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AIR COMBAT MANEUVERING PERFORMANCE MEASUREMENT

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ORLANDO, FLORIDA 32813

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AIR COMBAT MANEUVERING PERFORMANCE MEASUREMENT

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NOTICE

This final report was submitted by Canyon Research Group, Inc., under Contract F33615-77-C-0079, project 1123, with the Flying Training Division, Air Force Human Resources Laboratory (AFSC), Williams Air Force Base, Arizona 85224. Mr. John C. Reed was the Contract Monitor for this joint Air Force/Navy cooperative research effort.

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This technical report has been reviewed and is approved for publication.

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A study was conducted to define measures of Air Combat Maneuvering (ACM) for one-versus-one (1v1) free engagements on the Simulator for Air-to-Air Combat (SAAC). The study found a small set of measures which were (a) sensitive to differences in pilot ACM skill level, (b) diagnostic of performance proficiencies and deficiencies, (c) usable by instructor pilots and compatible with their judgments, (d) capable of providing results immediately after the end of the engagement, and (e) compatible with current projected training and measurement hardware.

The study was conducted in three phases: Phase 1 was an analytical study of ACM tasks using information from training material and instructor pilots; 28 measures reflected subject matter experts opinion on the important

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elements of ACM. Pilot control, aircraft performance and engagement outcome variables were measured in Phase 2 during 405 free engagements on the SAAC at Luke AFB using a total of 30 pilots with three different levels of experience. A computer analysis of the engagement data was conducted in Phase 3 to (a) check methodological assumptions that the three pilot experience levels represented different ACM skill levels and (b) develop the smallest comprehensive measure set.

Out of the original 28 measures, 13 were found to discriminate between high and low skilled pilots. These measures, when properly weighted, could be added together to form a single metric of ACM performance which accounted for 51% of the variance in the free engagement performance data and predicted membership in high or low skill groups with 92% accuracy. A method to further improve the measurement model accuracy was suggested. As a consequence of these results, further development of diagnostic measurement, cross-validation of these results, further development of diagnostic measurement, cross-validation of the study results, and implementation of the measurement model for developmental testing and ultimate training use on the SAAC were recommended.

PREFACE

This effort was jointly sponsored by the Flying Training Division of the Air Force Human Resources Laboratory, Williams AFB, Arizona and the Human Factors Laboratory of the Naval Training Equipment Center, Orlando, Florida. The research was performed by Canyon Research Group, Inc. along with the Tactical Research Branch at Luke AFB, Arizona. The effort was completed under project 1123, Flying Training Development; task 112312, Tactical Combat Aircrew Research and Development; and work unit 11231206 Air Combat Maneuvering Performance Measurement.

This report summarizes the work and outcome of Phases 1, 2 and 3 of the subject contract, conducted from September 1977 to May 1979. During Phase 1, the following people provided information, helped shape the approach, and assisted in coordination, scheduling, and in some cases, actual execution of the work:

Col R. F. McNally, TAWC/OLAH

Maj M. Tietge, TAWC/OLAH

Lt Col H. E. Branby, 57TTW/OLAA

Maj A. Lavoy, 4444th Operations Squadron (OTD)

Maj W. Douglas, 4444th Operations Squadron (OTD)

Capt B. Carmen, 4444th Operations Squadron (OTD)

Capt G. Williams, 311th TFTS

Maj J. Sullivan, TFWC/TA

Lt Col Kieth, 414th FWS

Capt B. Buzze, 414th FWS

Capt O. J. Davis, 414th FWS

Capt C. Phillips, 414th FWS

Maj Tietge and Capt Williams assumed active roles by performing as project pilots and instructors during Phase 2 data collection.

Analysis and programming of the real-time data collection software for the SAAC were provided by the Tactical Research Branch (AFHRL/FTO) by:

Mr. W. J. Hopkins, AFHRL/FTO

Mr. D. R. Martinson, AFHRL/FTO

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I. INTRODUCTION

An automated Air Combat Maneuvering Performance Measurement (ACMPM) system should be invaluable for the assessment or improvement of air-crew combat readiness. Because of the complex, dynamic and fast moving nature of the air combat task, present assessment techniques based on engagement outcome and instructor recall of a few of the characteristics of the engagement are inadequate. A good ACMPM system would provide a detailed, standardized appraisal of pilot performance that is not currently available.

Purposes of ACMPM Measurement

Information derived from such an ACMPM system would be used for several major purposes. First, it would provide improved feedback to Air Combat Maneuvering (ACM) students concerning their progress through the flight training curriculum. It also would provide diagnostic information to each pilot, indicating his areas of individual strength and weakness in the performance of ACM tasks. Second, it would provide ACM instructors with better information about their students' progress, allowing the instructors to adapt the training program, within given constraints, to the needs of the individual student. It also might provide instructors with diagnostic information about their own performance in teaching ACM if they can see a pattern of strengths and weaknesses in their students.

A third function of an automated ACMPM system would be to provide feedback to instructional system development (ISD) personnel concerning the efficacy of current training materials and syllabi. Consistent patterns of weakness in the students would serve as an indicator of a need for adjustment and improvement in the program. In areas where students consistently demonstrated much higher than expected performance, training emphasis could be decreased profitably.

A fourth use of an automated ACMPM system would be to provide better tactics assessment. When new tactics are devised and tested, a good ACMPM system would improve the speed and accuracy with which the results could be evaluated. Finally, an ACMPM system could provide accurate, standardized measures of the operational readiness of pilots and of units.

The most crucial aspect in the development of an automated ACMPM system is in the choice of measures to be taken. The measures must provide a valid and reliable assessment of pilot performance. This means that a highly skilled pilot consistently must achieve a higher score than a less skilled pilot. The measurement system must be usable by IPs and the results must be consistent with their expert judgment. Also, in order to provide maximum utility, the measurement system should be diagnostic of performance proficiencies and deficiencies. It must provide an indication of why the pilot achieved a given score rather than just providing a single score related to the pilot's overall performance.

Study Goals

The goal of this study was to develop a preliminary measurement structure and measure set for an automated ACMPM system which could be implemented on the Simulator for Air-to-Air Combat (SAAC) at Luke AFB, Arizona. A fully developed ACMPM system should be expected to provide valid, diagnostic measurement information in near real time for the use of the ACM instructor. The system is intended to be used to assess pilot performance during one-versus-one (1v1) free engagements. Although the measurement structure and measure set were to be specifically designed for the SAAC, it was the goal of the investigators to provide the basis for a system that could be implemented in a variety of ACM training settings such as the Air Combat Maneuvering Range (ACMR) and Air Combat Maneuvering Instrumentation (ACMI).

Alternative Approaches to the Problem

Three alternative approaches to the development of such an ACMPM system are possible, (a) purely analytical, (b) purely empirical, and (c) combined analytical and empirical.

Purely Analytical Approach. During the development of new training systems, the familiar ISD process has been successful. The process builds hierarchies of intermediate training and performance objectives (and criteria) through an analysis of the task and training requirements. Usually, expert judgment determines what the intermediate performance objectives and criteria should be. Although this works well for conventional task training, it might be a mistake to rely completely on an ISD analysis for ACM free engagements.

ACM may be viewed as a complex, but unitary, task in itself, with variable action requirements. The more complex and variable the task, the greater will be the peril that the long chain of assumptions and inferences (inherent in the analysis process) will lead to incorrect conclusions about performance criteria. Therefore, if the ACMPM system were developed by a purely analytic process, the chances of producing a successful measurement system would be minimal.

Purely Empirical Approach. The second alternative is to record a large amount of comprehensive data on ACM engagements, subdivide the data according to outcome success and expert judgment of skill, and then develop empirical relationships between the recorded performance, outcome and judged skill level. The list of variables would be large and unselected. One could record the time histories of these variables and perform multiple regression, multiple discriminant or factor analyses to determine the relationships between these variables and outcome success and judged skill level.

Without some initial rules for the selection of interpretable measures, the quantitative relationships that might be derived from this approach would be of questionable diagnostic value. For example, it might be difficult to derive useful training and performance diagnosis information from a measure such as average g's during a whole engagement. It is more useful to know if the student used his available g's when he should have, and did not waste energy pulling g's when it was not necessary. A set of comprehensive relationships such as these is difficult to define using purely an empirical approach.

Combined Approach. A combined analytic and empirical approach to the development of useful aircrew performance measurement has been shown to be effective by several researchers (e.g., Vreuls & Wooldridge, 1977; Waag & Knoop, 1977). In this approach, an analysis is performed to define candidate tasks and measures of importance, data are collected using these measures, and empirical analyses are performed on the data to determine the relative importance of the candidate measures. Performance measures, instructor ratings, and measures of outcome may be included in the candidate set so that the empirical analysis may find the functional relationships between them.

Although the emphasis of the approach is empirical, it does not mean that task and training analysis is unnecessary. On the contrary, the combined approach allows the performance and training analysis to be conducted with a wider scope because there are few initial restrictions on the variety of variables that can be considered as potentially important for a performance measurement system. In effect, variables which may appear to be of marginal importance can be included in the list of candidate measures. There are restrictions, however, in the number of measures that can be resolved by empirical analysis and for this reason one does not suggest candidate measures indiscriminantly. Nevertheless, the task and training analysis should be as thorough as possible to ensure that all important variables are included in the data collection, even those which might be excluded in a more conventional approach to the development of performance measurement systems.

The initial analysis provides understanding and insight into the way ACM performance is conceptualized by experts intimately involved in it. These insights are of critical importance for determining how the data collection is designed, and how the empirical data will be handled during subsequent analysis.

Each of these three alternative measurement approaches has certain advantages and disadvantages. Each may find favor in certain applications. If the task under scrutiny is relatively simple and straightforward or if no performance data are available, the purely analytic approach may be the method of choice. If large quantities of data and data processing capability are available and measurement results need not be interpreted by non-scientific personnel, the empirical approach may be used. If data processing capabilities are limited and the results will be used by operational personnel, the combined method may provide the best results. Thus, the choice of a performance measurement approach depends largely on the specific application for which it will be used.

Technical Approach

A combined analytical and empirical approach was used to identify those measures which would highlight the differences in performance between Replacement Training Unit pilots and experts during one-versus-one ACM free engagements. The project was conducted in three distinct but interconnected phases: Phase 1, problem analysis; Phase 2, data collection; and Phase 3, empirical data anlaysis. These phases are summarized below to provide an overview of the contents of this report.

Phase 1. Phase 1 was an analytical examination of the ACM task for the purpose of developing candidate measures. Information was obtained from two main sources,(a) ACM training materials and (b) interviews with subject matter experts including ISD and academic personnel, ACM instructors, and Fighter Weapons School personnel. From this information hypotheses were developed about the structure of ACMPM algorithms and about important parameters to be included in this structure.

Phase 2. Phase 2 involved collection of empirical data on ACM in the simulator for Air-to-Air Combat (SAAC) at Luke AFB. Data collection lasted for five weeks during which a total of 405 engagements were flown.

Each week a total of six F-4 pilots of varying training and experience levels took part in data collection over a period of three days. The first day of data collection during each week was devoted to determining the entry skill level of the participants. After filling out a background questionnaire, the pilots flew a set of pretest exercises. These exercises consisted largely of the Vought Corporation Good Stick Index (GSI) exercises (USAF, 1977). Each participant flew five attacks on a non-reactive target flown on instruments by a project pilot. Three of these were head-on attacks, one was a cine-tracking exercise, and one required a missile shot and a high deflection gun pass. These exercises were chosen because they represented an existing test of basic ACM skill level and because they would allow comparison of this data base with the existing Vought Corporation data base.

The second and third days of data collection each week consisted of a round robin series of engagements among the six participants. Every pilot flew against each of the other pilots in the group three times in F-4 versus F-4 competition. Three initial setups were used in which neither pilot had an advantage. On the third day of competition the two most experienced ACM pilots flew six engagements of dissimilar air combat with the simulator configured as F-4 versus MIG 21.

Data were recorded on 67 different variables for each cockpit. These included measures of relative aircraft position, energy states, weapons switchology, and control position and inputs. As another measure of pilot performance, the project pilots who were experienced ACM instructors observed each engagement and at the end of each day rated the participants on such characteristics as aggressiveness, situation awareness, application of basic fighter maneuvers (BFM) and overall ACM ability. Finally, after their last engagement, each of the participants were asked to rank order all of the pilots in their group in overall ACM performance. The project pilots also completed this ranking.

Phase 3. In Phase 3 an analysis of the Phase 2 data was performed. The engagements analysis data base contained well over 19 million data points (67 parameters for each of two cockpits, sampled an average of 360 times during 405 engagements), exclusive of control stick measures (which were sampled an average of 1800 times per engagement).

The data analyses were performed at three different levels of complexity, (a) definition of skill level, (b) engagement success versus skill level and (c) tactics versus skill level.

The first analysis, definition of skill level, was performed to insure that the initial assignment of pilots into groups of different skill levels was valid, because all subsequent analysis of data would presuppose that Group 1 pilots were in fact less skilled than those in Group 2 or 3. Sources of data included pilot background questionnaires, pretest performance peer ratings, project pilot ratings and actual engagement outcomes. The engagement success versus skill level analysis probed the data for measures which could be used for an entire engagement. Also, the analysis asked (a) whether the three setup conditions were equivalent, i.e., could they be collapsed to increase the replications, and (b) whether the pretest performance was predictive of free-engagement performance, i.e., could the canned pretest be used as a skill indicator.

The kind of measures which were characteristic of engagement level data included the following: (a) engagement outcome (win, lose or draw); (b) the percentage of time each pilot was in an offensive mode with advantage (low aspect and angle off), offensive with no advantage (head-on gun pass), in a neutral position, or at a disadvantage, and (c) global measures such as fuel flow, airspeed, throttle position, speed brake deployment and the amount of time the opponent was in visual contact.

It is important to note that the data for an individual pilot cannot stand alone. Each engagement had to be viewed as a confrontation between a pair of pilots. Thus, the analysis had to indicate both the metrics of performance and the relative skill level of the opponent.

A final tactics versus skill level analysis was an attempt to explore diagnostic measurement -- measures which could aid the instructor in determining why a student won or lost an engagement. The approach to the tactics analysis sought a method of describing what happened within an engagement that reflected pilot tactics, but did not require the use of classic BFM profile matching. The approach also sought a way to partition a whole engagement into factors within the engagement that might otherwise cause variability at the engagement level of analysis.

An analysis of the BFM and ACM curriculum revealed that students were taught to look for relative positions and rates of change of the two aircraft involved in an engagement. Rules for each possible combination of positions and closure rates are taught. Since relative positions and rates of the two aircraft were sampled every half-second, it was possible to subdivide the data according to the values of these variables over a whole engagement. This kind of structure is directly related to the way ACM is taught and should have meaning to instructors when the format is explained.

One (of many) possible subdivisions was a three dimensional matrix formed by sight angle, aspect angle and slant range. The matrix thus formed was called TACSPACE (or Tactical Space), and it contained 125 "boxes" which were defined by all possible combinations of five different values of sight angle, aspect angle and slant range. The measures which had been defined for the engagement level (i.e., fuel flow, aircraft attitudes and rates, altitude, speed, etc.) were placed in each box. In addition, calculations were made on the amount of time spent in each box and the number of times the box was entered. It was assumed from the onset that 125 cells in the TACSPACE matrix would be too many for a finalized measurement structure. For initial research, however, it was necessary to form this many cells to explore the performance space and to provide data which would support simplification.

Final Comment on Technical Approach. Frequently, it is asked: Why is it useful to have several measures of ACM performance when the ultimate criterion is the outcome of the fight? Certainly, the outcome is important; but, as discussed in Section II, there are many attributes of ACM performance that contribute to the outcome. These intermediate performance factors provide information which can be used (a) to diagnose why a particular outcome occurred, and (b) to guard against the reward of behavior that might be simulator specific and/or inappropriate in the air. For these reasons, many measures are sought to capture intermediate performance (as described in Sections III and IV), and the whole approach is guided by the assumption that the results of this study must be validated in the air.

II. PHASE 1: PROBLEM ANALYSIS

During Phase 1 an analysis was performed to develop information which would lead to the specification of a candidate set of performance measures and an algorithmic structure to use those measures. The analysis was guided by our past experience in performance measurement development and provided a framework for the empirical research during Phases 2 and 3. The results of this analysis are summarized below in terms of (a) current training and evaluation, (b) possible future training and evaluation, (c) elements of pilot ACM performance, (d) existing ACM models, and (e) the technical challenge.

Current Training and Evaluation

Students in F-4 Replacement Training Unit (RTU) training at Luke AFB begin their curriculum with basic flight and instrument training. They then begin training in Basic Fighter Maneuvers (BFM) where they are taught maneuvers to be used in attacking a target flying a known, predictable profile. BFM training involves a single attacking aircraft and a single target aircraft and is used as an introduction to ACM.

Training in ACM involves multiple aircraft attacks on a counter-offensively maneuvering target. This prepares the student for the kind of multiple aircraft engagements envisioned in current tactical doctrine.

Much of the academic and practical portion of BFM and ACM training involves learning the rules about proper responses to various adversary maneuvers. BFM students learn to perceive the aspect angle, angle-off, and closure rate of the opposing aircraft. They learn the proper maneuver for each possible combination of these three variables in order to reduce aspect and angle-off and to optimize closure rate or to maintain a desirable offensive position.

ACM training involves the same kinds of rules. One major difference, however, is that the opponent is maneuvering unpredictably. For this reason, the appropriate action usually changes before a maneuver is completed and the ACM pilot must change to a different maneuver. A successful ACM attack usually involves initiating portions of several of the BFM maneuvers rather than one single completed maneuver.

Evaluation of BFM/ACM performance during training is almost totally subjective. At the completion of a maneuver, the instructor provides a score of 0, 1, 2, 3, or 4 based on performance of the maneuver as a whole. The standards for assessment of the score provided by the instructor are:

0 - Indicates a lack of ability or knowledge.

1 - Performance is safe but indicates limited proficiency. Makes errors of commission or omission.

2 - Performance is essentially correct. Recognizes and corrects errors.

3 - Performance is correct, efficient, skillful and without hesitation.

4 - Performance reflects an unusually high degree of ability.

Many instructors indicated dissatisfaction with this method of assessing pilot performance, stating that not enough anchoring was provided to give them a good idea what each score meant. They felt, for example, that they could tell when a student was flying a maneuver deserving a score of 2, but could not readily verbalize why a score of 2 was given. They indicated a need for a more useful and diagnostic grading system.

Possible Future Training and Evaluation

In an attempt to eliminate many of the problems in current training and evaluation methods, the Fighter Weapons School (FWS) at Nellis AFB is developing an experimental program to train ACM pilots. Although students come into this program with varying amounts of ACM training and experience, all students are started at the beginning of the program and work through the syllabus at their own speed. This is in marked contrast to the traditional curriculum which prescribes a given number of hours and sorties to train each phase with little flexibility in the training times.

In contrast to the usual 0 to 4 scoring, all evaluation is on a criterion referenced pass-fail basis. Student advancement is determined by performance while flying specified maneuvers against a predictable target. If he is successful, the student advances to the next step in the syllabus; if not, he remains in the phase until he can pass the test. This appears to provide a promising advance in training and evaluation methods and may provide a basis for the syllabus of future ACM training at the RTU level.

It is important to note that FWS personnel have recognized their measurement problem. They have taken the approach of carefully controlling many setups and required maneuvers, then measuring the outcome. The setups are organized so that the trainee must demonstrate proper skill in (a) aircraft handling, (b) situation awareness and (c) assessment of turning room to be able to arrive in a firing position at the end of the maneuver. Given a carefully conceived gradation of setup exercises, the failure of a student to arrive in a firing position provides an avenue for performance diagnosis. This is one approach to improving performance information. Another approach is to try to empirically measure what the two aircraft are doing. FWS personnel recognize the potential power of the ACMI for training performance measurement. However, FWS has yet to develop ACMI for routine training, probably because the job is not a trivial one.

Elements of Fighter Pilot ACM Performance

In order to obtain a list of possible measures of ACM performance which were sensitive to skill level, a number (7 in-depth and 15-20 informally) of Air Force RTU Instructor Pilots, Fighter Weapons School Instructor Pilots, and ISD personnel were interviewed. These experts were questioned about current methods of assessing performance on BFM and ACM in their units. They were asked what characteristics distinguish the high skill level ACM pilot from the low skill level ACM pilot and how these characteristics can be observed and, hopefully, measured during an ACM engagement. From these interviews, a number of potential measures which may differentiate between fighter pilot skill levels were isolated.

Wins Engagements. The most intuitively obvious measure of fighter pilot skill level is the number of kills achieved by the pilot in real or simulated ACM engagements. It is natural to assume that the better pilot will achieve more kills and win more engagements than will the less apt pilot. While this measure is probably the most common criterion in use today, several problems are inherent in its employment.

In the modern air combat arena, sophisticated electronic equipment has eliminated much of the need for the kind of maneuvering associated with the classic ACM engagement. During the recent conflict in Southeast Asia, a high percentage of the kills recorded by both sides involved relatively long range missile shots with little or no high performance maneuvering taking place. The level of ACM skill of the pilots involved was only a minor factor in the outcome of these engagements. Now, with the advent of the all-aspect missile, pilot skill in high performance ACM may become even less a factor in outcomes of actual aerial engagements.

During actual combat, kills may be a relatively low-frequency occurrence. When dealing with such low-frequency events, chance plays an inordinately large role. Given a group of pilots with identical skill levels and similar opportunity, there will be large differences in the number of kills obtained, strictly as a result of chance.

During simulated ACM, the number of kills may also provide an unrealistic assessment of the pilots' potential for achieving kills in the combat environment. Such measures taken during simulated combat are contaminated by the absence of any real hazard. Simulated ACM, therefore, does not account for differences in the potentially important factor of risk-taking behavior.

This discussion does not attempt to show that winning engagements is totally worthless as an indicator of ACM skill level. The ability to win engagements may be the single most important measure of pilot skill level. The measure, however, can be contaminated by the presence or absence of many other variables and these potential confounding variables must also be examined in order to obtain a more valid measure of the pilot's ACM performance.

Energy Management. The pilot who manages his energy well probably has a significant advantage over the pilot who manages his energy less well. A recent factor-analytic study (Deberg, 1977) confirmed that energy measures provide the most important single measurement class to be used in empirical descriptions of an air combat engagement. The study did not attempt to show, however, how the outcomes of engagements are influenced by judicious energy management.

Aggressiveness. The trait most frequently cited by the experts during interviews was aggressiveness. The aggresive pilot spends little time in a neutral situation. He acts boldly making his opponent react to his moves. He is eager to get into the fight quickly and may, therefore, tend to employ lead pursuit, rather than pure or lag pursuit, when closing on his adversary. Some of the experts predicted a strong correlation between aggressiveness and the use of the roll axis of the aircraft. An important weapon of the aggressive pilot is intimidation. He makes feinting moves often and will occasionally point his aircraft nose at the opponent for a high angle gunshot, more for the psychological effect than as a serious kill attempt.

The aggressive pilot probably makes more use of the vertical dimension for maneuvering than those who are less aggressive. This use of the vertical results in better control of energy states than is possible for a pilot who is maneuvering strictly in the horizontal, as well as providing another dimension to the information the opponent must consider.

Situation Awareness. The highly skilled ACM pilot maintains a keen awareness of the changing situation around him. He knows where he is in relation to the terrain, friendly forces and opposing forces. He is aware of where his opponent is and what he is doing. He knows the relative velocities and velocity rates of his aircraft and that of his opponent. He is able to extrapolate his position and that of his opponent into the future in three dimensions. From this extrapolation, he knows when he is about to enter the effective envelope of one or another of his weapons and already has that weapon selected when he enters the envelope. Finally, the experienced, skilled ACM pilot develops what was described as a "sixth sense" concerning his fuel status. Rather than having to divert his attention into the cockpit to constantly monitor his fuel supply, he is almost instinctively aware of approaching "bingo" fuel.

Situation awareness may be one of the most difficult characteristics to measure empirically. It is only readily noticed during moments when it fails and an aircraft hits the ground, turns in the wrong direction, runs out of fuel, or commits some similar blunder. Good situation awareness is reflected by an absence of these types of errors. It is probable that one element of situation awareness is the ability to efficiently timeshare attention between the many aspects involved in ACM.

Knowledge of ACM. The winning ACM pilot spends a large amount of his ground time studying and thinking about ACM. He knows all the available information about his aircraft, weapons and tactics and about the opponent aircraft, weapons and tactics. He is especially aware of the effective envelopes of his weapons. Because of this knowledge, he fires a larger percentage of ordnance with a high probability of kill.

Piloting Skill. Much useful information about a pilot's level of ACM skill can be found by examining the way he flys the aircraft. The highly skilled ACM pilot is able to fly the aircraft to the limits of its performance parameters when necessary. It is important to note that this does not mean that he constantly maneuvers the aircraft at the maximum angle of attack, but that he is able to maximize the tradeoff involved between performance and energy.

Probably some information can be obtained by examining the pilot's control inputs. First, the highly skilled pilot is probably more active in his thrust control than is the less skilled pilot. The skilled pilot is constantly shifting from idle power, to MIL power, to afterburner. The less skilled pilot is more likely to remain at a relatively high power setting throughout an engagement.

There was some disagreement among the experts about whether control smoothness provides an indication of ACM skill. There was consensus that control smoothness, especially aileron control, is essential at high AOA to prevent loss of control. In low AOA regimes the importance of smoothness is less clear and this question warrants investigation.

Application of BFM. BFM is used largely to maneuver into weapons parameters against a non-maneuvering target. BFM, however, forms the foundation on which the maneuvers during an air combat engagement are based. The highly skilled ACM pilot is able to effectively apply BFM, using segments of several maneuvers, in combination or in smooth succession, in order to achieve a valid ordnance delivery. One important rule of thumb in successful application of BFM is that the attacker should never point his aircraft's nose at the foe until within weapons parameters and ready to fire. A common tendency among less skilled and experienced ACM pilots is to point the aircraft at the opponent early in the engagement and to attempt to decrease aspect angle and angle-off while still pointing at the opponent.

Existing Measurement Models

Three different classes of measurement models currently in use were examined, (a) the Automated Maneuvering Logic, (b) the Good Stick Index, and (c) the Air Combat Maneuvering Range or Air Combat Maneuvering Instrumentation.

Automated Maneuvering Logic (AML). This is a controller type of model which has been described by Hankins (1975) and by Burgin, Fogel and Phelps (1975). The AML has been implemented on the Differential Maneuvering Simulator at the NASA Langley Research Center and on the SAAC where it allows a computer to fly one cockpit, simulating a reasonably skilled fighter pilot, against a human opponent flying the other cockpit.

The actions of the AML are based on 12 decision rules concerning variables such as the basic position of the two aircraft, the visual contact potential of the two aircraft, the line of sight angle of the two aircraft, the firing position, the closure rate and the energy level. These decision variables are then supplemented by information on ground avoidance to prevent the AML from flight into terrain in mid-maneuver.

The decisions of the AML are based on a 5 second look-ahead. The computer continuously predicts the effect, 5 seconds in advance, of each of many possible courses of action. The action that will provide the best offensive advantage at the 5 second point in the future is then undertaken. The AML may not duplicate precisely the actions of a highly skilled ACM pilot. There is little gamesmanship and strategy involved in its actions. It simply takes the action most likely to bring it behind the other aircraft and into firing position. While this is not necessarily the optimum strategy, the AML does tend to win more engagements than it loses.

No detailed performance analysis of the AML has been attempted. Evaluations of AML engagements have been on the engagement level. These include such measures as number of kills, number of times killed, and the percentage of the engagement flown with an advantage.

Good Stick Index (GSI). This more empirically oriented measurement model was developed by Vought Corporation to evaluate the TAC ACES I training program (USAF, 1977). During performance assessment using the GSI, the pilot being tested flew attacks against a target flown in a predetermined pattern by an IP. One of the attacks flown for the record was a gun-tracking exercise in which the attacker was positioned behind the target and was required to close to gun range and then get as many gun hits as possible while the target maneuvered. In the other kind of attack flown for the record, the aircraft were set up head-on and the attacker was required to kill the target as quickly as possible, using any of the weapons at his disposal. Again, the target aircraft flew a standard profile.

The GSI scoring was based on four major measurements, (a) tracking error, (b) time in the pointing angle envelope, (c) time to first kill, and (d) offensive/defensive time. Tracking error and time in the pointing envelope were scored on the gun-tracking exercise while time to first kill and offensive/defensive time were scored on the attacks beginning with head-on setups. Tracking error was defined as the average mil error when the slant range was less than 3000 feet with the trigger depressed. This measure was used to "reflect the ability to maintain a good gun-tracking solution." Time in the pointing angle envelope was defined in terms of range and angular criteria and "provided a measure of one's ability to maintain a close gun-tracking solution." Time to first kill was the elapsed time between the start of a head-on engagement and the time a kill was recorded. This measure was selected because it "represented the ability of the student to maneuver in the most expeditious manner to a firing envelope and correctly launch a weapon." Finally, offensive/defensive time was the difference between the offensive and defensive time divided by the time of engagement (180 seconds). This parameter was used to provide credit for maneuvering that allowed the attacker to threaten the target and to penalize for allowing the target to gain an advantage. These data were then arbitrarily weighted and summed in order to provide a single total pilot score between 0 and 1000 points.

Several problems are inherent in the way the GSI is currently used. First, the four raw scores are weighted according to expert opinion. There is no empirical verification that the weights chosen are the optimal value. Second, there is a relatively large amount of unexplained variability in the GSI. A follow-up project is currently in progress at Vought which is exploring these potential problems (Moore, Madison, Sepp, Stracener and Coward, 1979).

Finally, the application of the GSI currently provides no diagnostic information to the instructor. A single score is given at the end of a set of sorties which may give an indication of overall ACM performance.

Air Combat Maneuvering Range or Air Combat Maneuvering Instrumentation (ACMR/ACMI). These systems have not been used to their full potential for training. In the strictest sense, the ACMR/ACMI is a simulator of weapons delivery. The system electronically tracks up to eight aircraft and, through telemetry, is able to compute precisely all interrelationships between these aircraft. When one combatant launches a simulated missile or gunshot, the ground-based computers calculate the path of the ordnance and, after adding a factor for the potential unreliability of the weapon system, indicates whether the target aircraft was killed.

To make these calculations, the ACMR/ACMI must collect and store huge amounts of data concerning aircraft position, states and switchology. This data pool has been used for little other than to provide a playback capability during debriefing. Recently, however, some attempt has been made to more fully exploit the ACMPM capability of the ACMR/ACMI (Simpson, 1976; Simpson & Oberle, 1977). This effort has produced the software for the calculation of an ACM Performance Index (PI) based on aircraft relative positions and position rates, aircraft capabilities, and various energy related measures. This approach has shown considerable promise during preliminary testing but no formal empirical validation of its ability to discriminate between pilots of different skill levels has been completed. Further, the algorithm does not account for several potentially important variables describing the way the aircraft is flown, for example, control activity.

The ACMR/ACMI, because of its data handling and storage capability, can provide the basis for an excellent ACMPM system. With the refinement of ACMPM technology, the ACMR/ACMI could be used for the assessment of pilot performance as well as being the effective testbed for aircraft and tactics it now represents. ACMPM technology, however, still lags far behind the available hardware technology.

The Technical Challenge

Several aspects of the ACM task make it different from other inflight tasks and make pilot performance measurement a real challenge.

No Profile. Most previous empirical performance measurement work has been conducted for instrument flight or specific visual maneuvers in which the desired profile of the aircraft was well known and for which performance criteria of some sort have been established. In ACM there are no fixed profiles against which to measure error, the reference datum is constantly changing, and performance criteria are vague.

Existing models such as Automated Maneuvering Logic (AML) offer the possibility of a profile of sorts, or at least a logical decision network, but no claims are made that the models are either representative of what a pilot does, or an optimum solution. They also disregard what may be important elements of the job such as gamemanship, intimidation and faking.

ACM Is Reactive. The dynamic relationship between the two aircraft in 1v1 is constantly changing because each pilot continously maneuvers to counteract the maneuvering of the other. The performance that results is a composite of a pair of pilots and aircraft with mutually exclusive objectives.

Dissimilar Aircraft. The performance and weapon system capability of the opponent aircraft are important tactical considerations. This implies that pilot performance should be different when maneuvering against different aircraft. If pilot performance is different, the measurement model that results from an empirical study should reveal the nature of the differences. It is important, therefore, to include at least a sample of dissimilar aircraft engagements during data collection for measurement model development.

Pilot Skill Level. In previous measurement work, the method of selecting and weighting final measures of training performance dependec on identifying two or more groups of pilots, whose skill level was beyond question or was established by empirical measurement of their performance. The same logic, to collect data on pilots of different skill levels, is important to the development of training performance measurement for ACM. Unfortunately, there is no good way to quantify pilot skill in ACM at the present time. In fact, that is why this work is so important.

Summary

The Phase I Problem Analysis consisted of (a) a review of current and future training, (b) an analysis of the elements of fighter pilot performance which were judged to be important by experts, (c) a review of existing models of ACM performance and (d) an analysis of the factors of the ACM task which create a major technical challenge for performance measurement. The results of this work guided the data collection (Phase 2) and analysis (Phase 3) approaches which are described in the remainder of this report.

III. PHASE 2: DATA COLLECTION

Pilot/system performance and rating form data were collected while pilots of different experience levels flew ACM against each other on the Simulator for Air-to-Air Combat (SAAC). The equipment and procedures used are described below in terms of the (a) simulator, (b) pilots, (c) general procedures, (d) pretest procedures, (e) free engagement procedures, and (f) raw data collected.

Simulator

SAAC is located at Luke AFB, Arizona, and is used for training air-to-air combat. It has two F-4 cockpits controlled by a common computer system which allows free air combat engagements between two pilots.

The visual system for each cockpit has a 296^{o} horizontal by 150^{o} vertical field of view. The visual scene is produced by a combination of a background scene and aircraft camera-model superimposition. The scene generated is displayed on Cathode Ray Tubes (CRT's) viewed through optical glass windows which provide continuity of the full visual field focused at infinity. The viewed area is monochromatic with a greenish cast. An analog system provides a representation of the earth, horizon, and sky. The earth representation consists of squares, 1/2 nautical mile on a side, displayed in four shades of gray. Each adjacent square is a different shade. Horizon appears as the top of a simulated haze band between the earth and the sky. The sky is homogenous except for a sun image. While the brightness of the sun is not simulated, i.e., a pilot cannot hide in the sun, it can be used effectively for defense against heat-seeking missiles.

Two camera-model systems provide each pilot with a display of the opposing aircraft. Each model is approximately .3 m. in length mounted on a gimbal. The gimbal, under control of the computer system, moves the model relative to a television camera so that the model is viewed by the opposing cockpit in the air. The aircraft image is electronically superimposed on the visual scene at a higher brightness than the background. The pilot sees the target aircraft superimposed over the earth, sky, horizon and moving relative to the background.

Each cockpit also has a g-seat system which contains 31 inflatable bladders under computer control. Inflation and deflation of the bladders provides sustained acceleration cues to the pilot. Cues to sustained g-forces are provided through a g-suit system identical to those used in actual aircraft. The g-suit is inflated and deflated by a compressed air system also controlled by computer command.

Although each cockpit is mounted on a six-degree-of-freedom synergistic motion system, motion was not used for this study. In the judgement of the current users of SAAC, the visual, g-seat and g-suit systems produce sufficiently vivid motion cues to make operation of the platform motion systems unnecessary.

SAAC is controlled by a Xerox SIGMA 5 Computer System with three central processing units. An operator/instructor controls the simulator through a console equipped with an Adage graphic display system which portrays a three-dimensional view of the two simulated aircraft. In addition to the F-4 characteristics, one of the cockpits can be operated with flight characteristics similar to the MIG-21 aircraft. Operation of the radar system, which in the actual F-4 is handled by a Weapons System Officer (WSO), is controlled by the computer system. All aircraft flight systems and weapons controls available in an F-4 are included and operate in each of the simulator cockpits.

<u>Pilots</u>

Thirty Air Force pilots, all F-4 qualified, participated in the study. A major purpose of the study was to develop measures which are sensitive to differences in air combat skill level. Accordingly, the pilots were selected for assignment to one of three proficiency groups.

Pilots assigned to Group 1 were the pilots with the lowest recent experience in ACM. Pilots in this group included students who had just completed the ACM phase of the Replacement Training Unit (RTU) course. It also included some more experienced pilots who had been assigned to ground attack units and had little or no recent ACM training.

Pilots assigned to Group 2 were currently undergoing ACM training in the TAC ACES program, an intensive course in air-to-air combat. The pilots in the group typically were recent RTU graduates. Most pilot skill differences between Group 1 and Group 2 can be attributed to the training received in the TAC ACES program.

Pilots assigned to Group 3 were those with the highest skill and most experience in ACM. The group consisted largely of TAC ACES instructor pilots and all pilots in the group had considerable ACM experience in the F-4 aircraft and in the SAAC simulator.

Measures of the training experience levels of the pilots in the three groups are shown in Table 1.

TABLE 1. PILOT EXPERIENCE DATA

Experience Factors	Skill Level Group 1	2	3
Median:			
Age	30	24	29
Total Flight Hours	1040	325	1675
F-4 Hours	672	90	1375
Fighter Hours	672	90	1500
Flight Hours Last 6 Months	75	90	120
Total ACM Engagements	35	23	275
Air-to-Air Simulator Engagements	5	10	60
Engagements Last 6 Months (Simulator and Actual Aircraft)	12	23	50
Number:			
Attended TAC ACES Courses	2	10	7

General Procedures

ACM data were collected 3 successive days a week for 5 consecutive weeks. Six different pilots participated each week. Procedures and conditions for data collection were identical during each of the 5 weeks. Table 2 summarizes the data collection.

On Day 1, the pilots were briefed on the background and purpose of the study. Those pilots who had not previously flown the SAAC were given an audio-visual orientation and briefing on the SAAC. The briefing was followed by approximately 30 minutes of familiarization flight instruction in the SAAC by one of the project pilots. Day 1 activities were concluded by 5 successive pretest engagements which are described later.

TABLE 2. SUMMARY OF DATA COLLECTION

Lapsed time of data collection	5 weeks
Approximate duration of each run	3.5 minutes
Number of pilots in each group	10
Total number of pilots	30
Number of pilots used each week (2 from each group)	6
Number of pretest engagements	30 per week
Number of 1v1 engagements F-4 configuration	45 per week
Number of 1v1 engagements F-4/MIG-21 configuration	6 per week

On Day 2 and Day 3 the pilots flew round robin ACM engagements. Three successive engagements were flown in each sortie, with a 1 or 2 minute break between engagements while the simulator was reset. Each pilot flew 2 sorties on one day and 3 sorties on the other. With few exceptions, the pilots had a 20 to 40 minute break between each sortie. Except for different setup conditions and schedules, the data collection procedures were generally the same for all three days.

One of the two project pilots operated the console, communicated with subject pilots in the cockpits and additional project personnel performed manual data recording. After the subject pilots were in the cockpits and ready, the project pilot read the instructions for each engagement to the pilots, checked that the initial setup conditions (which were preprogrammed) were correct and started the engagement by pressing a control button on the console. While the instructions were being read, one of the project personnel entered the engagement number on a set of thumbwheels to mark the data tape and started the data recording on the nine-track magnetic tape when the engagement began.

Each engagement ran for a maximum of approximately 3.5 minutes. The maneuvering could be observed in real time on a graphic display which portrayed the actions of the aircraft in three dimensional perspective. The display also contained a number of relevant variables such as airspeed, range between the aircraft and altitude. One of the project personnel made notes on events such as restarting an engagement, over-g (exceeding the g limits of the aircraft) and the outcome of the engagement. At the end of each engagement, conditions were reset for the next engagement and the procedure was repeated until the end of the engagement sequence.

At the end of Day 2 and Day 3, the project pilots, based on their observations of the console display, filled out a rating form for each of the subject pilots. At the end of Day 3, the project pilots also rank ordered the 6 subject pilots in terms of their demonstrated ACM skill. Each of the subject pilots filled out an identical ranking, including themselves, based on their experience of flying against each of the other pilots.

Pretest Procedures

The purpose of the pretest was to document the entry skill level of the pilots while flying against a maneuvering, but non-interactive target. Each pilot flew five times against a target aircraft which followed a predetermined flight profile on instruments without regard to the maneuvering of the attacking aircraft. The five engagements were subsumed under three maneuvers which had different initial conditions and objectives. Maneuvers I and II involved only one engagement each. Maneuver III involved three engagements with the same initial conditions but different maneuvering by the target aircraft. For all maneuvers, one of the project pilots flew the target aircraft through the specified profiles. Subject pilots were not allowed to observe the console display while waiting for their scheduled engagements.

Maneuver I. The purpose of Maneuver I was to obtain data on the ability of the pilot to hit the target aircraft with 20 mm cannon fire during a brief engagement. The engagement started with the attacking aircraft a short distance behind the target aircraft. Specific initial conditions are shown in Table A1 (in Appendix A). The instructions to the attacking pilot and the target pilot are shown in Table A2. The maneuver ended when the target pilot called "cease maneuver."

Normally, the SAAC stops when an aircraft is "killed" by gun or missile fire. This can be prevented, however, by use of a KILL OVERRIDE feature which counts cumulative hits but does not stop the simulation. KILL OVERRIDE was on during Maneuver I to allow tallying of the total number of 20 mm cannon hits on the target aircraft.

Maneuver II. The purpose of Maneuver II was to obtain data on the ability of the pilot to hit the target aircraft with both heat-seeking missiles (AIM-9J) and 20 mm cannon fire. The engagement started with the attacking aircraft well behind the target aircraft. The target remained straight and level until informed by the console operator that the attacker had closed to the 6,000 foot range. The target then began to maneuver. The specific initial conditions for this maneuver are shown in Table A3. The instructions to the attacking pilot and the target pilot are shown in Table A4. The maneuver ended after the attacking aircraft had passed the target aircraft and the separation between them exceeded 6,000 feet. KILL OVERRIDE was on during this maneuver.

Maneuver III. The purpose of Maneuver III was to obtain data on the pilot's ability to expeditiously kill the target aircraft using heatseeking missiles or 20 mm cannon fire. Three engagements, with the same starting conditions, were flown. The engagement began with the attacking and target aircraft passing head-on. The target aircraft then maneuvered according to the prescribed profile for the engagement. The exact initial conditions for this maneuver are shown in Table A5. Instructions given to the attacking pilot and the target pilot are shown in Table A6. KILL OVERRIDE was off for these three engagements. The engagement ended when a kill occurred or bingo fuel (i.e., minimum allowable fuel remaining) was reached. If a kill did not occur, the length of an engagement was approximately 3.5 minutes.

Free Engagement Procedures

A round robin of free engagements was flown among the six pilots participating during each week. Every pilot fought each of the other five pilots in three successive engagements. This round robin took place over the second and third day of data collection. A pilot usually fought two other pilots on one day and the remaining three pilots on the following day, or vice versa.

In addition, on the third day the two pilots considered to be the most experienced flew two additional sorties of three engagements in which one of the aircraft was programmed to have the same flight characteristics as a MIG-21. Each of these two pilots would fly one sortie in the F-4 configuration and one in the MIG configuration. These pilots all had prior experience with MIG-21 dynamics on the SAAC.

Different initial conditions were used for each engagement in the sortie of three. The same three sets of initial conditions were used, however, for each sortie of similar aircraft engagements (F-4 vs. F-4) and the two sorties of dissimilar aircraft engagements (F-4 vs. MIG). The only exception was that the weapons available for the dissimilar aircraft engagements were different than those available for the similar aircraft engagements. Tables A7 to A9 show the initial conditions of both the similar and dissimilar aircraft engagements. The object of each engagement was to kill the other aircraft.

For the similar aircraft engagements each aircraft had a full load, 640 rounds, of 20 mm cannon ammunition and two heat seeking missiles (AIM-9J). Only heat missiles and no radar missiles were provided in order to force the pilots to engage in close maneuvering. Radar missiles were allowed for the F-4, however, for dissimilar aircraft engagements because of the maneuvering advantage of the MIG-21.

Bingo fuel limits were set to allow engagements to run approximately 3.5 minutes unless a kill occurred first. A few rules were established for the engagements which either furthered the purpose of the study or overcame peculiarities of the SAAC. These rules were:

1. Upon reaching bingo fuel, the pilot had to call it out to the console operator, separate from the engagement and head in the "home" direction, southerly for one aircraft and northerly for the other. If the pilot failed to call bingo fuel and separate, a kill was credited to the other pilot. The engagement did not end until a kill occurred or <u>both</u> aircraft reached bingo fuel.

2. Beam and head-on heat missile kills were not permitted although the SAAC would allow them. That is, a kill was not allowed if an aircraft had an aspect angle 90° or greater from the tail and a missile was fired at him. In these cases the console operator would momentarily invoke the KILL OVERRIDE function which would prevent the missile from killing the aircraft.

3. G-forces were an important consideration in the engagements. At between 6 and 6.5 g's, the visual display would darken to simulate blackout. If the pilot pulled 8.5 g's a warning buzzer would sound and the console operator reminded the pilot he had over-g'd but the engagement would continue. If a pilot pulled 9.5 g's or more, he would have over-stressed an actual aircraft and therefore a kill was awarded to the other pilot under these conditions.

4. If a pilot flew into the ground during the engagement, a kill was awarded to the other aircraft. If both aircraft flew into the ground, a dual kill was declared.

5. To achieve a kill with the 20 mm cannons a total of 3 hits had to strike the other aircraft. Hits on non-critical aircraft surfaces were scored as fractions of a hit.

6. If, during the dissimilar aircraft engagements, the 2 aircraft separated by 5 miles or more, they were required to close to a distance of 3 miles before a weapon could be fired. This rule prevented the F-4 pilot from opening to a large distance and firing a radar missile during the dissimilar aircraft engagements.

<u>Raw Data Collected</u>

Four kinds of data were collected during the study. There were: (a) continuous samples of aircraft system variables; (b) a computer printout of selected variables; (c) engagement outcomes and events; and (d) evaluations of ACM performance in the form of pilot ratings and rankings.

Aircraft Variables. The most comprehensive data were taken by automatic recording of 67 aircraft variables from each aircraft. The basic data sets included aircraft position, altitude, airspeed, orientation, angle of attack, g-forces, fuel flow, control positions and force applied, aircraft control and armament switch settings, radar functions employed, weapons fired and hits. Table C2 is a complete listing of the variables recorded. All variables were sampled twice per second (2 Hz) except for control positions and forces which were sampled ten times per second (10 Hz).

The data were recorded on nine-tract magnetic tape in digital form. Data recording was started and stopped manually at the beginning and end of each engagement by one of the project personnel.

Scoring Print. The SAAC has the capability to print a time-marked history of major aircraft variables and events that occur during an engagement and summary data at the end of the engagement, i.e., who killed whom, the kill weapon, the number of rounds of each weapon expended, and the total engagement time. The information available in the Scoring Print is shown in Table 3. Scoring Print information was obtained at the same time as the tape recorded data described above. While much of the data obtained by these two automatic methods is the same, the Scoring Print provided a succinct summary of the key aircraft variable and event occurrences during an engagement and aided interpretation of the other data.

Engagement Outcomes and Events. During the fixed profile pretest engagements, data on weapons fired, number of hits, and kills were manually recorded. The fixed profile engagements were constructed primarily to determine how rapidly and accurately a pilot could use a 20 mm cannon and heat-missles to hit the target aircraft. The data were recorded by hand to provide a quick summary of each pilot's performance during the five fixed profile engagements. A copy of the data recording form is shown in Figure A1.

During the free engagements, outcome data were manually recorded. A free engagement could end (a) in a draw because bingo fuel was reached, (b) one aircraft had killed the other with weapons, or (c) one or both aircraft were killed from exceeding g limits, hitting the ground, or ignoring bingo fuel requirements.

The outcome and cause were recorded on a matrix form which, when completed, summarized the outcomes of the three engagements between all 15 possible pairs of pilots. These data were used to provide information to each pilot on his own performance and the performance of the other pilots, and also were used for partitioning the automatically recorded data in terms of engagement outcome for analysis purposes.

TABLE 3. SCORING PRINT INFORMATION

I. Header Information

- A. Pilots' names
- B. Aircraft type
- C. Date
- D. Clock time

II. Time Marked Information

- A. Both aircraft
  1. Altitude
  2. Mach
  3. g
  4. Line of sight to other aircraft
- B. Between aircraft
  1. Range
  2. Range rate
  3. Track error
     - a. Azimuth
     - b. Elevation
- C. Significant activities or status
  1. Radar lock-on
  2. Loss of radar lock-on
  3. Weapons selected
     - a. No weapons ready
     - b. AIM-9
     - c. AIM-7
     - d. Guns
  4. Heat missile fired
  5. Radar missile fired
  6. Guns fired
  7. Trigger pulled - no weapons ready
  8. Kill - missile
  9. Kill - guns
  10. No kill

TABLE 3. SCORING PRINT INFORMATION (Cont.)

a. Missile - (reason for miss, boresight angle, range, etc.)
b. Guns - number of rounds fired, number of hits

III. Engagement Summary Information

A. Engagement time

1. Elapsed seconds: total
2. Elapsed minutes: seconds total
3. Time of first kill - weapon (guns, AIM-7, AIM-9)

B. Weapon status

1. AIM-7: number available/number expended
2. AIM-9: number available/number expended
3. Guns: rounds expended/number of hits

Ratings and Rankings. At the end of each day of free engagements, the 2 project pilots, both ACM instructors, rated each of the 6 pilots on five factors: (a) decisiveness, (b) situation awareness, (c) maneuvering, (d) aggressiveness, and (e) overall ACM performance. A 5 point linear scale (see Figure A2) was used for rating each factor. The criteria definitions were the same as those used by ACM instructors for evaluating ACM pilot students and therefore were familiar to the project pilots.

At the end of the last day of free engagements, each of the participating pilots rank ordered the six pilots, including himself, in terms of demonstrated overall ACM ability. The 6 pilots were told that the ranking would be strictly confidential.

Data Analysis Facilities. The raw data were duplicated and transported to the Naval Training Equipment Center for analysis using a SIGMA-7 computer. The two principal reasons for using this facility were (a) the investigators had developed specialized performance measurement analysis software on prior research contracts and were familiar with the system, and (b) the principal statistical performance measurement analyst was resident in Orlando, Florida. Computer data analysis for measurement development is a highly interactive task between a computer and a skilled analyst. The task requires substantial experience with human/system performance data, simulator data collection, the nature of the simulated flight task, computer programming and multi-variate statistics. It was more cost effective to bring the data to the facility and experienced measurement analyst than to bring the analyst and specialized software to the data and an unfamiliar computer. The general data flow is shown in Figure C5.

IV. PHASE 3: DATA ANALYSIS

The goal of the data analysis was to find the smallest comprehensive set of measures which would discriminate the differences between RTU experience level pilots and acknowledged expert pilots in 1v1 free engagement ACM. To perform this measurement analysis, it was methodologically necessary to first determine that the pilots were assigned properly to the three experience level groups. After the group assignment was confirmed, the analysis was conducted at two levels of detail, (a) general measures of performance (i.e., energy used, amount of time opponent out of view, throttle use, average airspeed, etc.) which could be taken over a whole engagement without complex subdivision of the engagement or maneuvering, and (b) more detailed measures of performance within certain segments of the engagement that might reflect the tactics being employed by the pilots. Accordingly, this section is subdivided into three major subsections, (a) skill level assessment, (b) whole engagement performance measurement and (c) preliminary tactics performance analysis.

A. Skill Level Assessment

The subject pilots were chosen from three somewhat loosely defined groups ranging from novices through "expert" ACM instructors. This assured that the pilots would represent a broad spectrum of experience and skill levels in ACM. While this grouping of pilots provided a preliminary attempt at skill level classification, the investigators expected a large degree of overlap in ACM skill among the three groups. It was, therefore, the plan to make a final reassignment of pilots into skill level groups at the conclusion of data collection on the basis of the data collected.

In order to make this final skill level assessment the investigators collected several types of skill level data. These included performance on the pretest in which each pilot made five attacks on a target maneuvering in a predetermined pattern. They included the peer rankings and expert ratings collected at the completion of each week's exercises. Finally, they included records of the outcomes of the free engagements flown during each week.

Pretest Exercises

In the first pretest exercise (Maneuver I), the pilot was required to track a maneuvering target within gun range and to score as many hits as possible within the allotted time. Of the 30 pilots taking part in the study, only 10 scored a gun hit. This exercise, therefore, provided little information which could be used to rank the 30 pilots according to skill level.

The second pretest exercise (Maneuver II) required the pilot to fire an AIM-9 missile at the target and then to close for a high angle gun pass. In this exercise 15 of the 30 pilots scored a missile kill and only two scored a gun hit. The pilots' performance on the first exercise and their performance on the second showed no significant correlation.

In the third, fourth and fifth exercises (Maneuver III) the pilots were required to attack a maneuvering target and to achieve a kill as expeditiously as possible. The variable of primary interest here was the elapsed time required to score a kill. Table B1 shows the time to kill for each of the 30 pilots for each of the three attacks on the target. While performance during these three attacks did not correlate with performance during the first two exercises, it did correlate significantly with other measures of pilot skill level including peer rankings, expert ratings, and performance during the subsequent free engagements. These correlations will be discussed later.

Ranking Data

Table D1 presents a summary of the peer rankings and the expert rankings obtained for each pilot during each of the 5 weeks. It is interesting to note that in each of the 5 weeks the pilots in Group 3 (pilots number 5 and 6) were ranked as the top 2 pilots in both the peer rankings and in the project pilot rankings. Pilots in Group 2 (pilots number 3 and 4) generally fell in the middle of the rankings while pilots in Group 1 (pilots number 1 and 2) fell at or near the bottom of the rankings. Also interesting is the strong degree of correspondence between the expert rankings and the average of the peer rankings. This indicates that a strong interobserver reliability is possible when rating overall ACM performance in the SAAC.

Expert Ratings

In addition to the ranking forms, the project pilots were asked to rate each of the pilots on a 0 to 4 scale on several dimensions of ACM performance. The dimensions rated were: (a) Decisiveness; (b) situation awareness; (c) maneuvering skill; (d) aggressiveness; and (e) overall performance. Table D2 gives the mean ratings for each of the three groups of pilots for these dimensions. For each measure except aggressiveness, the scores show a consistent increase across the skill level groups. It is not surprising that aggressiveness does not show a perfect correlation with experience level. Aggressiveness is perhaps more a personal trait than the other measures which depend on experience, training, and recency.

As might be expected, the overall performance ratings were highly correlated with the other scores of ACM performance. Table D3 presents a matrix of the intercorrelations among the five dimensions in the expert ratings as well as the peer rankings and project pilot rankings.

Two cautions should be emphasized when looking at this table. The first involves the negative correlations between the ranking data and the rating data. In the case of the ranking data, a low score indicates the best performance while the reverse is true for the rating data. The high negative correlations, therefore, indicate that pilots tended to be similarly rated in both types of scales. Secondly, these correlations may be spuriously low. Several statistically important assumptions may have been violated in the calculation of the correlations between the rating data and the ranking data. The ranking data only achieves ordinal level scaling while the correlational analysis requires that at least interval scaled data be used. In addition, the desired linear relationship between the two sets of correlated data may not exist. If so, this would explain why, for example, the correlation between the expert ranking and the overall performance rating is -.856 when, desirably, it should approach -1.000.

Engagement Outcomes

The most commonly accepted measure of ACM skill level is the number of kills achieved. Therefore, the outcomes of the free engagements flown by the pilots were considered an important source of information in assessing skill level. Figure 1 shows that engagement outcomes reveal clear differences between the three skill level groups.

In order to determine the strength of relationship between some of these measures of pilot ACM skill, rank correlations between them were calculated. The pilots were first ranked from 1 to 30 on time to kill on the last three pretest exercises, on the expert's overall performance ratings from the free engagements, and on the total number of kills during the free engagements. Spearman Rank Correlations were then calculated between the pairs of these measures. The correlation between number of kills and overall performance rating was .695. The correlation between time to kill and overall performance ratings was .694. Finally, the correlation between time to kill and number of kills was .716.

The high correlation between the number of kills and the overall performance rating was to be expected. The final criterion for ACM performance is the accomplishment of the kill. In the sample, the pilots achieving the largest number of kills also tended to have the highest overall rating. Since this correlation was not 1.000, however, there is evidence that the experts were also rating the pilots on some dimension or dimensions other than just kills.

The correlation between the *pretest time to kill* and the overall performance rating during the *free engagements* is interesting. It indicates that the time to kill measure is highly predictive of performance during 1v1 free engagements. This is also indicated by the similarly high correlation between time to kill during pretest and the number of kills during free engagements. This evidence suggests that the pretest time to kill is a valid measure of ACM performance, at least in the SAAC simulator.

The purpose of the skill level assessment was to provide the basis for a final assignment of the pilots into skill level groups. Examination of the data described above, however indicates that the preliminary group assignments provided us three distinctly different skill levels. This is especially apparent in the engagement outcome data. Pilots in Group 3 dominated the pilots in both Groups 1 and 2 during the free engagements. While there was not so pronounced a difference between Groups 1 and 2 in total kills, Group 1 pilots did not achieve a single weapons kill against a Group 2 pilot during the 5 weeks of engagements.

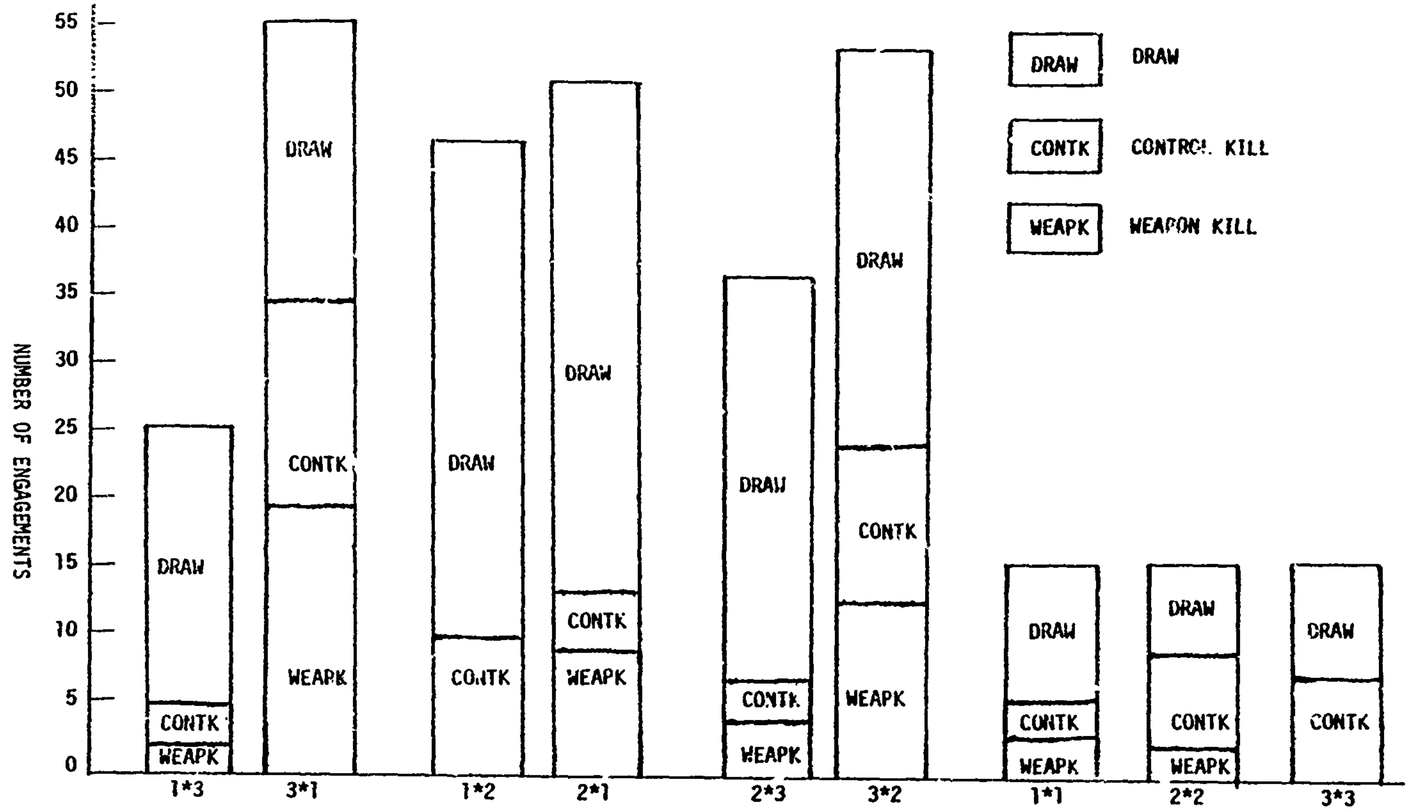
This difference between the three groups was also apparent in the ranking data, the expert rating data and, to a lesser extent, in the pretest data. This study, therefore, concluded that the original assignment of pilots into skill level groups provides adequate group differences. All further analyses were based on the original assignments.

B. Whole Engagement Performance Measurement

The analysis of whole engagement performance measures was conducted in four major steps, (a) the development of candidate measures from the time history data tapes of all relevant aircraft variables, (b) an analysis of the pretest exercises using the candidate measures, (c) a univariate (one measure at a time) analysis of free engagements, and (d) a multivariate analysis of free engagements.

Development of Candidate Measures

From the 67 aircraft and system variables recorded on time history data tapes from each cockpit, 28 measures of whole engagement performance were calculated. Some of these measures were taken directly from the original 67, while others of the candidate set were composite measures formed by mathematical combination of two or more variables. The formulation of candidate measures was guided by the results of Phase 1. A description of each candidate measure follows:



SKILL GROUP VERSUS SKILL GROUP
(1*3 indicates outcomes of Group 1 when fighting Group 3)

Figure 1. Engagement Outcomes

1. Altitude Rate: The arithmetic mean of the absolute values of the altitude rates recorded for a pilot during a given engagement.

2. Out of View: The percentage of time the opponent was out of the pilot's field of view during a given engagement as calculated by the SAAC.

3. Airspeed: The arithmetic mean of the values of indicated airspeed recorded for a pilot during a given engagement.

4. Speedbrake: The average speedbrake deflection (maximum deflection is 10) during an engagement.

5. Fuel Flow: The average fuel, in pounds per hour, used by the pilot during the engagement.

6. Relative Altitude Use: The pilot's use of the vertical dimension relative to his opponent's use, calculated as the ratio of the given pilot's altitude standard deviation to that of his opponent during a single engagement.

7. Energy Management Index: A composite representing the ability of the pilot to obtain and maintain the maximum amount of energy (kinetic and potential) for a given expenditure of fuel. It is a function of remaining fuel, fuel flow, airspeed and altitude integrated across the length of the engagement as shown in Table C3.

8. Offensive Time: The percentage of time the given pilot's opponent is positioned at a sight angle of less than 60^{0}.

9. Offensive with Advantage: The percentage of time the given pilot's opponent is positioned at a line-of-sight of less than 60^{0} and with an aspect angle of less than 90^{0}.

10. Throttle Idle. The percentage of time the throttle is in the idle position during an engagement.

11. Throttle LO MIL: The percentage of time the throttle is in the LO MIL position during an engagement.

12. Throttle HI MIL: The percentage of time the throttle is in the HI MIL position during an engagement.

13. Throttle Afterburner: The percentage of time the throttle is in the afterburner position during an engagement.

14. RMS Heading: The root-mean-squared error about the average heading.

15. Absolute Average Heading: The average heading held by the pilot during the engagement.

16. Lead Time: The percentage of time the given pilot is employing lead pursuit, i.e., his aircraft nose is pointed ahead of his opponent's nose during an engagement.

17. Time in Range: The percentage of time the pilot's opponent is positioned with a sight angle of less than 60^{o}, an angle of less than 90^{o} and at a range of less than 2000 feet.

18. Roll Rate: The average absolute roll rate, in degrees per second, used by a pilot during an engagement.

19. Roll Rate Times Altitude Rate: A composite measure of the maneuvering rate used during an engagement. The roll rate is multiplied by the altitude rate and the absolute value is taken. This measure is the mean value of this product during an engagement.

20. Plane of Action: The plane in which the aircraft is moving at a given instant. It is a composite function of X, Y, and Z. The measure is the arithmetic mean of values recorded during an engagement.

21. Defensive Time: The percentage of time that the given pilot's opponent is positioned at a sight angle of greater than 120^{o}, an aspect angle greater than 90^{o} and at a range of less than 4000 feet.

22. Angle of Attack: The percentage of time that a pilot's angle attack exceeds 28 units during an engagement.

23. AIM-9 Success: The probability that the pilot achieved an AIM-9 kill during the given engagement. On the record, an AIM-9 kill was scored as a 1 while any other outcome was scored as an 0. The measure, therefore, represents the percentage of engagements ending in an AIM-9 kill by the given pilot or pilots.

24. AIM-7 Success: Does not apply to the present data since no AIM-7 missiles were available to the pilots during similar aircraft engagements. This calculation is analogous to that for measure Number 23.

25. Gun Success: The probability that the pilot achieved a gun kill during the given engagement. The calculation is analogous to that for measure Number 23.

26. Ground Kill Success: The probability that the pilot achieved a kill due to his opponent's flight into terrain during the given engagement. The calculation is analogous to that for measure Number 23.

27. Over-g Success: The probability that the pilot achieved a kill due to his opponent overstressing the aircraft, i.e., exceeding 9.5 g, during the given engagement. The calculation is analogous to that for measure Number 23.

28. Fuel Kill Success: The probability that the pilot achieved a kill due to his opponent passing the "bingo" fuel limit without turning to his "home" heading. This calculation is analogous to that for measure Number 23.

Pretest Exercises

All 28 of the candidate measures were calculated for the pretest exercises. On the pretest exercises, the most striking feature of these data is a near absence of consistent and explainable differences between the three skill level groups of pilots. The only noteworthy difference between the three groups was in their use of the throttle control. Group 1 pilots tended to use their afterburner to a greater extent than pilots in the other groups. Groups 1, 2, and 3 used the afterburner 42%, 38%, and 28% of the engagement, respectively. Conversely, Group 3 pilots spent more time with their throttles at idle (15%) than did Group 1 (11%) or Group 2 (8%). Use of the throttle control is graphically depicted in Figure 2.

Consistent with the findings concerning throttle usage, the measure of fuel flow reflected the same difference between the three groups. As would be expected from the data on throttle use, Group 3 had the lowest average fuel flow (22607 lb./hr.). Group 1 had the highest average fuel flow (26142 lb./hr.). The average fuel flow for Group 2 pilots was 25969 lb./hr. These findings concerning throttle use by the three groups were consistent with the data recorded during the 1v1 free engagements (to be discussed later).

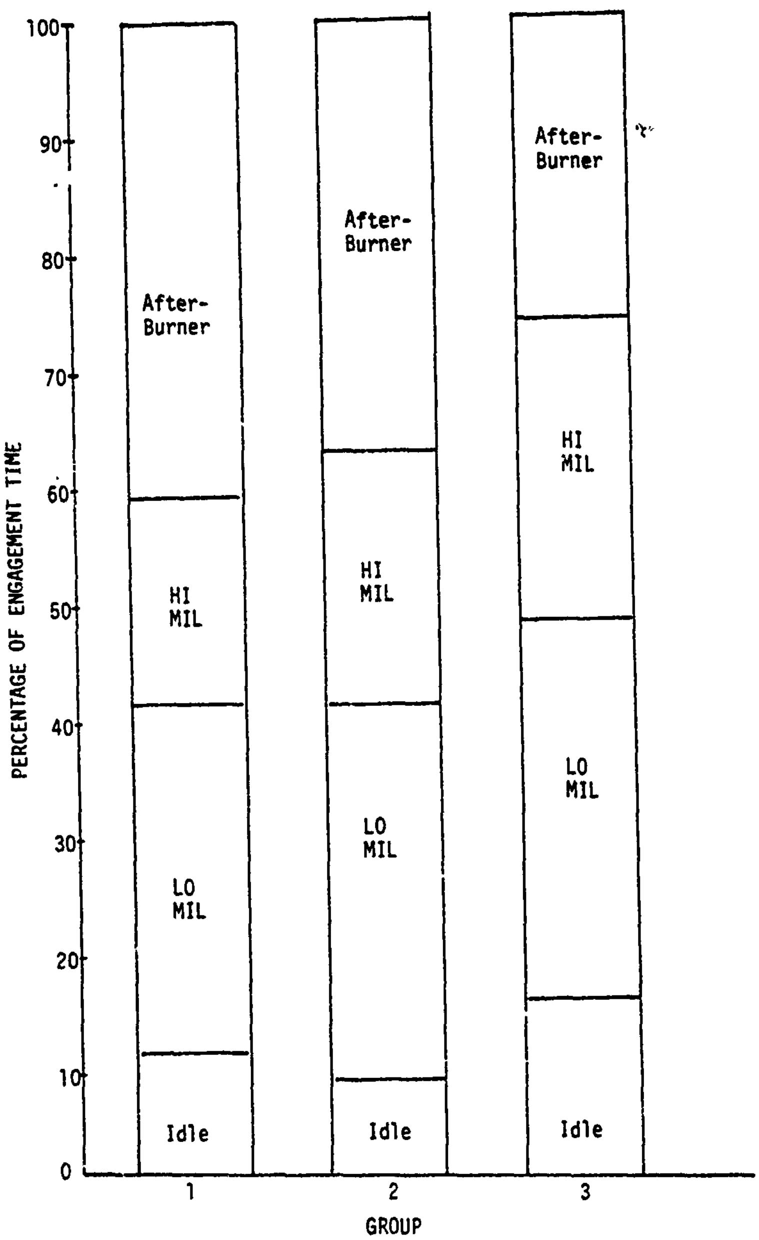


Figure 2. Throttle Use During Pretest

This near absence of clear differences between the pilots during the pretest exercises may have strong implications for the prediction of pilot performance during ACM. The pilots taking part in our testing were deliberately chosen to represent widely different experience and skill levels. The pretest consisted of standard exercises used to test pilot ACM performance in training and during operational readiness inspection exercises. Yet, although the pretests were carefully controlled and the results precisely examined, there was little in all the data collected to indicate the group differences which existed.

The investigators believe that this absence of group differences was largely due to the well defined nature of the task. In the first two pretest exercises, the pilots were told which profile their target would be flying and what actions were expected of them. All pilots, therefore, flew a standardized attack profile which eliminated the need for much of the rapid decision-making which characterizes free engagements. This was also true to a lesser extent during the three attacks which comprised Maneuver III on the pretest. The pilots realized that their target was merely flying a predetermined pattern rather than responding to their actions. There was no need for counteroffensive maneuvering which greatly decreased the cognitive requirements placed on the pilots and limited their task almost to a simple BFM problem. Thus, the highly skilled and experienced pilots were unable to take full advantage of their greater experience and skill during the pretest. Most of the group differences were obscured by the differences between individuals within the groups.

Univariate Analysis of Free Engagements

By contrast, the 1v1 free engagements allowed the obvious group differences to be demonstrated. The whole engagement performance measures provided clear and predictable indications of group differences for nearly every parameter. Table 4 shows the mean values and standard deviations for all the whole engagement measures, most of which are discussed in the following:

Throttle Use. Clear differences were found between the groups in their use of the throttle. These differences were in the same direction as those found in the pretest data but were much more pronounced (see Figure 3). As skill level increased there was a definite tendency to use the afterburner less and the idle position more.

Fuel Flow. Because of the tendency for the lower skilled pilots to use higher power settings during the engagements, it was predictable that their average fuel flow should be higher than that of the more skilled pilots. This, indeed, was the case. For each of the three initial setups flown by the pilots, Group 1 had the highest average fuel flow and Group 3 had the lowest.

TABLE 4. WHOLE ENGAGEMENT MEASURES

		Measure							
		Altitude Rate		Out Of View		Indicated Airspeed		Speedbrake Position	
Group	Setup	Mean	S.D	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1	275.97	49.407	.36	.155	246.68	84.617	.00	.014
1	2	279.36	67.481	.37	.163	262.93	93.183	.17	.907
1	3	274.99	59.334	.39	.134	248.94	75.088	.39	2.371
1	m	276.77		.37		252.85		.19	
2	1	249.96	45.444	.41	.160	223.78	74.753	.68	2.186
2	2	258.91	56.162	.40	.163	242.16	76.067	1.40	5.776
2	3	261.74	58.045	.45	.140	244.46	89.517	1.93	6.792
2	m	256.87		.42		236.80		1.34	
3	1	246.53	35.958	.48	.186	231.96	77.937	1.59	4.660
3	2	251.87	49.449	.50	.171	245.32	70.489	1.44	3.937
3	3	233.76	50.815	.47	.130	209.18	50.942	1.72	4.748
3	m	244.05		.48		228.82		1.58	

TABLE 4. WHOLE ENGAGEMENT MEASURES (Cont.)

		Measure							
		Average Fuel Flow		Relative Altitude Use		Energy Management Index		Offensive Time	
Group	Setup	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1	28089	2852	1.09	.266	4.11	2.30	.21	.22
1	2	26948	2593	1.02	.189	4.99	3.90	.23	.24
1	3	28841	2546	1.09	.341	4.71	5.24	.31	.19
1	m	27959		1.07		4.60		.25	
2	1	26847	3667	96	.144	5.32	3.74	.44	.25
2	2	26896	2734	1.02	.123	6.95	7.42	.37	.25
2	3	27670	3094	1.06	.336	8.06	8.35	.40	.18
2	m	27138		1.01		6.77		.40	
3	1	24920	3679	.99	.142	11.33	9.39	.52	.27
3	2	24641	3825	1.00	.202	11.01	10.31	.53	.26
3	3	25619	3336	.99	.298	11.68	8.84	.50	.17
3	m	25060		.99		11.34		.52	

TABLE 4. WHOLE ENGAGEMENT MEASURES (Cont.)

Measure									
		Offensive With Advantage		Throttle Idle		Throttle LO MIL		Throttle HI MIL	
Group	Setup	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1	.06	.16	.05	.10	.13	.18	.05	.10
1	2	.10	.19	.05	.09	.18	.15	.09	.14
1	3	.08	.15	.05	.09	.12	.18	.04	.11
1	m	.08		.05		.12		.06	
2	1	.20	.25	.11	.14	.17	.17	.11	.14
2	2	.16	.23	.12	.14	.09	.13	.12	.14
2	3	.11	.17	.15	.16	.15	.17	.09	.12
2	m	.16		.13		.14		.11	
3	1	.28	.29	.16	.10	.29	.13	.18	.13
3	2	.31	.28	.14	.12	.25	.16	.16	.15
3	3	.15	.19	.15	.13	.20	.15	.18	.13
3	m	.25		.15		.25		.17	

TABLE 4. WHOLE ENGAGEMENT MEASURES (Cont.)

		Measure							
		Throttle After Burner		Absolute Average Heading		RMS Heading		Lead Pursuit Time	
Group	Setup	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1	.76	.28	16.52	5.28	68.55	26.34	.06	.15
1	2	.76	.27	16.46	4.49	73.62	19.09	.08	.18
1	3	.79	.27	18.25	6.80	75.67	26.18	.07	.13
1	m	.77		17.08		72.61		.07	
2	1	.60	.28	16.13	4.75	65.11	26.61	.18	.22
2	2	.67	.30	14.70	4.86	57.37	28.19	.13	.22
2	3	.61	.28	18.81	5.76	77.29	27.34	.10	.15
2	m	.63		16.55		66.59		.14	
3	1	.37	.13	16.41	4.56	67.75	24.29	.24	.26
3	2	.45	.23	15.92	6.01	63.87	30.89	.26	.26
3	3	.46	.26	19.62	4.94	81.37	21.63	.14	.17
3	m	.43		17.32		71.00		.21	

TABLE 4. WHOLE ENGAGEMENT MEASURES (Cont.)

		Measure							
		Time In Range		Absolute Average Roll Rate		Roll Rate X Altitude Rate		Plane Of Action	
Group	Setup	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1	.01	.05	22.36	9.27	21.82	1171.5	-7.04	4.51
1	2	.01	.02	21.20	8.16	87.03	1148.1	-7.29	4.37
1	3	.00	.02	19.35	10.27	570.44	1040.2	-6.51	3.81
1	m	.01		20.97		226.43		-6.95	
2	1	.03	.05	24.96	7.54	19.95	1078.5	-8.15	4.48
2	2	.03	.07	23.36	8.22	-95.10	1218.2	-8.59	4.42
2	3	.02	.05	18.77	7.57	538.89	1311.8	-7.39	4.23
2	m	.03		22.36		154.58		-8.04	
3	1	.05	.09	22.09	6.55	52.33	992.2	-9.06	3.53
3	2	.07	.08	23.67	9.84	-56.34	1002.9	-8.40	4.29
3	3	.02	.04	17.99	8.76	235.26	1021.7	-7.87	4.91
3	m	.05		21.25		77.08		-8.44	

TABLE 4. WHOLE ENGAGEMENT MEASURES (Cont.)

		Measure							
		Defensive Time		AOA Greater Than 28 Units		AIM-9 Kills		Gun Kills	
Group	Setup	Mean	S.D.	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1	.10	.12	.01	.03	.04	.20	.00	.00
1	2	.08	.10	.01	.02	.02	.14	.00	.00
1	3	.06	.09	.01	.04	.06	.24	.00	.00
1	m	.08		.01		.04		.00	
2	1	.07	.14	.01	.03	.08	.27	.04	.20
2	2	.09	.13	.01	.02	.08	.27	.02	.14
2	3	.04	.07	.01	.03	.06	.24	.04	.20
2	m	.07		.01		.07		.03	
3	1	.04	.08	.01	.01	.20	.40	.12	.33
3	2	.05	.10	.02	.04	.16	.37	.06	.24
3	3	.02	.06	.01	.02	.13	.33	.10	.31
3	m	.04		.01		.16		.09	

TABLE 4. WHOLE ENGAGEMENT MEASURES (Cont.)

		Measure					
		Ground Kills		Over-g Kills		Fuel Kills	
Group	Setup	Mean	S.D.	Mean	S.D.	Mean	S.D.
1	1	.06	.24	.04	.20	.06	.24
1	2	.04	.20	.02	.14	.06	.24
1	3	.04	.20	.06	.25	.04	.20
1	m	.05		.04		.05	
2	1	.06	.24	.08	.27	.06	.24
2	2	.04	.20	.02	.14	.02	.14
2	3	.02	.14	.02	.14	.04	.20
2	m	.04		.04		.04	
3	1	.08	.27	.04	.20	.04	.20
3	2	.10	.31	.02	.14	.04	.20
3	3	.13	.33	.00	.00	.06	.25
3	m	.10		.02		.05	

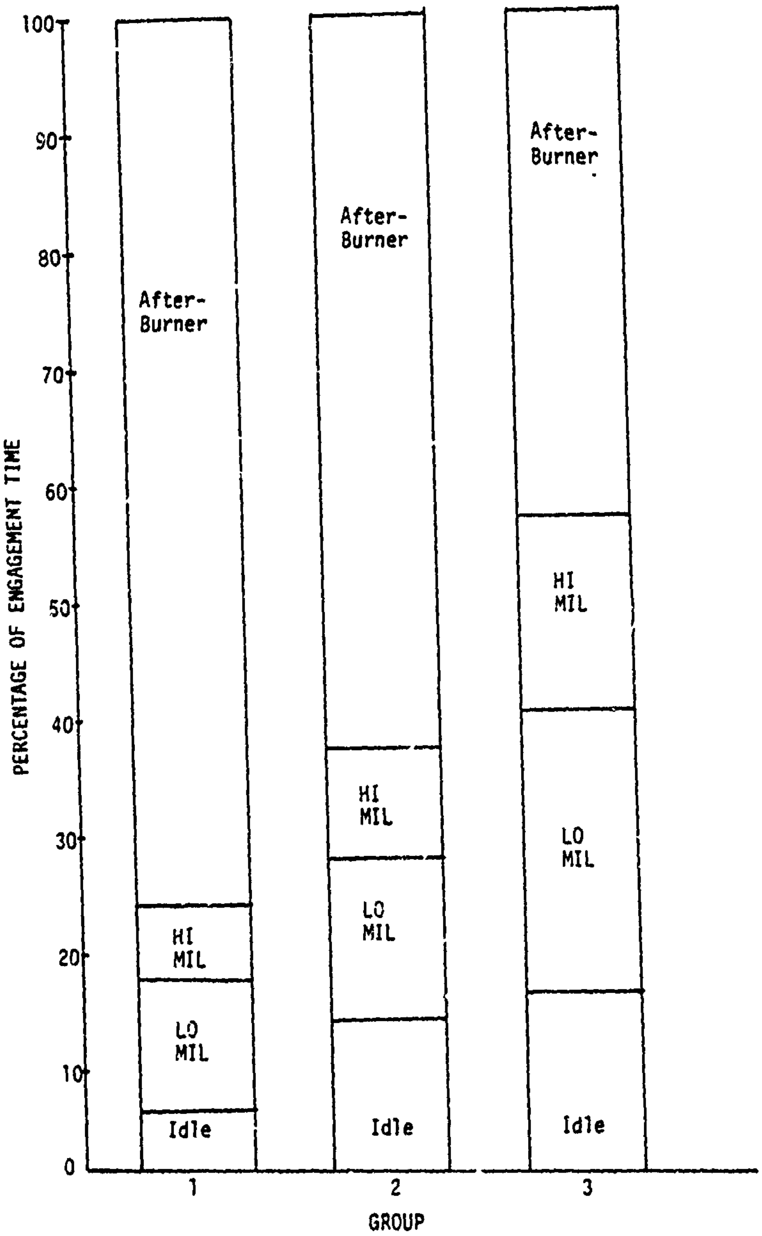


Figure 3. Throttle Use During ?V1

Airspeed. Similarly, the data on throttle use would suggest that the lower skilled pilots fought at a higher airspeed, on the average, than did the more highly skilled pilots. Table 4 shows this to be the case. This difference, in itself, provided an advantage to the more highly skilled pilots with the lower airspeeds allowing tighter turns during the engagement. This is in agreement with the predictions of the subject matter experts who suggested that the more aggressive pilots operate at lower airspeeds in order to maximize the probability of a kill, eventhough this increases the chance that they, themselves, will be killed.

Energy Management Index. Another measure which indicated a difference between the three skill level groups during the free engagements was the Energy Management Index (EMI). This finding confirmed previous speculation from many sources that the skilled ACM pilot manages his energy more efficiently than does the less skilled pilot. Note that in every one of the initial setups Group 3 pilots had the highest EMI score followed by Group 2 pilots and then Group 1 pilots.

Speedbrake. The more skilled pilots tended to use the speedbrake to a greater extent than did the less skilled pilots. It is important, however, to note the highly skewed nature of the distributions. It is apparent from a comparison of the means and standard deviations that most of the pilots in all three groups used the speedbrake very little. The relatively small means and large standard deviations indicate that most of the speedbrake use was done by a small percentage of the pilots.

Altitude Rate. Altitude rate is the mean absolute vertical speed that a pilot maintains during an engagement. This is one means of assessing the degree to which a pilot uses the vertical dimension of the airspace during an engagement. A pilot who makes little use of the vertical will, of course, have a low value for the average altitude rate while a pilot who makes greater use of the vertical will tend to have a higher value. Because it has been assumed by many authorities that the more skilled and successful ACM pilot makes greater use of the vertical dimension, the investigators expected the Group 3 pilots have the highest value for altitude rate. We found, however, just the opposite trend. The lower skilled Group 1 showed the highest average altitude rate (276 ft./min.) while Group 3 pilots had the lowest value (244 ft./min.) with Group 2 in between (256 ft./min.).

Relative Altitude Use. A related measure is the relative altitude use which compared the amount of vertical airspace used by the pilot with the amount used by his opponent. These data reflected the same trend as the data on altitude rate. The ratios calculated for Groups 1, 2, and 3 were 1.07, 1.01, and .99, respectively. While these differences were not large, they provided further evidence that, at least in this study, the lower skilled pilots made at least as much use of the vertical dimension as their more highly skilled counterparts.

There is one possible explanation for this unexpected finding which deserves future exploration. Pilots in Group 1 were killed by terrain contact approximately four times as often as pilots in Group 3. It is possible that much of the difference between groups found here is the result of high speed, uncontrolled descents by the less skilled pilots. Future examinations of the data should investigate this possibility.

Average Roll Rate. The investigators expected that the skilled pilots would make more use of the roll axis of the aircraft than would their less skilled counterparts. This would have been reflected in the data on absolute average roll rate with the skilled pilots showing a higher rate. While this prediction was not confirmed by these univariate analyses, they were confirmed by later multivariate analyses of the measures.

Angle of Attack. Pilots exceeding 28 units AOA are approaching loss of control. The investigators expected that during ACM, when pilots are maneuvering in high angle of attack regimes, the pilots more highly skilled in aircraft maneuvering would approach, but not surpass, this value. There was, however, little or no difference between the skill level groups in the percentage of time spent with an AOA of more than 28 units. Pilots in all three skill level groups spent approximately one percent of their engagement time at more than 28 units AOA.

Offensive Time. It is logical to expect pilots of higher skill level to spend a larger percentage of the engagement in an offensive posture than less skilled pilots. This expected trend was clearly shown in our data. Pilots in Group 3 spent more than twice as much time in the offensive as did Group 1 pilots. Group 2 pilots fell approximately halfway between the other groups.

Offensive Time with Advantage. The above measure of offensive time is simply a measure of the percentage of the engagement the pilot is pointed toward his opponent. It is possible for both pilots to be offensive simultaneously. This occurs, for example, when both are approaching for a head on gun pass. By contrast, to be offensive with advantage, the pilot had to be pointed in the direction of his opponent's tail. Again, the investigators expected the Group 3 pilots to accrue more time in an offensive with advantage position than the less skilled pilots. Indeed, Group 3 pilots spent about 25% of their engagements offensive with advantage compared to 8% and 16% for Groups 1 and 2, respectively.

Time in Range. This is the amount of time spent within gun range during an engagement. As expected there is a strong and consistent relationship between the skill level of the pilot and the amount of time spent within gun range.

Out of View Time. Directly related to the measures of offensive time and offensive with advantage is the out of view time. Ideally, it could be expected that highly skilled pilots would spend a large percentage of the engagement out of their opponent's field of view. The less skilled pilot could be expected to spend a smaller portion of time out of his opponent's view. This was, indeed, found to be the case. Group 3 pilots spent about a third more time out of view than did the Group 1 pilots. The out of view time for Group 2 pilots was midway between those found for the other two groups.

Lead Pursuit Time. A pilot employing lead pursuit to intercept his opponent can enter the fight more quickly than a pilot employing pure pursuit or lag pursuit. Lead pursuit time, therefore, may correlate with aggressiveness. The investigators expected the less skilled pilots to spend a smaller portion of the engagement in lead pursuit than their more skilled counterparts. Group 1 pilots actually spent about half as much time in lead pursuit as Group 2 pilots and a third as much as Group 3 pilots.

Defensive Time. Since the more skilled pilots tended to spend a larger percentage of their engagement time on the offensive, it was reasonable to assume that they might spend a smaller percentage of time in a defensive position. The data confirmed this assumption.

Mission Success. The success of an ACM mission is generally determined by the kills occurring during that mission. For that reason some emphasis was placed on examining the numbers and kinds of kills scored by the pilots. Summaries of kills using AIM-9 missiles, guns, ground kills, over-g kills, and out of fuel kills showed a considerable effect of skill level on the numbers and types of kills scored. These data are summarized in Figure 4.

It was apparent that success with weapons was an excellent indicator of skill level. The success ratio, using missiles, for Group 3 pilots was more than double that of Group 2 pilots and about four times that of Group 1 pilots. The differences between the groups was even more marked for the data on gun success. Group 3 pilots had about three times the number of gun kills scored by Group 2 pilots while Group 1 pilots did not score a gun kill. The combined success with both missiles and guns again showed a strong difference between the three groups of pilots.

Kills scored by other than weapons delivery showed less promise as an indicator of ACM performance. The data indicated only small differences between the groups in kills due to ground impact, over-g and fuel depletion. These outcomes appeared to be influenced by chance to a much greater degree than did the weapons kills and are probably of little value in measurement of ACM performance.

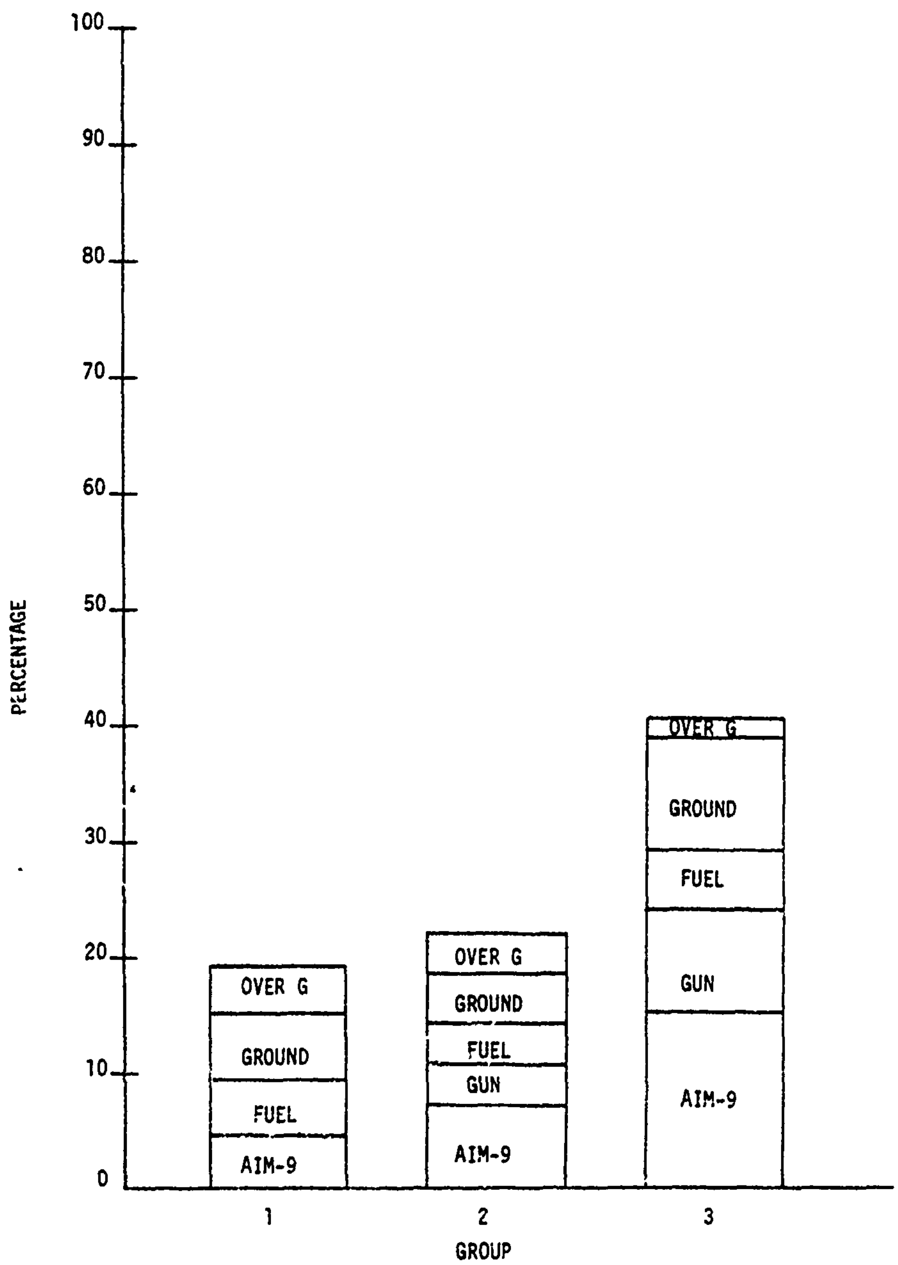


Figure 4. Kills During 1v1

Other Measures. Data analyses indicated that the measures of Absolute Average Heading, RMS Heading, Roll Rate times Altitude Rate, and Plane of Action, as calculated using the initial algorithms, did not discriminate between pilots of different skill levels.

Multivariate Analyses of Whole Engagement Measures

The univariate analyses of whole engagement measures indicated that these measures could provide the basis for an ACMPM system which would discriminate between pilots on the basis of ACM skill level. These data, however, had too much underlying variance within Groups to be employed in a univariate manner in an ACMPM system. Because there was a high degree of correlation between many of the measures, the investigators employed multivariate analyses in an attempt to reduce this unexplained variance and to improve the efficacy of the ACMPM structure.

Because this effort represented a preliminary study to determine the feasibility of developing an ACMPM system, the investigators determined that a structure that could discriminate between the two most diverse skill levels of pilots would serve this purpose. The multivariate measures were, therefore, applied to data representing engagements flown by (a) Group 1 pilots versus pilots from the higher skill groups and (b) Group 3 pilots versus pilots from the lower skill level groups.

Candidate Measures. The multivariate analyses began with 31 whole engagement variables. These included the measures examined during the univariate analyses described above with several additions and modifications which the investigators believed might account for portions of the total variance. These additions included measures accounting for any learning effect and for any difference between the three setup conditions which started the engagements. To account for a possible learning effect a variable representing the position of the engagement in the sequence of 15 engagements flown by each pilot was included. To account for differences due to initial setup, dummy variables were included to flag data from engagements initialized at each starting position.

In addition, minor changes were made in the algorithms for calculating two candidate measures to improve the discrimination between pilot skill level. First, the algorithm for determining opponent out of view was calculated as shown in Figure C8, rather than using the simulation parameter for out of view. Second, counting transitions into each throttle zone was found to be more discriminating than the time in each zone. The number of transitions into each throttle zone was divided by the total number of data samples to form the revised throttle activity measures.

All 31 candidate measures for the initial multivariate analysis are presented in Table 5. More complete definitions of the algorithms are contained in Appendix C.

TABLE 5. WHOLE ENGAGEMENT CANDIDATE MEASURES FOR MULTIVARIATE ANALYSES

Meas. No.	Variable	Transform	Units	Abbrev.
1	Altitude Rate	AAV[1]	Ft./Sec.	ARAA
2	Current Out of View	%[2]	--	OOVP
3	IAS Range (Maximum-minimum)	AVG[3]	Knots	ASRA
4	Speed Brake Position	AVG	--	SBPA
5	Fuel Flow	AVG	Lbs.Hr.	FFA
6	Altitude Rate S.D. Ratio (p/o)[5]	--	--	ARSR
7	Energy Management Index	RMS[4]	--	EMRM
8	Offense Time	%	--	OFFP
9	Offensive with Advantage [6]	%	--	SADP
10	Throt 1[7]	AVG[7]	--	TH1A
11	Throt 2	AVG	--	TH2A
12	Throt 3	AVG	--	TH3A
13	Throt 4	AVG	--	TH4A
14	Hdg Rate	RMS	Deg./Sec.	HDGRM
15	Hdg Rate	AAV	Deg./Sec.	HDGRAA
16	Time in a Lead Pursuit Position	%	--	LEADP
17	In Range	%	--	IRP
18	Roll Rate	AAV	Deg. /Sec.	RRAA
19	Roll Rate X Alt Rate	AAV	Deg. Ft./Sec.	RRARA
20	Plane of Action [8]	AAV[8]	Deg.	PLOAAA
21	Defensive with Disadvantage[9]	%	--	DDP
22	AOA>28^0	%	--	A28P

TABLE 5. WHOLE ENGAGEMENT CANDIDATE MEASURES FOR MULTIVARIATE ANALYSES (Cont.)

Meas. No.	Variable	Transform	Units	Abbrev.
23	AIM-9 Success	---	--	AIM9P
24	Initialization 2 (Negative State for Initialization 1)	---	--	INIT2
25	Gun Kill Success	---	--	GUN
26	Ground Kill Success	---	--	GND
27	g's	---	--	G
28	Bingo Kill Success	---	--	BING
29	Leading/Offense[10]	---	--	L/O
30	Sequence Number[11]	---	--	SEQN
31	Initialization 3 (Negative State for Initialization 1)	---	--	INIT3

1. AAV = Absolute Average
2. % = Percent of engagement time.
3. AVG = Average.
4. RMS = Root-Mean-Square.
5. The ratio of proponent standard deviation to opponent standard deviation.
6. When the line of sight to the target is $<60^{o}$ and aspect is $<90^{o}$.
7. The number of transitions into each throttle zone divided by the number of data samples in each engagement.
8. The average absolute maneuvering plane of each cockpit.
9. When the line of sight $>120^{o}$, aspect $>90^{o}$, and range <4000 ft.
10. Lead pursuit time divided by offensive time.
11. A count of successive free engagements for each pilot throughout Day 2 and Day 3.

Data Editing. The first step in the preparation of data for analysis was to sort the data into two groups. Group A was composed of data from relatively inexperienced pilots (Group 1) when they were fighting more experienced pilots (Group 2 and Group 3). Group B was composed of data from the most experienced pilots (Group 3) when they were fighting less experienced pilots (Group 2 and Group 1).

The next step was to remove useless leading and trailing data tape records which were caused by manual control of recording during data collection. Computer logic was written to detect and remove data prior to engagement start and after its termination.

The third step was to remove uncharacteristic performance from the data of the undesireable effects of a few highly variant performances on a regression analysis. These atypical observations, called outliers, were detected by looking for any single measure which was more than 3.5σ away from that groups' mean for that particular measure. Table 6 is a tally of the measures for each group that were found to be outliers. There were 130 observations for each group, but after outlier removal there were 112 in Group A and 115 in Group B. The group means and standard deviations for the remaining measures may be found in Appendix E.

A fourth step was necessary to look closely at the group correlation matrices (also in Appendix E) because highly correlated measures will have a negative effect on the discriminant analysis. A program was written which would identify couplets of highly correlated measures and determine which of the measures in the pair was most correlated to all the other measures in their group. Six measures were eliminated from analysis as they correlated greater than .83 with some other measure. The results of this step are shown in Table 7. The criterion for elimination was arbitrary and it left 25 measures for further analysis.

Data Analysis. The results reported in this section are but the highlights of several multivariate analyses of the ACM data. The final model was developed through many successive approximations guided by the analysts' decisions regarding tradeoffs between group discrimination and accounted for variance in the model. Five to ten percent of the variance was sacrificed for the sake of discriminability and other pragmatic criteria. Linear relationships could be found which accounted for 67.5% of the variance but relied very heavily on energy control measures. Practically, the performance measurement model had to include several other aspects of the ACM task. With this in mind, the analysis algorithm could not be given free rein, but had to be carefully controlled at all stages.

TABLE 6. OUTLIER REMOVAL DURING DATA EDITING

Measure Number	Measure Name[2]	Group 1 Frequency[1]	Group 2 Frequency
3	ASRA		1
4	SBPA	2	3
5	FFA	1	-
7	EMRM	5	-
9	SADP	2	-
10	TH1A	2	-
11	TH2A	1	1
12	TH3A	1	2
14	HDGRAA	1	-
17	IRP	1	2
18	RRAA	1	-
19	RRARA	-	1
21	DDP	1	3
22	A28P	-	2
Total Observations Removed		18	15

1 Frequency is the number of times in a group that a particular measure was found to be more than 3.5σ outside the group membership.

2 See Ta[illegible] for definitions.

TABLE 7. HIGHLY CORRELATED MEASURES REMOVED

1st Variable in Pair		2nd Variable in Pair			
Measure Number	Measure Name[1]	Measure Number	Measure Name	Correlation	Variable Removed
8	OFFP	16	LEADP	.86	8
9	SADP	29	L/O	.97	29
9	SADP	16	LEADP	.99	9
11	TH2A	13	TH4A	.82	11
14	HDGRM	15	HDGRAA	.95	15
18	RRAA	19	RRARA	.84	19

[1]See Table 5 for definitions.

Several stepwise regression and discriminant analyses were performed in search of a useable measurement model. Although many useful insights about the available data were gained, a practical performance model was not immediately revealed by these stepwise procedures. Being stepwise, the results of these programs were dependent on the decisions, related to the F level or communalities, made early in the selection or deletion of measures. Different measure sets, of course, were selected by the programs. This provided a hint at the common set that would give practical utility.

A regression analysis of the entire measure set was performed and can be seen in Table 8. In Table 8 the assigned number relates to the measures remaining after the data editing stage. Based on the appearance of certain measures in previous analyses and the significance test in the regression analysis, 16 final candidate measures were selected. It was felt that these measures would be the best starting point for the final analyses, using a step down discriminant analysis.

Table 9 shows the correlation matrix of the 16 remaining candidate measures. Table 10 shows their correlations to group membership.

TABLE 8. RESULTS OF REGRESSION ANALYSIS ON ALL EDITED DATA

Variable Number/Name[2]	Assigned Number	Pooled Means	Pooled S.D.	B(I)	T(I)	S.E.
1 ARAA	1	261.81	55.85	-.0015	2.5	.0006
2 OOVP	2	.20	.16	-.4386	1.5	.284
3 ASRA	3	238.09	74.98	.00026	.6	.0004
4 SBPA	4	.49	1.62	.0236	1.3	.0178
5 FFA	5	26775.90	3151.11	-.00001	1.0	.00001
6 ARSR	6	.47	.49	-.0004	.0	.0508
7 EMRM	7	18.24	24.45	.0008	.5	.0017
8[1] OFFP	--	.39	.21	---	---	---
9 SADP	--	---	---	---	---	---
10 TH1A	8	.003	.004	15.9550	1.5	10.40
11 TH2A	--	---	---	---	---	---
12 TH3A	9	.004	.005	14.3737	2.2	6.39
13 TH4A	10	.006	.006	10.5731	1.4	7.62
14 HDGRM	11	73.22	24.75	-.00062	.6	.0011
15 HDGRAA	--	---	---	---	---	---
16 LEADP	12	.12	.18	.1183	.6	.212
17 IRP	13	.02	.05	1.3210	2.2	.607
18 RRAA	14	20.99	7.82	.0055	1.4	.0040
19 RRARA	--	---	---	---	---	---
20 PLOAAA	15	76.52	4.47	-.0026	.4	.0073
21 DDP	16	.04	.07	.0909	.2	.447

TABLE 8. RESULTS OF REGRESSION ANALYSIS ON ALL EDITED DATA (Cont.)

Variable Number/Name[2]	Assigned Number	Pooled Means	Pooled S.D.	B(I)	T(I)	S.E.
22 A28P	17	.008	.01	-2.2405	1.6	1.42
23 AIM9P	18	.10	.30	.1948	2.3	.0839
24 INIT2	19	.33	.47	.0228	.4	.0059
25 GUN	20	.04	.21	.2825	2.4	.116
26 GND	21	.06	.24	.0525	.5	.104
27 G	22	.03	.17	-.1191	.8	.140
28 BING	23	.05	.22	-.0052	.0	.110
29 L/O	--	---	---	---	--	---
30 SEQN	24	7.23	4.32	-.0039	.7	.0059
31 INIT3	25	.31	.46	.1154	1.7	.0668
CONSTANT				1.0663		
NO. OBSERVATIONS				227		
F-VALUE				10.4		
R^2				.5645		
NDF				25		

1 Variable OFFP (8) was not included in complete regression set because of high correlation with LEADP (16). Since LEADP (16) was not included in DISCRIM set, OFFP could be included without conflict, and the means and S.D. are included here for the reader's information.

2 See Table 5 for definitions.

TABLE 9. CORRELATION MATRIX FOR 16 DISCRIMINANT ANALYSIS MEASURES

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. ARAA[1]	1.00															
2. OOVP	.24	1.00														
3. SBPA	-.16	-.10	1.00													
4. FFA	.04	.34	-.25	1.00												
5. EMRM	-.24	-.23	.53	-.42	1.00											
6. OFFP	-.18	-.78	.13	-.28	.28	1.00										
7. TH1A	-.26	-.26	.46	-.45	.78	.25	1.00									
8. TH3A	-.19	-.24	.07	-.45	.35	.27	.41	1.00								
9. TH4A	-.31	-.35	.26	-.50	.56	.38	.70	.70	1.00							
10. IRP	-.17	-.40	.04	-.10	.13	.54	.20	.18	.28	1.00						
11. RRAA	.14	-.03	-.00	.03	-.05	.02	.05	.08	.03	.19	1.00					
12. AIM9P	.01	.06	-.07	-.12	-.01	-.10	.02	.11	.02	.00	.36	1.00				
13. INIT2	.04	-.18	-.01	-.05	.04	.18	.04	.12	.08	.03	.12	.06	1.00			
14. GUN	-.08	-.11	.04	-.04	.10	.13	.10	.11	.11	.18	-.02	-.02	-.08	1.00		
15. G	.09	.03	-.00	-.02	-.02	.01	.00	-.01	-.01	-.05	-.01	-.04	-.06	-.04	1.00	
16. INIT3	-.10	-.01	.07	.15	.08	.07	-.04	-.02	-.08	-.15	-.30	-.14	.06	-.02	-.01	1.00

1 See Table 5 for definitions

TABLE 10. CORRELATION WITH GROUP MEMBERSHIP OF THE FINAL 16 CANDIDATE MEASURES

Measure Number	Measure Abbrev.[1]	Correlation with Group Membership
1	ARAA	-.36
2	OOVP	-.45
3	SBPA	.30
4	FFA	-.37
5	EMRM	.49
6	OFFP	.53
7	TH1A	.53
8	TH3A	.49
9	TH4A	.60
10	IRP	.39
11	RRAA	.08
12	AIM9P	-.04
13	INIT2	.19
14	GUN	.22
15	G	-.08
16	INIT3	.04

1 See Table 5 for definitions.

Table 11 shows the discriminant analysis results. The assigned number relates purely to those 16 candidate measures in the analysis as an identifier. The first column of coefficients and communalities is for the complete group with all measures present. The second column is with AIM9P and INIT3 removed. These two measures were eliminated on the basis that their communalities were less than .0025. The third column shows the final discriminant analysis of 13 measures. Measure "g" was eliminated on the basis of low communality.

A ridge adjusted discriminant analysis (Vreuls, et al, 1976) was performed on the final 13 measures. The ridge procedure removes some of the "overfit" of a linear discriminant model and makes subsequent applications of the model more reliable. The results are shown in Table 12. As bias (K = .1, K = .2, etc.) was added to the diagonal of the intercorrelation matrix prior to successive discriminant analyses, the linear combination of the coefficients for each measure tends to stabilize. This is illustrated also in Figure 5 for five selected measures.

Test of Resulting Model. The discrimant measurement models were tested using Monte Carlo type data simulations to explore their relative potential reliability. With the aid of this data simulation technique and the changes in the coefficient trace of the ridge adjusted discriminant analysis, the most potentially reliable model could be selected by choosing the model which revealed the minimum misclassification error. The resultant model had a K value of 0.3 and a total average misclassification error of 16%. The complete results of these tests are presented in Appendix F.

Summary of Multivariate Analysis Results. The multivariate analyses of time history data collected during the 1v1 ACM free engagements demonstrated the feasibility of an ACMPM structure based on such data. The results of a 13 measure discriminant analysis provided an effective model. While the optimum value for K was not determined, a value of 0.3 was found to be a satisfactory approximation.

Given that a pilot flies the F-4 in the SAAC simulator in the same configuration as this study, and given the same initializations before release, and under the same rules and restrictions, the criterion of performance is based on the algorithms presented in Table 13.

If the score is greater than -1.8999 there is a probability greater than 0.921 that the pilot belongs to the criterion group of experienced pilots (analysis Group 3). The criterion can be adjusted by tuning the cut off score about the group mean, -1.1438. To be absolutely sure of the decisions made by this scoring model, some 3.5σ negative extrema tests for particular parameters should be made before scoring. This would insure that the pilot performance being scored reasonably belongs to a sample group from which the scoring model was developed.

TABLE 11. DISCRIMINANT ANALYSIS COEFFICIENTS AND COMMUNALITIES

Variable Number	Name[1]	Assigned Number	16 Measures COEF(I)	16 Measures COMM(I)	14 Measures COEF(I)	14 Measures COMM(I)	13 Measures COEF(I)	13 Measures COMM(I)
1	ARAA	1	- .00476	.2360	- .00449	.2167	-.00448	.2186
2	OOVP	2	-3.9603	.4385	- .38201	.4301	-.36753	.3992
4	SBPA	3	.06571	.1664	.06840	.1567	.06642	.1571
5	FFA	4	- .00006	.2608	- .00006	.2389	-.00006	.2410
7	EMRM	5	.01111	.4492	.01089	.4129	.00986	.4163
8	OFFP	6	1.34285	.5522	1.06970	.5436	.76394	.5018
10	TH1A	7	-4.07008	.3681	-6.24604	.3416	6.57812	.3701
12	TH3A	8	10.44849	.2469	-2.87643	.1901	-3.33729	.1856
13	TH4A	9	7.35339	.4263	10.05314	.3898	7.93817	.3959
17	IRP	10	3.40843	.3276	5.91282	.4263	7.71286	.4856
18	RRAA	11	.01137	.0115	.00565	.0107	.00305	.0108
23	AIM9P	12	1.13661	.0010	---	---	---	---
24	INIT2	13	.42505	.0508	.67922	.0783	.64878	.0669
25	GUN	14	.87338	.1059	.71056	.0864	.48438	.0644
27	G	15	- .19028	.0074	- .22738	.0096	---	---
31	INIT3	16	.11457	.0024	---	---	---	---
	R^2		.531		.542		.533	
	χ^2		164		170		167	
	Λ		.47		.46		.47	
	NDF		16		14		13	

1. See Table 5 for definitions.

TABLE 12. RIDGE ADJUSTED DISCRIMINANT ANALYSIS

Variable Number/Name[1]		Assigned Number	K = 0.0		K = 0.1		K = 0.2		K - 0.3	
			COEF(I)	COMM(I)	COEF(I)	COMM(I)	COEF(I)	COMM(I)	COEF(I)	COMM(I)
1	ARAA	1	-.00448	.2186	-.00518	.2350	-.00540	.2545	-.00529	.2443
2	OOVP	2	-.36753	.3992	-.38777	.4217	-.41901	.4607	-.41231	.4544
4	SBPA	3	.06642	.1571	.05901	.1683	.05556	.1727	.05922	.1746
5	FFA	4	-.00006	.2410	-.00006	.2600	-.00006	.2676	-.00006	.2690
7	EMRM	5	.00986	.4163	.01127	.4479	.01224	.4617	.01212	.4649
8	OFFP	6	.76394	.5018	1.22550	.5095	1.61332	.5628	1.42378	.5593
10	TH1A	7	6.57812	.3701	3.94475	.3764	1.71044	.3744	2.27077	.3828
12	TH3A	8	-3.33729	.1856	-2.35641	.1984	-.93395	.1982	-1.20926	.1980
13	TH4A	9	7.93817	.3959	4.54957	.3924	1.86822	.3906	2.68293	.3996
17	IRP	10	7.71286	.4856	2.99056	.3011	1.37984	.2586	3.05355	.3141
18	RRAA	11	.00305	.0108	.01080	.0115	.01389	.0119	.01131	.0120
23	AIM9P	12	---	---	---	---	---	---	---	---
24	INIT2	13	.64878	.0669	.67911	.0761	.53560	.0650	.55229	.0658
25	GUN	14	.48438	.0644	1.17136	.1385	.88202	.0969	.62546	.0711
27	G	15	---	---	---	---	---	---	---	---
31	INIT3	16	---	---	---	---	---	---	---	---
	R^2		.533		.524		.515		.514	
	χ^2		167		162		158		158	
	Λ		.47		.48		.48		.49	
	NDF		13		13		13		13	

[1] See Table 5 for definitions.

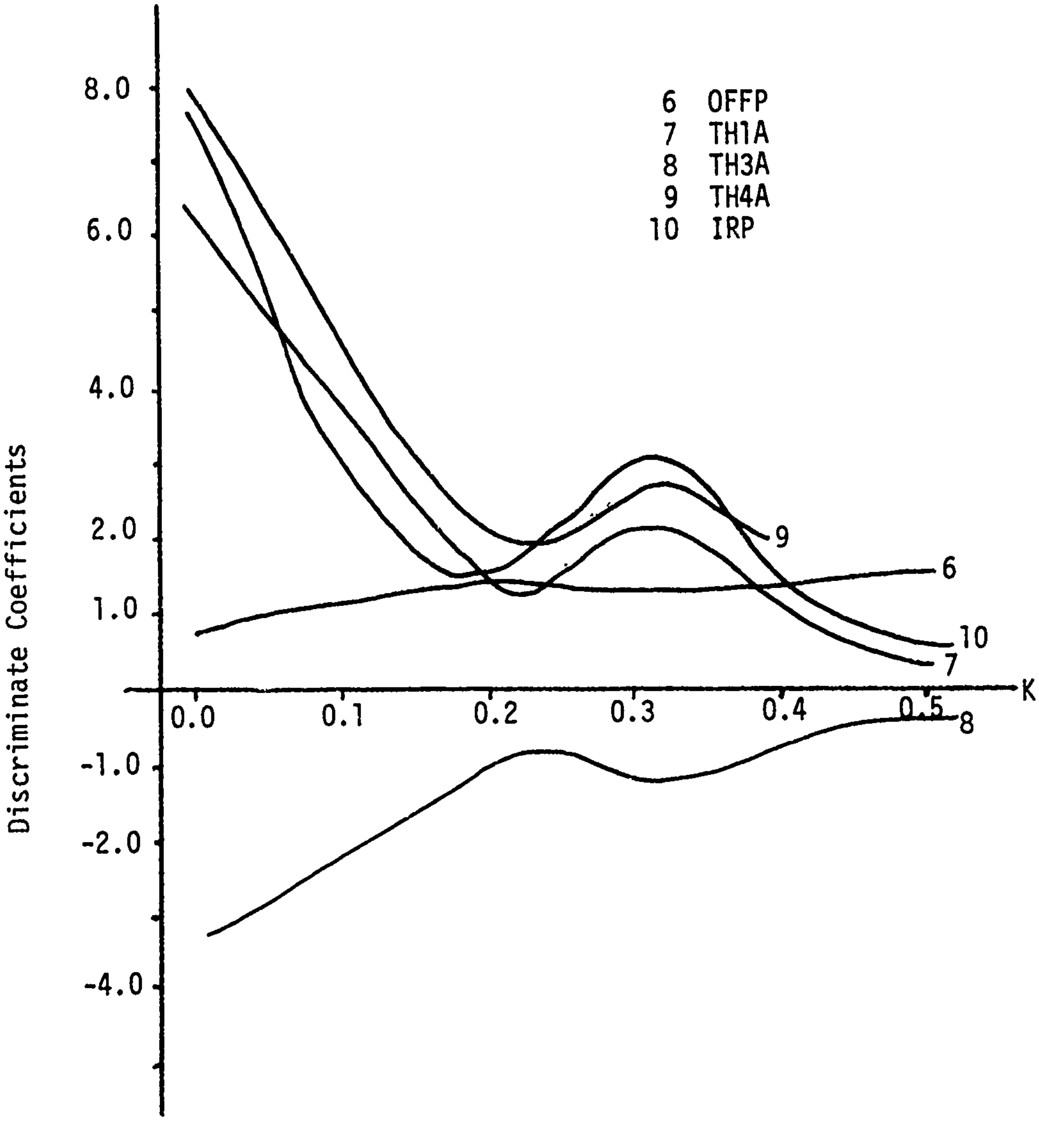


Figure 5. Coefficient Trace of Relevant Performance Measures for Ridge Adjusted Discriminant Analysis

TABLE 13. PERFORMANCE ALGORITHM FOR 1v1 ON SAAC

Weighting Coefficient	Measure
- .00529	Absolute Average Altitude Rate
- .41231	Percent Opponent Out of View
+ .05922	Average Speed Brake Position
- .00006	Average Fuel Flow
+ .01212	RMS Energy Management Index
+1.42378	Percent Offensive
+2.27077	Average Throttle Position 1 Transitions
-1.20926	Average Throttle Position 3 Transitions
+2.68293	Average Throttle Position 4 Transitions
+3.05355	Percent in Range
+ .01131	Absolute Average Roll Rate
+ .55229	1.0 if Initialized in Position 2
+ .62546	1.0 if Successful Gun Kill

C. Tactical Level Performance Measurement

During training in BFM, pilots are taught maneuvering rules for various combinations of range, range rate, line-of-sight angle, and aspect angle between their aircraft and the target aircraft. The tactical level analyses are based on the assumption that range, LOS, and aspect angle are important variables in determining the proper course of action for each pilot and for determining the outcome of the engagement.

A three dimensional structure (TACSPACE) was imposed on the time history data from the 1v1 free engagements. TACSPACE is best described as sectors of a volume with LOS angle, aspect angle and range as the three axes (see Figure 6). Note that the scales on the three axes are not linear since the sectors were dimensioned to relate to expected population densities.

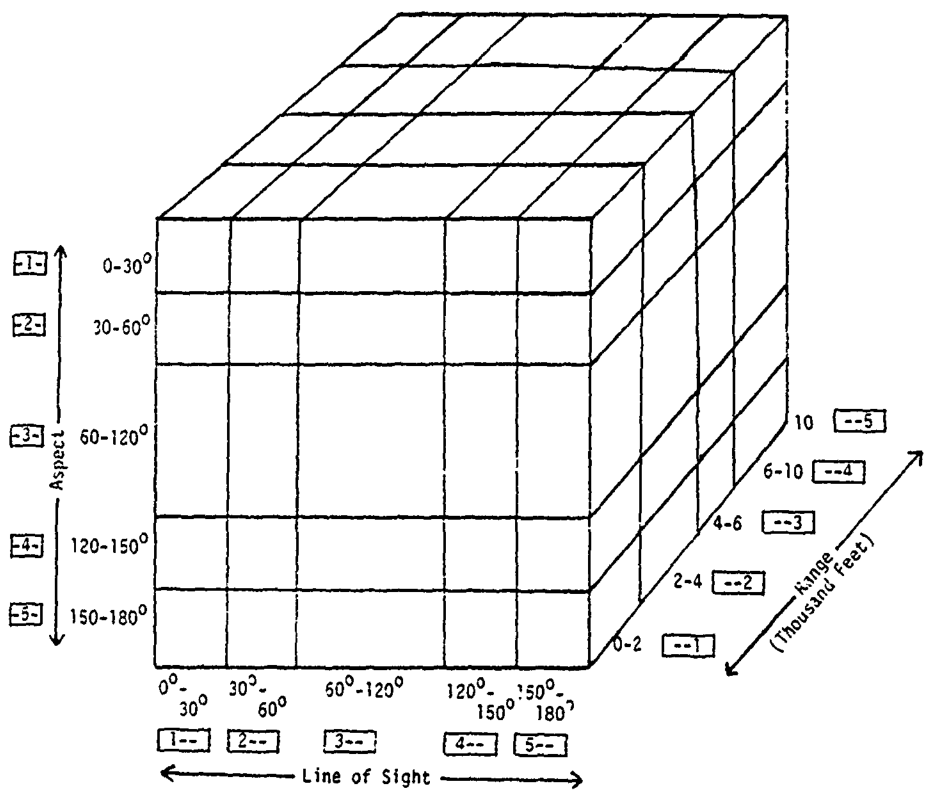


Figure 6. General Arrangement of TACSPACE

NOTE: Boxes Like [2--] Indicate Data Box Codes

The initial tactical analysis tested the hypothesis that a relationship existed between the various parts of TACSPACE used by pilots and the outcome of the engagement (winner or loser). This hypothesis received some support from relative aircraft position data (e.g., offensive time, out of view time) in the univariate analyses. The TACSPACE analysis, however, examined the relative position data with somewhat greater precision.

TACSPACE data were examined for the winners and losers of all engagements in which a weapons kill was accomplished. The percentage of engagement time the pilots spent in each of the 125 TACSPACE "boxes" was calculated. The "population" in each box was scaled by a population scaling factor (PSF) to compensate for unequal box volumes of TACSPACE. The boxes were ranked according to the percentage of mission time spent in each box by the winners and by the losers. The distributions of the resultant corrected box mission times are shown in Tables G1 and G2.

Note that the distribution is symmetrical as the "most winning" sequence of boxes, starting with Box 122, degrades toward the "most losing" box (452). At this stage, it was decided to further examine the top 10% of winner and loser boxes since these probably contained the most descriptive significance. Table G3 shows that, with two exceptions, the losing box was the "reciprocal" of the winning box. This suggests that the percentage of time each pilot spent in each of these boxes could be used as a measure of performance.

These preliminary TACSPACE data provide only a suggestion of the potential utility of the TACSPACE approach to ACMPM. Future analyses might examine the way in which pilots fly their aircraft as a function of their position in TACSPACE. Preliminary glances at these data suggest interesting trends. For example, when highly skilled pilots were in a position of small aspect and LOS angles, they were very active in throttle and speedbrake control. The lower skilled pilots became so busy tracking their opponents that their throttle and speedbrake activity approached zero.

Additionally, when high skilled pilots were in the offensive with advantage position, their mean g-loading was significantly lower than that of the lower skilled pilots when in similar positions. Conversely, when the highly skilled pilots were defensive with disadvantage, they used considerably higher g-loading during their counteroffensive maneuvering than did their lower skilled counterparts.

These initial examinations of the TACSPACE data base indicate that this approach can provide information of considerable diagnostic value when the TACSPACE concept is fully developed and refined.

V. CONCLUSIONS

This study represents the development and preliminary analysis of a fertile body of data collected during 1v1 ACM free engagements. The data collected and the measurement structures developed contain the seeds of an effective ACMPM system which, when further refined, could be implemented on the SAAC and, with some revision, on the ACMR/ACMI.

Many measures, taken at the whole engagement level, were found to correlate with pilot ACM skill level. For example, the highly skilled pilots achieved more kills, used less fuel, flew slower speeds, and were more active in throttle and speedbrake control than the pilots of lesser skill. All of these individual measures, however, contained large amounts of underlying within-groups variance which precluded the use of any single measure as a reliable metric of ACM skill level.

In order to minimize this unexplained variance, multivariate analysis yielded a measurement model containing 13 variables including measures of energy management, control activity, relative aircraft positions, aircraft maneuvering, and success with guns. This model, with optimal weights placed on each of the measures, accounted for 51% of the performance variance. It was able to discriminate between pilots of high skill and pilots of lower skill with an accuracy of 92.1 percent. Future iterations of the analysis process and the addition of diagnostic measures could be expected to further refine the measurement structure and improve this accuracy.

The tactics analysis represents a potentially useful way of examining performance within an engagement for the purpose of suggesting diagnostic measures. These data, however, are very preliminary and the TACSPACE concept requires considerable development before much useful information can be derived from it. The investigators believe that this further development will demonstrate that the TACSPACE concept has great potential as an ACMPM diagnostic structure.

It is important to recognize that the measurement structures and algorithms developed here are very application specific. They apply only to 1v1 free engagements flown on the SAAC in an F-4 versus F-4 mode using the three initial setups tested here. It is expected that, with some revision, the model could be applied in other ACM environments. Any attempt to do so without prior empirical evaluation of the model in the new application would be extremely ill-advised, especially since it is relatively straightforward to perform empirical tests.

The major investment required to perform future empirical tests will be in the data collection activities. The basic approach and methods to analyze the data for measurement model development have been developed. Thus, future analyses of new data to improve the model for changes in task conditions can be performed with a minimum level of effort and in a very short time.

It must be emphasized that none of the ACMPM structures developed during this effort represents a finished product ready for implementation and operational use. Further analyses, total system design and development activities, developmental testing and validation testing should be undertaken along the lines suggested in the next section.

VI. RECOMMENDATIONS

This study achieved its goals by providing an empirical data base, a methodology, and an initial algorithm for measuring 1v1 ACM performance. Several further steps are required, however, to produce an effective ACMPM system which will be useable by instructor pilots on the SAAC:

1. The measure set should be refined through iterative computer analyses of the existing data base. First, an analysis of dissimilar aircraft engagements should be conducted to develop a measurement model which is appropriate for F-4 versus MIG engagements. Second, the diagnostic measurement capability simplification of TACSPACE should be explored. Finally, the results of these analyses and other ACMPM efforts should be incorporated in the measurement structure where appropriate, and final algorithms developed.

2. The algorithms should be cross-validated with a new sample of pilots on the SAAC. The Monte Carlo type data simulation which was performed in this study represents a good initial test of the measurement model. A cross-validation, however, would represent a more complete and final test.

3. The design requirements for the total, real-time ACMPM system should be specified. This includes a description of the measurement structures and algorithms, the user interface (what data are provided to the instructors and how they are presented), instructional materials to aid the instructor in interpreting the data, and the possible design and use of the data for a training management system.

4. Given a complete specification, the total ACMPM system can be designed, built and implemented for developmental testing of the measures, user interface, instructional materials and training management data base. Developmental testing will be required to discover and correct any unanticipated problems with the system.

Other recommendations are offered. These are less intimately related to the development of the ACMPM system for the SAAC, but may have an impact on the development of measurement for ACMR/ACMI and on future evaluation and training techniques:

5. In parallel with Steps 3 and 4 above, a computer reanalysis of the data base should be undertaken with a reduced measure set which is limited to the data that are readily available on the ACMR/ACMI. The purpose of this analysis will be to offer the seeds of a measurement model which can be used for airborne performance evaluation and can be used for direct comparison of range data and simulator data for training effectiveness evaluations. As a part of this analysis, a thorough examination is required of all current measurement and related studies on the ACMR and ACMI. There were several in progress during the conduct of this study. Their results might be important in future work.

6. To be completely valid, especially for applications in the air, the final ACMPM system should include provisions for measuring the performance of the WSO. In the SAAC, WSO functions are automated. Much of the system performance variance, which can be expected to be increased with a human operating this crew position, has been held constant in the SAAC.

7. The use of elaborate ACMPM structures to measure attacks on a non-reactive target should be examined closely. Detailed performance measures may diagnose pilot performance against a non-reactive target and might be useful for that purpose; but, detailed measures do not predict free engagement performance. One reason might be that ACM against a non-reactive target does not permit the pilot to demonstrate the full range of perceptual and cognitive skills required in free engagement. Of the measures taken in this study, against a non-reactive target, the only one which appears to predict free engagement is time to kill.

8. It must be emphasized that no ACMPM system should be implemented and put to operational use until a thorough empirical evaluation of its efficacy is performed.

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APPENDIX A:

EXPERIMENTAL CONDITIONS AND DATA COLLECTION FORMS

TABLE A1. INITIAL CONDITIONS FOR MANEUVER I

Variables	Units	Cockpit 1		Cockpit 2
Indicated Speed	(Knots)	400		400
Altitude	(feet)	10,000		10,000
Heading	(degrees)	0		0
Line of Sight Angle	(degrees)	0		0
Slant Range			4,000	
Relative Horizontal Offset	(feet)		0	
Cannon Rounds	(#)	640		640
AIM-9 (Heat) Missiles	(#)	0		0
AIM-7 (Radar) Missles	(#)	0		0
Fuel Quantity	(Lbs.)	8,000		8,000
Bingo Fuel Limit	(Lbs.)	5,000		5,000

TABLE A2. INSTRUCTIONS FOR MANEUVER I

1. Initial Conditions. The threat aircraft is positioned 4,000 ft ahead of you at 400 Knots and 10,000 ft altitude. You are co-speed co-altitude and on the same heading. You have a full load (640 rounds) of 20mm, are clean, have no missiles, and have 8,000 pounds of fuel.

2. Target Maneuvers. Upon commencement of the engagement, the threat aircraft will maintain straight and level at 400 Knots while you close to gun range. Three seconds after you pass 2,500 ft range the target will begin a 4 g, full AB turn in either direction, maintaining this for 90 degrees of turn. After 90 degrees, 4 g's will be maintained but the bank angle will be reduced to 30 degrees. The target will then be in a climb maintaining 4 g's until 300 Knots. At 300 Knots, the target will roll inverted and pull down to the horizon. When his caged sight line touches the horizon, he will roll wings level and call cease maneuver.

3. Object of Mission. Attempt to hit the target with 20mm as many times as possible. Are there questions?

INSTRUCTIONS TO TARGET PILOT
(Not read to attacking pilot)

Maneuver. Perform the exercise on instruments. The console operator will inform you when the attacker is at 2,500 ft. Wait 3 seconds and start the maneuver. Call cease maneuver when you have rolled wings level after your pull down to the horizon.

TABLE A3. INITIAL CONDITIONS FOR MANEUVER II

Variables	Units	Cockpit 1		Cockpit 2
Indicated Airspeed	(Knots)	400		400
Altitude	(feet)	15,000		15,000
Heading	(degrees)	0		0
Line of Sight Angle	(degrees)	30		150 Left
Slant Range	(feet)		9,000	
Relative Horizontal Offset	(feet)		4,500	
Cannon Rounds	(#)	640		640
AIM-9 (Heat) Missiles	(#)	4		4
AIM-7 (Radar) Missiles	(#)	0		0
Fuel Quantity	(Lbs.)	8,000		8,000
Bingo Fuel Limit	(Lbs.)	5,000		5,000

TABLE A4. INSTRUCTIONS FOR MANEUVER II

1. Initial conditions. The threat aircraft is positioned in your forward quadrant at 15,000 ft MSL and 400 Knots. You are at 30 degrees aspect to the target at approximately 9,000 ft slant range. You have a full load of 20mm, no tanks, 4 AIM-9Js, and 8,000 pounds of fuel.

2. Target Maneuvers. Upon commencement of the engagement, the threat aircraft will maintain 400 Knots, straight and level until you are at 6,000 ft slant range. At 6,000 ft range, the target will break into you using 5-6 G's, idle power, and speed brakes. As you overshoot and begin a separation maneuver, the threat will reverse and attempt to fire an AIM-9.

3. Object of Mission. Accelerate and close on the target aircraft. As you approach 6,000 ft range, fire an AIM-9 at the target. As the target breaks into your attack, select guns and set up for a high-angle raking gun pass. Attempt to hit the target with as many 20mm rounds as possible prior to initiating a separation maneuver. Maneuver will cease when attacker has opened to 6,000 ft slant range. Are there any questions?

INSTRUCTIONS TO TARGET PILOT
(Not read to attacking pilot)

Maneuver. Perform the exercise on instruments. The console operator will tell you when attacker is at 6,000 ft. Break into the attacker. He will be on your left side. Perform an unloaded reversal when the attacker disappears behind you. Launch an AIM-9 if possible. Any questions?

TABLE A5. INITIAL CONDITIONS FOR MANEUVER III

Variables	Units	Cockpit 1		Cockpit 2
Indicated Airspeed	(Knots)	400		400
Altitude	(feet)	14,000		12,000
Heading	(degrees)	0		0
Line of Sight Angle	(degrees)	0		0
Slant Range	(feet)		18,000	
Relative Horizontal Offset	(feet)		0	
Cannon Rounds	(#)	640		640
AIM-9 (Heat Missiles	(#)	4		4
AIM-7 (Radar) Missiles	(#)	0		0
Fuel Quantity	(Lbs.)	8,000		8,000
Bingo Fuel Limit	(Lbs.)	5,000		5,000

TABLE A6. INSTRUCTIONS FOR MANEUVER III

There will be three successive engagements during this maneuver. The following information is applicable to all three.

1. First Run. Initial Conditions. The threat aircraft is positioned on your nose at 3 NM, opposite heading. He is at 12,000 ft MSL and 450 Knots. You should be at 14,000 ft and 400 Knots. You have 4 AIM-9s, a full load of 20mm, no tanks, and 8,000 pounds of fuel. This will be your starting condition for the next 3 engagements.

2. Second Run. Target Maneuvers. The target will maneuver counter-offensively in an unpredictable manner on all three runs. Take no action until you pass the target aircraft. After the initial pass the target aircraft will fire on you with AIM-9 missiles or guns if you give him the opportunity to do so.

3. Third Run. Object of the Mission. Kill override will be off. The object is to expeditiously achieve a kill on the threat with the ordnance available. Bingo is 5,000 pounds. Call Bingo. Are there any questions?

INSTRUCTIONS TO TARGET PILOT
(Not read to attacking pilot)

1. First Run. As you pass the attacker, enter a 4-5g AB half cuban eight. Accelerate in the 45 degree dive to 400 Knots, then pull up to enter a 3 g/500 Knots level turn right. Do this on instruments. Any questions?

2. Second Run. Delay for 5 seconds after you pass the attacker then perform a 4-5g AB loop followed by a 3g, 500 Knots level turn right. Do this on instruments. Any questions?

3. Third Run. As you pass the attacker, initiate a 3g/450 Knots level turn left. Maintain this turn for 20 seconds, then reverse the turn and continue at 3g, 450 Knots. Do this on instruments. Any questions?

(For all three runs, the target pilot would continue to make alternate direction left and right level turns until the maneuver ended.)

TABLE A7. INITIAL CONDITIONS FOR THE FIRST OF THREE 1v1 FREE ENGAGEMENT

Variables	Units	Cockpit 1		Cockpit 2
Indicated Airspeed	(Knots)	400		400
Altitude	(feet)	15,000		15,000
Heading	(degrees)	0		0
Line of Sight Angle	(degrees)	90 Left		90 Right
Slant Range	(feet)		6,000	
Relative Horizontal Offset	(feet)		6,000	
Cannon Rounds	(#)	640		640
AIM-9 (Heat) Missiles	(#)	2		2 (4)*
AIM-7 (Radar) Missiles	(#)	0 (2)*		0
Fuel Quantity	(Lbs.)	7,000		7,000
Bingo Fuel Limit	(Lbs.)	4,000		4,000 (2500)*

* For F-4 vs MIG (cockpit 2) differences in initial conditions are shown in parenthesis.

TABLE A8. INITIAL CONDITIONS FOR SECOND FREE ENGAGEMENT

Variables	Units	Cockpit 1		Cockpit 2
Indicated Airspeed	(Knots)	450		350
Altitude	(feet)	15,000		17,000
Heading	(degrees)	0		0
Line of Sight Angle	(degrees)	90 Left		90 Right
Slant Range	(feet)		6,300	
Relative Horizontal Offset	(feet)		6,000	
Cannon Rounds	(#)	640		640 (400)*
AIM-9 (Heat) Missiles	(#)	2		2 (4)
AIM-7 (Radar) Missiles	(#)	0 (2)*		0
Fuel Quantity	(Lbs.)	7,000		7,000 (4000)*
Bingo Fuel Limit	(Lbs.)	4,000		(2500)*

*For F-4 vs MIG (Cockpit 2) differences in initial conditions are shown in parenthesis.

TABLE A9. INITIAL CONDITIONS FOR THIRD FREE ENGAGEMENT

Variables	Units	Cockpit 1		Cockpit 2
Indicated Airspeed	(Knots)	400		400
Altitude	(feet)	15,000		15,000
Heading	(degrees)	0		180
Line of Sight Angle	(degrees)	90 Left		90 Left
Slant Range	(feet)		2,000	
Relative Horizontal Offset	(feet)		2,000	
Cannon Rounds	(#)	640		640 (400)*
AIM-9 (Heat) Missiles	(#)	2		2 (4)*
AIM-7 (Radar) Missiles	(#)	0 (2)*		0
Fuel Quantity	(Lbs.)	7,000		7,000 (4000)*
Bingo Fuel Limit	(Lbs.)	4,000		(2500)*

* For F-4 vs MIG (Cockpit 2) differences in initial conditions are shown in parenthesis.

MANEUVER I		PILOT #1	PILOT #2	PILOT #3	PILOT #4	PILOT #5	PILOT #6
20 MM.	HITS						
	REMAINING						
MANEUVER II							
AIM-9s	LAUNCHED						
	KILLS						
20 MM.	HITS						
	REMAINING						
MANEUVER III A							
AIM-9s	LAUNCHED						
20 MM.	REMAINING						
KILL(AIM-9 or GUN)							
TIME	AT END OR KILL						
MANEUVER III B							
AIM-9s	LAUNCHED						
20 MM.	REMAINING						
KILL(AIM-9 or GUN)							
TIME	AT END OR KILL						
MANEUVER III C							
AIM-9s	LAUNCHED						
20 MM.	REMAINING						
KILL(AIM-9 or GUN)							
TIME	AT END OR KILL						

Figure A1. Pretest Recording Form

FACTORS:	RATING SCALE					
DECISIVENESS	U	0	1	2	3	4
SITUATION AWARENESS	U	0	1	2	3	4
MANEUVERING	U	0	1	2	3	4
AGRESSIVENESS	U	0	1	2	3	4
OVERALL PERFORMANCE	U	0	1	2	3	4

COMMENTS: ____________________

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RATING CRITERIA

U- Performance not observed or insufficent information to make judgment.

0- INDICATES LACK OF ABILITY OR KNOWLEDGE.

1- INDICATES LIMITED PROFICIENCY. MAKES ERRORS OF OMISSION OR COMMISSION.

2- PERFORMANCE IS ESSENTIALLY CORRECT. RECOGNIZES AND CORRECTS ERRORS.

3- PERFORMANCE IS CORRECT, EFFICIENT, SKILLFUL AND WITHOUT HESITIATION

4- PERFORMANCE REFLECTS AN UNUSUALLY HIGH DEGREE OF PROFICIENCY.

Figure A2. Pilot Rating Form

APPENDIX B:
PRETEST DATA

TABLE B1. MANEUVER III, TIME TO KILL (SEC) & NUMBER OF KILLS

Week	Pilot	Engagement 1	Engagement 2	Engagement 3	Total Kills	Mean Time
1	1	-	-	-	0	-
1	2	-	-	115	1	115
1	3	232	97	114	3	148
1	4	134	109	66	3	103
1	5	116	75	70	3	87
1	6	135	113	126	3	125
2	1	180	189	-	2	185
2	2	-	-	-	0	-
2	3	-	191	153	2	172
2	4	-	-	-	0	-
2	5	35	74	46	3	52
2	6	187	45	132	3	121
3	1	152	-	-	1	152
3	2	-	-	56	1	56
3	3	126	-	46	2	86
3	4	120	149	-	2	135
3	5	85	64	120	3	90
3	6	38	40	30	3	36
4	1	120	-	112	2	116
4	2	79	97	-	2	88
4	3	-	-	-	0	-
4	4	-	189	118	2	154
4	5	198	125	95	3	139
4	6	43	167	105	3	105
5	1	-	122	95	2	108
5	2	73	122	-	2	98
5	3	110	-	117	2	114
5	4	166	174	111	3	150
5	5	41	-	90	2	66
5	6	43	-	95	2	69

APPENDIX C:

DATA TAPE CONTENTS, FORMAT AND MEASUREMENT CALCULATIONS

Air combat aircraft and aircrew performance data were collected using the SAAC simulator at Luke Air Force Base for numerous one versus one ACM engagements three days a week for five weeks. This collection effort resulted in 15 tapes containing the results of over 640 simulated engagements. The contents and the format of the data tapes produced during this study by the SIGMA 5 computers (which control the SAAC simulator) are documented in this section. Also contained in this section are details on the further manipulation of the data required to perform timely analyses with the SIGMA 7 computer at the NAVAL TRAINING EQUIPMENT CENTER in Orlando.

Organization of This Appendix. To aid information retrieval, all of the figures and tables in this appendix are at the end of the text. Figures C1 through C8 appear first and are followed by Tables C1 through C4.

SAAC Data Tapes. Each ACM engagement, as it was recorded on tape, consisted of one header record and a variable number of data blocks followed by a trailer record (Figure C1). These time histories contained a variable number of data blocks, as the time required to complete an ACM engagement could not be predetermined. All of the buffers or data blocks were 400 words in length.

The header record and trailer record contain information specific to the operation of the SAAC data collection system and are not directly pertinent to decoding the rest of the data base. These records were not retained in any further copy of the data and need not be documented in this report.

Each data record was written at a two hertz rate and contained both two hertz and ten hertz parameters. The general structure of each data record is shown in Figure C2. Each record consists of a record information section, the two hertz parameters and finally five sets of ten hertz parameters. The data record information section is represented in Figure C3. Of primary importance are the mission numbers and pilot numbers contained in this data section. Following the information section (as can be seen in Figure C2) are the actual values of the two hertz flight parameters. These values come in pairs; one for each cockpit. Each set of ten hertz parameters are preceded by two information words (Hertz count and simulator mode). There are 62 pairs of two hertz parameters and ten pairs of ten hertz parameters contained in their respective sections. More about the specific parameters is contained in a later section of this appendix.

The data records are written continuously across the data blocks with the first word in each data block being the number of good words contained in that respective block. Since the data record size is not related to the block size, the location of any particular parameter is not fixed in every data block. The data must, therefore, be uncoded/unpacked relative to the start of the first data block in the engagement. The data block structure imposed on the records is illustrated in Figure C4.

New Header Blocks. Any further analysis of the ACM data required the inclusion of engagement outcome (kill data) or pilot questionnaire data. To this end a new header block structure was developed (Table C1). Kill data and questionnaire results were punched on cards and then merged with other miscellaneous information on tape to produce a new header block for each ACM engagement.

Analysis Generation. In one pass through the 15 SAAC data tapes one summary data tape and seven compressed data tapes were produced. The summary data tape is a merger of the new header blocks and summary statistics computed on each engagement. This tape is useful for rapid glances at selected mission success factors. The compressed data tapes are a merger of the header blocks and reblocked two hertz data records. The original header and trailer records were dropped and the two hertz data records reorganized into blocks containing 30 second multiples. This reblocking simplifies the extraction of selected parameters for tactical analysis and reduces the number of tapes to be handled in any analysis. The generation of these new tapes is illustrated in Figure C5.

Before describing the final tape structures, it is important to mention that some data editing was performed in the process of generating these last tapes. Data recording, being a manual function, was not always synchronized with the release of the aircraft at the start of an engagement and with the termination of the engagements. Therefore, useless data appears at the beginning and end of most of the engagements on tape. There were also false starts where recording began but the engagement had to be reinitialized and then restarted. Compression of the data and computation of summary statistics could not begin until the detection and removal of these problematic data. Logic was implemented to detect the release of the aircraft at the beginning of an engagement by checking for consistent changes in the ground track of both aircraft. If either aircraft struck the ground, ran out of fuel, stopped moving, or was reset, the engagement was considered terminated. With these boundaries defined, the engagement also had to last over 10 seconds before it was considered good data and included in the generation process.

Data Summary Tape Structure. Each of the 172 parameters (86 parameters for 2 pilots) are represented in the DATA SUMMARY BLOCK. To access the summary data an integer block 2500 words long must be read and equivalenced to a real array 250 x 10. The first dimension of the array corresponds to the variable number or location found in the compressed data block. The second dimension corresponds to each of the measure transforms. In other words, there are 10 transforms for each of 172 parameters on store for each mission. Also, on the tape can be found corresponding HEADER BLOCKS with other related information about each run. The HEADER BLOCK is represented on the tape as entirely integer and 160 words long. It also must be equivalenced to a real array to access the floating point portions. The summary data tape structure is illustrated in Figure C6. The statistical transforms are contained in Table C5.

Raw Data Tape (Compressed) Structure. Each mission record is preceded by the same HEADER BLOCK previously described. These data are then stored in integer form in 30 second multiples of 214 in blocks, a maximum of 7000 words long, for each complete mission. The last block may be less than 30 seconds (i.e., 6420 words) long depending on mission duration. Each entire mission is followed by one EOF mark. To access data in the DATA BLOCKS, like all the others, it must be equivalenced to a real array. The compressed data structure is illustrated in Figure C7 and the contents are described in Tables C2 and C3.

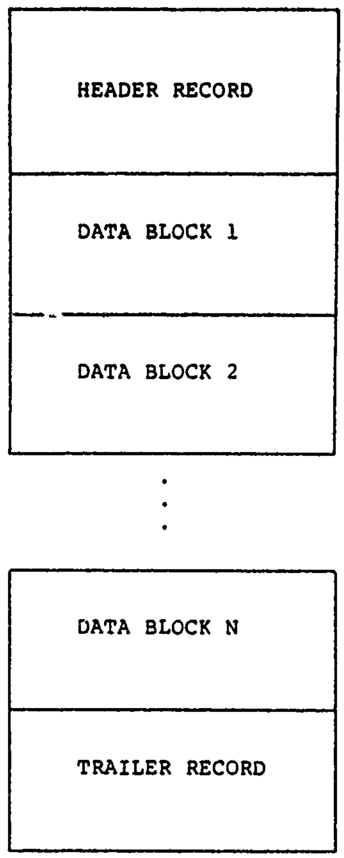

Figure C1. SAAC Data Tape Structure
for Entire Engagement

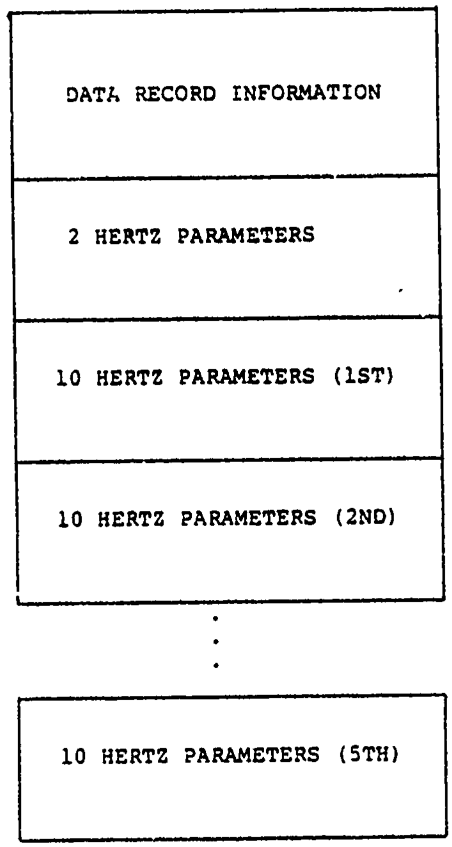

Figure C2. SAAC Data Record Organization for Single 2 Hertz Observation

DATA TYPE INDICATOR
MISSION NUMBER
SET UP NUMBER
PILOT'S NAME COCKPIT 1 (PART 1)
PILOT'S NAME COCKPIT 1 (PART 2)
PILOT'S NAME COCKPIT 2 (PART 1)
PILOT'S NAME COCKPIT 2 (PART 2)
SIMULATOR MODE

Figure C3. Data Record Information Contents

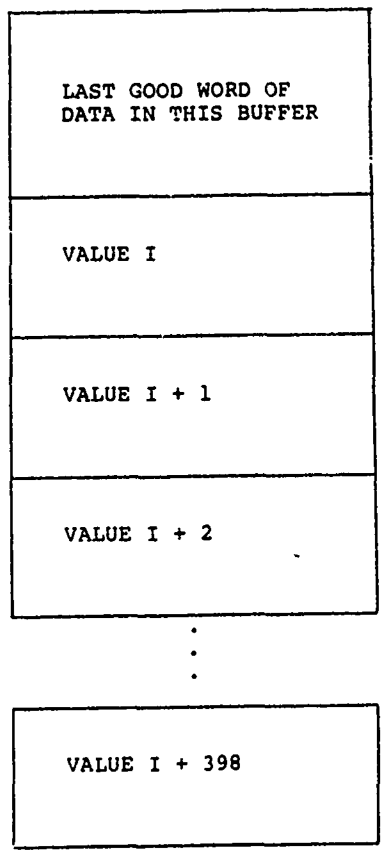

Figure C4. SAAC Data Block Structure

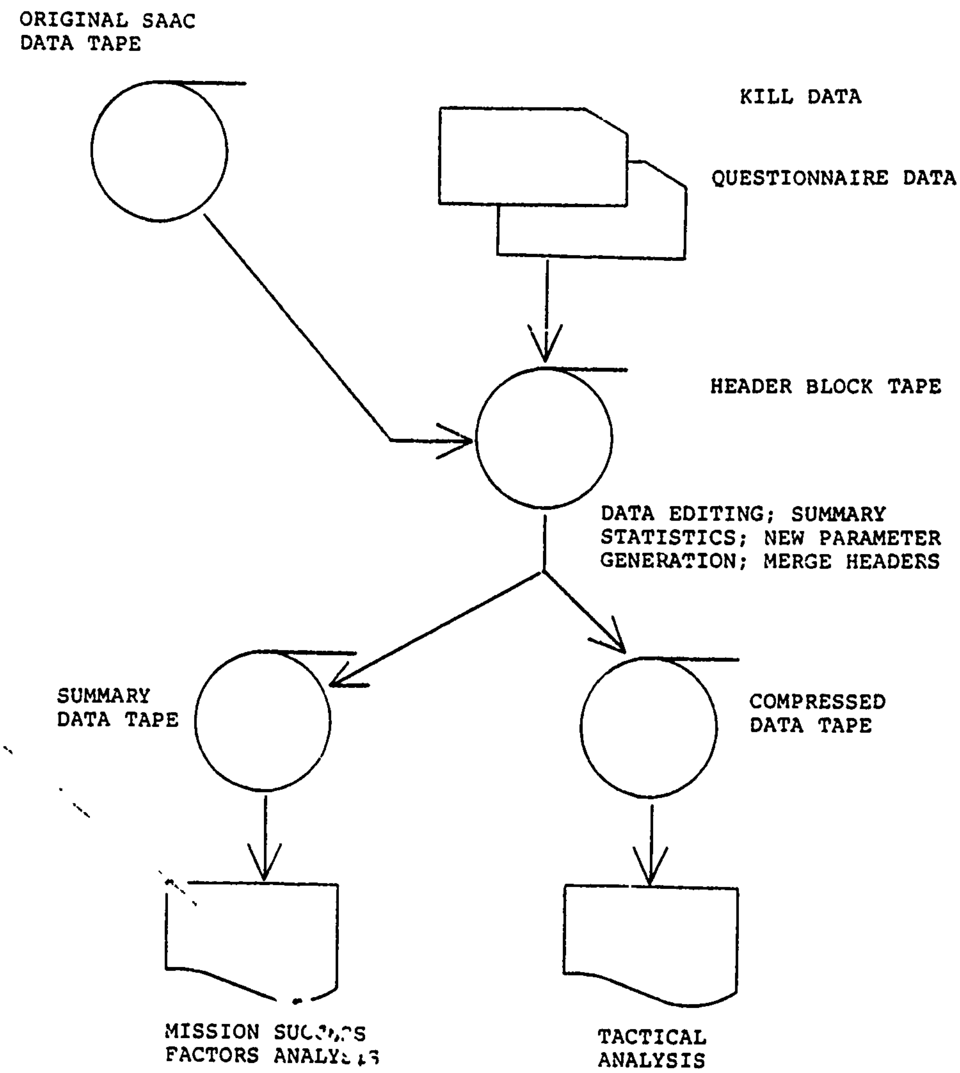

Figure C5. Analysis Generation Process

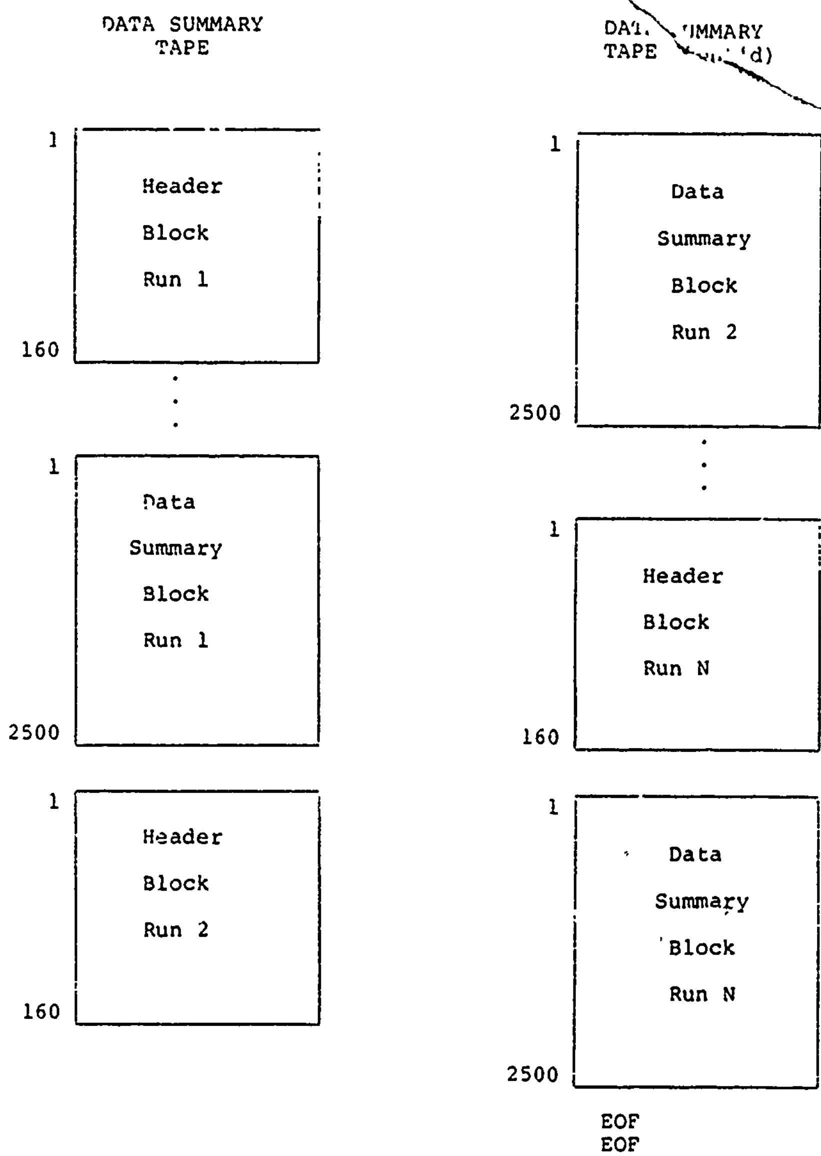

Figure C6. Summary Data Tape Structures.

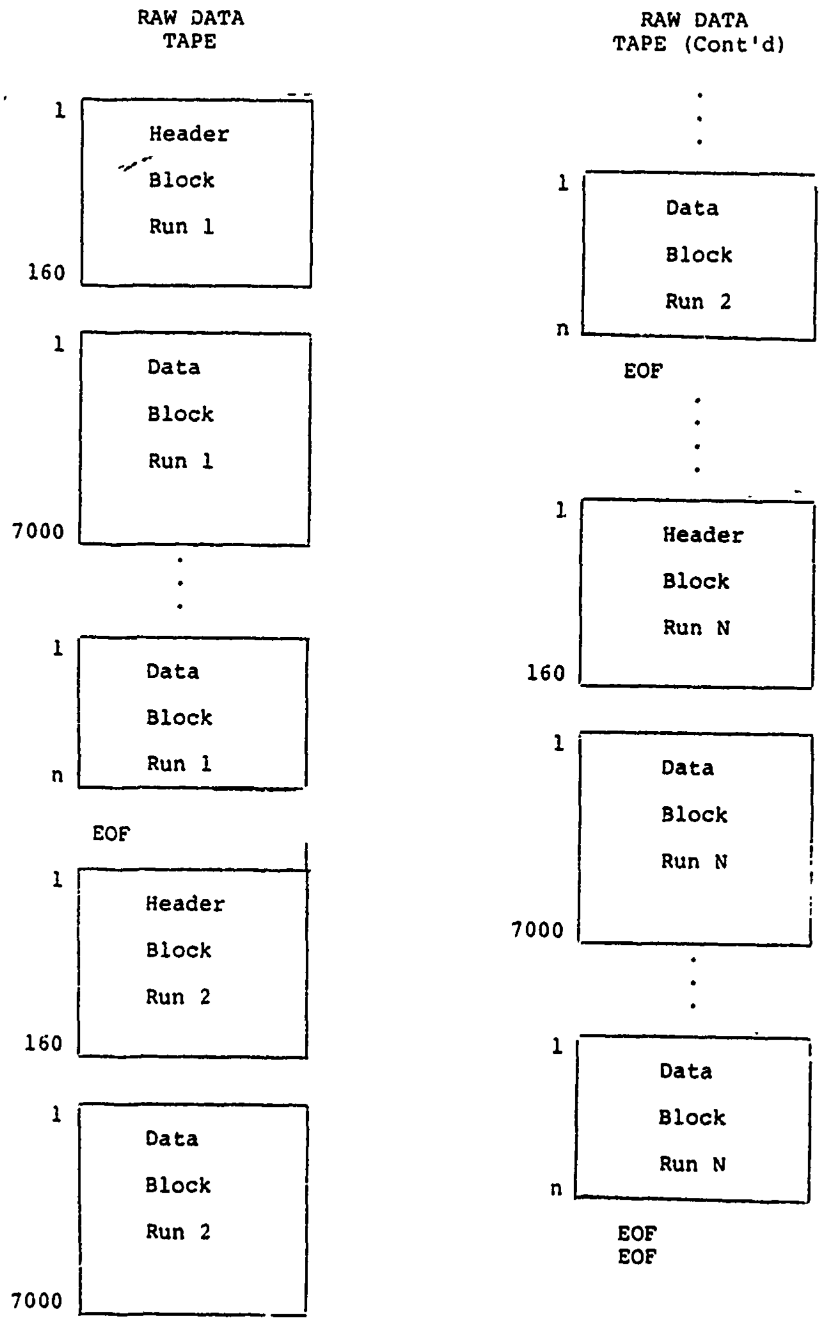

Figure C7. Compressed Data Tape Structures

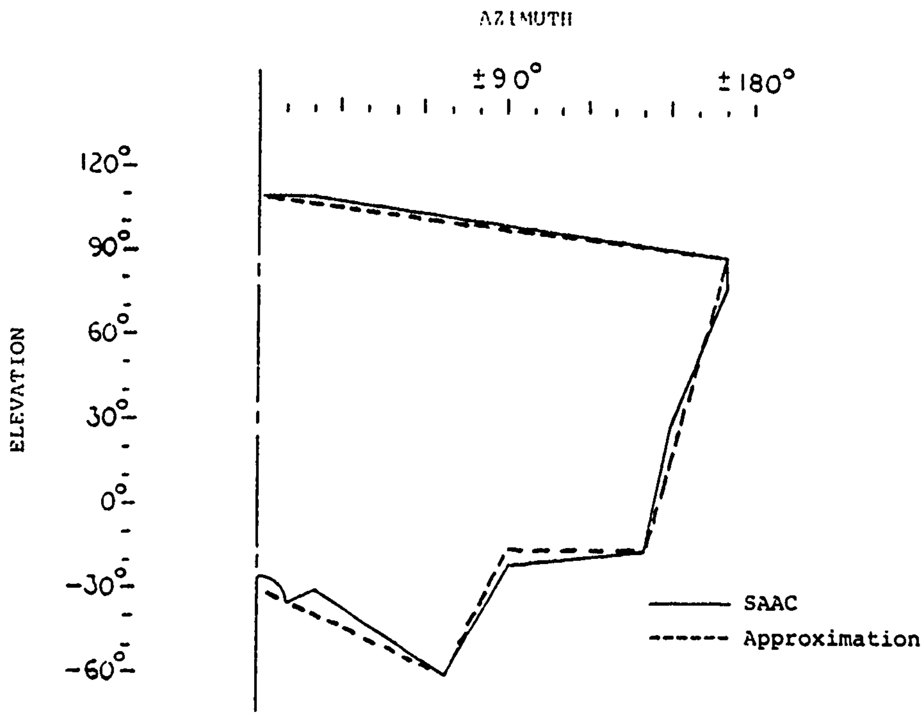

Figure C8. Approximate Field of View From SAAC Cockpit Vs. Canyon Approximation.

TABLE C1. HEADER BLOCK CONTENTS

Origin[1]	Word	Contents		Char. Type
1	1	RUN NUMBER		I
1	2	PROBLEM SET-UP NUMBER		I
1	3-4	PILOT NAME COCKPIT 1 (AT RUNTIME)		A
1	5-6	PILOT NAME COCKPIT 2 (AT RUNTIME)		A
2	7	LENGTH OF RUN (NO. OF 1/2 SEC FRAMES)		I
-	8-10	UNUSED		-
3	11	PILOT KILLED 1,2,3 (BOTH)		I
3	12	AIM 9 (0-1)		I
3	13	AIM 7 (0-1)		I
3	14	GUN (0-1)		I
3	15	GROUND (0-1)		I
3	16	'G's (0-1)		I
3	17	BINGO (0-1)		I
3	18	COCKPIT 1 PILOT NO.		I
3	19	COCKPIT 1 WK NO.		I
3	20	COCKPIT 2 PILOT NO.		I
3	21	COCKPIT 2 WK NO.		I
3	22	ERROR CODE (0-PRE, 1-NORM, 2-DSM, 9-ERR, 7-DROP)		I
4	23-24	COCKPIT 1 PILOTS NAME		A
4	25-26	COCKPIT 1 PILOTS SQUADRON		A
4	27-28	COCKPIT 1 PILOTS WING		A
4	29	AGE	PILOT 1	I
4	30	TOT. HR	"	I
4	31	TOT. FIGHTER HR.	"	I
4	32	F4 FRONT HR.	"	I
4	33	F4 BACK HR.	"	I

TABLE C1. HEADER BLOCK CONTENTS (Cont.)

Origin[1]	Word	Contents		Char. Type
4	34	TOT. HR. LAST 6 MO.	PILOT 1	I
4	35	TOT. F4 HR. LAST 6 MO.	"	I
4	36	TOT. SIM. HRS. LAST 6 MO.	"	I
4	37	ACM ENGAGEMENTS	"	I
4	38	ACME LAST 6 MO.	"	I
4	39	A/A SIM (0-1)	"	I
4	40	A/A SIM LAST 6 MO.	"	I
4	41	DACT (0-1)	"	I
4	42	DACT LAST 6 MO.	"	I
4	43	SAAC TIME	"	I
4	4	COMBAT HRS.	"	I
4	45	COMBAT ENGAGEMENTS	"	I
4	46	FWIC GRADUATE (0-1)	"	I
4	47	FWIC RECENCY	"	I
4	48	TAC ACES (0-1)	"	I
4	49	DACT RECENCY	"	I
4	50	TAC ACES RECENCY	"	I
4	51	FWS AGRESSOR (0-1)	"	I
4	52	ACM INSTRUCTOR (0-1)	"	I
4	53	AIM-7 FIRED	"	I
4	54	AIM-9 FIRED	"	I
4	55	TCM 3-1 RECENCY	"	I
4	56	HEIGHT	"	I
4	57	WEIGHT	"	I
4	58	SPORTS (0-1)	"	I
4	59	PHYS COND. (0-1)	"	I

TABLE C1. HEADER BLOCK CONTENTS (Cont.)

Origin[1]	Word	Contents		Char. Type
4	60	OTHER PILOTS (0-1)	PILOT 1	I
4	61	PILOTS NO.	"	I
4	62	WEEK NO.	"	I
-	63	UNUSED	"	-
5	64	PEER RANK	"	F
5	65	PROJ. PILOT RANK	"	F
5	66	AVG. DECISIVENESS	"	F
5	67	AVG. SIT. AWARENESS	"	F
5	68	AVG. MANEUVERING	"	F
5	69	AVG. AGGRESSIVENESS	"	F
5	70	AVG. PERFORMANCE	"	F
4	71-72	COCKPIT 2 PILOTS NAME		A
4	73-74	COCKPIT 2 PILOTS SQUADRON		A
4	75-76	COCKPIT 2 PILOTS WING		A
4	77	AGE	PILOT 2	I
4	78	TOT. HR.	"	I
4	79	TOT. FIGHTER HR.	"	I
4	80	F4 FRONT HR.	"	I
4	81	F4 BACK HR.	"	I
4	82	TOT. HR. LAST 6 MO.	"	I
4	83	TOT. F4 HR. LAST 6 MO.	"	I
4	84	TOT. SIM. HR. LAST 6 MO.	"	I
4	85	ACM ENGAGEMENTS	"	I
4	86	ACME LAST 6 MO.	"	I
4	87	A/A SIM (0-1)	"	I
4	88	A/A SIM LAST 6 MO.	"	I
4	89	DACT (0-1)	"	I

TABLE C1 HEADER BLOCK CONTENTS (Cont.)

Origin[1]	Word	Contents		Char. Type
4	90	DACT LAST 6 MO.	PILOT 2	I
4	91	SAAC TIME	"	I
4	92	COMBAT HRS.	"	I
4	93	COMBAT ENGAGEMENTS	"	I
4	94	FWIC GRADUATE (0-1)	"	I
4	95	FWIC RECENCY	"	I
4	96	TAC ACES (0-1)	"	I
4	97	DACT RECENCY	"	I
4	98	TAC ACES RECENCY	"	I
4	99	FWS AGGRESSOR (0-1)	"	I
4	100	ACM INSTRUCTOR (0-1)	"	I
4	101	AIM-7 FIRED	"	I
4	102	AIM-9 FIRED	"	I
4	103	TCM 3-1 RECENCY	"	I
4	104	HEIGHT	"	I
4	105	WEIGHT	"	I
4	106	SPORTS (0-1)	"	I
4	107	PHYS COND. (0-1)	"	I
4	108	OTHER PILOTS (0-1)	"	I
4	109	PILOTS NO.	"	I
4	110	WEEK NO.	"	I
-	111	UNUSED	"	I
5	112	PEER RANK	"	F
5	113	PROJ. PILOT RANK	"	F
5	114	AVG. DECISIVENESS	"	F
5	115	AVG. SIT. AWARENESS	"	F
5	116	AVG. MANEUVERING	"	F

TABLE C1. HEADER BLOCK CONTENTS (Cont.)

Origin[1]	Word	Contents		Char. Type
5	117	AVG. AGGRESSIVENESS	PILOT 2	F
5	118	ABG. PERFORMANCE	"	F

1. Key to Origin
   1. Original SAAC Data
   2. Calculated during data editing phase
   3. Kill data cards
   4. Pilot questionnaires
   5. Peer ranking questionnaires

TABLE C2. COMPRESSED DATA BLOCK STRUCTURE

Words	Parameters	Sampling Rate[1]	Unit
1-2	NORTH		FT.
3-4	EAST		FT.
5-6	ALTITUDE		FT.
7-8	ALT RATE		FT/SEC
9-10	NAV PITCH		$\pm 180^0$
11-12	NAV ROLL		$\pm 180^0$
13-14	NAV HDG		$\pm 180^0$
15-16	SLANT RANGE		FT.
17-18	SINE) LOS AZIMUTH		-
19-20	COS) LOS AZIMUTH		-
21-22	SINE) LOS ELEVATION		-
23-24	COS) LOS ELEVATION		-
25-26	SINE) LOS ROLL		-
27-28	COS) LOS ROLL		-
29-30	OUT OF VIEW		LOGICAL
31-32	A/C HEG		DEG.
33-34	A/C PITCH		DEG.
35-36	A/C ROLL		DEG.
37-38	SIDE SLIP		DEG.
39-40	AOA		UNITS
41-42	AIRSPEED		KNTS
43-44	COEF LIFT		-
45-46	TURN RATE		RAD/SEC
47-48	'G'		-
49-50	LONG) A/C AXIS VEL		FT./SEC
51-52	LAT) A/C AXIS VEL		FT./SEC
53-54	VERT) A/C AXIS VEL		FT./SEC

TABLE C2. COMPRESSED DATA BLOCK STRUCTURE (Cont.)

Words	Parameters		Sampling Rate[1]	Units
55-56	SPEED BRAKES			POSITION
57-58	THROTTLE LEFT			POSITION
59-60	THROTTLE RIGHT			POSITION
61-62	INTERNAL FUEL			LBS.
63-64	FUEL FLOW-L			LBS./HR.
65-66	FUEL FLOW-R			LBS./HR.
67-68	PITCH TRIM			LOGICAL
69-70	HORIZ TRIM			LOGICAL
71-72	OFF	SELECT (INST. CONSOLE)		LOGICAL
73-74	BST	SELECT (INST. CONSOLE)		LOGICAL
75-76	RDR	SELECT (INST. CONSOLE)		LOGICAL
77-78	AUTO RNG	RDR RNG / INST. CONS		LOGICAL
79-80	RNG 1	RDR RNG / INST. CONS		LOGICAL
81-82	RNG 2	RDR RNG / INST. CONS		LOGICAL
83-84	RNG 3	RDR RNG / INST. CONS		LOGICAL
85-86	RNG 4	RDR RNG / INST. CONS		LOGICAL
87-88	TGT ON	INST. CONS		LOGICAL
89-90	AUTO LOCK	INST. CONS		LOGICAL
91-92	AUTO ACQUISITION	INST. CONS		LOGICAL
93-94	MASTER ARM	TOGGLES		LOGICAL
95-96	GUN SELECT	TOGGLES		LOGICAL
97-98	GUN/STORE SELECT	TOGGLES		LOGICAL
99-100	NOSE SELECT	TOGGLES		LOGICAL
101-102	GUN HIGH RATE	TOGGLES		LOGICAL
103-104	PWR H	RADAR PWR		LOGICAL
105-106	PWR E	RADAR PWR		LOGICAL
107-108	RADAR K	RADAR/HEAT/REJECT		LOGICAL
109-110	RADAR J	RADAR/HEAT/REJECT		LOGICAL
111-112	INTERLOCK OUT	TOGGLES		LOGICAL
113-114	MASTER ARM	TOGGLES		LOGICAL
115-116	TRIGGER	TOGGLES		LOGICAL

TABLE C2. COMPRESSED DATA BLOCK STRUCTURE (Cont.)

Words	Parameters	Sampling Rate[1]	Units
117-118	AIM-7 FIRED		-
119-120	AIM-9 FIRED		-
121-122	GUNS		-
123-124	GUN HITS		-
125-126[2]	LOS AZIMUTH ANGLE		RAD.
127-128[2]	LOS ELEVATION ANGLE		RAD.
129-130[2]	LOS GRAND ANGLE		RAD.
131-132[2]	ASPECT GRAND ANGLE		RAD.
133-134[2]	ENERGY MANAGEMENT INDEX		-
135-136[2]	CLOSING RATE		FT./SEC
137-138[2]	OFFENSE		LOGICAL
139-140[2]	DEFENSE		LOGICAL
141-142[2]	SADDLE		LOGICAL
143-144[2]	HEAD ON		LOGICAL
145-146[2]	TAC ACES		-
147-148[2]	THROTTLE POS		UNITS
149-150[2]	LEADING		LOGICAL
151-152[2]	IN RANGE		LOGICAL
153-154[2]	ROLL RATE		DEG/SEC
155-156[2]	(ROLL RATE X ALT RATE)		-
157-158[2]	PLANE OF ACTION		DEGREES
159-160[2]	DEFENSIVE W/DISADVANTAGE		LOGICAL
161-162[2]	$AOA>28^{\circ}$		LOGICAL
163-164[2]	HEADING RATE		DEG/SEC
165-166	FORCE) PITCH	These measures	LBS.
167-168	POSITION)	were sampled	RAD.
169-170	FORCE) AILERON	at 10 Hz.	LBS.
171-172	POSITION)		RAD.

TABLE C2. COMPRESSED DATA BLOCK STRUCTURE (Cont.)

Words	Parameters		Sampling Rate[1]	Units
173-174	POSITION	RUDDER		RAD.
175-176	FORCE)	PITCH	These measures were	LBS.
177-178	POSITION)		sampled at 10 Hz.	RAD.
179-180	FORCE)	AILERON		LBS.
181-182	POSITION)			RAD.
183-184	POSITION	RUDDER		RAD.
185-186	FORCE)	PITCH	" " " "	LBS.
187-188	POSITION)			RAD.
189-190	FORCE)	AILERON		LBS.
191-192	POSITION)			RAD.
193-194	POSITION	RUDDER		RAD.
195-196	FORCE)	PITCH	" " " "	LBS.
197-198	POSITION)			RAD.
199-200	FORCE)	AILERON		LBS.
201-202	POSITION)			RAD.
203-204	POSITION	RUDDER		RAD.
205-206	FORCE)	PITCH	" " " "	LBS.
207-208	POSITION)			RAD.
209-210	FORCE)	AILERON		LBS.
211-212	POSITION)			RAD.
213-214	POSITION)	RUDDER		RAD.

1 All of the measures were sampled at 2 Hz., unless otherwise stated.

2 These measures were calculated from other available measures or parameters during the data verification phase of the program.

TABLE C3. CALCULATED VARIABLES ADDED TO COMPRESSED DATA BLOCK

Variable No.	Name	Calculation
125-126	LOS AZIMUTH ANGLE	ATAN2 (SINE LOS AZ, COS LOS AZ)
127-128	LOS ELEVATION ANGLE	ATAN2 (SINE LOS EL, COS LOS EL)
129-130	LOS GRAND ANGLE	ACOS (COS LOS AZ) (COS LOS EL)
131-132	ASPECT GRAND ANGLE	180^{o}-OPPONENT'S LOS GRAND ANGLE
133-134	ENERGY MANAGEMENT INDEX	
(Fuel Remaining-Bingo Fuel)		$\left\{\frac{\text{2G Altitude} + V^2}{\text{Fuel Flow (Left) + Fuel Flow (Right)}}\right\}\Delta t$ Where: Δt is 015 seconds, V is velocity in ft./sec.
135-136	CLOSING RAGE	ΔSlant Range/Sec.
137-138	OFFENSE	LOS CONE $< 60^{o}$
139-140	DEFENSE	LOS CONE $> 120^{o}$
141-142	SADDLE	OFFESNIVE, ASPECT $< 90^{o}$
143-144	HEAD ON	BOTH LOS $<30^{o}$
145-146	TAC ACES	N/A
147-148	THROTTLE TRANSITIONS INTO:	
	Zone 1	$0 \leq$ Throttle Setting < 35 Units
	Zone 2	$35 \leq$ Throttle Setting < 80 Units
	Zone 3	$80 \leq$ Throttle Setting <105 Units
	Zone 4	$105 \leq$ Throttle Setting
149-150	LEADING	LOS $< 60^{o}$, ASPECT $< 90^{o}$, LOS < ASPECT
151-152	IN RANGE	LOS $< 60^{o}$, ASPECT $< 90^{o}$, RANGE < 2000 ft.
153-154	ABSOLUTE ROLL RATE	Δ |ROLL ANGLE/SEC|
155-156	ABSOLUTE ROLL RATE X ALT RATE	|ROLL RATE X ALT RATE|
157-158	PLANE OF ACTION	(See TABLE C4)
159-160	DEFENSIVE w/DISADVANTAGE	LOS>120, ASPECT>90,RANGE<4000 ft.
161-162	$AOA>28^{o}$	$AOA>28^{o}$
163-164	HEADING RATE	ΔHEADING/SEC.
29-30	OUT OF VIEW (OOV)	(See Figure C8).

TABLE C4. PLANE OF ACTION CALCULATION

To determine the plane of action (PCA) for the a/c it was necessary to convert the body axis to the inertial axis using pitch (θ) and roll (ϕ). Yaw was held zero for convenience since any yawing action would be entirely contained in the POA. The body to inertial transformation matrix, R, is:

$$R = \begin{bmatrix} \cos\theta & \sin\theta\sin\phi & \sin\theta\cos\phi \\ 0 & \cos\phi & -\sin\phi \\ -\sin\theta & \cos\theta\sin\phi & \cos\theta\cos\phi \end{bmatrix}$$

$$\text{Let } \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = R \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix}, \quad \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} = R \begin{bmatrix} 0 \\ 1 \\ 0 \end{bmatrix}$$

$$\text{Thus: } \begin{bmatrix} b_1 \\ b_2 \\ b_3 \end{bmatrix} = \begin{bmatrix} \cos\theta \\ 0 \\ -\sin\theta \end{bmatrix} \text{ and } \begin{bmatrix} c_1 \\ c_2 \\ c_3 \end{bmatrix} = \begin{bmatrix} \sin\theta\sin\phi \\ \cos\phi \\ \cos\theta\sin\phi \end{bmatrix}$$

The equation of the plane (obc) through (0,0,0), (b_1,b_2,b_3) and (c_1,c_2,c_3) is $Ax-By+Cz=0$,

$$\text{Where } A = \begin{vmatrix} b_2 & b_3 \\ c_2 & c_3 \end{vmatrix} = (b_2c_3-b_3c_2),$$

$$B = \begin{vmatrix} b_1 & b_3 \\ c_1 & c_3 \end{vmatrix} = (b_1c_3-b_3c_1),$$

$$\text{and } C = \begin{vmatrix} b_1 & b_2 \\ c_1 & c_2 \end{vmatrix} = (b_1c_2-b_2c_1).$$

The angle between obc and the horizontal plane $Z = -1$ is

$$\hat{\phi} = \tan^{-1}\left[\frac{\sqrt{A^2+B^2}}{|C|}\right]$$

But if $C_2<0$, then the a/c is inverted and $\hat{\phi}$ becomes $\pi-\hat{\phi}$.

The final equation becomes

$$\hat{\phi} = \tan^{-1}\left[\frac{\sqrt{(\sin\theta\cos\phi)^2 + \sin\phi^2}}{|\cos\theta\cos\phi|}\right]$$

TABLE C5. TRANSFORMATIONS USED FOR SUMMARY DATA STATISTICS

Transforms on each parameter in Summary Data Block		
1. MEAN	-	$\frac{\Sigma X}{n}$
2. S.D.	-	$\left[\frac{\Sigma X^2 - \frac{(\Sigma X)^2}{n}}{n-1}\right]^{\frac{1}{2}}$
3. MIN	-	Minimum of X
4. MAX	-	Maximum of X
5. RMS	-	$\left[\frac{\Sigma x^2}{n}\right]^{\frac{1}{2}}$
6. C.P.	-	1 - Lowpass/Highpass
7. INIT	-	Initial Value of X
8. FINAL	-	Final Value of X
9 AAV	-	$\frac{\Sigma \lvert X \rvert}{n}$
10. RANGE	-	MAX - MIN

APPENDIX D:

RANKING AND RATING DATA FROM FREE ENGAGEMENTS

TABLE D1. EXPERT RANKINGS AND PEER RANKINGS

Pilot	Week				
	1	2	3	4	5
1	6 (5)*	6 (5.5)	5 (6)	4 (4)	3.5 (6)
2	5 (6)	5 (5.5)	3 (3.5)	5 (6)	3.5 (3)
3	3 (3)	4 (4)	6 (3.5)	6 (5)	5 (4)
4	4 (4)	3 (3)	4 (5)	3 (3)	6 (5)
5	1 (1)	1.5 (2)	1 (1)	2 (1.5)	2 (2)
6	2 (2)	1.5 (1)	2 (2)	1 (1.5)	1 (1)

* 6(6) = Rank by Expert (Rank by Peers).

TABLE D2. EXPERT RATINGS

	Decis-iveness	Situation Awareness	Maneuvering Skill	Aggress-iveness	Overall Performance
Group 1	2.05*	1.97	2.05	2.32	2.04
Group 2	2.13	2.11	2.15	2.30	2.14
Group 3	2.81	2.85	2.84	2.95	2.84

*Mean ratings

TABLE D3. CORRELATION MATRIX FOR RATINGS AND RANKINGS

	1	2	3	4	5	6	7
1. Peer Ranking	1.000						
2. Project Pilot Ranking	.873	1.00					
3. Decisiveness	- .793	- .821	1.00				
4. Situation Awareness	- .800	- .835	.894	1.000			
5. Maneuvering Skill	- .743	- .801	.846	.936	1.000		
6. Aggressiveness	- .705	- .802	.811	.842	.862	1.000	
7. Overall Performance	- .816	- .856	.919	.980	.941	.858	1.000

APPENDIX E:

SUPPORTING DATA FROM MULTIVARIATE ANALYSES

TABLE E1. GROUP MEANS AND STANDARD DEVIATIONS

Variable Number/Name	Group A Means	S.D.	Group B Means	S.D.
1. ARAA	281.96	59.74	242.18	43.84
2. OOVP	.27	.16	.13	.11
3. ASRA	254.08	85.98	222.51	58.75
4. SBPA	.0008	.009	.98	2.18
5. FFA	27967.84	2571.04	25614.04	3242.51
6. ARSR	.47	.50	.48	.49
7. EMRM	6.08	6.09	30.13	29.47
8. OFFP	.25	.20	.51	.22
9. SADP	.06	.13	.23	.24
10. TH1A	.0007	.001	.005	.005
11. TH2A	.002	.003	.01	.007
12. TH3A	.001	.002	.006	.006
13. TH4A	.003	.004	.01	.005
14. HDGRM	74.04	20.26	72.43	28.53
15. HEGRAA	17.60	4.59	18.20	5.98
16. LEADP	.05	.12	.19	.21
17. IRP	.003	.01	.04	.06
18. RRAA	20.36	7.72	21.60	7.91

TABLE E1. GROUP MEANS AND STANDARD DEVIATIONS (Cont.)

Variable Number/Name	Group A Means	S.D.	Group B Means	S.D.
19. RRARA	5687.26	2511.80	5344.11	2294.52
20. PLOAAA	77.64	4.22	75.42	4.49
21. DDP	.06	.08	.02	.06
22. A28P	.009	.02	.007	.01
23. AIM9P	.04	.20	.15	.36
24. INIT2	.34	.47	.33	.47
25. GUN	.00	.00	.09	.29
26. GND	.04	.20	.07	.26
27. G	.04	.20	.01	.13
28. BING	.05	.22	.05	.22
29. L/O	.10	.20	.29	.25
30. SEQN	7.18	4.32	7.28	4.34
31. INIT3	.29	.45	.33	.47

TABLE E2. CORRELATION MATRIX OF MEASURES WITHIN GROUP A

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. ARAA	1.00															
2. OOVP	.25	1.00														
3. ASRA	.66	.26	1.00													
4. SBPA	.02	.05	-.07	1.00												
5. FFA	-.16	.36	-.20	.01	1.00											
6. ARSR	-.23	-.20	-.30	.15	-.15	1.00										
7. EMRM	.03	-.17	.17	.09	-.41	.11	1.00									
8. OFFP	-.11	-.68	-.08	-.09	-.19	.18	.17	1.00								
9. SADP	.05	-.56	.09	-.04	-.21	.08	.27	.77	1.00							
10. TH1A	-.04	-.06	.08	.19	-.28	-.01	.71	.05	.01	1.00						
11. TH2A	-.09	-.10	-.0[illegible]	-.06	-.12	-.09	.38	.16	.16	.56	1.00					
12. TH3A	-.12	.19	.12	.11	-.07	.09	.24	-.13	-.00	.26	.41	1.00				
13. TH4A	-.11	-.00	-.04	.03	-.07	-.05	.43	.05	.14	.49	.82	.57	1.00			
14. HDGRM	-.15	-.19	-.14	.14	-.03	.05	.01	.08	.03	.00	-.12	-.08	-.14	1.00		
15. HDGRAA	-.25	-.27	-.30	.16	.01	.12	.00	.09	.01	.01	-.14	-.14	-.16	.95	1.00	
16. LEADP	.04	-.55	.08	-.04	-.20	.07	.26	.76	.99	.01	.18	.00	.15	.04	.02	1.00

TABLE E2. CORRELATION MATRIX OF MEASURES WITHIN GROUP A (Cont.)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17. IRP	-.00	-.30	-.10	.04	-.04	.04	.04	.31	.46	-.04	.28	.01	.26	-.05	-.01	.45
18. RRAA	.11	-.06	.04	.08	-.11	.24	.32	.04	.16	.21	.09	.06	.10	-.22	-.21	.16
19. RRARA	.51	.07	.31	.13	-.13	.09	.29	-.05	.12	.18	.04	.00	.04	-.25	-.26	.12
20. PLOAAA	.36	-.32	.15	.05	-.32	-.02	-.12	.16	.18	-.15	-.15	-.15	-.12	.17	.13	.19
21. DDP	.03	.57	.01	.14	.14	.04	.01	-.65	-.35	.05	-.14	.10	-.08	.01	-.00	-.35
22. A28P	-.05	.01	.09	.06	-.22	.07	.42	-.07	.01	.34	-.00	.06	.01	.00	.02	-.01
23. AIM9P	.13	-.18	.13	-.02	-.12	-.13	.11	.18	.28	.00	-.00	.02	.00	.18	.16	.24
24. INIT2	.05	-.04	.11	-.07	-.31	-.03	.08	-.05	.02	-.03	-.04	.14	-.04	-.07	-.14	-.01
25. GUN	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00	.00
26. GND	-.05	-.09	-.14	-.02	-.02	-.06	-.04	-.02	.04	-.09	.03	-.10	-.01	.14	.15	.04
27. G	.09	-.03	-.03	-.02	-.09	-.04	-.03	.08	.01	.13	.12	-.03	.07	-.17	-.11	.01
28. BING	-.01	-.08	-.08	-.02	-.06	.01	-.08	-.07	-.11	-.09	-.08	-.01	-.08	-.15	-.16	-.11
29. L/O	.06	-.55	.09	.01	-.20	.04	.29	.72	.97	.05	.18	.01	.16	.06	.04	.98
30. SEQN	-.19	-.27	-.14	-.00	-.03	.24	.02	.23	.08	.13	-.06	-.11	-.06	.08	.09	.08
31. INIT3	-.06	-.08	-.08	-.06	.37	-.05	-.22	.24	.09	-.16	-.12	-.15	-.15	.20	.23	.10

TABLE E2. CORRELATION MATRIX OF MEASURES WITHIN GROUP A (Cont.)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
17. IRP	1.00														
18. RRAA	.13	1.00													
19. RRARA	.04	.84	1.00												
20. PLOAAA	.06	.07	.25	1.00											
21. DDP	-.15	.16	.15	-.22	1.00										
22. A28P	-.03	.32	.29	-.10	.15	1.00									
23. AIM9P	-.05	.02	.03	.02	-.12	.12	1.00								
24. INIT2	.03	.16	.12	.02	.06	.06	-.07	1.00							
25. GUN	.00	.00	.00	.00	.00	.00	.00	.00	.00						
26. GND	.32	-.08	-.14	-.01	-.03	-.10	-.05	-.07	.00	1.00					
27. G	.06	-.01	.02	-.09	-.11	-.04	-.05	-.07	.00	-.05	1.00				
28. BING	-.04	.15	.06	.12	-.09	-.03	-.05	.08	.00	-.05	-.05	1.00			
29. L/O	.49	.19	.15	.19	-.34	.01	.24	-.01	.00	.07	.01	-.11	1.00		
30. SEQN	-.12	.09	.03	-.05	-.20	.24	.11	-.04	.00	-.22	-.04	.09	.09	1.00	
31. INIT3	-.14	-.32	-.28	.00	-.20	-.20	.14	-.47	.00	-.04	.05	-.07	.10	.20	1.00

TABLE E3. CORRELATION MATRIX OF MEASURES WITHIN GROUP B

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. ARAA	1.00															
2. OOVP	-.20	1.00														
3. ASRA	.33	-.05	1.00													
4. SBPA	-.09	.07	-.08	1.00												
5. FFA	-.05	.06	-.09	-.20	1.00											
6. ARSR	.01	.11	-.03	-.03	.18	1.00										
7. EMRM	-.14	.03	-.29	.46	-.32	.05	1.00									
8. OFFP	.14	-.79	.10	-.05	-.05	-.17	-.00	1.00								
9. SADP	.17	-.56	.25	.00	-.08	-.16	-.06	.88	1.00							
10. TH1A	-.13	-.03	-.16	.40	-.36	-.08	.72	-.08	-.09	1.00						
11. TH2A	-.10	-.12	.00	.07	-.53	-.18	.28	.16	.18	.49	1.00					
12. TH3A	.04	-.15	-.02	-.10	-.43	-.10	.13	.08	.09	.20	.47	1.00				
13. TH4A	-.15	-.23	-.11	.13	-.53	-.14	.43	.14	.12	.62	.76	.61	1.00			
14. HDGRM	-.11	.06	-.10	-.04	.02	.12	.13	-.00	-.11	-.02	-.10	.07	-.00	1.00		
15. HDGRAA	-.10	.04	-.19	-.04	.05	.14	.14	.01	-.11	-.02	-.11	.06	-.03	.96	1.00	
16. LEADP	.19	-.65	.27	.02	-.09	-.15	-.05	.86	.99	-.08	.17	.06	.11	-.14	-.14	1.00

TABLE E3. CORRELATION MATRIX OF MEASURES WITHIN GROUP B (Cont.)

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
17. IRP	-.06	-.39	-.13	-.09	.08	-.07	-.01	.52	.59	-.02	.06	-.02	.04	-.12	-.04	.56
18. RRAA	.28	.10	.02	-.04	.09	.13	-.04	-.17	-.06	-.06	-.06	.05	-.10	-.38	-.35	-.07
19. RRARA	.56	.05	.17	-.04	.04	.09	-.07	-.09	.02	-.05	.01	.09	-.06	-.40	-.36	.01
20. PLOAAA	.62	-.12	.37	-.17	.05	-.03	-.27	.04	.11	-.32	-.30	-.05	-.32	.05	.07	.12
21. DDP	-.09	.67	.05	.08	.06	.07	-.00	-.62	-.33	-.03	-.11	-.04	-.19	-.15	-.17	-.32
22 A28P	.07	.10	.16	-.09	-.08	-.07	-.07	-.10	-.03	-.06	.15	.21	.10	-.05	-.04	-.06
23. AIM9P	.13	-.08	.10	-.08	.08	.06	-.08	.06	.04	-.09	-.03	.04	-.06	.09	.04	.05
24. INIT2	.11	-.12	.09	-.01	.01	-.07	-.13	.14	.24	-.11	-.10	-.12	-.14	-.25	-.21	.24
25. GUN	.01	-.02	-.04	-.03	.06	.06	-.01	.01	-.08	-.03	-.10	.00	-.04	-.09	-.05	-.07
26. GND	.13	-.11	.00	-.02	-.07	.02	.18	.13	.10	.06	-.08	.04	.13	.18	.20	.09
27. G	.01	.03	-.05	.04	-.03	.16	.04	.03	.10	.03	.13	.09	.02	-.03	-.05	.09
28. BING	-.03	-.06	-.07	-.11	-.13	-.01	-.04	-.07	-.09	.04	.07	.11	.05	.03	.05	-.09
29. L/O	.23	-.66	.26	-.00	-.10	-.16	-.06	.82	.95	-.07	.17	.09	.12	-.20	-.19	96
30. SEQN	.09	-.12	-.02	-.03	-.05	-.01	-.06	.03	-.03	-.09	-.10	-.01	-.04	-.08	-.03	-.03
31. INIT3	-.14	.14	-.15	.09	.03	.09	.14	-.09	-.27	-.05	-.15	-.00	-.11	.33	.36	-.26

TABLE E3. CORRELATION MATRIX OF MEASURES WITHIN GROUP B (Cont.)

	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
17. IRP	1.00														
18. RRAA	.22	1.00													
19. RRARA	.14	.87	1.00												
20. PLOAAA	.06	.26	.38	1.00											
21. DDP	-.17	.28	.21	.10	1.00										
22. A28P	.04	.41	.39	.14	.14	1.00									
23. AIM9P	-.05	.16	.14	.05	-.03	.04	1.00								
24. INIT2	.28	.23	.16	.08	.01	.13	.00	1.00							
25. GUN	.10	-.06	-.05	-.02	-.10	-.02	-.14	-.04	1.00						
26. GND	.02	-.08	-.04	.11	-.09	.09	-.13	-.07	-.09	1.00					
27. G	-.05	.00	.01	-.11	.05	-.06	-.06	-.09	-.04	-.04	1.00				
28. BING	.05	.00	-.01	.05	-.06	.06	-.10	.00	-.08	-.07	-.03	1.00			
29. L/O	.57	.01	.09	.19	-.32	-.03	.07	.27	-.05	.08	.12	-.08	1.00		
30. SEQN	.09	.13	.13	.03	-.12	.03	.01	.00	-.09	.17	.04	.04	-.00	1.00	
31 INIT3	-.23	-.30	-.29	-.07	-.20	-.06	.00	-.49	-.04	.14	-.09	.00	-.28	.16	1.00

APPENDIX F

TEST OF MULTIVARIATE MODEL WITH SIMULATED DATA

The resulting discriminant models were tested with Monte Carlo type of data simulations to explore its relative and potential reliability. Simulations were performed on the 13 measure model for 4 values of K and unit scaling. The results for the 13 measure model are detailed in Table F1. A simulation was performed by weighting the ACM data by the discriminant coefficients to produce two distributions. These distributions represented the two groups in discriminant space. To test the discriminating capability of the model a break-even point was determined. This break-even point is the position on the discriminant axis (Y) where the selection error was minimum. The average predicted selection error can be determined by dividing by two the total observations that lie on the wrong side of the break-even point.

A test sample of a thousand observations for each group was generated. These simulated observations had a random normal distribution with the same means and variance-covariance matrices as the group they were intended to simulate. Although they were not precisely similar to the actual sample data or, probably, the real population, they did provide an independent measure of the discriminating ability of the performance measurement models. This simulated data was then weighted by the discriminant coefficients and the average simulated total misclassifications were calculated for each model using the break-even points.

The reduction in simulated misclassifications by increasing K as observed in Table F1 along with the reduction in overly large coefficients (as observed in the coefficient trace in Figure 5) is a demonstration of the reduction of overfit with a ridge adjustment. Further, it can be seen that the model discriminates better for particular values of K. The discriminant model outperformed its respective unit scaling equation.

Figures F1 through F3 are computer frequency plots of the measurement models in Table F1. The trend of improvement of the distributions with the increase in K was reaffirmed when looking at these plots. (Note the reduction in skewness and kurtosis in Table F1 also.) An improvement in group distribution separation would not be expected when looking at a ridge distortion of the original ACM data. Logically, the improvement in group separation would be evident if the series of coefficients could be tried on another sample from the same population.

To look at the discriminant models differently, another set of simulated samples was generated as previously described. These were weighted with the coefficients from the 13 measure solutions to form new group distributions. These new distributions are described in Table F2. As expected, the average total percent misses predicted decreased as K increased. Quite visibly, the statistical differences in the two distributions became larger. Figure F4 and F5 are frequency distribution plots of the simulated samples. An improvement in the group separation as K increases is visibly evident. Both the classification of simulated test data and the injection of simulated data into the discriminant model to estimate predicted missclassification errors are two ways to demonstrate the reliability of various measurement models.

TABLE F1. GROUP DISTRIBUTION STATISTICS IN DISCRIMINANT SPACE AND SIMULATED CLASSIFICATION RESULTS

		K = 0.0	K = 0.1	K = 0.2	K = 0.3[1]	Unit Scaling
Group A	Mean	- 2.6455	- 2.5887	- 2.5100	- 2.5710	2.3347
	S.D.	.4827	.5618	.6213	.5908	.5248
	Skewness	.2549	.1588	.1516	.1365	.9418
	Kurtosis	.6449	.3341	.1250	.2033	.5324
Group B	Mean	- 1.2524	- 1.1622	- 1.1011	- 1.1438	3.6275
	S.D.	.8680	.8118	.7608	.7911	.9376
	Skewness	.6583	.4029	.2140	.3230	.2240
	Kurtosis	.2310	.1082	.2587	.1127	- .4883
Break Point		- 2.0145	- 1.9659	- 2.0246	- 1.8999	2.6938
Percent Misses	Group 1	12.90	10.80	6.20	10.40	9.20
	Group 2	6.30	7.40	12.40	5.40	23.20
	Average Predicted Total	15	16	16	16	19
	Average Simulated Total	9.60	9.10	9.30	7.90	16.20

1. An analysis was performed also for K = 0.4 and the average simulated error revealed an increase, indicating that K = 0.3 was a convenient stopping point for this analysis.

TABLE F2. GROUP DISTRIBUTION STATISTICS FOR SIMULATED POPULATIONS IN DISCRIMINANT SPACE AND PREDICTED MISCLASSIFICATIONS.

		K = 0.0	K = 0.1	K = 0.2	K = 0.3
Group 1	Mean	- 2.6310	- 2.5676	- 2.4870	- 2.5510
	S.D.	.4125	.4252	.4292	.4232
	Skewness	.0653	.1874	.1971	.2065
	Kurtosis	.2419	.4638	.5478	.4922
Group 2	Mean	- 1.3110	- 1.2186	- 1.1104	- 1.1665
	S.D.	.6967	.6808	.5969	.6109
	Skewness	- .0068	.1197	- .0027	- .0020
	Kurtosis	- .7050	- .4984	- .5418	- .5961
Break Point		- 2.1913	- 1.9584	- 1.8711	- 1.8192
	Average Total Percent Misses Predicted	10	10	9	9

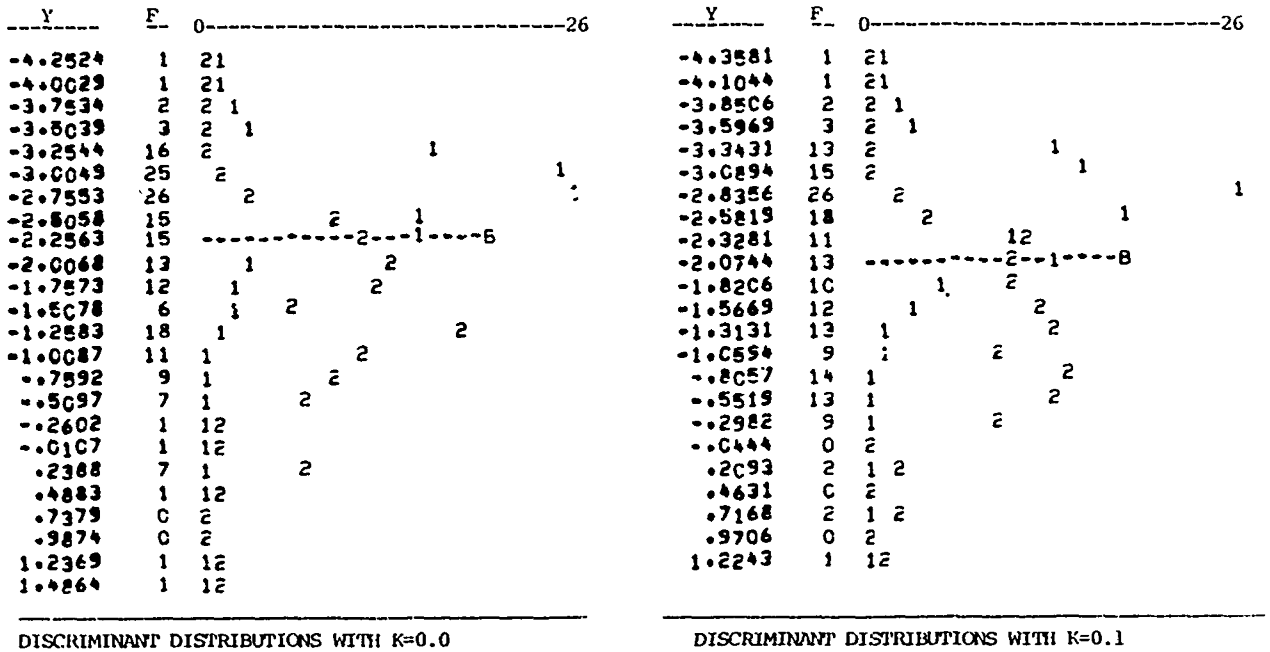

Figure F1. Frequency Plots of ACM Data for 2 Groups in Discriminant Space With K = 0.0 and 0.1.

(Group A = 1, Group B = 2, N = 112 for each group)

```
     Y        F   0----------------------21
-4.38C4       1   21
-4.1449       1   21
-3.9C94       1   21
-3.6739       2   2 1
-3.4383       8   2       1
-3.2C28      14   2             1
-2.9673      14    2            1
-2.7318      21     2                   1
-2.4562      12     2         1
-2.2607      14       2         1
-2.0252      14   ------------1-2----B
-1.7897      12     1       2
-1.5541      1C         1   2
-1.3186      11     1        2
-1.C831      15    1             2
-.8476        8    1      2
-.612C       12   1           2
-.3768       12   1           2
-.141C        4   1   2
.C946         C   2
.33C1         3   1  2
.5656         C   2
.8C11         2   1 2
```

DISCRIMINANT DISTRIBUTIONS WITH K=0.2

```
     Y        F   0--------------------20
-4.4CC1       1   21
-4.1595       1   21
-3.9185       1   21
-3.6783       3   2  1
-3.4377       8   2       1
-3.1971      14   2             1
-2.9565      19     2                1
-2.7159      20    2                  1
-2.4753      16      2          1
-2.2348      11            1 2
-1.9942      11   ----------12----B
-1.7536      13        1       2
-1.513C      10      1    2
-1.2724      11    1       2
-1.C318      13    1         2
-.7912       11   1        2
-.55C6       1C   1       2
-.310C        9   1      2
-.C694        2   1 2
.1712         C   2
.4118         3   1  2
.6523         0   2
.8929         2   1 2
```

DISCRIMINANT DISTRIBUTIONS WITH K=0.3

Figure F2. Frequency Plots of ACM Data for 2 Groups in Discriminant Space With K = 0.2 and 0.3.

(Group A = 1, Group B = 2, N = 112 in each group)

```
  Y          F   0-------------------------22

1.2561       C   2
1.4548       6    2     1
1.6536       7   2       1
1.8523      23      2                       1
2.0511      22        2                    1
2.2498      19    2                     1
2.4486      10             2 1
2.6473       9   --------21----B
2.846C       5        2
3.0448       9   1           2
3.2435       6        12
3.4423      11      1          2
3.641C      16      1               2
3.8398       6   1     2
4.0385       3   1  2
4.2373       6   1     2
4.436C       6   1     2
4.6348       7   1      2
4.8335       3   1  2
5.0323       1   12
5.231C       2   1 2
5.4298       2   1 2
5.6285       2   1 2
5.8273       1   12
```

Figure F3. Frequency Plot of ACM Data for 2 Groups in Discriminant Space With Unit Sealing.

(Group A = 1, Group B = 2, N = 112 for each group)

```
    Y       F   0--------------------21
-3.8879     1   21
-3.6867     0   2
-3.4856     5   2    1
-3.2845     8   2       1
-3.0834    15   2              1
-2.8822    14    2            1
-2.6811    21        2              1
-2.4800    19      2          1
-2.2788     8   ------2-1----B
-2.0777     5        2
-1.8764    14      1        2
-1.6755     9   1        2
-1.4743     8    1      2
-1.2732     8   1       2
-1.0721    13   1            2
 -.8710     8   1       2
 -.6698     8   1       2
 -.4687     6   1     2
 -.2676     3   1  2
 -.0665     2   1 2
  .1347     1   12
--------------------------------------
SIMULATED DISCRIMINANT DISTRIBUTIONS
WITH K=0.0
```

```
    Y       F   0---------------------22
-3.7924     1   21
-3.5944     2   2 1
-3.3964     5   2    1
-3.1984     5   2    1
-3.0003    16   2               1
-2.8023    17   2                1
-2.6043    22        2               1
-2.4063    14       2         1
-2.2082     8   ----2---1----B
-2.0102     8         1 2
-1.8122     5     1  2
-1.6141    14    1           2
-1.4161     9    1       2
-1.2181    10   1         2
-1.0201    18   1                 2
 -.8220     5   1    2
 -.6240     3   1  2
 -.4260     5   1    2
 -.2279     6   1     2
 -.0299     2   1 2
  .1681     2   1 2
--------------------------------------
SIMULATED DISCRIMINANT DISTRIBUTIONS
WITH K=0.1
```

Figure F4. Frequency Plots of Simulated Data for 2 Groups in Discriminant Space With K = 0.0 and 0.1.

(N = 11? for each group)

```
    Y        F   0-------------------------23
-3.6665      1   21
-3.4844      4   2   1
-3.3023      2   2 1
-3.1202      4   2   1
-2.9380     13   2             1
-2.7559     15   2                1
-2.5738     23    2                       1
-2.3917     15     2               1
-2.2095     11         2     1
-2.0274      5   ------2----B
-1.8453      5        12
-1.6632      9    1         2
-1.4811     11    1           2         ,
-1.2989      5    1    2
-1.1168     20   1                     2
 -.9347     13   1              2
 -.7526      2   1 2
 -.5704     12   1             2
 -.3883      3   1  2
 -.2062      3   1  2
 -.0241      4   1   2
```

SIMULATED DISCRIMINANT DISTRIBUTIONS
WITH K=0.2

```
    Y        F   0-------------------------23
-3.7472      1   21
-3.5662      2   2 1
-3.3852      4   2    1
-3.2041      4   2    1
-3.0231     11   2           1
-2.8421     16   2                 1
-2.6611     23    2                       1
-2.4800     14    2              1
-2.2990     12        2      1
-2.1130      6   ----2-1----B
-1.9370      5       12
-1.7560      9    1        2
-1.5749      5    1    2
-1.3939     17    1                 2
-1.2129     13   1             2
-1.0315     10   1          2
 -.8508      9   1         2
 -.6698      2   1 2
 -.4888      7   1      2
 -.3078      6   1     2
 -.1268      5   1    2
```

SIMULATED DISCRIMINANT DISTRIBUTIONS
WITH K=0.3

Figure F5. Frequency Plots of Simulated Data for 2 Groups in Discriminant Space
With K = 0.2 and 0.3.

(N = 112 for each group)

APPENDIX G

TACSPACE DATA

TABLE G1. BOXES USED BY WINNERS IN TERMS OF PERCENTAGE MISSION TIME

PERCENT OF MISSION TIME WINNER SPENT IN BOX (1/10%)	DISTRIBUTION OF BOXES								
34									
33	100	122							
32									
31									
30									
29									
28	99.2	121							
27									
26									
25									
24	98.4	123							
23									
22									
21	97.6	132	222						
20									
19									
18									
17									
16									
15									
14	96.0	111	112						
13	94.4	133	232						
12									
11	92.8	152	233						
10									
9	91.2	113	223	124					
8		- - -	- - -	- - -	- - -	- - -	- - -	- - -	- - -
7	89	131	153	151					
6	86	333	231	243	332				
5	83	114	134	142	143	154	221	234	
		322	343	422	423				
4	74	212	125	323	342				
3	71	135	331	211	213	224	242		
		334	335	352	424	432	144		
2	62	141	145	244	235	251	252	253	255
		312	321	324	325	345	351	412	413
		433	434	441	521	112			
1	45	241	311	313	314	341	344	353	354
		411	421	431	442	511	512	522	523
		532	155	214	215	225	245	254	414
0	26	315	355	415	425	435	443	444	445
		451	452	453	454	455	513	514	515
		524	525	531	533	534	535	541	542
		543	544	545	551	552	553	554	555

Note: 23% of mission time was spent in the boxes above dotted line.

TABLE G2. BOXES USED BY LOSERS IN TERMS OF PERCENTAGE MISSION TIME

PERCENT OF MISSION TIME LOSER SPENT IN BOX (1/10%)	DISTRIBUTION OF BOXES	BOX CODES							
34	100	452							
33									
32									
31									
30									
29									
28	99.2	451							
27									
26									
25									
24	98.4	453							
23									
22									
21	97.6	352	442						
20									
19									
18									
17									
16									
15	95.2	551							
14									
13	94.4	342	353						
12	92.8	552							
11	92.0	152							
10	91.2	343							
9	90.4	553	443	454					
8									
7	88	151	153	351					
6	86	233	243	441	332	333	423		
5	81	554	252	253	341	344	354	422	436
		542	154						
4	73	232	242	433	541	543			
3	69	132	143	424	322	331	334	335	355
		412	444	455	254	255			
2	58	141	142	234	235	241	251	323	324
		345	411	413	431	434	435	511	512
		522	523	555	145	155	244	245	
1	41	131	133	134	221	222	545	231	312
		321	325	421	544	521	532	533	534
		144	524						
0	26	111	112	113	114	115	121	122	123
		124	125	135	211	212	213	214	215
		223	225	311	313	314	315	414	415
		425	513	514	515	525	531	535	224
		445							

Note: 23% of mission time was spent in the boxes above dotted line.

BOX CODES

TABLE G3. RECIPROCAL RELATIONSHIPS OF TOP FOURTEEN BOXES

RANK	BOX CODES FOR LOSERS		BOX CODES FOR WINNERS	RANK
1	452	↔	122	1
2	451	↔	121	2
3	453	↔	123	3
4	352	↔	132	4
5	442	↔	222	5
6	551	↔	111	6
7	342	✕	112	7
8	353	↔	133	8
9	552	✕	232	9
10	152	↔	152	10
11	343	↔	233	11
12	553	↔	113	12
13	443	↔	223	13
14	454	↔	124	14

Note: Arrows show boxes which correspond by winner's and loser's point of view, i.e., Box 122 LOS=1 Aspect=2 Range=2 is winner's point of view for same relationship between airplanes as Box 452 LOS=4 Aspect=5 Range=2 from loser's point of view.

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