP..ESUP..SJAM..CJAM..EJAM..RECC..SREC...AEW...AAR..LIFT
..XXXX..RESV
     70      0      0      0      0      0      0      0      0      0      0
0      0   100
  ORDERS
  END.ORDERS

11501  "F-15C_INCIRLIK"   Change "F-15C" to "F-XX" for F-XX scenarios
  SIDE..SUP.CMD.ID..TYPE.AC.ID..AUTH.QTY..AR.PRIORITY...RECCE.PRIORITY
    1       1200          1015        28          1             0
  MOB.ID..DISP.AB.ID..SERV.KIT.ID..SORT.PROF.ID..MISSION.CLASS
    1003       1004          1015          1015
INCIRLIK.AIR.SUPERIORITY

..DCA..ODCA..HVAA..BARC..FSWP..EAIR...STI...CAS...BAI...INT...OCA..OTBM
..DTBM
     70     70     70      0      0     90      0      0      0      0      0
0      0

.DSED..SSUP..CSUP..ESUP..SJAM..CJAM..EJAM..RECC..SREC...AEW...AAR..LIFT
..XXXX..RESV
      0      0      0      0      0      0      0      0      0      0      0
0      0     70
  ORDERS
  END.ORDERS
.
.
.
```

```
@ TABUK
11502 "F-15C_TABUK"        Change "F-15C" to "F-XX" for all F-XX
  SIDE..SUP.CMD.ID..TYPE.AC.ID..AUTH.QTY..AR.PRIORITY...RECCE.PRIORITY
    1       1200          1015        24          1              0
  MOB.ID..DISP.AB.ID..SERV.KIT.ID..SORT.PROF.ID..MISSION.CLASS
    1004       1007          1015          1015        AIR.SUPERIORITY

..DCA..ODCA..HVAA..BARC..FSWP..EAIR...STI...CAS...BAI...INT...OCA..OTBM
..DTBM
     50     70     70     70     70     70      0      0      0      0      0
0      0

.DSED..SSUP..CSUP..ESUP..SJAM..CJAM..EJAM..RECC..SREC...AEW...AAR..LIFT
..XXXX..RESV
      0      0      0      0      0      0      0      0      0      0      0
0      0   100
  ORDERS
    2.0 ARRIVE
  END.ORDERS
.
.
.

@ AL-KHARJ
11503 "F-15C_AL-KHARJ"     Change "F-15C" to "F-XX" for all F-XX scenarios
  SIDE..SUP.CMD.ID..TYPE.AC.ID..AUTH.QTY..AR.PRIORITY...RECCE.PRIORITY
    1       1200          1015        24          1              0
  MOB.ID..DISP.AB.ID..SERV.KIT.ID..SORT.PROF.ID..MISSION.CLASS
    1007       1008          1015          1015        AIR.SUPERIORITY

..DCA..ODCA..HVAA..BARC..FSWP..EAIR...STI...CAS...BAI...INT...OCA..OTBM
..DTBM
     70     70     70     70     70     70      0      0      0      0      0
0      0

.DSED..SSUP..CSUP..ESUP..SJAM..CJAM..EJAM..RECC..SREC...AEW...AAR..LIFT
..XXXX..RESV
      0      0      0      0      0      0      0      0      0      0      0
0      0   100
  ORDERS
    3.0 ARRIVE
  END.ORDERS
.
.
.
@ DHAHRAN
11504 "F-15C_DHAHRAN1"     Change "F-15C" to "F-XX" for all F-XX scenarios
  SIDE..SUP.CMD.ID..TYPE.AC.ID..AUTH.QTY..AR.PRIORITY...RECCE.PRIORITY
    1       1200          1015        24          1              0
  MOB.ID..DISP.AB.ID..SERV.KIT.ID..SORT.PROF.ID..MISSION.CLASS
    1009       1011          1015          1015        AIR.SUPERIORITY

..DCA..ODCA..HVAA..BARC..FSWP..EAIR...STI...CAS...BAI...INT...OCA..OTBM
..DTBM
     70     70     70     70     70     70      0      0      0      0      0
0      0
```

```
.DSED..SSUP..CSUP..ESUP..SJAM..CJAM..EJAM..RECC..SREC...AEW...AAR..LIFT
..XXXX..RESV
       0      0      0      0      0      0      0      0      0      0      0
0      0   100
  ORDERS
    4.0 ARRIVE
  END.ORDERS
```

11505 "F-15C_DHAHRAN2" ***Change "F-15C" to "F-XX" for all F-XX scenarios***

```
  SIDE..SUP.CMD.ID..TYPE.AC.ID..AUTH.QTY..AR.PRIORITY...RECCE.PRIORITY
    1      1200         1015       24          1            0
  MOB.ID..DISP.AB.ID..SERV.KIT.ID..SORT.PROF.ID..MISSION.CLASS
    1009      1011         1015         1015        AIR.SUPERIORITY

..DCA..ODCA..HVAA..BARC..FSWP..EAIR...STI...CAS...BAI...INT...OCA..OTBM
..DTBM
      70     70     70     70     70     70      0      0      0      0      0
0      0

.DSED..SSUP..CSUP..ESUP..SJAM..CJAM..EJAM..RECC..SREC...AEW...AAR..LIFT
..XXXX..RESV
       0      0      0      0      0      0      0      0      0      0      0
0      0   100
  ORDERS
    5.0 ARRIVE
    5.0 MERGE 11504
  END.ORDERS
.
.
.

END.SQUADRONS
```

`typeac.dat` - All F-XX scenarios and all w/AIM-X scenarios

```
TYPE.AIR.CRAFT.302

NUMBER.OF.AIR.TO.AIR.CLASSES: 1
10000  DEFAULT
END.AIR.TO.AIR.CLASSES
@
@  -----------------------------------------------------------
@  DESERT STORM DATABASE
@  -----------------------------------------------------------
@  DATA IN THIS FILE FROM UNCLASSIFIED SOURCES
@  IN PARTICULAR, PERFORMANCE DATA, RCS ETC TAKEN DIRECTLY
@  FROM CACI DISTIBUTION TAPE FOR ME & DATASMALL SCENARIO
@  PARAMETERS ARE NOT NECESSARILY AUTHORITATIVE
@  -----------------------------------------------------------
@
NUMBER.OF.RADAR.SIGNATURE.OBJECTS:      12   Replace "12" with "13" for F-XX
scenarios
 1010 "A-10"
      .RADAR.CROSS.SECTION(SQ.MTRS).BY.RADAR.BAND..
       5.00
 1013 "F-XX"                                               New RCS object added
for F-XX
      .RADAR.CROSS.SECTION(SQ.MTRS).BY.RADAR.BAND..        scenarios only
       0.05
.
.
.

1015 "F-15C"            Replace "F-15C" with "F-XX" for F-XX scenarios

SIDE....FIT.IN.SHELTER....TGT.CLASS...TGT.INDEX...OCA.TGT.PRIORITY..GRA
PH
   1           1            "FIGHTER"         110          1
2
  AIR.TO.AIR.CLASS
    10000
  RPV.DATA(0.FOR.NON.RPV)
    RPV.TYPE(0,1,2)                 0
    TBM.AIR.MUNITION.TYPE.ID        0
    PROB.ENEMY.INT.LAUNCH(0-100)   25
  ONBOARD.EQUIPMENT
    RADAR.ID          1003   Replace "1003" with "1004" for F-XX and F-15C w/Radar
                             scenarios
    TARGET.LOC.ID        2001
  PERFORMANCE.DATA.....ALTITUDE(METERS)...SPEED(KNOTS)
      LOW.DASH                   200              540
      LOW.PENETRATE              200              540
      HIGH.DASH                 8000              540
      HIGH.PENETRATE            8000              540
      HIGH.CRUISE               8000              540
      CAP.ENEMY                 8000              540
      CAP.FRIENDLY              8000              540
    BASE.RADAR.SIGNATURE.OBJECT.ID    1015    Replace "1015" with "1013" for
all F-XX
```

```
    TAKEOFF.LENGTH(METERS)...MISSION    900  DISPERSAL    900
    LANDING.LENGTH(METERS)...MISSION    900  NIGHT    900
    DAMAGED.RWY.FACTOR(METERS)    250
  SORTIE.GENERATION.DATA
    FLYING.PERIODS...DAY  3  NIGHT  2
  MISSION.DATA
    MIN.FLT.SIZE 1  ORBIT.WIDTH(MTRS)   50000  ORBIT.DEPTH(MTRS)   40000
    MAX.TARGETS.PER.SORTIE    1
    FLY.DIRECT(1=YES,2=NO)    1
    DURATION.OF.ALERT.WITHOUT.LAUNCH(MINUTES)  180
    PRIORITIES.FOR.SUPPORT.BY...EAIR...EJAM...ESUP...CORRIDOR
                                    1      1      1       1
    MISSION.EFFECTIVENESS.DATA(0-100)

..DCA..ODCA..HVAA..BARC..FSWP..EAIR...STI...CAS...BAI...INT...OCA..OTBM
..DTBM
     50     75     75     80     75     75      0      0      0      0      0
0      0

.DSED..SSUP..CSUP..ESUP..SJAM..CJAM..EJAM..RECC..SREC...AEW...AAR..LIFT
..XXXX..RESV
      0      0      0      0      0      0      0      0      0      0      0
0      0    100
    MISSION.ALTITUDE.DATA(1=LOW,2=HIGH)

..DCA..ODCA..HVAA..BARC..FSWP..EAIR...STI...CAS...BAI...INT...OCA..OTBM
..DTBM
      2      2      2      2      2      2      2      2      2      2      2
2      2

.DSED..SSUP..CSUP..ESUP..SJAM..CJAM..EJAM..RECC..SREC...AEW...AAR..LIFT
..XXXX
      2      2      2      2      2      2      2      2      2      2      2
2      2

     FUEL.CONFIGURATIONS
      3006 "38660 LBS. FUEL CAPACITY"

CAPACITY(LBS)..REFUEL1(LBS)..REFUEL2(LBS)..DELTA.RADAR.SIG.OBJ
              38660          3000          3000                0

     FUEL.BURN.PROFILES(LBS/MINUTE)
      4006 "FUEL PROFILE 1"

L.DASH..L.PENETRT..H.DASH..H.PENETRT..H.CRUISE..CAP.ENEMY..CAP.FRIEND
             10          10          10          10          10          100
100

     AIR.TO.AIR.CONFIGURATIONS
      1 "4: AMRAAM + 4: AIM-9"
```

Replace "AMRAAM" with "AIM-X" for all w/AIM-X scenarios

```
FUEL.CONFIG..FUEL.BURN.PROF..DELTA.RADAR.SIG.OBJ..VULNERABILITY
              3006          4006                0                  2

LAUNCHES/AIR.ENG..PCT.C2.NO.AEW..PCT.C2.WITH.AEW..RECCE.SENSOR.ID
```

```
                2              70              95              101
      MISSION.EFFECTIVENESS
        ..DCA..ODCA..HVAA..BARC..FSWP..EAIR..DTBM
           75    75    75    75    75    75    0
      MUNITIONS..ID..NUMBER..CEP(METERS)..DELTA.RADAR.SIG.OBJ
                102     1        0                 0    Replace "102"
with
                103     1        0                 0    "101" for all
AIM-X
                102     1        0                 0    scenarios
                103     1        0                 0
                102     1        0                 0
                103     1        0                 0
                102     1        0                 0
                103     1        0                 0
      JAMMERS....ID..NUMBER
      END.CONFIG

   AIR.TO.GROUND.CONFIGURATIONS

   SPECIAL.CONFIGURATIONS

  END.CONFIGURATIONS
END.AIRCRAFT
.
.
.

END.TYPE.AIRCRAFT
```

typerdr.dat – F-15C w/Radar and all F-XX Scenarios

```
TYPE.RADAR.101

NUMBER.OF.RADAR.BANDS: 1
   ID....NAME
  10001  "RADAR BAND 1"
END.RADAR.BANDS

NUMBER.OF.RADAR.DETECTION.OBJECTS:  11
```

Additional radar object added for F-15C w/Radar and all F-XX scenarios

```
   1001 "BLUE AD FC RADAR"
    SIDE                             1
    BAND                         10001
    SWEEP.ANGLE(DEG)                60
    1.SQ.MTR.RANGE(M)            95000
    1.SQ.MTR.ALTITUDE(M)         25000
    MAX.RANGE(M)                 50000

   1002 "BLUE AD ACQ RADAR"
    SIDE                             1
    BAND                         10001
    SWEEP.ANGLE(DEG)               360
    1.SQ.MTR.RANGE(M)           146000
    1.SQ.MTR.ALTITUDE(M)         25000
    MAX.RANGE(M)                100000

   1003 "BLUE AC RADAR"
    SIDE                             1
    BAND                         10001
    SWEEP.ANGLE(DEG)                90
    1.SQ.MTR.RANGE(M)           120000
    1.SQ.MTR.ALTITUDE(M)        120000
    MAX.RANGE(M)                250000

   1005 "BLUE AC RADAR - DUAL"
    SIDE                             1
    BAND                         10001
    SWEEP.ANGLE(DEG)               120
    1.SQ.MTR.RANGE(M)           240000
    1.SQ.MTR.ALTITUDE(M)        120000
    MAX.RANGE(M)                500000
```

New radar added for F-15C w/Radar and all F-XX scenarios

```
.
.
.
END.GROUND.TYPE.RADARS

NUMBER.OF.AIR.TYPE.RADARS:    3
```

Number of type radars changed from "2" to "3" for F-15C w/Radar and all F-XX scenarios

```
   1003 "BLUE AC RADAR"
    SIDE                             1
    DETECT.OBJ.ID                 1003
```

```
   1005 "BLUE AC RADAR - DUAL"            New radar added for F-15C w/Radar and all
    SIDE                           1      F-XX scenarios
    DETECT.OBJ.ID               1005

   2003 "RED AC RADAR"
    SIDE                           2
    DETECT.OBJ.ID               2003
END.AIR.TYPE.RADARS

END.TYPE.RADARS
```

typejam.dat – F-15C w/Radar and all F-XX Scenarios

```
TYPE.JAMMERS.102

.
.
.
```

Radar 1005 added for F-15C w/Radar and all F-XX scenarios

```
    1005
      RED.JAMMER.IDS....CURVES..(x=RANGE.TO.JAMMER....y=1m.BURNTHRU)
       2001   1 1200   79 11891   283 22582   617 33273   1084 43964   1696
54655
            2484 65345   3507 76036   4900 86727   7010 97418   11115
108109
            39499 118800     END.CURVE
       2002   1 1200   103 11891   372 22582   810 33273   1422 43964   2227
54655
            3260 65345   4603 76036   6432 86727   9201 97418   14589
108109
            51843 118800     END.CURVE
      END.RED.JAMMER.DATA
      .
      .
      .
      END.RED.JAMMER.DATA
```

```
    1005
      RED.JAMMER.IDS....(1m.BURNTHRU)
       2001                119840
       2002                119725
      END.RED.JAMMER.DATA
```

Radar 1005 added for F-15C w/Radar and F-XX scenarios

```
      .
      .
      .
   END.BLUE.RADAR.DETECTION.OBJ.DATA

END.TYPE.JAMMERS
```

detect.dat – F-15C w/Radar and all F-XX Scenarios

```
DETECT.PROBS.205
  MULT.FACTORS...BLUE...RED
    NO.AEW       1.00  1.00
    BLUE.AEW     1.00  1.00
    RED.AEW      1.00  1.00
    BOTH.AEW     1.00  1.00

BLUE.KILLER.AC
               2001               2006          2021               2023
               2025               2029

END.RED.TGT.AC...PROB.DETECT.IF..NO.AEW..BLUE.AEW..RED.AEW..BOTH.AEW
   1010      20   25   15   20    20   25   15   20    20   25   15   20    20   25
15  20
             20   25   15   20    20   25   15   20
   1099       0    0    0    0     0    0    0    0     0    0    0    0     0    0
0   0
              0    0    0    0     0    0    0    0
   1016      60   75   45   60    60   75   45   60    60   75   45   60    60   75
45  60
             60   75   45   60    40   50   30   40
   1004      40   50   30   40    40   50   30   40    40   50   30   40    40   50
30  40
             40   50   30   40    40   50   30   40
   1011      40   50   30   40    40   50   30   40    40   50   30   40    40   50
30  40
             40   50   30   40    40   50   30   40
   1211       0    0    0    0     0    0    0    0     0    0    0    0     0    0
0   0
              0    0    0    0     0    0    0    0
   1015      95   99   76   95    95   99   76   95    95   99   76   95    95   99
76  95
             95   99   76   95    70   93   58   70    Detection probabilities changed to
values                                                        in bold for F-15C
w/Radar and all F-XX
      scenarios
   1215      75   94   56   75    75   94   56   75    75   94   56   75    75   94
56  75
             75   94   56   75    50   63   38   50
   1017       0    0    0    0     0    0    0    0     0    0    0    0     0    0
0   0
              0    0    0    0     0    0    0    0
   1052       0    0    0    0     0    0    0    0     0    0    0    0     0    0
0   0
              0    0    0    0     0    0    0    0
   1008      20   25   15   20    20   25   15   20    20   25   15   20    20   25
15  20
             20   25   15   20    20   25   15   20
   1018      75   94   56   75    75   94   56   75    75   94   56   75    75   94
56  75
             75   94   56   75    50   63   38   50
   1006       0    0    0    0     0    0    0    0     0    0    0    0     0    0
0   0
```

```
          0   0   0   0     0   0   0   0
  1026    0   0   0   0     0   0   0   0     0   0   0   0     0   0
0   0
          0   0   0   0     0   0   0   0
  1007    0   0   0   0     0   0   0   0     0   0   0   0     0   0
0   0
          0   0   0   0     0   0   0   0
  1014   75  94  56  75    75  94  56  75    75  94  56  75    75  94
56  75
         75  94  56  75    50  63  38  50
  1003    0   0   0   0     0   0   0   0     0   0   0   0     0   0
0   0
          0   0   0   0     0   0   0   0
  1098    0   0   0   0     0   0   0   0     0   0   0   0     0   0
0   0
          0   0   0   0     0   0   0   0

RED.KILLER.AC
                        1010        1099        1016
1004
                        1011        1211        1015
1215
                        1017        1052        1008
1018
                        1006        1026        1007
1014
                        1003        1098

END.BLUE.TGT.AC...PROB.DETECT.IF..NO.AEW..BLUE.AEW..RED.AEW..BOTH.AEW
   2001                 60 75 45 60   12 12 12 12   60 75 45 60   60
75 45 60
                        60 75 45 60   60 75 45 60   14 14 14 14   60
75 45 60
```

Detection probabilities changed to values in bold for all F-XX scenarios

```
                        14 14 14 14   60 75 45 60   60 75 45 60   60
75 45 60
                        60 75 45 60   60 75 45 60   60 75 45 60   60
75 45 60
                        60 75 45 60   60 75 45 60
   2006                  0  0  0  0    0  0  0  0    0  0  0  0    0
0  0  0
                         0  0  0  0    0  0  0  0    0  0  0  0    0
0  0  0
                         0  0  0  0    0  0  0  0    0  0  0  0    0
0  0  0
                         0  0  0  0    0  0  0  0    0  0  0  0    0
0  0  0
                         0  0  0  0    0  0  0  0
   2021                 60 75 45 60   12 12 12 12   60 75 45 60   60
75 45 60
                        60 75 45 60   60 75 45 60   14 14 14 14   60
75 45 60
```

Detection probabilities changed to values in bold for all F-XX scenarios

```
                        14 14 14 14   60 75 45 60   60 75 45 60   60
75 45 60
```

```
                         60 75 45 60   60 75 45 60   60 75 45 60    60
75 45 60
                         60 75 45 60   60 75 45 60
  2023                   60 75 45 60   12 12 12 12   60 75 45 60    60
75 45 60
                         60 75 45 60   60 75 45 60   14 14 14 14    60
75 45 60                   Detection probabilities changed to values in bold for all F-
XX scenarios
                         14 14 14 14   60 75 45 60   60 75 45 60    60
75 45 60
                         60 75 45 60   60 75 45 60   60 75 45 60    60
75 45 60
                         60 75 45 60   60 75 45 60
  2025                    0  0  0  0    0  0  0  0    0  0  0  0     0
0  0  0
                          0  0  0  0    0  0  0  0    0  0  0  0     0
0  0  0
                          0  0  0  0    0  0  0  0    0  0  0  0     0
0  0  0
                          0  0  0  0    0  0  0  0    0  0  0  0     0
0  0  0
                          0  0  0  0    0  0  0  0
  2029                   60 75 45 60   12 12 12 12   60 75 45 60    60
75 45 60
                         60 75 45 60   60 75 45 60   14 14 14 14    60
75 45 60                   Detection probabilities changed to values in bold for all F-
XX scenarios
                         14 14 14 14   60 75 45 60   60 75 45 60    60
75 45 60
                         60 75 45 60   60 75 45 60   60 75 45 60    60
75 45 60
                         60 75 45 60   60 75 45 60
END.DETECT.PROBS
```

critres.dat - All w/AIM-X Scenarios

```
CRITICAL.RESOURCES.380

  NUMBER.OF.CRITICAL.RESOURCES   39

1101      AIM-7        ID 1101 changed from "AIM-7" to "AIM-X" for all AIM-X
                       scenarios
    TYPE...(1=AIR.MUNT,2=SA.MUNT,3=EQUIP)                          1
    URGENCY.CURVE                                                  1
    LOW.RES.INITIAL.STOCK                                          0
    LOW.RES.RESUPPLY...START.TIME(DEC.DAYS)...NUMBER/DAY
    HI.RES.INITIAL.STOCKS............LOG.FAC.ID...NUMBER
                                         1006        250
    HI.RES.RESUPPLY...TIME(DAYS)...NUMBER...TARGET.TYPE...ID.LIST
    END.RESOURCE
       .
       .
       .

END.CRITICAL.RESOURCES
```

relrngadvn.dat – All w/AIM-X Scenarios

```
RRA.204
  BLUE
         20  21  22  23
      10  1   1   1   1   New weapon ID and range advantages added for all w/AIM-X
scenarios
      11  1   1   1   1
      12  0   0   0   1
      13  0   0   0   0
  RED
          10  11  12  13  New weapon ID and range advantages (in bold) added for all w/AIM-
X
      20  0   0   0   1   scenarios
      21  0   0   0   1
      22  0   0   1   1
      23  0   0   0   0
END.RRA
```

airmunit.dat – All w/AIM-X Scenarios

```
TYPE.AIR.MUNITIONS.301

NUMBER.OF.AIR.MUNITION.TYPES  25
...ID..NAME..........................SIDE.FUNC.EXPN.WEIGHT.OVERFLY
  1101 "AIM-7"                        1    AA    2    500     1
      ID 1101 changed from "AIM-7" to "AIM-X" for all w/AIM-X scenarios
  1102 "AMRAAM"                       1    AA    2    400     1
  1103 "AIM-9"                        1    AA    2    200     1
  1104 "20MM CANNON"                  1    AA    2     50     1
  1105 "MK-82"                        1    AG    2    500     1
  1106 "AGM-65"                       1    AG    2    500     1
  1107 "AGM-88"                       1  HARM   2    500     1
  1108 "SPW-45"                       1   SPW   2    500     1
  1109 "B-DELAY MINE"                 1  MINE   2    500     1
  1110 "B-LETHAL MINE"                1  MINE   2    500     1
  1111 "CBU-87 CEM"                   1    AG    2    200     2
  1112 "CBU-97 SFW"                   1    AG    2    200     2
  1113 "LGB GBU"                      1    AG    2    500     1
  1114 "GPS ALL WX GBU"               1    AG    2    500     1

  2201 "AA-7"                         2    AA    2    500     1
  2202 "AA-8"                         2    AA    2    500     1
  2203 "AA-10"                        2    AA    2    500     1
  2204 "FAB-250"                      2    AG    2    500     1
  2205 "AS-10"                        2    AG    2    500     1
  2206 "HARM-RED"                     2  HARM   2    500     1
  2207 "SPW-RED"                      2   SPW   2    500     1
  2208 "GSH-23"                       2    AA    2    500     1
  2209 "R-DELAY MINE"                 2  MINE   2    500     1
  2210 "R-LETHAL MINE"                2  MINE   2    500     1
  2211 "RBK-500 AT"                   2    AG    2    500     1

END.AIR.MUNITION.TYPES
```

NUMBER.OF.AIR.MUNITION.STICK.TYPES 25
...ID..NAME.............................TYPE.NUM.MULT.RAD..NUM.STDOFF.
PCT
....................................ID..WPN.KILL.EFF.SUBM..RANGE.
.FC

ID	NAME	TYPE ID	NUM WPN	MULT KILL	RAD EFF	NUM SUBM	STDOFF RANGE	PCT FC
101	"AIM-7"	1101	1	2	0	0	0	0

ID 101 changed from "AIM-7" to "AIM-X" for all w/AIM-X scenarios

ID	NAME	TYPE ID	NUM WPN	MULT KILL	RAD EFF	NUM SUBM	STDOFF RANGE	PCT FC
102	"AMRAAM"	1102	1	2	0	0	0	0
103	"AIM-9"	1103	1	2	0	0	0	0
104	"20MM CANNON"	1104	1	2	0	0	0	0
105	"6 MK-82"	1105	6	1	1	0	1000	0
106	"AGM-65"	1106	1	2	1	0	5000	0
107	"AGM-88"	1107	1	2	1	0	10000	50
108	"SPW-45"	1108	1	2	1	0	10000	50
109	"B-DELAY MINE"	1109	4	2	1	200	1000	0
110	"B-LETHAL MINE"	1110	4	2	1	200	1000	0
111	"4 CBU-87"	1111	4	1	1	0	1000	0
112	"6 CBU-97"	1112	6	1	1	0	1000	0
113	"LGB GBU"	1113	1	2	1	0	10000	0
114	"GPS GBU"	1114	1	2	1	0	10000	0
201	"AA-7"	2201	1	2	0	0	0	0
202	"AA-8"	2202	1	2	0	0	0	0
203	"AA-10"	2203	1	2	0	0	0	0
204	"6 FAB-250"	2204	6	1	1	0	1000	0
205	"AS-10"	2205	1	2	1	0	10000	0
206	"HARM-RED"	2206	1	2	1	0	10000	50
207	"SPW-RED"	2207	1	2	1	0	10000	50
208	"GSH-23"	2208	1	2	1	0	1000	0
209	"R-DELAY MINE"	2209	4	2	1	200	1000	0
210	"R-LETHAL MINE"	2210	4	2	1	200	1000	0

```
   211 "6 RBK-500"                        2211    6    1    1    0    1000
0

END.AIR.MUNITION.STICK.TYPES

END.TYPE.AIR.MUNITIONS
```

Appendix E, Estimated Half Length for 90% Interval

The table below lists the estimated 90% h.l. for each of the output responses for 31 replications of the simulation based on the variance of the first four replications of each

MOEs	Aircraft/ Weapons	F-15C	F-15C w/Radar	F-15C w/RCS & Radar
RedLoss	Standard Load	4	4	4
RedSort30		0.0068	0.0023	0.0011
BLossSort		0.0002	0.0001	0.0001
AirSup		1.1	0.4	0.5
BlueSA		2	3	6
BlueGrnd		5	4	1
RedOpen		5	2	4
RedTEL		192	69	176
RedACQ		3	7	3
RedFC		157	64	133
RedLoss	New Missile	7	4	3
RedSort30		0.0040	0.0041	0.0002
BLossSort		0.0002	0.0002	0.0002
AirSup		0.7	0.5	0.2
BlueSA		9	8	6
BlueGrnd		3	5	2
RedOpen		5	5	4
RedTEL		73	178	194
RedACQ		2	2	8
RedFC		96	176	158

alternative solution.

Alternative	Run	Red A-A Losses	Red Percent Sortie	Blue Loss /Sortie	Air Supremacy (.10)	Blue S-A Losses	Total Blue Destroyed on Ground	Total Red Destroyed in the Open	Total Red TELs Killed	Total Red Acquistion Radars Killed	Total Red FC Radars Killed
F-15C	1	214	0.0263	0.0026	22	0.004932	97	250	6030	20	4811
F-15C	2	200	0.0429	0.0025	25	0.00497	73	243	6489	13	5214
F-15C	3	206	0.0305	0.0027	23	0.005162	110	242	6743	0	5424
F-15C	4	182	0.0756	0.0033	30	0.005396	99	214	5311	15	4254
F-15C	5	209	0.0381	0.0031	23	0.004487	101	242	6800	30	5470
F-15C	6	206	0.0448	0.0032	24	0.005169	103	261	5385	31	4286
F-15C	7	214	0.0246	0.0029	23	0.005244	93	250	6369	49	5059
F-15C	8	230	0.0391	0.0027	25	0.004608	126	221	6794	33	5519
F-15C	9	227	0.0561	0.0024	25	0.004757	105	213	5894	12	4882
F-15C	10	199	0.0426	0.0026	25	0.005291	90	250	5822	34	4730
F-15C	11	181	0.0426	0.0026	23	0.005745	116	259	5650	382	4572
F-15C	12	221	0.0391	0.0026	24	0.004601	88	232	7348	35	6114
F-15C	13	204	0.0499	0.0026	25	0.004898	97	243	6059	28	4800
F-15C	14	227	0.0333	0.0026	25	0.004913	95	241	6264	11	4962
F-15C	15	203	0.0318	0.0027	24	0.005417	97	233	6405	14	5179
F-15C	16	198	0.0346	0.003	24	0.004594	98	248	6331	6	5177
F-15C	17	201	0.0541	0.0028	24	0.005273	83	231	5950	74	4839
F-15C	18	198	0.0547	0.003	26	0.005585	90	233	5102	138	4102
F-15C	19	170	0.0508	0.0027	24	0.004901	97	244	7222	69	5996
F-15C	20	235	0.0282	0.0026	23	0.00461	83	234	6424	24	5197
F-15C	21	205	0.0185	0.0026	22	0.004843	92	250	6377	18	5295
F-15C	22	186	0.0377	0.0028	23	0.004353	98	268	6389	21	5137
F-15C	23	219	0.0515	0.0032	26	0.005231	101	208	5901	24	4911
F-15C	24	187	0.0397	0.0026	23	0.005018	125	269	6425	23	5326
F-15C	25	186	0.0412	0.0028	24	0.004724	102	262	5801	9	4788
F-15C	26	195	0.0377	0.0026	26	0.005037	121	244	6340	27	5196
F-15C	27	205	0.0206	0.0028	23	0.005009	86	248	6449	36	5169
F-15C	28	204	0.049	0.0029	23	0.005304	92	247	5894	47	4646
F-15C	29	213	0.0386	0.0028	22	0.00535	85	228	5691	7	4486
F-15C	30	195	0.0407	0.0028	25	0.004928	104	242	5936	12	4884

Alternative	Run	Red A-A Losses	Red Percent Sortie	Blue Loss /Sortie	Air Supremacy (.10)	Blue S-A Losses	Total Blue Destroyed on Ground	Total Red Destroyed in the Open	Total Red TELs Killed	Total Red Acquistion Radars Killed	Total Red FC Radars Killed
F-15C	31	188	0.0371	0.0026	25	0.005109	107	245	6095	117	4876
F-15C Msl	1	254	0.0211	0.0023	19	0.0045	92	217	6887	11	5690
F-15C Msl	2	239	0.0387	0.002	23	0.004856	92	215	6698	23	5454
F-15C Msl	3	279	0.0241	0.0025	22	0.004818	103	184	6749	26	5614
F-15C Msl	4	222	0.0489	0.0023	24	0.005839	112	215	6330	10	4991
F-15C Msl	5	210	0.0349	0.0024	23	0.004078	83	258	7215	8	6016
F-15C Msl	6	200	0.0283	0.0025	22	0.004842	86	243	7262	15	5998
F-15C Msl	7	204	0.0315	0.0027	23	0.00527	105	226	5658	24	4533
F-15C Msl	8	256	0.0221	0.0025	22	0.004562	72	215	6783	35	5720
F-15C Msl	9	208	0.0346	0.0024	23	0.004415	101	238	6686	22	5566
F-15C Msl	10	214	0.0722	0.0031	28	0.00557	117	201	5720	21	4721
F-15C Msl	11	226	0.0231	0.0027	23	0.004699	94	215	6467	16	5392
F-15C Msl	12	203	0.0452	0.0028	23	0.005085	104	264	6587	20	5326
F-15C Msl	13	201	0.0556	0.0023	25	0.005257	78	247	6331	27	5185
F-15C Msl	14	209	0.0201	0.0027	21	0.004506	84	262	6452	6	5143
F-15C Msl	15	271	0.0381	0.0029	24	0.004583	106	183	6464	24	5314
F-15C Msl	16	229	0.0292	0.0025	22	0.004362	93	239	7154	26	5859
F-15C Msl	17	260	0.0382	0.0028	25	0.004683	82	207	6257	23	5015
F-15C Msl	18	213	0.039	0.0028	24	0.004599	98	246	6757	7	5604
F-15C Msl	19	213	0.0218	0.0023	23	0.004969	66	242	7049	9	5740
F-15C Msl	20	272	0.0209	0.0026	22	0.004846	82	198	5554	22	4537
F-15C Msl	21	217	0.0394	0.0025	24	0.005323	99	227	7043	32	5778
F-15C Msl	22	232	0.025	0.0021	23	0.004756	66	228	6624	33	5327
F-15C Msl	23	198	0.0324	0.0025	22	0.005182	89	254	6731	19	5647
F-15C Msl	24	236	0.0119	0.0024	21	0.00466	73	243	6316	89	5216
F-15C Msl	25	212	0.0348	0.003	26	0.005813	86	230	5360	122	4396
F-15C Msl	26	214	0.0329	0.0024	23	0.00509	93	230	6811	3	5878
F-15C Msl	27	269	0.0145	0.0021	21	0.004674	76	237	5669	11	4565
F-15C Msl	28	250	0.019	0.0023	21	0.004805	71	243	7077	193	5942
F-15C Msl	29	206	0.0359	0.0026	23	0.005118	86	249	6364	15	5186
F-15C Msl	30	207	0.0451	0.0026	23	0.005103	115	252	5935	7	4783
F-15C Msl	31	206	0.0263	0.0024	23	0.005236	92	239	7043	21	5762
F-15C Rdr	1	215	0.0247	0.0027	22	0.004552	73	251	6644	4	5337
F-15C Rdr	2	206	0.0352	0.0029	24	0.00467	72	252	6383	14	5439
F-15C Rdr	3	237	0.0163	0.0023	22	0.004881	97	246	6462	54	5249
F-15C Rdr	4	223	0.0237	0.0027	24	0.004966	76	241	6889	1	5731

Alternative	Run	Red A-A Losses	Red Percent Sortie	Blue Loss /Sortie	Air Supremacy (.10)	Blue S-A Losses	Total Blue Destroyed on Ground	Total Red Destroyed in the Open	Total Red TELs Killed	Total Red Acquistion Radars Killed	Total Red FC Radars Killed
F-15C Rdr	5	202	0.0283	0.0027	24	0.004932	77	255	5974	10	5059
F-15C Rdr	6	223	0.0356	0.0027	22	0.005359	100	236	5937	45	4709
F-15C Rdr	7	228	0.0199	0.0023	23	0.004841	91	244	6624	26	5721
F-15C Rdr	8	236	0.0191	0.0026	22	0.005595	118	229	5701	15	4492
F-15C Rdr	9	193	0.0555	0.0029	27	0.004603	105	236	6923	42	5717
F-15C Rdr	10	246	0.0217	0.0023	21	0.004588	101	230	6247	31	5059
F-15C Rdr	11	212	0.053	0.0025	24	0.005118	66	215	5369	41	4462
F-15C Rdr	12	192	0.0459	0.0029	24	0.004853	132	248	5800	18	4716
F-15C Rdr	13	250	0.028	0.0027	23	0.004964	91	220	5866	20	4739
F-15C Rdr	14	195	0.0504	0.0031	22	0.005365	95	251	5758	186	4608
F-15C Rdr	15	194	0.033	0.0028	23	0.004678	96	245	5990	65	4839
F-15C Rdr	16	205	0.0264	0.0025	22	0.004718	76	256	6784	87	5591
F-15C Rdr	17	215	0.0431	0.0026	23	0.004719	102	250	6121	56	4886
F-15C Rdr	18	209	0.0241	0.0029	25	0.005011	97	241	6512	6	5367
F-15C Rdr	19	225	0.0215	0.0023	24	0.00409	73	252	6552	16	5408
F-15C Rdr	20	210	0.0366	0.0029	23	0.005114	87	242	6064	49	5066
F-15C Rdr	21	198	0.0292	0.0025	23	0.004946	91	241	6857	66	5525
F-15C Rdr	22	191	0.0448	0.0024	24	0.004958	73	230	5740	166	4672
F-15C Rdr	23	180	0.0508	0.0028	23	0.005175	90	249	6121	19	4965
F-15C Rdr	24	220	0.0306	0.0027	23	0.004495	74	241	6528	16	5344
F-15C Rdr	25	211	0.0563	0.003	26	0.005377	108	237	6870	18	5581
F-15C Rdr	26	250	0.0362	0.0028	20	0.00566	126	204	6497	11	5117
F-15C Rdr	27	231	0.0148	0.0021	19	0.003986	65	243	6728	16	5559
F-15C Rdr	28	211	0.0153	0.0023	20	0.004086	103	269	6201	38	4878
F-15C Rdr	29	239	0.0282	0.0027	21	0.00422	103	197	6883	6	5723
F-15C Rdr	30	191	0.0204	0.0022	23	0.004992	70	274	6280	50	5057
F-15C Rdr	31	198	0.0108	0.0025	23	0.0048	90	287	6267	30	5128
F-15C Rdr/Msl	1	241	0.0236	0.0024	20	0.004549	72	228	6929	6	5723
F-15C Rdr/Msl	2	272	0.0118	0.0021	20	0.00456	108	212	6261	20	5087
F-15C Rdr/Msl	3	265	0.0379	0.0027	23	0.005521	97	198	6083	15	4988
F-15C Rdr/Msl	4	263	0.0409	0.0026	23	0.005341	105	195	5513	17	4313
F-15C Rdr/Msl	5	210	0.0529	0.0027	23	0.005107	66	232	6508	158	5299
F-15C Rdr/Msl	6	251	0.0103	0.0024	19	0.004282	66	230	6692	30	5575
F-15C Rdr/Msl	7	248	0.0253	0.0021	20	0.005132	70	226	7108	6	5862
F-15C Rdr/Msl	8	228	0.03	0.0023	23	0.004511	73	207	7089	0	5767
F-15C Rdr/Msl	9	254	0.0287	0.0026	21	0.004935	109	215	5938	59	4900

Alternative	Run	Red A-A Losses	Red Percent Sortie	Blue Loss /Sortie	Air Supremacy (.10)	Blue S-A Losses	Total Blue Destroyed on Ground	Total Red Destroyed in the Open	Total Red TELs Killed	Total Red Acquistion Radars Killed	Total Red FC Radars Killed
F-15C Rdr/Msl	10	282	0.0107	0.0025	19	0.004359	82	211	6109	20	4916
F-15C Rdr/Msl	11	280	0.0202	0.0028	22	0.004384	88	212	7098	18	5956
F-15C Rdr/Msl	12	215	0.0484	0.0024	25	0.005342	79	213	6221	15	5092
F-15C Rdr/Msl	13	255	0.0276	0.0027	22	0.004615	104	220	6143	13	5005
F-15C Rdr/Msl	14	279	0.0187	0.0025	22	0.00482	112	216	6060	57	4913
F-15C Rdr/Msl	15	235	0.0215	0.0027	24	0.005474	79	220	5145	17	4185
F-15C Rdr/Msl	16	277	0.0108	0.0025	20	0.004792	91	205	6126	37	4983
F-15C Rdr/Msl	17	234	0.025	0.0028	24	0.004897	99	232	6511	7	5293
F-15C Rdr/Msl	18	243	0.0344	0.0025	21	0.004489	90	229	6129	9	4886
F-15C Rdr/Msl	19	253	0.0301	0.0029	23	0.005478	88	201	5546	36	4414
F-15C Rdr/Msl	20	270	0.0107	0.0024	21	0.004646	79	213	6825	20	5458
F-15C Rdr/Msl	21	296	0.0178	0.0019	19	0.004347	77	205	6641	100	5488
F-15C Rdr/Msl	22	259	0.0269	0.0023	22	0.00493	108	208	6083	23	5009
F-15C Rdr/Msl	23	277	0.0163	0.0019	19	0.004723	72	226	6167	42	5031
F-15C Rdr/Msl	24	203	0.0238	0.0026	23	0.005523	87	243	6269	11	5117
F-15C Rdr/Msl	25	213	0.0238	0.0026	21	0.005263	87	250	6586	31	5367
F-15C Rdr/Msl	26	253	0.0207	0.0024	21	0.005383	78	202	6548	58	5340
F-15C Rdr/Msl	27	263	0.0197	0.0025	23	0.004745	113	218	6645	17	5475
F-15C Rdr/Msl	28	257	0.0266	0.0027	23	0.005645	96	195	6457	104	5261
F-15C Rdr/Msl	29	269	0.0223	0.0021	22	0.00547	59	215	6560	20	5429
F-15C Rdr/Msl	30	259	0.0311	0.0025	21	0.004641	87	214	7073	24	5888
F-15C Rdr/Msl	31	241	0.033	0.0029	23	0.005457	84	207	5289	31	4304
F-XX	1	344	0.0149	0.0019	20	0.004167	81	169	6399	23	5322
F-XX	2	326	0.0061	0.0016	19	0.004881	71	171	5136	27	4407
F-XX	3	335	0.0128	0.0021	22	0.004483	73	146	6293	44	5334
F-XX	4	316	0.0097	0.0016	18	0.004521	73	177	6078	26	5086
F-XX	5	319	0.0107	0.0015	20	0.005121	95	187	5714	238	4915
F-XX	6	335	0.0066	0.002	20	0.004942	87	164	6908	42	5761
F-XX	7	306	0.0103	0.0018	19	0.005018	99	185	6317	36	5270
F-XX	8	297	0.0052	0.0015	19	0.004218	64	204	6866	11	5549
F-XX	9	355	0.0092	0.0015	19	0.004283	90	159	7243	25	6269
F-XX	10	315	0.0127	0.0017	20	0.004763	103	178	5923	363	5105
F-XX	11	310	0.0077	0.0012	18	0.004922	71	182	6033	29	5062
F-XX	12	303	0.0209	0.0017	20	0.004694	88	186	5699	93	4940
F-XX	13	303	0.0067	0.0013	19	0.004286	97	201	7231	23	6151
F-XX	14	297	0.0067	0.0014	18	0.003932	64	194	6717	16	5767

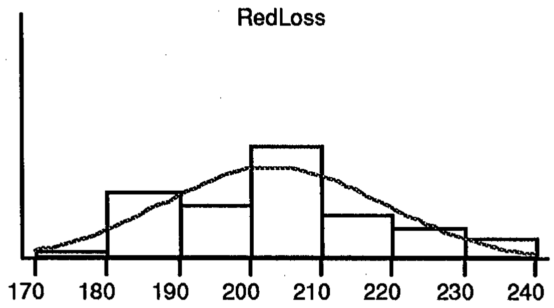
Alternative	Run	Red A-A Losses	Red Percent Sortie	Blue Loss /Sortie	Air Supremacy (.10)	Blue S-A Losses	Total Blue Destroyed on Ground	Total Red Destroyed in the Open	Total Red TELs Killed	Total Red Acquistion Radars Killed	Total Red FC Radars Killed
F-XX	15	324	0.0094	0.0013	20	0.004411	89	177	6047	124	5213
F-XX	16	315	0.0041	0.0017	18	0.003973	74	179	6319	30	5298
F-XX	17	312	0.0091	0.0015	19	0.004549	88	189	6310	17	5275
F-XX	18	338	0.0098	0.002	18	0.004713	94	166	5641	17	4782
F-XX	19	298	0.0056	0.0018	17	0.005339	65	199	5773	8	4672
F-XX	20	291	0.0061	0.0015	19	0.004755	70	206	5789	45	4985
F-XX	21	294	0.0167	0.0021	20	0.005146	108	200	5235	46	4298
F-XX	22	331	0.0109	0.0019	19	0.004614	74	168	6074	11	5139
F-XX	23	317	0.0081	0.0016	19	0.004389	88	182	6096	8	5047
F-XX	24	315	0.0114	0.0017	18	0.004214	71	184	7255	4	6199
F-XX	25	325	0.0149	0.0019	19	0.004787	68	128	6716	134	5594
F-XX	26	322	0.0087	0.0016	19	0.004539	89	184	6546	27	5607
F-XX	27	314	0.0055	0.0016	19	0.004549	81	192	5790	38	4933
F-XX	28	335	0.0081	0.0018	20	0.004534	82	178	6442	13	5529
F-XX	29	304	0.0062	0.0014	18	0.004094	52	189	6464	13	5598
F-XX	30	305	0.0051	0.0019	21	0.004273	87	184	6264	24	5291
F-XX	31	323	0.0087	0.0017	18	0.004522	77	195	6704	34	5748
F-XX Msl	1	362	0.002	0.0018	18	0.004853	73	157	5491	27	4710
F-XX Msl	2	349	0	0.0011	16	0.004238	81	183	5866	63	5052
F-XX Msl	3	358	0.001	0.001	17	0.00439	80	163	6407	15	5520
F-XX Msl	4	369	0.0005	0.0013	17	0.003949	71	155	6944	7	5890
F-XX Msl	5	375	0.0026	0.0013	17	0.004321	70	165	5893	148	5214
F-XX Msl	6	351	0.0005	0.0015	17	0.004553	64	181	6419	19	5485
F-XX Msl	7	344	0.001	0.0013	16	0.004327	56	136	6953	11	5874
F-XX Msl	8	358	0.0005	0.0015	17	0.0045	96	165	6499	20	5563
F-XX Msl	9	342	0.001	0.0013	17	0.004049	64	185	6377	21	5590
F-XX Msl	10	374	0.001	0.0014	17	0.004012	77	156	6167	26	5292
F-XX Msl	11	362	0	0.0013	17	0.004069	82	174	6994	21	6015
F-XX Msl	12	341	0.0005	0.0014	16	0.004288	81	183	6359	17	5366
F-XX Msl	13	366	0.0005	0.0013	17	0.004428	96	157	6413	61	5392
F-XX Msl	14	382	0.0086	0.0014	17	0.004544	62	137	7125	0	6048
F-XX Msl	15	389	0.0021	0.0016	18	0.005111	76	142	6172	356	5417
F-XX Msl	16	388	0.0005	0.0014	18	0.00399	77	130	6132	40	5203
F-XX Msl	17	363	0.0021	0.0015	17	0.004401	66	152	6425	6	5449
F-XX Msl	18	394	0.0015	0.0015	18	0.00477	74	125	6195	4	5244

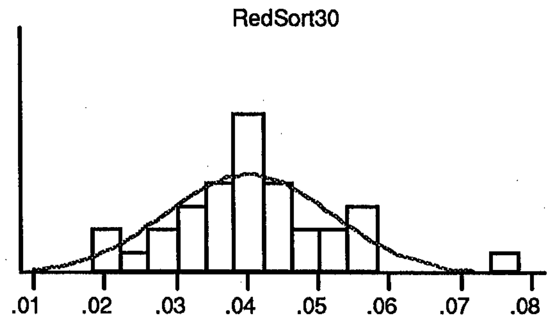
Alternative	Run	Red A-A Losses	Red Percent Sortie	Blue Loss /Sortie	Air Supremacy (.10)	Blue S-A Losses	Total Blue Destroyed on Ground	Total Red Destroyed in the Open	Total Red TELs Killed	Total Red Acquistion Radars Killed	Total Red FC Radars Killed
F-XX Msl	19	315	0.0005	0.0014	17	0.004345	51	177	6474	37	5797
F-XX Msl	20	356	0	0.0013	15	0.004125	76	163	6768	245	5806
F-XX Msl	21	343	0	0.0013	17	0.004109	72	174	6503	20	5578
F-XX Msl	22	371	0.0031	0.0015	18	0.004196	81	150	6209	24	5116
F-XX Msl	23	346	0.0021	0.0012	16	0.004354	73	180	7120	28	6118
F-XX Msl	24	339	0.0046	0.0015	17	0.004161	72	178	7283	18	6308
F-XX Msl	25	323	0.001	0.0012	15	0.003961	68	174	6256	20	5350
F-XX Msl	26	365	0.0015	0.0013	15	0.004616	69	161	6395	50	5346
F-XX Msl	27	361	0	0.0017	17	0.00426	64	157	5896	4	5134
F-XX Msl	28	367	0.0025	0.0012	17	0.004216	70	147	6401	20	5443
F-XX Msl	29	350	0.001	0.0014	16	0.003935	61	183	6536	22	5656
F-XX Msl	30	370	0.0021	0.0012	16	0.004372	85	170	6036	24	5009
F-XX Msl	31	344	0.001	0.001	15	0.004323	70	143	6241	26	5251

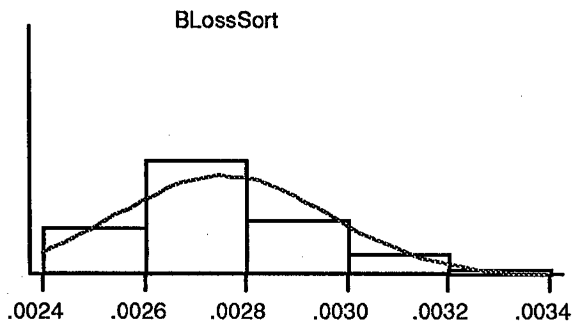
Appendix G, Response Distributions

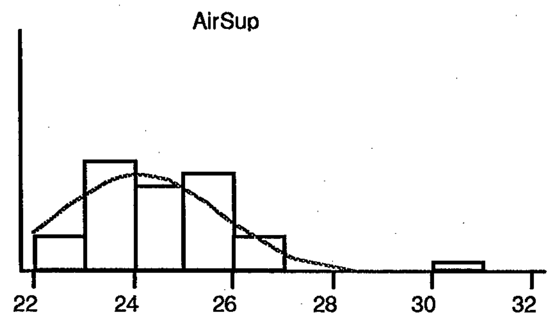
.JMP histograms below for the output responses listed in Appendix F are from 31 replications of THUNDER 6.4.2 for six alternative aircraft/weapons combinations. Normal curves superimposed on the graphs are constructed from the mean and standard deviation of the column.

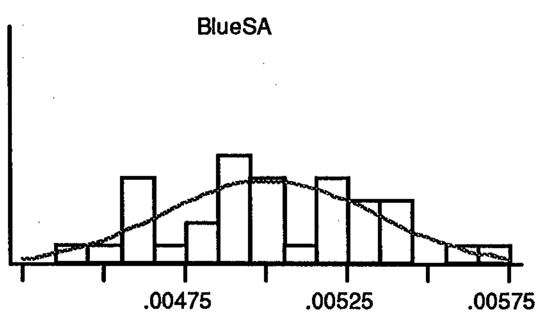
F-15C

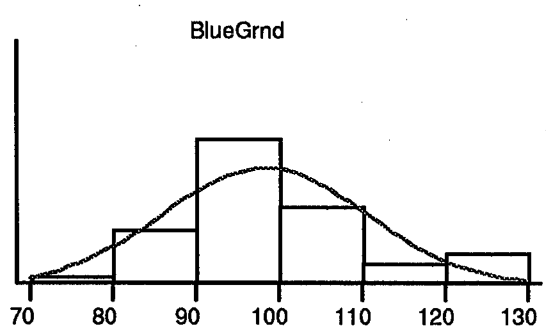


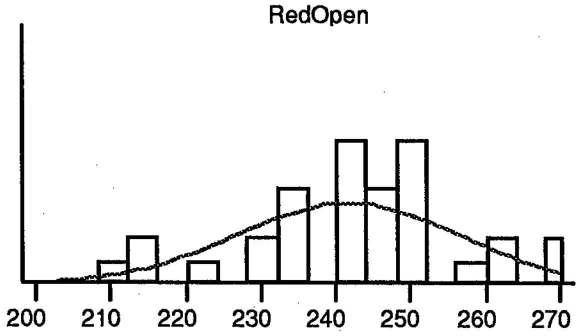


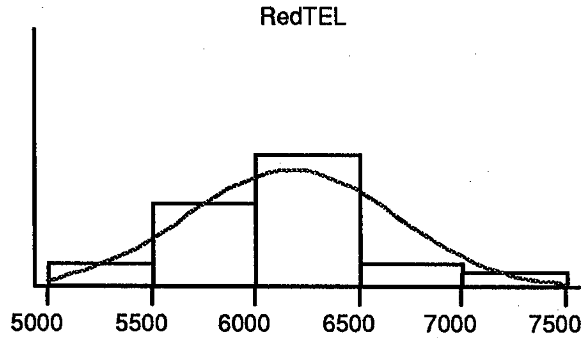


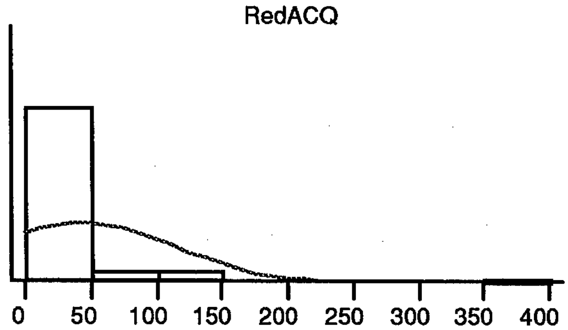


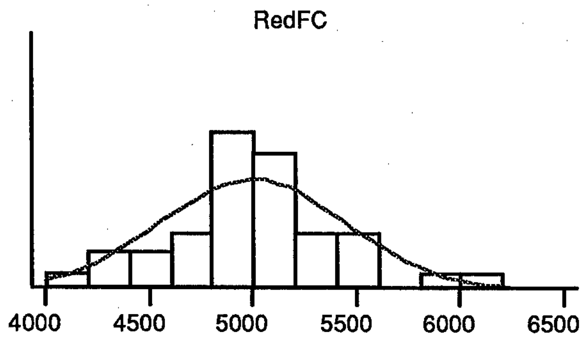




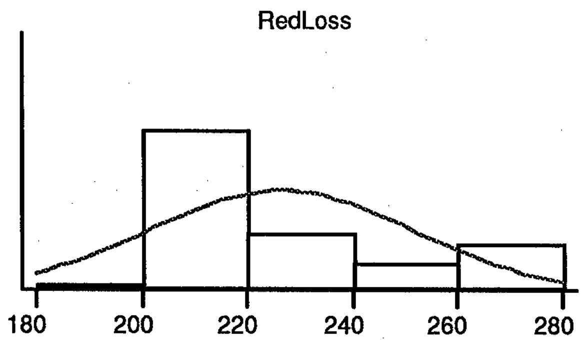


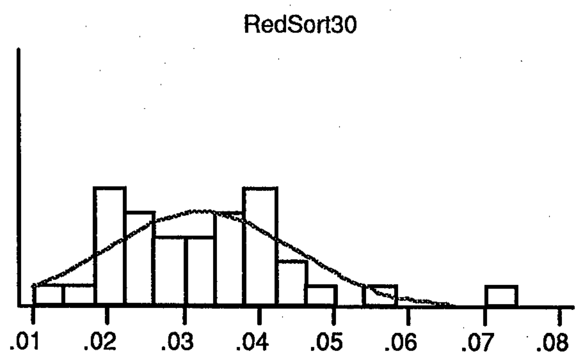


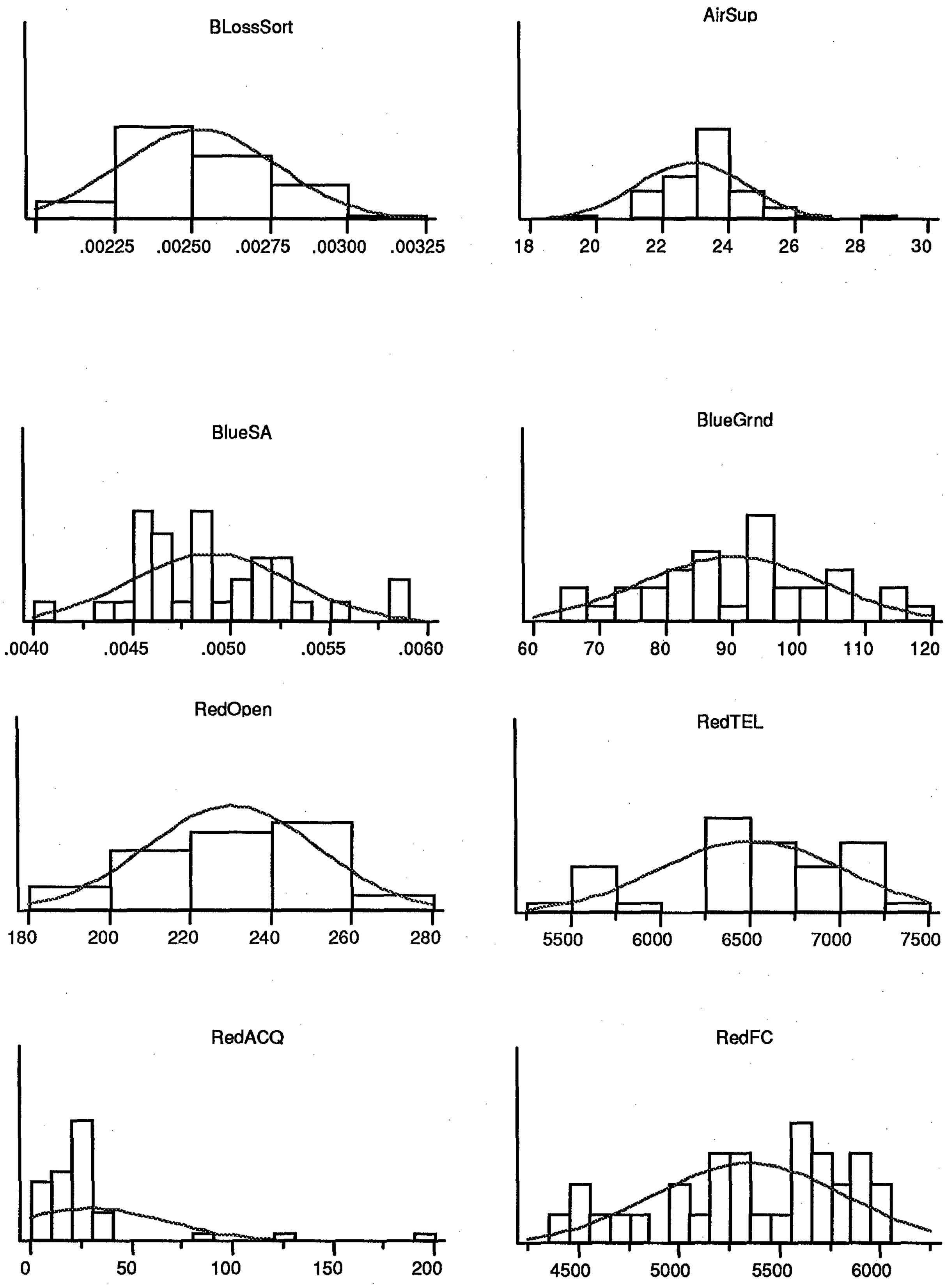




F-15C w/Missile



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BlueGrnd
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RedOpen
180 200 220 240 260 280
RedTEL
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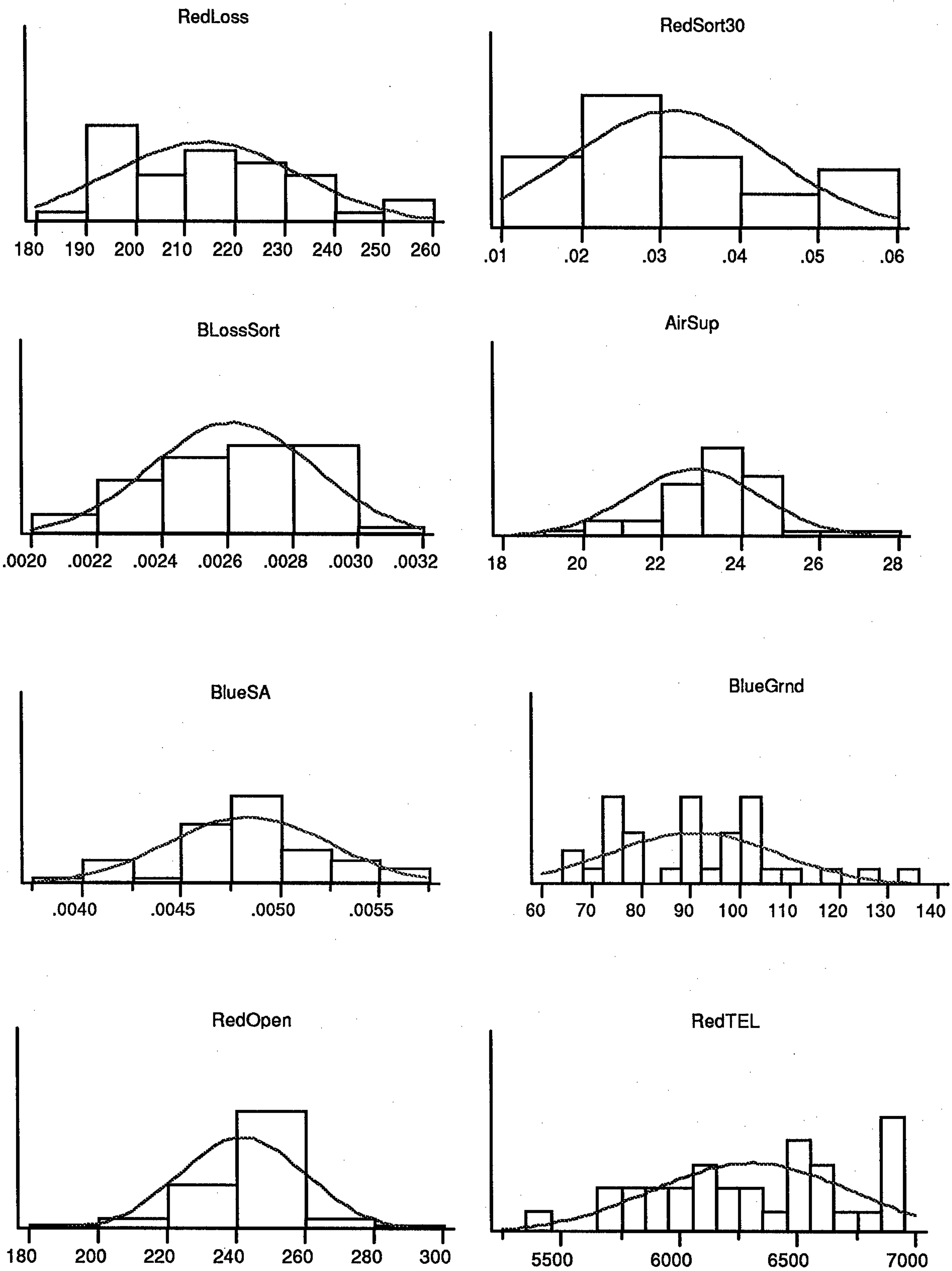
RedACQ
0 50 100 150 200
RedFC
4500 5000 5500 6000

F-15 w/Radar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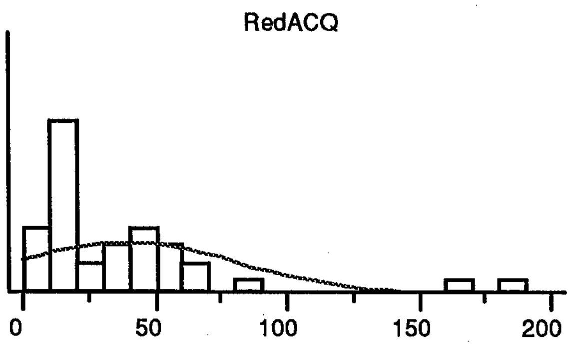
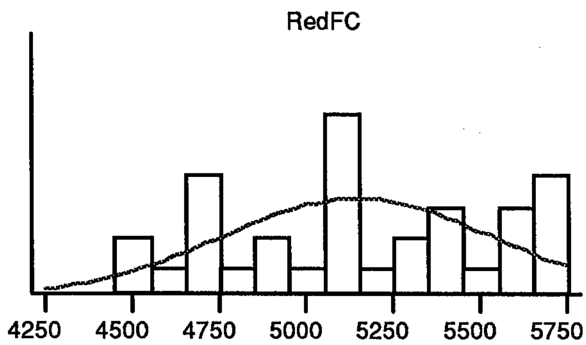
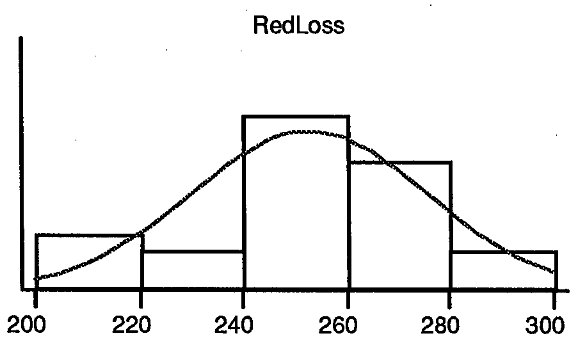
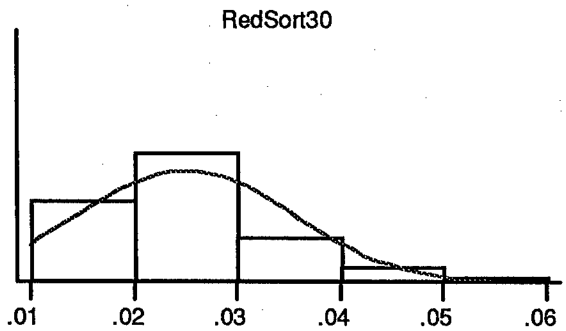
AirSup
18 20 22 24 26 28
BlueSA
.0040 .0045 .0050 .0055
BlueGrnd
60 70 80 90 100 110 120 130 140
RedOpen
180 200 220 240 260 280 300
RedTEL
5500 6000 6500 7000

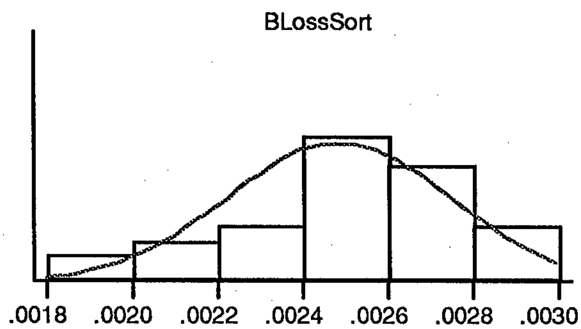


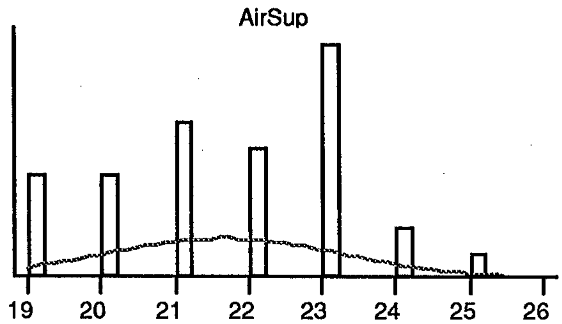


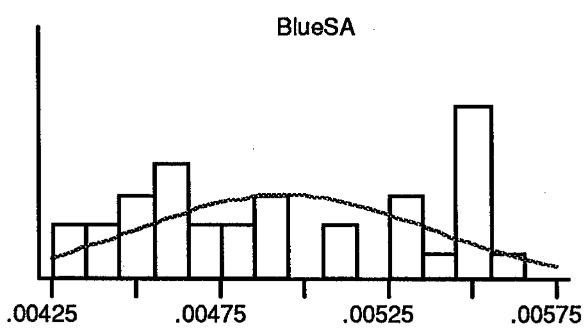
F-15C w/Radar and Missile

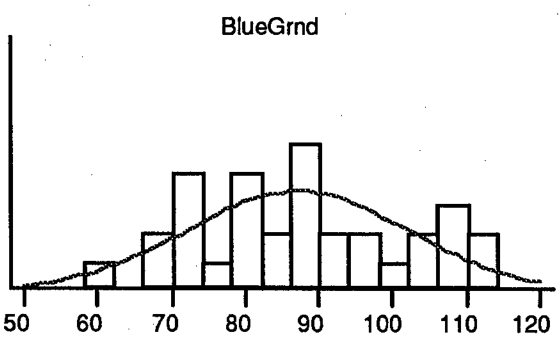


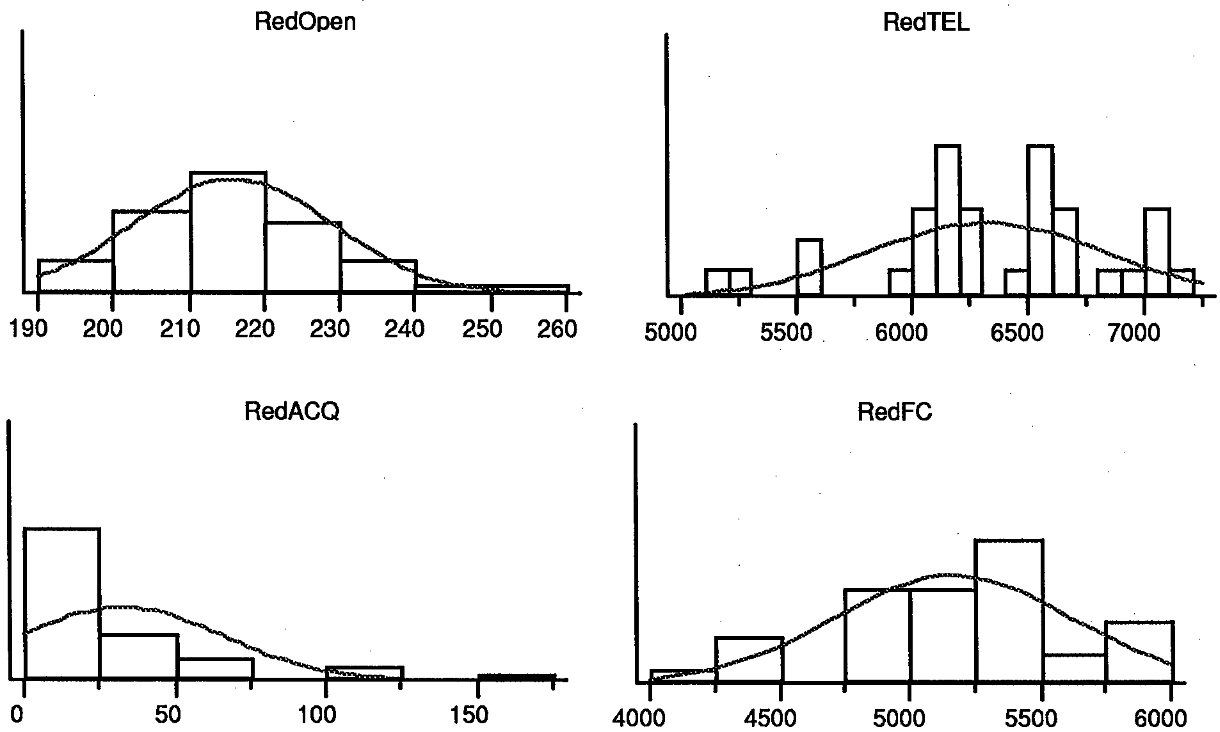








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RedACQ
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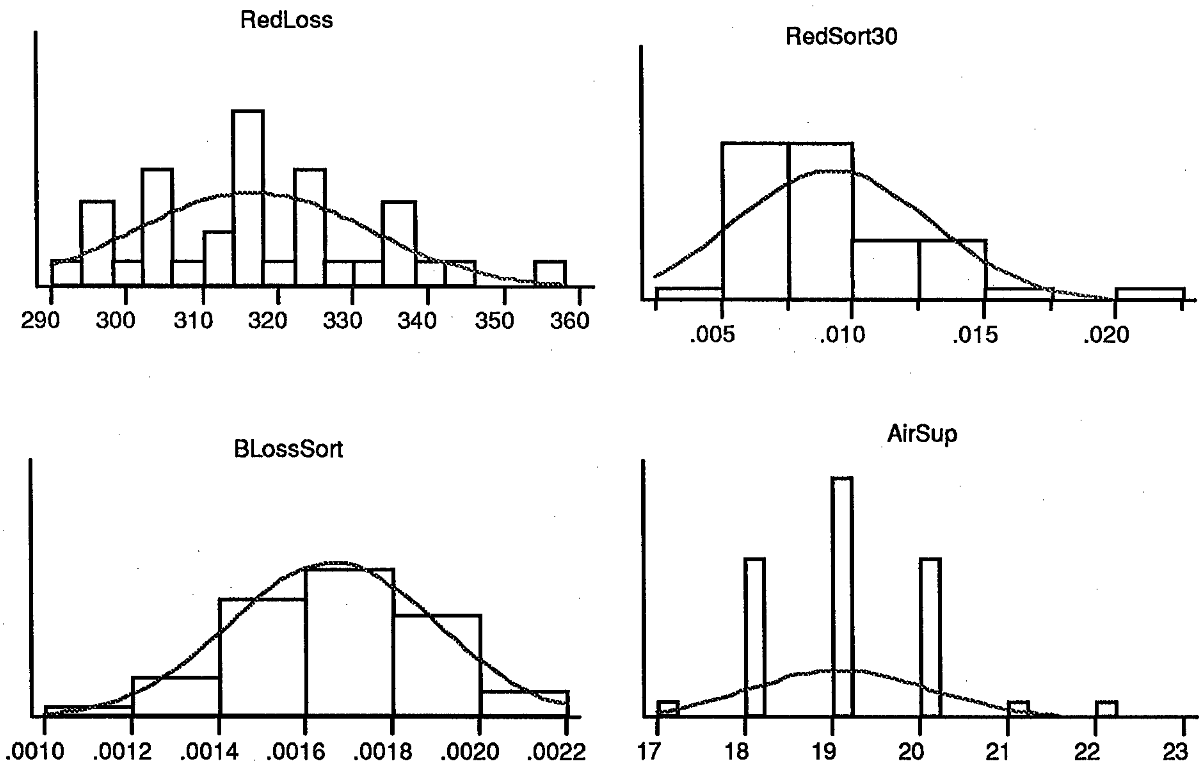
RedFC
4000 4500 5000 5500 6000

F-XX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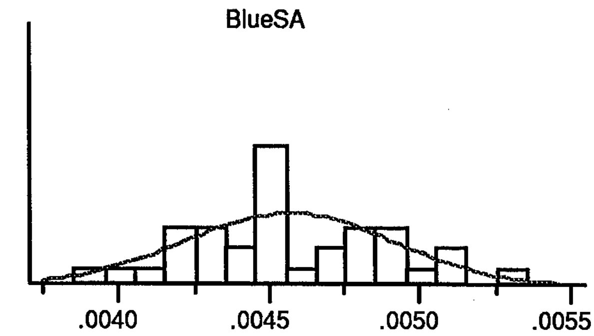
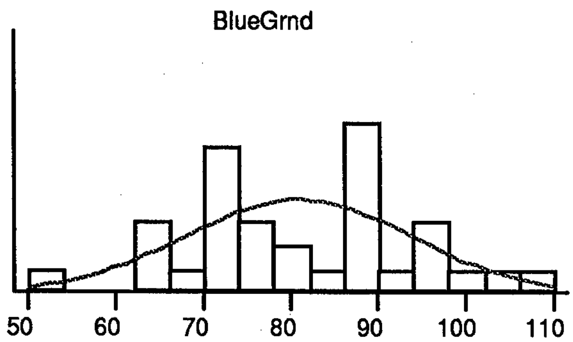
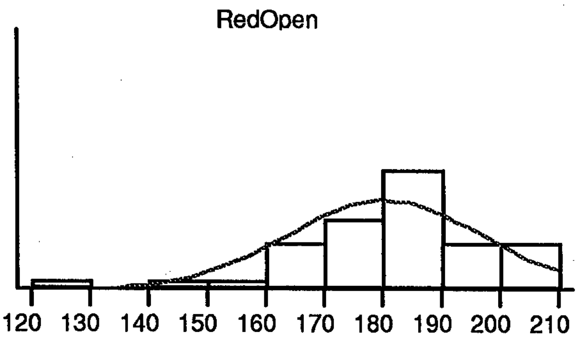
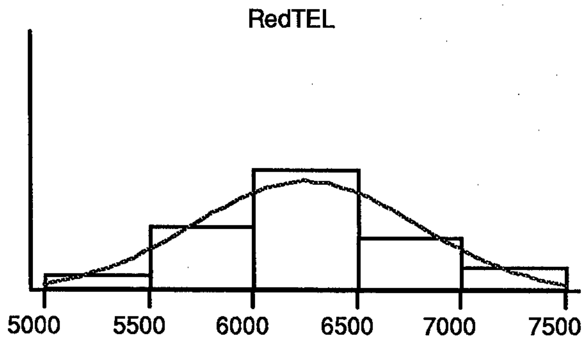
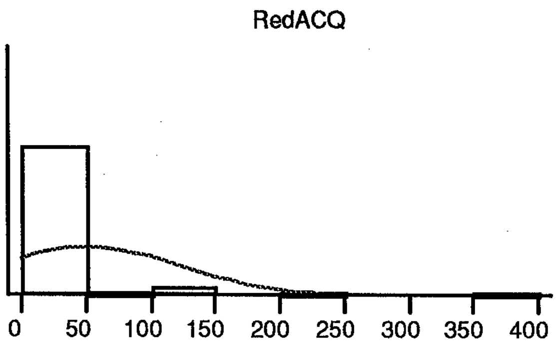
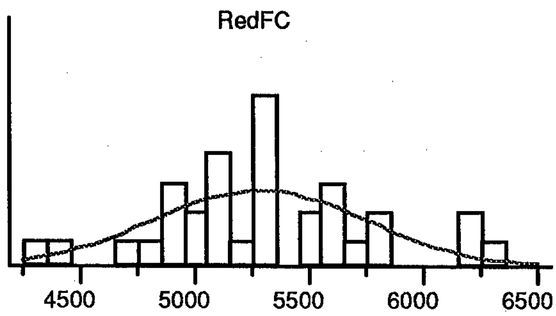




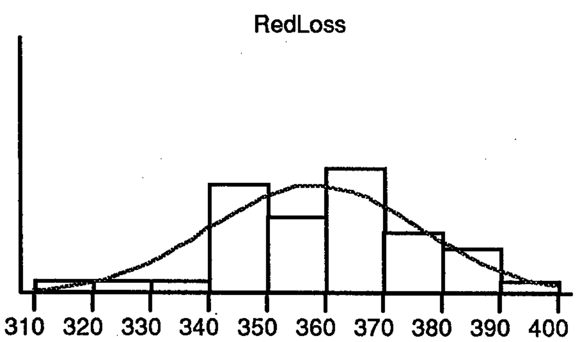


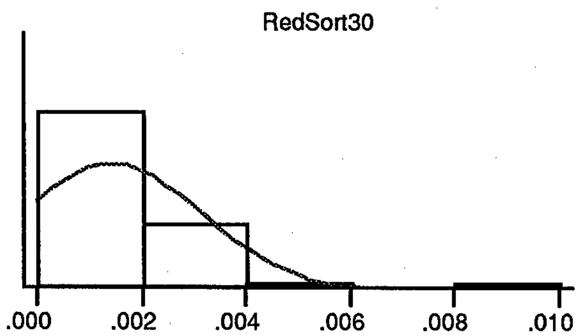


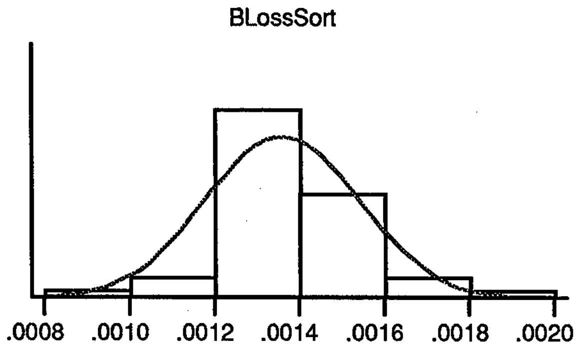




F-XX w/Missile



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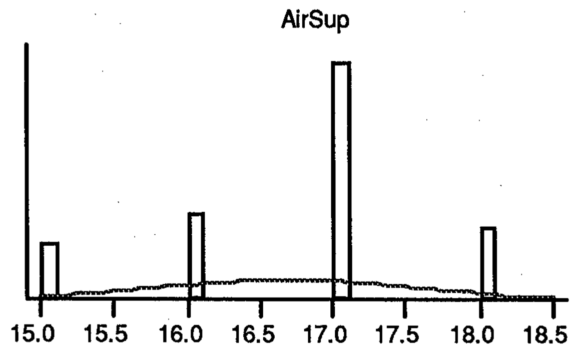
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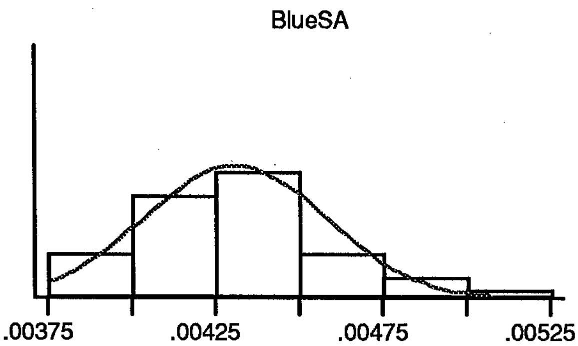
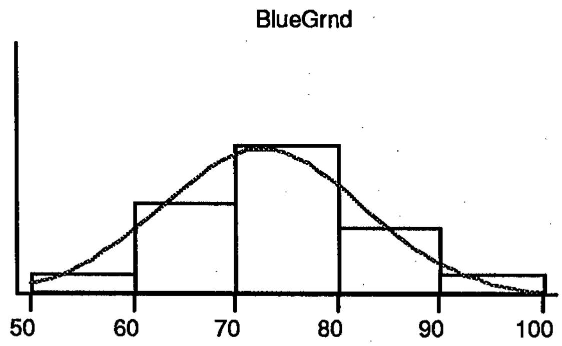
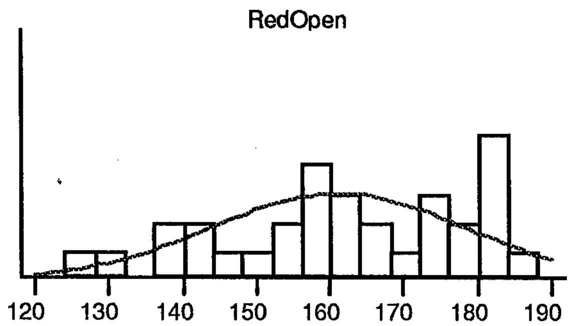
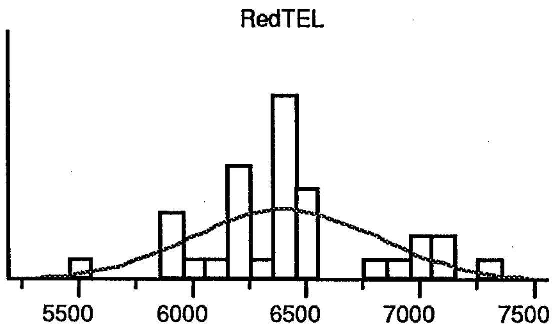
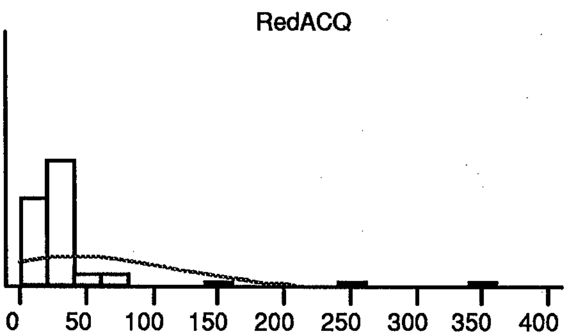
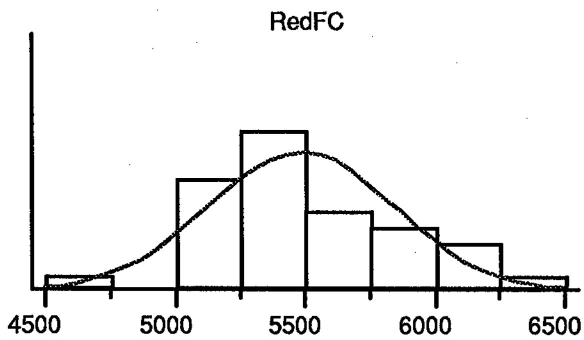

BlueSA
.00375 .00425 .00475 .00525


BlueGrnd
50 60 70 80 90 100

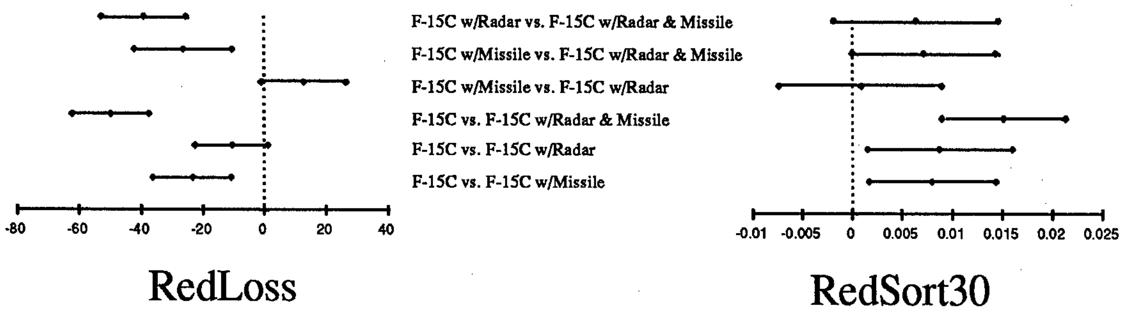

RedOpen
120 130 140 150 160 170 180 190

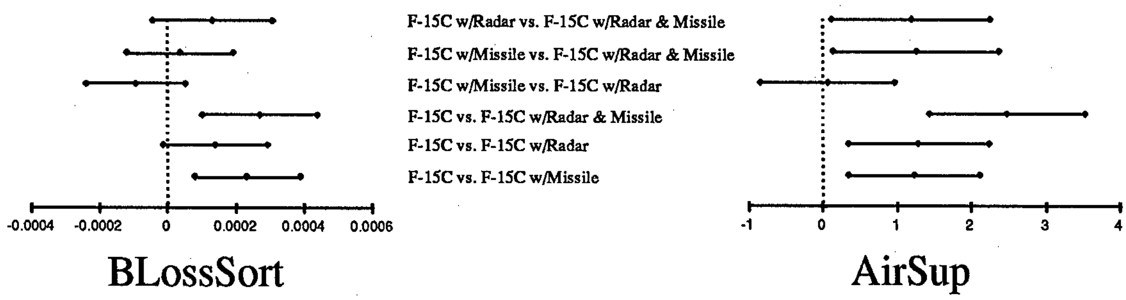

RedTEL
5500 6000 6500 7000 7500

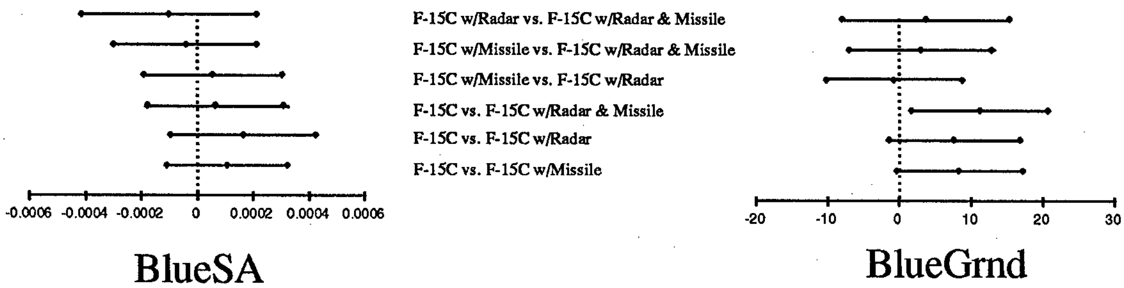

RedACQ
0 50 100 150 200 250 300 350 400

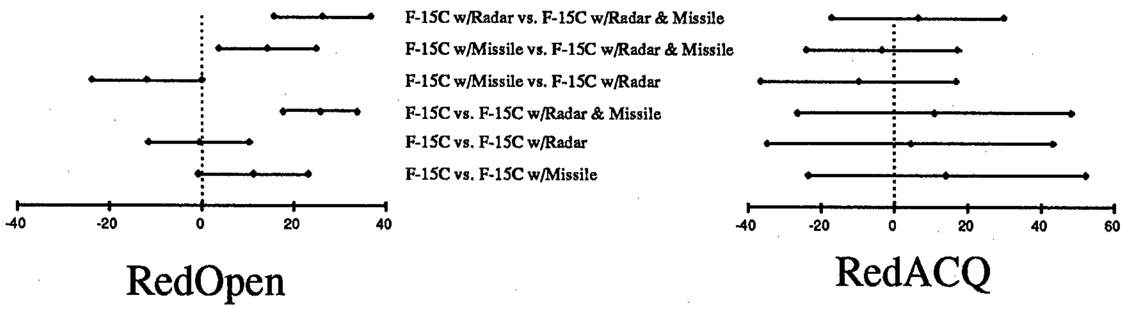

RedFC
4500 5000 5500 6000 6500

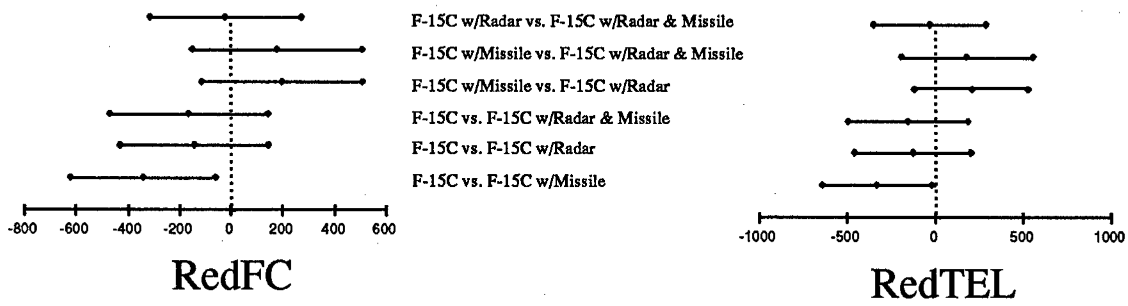
Appendix H, 90% Bonferroni Confidence Intervals for Output Responses










F-15C w/Radar vs. F-15C w/Radar & Missile
F-15C w/Missile vs. F-15C w/Radar & Missile
F-15C w/Missile vs. F-15C w/Radar
F-15C vs. F-15C w/Radar & Missile
F-15C vs. F-15C w/Radar
F-15C vs. F-15C w/Missile
-800 -600 -400 -200 0 200 400 600
RedFC
-1000 -500 0 500 1000
RedTEL

Appendix I, Centroid Clustering Data

The first column of each alternative lists the cluster membership for centroid linkage under unconstrained conditions. The second column under each alternative lists the cluster membership for centroid linkage under constraints of six total clusters.

Cluster Membership						
	F-15C		F-15C Msl		F-15C Rdr	
Run	All	Six Clusters	All	Six Clusters	All	Six Clusters
1	1	1	1	1	1	1
2	15	1	1	1	1	1
3	17	1	26	1	1	1
4	3	3	23	1	1	1
5	1	1	5	5	1	1
6	17	1	1	1	17	1
7	1	1	17	1	1	1
8	11	1	1	1	7	1
9	37	1	1	1	12	1
10	17	1	22	3	26	1
11	21	1	1	1	15	1
12	12	1	17	1	4	4
13	17	1	15	1	27	1
14	17	1	1	1	17	1
15	1	1	26	1	17	1
16	1	1	1	1	1	1
17	17	1	25	1	17	1
18	18	1	1	1	1	1
19	12	1	1	1	34	5
20	1	1	27	1	1	1
21	1	1	1	1	1	1
22	1	1	1	1	15	1
23	36	1	1	1	17	1
24	17	1	1	1	1	1
25	17	1	18	1	19	1
26	17	1	1	1	14	1
27	1	1	27	1	13	5
28	17	1	1	1	6	6
29	18	1	1	1	26	1
30	17	1	17	1	33	1
31	17	1	1	1	33	1

	F-15C Rdr/Msl		F-XX		F-XX Msl	
Run	All	Six Clusters	All	Six Clusters	All	Six Clusters
1	1	1	2	2	8	2
2	26	1	8	2	31	2
3	16	1	2	2	31	2
4	32	1	2	2	31	2
5	15	1	2	2	31	2
6	13	5	2	2	31	2
7	10	1	2	2	30	2
8	1	1	24	2	31	2
9	26	1	28	2	31	2
10	27	1	2	2	31	2
11	1	1	2	2	31	2
12	15	1	2	2	31	2
13	26	1	35	2	31	2
14	26	1	24	2	30	2
15	18	1	2	2	20	2
16	27	1	31	2	31	2
17	1	1	2	2	31	2
18	27	1	2	2	20	2
19	18	1	29	2	24	2
20	1	1	2	2	31	2
21	2	2	9	1	31	2
22	26	1	2	2	31	2
23	27	1	2	2	28	2
24	1	1	28	2	28	2
25	1	1	2	2	31	2
26	10	1	2	2	31	2
27	26	1	2	2	31	2
28	16	1	2	2	31	2
29	10	1	24	2	31	2
30	1	1	2	2	31	2
31	18	1	2	2	31	2

Appendix J, Two and Four Factor Rotations

2 Factor Rotation

Variables	Factor 1	Factor 2
RedLoss	0.9531	-0.1893
RedSort30	-0.8227	0.3847
BLossSort	-0.8678	0.3543
AirSup	-0.8659	0.3541
BlueSA	-0.4294	0.7258
BlueGrnd	-0.4563	0.4675
RedOpen	-0.8968	0.0451
RedFC	0.0318	-0.8978

4 Factor Rotation

Variables	Factor 1	Factor 2	Factor 3	Factor 4
RedLoss	0.9236	0.0889	0.1584	-0.2902
RedSort30	-0.6734	-0.0780	-0.2801	0.5664
BLossSort	-0.7734	-0.1431	-0.2821	0.4250
AirSup	-0.7355	-0.0796	-0.2703	0.5216
BlueSA	-0.2515	-0.3464	-0.1391	0.8278
BlueGrnd	-0.2491	-0.1337	-0.9389	0.1730
RedOpen	-0.9514	-0.1008	-0.1069	0.0311
RedFC	0.1045	0.9549	0.1203	-0.2221

Appendix K, Factor Scores

Alternative	Run	Factor1	Factor2	Factor3
F-15C	1	0.480919	0.548971	0.216267
F-15C	2	1.366895	0.19662	-1.25214
F-15C	3	0.635834	-0.32316	1.34442
F-15C	4	1.28043	2.170791	0.512451
F-15C	5	1.030937	-1.01889	0.901985
F-15C	6	0.850912	1.587605	0.448981
F-15C	7	0.78933	0.508747	-0.02169
F-15C	8	0.362639	-1.08374	2.843527
F-15C	9	0.415551	0.412232	1.223692
F-15C	10	0.974603	1.14511	-0.31914
F-15C	11	0.558969	1.566969	1.252036
F-15C	12	1.240584	-1.7737	0.264665
F-15C	13	0.928554	0.589963	0.352068
F-15C	14	0.713212	0.372507	0.276332
F-15C	15	0.722563	0.532509	0.367666
F-15C	16	1.052536	-0.43664	0.502104
F-15C	17	1.064663	1.128427	-0.6077
F-15C	18	0.868445	2.613054	-0.40306
F-15C	19	1.55363	-1.46102	0.636092
F-15C	20	0.709182	-0.18957	-0.4089
F-15C	21	0.75963	-0.33222	-0.00949
F-15C	22	1.22755	-0.73989	0.372384
F-15C	23	0.74637	0.920543	0.904748
F-15C	24	0.806396	-0.60967	2.203446
F-15C	25	1.028317	0.237347	0.530032
F-15C	26	0.730344	-0.20068	2.078024
F-15C	27	0.892793	0.130395	-0.46737
F-15C	28	0.917999	1.313349	-0.15647
F-15C	29	0.505343	1.788631	-0.61966
F-15C	30	0.840703	0.3876	0.81978
F-15C	31	0.774616	0.534791	0.94022
F-15C Msl	1	0.071306	-1.12163	0.479823
F-15C Msl	2	0.34958	-0.32885	0.399587
F-15C Msl	3	-0.29741	-0.5574	1.490017
F-15C Msl	4	0.183107	1.295909	1.492568
F-15C Msl	5	1.431326	-2.27557	-0.24831
F-15C Msl	6	1.133735	-1.40579	-0.14572
F-15C Msl	7	0.20484	1.408104	0.780934
F-15C Msl	8	0.621396	-0.89036	-0.86698
F-15C Msl	9	0.782451	-1.24566	0.926985
F-15C Msl	10	0.687071	1.504795	2.025651
F-15C Msl	11	0.446746	-0.45859	0.487439
F-15C Msl	12	1.118282	-0.26879	0.82013
F-15C Msl	13	1.349878	0.507042	-0.94854

Alternative	Run	Factor1	Factor2	Factor3
F-15C Msl	14	0.905896	-0.41059	-0.62447
F-15C Msl	15	-0.01146	-0.32167	1.716966
F-15C Msl	16	0.819992	-1.69436	0.493286
F-15C Msl	17	0.537432	0.390475	-0.25593
F-15C Msl	18	1.11478	-1.10407	0.700786
F-15C Msl	19	1.179393	-0.62423	-1.63703
F-15C Msl	20	-0.27156	1.396839	-0.45404
F-15C Msl	21	0.839864	-0.52638	0.814952
F-15C Msl	22	0.758564	-0.06102	-1.59181
F-15C Msl	23	1.084095	-0.53314	-0.16881
F-15C Msl	24	0.572641	-0.13815	-1.25409
F-15C Msl	25	0.744865	2.410819	-0.64258
F-15C Msl	26	0.836168	-0.91502	0.40084
F-15C Msl	27	-0.06817	1.018012	-1.13822
F-15C Msl	28	0.864353	-1.14152	-1.12522
F-15C Msl	29	1.010153	0.241784	-0.43615
F-15C Msl	30	0.506072	0.611483	1.486412
F-15C Msl	31	0.888106	-0.62074	0.169887
F-15C Rdr	1	1.106785	-0.50569	-1.23388
F-15C Rdr	2	1.520838	-0.53865	-1.25672
F-15C Rdr	3	0.308273	-0.20021	0.406628
F-15C Rdr	4	1.195037	-0.68817	-0.86873
F-15C Rdr	5	1.205611	0.295159	-1.13633
F-15C Rdr	6	0.342442	1.247506	0.468198
F-15C Rdr	7	0.727659	-0.96938	0.156917
F-15C Rdr	8	-0.3815	1.710145	1.632535
F-15C Rdr	9	1.473979	-1.31234	1.329934
F-15C Rdr	10	-0.01652	-0.13688	0.811896
F-15C Rdr	11	0.821854	1.853641	-1.78816
F-15C Rdr	12	0.458956	0.283723	2.713712
F-15C Rdr	13	0.174033	0.967953	0.067409
F-15C Rdr	14	0.930477	1.381789	-0.01739
F-15C Rdr	15	0.810348	0.244073	0.223895
F-15C Rdr	16	1.215553	-0.8176	-1.02995
F-15C Rdr	17	0.692005	0.174008	0.703818
F-15C Rdr	18	0.928589	-0.26069	0.460272
F-15C Rdr	19	1.096869	-1.11632	-1.11419
F-15C Rdr	20	0.966583	0.469945	-0.33453
F-15C Rdr	21	0.930034	-0.5445	0.053647
F-15C Rdr	22	0.969787	1.141428	-1.37983
F-15C Rdr	23	1.183884	0.616894	-0.24892
F-15C Rdr	24	1.099007	-0.5224	-1.04532
F-15C Rdr	25	1.203613	-0.25784	1.394683
F-15C Rdr	26	-0.45249	0.829633	2.627694
F-15C Rdr	27	0.669247	-1.36093	-1.62237
F-15C Rdr	28	0.341102	-0.65054	0.617179
F-15C Rdr	29	0.146512	-1.50116	1.456936
F-15C Rdr	30	1.217116	0.308675	-1.84756
F-15C Rdr	31	1.074143	-0.28355	-0.46517

Alternative	Run	Factor1	Factor2	Factor3
F-15C Rdr/Msl	1	0.682254	-0.99429	-1.00208
F-15C Rdr/Msl	2	-0.67991	-0.17351	1.441485
F-15C Rdr/Msl	3	-0.02049	1.23893	0.682831
F-15C Rdr/Msl	4	-0.45339	2.109338	1.074034
F-15C Rdr/Msl	5	1.368989	0.357848	-1.62246
F-15C Rdr/Msl	6	0.463618	-0.99126	-1.46993
F-15C Rdr/Msl	7	0.583216	-0.55558	-1.17989
F-15C Rdr/Msl	8	0.75092	-1.02489	-0.77257
F-15C Rdr/Msl	9	-0.23451	0.519494	1.411805
F-15C Rdr/Msl	10	-0.34562	0.174084	-0.36597
F-15C Rdr/Msl	11	0.418831	-1.58682	0.454954
F-15C Rdr/Msl	12	0.846689	0.919755	-0.69834
F-15C Rdr/Msl	13	0.037791	0.02598	1.135017
F-15C Rdr/Msl	14	-0.47792	0.361228	1.676029
F-15C Rdr/Msl	15	0.192365	2.528429	-1.09868
F-15C Rdr/Msl	16	-0.43292	0.460235	0.244736
F-15C Rdr/Msl	17	0.57986	-0.19639	0.710755
F-15C Rdr/Msl	18	0.265397	0.176109	0.050586
F-15C Rdr/Msl	19	-0.04897	2.196229	-0.19938
F-15C Rdr/Msl	20	0.078762	-0.4208	-0.48238
F-15C Rdr/Msl	21	-0.29569	-0.68293	-0.45508
F-15C Rdr/Msl	22	-0.33423	0.381024	1.423219
F-15C Rdr/Msl	23	-0.13976	0.400459	-1.20778
F-15C Rdr/Msl	24	0.785061	0.787326	-0.47456
F-15C Rdr/Msl	25	0.781893	0.071208	-0.38283
F-15C Rdr/Msl	26	0.111223	0.62402	-0.66314
F-15C Rdr/Msl	27	-0.06696	-0.70127	1.901657
F-15C Rdr/Msl	28	-0.01197	0.909589	0.634333
F-15C Rdr/Msl	29	0.448551	0.722447	-2.01881
F-15C Rdr/Msl	30	0.453344	-1.21101	0.26223
F-15C Rdr/Msl	31	0.105828	2.353894	-0.57275
F-XX	1	-0.98571	-0.39558	0.153998
F-XX	2	-1.4176	1.948727	-1.09175
F-XX	3	-0.89072	0.100158	-0.32425
F-XX	4	-1.04477	0.368379	-0.72405
F-XX	5	-1.29407	1.038164	0.622006
F-XX	6	-1.00092	-0.35684	0.558653
F-XX	7	-1.11026	0.283747	1.017317
F-XX	8	-0.35251	-0.81012	-1.37896
F-XX	9	-1.15963	-1.88664	1.115624
F-XX	10	-1.30056	0.297044	1.369576
F-XX	11	-1.13954	0.822195	-1.01811
F-XX	12	-0.90403	0.60478	0.224057
F-XX	13	-0.72934	-2.04588	1.151381
F-XX	14	-0.44977	-1.43111	-1.2066
F-XX	15	-1.26183	-0.10991	0.484782
F-XX	16	-0.95722	-0.60579	-0.51937
F-XX	17	-1.03551	-0.13289	0.303743
F-XX	18	-1.58862	0.962461	0.760841
F-XX	19	-0.88041	1.87976	-1.76821
F-XX	20	-0.64916	0.632722	-1.26323

Alternative	Run	Factor1	Factor2	Factor3
F-XX	21	-1.20769	1.875743	1.231786
F-XX	22	-1.03404	0.440107	-0.53112
F-XX	23	-1.17688	0.116558	0.317275
F-XX	24	-0.43876	-1.83448	-0.48606
F-XX	25	-1.09049	0.11836	-0.59204
F-XX	26	-0.98549	-0.6689	0.544199
F-XX	27	-1.04343	0.491084	-0.31904
F-XX	28	-0.91281	-0.42505	0.116318
F-XX	29	-0.43381	-0.82055	-2.08489
F-XX	30	-0.76833	-0.43772	0.324732
F-XX	31	-0.68294	-0.85499	-0.32088
F-XX Msl	1	-1.6643	1.509489	-0.67747
F-XX Msl	2	-1.68692	0.044704	-0.14768
F-XX Msl	3	-1.67985	-0.45026	0.064266
F-XX Msl	4	-1.41195	-1.39826	-0.27856
F-XX Msl	5	-1.62739	0.105013	-0.67573
F-XX Msl	6	-1.10985	-0.15511	-1.21254
F-XX Msl	7	-1.35205	-0.76005	-1.36641
F-XX Msl	8	-1.731	-0.5725	1.18875
F-XX Msl	9	-1.00937	-0.90594	-1.14284
F-XX Msl	10	-1.74387	-0.38747	-0.05135
F-XX Msl	11	-1.33196	-1.69167	0.373149
F-XX Msl	12	-1.39778	-0.43701	-0.05947
F-XX Msl	13	-1.98782	-0.31396	1.207931
F-XX Msl	14	-1.39196	-0.81024	-0.78959
F-XX Msl	15	-1.7862	0.69079	-0.12674
F-XX Msl	16	-2.03701	-0.11458	0.130382
F-XX Msl	17	-1.48225	-0.11616	-0.84094
F-XX Msl	18	-2.04373	0.722656	-0.1509
F-XX Msl	19	-0.64857	-0.80661	-2.06205
F-XX Msl	20	-1.52358	-1.17779	-0.09244
F-XX Msl	21	-1.24876	-0.8477	-0.52753
F-XX Msl	22	-1.80473	0.093311	0.190051
F-XX Msl	23	-1.09074	-1.51726	-0.36144
F-XX Msl	24	-0.79467	-2.02943	-0.31219
F-XX Msl	25	-1.33475	-0.61578	-0.93146
F-XX Msl	26	-1.71167	0.215174	-0.78298
F-XX Msl	27	-1.43981	0.247645	-1.08962
F-XX Msl	28	-1.67594	-0.31519	-0.49523
F-XX Msl	29	-1.03948	-1.0875	-1.28506
F-XX Msl	30	-1.95128	0.320667	0.243709
F-XX Msl	31	-1.92994	0.102176	-0.65274
F-XX Msl	31	-1.92994	0.102176	-0.65274

Appendix L, MineSet Schema

Schema for Output Response Visualization

```
#
#
#
input {
#   Data input file
#
   file "new8moe.data";

        string  alternative;
        string run;
        int redloss;
     float redpercnt;
        float blosssort;
        float airsup;
     float bluesa;
        int bluegrnd;
        int redopen;
        int redfc;

}
```

Schema for Factor Score Visualization

```
#
#
#
input {
#   Data input file
#
   file "invcosts.data";

        string  alternative;
        string run;
        int redloss;
     float redpercnt;
        float blosssort;
        float airsup;
        float bluesa;
        int bluegrnd;
        int redopen;
        int redfc;
```

```
float factor1;
float factor2;
float factor3;
float factor12;
float factor22;
float factor111;
float invfac1;
float invfac2;
float invfac3;
float invfac12;
float invfac22;
float invfac111;
float LCC;

}
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Vita

Lieutenant Colonel John J. Siegner earned his Bachelor of Science in Chemical Engineering from North Carolina State University at Raleigh. He attended Undergraduate Navigator Training (UNT) at Mather AFB, earning his aeronautical rating in November 1980.

His first operational assignment was as an F-4D Weapon Systems Officer (WSO), assigned to the 614th Tactical Fighter Squadron (TFS), Torrejon AB, Spain in February 1982. Subsequently, he was assigned as an F-4E WSO to the 36th TFS, Osan AB, ROK in June 1983. After Osan AB, Lieutenant Colonel Siegner was assigned to the 21st Tactical Fighter Training Squadron, George AFB, where he served as an instructor WSO in the F-4 Replacement Training Unit (RTU).

Lieutenant Colonel Siegner was assigned to the Seventh Air Force staff, Osan AB, ROK in June 1989. He served as an action officer in the 7AF Range Management and Exercise Plans Divisions. He was assigned to the Air Force Operational Test and Evaluation Center (AFOTEC), Kirtland AFB, in July 1993. During this assignment, he served in the center's test resources branch.

He entered the School of Engineering at the Air Force Institute of Technology in August 1996. Upon receiving a Masters of Science degree from the institution, he was assigned to the Air Staff, HQ USAF/XPY, Pentagon ADM VA.

Permanent address: 1006 Misty Lea Lane

Houston, TX 77090

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13. ABSTRACT *(Maximum 200 words)*

The Aeronautical System Center (ASC) is developing a Simulation and Analysis Facility (SIMAF) that will link models, simulations, hardware-in-the-loop, and system-in-the-loop resources to create a robust virtual environment supporting assessment of alternate systems in the defense acquisition process. ENS is assisting ASC with scenario development, experimental design, and battleroom visualization efforts for a SIMAF capability demonstration.

This thesis uses multivariate analysis and visualization tools to develop an approach for reducing the dimensionality of multiple campaign level measures of effectiveness (MOE) for a notional analysis of alternatives (AoA) study. Additionally, the thesis advances an AoA visualization paradigm for the SIMAF capability demonstration.

The results of this study suggest that multivariate data reduction techniques and user interactive visualization of multivariate analysis results cane be employed to combine multiple MOEs into a reduced set of interpretable factors capturing the operational effectiveness performance of competing alternatives. The thesis research also successfully demonstrated a visual data mining approach applied to the visualization of campaign level analysis results and the cost/effectiveness integration of an AoA effort.

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