Technical Report: NAVTRAEQUIPCEN IH-342
AFHRL-TR-82-15

AIR COMBAT MANEUVERING PERFORMANCE MEASUREMENT STATE SPACE ANALYSIS

October 1982

NAVAL TRAINING EQUIPMENT CENTER
ORLANDO, FLORIDA 32813

AIR FORCE HUMAN RESOURCES LABORATORY
BROOKS AIR FORCE BASE, TEXAS 78235

COOPERATIVE STUDY SERIES

NOTICE

This report has been reviewed and is approved for publication.

WILLIAM P. LANE
Head, Human Factors Laboratory
Naval Training Equipment Center

CARL D. ELIASON, Colonel, USAF
Chief, Operations Training Division
Air Force Human Resources Laboratory

DAVID P. GLENN
Research and Technology Department
Naval Training Equipment Center

RONALD W. TERRY, Colonel, USAF
Commander
Air Force Human Resources Laboratory

Unclassified

SECURITY CLASSIFICATION OF THIS PAGE (*When Data Entered*)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER NAVTRAEQUIPCEN IH-342 AFHRL-TR-82-15	2. GOVT ACCESSION NO. AD-A122 907	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (*and Subtitle*) AIR COMBAT MANEUVERING PERFORMANCE MEASUREMENT STATE SPACE ANALYSIS		5. TYPE OF REPORT & PERIOD COVERED Final 6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(*s*) Lee Wooldridge, Richard W. Obermayer, William H. Nelson, Michael J. Kelly, Donald Vreuls, Don A. Norman		8. CONTRACT OR GRANT NUMBER(*s*) F33615-80-C-0024
9. PERFORMING ORGANIZATION NAME AND ADDRESS Vreuls Research Corporation 86 Long Court, Suite C Thousand Oaks, California 91360		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 62205F 11231220
11. CONTROLLING OFFICE NAME AND ADDRESS HQ Air Force Human Resources Laboratory (AFSC) Brooks Air Force Base, Texas 78235		12. REPORT DATE October 1982 13. NUMBER OF PAGES 92
14. MONITORING AGENCY NAME & ADDRESS (*if different from Controlling Office*) Operations Training Division Air Force Human Resources Laboratory Williams Air Force Base, Arizona 85224		15. SECURITY CLASS (*of this report*) Unclassified 15.a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (*of this Report*)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (*of this abstract entered in Block 20, if different from Report*)

18. SUPPLEMENTARY NOTES

This report documents a cooperative effort by the Air Force Human Resources Laboratory and the Naval Training Equipment Center, Human Factors Laboratory (Code N-711), Orlando, Florida 32813.

19. KEY WORDS (*Continue on reverse side if necessary and identify by block number*)

Air Combat Maneuvering (ACM)
Air Combat Maneuvering Performance Measurement (ACMPM)
Simulator for Air-to-Air Combat (SAAC)
performance measurement
simulation
TACSPACE

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

Air combat maneuvering free engagements provide a challenging environment for the measurement of aircrew performance. The rapidly evolving technology in ground-based flight simulation and the data collection and analyses capabilities of the airborne Air Force Air Combat Maneuvering Instrumentation/Navy Tactical Air Combat Training System (ACMI/TACTS) show promise for providing the kinds of data needed for detailed air combat maneuvering performance measurement.

An existing database of time history data collected during ACM free engagements on the Simulator for Air-to-Air

Item 20 (*Continued*)

Combat (SAAC) was re-analyzed using an analyses scheme called TACSPACE. This approach divided each engagement into segments according to the relative positions of the proponent and opponent aircraft in terms of aspect angle, line-of-sight angle, and range between aircraft.

Several different performance measurement models were developed from the TACSPACE analyses. These models vary greatly in complexity as different sizes of TACSPACE segments and different analyses within the TACSPACE segments were tested. Large differences were found between the models in their ability to account for performance variance. Strong evidence was found for the efficacy of including measures of control activity in TACSPACE segments corresponding to offensive and defensive positions.

Functional specifications based on these analyses were produced for several concepts of displaying ACMPM information to SAAC instructor pilots. In addition, the feasibility of including a similar ACMPM system on ACMI/TACTS was examined and discussed.

SUMMARY

Objectives

The objectives were (a) to examine alternative approaches for Air Combat Maneuvering Performance Measurement (ACMPM) based on a state-space measurement concept called TACSPACE, (b) to develop a functional specification by which performance measurement information from free engagements could be displayed on the Simulator for Air-to-Air Combat (SAAC) console for the benefit of the Instructor Pilot (IP), and (c) to examine the feasibility and efficacy of utilizing such a system on the Air Force Air Combat Maneuvering Instrumentation (ACMI) or the Navy Tactical Air Combat Training System (TACTS).

Background/Rationale

Measurement of pilot performance during free air combat engagements provides a unique and important measurement challenge. Existing automated performance measurement structures that compare the aircraft's maneuvering with a standard profile, or that examine only mission success, are of limited utility in this application.

It was hypothesized that a measurement structure which could examine interactions between relative aircraft position and pilot control behavior would provide improved measurement capability. The TACSPACE model provides such a structure.

Approach

A two-stage approach was taken: (a) specification and testing of candidate measurement models, and (b) development of a functional specification for candidate display concepts. Multivariate discriminant analyses of the data were computed, and an algorithm was developed. The algorithm was then applied to the TACSPACE concept to test its validity, generalization, and efficacy using the existing data base.

Specifics

Hypotheses were developed about candidate TACSPACE related measurement structures and tested using a data base of time history records. Several different ACMPM models varying greatly in complexity were developed and tested. A refined version of TACSPACE was then constructed. Analyses of pilot control behavior were then superimposed over the TACSPACE structure. Finally, a TACSPACE structure, including only three regions (offensive, neutral, and defensive) with overlaid pilot control measures, was evaluated. Analyses were also computed using only measures available from ACMI/TACTS. Training on the SAAC was observed, and SAAC instructional, administrative, and engineering personnel were interviewed.

Large differences were found between the models in their ability to account for performance variance. The TACSPACE structure was reduced from 616 individual cells (identified by aspect angle, line of sight, and range) to 80 cells. This combining of the cells facilitated analyses and at the same time provided a more realistic working model for the user.

Conclusions/Recommendations

The TACSPACE concept provides a useful framework on which to build an ACMPM system. However, additional information should be included and both further development and validation are required. The TACSPACE and data-analysis procedures that were developed provide a reasonable method to assess overall maneuvering performance. However, in their present form, the structure and resulting equations provide only indirect performance diagnosis. For direct diagnosis in a language that instructor pilots could use, future work should consider combining TACSPACE with

the evolving technology of expert systems by inserting some decision rules to guide the selection of subsequent measurement within appropriate TACSPACE cells.

Although real-time implementation on the SAAC was found to be feasible, its usefulness appeared questionable due to the lack of sufficient diagnostic information.

The TACSPACE concept was found to be applicable to the ACMI/TACTS with very little loss of predictive validity as a result of the reduced number of available measures.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF TABLES - (continued)

LIST OF FIGURES

I. INTRODUCTION

Measurement of pilot performance during free air combat engagements provides a technical challenge that is at once unique and importan.. Free air combat maneuvering (ACM) is unique in terms of performance measurement requirements for two main reasons. First, most previous aircrew performance measurement work has been conducted on relatively simple visual or instrument flight maneuvers for which a desired profile has been defined and is known by both the pilot and the performance analyst. It is a comparatively simple procedure to measure error from the established profile and to use various transforms of this error as measures of performance.

In free ACM, there are no such established profiles against which to measure; the reference datum is continually changing and performance criteria are vague. Some existing models, such as the Automated Maneuvering Logic (AML), offer a logical decision network that attempts to simulate the movements of an aircraft during free engagements. No claims are made that these either provide an optimum solution representative of what a skilled pilot does. Thus, any attempt to measure ACM performance against any kind of derived profile is probably futile, unless a representative sample of all possible profiles is considered by the measurement logic.

It may be feasible to develop an AML type system based on a knowledge representation model of a skilled pilot. This, however, has never been done. Even this approach may not capture all of what may be important elements of the task such as gamesmanship, intimidation, and faking. It might, however, provide a good foundation for a future diagnostic air combat measurement system when combined with the approach taken in this study.

The second factor that makes ACM performance measurement different from usual aircrew performance measurement techniques is that most performance measurement applications involve a single pilot or aircrew pursuing a recognizable objective. ACM involves, at a minimum, a pair of pilots and aircraft with mutually exclusive objectives. The dynamic relationship between the two aircraft is constantly changing as each pilot maneuvers to counteract the maneuvering of the other. Any valid performance measurement system must, therefore, take into account the maneuvering of both proponent and opponent aircraft in order to obtain an accurate index of pilot performance.

Development of automated capability for ACM Performance Measurement (ACMPM) is important for one primary reason. The dynamic and fast moving actions of a pair or a number of pilots and aircraft are difficult for an instructor pilot (IP), encumbered by normal human limitations, to perceive and evaluate. An automated ACM performance measurement system would provide a valuable complement to the IP's own abilities.

An automated system for ACMPM requires a considerable amount of data measurement, transmission, storage, processing, and display capability. Until recently, such required capability could only be found in ground based flight simulators such as the Simulator for Air-to-Air Combat (SAAC) at Luke AFB. During the past few years, however, capabilities for the airborne measurement of pilot performance have been developed and refined. The Air Force Air Combat Maneuvering Instrumentation (ACMI) and Navy Tactical Air Combat Training System (TACTS) now provide the basic capabilities required for an ACMPM system.

A number of recent attempts to provide an ACMPM system have been made. DeBerg (1977) performed a factor analytic study of maneuvering data obtained during simulated ACM. He found that the most important factor in describing ACM involved measures of energy management.

Simpson and Oberle (1977) developed a method for assessing pilot performance during ACM based largely on tracking the relative positions of the two or more aircraft involved in a fight. This ACMPM method uses measures available on flight simulators as well as on ACMI/TACTS.

The Vought Corporation "Good Stick Index," developed and refined by Moore, Madison, Sepp, Stracener, and Coward (1979), was developed to assess the effects of air combat training. The GSI measures several aspects of the performance of pilots attacking a target that is flying a pre-defined profile.

Brictson and his associates at Dunlap and Associates, Inc., Western Division, have created a model of ACM engagements based on a hypothetical ideal mission sequence. The ACM mission sequence (Figure 1) includes the chain of events that theoretically occur during a successful engagement. Any deviation from this sequence is indicative of a less than entirely successful engagement. Figure 2 shows the best and worst possible cases for a given engagement. Based on these models, the Dunlap and Associates group has developed a performance feedback system called PACE (e.g., Ciavarelli (1980)). Performance assessment is provided on five kinds of measures:

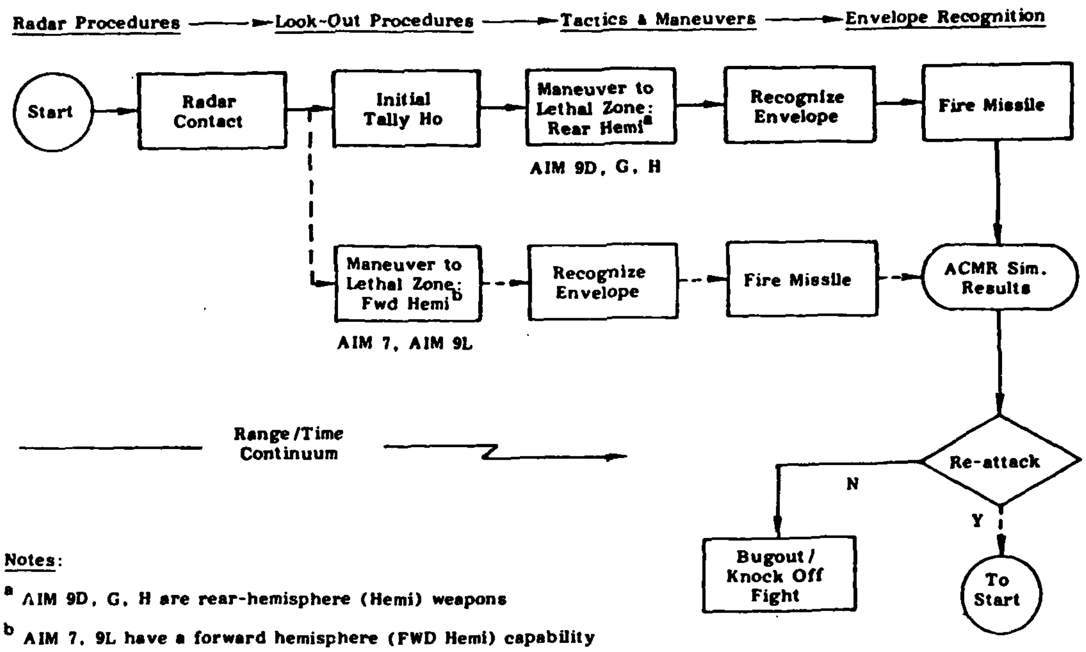
1. Whether radar contact is obtained and the range between aircraft.

2. Whether visual contact is obtained and the range between aircraft.

3. Whether the pilot took the first shot during the engagement.

4. The aircraft position in terms of weapons envelope when weapon was fired.

5. Win/loss as a function of weapon type.



Notes:

[a] AIM 9D, G, H are rear-hemisphere (Hemi) weapons

[b] AIM 7, 9L have a forward hemisphere (FWD Hemi) capability

Figure 1. ACM mission sequence.
(from Ciavarelli, 1980)

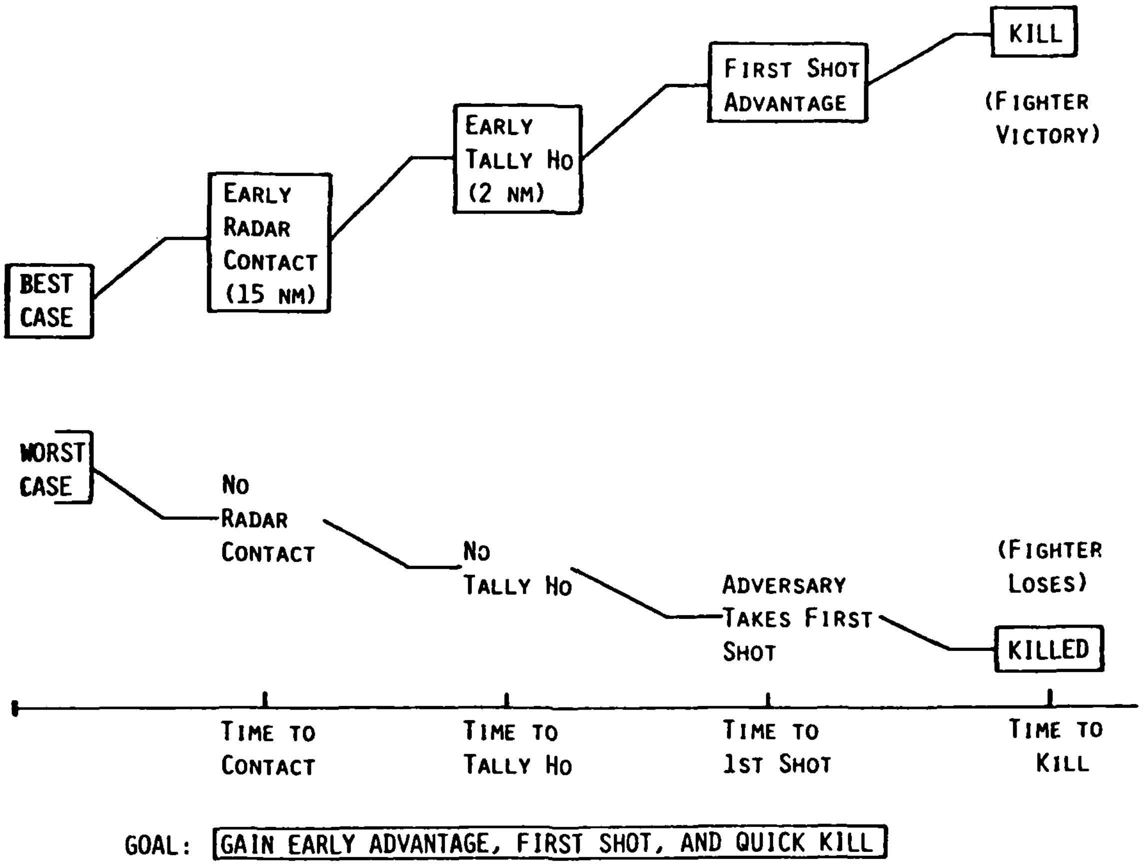


Figure 2. The air combat model: best and worst cases. (from Ciavarelli, 1980)

The PACE system collects and records these measures at both individual pilot and operational unit levels of summation. This allows the squadron commander to obtain quickly and easily a global picture of the performance of the unit as compared to a desired standard of performance, suggesting areas for future training concentration.

In contrast to the rather global measures of performance provided by the PACE model, Kelly, Wooldridge, Hennessy, Vreuls, Barnebey, Cotton, and Reed (1979) examined in considerable detail the performance of the pilot in a smaller segment of the mission sequence, that associated with maneuvering to the lethal zone and firing a missile. Their results demonstrated the feasibility of measuring ACM performance using detailed performance measures in a multivariate measurement structure.

The Kelly et al. (1979) report suggested several improvements that could be made by more extensive multivariate data analysis techniques. This current technical report summarizes the results of data analyses performed on that data base using a more complex data analysis structure. It further provides a functional specification which could be used to implement a performance measurement package on the SAAC.

II. DATA COLLECTION

This section summarizes the procedures used to collect the data that were analyzed for this report. This is the same database used for analysis in the earlier Kelly et al. (1979) report, which provides a more detailed description of data collection techniques.

The technical approach involved a combined analytical and empirical examination of the performance measurement problem. First, an examination of the ACM task, training and evaluation techniques provided the framework for a candidate measurement structure and a list of possible measures. Data were then collected during ACM free engagements and the measurement structures were applied to the data.

ANALYTICAL PHASE

During the analytical phase of the prior effort, information was obtained from ACM training materials and from interviews with academic, ISD, and Fighter Weapons School personnel as well as from line ACM instructors at Luke AFB. From these information sources, hypotheses were developed about global differences between skilled and less skilled ACM pilots. Then, within these hypotheses, lists of specific measures were developed that would correlate with the differences.

The analysis revealed several different, although probably not orthogonal, dimensions of ACM performance to be tested for inclusion in an ACMPM structure. Also listed were groups of measures that should be correlated with each of the global dimensions. These were summarized by Kelly, Wooldridge, Hennessy, and Reed (1979).

Engagement outcomes. The most obvious measure of ACM skill is the number of kills achieved by a pilot in real or simulated ACM engagements. This measure is probably the most common criterion in use today. Engagement outcomes can be contaminated, however, by many other variables (e.g., the less skilled pilot can get a lucky shot). Other variables must, therefore, be examined in order to provide a fully valid measure of pilot performance.

Energy management. It is axiomatic that pilots who manage their kinetic and potential energy well have a significant advantage over pilots who manage their energy less well. A factor analytic study by DeBerg (1977) demonstrated that energy measures provide the most important class of measures to be used in describing an air combat engagement. More recently, Moroney, Pruitt, and Lau (1979) recommended the use of energy maneuverability displays during training of ACM.

Although this class of measures offers attractive results, exsisting models that combine variables of potential and kinectic energy require sophisticated computations. Extensive developmental work needs to be done to optimize just these measures. Inclusion of these measures would seriously have effected the timeliness of this study and limited the probability of their implementation in an operational simulator or instrumented range system.

Aggressiveness. The trait most often cited as an indicator of ACM performance was aggressiveness. The aggressive pilot spends little time in a neutral position. He is continually maneuvering, making the opponent react to his moves. He is eager to get into the fight quickly and employs lead pursuit and lead turns more skillfully when moving into firing position. Some experts postulated a correlation between pilot aggressiveness and greater use of the roll axis and of the vertical dimension. Measures of turn rate, roll rate, plane of action and lateral velocity were included to indicate relative aggresiveness.

Situation awareness. Skilled pilots maintain a keen awareness of the changing situation around them. They know where they are in relation to the terrain, friendly forces, and opposing forces. They are able to extrapolate their position and that of the opponent into the future. The pilots exhibiting good situation awareness are probably more active in use of controls such as throttle and speedbrake as they anticipate the opponent's moves. They are aware of weapons envelopes and anticipate moving from one envelope to another; they have the appropriate weapon ready for use when entering the envelope. They have a lower probability of flying into terrain or losing an aircraft due to fuel exhaustion.

Throttle activity was deemed the most significant situation awareness variable contained in the existing data base.

Control inputs. Useful information about the level of ACM skill can be derived by examining the way the pilot flies the aircraft. A highly skilled pilot is able to fly the aircraft at the limits of its performance parameters when necessary. It is important to note that this does not mean that the pilot constantly maneuvers the aircraft at maximum angle of attack, but rather is able to maximize the tradeoff between turn rate and energy expenditure in each situation.

As previously noted, important information can be gleaned from pilot control inputs. The skilled pilot reacts to changing situations by throttle and speedbrake changes but the less skilled pilot is likely to maintain a relatively high power setting throughout an engagement, reflecting either a lack of situation awareness or an overwhelming workload.

There is some disagreement among experts as to whether control smoothness provides an indication of ACM skill. The consensus is that aileron smoothness is essential at high angles of attack to prevent loss of control. At other times, the importance of control smoothness is less clear.

Application of basic fighter maneuvers. Basic fighter maneuvers (BFM) are used primarily to maneuver into the weapons envelope against a non-reactive target. BFM, however, forms the foundation on which all maneuvers in ACM are based. The skilled pilot is able to apply BFM, using parts of several maneuvers, in combination or succession, in order to arrive in firing position.

Candidate measures. Based on results of the analytical phase, a group of 28 candidate measures was produced. These measures could be derived from time histories of ACM engagements flown on the SAAC. The list included measures of engagement outcome, relative aircraft position, control activity, aircraft maneuvering, and situation awareness. The measures were chosen to reflect the dimensions of ACM skill just described. Details on their derivation can be found in Kelly et al. (1979).

EMPIRICAL DATA COLLECTION PHASE

After the analytical phase was completed, collection of empirical ACM data began. Performance and time history data were collected during a total of 405 engagements on the SAAC at Luke AFB. The configuration of the SAAC was described in detail in Kelly et al. (1979) Technical Report.

Pilots. A total of 30 F-4 qualified Air Force pilots took part in this portion of the study. The pilots were selected on the basis of their prior training and ACM experience and were divided on this basis into three groups of 10 pilots each, representing three ACM experience level ranging from novice to expert.

Procedure. During each of five consecutive weeks, six pilots (two from each of the three experience levels) took part in the testing. The first of three days of data collection each week was devoted to carefully defining the skill levels of each participant. After completing a detailed questionnaire concerning their flight experience, especially recent ACM experience, the pilots completed an orientation flight in the SAAC. They then flew a set of pretest exercises involving five attacks on targets being flown in a predetermined pattern by one of two project pilots.

The second and third days of data collection each week consisted of a round robin series of free engagements among the six pilots. Every pilot flew against each of the other five pilots three times in F-4 versus F-4 competition. Three neutral initial setups were used. On the third day of testing, the two most experienced ACM pilots flew six engagements of dissimilar air combat with the SAAC 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 inputs. Project pilot ratings of the participants and peer rankings were also obtained. From these 67 measures could be calculated the 28 candidate performance measures described previously.

Multivariate discriminant analyses were performed on the data obtained during the F-4 versus F-4 free engagements. Based on these analyses, an algorithm was developed containing 13 measures which accounted for over 51% of the variance in the performance data and which could discriminate between members of the high and low skill level groups with over 92% reclassification accuracy.

Examination of the results of the effort suggested an alternative measurement structure which might be used to account for a larger portion of the variance and might provide more diagnostic information. This structure, termed TACSPACE, involved a multi-dimensional state space model involving relative aircraft positions. The purpose of the effort reported in this document was to develop and refine the TACSPACE concept, then test its validity, generalizability, and efficacy using the existing database.

III. ANALYSIS METHOD

The previous work (Kelly et al., 1979) focused on the development of measurement models to distinguish novice ACM pilots from those more experienced. Two rudimentary models were created from measures of relative aircraft position, energy states, weapons switchology, and control inputs. The first model, referred to as Whole Engagement Success Factors, related to the use of aircraft controls and gross measures of relative positional superiority, and can be called a technique model. The second model, referred to as the TACSPACE Model, related entirely to the relative positions of the opponents and was, therefore, a tactics model.

The Kelly et al., (1979) study represented the development and preliminary analysis of data collected during ACM free engagements. The measurement structures thus developed contained the framework for an effective ACM performance measurement system. While the whole engagement technique model was excellent for the classification of pilots into skill levels, performance diagnosis was difficult using this approach. It was suggested that a combination of the two models might provide the needed capability by imposing a context-specific structure on the control activity of the pilot. The following sections describe the further development and refinement of an ACM performance measurement approach.

While whole engagement data analysis could successfully classify pilots into skill levels, little diagnostic information was found by this approach. Summary data confirmed that experienced pilots tend to adjust their throttle more, roll and pitch more adroitly, use the vertical plane to their advantage, and keep their opponent in view. Quantifying the tendency to do these things is different from telling someone when and where inappropriate control activity took place during the course of an engagement. A different measurement structure was needed to provide diagnostic capability.

The relative position and orientation of the opposing aircraft are of great importance, since the main goal of an engagement is to achieve a position for weapons release. Therefore, diagnosis, at a minimum must be done in the context of relative aircraft states.

During training in ACM, 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. Line-of-sight (LOS) is the angle of the opponent's aircraft off the aircraft axis or nose of the defender. The aspect angle used for the defender is the angle off the opponent aircraft axis or tail of the defender. This angular relationship is diagramed in Figure 3.

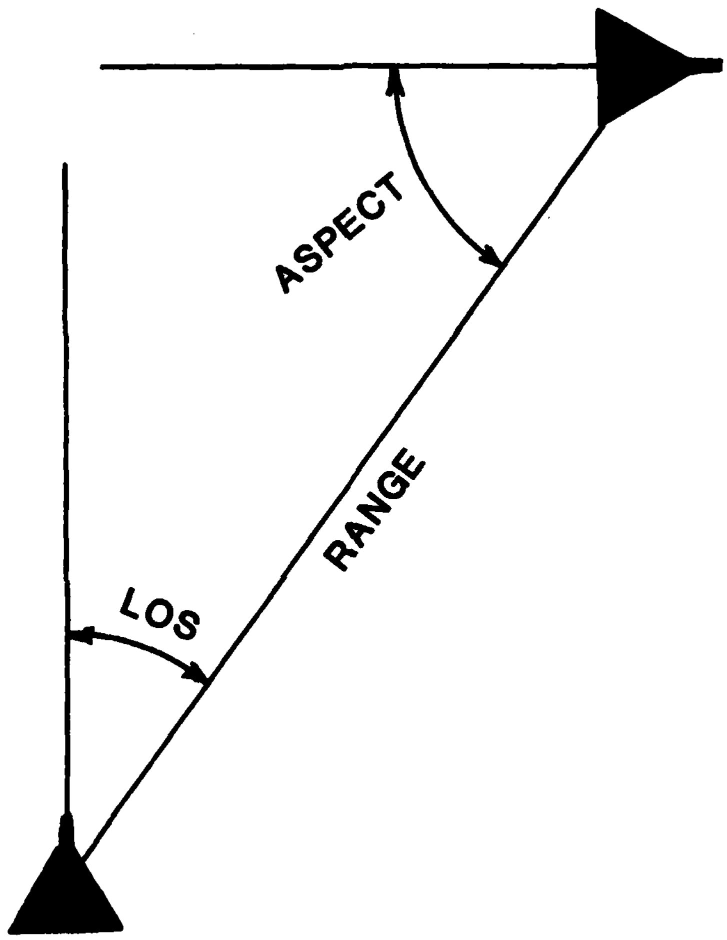


Figure 3. Relationships between LOS, ASPECT, and RANGE.

Given that range, LOS, and aspect angle sufficiently describe the situation, performance assesssment can be based on control activity as a function of these three states. This is done by creating a coordinate system called TACSPACE, using range, LOS, and aspect as the axes. TACSPACE can be broken into a matrix of sectors or cells (Figure 4). The cells of TACSPACE reflect tactical function or expected population densities and are not necessarily of equal size.

In the previous work, TACSPACE was divided into 125 cells along these three dimensions (LOS angle, aspect angle and range). A preliminary analysis of a very small sample of cells examined the feasibility of this approach.

It was found that the percentage of time spent in certain cells of TACSPACE tended to discriminate between winners and losers. Also, it was found that pilots occupying a given cell flew differently depending on their skill level. These results suggested that further work with TACSPACE should provide a more descriptive and diagnostic measurement model than is represented by the Whole Engagement algorithm. The new approach is illustrated in Figure 5 and is described in the following paragraphs.

SEGMENT ENGAGEMENTS

Expert pilots sometimes make errors during engagements resulting in unnecessary losses. Conversely, relatively novice pilots occasionally win an engagement through accident or circumstance. Obviously these uncharacteristic performances contribute a certain amount of error variance to the analysis. Presorting the data according to engagement outcome as well as level of training is not the final solution. It is possible for a pilot to gain and lose the advantage more than once within an engagement, yet ultimately win.

There are three apparent conditions that occur during an engagement: (a) a totally neutral situation when neither pilot has the advantage, (b) an offensive situation when the defender is approaching a weapon release envelope, and (c) a defensive situation which is the direct opposite of the offensive situation. An expert's ability to gain the advantage from the neutral situation, maintain the offensive and escape from the defensive positions are of greatest interest.

Therefore, to preserve the terminal status of each segment, it was necessary to divide the time history into segments and sort into groups of trained winners against relatively untrained losers. When not considering the entire engagement, positions of relative advantage, disadvantage or neutrality were defined in terms of line-of-sight, aspect angle and range. Three primary contrasting situations were created:

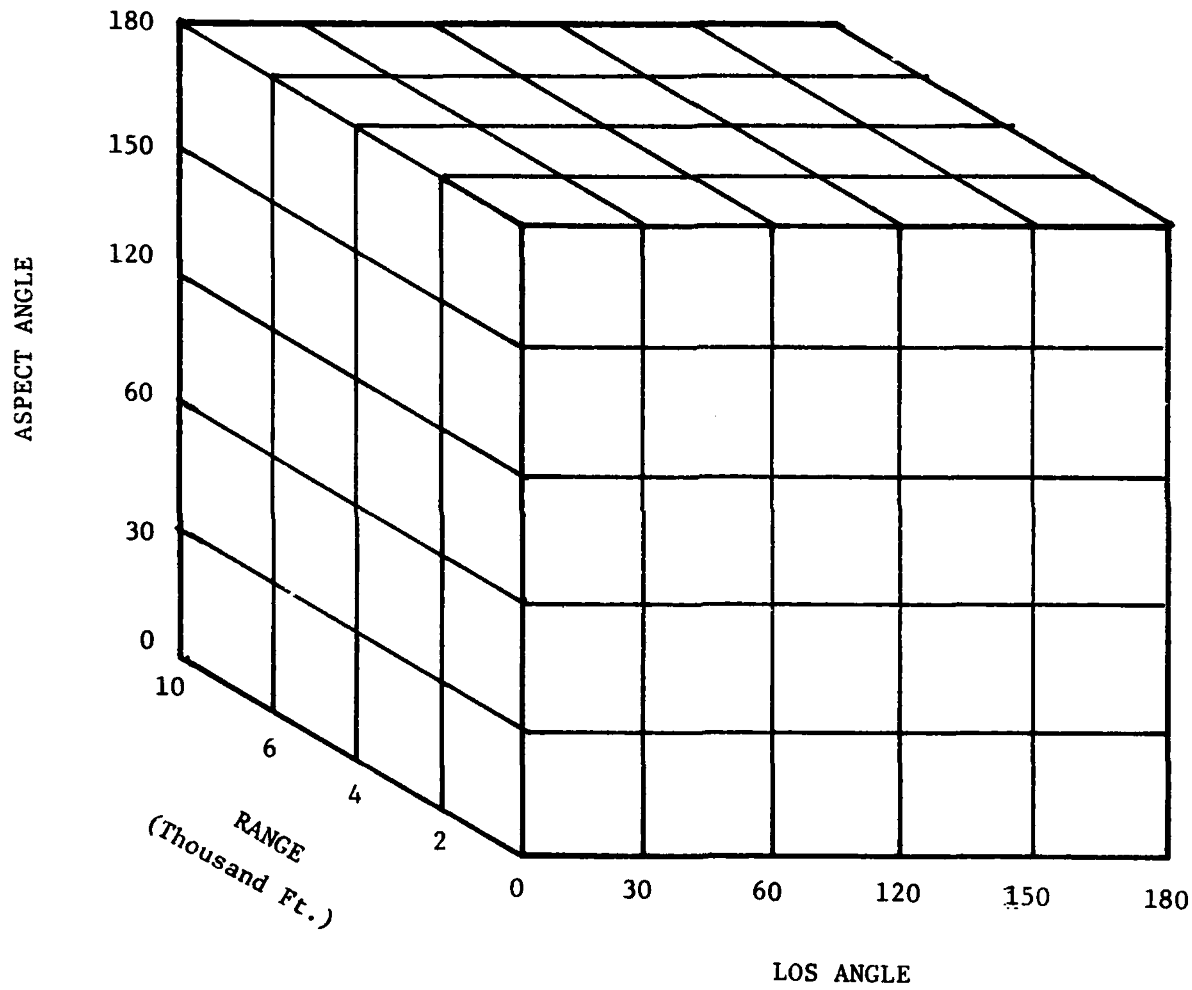


Figure 4. TACSPACE.

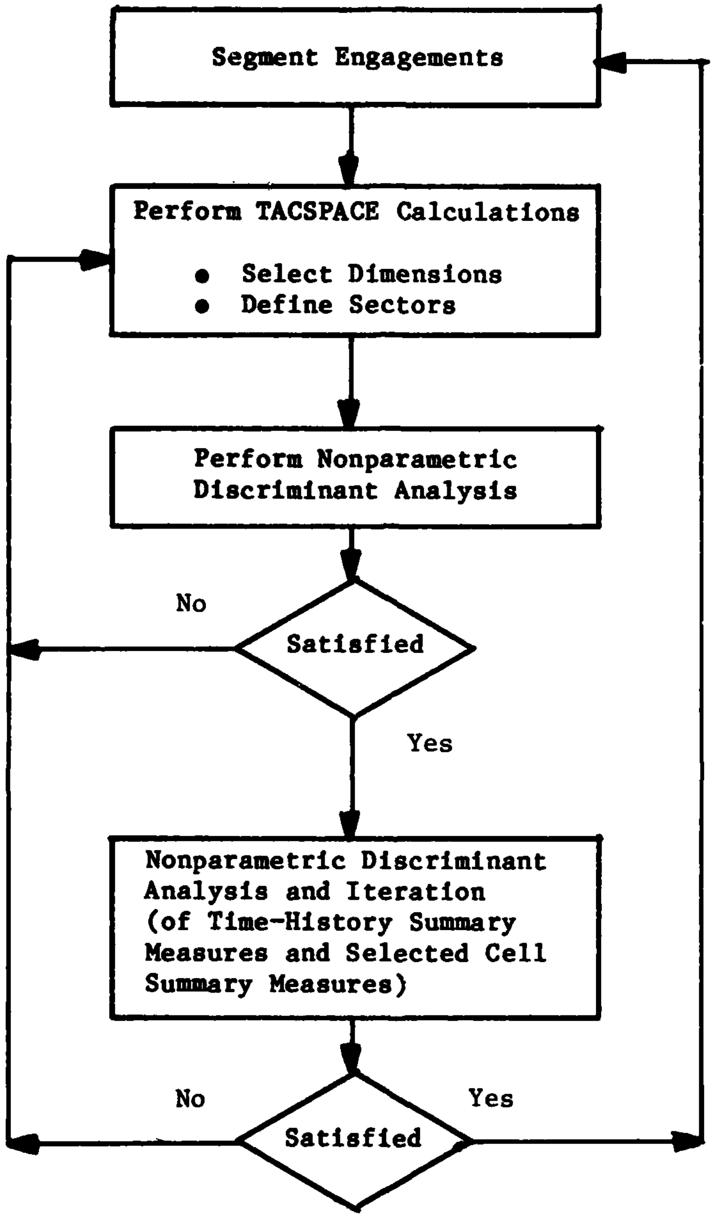


Figure 5. Flow Diagram. Analysis Methods.

1. Initially neutral and emerging in either a defensive or offensive relative position.

2. Initially offensive and terminating either by firing or losing the offensive.

3. Initially defensive and terminating either by being killed or by escaping.

The definition of offensive and defensive regions were highly dependent on the weapons selected by each of the two pilots. Unfortunately, it was impossible to uniquely identify weapons selection from the switches monitored in the existing data base. For analysis purposes, it was assumed that the ideal weapons selection strategy was followed during the course of the engagement by both pilots. The segment boundaries related to the most extreme angles and ranges allowed for either missiles or guns.

PERFORM TACSPACE CALCULATIONS

Two sets of performance measures were used. The set called time-history segment summary measures, listed in Table 1, were applied to time-history segments. If these measures were applied to the entire engagement, the result would be comparable to the Whole Engagement Success Factors which had been developed previously (Kelly et al., 1979). A different set of measures, called TACSPACE cell summary measures, listed in Table 2, were applied to performance within a single TACSPACE cell. While there is one time-history segment summary measure set associated within any particular time-history segment, there may be a number of TACSPACE cell measure sets, one relating to each TACSPACE cell occupied during that time-history segment. The resulting summary measure sets can each be used to develop a discriminant model for performance measurement. For the convenience of the user the analysis software generated four transforms for each selected variable. Coincidentally, the two candidate measure sets are quite similar in this particular case.

The previous exploration of the TACSPACE approach was very limited and was performed manually. Software development was therefore required to perform the analyses of this study in a timely fashion. New data base architecture, graphic display programs and file manipulation programs were implemented to allow the TACSPACE manipulation and discriminant analysis algorithm to work jointly and effectively.

Dynamic graphic display routines were developed to evaluate engagement segmentation, to verify calculation of cell measurement transforms, and to more rapidly identify practical TACSPACE regions or significant patterns of activity in TACSPACE. These time history plots of performance measures or TACSPACE activity were invaluable for rapidly debugging the new analysis routines for effective presentation of analysis results. They were also useful for checking for proper segmentation of the time history data.

TABLE 1. CANDIDATE TIME-HISTORY SEGMENT SUMMARY MEASURES

Number	Measure	Units
1	AVG Airspeed	Knts
2	RNG Airspeed	Knts
3	RMS Airspeed	Knts
4	AVG Turn Rate	Rad/Sec
5	RNG Turn Rate	Rad/Sec
6	RMS Turn Rate	Rad/Sec
7	AVG G - Forces	-
8	RNG of G - Forces	-
9	RMS G - Forces	-
10	AVG LOS Azimuth	Deg
11	LOS Azimuth Range	Deg
12	RMS LOS Azimuth	Deg
13	AVG Closing Rate	Ft/Sec
14	RNG Closing Rate	Ft/Sec
15	RMS Closing Rate	Ft/Sec
16	AVG Throttle Position	-
17	RNG Throttle Position	-
18	RMS Throttle Position	-
19	AVG Roll Rate	Deg/Sec
20	RNG Roll Rate	Deg/Sec
21	RMS Roll Rate	Deg/Sec
22	AVG Plane of Action	Deg
23	RNG Plane of Action	Deg
24	RMS Plane of Action	Deg
25	AVG LOS Elevation % Neg	-
26	AVG % Aspect + LOS > 180	-
27	AVG % Aspect + LOS < 180	-
28	AVG Lateral Velocity	Ft/Sec
29	RNG Lateral Velocity	Ft/Sec
30	RMS Lateral Velocity	Ft/Sec

AVG = Average
AAV = Average Absolute
RMS = Root-Mean Squared
SD = Standard Deviation
RNG = Range

TABLE 2. CANDIDATE TACSPACE CELL SUMMARY MEASURES

Number	Measure	Units
1	AVG Airspeed	Knts
2	AAV Airspeed	Knts
3	RMS Airspeed	Knts
4	SD Airspeed	Knts
5	AVG Turn Rate	Rad/Sec
6	AAV Turn Rate	Rad/Sec
7	RMS Turn Rate	Rad/Sec
8	SD Turn Rate	Rad/Sec
9	AVG G - Force	-
10	AAV G - Force	-
11	RMS G - Force	-
12	SD G - Force	-
13	AVG LOS Azimuth	Rad
14	AAV LOS Azimuth	Rad
15	RMS LOS Azimuth	Rad
16	SD LOS Azimuth	Rad
17	AVG Closing Rate	Ft/Sec
18	AAV Closing Rate	Ft/Sec
19	RMS Closing Rate	Ft/Sec
20	SD Closing Rate	Ft/Sec
21	AVG Throttle Position	-
22	AAV Throttle Position	-
23	RMS Throttle Position	-
24	SD Throttle Position	-
25	AVG Roll Rate	Rad/Sec
26	AAV Roll Rate	Rad/Sec
27	RMS Roll Rate	Rad/Sec
28	SD Roll Rate	Rad/Sec
29	AVG Plane of Action	Deg
30	AAV Plane of Action	Deg
31	RMS Plane of Action	Deg
32	AVG Plane of Action	Deg

AVG = Average
AAV = Average Absolute
RMS = Root-Mean Squared
SD = Standard Deviation
RNG = Range

Programs were implemented to perform the cell merger, TACSPACE re-dimensioning, and cell measure transformations required for the analysis. A program was also written to interface the TACSPACE analysis with the already existing discriminant analysis programs.

NONPARAMETRIC DISCRIMINANT ANALYSIS

Some difficulty was encountered in applying standard multivariate discriminant analyses with the TACSPACE approach. Not every pilot was observed in any specific segment of TACSPACE, and an even smaller subset was observed in a particular cell in that segment. Therefore, these analyses can often be characterized by a large number of variables and a relatively small number of observations. If an attempt was made to use standard discriminant analysis methods, the degrees of freedom would vanish or the mathematics would yield a trivial solution. Nonparametric techniques were therefore used in these situations.

The t-test and Tukey Quick Test of Location (TQTL) (see Appendix A) were applied to the TACSPACE cell occupancy data and summary measures. The TQTL was found to have critical limitations when applied to the TACSPACE data. The t-test became the only metric for measure selection in the nonparametric analyses. The t-test was used to select measures, and the unit-scaling procedure (see Appendix A) was used to provide weighting coefficients. Nonparametric models were devised for each set of measures, and the results were used to guide more elaborate multivariate discriminant analyses for the more suitable data sets.

SUITABILITY DECISIONS

Once TACSPACE was defined and the resulting discriminant model calculated, statistical indicators and graphic representations could be used to determine whether the time-history segmentation and cell structure was suitable. The segmentation and TACSPACE definition was then modified to produce the desired balance between complexity and discriminant quality.

The appropriate discriminant analyses were performed on the summary measures to produce assessment models relating to the entire segment or the individual TACSPACE cells. If these results proved to be inadequate, the entire process was repeated from whatever starting point seemed appropriate, until no further improvements could be produced.

IV. ANALYSIS RESULTS

Many measurement models were developed. The models varied greatly in complexity and ability to account for performance variance. The final models are described in detail in Appendix B, Functional Specifications, and the coefficients are tabulated in Appendix C, Data for Discriminant Models. Appendix D contains normative data.

This section contains the results of the (a) similar aircraft analysis, (b) reduced measure set analysis for the ACMI/TACTS, (c) dissimilar aircraft analysis and (d) weapons envelope study. The similar aircraft analysis is outlined in Table 3, along with a reference to the appropriate figure or table number to assist the reader. Table numbers beginning with "C-" are located in Appendix C. Notice that the TACSPACE structure, or resolution, changed as a result of the initial whole engagement analyses, and that all remaining analyses used the medium resolution TACSPACE structure.

Three types of analyses were performed. First, the TACSPACE analysis contained only measures of the percent time that the pilots occupied each cell in TACSPACE. Second, the cell summary analysis contained the performance measures within each TACSPACE cell; these measures were shown in Table 2, Section III. Third, the segment summary analysis contained performance measures taken from the beginning of a segment (neutral, offensive or defensive) to the end, independent of the TACSPACE cells through which the aircraft may have passed; these measures were shown in Table 1, Section III. Generally, the unit-scaled, non-parametric discriminant analysis was used, but there were a few cases where it was possible to perform a parameteric, ridge-adjusted multiple discriminant analysis; these exceptions are noted in the text.

WHOLE ENGAGEMENT ANALYSIS, SIMILAR AIRCRAFT

Entire engagements were analyzed. A time history subfile, exclusively composed of engagements between novices and experts, was generated. This subfile required 4 hours of CPU time to build, and it occupied 25 percent of the allocated 115 thousand block space on the VAX computer. This provided a benchmark of the largest possible volume of data; also, it produced results that were directly comparable to the prior analyses. As expected, the same pattern of winners and loosers shown in Kelly et al. (1979) was observed, but differences in the performance measurement models resulted.

<u>TACSPACE - high resolution analysis</u>. TACSPACE processing was started with an 11 by 8 by 7 cell structure defined in Figure 6. Out of the 616 TACSPACE cells, 499 were found to be occupied by one of the groups during the engagement. Table 4 shows the unit-scaled discriminant model of these cells. This model, even in its simplicity, accounted for more than 50 percent of the ACM maneuvering variance.

TABLE 3. SIMILAR AIRCRAFT ANALYSES

Analysis	TACSPACE Resolution High	Medium	Low	Figure or Table Number
Whole Engagement				
TACSPACE, Hi Resolution	X			Figure 6, Table 4
Relative Advantage	X			Table 5
TACSPACE, Low Resolution			X	Figure 7
Cell Summary			X	Table 6
TACSPACE, Med. Resolution		X		Figure 8, Table C-2
Segment Summary		N/A		Table C-1
Neutral Segment				
TACSPACE		X		Table C-4
Cell Summary		X		Table 7
Segment Summary		N/A		Table C-3
Offensive Segment				
TACSPACE		X		Table C-6
Cell Summary		X		Table 8
Segment Summary		N/A		Table C-5
Defensive Segment				
TACSPACE		X		Table C-8
Cell Summary		X		Table 9
Segment Summary		N/A		Table C-7
Summary of Similar Analysis				Table 10

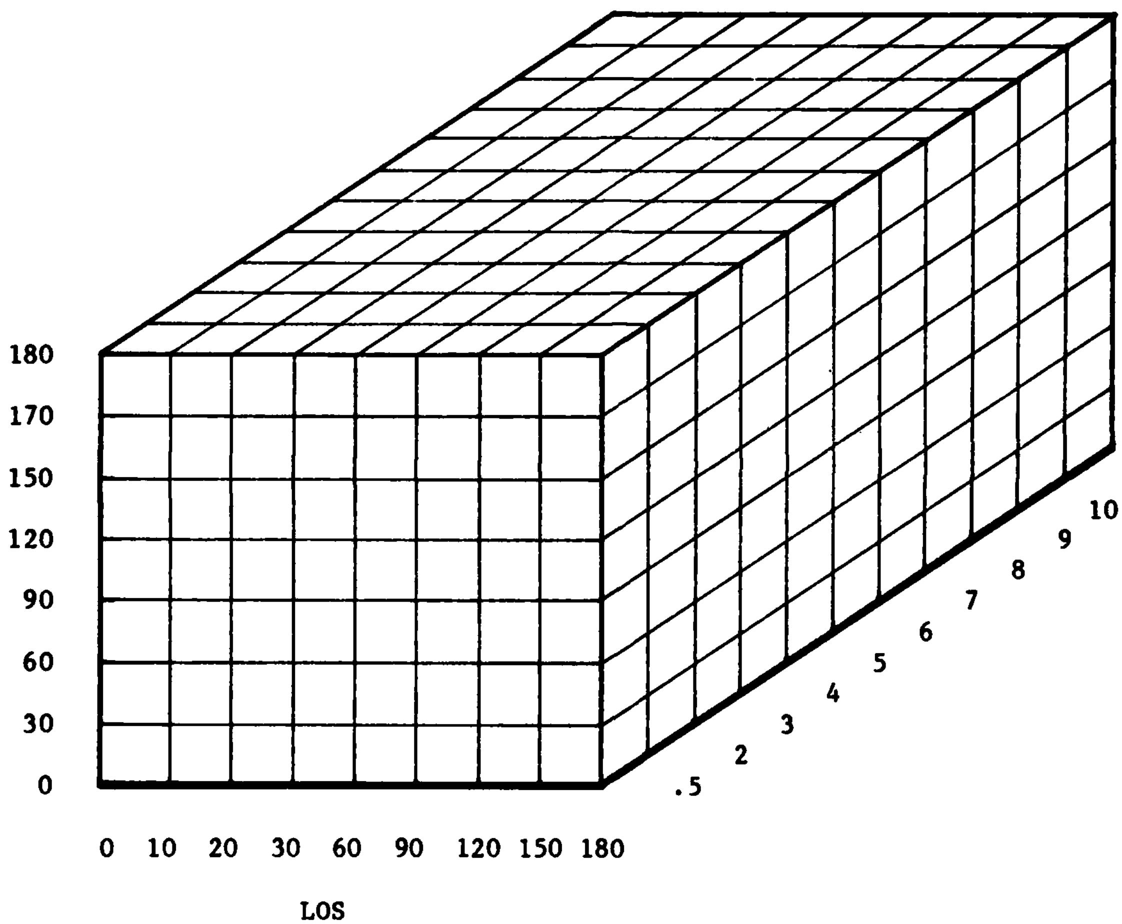


Figure 6. High Resolution TACSPACE.

TABLE 4. WHOLE ENGAGEMENT TACSPACE DISCRIMINANT VARIABLE

	Mean	S.D.
Novices	8.324	9.460
Experts	-12.131	9.811
Pooled	- 1.903	14.054

Break Point: -2.265

F1: 264.6 F2: 30833.6

Wilkes - Lambda: 0.468 S-OMEGA: 0.528

R^2: 0.531 Estimated Error: 15.38%

Relative advantage and disadvantage. An overall measure of tactical maneuvering skill was evident in the TACSPACE computer plots for entire engagements. A plot of contrasts between novice and expert groups in terms of LOS and aspect can be seen in Table 5. The greater percentage of time that the novices spent in each LOS/aspect cell, independent of range, is shown in this table. As the sum of LOS and aspect increases, the novice is more likely to spend more time in the corresponding cells than is the expert. Of course, a sum equal to 360 degrees represents the condition of greatest disadvantage. There is a clear line of demarcation; this line represents the condition where the sum is equal to 180 degrees. Consequently, the percentage of time the sum of LOS and aspect is greater than 180 degrees can be considered as a measure of relative disadvantage.

The statistical importance of relative disadvantage during the whole engagement can be implied from Table C-1, Measure 10; relative disadvantage has the highest communality (.714) of the twelve measures in the model. This model, however, accounted for only 37 percent of the variance. More striking is the importance of relative advantage in the neutral segment multivariate discriminant model (Table C-3, Measure 27); its communality (.989) is an order of magnitude higher than the other measures, and the neutral segment model accounted for 91 percent of the variance.

TACSPACE - low resolution analysis. It became clear that many cells in TACSPACE were occupied infrequently or for short durations. Little information can be acquired from analysis of such cells by themselves. Contiguous cells of low information content or highly similar information content can be combined. This facilitates the analysis and future application of the results by reducing the number of cells in TACSPACE and by finding those cells which might acquire more meaning by their merger.

TABLE 5. CONTRAST TABLE OF LOS AND ASPECT FOR WHOLE ENGAGEMENT.

		LOS 1	2	3	4	5	6	7	8
A	1			-					1*
S	2		+					3	6
P	3					+	1	10	8
E	4					1	20	23	11
C	5			+	3	19	30	26	14
T	6		.	1	10	24	35	28	17
	7	+	+	1	8	22	33	26	27

*Percentage of engagement x 10 that less experienced pilots occupied TACSPACE cells more than expert pilots. Symbols represent data less than one-tenth of a percent as follows:

$$.1 > + \geq .05$$
$$.05 > - \geq .02$$
$$.02 > . \geq 0$$

Three criteria were used to combine cells: (a) contiguous cells which had not been occupied, (b) contiguous cells which had been occupied about the same amount of time by both groups being compared, and (c) contiguous cells where behavior was apparently influenced by weapon capabilities. Great care had to be exercised when using the second two criteria so that measures of pilot performance were not confounded or deleted by improper merging of cells.

A reduction of TACSPACE to a low resolution version was performed to determine the magnitude of information that would be lost by merging cells. In the interest of time and software complexity, the cells were merged by combining entire rows or columns of cells. This was done by dropping breakpoints along individual TACSPACE axes, based on the distribution of cell occupancy data for the whole engagement. The resulting 5 by 4 by 4 TACSPACE is shown in Figure 7.

This 80-cell TACSPACE dramatically reduced the analysis time and storage space requirements. Another unit-scaled discriminant model was created using 69 of the cells and accounted for 46 percent of the variance between the two groups. This was a considerable reduction of model complexity (from 499 to 69 measures) with a loss of only 4 percent of the descriptive power. This interim analysis is not presented in Appendix C because a subsequent analysis improved this model.

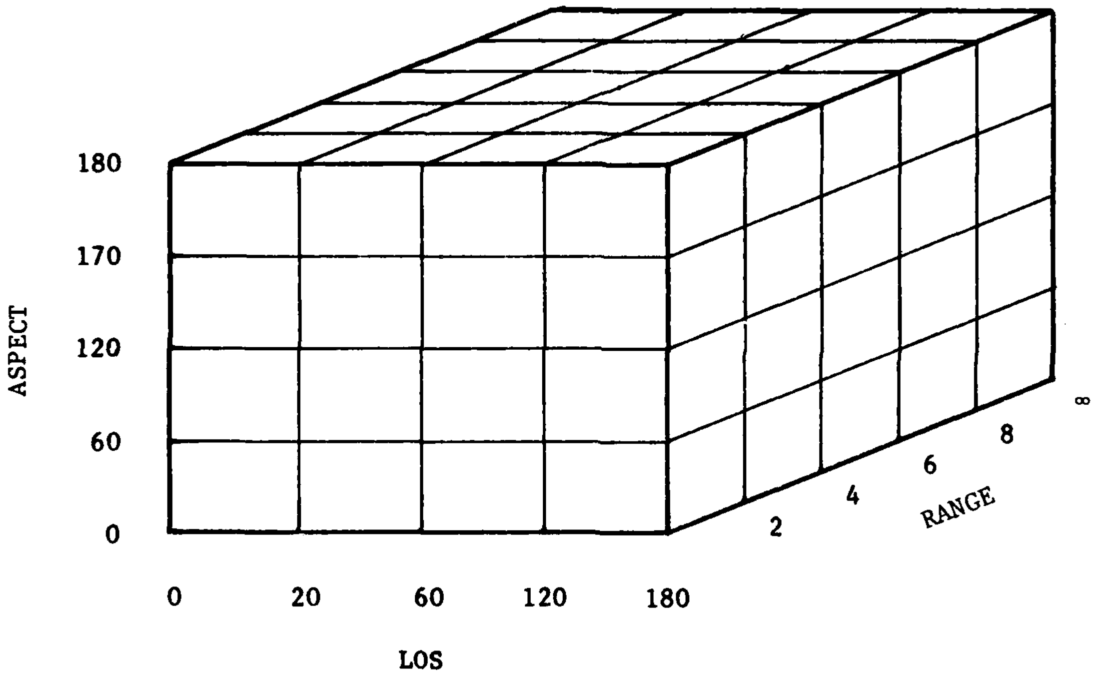


Figure 7. Low Resolution TACSPACE.
All angles are in absolute degrees.

Cell summary analysis. Nonparametric discriminant models were developed using various cells from the existing low-resolution TACSPACE. The cell coordinates (in terms of range, LOS and aspect), the number of observations in each group, the number of significant measures used in the model, and the resulting R^2 values can be found in Table 6.

TABLE 6. LOW RESOLUTION WHOLE ENGAGEMENT
TACSPACE CELL SUMMARY MODELS

Cell			No. of Observations		No. of Measures	
Range,	LOS,	Aspect	Novice	Expert	Used in Model	R^2
1	1	1	8	35	14	.15
2	1	1	11	41	16	.15
3	1	1	9	37	15	.29
5	1	1	12	30	7	.22
1	2	1	16	55	18	.17
2	2	1	19	60	11	.15
3	3	1	40	83	16	.17
2	1	1	24	66	18	.14
2	2	1	43	88	19	.17
3	2	1	48	82	17	.15
2	3	1	75	81	19	.15
3	3	1	77	85	17	.16
3	4	1	84	36	20	.24
2	2	1	78	81	19	.27
3	3	1	54	13	16	.23
3	1	1	23	61	20	.14
4	1	1	12	41	15	.25

Examination of the results of this cross section of TACSPACE shows that only limited information was derived from the discriminant models. In a majority of the cases, the measurement functions described less than 18 percent of pilot performance. All of the models accounted for only a trivial portion of the total variance compared to what normally would be expected.

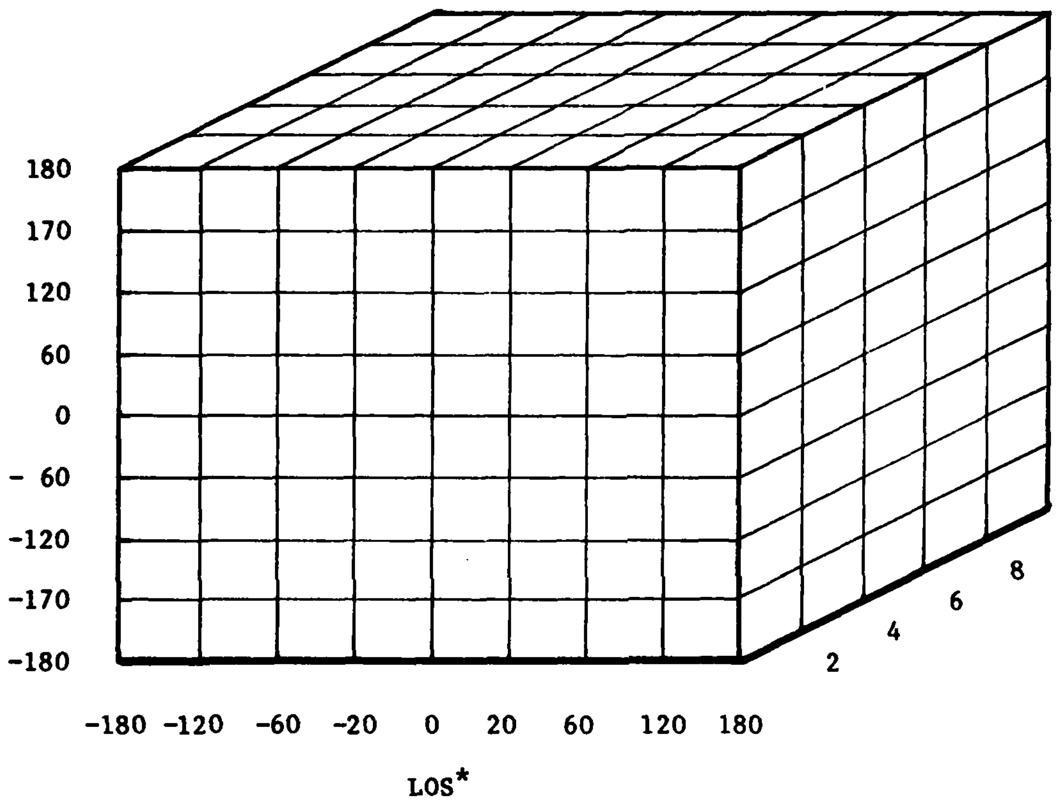
This disappointing result may be explained in any of several ways. First, the data were sorted by skill level and not by engagement outcome. Performances which ultimately led to victory were confounded with those that resulted in defeat. Even though the general trend was for experts to win more engagements, it was possible that a delicate relationship was nullified by a few defeats. Second, when the cells were merged, some effects may have been lost. Third, TACSPACE is still large (80 cells) and a limited number of engagements were used in this comparison. Considering the variability of performance that could be expected in each cell, the limited number of observations could detract from finding any significant relationship. Fourth, the reduction in resolution was performed without considering its effect on the contained measures. The resulting sample size and complexity of the model become limiting factors. Some rearrangement of cell boundaries might produce more significant models.

TACSPACE - medium resolution analysis. One corrective action was to break LOS and aspect into positive and negative regions based on the sign (plus or minus) of the elevation of those two angles. Maneuvering right and left usually results in symmetrical performance. Unfortunately, this is not true for performance in the vertical axis of the aircraft. Also, the maneuvering behavior may be different, depending on whether the opponent is above the wing line (positive LOS and probably in sight) or below the wing line (negative LOS and possibly not in sight) of the aircraft. The opponent's view was expressed by a negative elevation of aspect angle. Note that the sign does not relate to left or right, only to up or down.

The medium resolution (and final) TACSPACE structure is illustrated in Figure 8. Whole engagement TACSPACE was re-analyzed using this structure, as shown in Table C-2. The new structure accounted for 54 percent of the variance, which represented an improvement of 8 percent over the low resolution model. Thus, all remaining analyses (neutral segment, offensive segment, defensive segment, dissimilar aircraft and reduced measure set for ACMI/TACTS) were performed with positive and negative LOS and aspect elevation angles.

Segment summary analysis. There were no segments in the whole engagement analyses. Twenty-four time-history summary measures for whole engagement data produced a unit-scaled discriminant model (15 measures) that accounted for about 30 percent of the variance. The same measures were re-analyzed using the parametric multivariate techniques to produce a discriminant model accounting for about 37 percent of the variance.

The time-history segment summary measures, composed of aircraft performance and maneuvering variables, provided relatively weaker results when compared to TACSPACE and to previous summary models. When these summary models were examined, the critical roles of situation awareness and relative advantage measures were apparent. The pilot performance is taken out of the specific positional context in an analysis of an entire engagement. Thus, only general control differences show up in these models. In general, these measures alone may not be a powerful delineator of skills. These analyses, however, led to the full set of 30 time-history segment summary measures used in the rest of this study. The re-analysis of the new measure set for the whole engagement accounted for more than 63 percent of the variance, as shown in Table C-1.



*Negative LOS means line-of-sight below the wing line. Negative Aspect means the angle is below the wing line of the opponent.

Figure 8. Final TACSPACE Model.

NEUTRAL SEGMENT ANALYSES, SIMILAR AIRCRAFT

The time history data were segmented into those portions of the engagement where neither aircraft was within an opponent's weapons envelope. The data from each segment were divided into groups based on the pilots' relative situation at the end of the segment. The data from the cockpits terminating in a defensive or disadvantaged relative position went into one group. The data from those terminating in an offensive or advantageous position went into the other. The placement of data into groups was additionally constrained in that only the skilled or expert pilot data were permitted into the offensive group. This allowed a certain control over the quality of the criterion data by allowing inclusion of only the superior performance data.

TACSPACE analysis. A unit-scaled discriminant model of the TACSPACE transformation of these data accounted for 84 percent of the neutral maneuvering performance variance (Table C-4). The results are similar to those obtained with the relative advantage measure analysis, but on a smaller scale. Starting from a neutral condition, the more skilled pilots consistently gravitated to specific regions in the direction of improved relative advantage.

Cell summary analysis. Neutral TACSPACE contained a large number of cells. A complete model including all possible TACSPACE cell summary equations would be prohibitively complex for application in the SAAC or ACMI/TACTS. As a check on the previous poor performance of cell summary models, analyses were performed on several neutral cells. Table 7 summarizes the results of seven representative TACSPACE summary discriminant analyses. Looking back at the whole engagement summary measures in Table 4, it appears that the new segmenting, sorting and TACSPACE definition had beneficial effects on these models. On the average, the new cell summary models accounted for more of the variance, although less than half of them are significant. Better models resulted from those cells that had the highest number of occurrences in common with both groups.

TABLE 7. NEUTRAL SEGMENT TACSPACE CELL SUMMARY MEASURES

Cell Range	Cell LOS	Cell Aspect	No. of Observations Defensive	No. of Observations Offensive	No. of Measures Used in Model	R^2
1	6	6	35	4	14	.225
1	7	6	19	15	16	.255
2	7	6	31	36	16	.315
3	7	6	24	21	11	.347
4	7	6	11	11	7	.223
5	7	6	7	11	14	.464
3	8	6	4	58	16	.156

Segment summary analysis. The unit-scaled time-history segment summary model accounted for over 67 percent of the general performance and of the tendency to improve one's relative advantage. As a demonstration of possible gains with the advanced multivariate techniques, a ridge discriminant model was developed. This model accounted for more than 91 percent of the same between-groups variance (Table C-3). Since past experience has shown typical gains of 10 to 15 percent over the nonparametric techniques, this is an exceptional case.

OFFENSIVE AND DEFENSIVE TACSPACE ANALYSES, SIMILAR AIRCRAFT

Two more segments of time history data were developed in the same fashion as was done for the neutral zone analysis. An offensive segment was produced to study the difference between those who lost or kept their advantage by dividing the offensive time-history data into groups by the outcome of the segment. Likewise, the time histories of those on the defensive were divided into those who escaped or those who fell into a weapons envelope recognized by the opponent (i.e., were fired upon). The same TACSPACE processing was done on these two sets of groups.

TACSPACE analysis. The unit-scaled TACSPACE model for the offensive segment accounted for about 24 percent of the variance (Table C-6). The defensive model (Table C-8) accounted for more than 45 percent. More detailed descriptions of these models may be found in Appendix C.

Cell summary analysis. The discriminant models of TACSPACE cell summary measures provided encouraging results. Tables 8 and 9 summarize the results of several analyses. The number of defensive and offensive cells occupied by both groups was relatively small. The number of observations in each cell also was small. The tables reveal that once pilots entered defensive cells they were more likely to be killed than to escape. Conversely, once an offensive stance is assumed, the opponent is not likely to be lost. Again, this is in line with the fact that skilled pilots dominated the advantageous relative positions.

Even though some of the sample sizes are small, the offensive and defensive cell summary models are accounting for more variance (by several orders of magnitude) than the time-history segment summary models. This is a very strong argument for context specific measurement of pilot performance in the offensive and defensive situations.

TABLE 8. OFFENSIVE SEGMENT TACSPACE CELL SUMMARY MEASURES

Cell Range	LOS	Aspect	No. of Observations Escape	In Envelope	No. of Measures Used in Model	R^2
5	5	5	3	10	23	.324
4	6	5	3	9	16	.665
4	5	5	6	14	12	.250
3	6	5	10	13	8	.247
3	5	5	12	24	8	.152
2	6	5	12	16	19	.262
2	5	5	19	20	19	.302
2	4	5	2	7	17	.494
1	6	5	6	10	10	.584
1	5	5	8	12	22	.625
1	4	5	4	3	12	.878

TABLE 9. DEFENSIVE SEGMENT TACSPACE CELL SUMMARY MEASURES

Cell Range	LOS	Aspect	No. of Observations Escape	In Envelope	No. of Measures Used in Model	R^2
1	8	1	8	11	16	.259
4	8	8	4	10	16	.636
3	8	8	6	11	16	.546
1	8	8	5	8	21	.629
2	8	8	16	13	18	.453
4	8	7	2	13	20	.197
3	8	7	10	17	13	.204
2	8	7	17	19	13	.247
1	8	7	7	12	5	.133
1	8	2	9	5	15	.457
5	8	1	3	6	17	.597
4	8	1	5	10	15	.583
3	8	1	8	15	9	.268
2	8	1	11	15	9	.268
1	8	1	8	11	16	.259

Segment summary analysis. Both offensive and defensive time-history segment summary models accounted for insignificant amounts of performance. These data (Tables C-5 and C-7) are provided for documentation rather than as useful material for implementation.

SUMMARY OF SIMILAR AIRCRAFT

The prominent similar aircraft analysis results are summarized in Table 10. Several conclusions are offered: The TACSPACE cell summary measures describe pilot control behavior in the tail chase; they are less descriptive of tactical maneuvering. Once an offensive position is attained, it requires more anticipation and rigorous control activity than tactics to bring the opponent into a weapons envelope. Escape has more to do with the pilot's relative position and control performance than does making a kill. Although these conclusions may be obvious to ACM pilots, it is important to note that the performance measurement models were able to isolated them.

TABLE 10. SUMMARY OF SIMILAR AIRCRAFT ANALYSES

	R2	Measures	No. of Models
Whole Engagement			
Segment Summary	.63	13	1
TACSPACE	.46	69	1
Cell Summary	.15-.29	7-16	17
Neutral Segment			
Segment Summary	.91	9	1
TACSPACE	.84	128	1
Cell Summary	.16-.46	7-16	7
Defensive Segment			
Segment Summary	.05	12	1
TACSPACE	.45	7	1
Cell Summary	.13-.63	5-21	15
Offensive Segment			
Segment Summary	.02	14	1
TACSPACE	.24	11	1
Cell Summary	.21-.83	9-15	11

REDUCED MEASURE SET ANALYSIS FOR ACMI/TACTS

One of the major criteria established for the ACM performance measurement system is that it must be applicable on a variety of training devices rather than being SAAC specific. An environment in which a measurement system would provide an important tool is the ACMI TACTS.

In the strictest sense, the ACMI/TACTS 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, indicate whether the target aircraft was killed.

To make these calculations, the ACMI/TACTS must collect and store huge amounts of data concerning aircraft position, states and switchology. Currently this data pool is primarily used to provide a playback capability during debriefing. The only kind of performance measurement actually made is the mission-level score of number of kills. However, several groups are currently working to develop the advanced capabilities of this system. In the future, the ACMI/TACTS may become an important source of ACM performance measurement data as well as being the excellent testbed for aircraft and tactics which it now represents.

A potential difficulty exists for the direct transfer of the SAAC ACM performance measurement package to the ACMI/TACTS environment because the ACMI/TACTS is incapable of measuring stick and throttle movements. However, re-analyses were made of most of the relevant time-history segment summary measures and cell summary measures without throttle and plane-of-action measures. The neutral model is presented in Table C-3. Tables 11 and 12 summarize the defensive and offensive cell summary models.

TABLE 11. DEFENSIVE SEGMENT REDUCED TACSPACE CELL SUMMARY MEASURES SET

Cell			No. of Observations		No. of Measures	
Range	LOS	Aspect	Escape	In Envelope	Used in Model	R^2
4	8	1	5	10	11	.585
3	8	1	8	15	11	.325
2	8	1	11	15	7	.229
2	8	7	17	19	8	.221
2	8	8	16	13	12	.339

TABLE 12. OFFENSIVE SEGMENT REDUCED TACSPACE CELL SUMMARY MEASURES

Cell Range	Cell LOS	Cell Aspect	No. of Observations Escape	No. of Observations In Envelope	No. of Measures Used in Model	R^2
1	4	5	4	3	9	.831
1	5	5	8	12	15	.684
1	6	5	6	10	9	.524
2	5	5	19	20	15	.212

DISSIMILAR AIRCRAFT ANALYSIS

It was possible to perform only two major analyses on the dissimilar aircraft data due to the very limited number of these engagements collected. Segmentation and cell summary analyses could not be performed with just a few observations in each group, therefore, all analyses were performed on the whole engagement.

TACSPACE analysis. The unit-scaled TACSPACE model for the offensive segment accounted for about 84 percent of the variance (C-10). This result compares favorably to the similar aircraft, although there is an explicit tactical maneuvering difference between the two conditions. This difference is clearly seen when the occupancy plots are compared and is also reflected in the cells that comprise each model.

Segment summary analysis. The reduced, ACMI/TACTS measure set was analysed for the whole engagement, and accounted for over 66 percent of the variance in a unit-scaled model (C-9).

Some information was sacrificed by the removal of throttle and plane-of-action measures, but the result is not so severe as to render them significantly less useful than models which could be implemented on SAAC. Application of the TACSPACE and summary models should benefit both simulator and aircraft environments.

WEAPON ENVELOPE STUDY

Accurate recognition of the weapon envelope is an important factor in the successful completion of an engagement. Good tactical skills cannot overcome the inability to unleash weapons within their effective limits. The measures in Table 13 were developed to study the state of the aircraft when the pilots thought they were in the envelope. Although it was impossible to track weapons selection throughout this engagement, the nature and condition of the trigger pull could be determined. This was done by matching each trigger pull in the time history data to the weapon indicated in the real time engagement printout saved during data collection.

Essentially, the computer made the first guess and the researcher manually inserted the correct weapon from the engagement printout for each of several hundred trigger pulls. Thus, each time a pilot pulled the trigger, the kind of weapon selected and the indicated measures were recorded for analysis.

TABLE 13. KILL ENVELOPE ANALYSIS VARIABLES

Variable No.	Name
1	Range
2	LOS
3	Aspect
4	Closing Rate
5	LOS Rate
6	Aspect Rate
7	Delta Turn Rate
8	Delta Plane of Action
9	In Envelope
10	Kill
11	Absolute Closing Rate
12	Absolute LOS Rate
13	Absolute Aspect Rate
14	Absolute Delta Turn Rate
15	Absolute Plane of Action
16	Dummy Start 1
17	Dummy Start 2

It should not be possible to fire a low-aspect AIM-9 missile and achieve a kill when the opponent aircraft is approaching. However a number of such kills did occur in the data collected. An investigation revealed that it was indeed possible in the simulator. It was also discovered that whoever fired first would lock-out the trigger of the opponent for the duration of firing. These two anomalies surely had an impact on the study of kill envelopes as well as the course of the engagements.

Three other realistic weapons situations were studied in detail. Trigger-pull events were divided into: (a) high-aspect guns, (b) low-aspect guns, and (c) low-aspect missiles. Discriminant models were built based on relative experience level. The results of these analyses are summarized in Table 14. There was very little difference between novice and expert pilots as to when they were likely to pull the trigger. The experienced pilots had more kills than the novice pilots, apparently because they had gained more opportunities to shoot, not because of superior marksmanship.

TABLE 14. KILL ENVELOPE STUDY RESULTS

Relative Position	Weapon	R^2
High Aspect	Gun	0.124
Low Aspect	Gun	0.192
Low Aspect	Aim9	0.139

V. DEVELOPMENT OF FUNCTIONAL SPECIFICATIONS

One study objective was to use the analyses from this study to provide functional specifications for a performance measurement system that will serve to aid training in the SAAC. To this end, current training was observed to determine the information needed by the IPs and the information not provided by current instrumentation. Then, SAAC operations and support personnel were interviewed to determine constraints on implementation of additional measurements and displays. Finally, functional specifications were developed which should be suitable for design and development of an add-on display and measurement system.

CURRENT TRAINING

The SAAC is currently used primarily to train F-4 ACM pilots in the TAC ACES program. The TAC ACES training syllabus contains the following set of simulator sessions:

1. Familiarization
2. Weapons Employment
3. BFM - Offensive
4. BFM - Offensive/Counter Offensive
5. BFM - Counter-Offensive/Low Altitude
6. Advanced BFM
7. Introduction to Threat, Introduction to 2v1 (two against one)
8. ACM (2v1)
9. MIG (Russian design aircraft) Exploitation
10. Turkey Shoot

In addition, the SAAC is used for special training. For example, training sessions were observed in which reconnaissance pilots were taught to be credible adversaries so that they could teach others in their units how to defend themselves.

For the most part, the IP occupied the second cockpit while teaching. Consequently, most of the information needed by the IP was acquired from the cockpit instruments and a visual assessment of the relative spatial positions of the simulated aircraft. Also, heavy use was made of problem freeze. The IP would move through the engagement in short increments, stopping to instruct and critique at critical moments. Consequently, when the IP needed information in a fast-moving situation, he could freeze the action to make a careful assessment.

During those training sessions where both cockpits were occupied by students (e.g., 2v1), the IP used the Instructor Station. His primary need there was a graphical display of the relative positions of the two aircraft. This display is currently provided at the console.

There is no method, however, for providing a global score of performance, either during a session, or at the end of the session. Also, there are no means for providing diagnostic end-of-run measurement to indicate performance relative to others who have performed in the same training. It is concluded, therefore, that functional specifications should emphasize measurement and display of such summary and comparative information.

The investigators observed that significant changes have been made in TAC ACES training since the original data were obtained. In contrast to a training program which largely involved trial-and-error experimentation by the students, a rigidly structured program consisting of demonstration and practice has evolved. As a result only the Turkey Shoot at the end of the syllabus is comparable to the conditions under which the data of this study were collected. Consequently, recommendations for measurement based on this study apply only to this phase of training.

IMPLEMENTATION CONSTRAINTS

Engineering and operations personnel associated with the SAAC were interviewed to determine limitations for add-on measurement and display. No clear-cut limits could be established. There is a large capability for additional measurement, but a specific proposal would have to be generated to obtain a firm assessment of feasibility. The following comments were noted to guide the development of a feasible specification:

1. A Sigma 5/7 computer with 64K memory is available for measurement computation. Extensive computations could be accomplished in a short time directly after each flight.

2. Even extreme estimates of the amount of measurement computation, with sampling rates of 2 Hz, seemed to be within capability.

3. The ADAGE graphical display is quite full; however, a simple display may be possible in addition to the current display. Communication speed with the ADAGE will probably be a severe limitation.

4. Additional cockpit display would be limited to use of an existing cockpit instrument (e.g., tachometer) which is not used for SAAC flights.

DESIGN APPROACH ADOPTED

Based on the foregoing analyses, a decision was made to compute three different scores: (a) relative advantage (percentage of time the sum of LOS and aspect is greater than 180 degrees), (b) a discriminant score based on summary measures, which can be termed a technique discriminant score, and (c) a discriminant score based on TACSPACE, which can be termed a tactics discriminant score. These data would be displayed directly after each session, along with a tabulation of the summary measures. An optional addition is a real-time display of one of the previous three scores, selected by the IP, computed and displayed on a thermometer-type display as the engagement progresses.

The analyses of this study showed that LOS and aspect, independent of range, allowed the computation of a measure of relative advantage which was a strong discriminator between novices and experts. Since this score is both easy to compute and easy to interpret, it is recommended that this score be displayed.

The measurement analyses performed in this study result in the selection of a set of measures that collectively discriminate, as well as the definition of a score that can be used for discrimination between experts and novices. Furthermore, a discriminant score can also be computed using nonparametric techniques and TACSPACE. The first discriminant score is based on measures of aircraft control and can be termed a technique discriminant score; the second is based on measures of relative position in TACSPACE and can be termed a tactics discriminant score. The discriminant function scores can be computed during each training flight for display directly after the training session. In this way, overall scores will be available for unbiased comparison, together with the set of summary measures. It is proposed that normative data be collected so that students can readily compare their performance with that of others.

The analyses performed in this study include development of discriminant models for the neutral, offensive and defensive portions of TACSPACE; consequently, one could consider display of technique and tactics discriminant scores for each of three zones as well as the total engagement. However, from examination of the variance accounted for, only the neutral zone scores are strong candidates. Better discrimination could be obtained by using a model which changes with each TACSPACE cell; however, it is believed that such an implementation is infeasible. It is concluded from these considerations that only neutral zone and total engagement discriminant scores should be computed.

Furthermore, as an option, depending on the feasibility of display on the ADAGE, one of the discriminant scores (as selected by the IP) will be computed in real time during the training flight so that a continuous assessment of performance is available. A simple thermometer-type scale in the upper left corner of the ADAGE (one display for each student) is proposed for the optional display of the progressive discriminant score.

The format for the thermometer-type display is shown in Figure 9, and the display format for summary and discriminant scores is shown in Figure 10.

The specifics of the proposed add-on measurement and display are presented in Appendix B in a form which should support development of the necessary software. No hardware engineering changes are believed to be necessary.

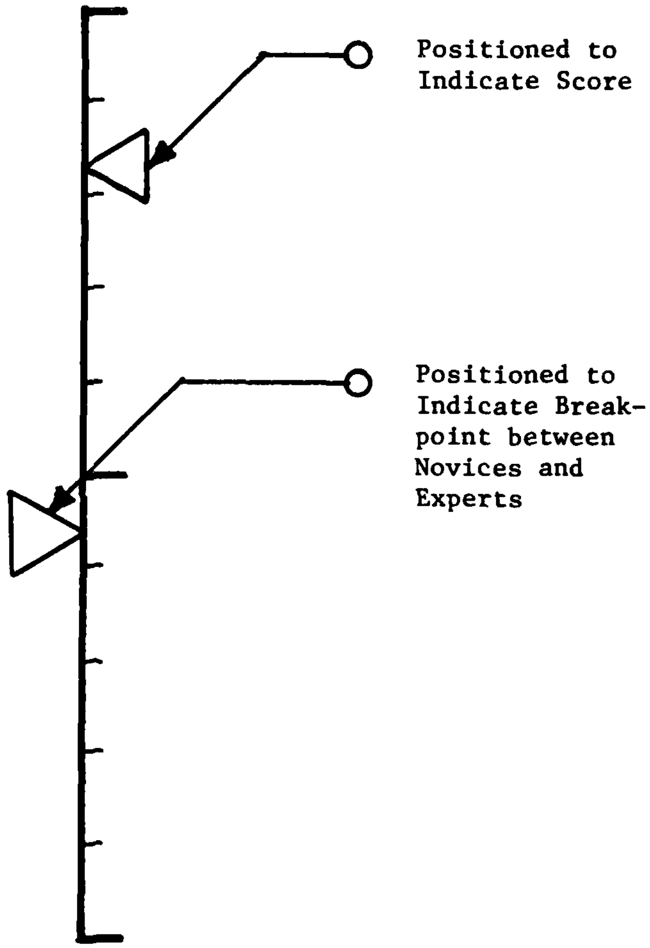


Figure 9. Real-Time Display Format.

SCORES

	Total Engage	Neutral zone	Offensive zone	Defensive zone
% REL. ADVANT.	x	-	-	N/A
TECHNIQUE SCORE	x/x[a]	x/x	TBD	TBD
TACTICS SCORE	x/x	x/x	TBD	TBD

SUMMARY MEASURES

Measure	XForm	Data	Novice[b] Level	Expert[b] Level
AIRSPEED	AVG	x	x	x
	SD	x	x	x
	RNG	x	x	x
TURN RATE	AVG	x	x	x
	SD	x	x	x
	RNG	x	x	x
G	AVG	x	x	x
	SD	x	x	x
	RNG	x	x	x
LOS AZ	AVG	x	x	x
	SD	x	x	x
	RNG	x	x	x
CLOSING RATE	AVG	x	x	x
	SD	x	x	x
	RNG	x	x	x
THROTTLE	AVG	x	x	x
	SD	x	x	x
	RNG	x	x	x
ROLL RATE	AVG	x	x	x
	SD	x	x	x
	RNG	x	x	x
LAT. VEL.	AVG	x	x	x
	SD	x	x	x
	RNG	x	x	x

% LOS EL NEG
% LOS + ASP > 180

NOTES: a: x/x = data/breakout between novices and experts
b: normative data previously collected

Figure 10. Summary Display Format.

VI. CONCLUSIONS

As a result of this effort, it was concluded that:

1. SAAC provides an excellent environment for the implementation of an instructor oriented system for ACMPM.

2. There was little difference between skilled and unskilled ACM pilots in their ability to recognize effective weapons envelopes. The primary difference between the two groups of pilots was in their ability to maneuver into the weapons firing envelope.

3. The TACSPACE concept provides an excellent framework on which to build an ACMPM system; however, additional intelligence should be added to have a comprehensive system.

4. A relatively simple matrix involving the sum of aspect and LOS angles provides a powerful "how-goes-it" indicator of maneuvering during an engagement that is conducted with limited aspect weapons. This offers the potential for a useful interim metric.

5. The training procedures used on the SAAC have changed since the data used for this analysis were collected. The syllabus of instruction and instructional methods have evolved to the point that the database from the program is applicable only to the last phase of training, the "Turkey Shoot."

6. Because very little active instruction is done from the console, and the engagements are frequently halted using "Freeze," the utility of a real-time performance measurement display on the console has to be seriously questioned. Nevertheless, several display concepts were developed; they can provide performance information to the instructor at the console (or the instructor in the cockpit) during applicable phases of training. It is recommended, however, that, for future applications in the SAAC, emphasis be placed on performance measurement to be used for post-training debriefing, rather than on real-time performance measurement.

7. The measurement algorithms could be adapted to the more restricted measurement capabilities of the "Basic" ACMI/TACTS with only a slight loss of efficacy. They could be adapted to a more complex ACMI/TACTS, such as the system at Nellis AFB, with little or no loss of efficacy. Because they measure free engagements (rather than an active and interruped instructional process), they might be better suited for ACMI/TACTS application than for use in the SAAC at the present time. Because of possible set-up differences and other than 1 versus 1 engagements, new data should be collected from the ACMI/TACTS and analyzed before implementation.

8. There were instances of questionable data in the database used for this analysis, primarily due to software peculiarities in the SAAC at the time these data were collected. Many of the noted problems have since been corrected. Also, as noted previously, the results of this analysis have limited applicability for future implementation because of changes in instructional methods. For these reasons, a new set of data should be collected and analyzed before implementation of these ACMPM concepts. It should be noted that the data analysis methods have matured to a point where a future analysis could be performed with optimum efficiency.

9. The TACSPACE and data analysis concepts developed as part of this effort provide a good method of assessing overall maneuvering performance. At this time, however, the structure and resulting equations provide only indirect performance diagnosis. An analyst who is familiar with the structure and mathematics can infer performance deficiencies from the behavior of individual measures, but the system does not directly tell an IP precisely what went wrong, where it went wrong, and why. For direct diagnosis presented so that IPs would understand, future work with ACMPM should consider combining TACSPACE with the evolving technology of expert systems representations, by inserting some decision rules to guide the selection of subsequent measurement within appropriate TACSPACE cells.

REFERENCES

Bruning, J., & Kintz, B. Computational handbook of statistics. Chicago: Scott Foresman and Co., 1977.

Ciavarelli, A.P. Development and application of aircrew performance criteria and assessment methods for TACTS. In Proceedings of the Seventh TACTS/ACMI Users Seminar. San Diego, CA: NAVAIRSYSCOM, May 1980.

DeBerg, O.H. A scoring algorithm for assessing air-to-air combat performance, Phase I: A factor analysis. Report 0590-77. Air University: Air Command and Staff College, 1977.

Kelly, M.J., Wooldridge, A.L., Hennessy, R.T., Vreuls, D., Barnebey, S.F., Cotton, J.C., & Reed, J.C. Air Combat Maneuvering Performance Measurement. AFHRL-TR-79-3, AD-A077 429. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, September 1979.

Kelly, M.J., Wooldridge, A.L., Hennessy, R.T., & Reed, J.C. Air Combat Maneuvering Performance Measurement. In C. K. Bensel (Ed.), Proceedings of the Human Factors Society, 23rd Annual Meeting. Boston: The Human Factors Society, 1979.

Moore, S.B., Madison, W.G., Sepp, G.D., Stracener, J.T., & Coward, R.E. Air combat training: Good stick index validation. AFHRL-TR-79-15, AD-A071 033. Williams AFB, AZ: Flying Training Division, Air Force Human Resources Laboratory, June 1979.

Moroney, W.F., Pruitt, R., & Lau, C. Utilization of energy management data in improving inflight performance and performance in air combat maneuvering. In C.K. Bensel (Ed.), Proceedings of the Human Factors Society, 23rd Annual Meeting. Boston: The Human Factors Society, 1979.

Neave. H.R. Quick and Simple Tests Based on Extreme Observations. Journal of Quality Technology, 1979, 11(2), 66-79.

Simpson, W.R., & Oberle, R.A. The numerical analysis of air combat engagements dominated by maneuvering performance. TM 77-2 SA. Patuxent River, MD: Naval Air Test Center, June 1977.

Vreuls, D., Wooldridge, A.L., Obermayer, R.W., Johnson, R.M., Norman, D., & Goldstein, I. Development and evaluation of trainee performance measures in an automated instrument flight maneuvers trainer. NAVTRAEQUIPCEN 74-C-0063-1. Orlando, FL: Naval Training Equipment Center, May 1976.

Wooldridge, A.L., & Helms, J.A. A study of the expanded adaptive module for basic instrument flight instruction. NAVTRAEQUIPCEN 74-C-0141-2. Orlando, FL: Naval Training Equipment Center, In press.

APPENDIX A

DISCUSSION OF STATISTICAL PROCEDURES

PREVIOUS WORK

Previous work (Vreuls et al., 1976) has established and tested (a) a descriptive structure, or model, for obtaining measurement in man-machine training and (b) measure selection methods based on multivariate statistical models which evaluate the total set of measures taken together and which produce weighting coefficients. These coefficients were then used to combine the measures into a linear equation which maximally discerns the change in performance due to training.

However, all of the previously used modeling techniques suffer when applied to diminished samples of data. Regardless of sample size, performance measures are difficult to analyze. Human performance data, being inherently noisy and non-normally distributed, violate many of the fundamental assumptions of multivariate analyses. Any multivariate regression or discriminant procedure begins to suffer from a lack of degrees of freedom as the sample size is reduced. Although regression mathematics still function adequately under these circumstances, interpretation of the reliability of the results becomes muddled even with ridge adjustments. Discriminant analysis mathematics are such that the inverse of the within-groups variance matrix, used to estimate the discriminant coefficients, becomes indeterminant or trivial as the degrees of freedom decrease. New techniques need to be used or developed to probe samples of data for significant training measures and to build valid, sensitive and rational performance models.

The normative model, referred to in previous research (Vreuls et al., 1976) went a long way toward equaling the discriminant model while using a very simple premise. A performance criterion was based on the empirical distribution of scores made up of speculatively weighted system measures (i.e., measures of aircraft position and rates) for fully proficient pilots. Its major drawback was the lack of control measures (i.e., stick, rudder, and throttle measures) included in the scoring scheme. It would be difficult, though, to speculate as to the weight to be assigned to each control measure for its inclusion in the score. The lesson learned from this example is that while the specific coefficients or weights for each measure are important, they are not nearly as critical as the inclusion or exclusion of measures and the determination of reasonable values of the model for performance criteria.

T-TEST

It can also be surmised that much simpler measurement analysis techniques than multivariate analyses can be used to develop satisfactory performance models (Wooldridge & Helms, in press). Measure selection analyses can be performed by univariate parametric techniques (Bruning & Kintz, 1977). Considering each measure independent of all other measures, the average value of each measure on a pretest can be compared to the average value of that measure on a posttest. A t-test can be used to determine statistically significant changes occurring in individual measures due to intervening training. This method differs little from the pre-screening programs used in previous research to limit the vast number of candidate measures to the number that the analyses programs could accomodate. The main difference is that the t-test was the sole standard for inclusion in the model.

The t-test is one of the best known and most commonly used method for the two-sample location problem discussed earlier, but it is unsatisfactory in some respects. The most serious drawback is the need to assume that the populations being sampled have normal distributions. Human performance measures are often skewed or have other non-normal characteristics. There is no consensus among statisticians as to how robust the t-test is or precisely where the test breaks down. There is no doubt that with small samples there are some distributions which extensively reduce the reliability of the t-test.

There are ways to transform the sample to make it more normally shaped, but this requires yet another mathematical manipulation of the data. Rather than fit the data to the technique, perhaps it would be better to devise a statistical procedure unaffected by the distribution. Non-parametric or distribution-free tests need no test of normality and are, therefore, much more generally applicable. In non-normal situations, the t-test can often be shown to be inferior to some of the non-parametric tests.

TUKEY'S QUICK TEST OF LOCATION

Tukey's Quick Test of Location (TQTL) was chosen for implementation out of a large number of existing non-parametric tests for its simplicity. Unlike most other non-parametric tests, TQTL does not require the rank ordering of data. The TQTL does not usually need statistical tables to find the critical values. It is sufficient to memorize three numbers and perhaps also an elementary algorithm.

Furthermore, an improvement was also made to the TQTL algorithm (discussed by Neave, 1979). When the Tukey test fails to diagnose a real difference in means, it is often because of just one observation taking a rather atypical value. If one sample contains both the highest and the lowest value, the TQTL yields inconclusive results. Thus a procedure was also implemented whereby one observation could be discarded. The algorithm throws out the data point which results in the largest possible Tukey statistic. Of course, the critical values are recalculated for the unequal populations.

UNIT-SCALING TECHNIQUE

Multivariate techniques offer the only methods powerful enough to capture the complexity of the real world while providing single metrics. These metrics are performance functions composed of several variables or measures. Performance functions are very useful for higher-level decision making or automated program control, while at the same time being excellent descriptive statistics. The simplest of these performance models or functions take the linear form:

$$Y = b_1x_1 + b_2x_2 + b_3x_3 + \ldots + b_nx_n$$

The Y term is usually the effect that the equation is trying to enumerate, and the b values are weighting coefficients derived by some multivariate analyses using several samples of n number of performance measures, or x values. In the past, coefficients have been the product of highly tailored tailored regression or discriminant analyses. Simply put, multivariate models evidently combine information more effectively than do humans. Yet, as discussed before, a noticeable degradation of performance or loss of utility occurs when these complex techniques are applied to small samples.

The term unit scaling is used to describe a model using the unit weighting technique with full excursion scaling as opposed to unit normal scaling. The predictor variables are scaled by their sample range after they have been translated by the subtraction of the sample minimum. Thence, the predictor variables are relocated as well as scaled. Although not mathematically required, the translation is performed for convenience. The resulting model values for n variances will lie between zero and n. For a set of n raw measures the unit scaling equation would take the form:

$$Y = \frac{a_1x_1 - \#Min_1}{range_1} + \frac{a_2x_2 - \#Min_2}{range_2} + \ldots + \frac{a_nx_n - \#Min_n}{range_n}$$

where a is still the unit direction variable, Min is the sample minimum and range is the sample maximum minus the minimum.

The sample location provides no useful information, so that for either unit weighting or unit scaling, the predictor variable could be relocated in the same manner. Disregarding the sign variable and the relocation, the comparable coefficients become "+," respectively. The primary difference

$$\frac{1}{sigma}_n \text{ and } \frac{1}{range}_n$$

between the standard deviation and the range is that the latter is totally unaffected by the shape of the sample distribution. This feature should provide more latitude in the application of the equal weighting scheme.

APPENDIX B

SPECIFICATIONS

SCOPE

The purpose of this appendix is to provide information that should be sufficient to implement the measurement findings of the reported study. It should be sufficient in the sense of defining the mathematical models and the desired outputs. However, it is not intended to fully delimit a design; this is left to the systems and applications programmers.

FLOW DIAGRAM

A top-level software flow diagram is provided in Figure B-1. During an air-air engagement, the measurement software must loop through a number of computations twice per second; this includes

(1) Sampling of parameters.

(2) Determination of the cell occupied in TACSPACE.

(3) Determination of the zone occupied in TACSPACE.

(4) Performing some transformation computations on the parameters and, optionally, computing a real-time discriminant score and displaying this in real time.

At the end of the engagement, there are more transformations, computation of discriminant scores for each TACSPACE zone, and displays for each zone, as well as for the total engagement. The following sections will provide additional data for each block in the flow diagram.

PARAMETER SAMPLING

To avoid sampling and storing parameters for an entire engagement, a set of parameters will be sampled at fixed intervals and basic computations made during the time between samples. The list of parameters required is presented in Table B-1. Each parameter must be sampled twice per second.

TACSPACE COMPUTATIONS

Three-dimensional TACSPACE is depicted in Figure 4, Section III, and the relationships between the parameters forming the axes is shown in Figure 3, Section III. The cells are numbered for use in measurement calculations as shown in Table B-2. Also, note that TACSPACE is divided into neutral, offensive, and defensive zones, and definitions for these zones are available in Table B-2.

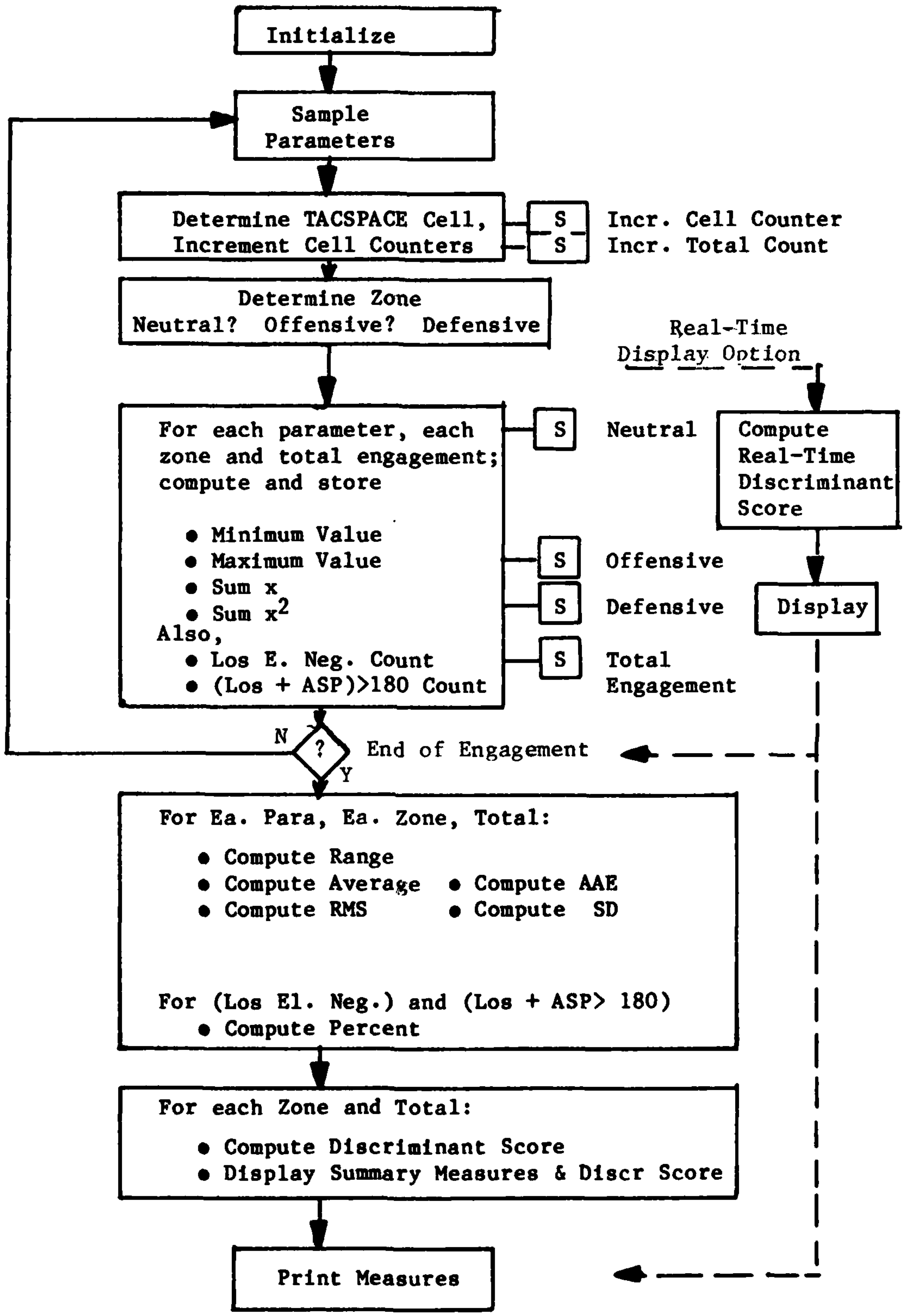


Figure B-1. Top-level flow diagram.

TABLE B-1. BASIC PARAMETERS

Parameters	Units
Airspeed	Knts
Turn Rate	Rad/Sec
G	-
LOS Azimuth	Rad
Closing Rate	Ft/Sec
Throttle Position	-
Roll Rate	Deg/Sec
Pitch Angle	Deg
Roll Angle	Deg
Lateral Velocity	Ft/Sec
LOS Elevation	Rad
LOS Cell	-
Aspect Angle Cell	-
Range Cell	-

TABLE B-2. NUMBERING OF TACSPACE CELLS

Range

$(R=1) < 2000 < (R=2) < 4000 < (R=3) < 6000 < (R=4) < 8000 < (R=5)$

Line-of-Sight Angle

$(L=1) < -120 < (L=2) < -60 < (L=3) < -20 < (L=4) < 0$
$0 < (L=5) < 20 < (L=6) < 60 < (L=7) < 120 < (L=8)$

Aspect Angle

$(A=1) < -170 < (A=2) < -120 < (A=3) < -60 < (A=4) < 0$
$0 < (A=5) < 60 < (A=6) < 120 < (A=7) < 170) < (A=8)$

Numbering of TACSPACE Cells

$$\text{Cell Number} = [R + 5(L-1) + 40\,(A-1)]$$

Zones

Neutral	$60 < \lvert LOS \rvert < 120$	(L=8)
	$60 < \lvert ASP \rvert < 120$	(A=6)
Offensive	$\lvert LOS \rvert < 60$	
	$\lvert ASP \rvert < 60$	
Defensive	$\lvert LOS \rvert > 120$	
	$\lvert ASP \rvert > 120$	

A count of the number of times each TACSPACE cell is occupied is required for computing the nonparametric discriminant score. Consequently, a test of LOS, Aspect, and Range must be made during each sampling cycle, and an array of cell counters must be updated.

COMPUTATIONS DURING EACH SAMPLING CYCLE

Computations to be made during each 0.5 second are listed in Table B-3. Some processing is required for each parameter and several tests of relationships are also necessary. Additionally, if the real-time display option is selected (i.e., proves to be feasible) additional transformations of some parameters and a weighted sum of these transformations is required during each sampling cycle (see total engagement discriminant score for further detail). Of course, feasibility will largely depend on the availability of sufficient time during each cycle for this processing.

TABLE B-3. COMPUTATIONS TO BE MADE DURING EACH SAMPLING CYCLE

EACH PARAMETER

- Minimum Value
- Maximum Value
- Accumulative Sum of Samples
- Accumulative Sum of Samples Squared

ALSO

- Count of Samples Where LOS El < 0
- Count of Samples Where $|(LOS + ASP)| > 180$
- Count of Occupation of TACSPACE Zone (N, O, D)

REAL-TIME DISPLAY OPTION

- Weighted Sum of Specific Transformed Parameters to Yield Discriminant Score at Each Sample

Note that end-of-engagement computations will be made for each TACSPACE Zone as well as for the total engagment. Therefore the intermediate calculations shown in Table B-3 must be accumulated for the zone occupied at the time of the sampling cycle and for the total engagement. Consequently four areas of storage are required. Note also that at this time available data only support computation of scores for the neutral zone and total engagment, but provision should be made for future computation of offensive and defensive zone scores.

END-OF-ENGAGEMENT COMPUTATIONS

At the end of the engagment, the transformations defined in Table B-4 must be computed. Discriminant scores for the neutral zone and the total engagement are calculated in accordance with the tables in Appendix C. As shown, there are two methods for computing the discriminant score (see Table B-5). It should be apparent from the form of the data which method of computation should be used.

DISPLAYS

There are two types of displays: the Summary Display (including the discriminant score at the bottom) as shown in Figure 10, Section V, and the Real-Time Display as shown in Figure 9, Section V.

The Summary Display Format includes data corresponding to TACSPACE zones: neutral, offensive, defensive, and total engagement. These displays are only generated at the end of the engagement, and are produced on any available output device (e.g., line printer). These displays include normative data for comparison to trainee performance. The trainee's score can be compared to average novice and expert performance. The current normative data are presented in Appendix D. Ideally, provision will be made to update these numbers after each scored simulator engagement. The relative advantage score is based on computations of LOS + ASP; the techniques score is a discriminant score based on the parameters of Table B-1; and the tactic score is a discriminant score based on TACSPACE cell counts.

The Real-Time Display is a thermometer-type of a discriminant score which is progressively generated throughout the engagement. One index provides the discriminant score at that instant, and the other index provides the breakpoint between novice and expert groups. This display, if computation proves feasible, will be generated in the upper-left corner of the ADAGE display screen for viewing by the instructor at the Instructor's Console. Optionally, if the instructor is to occupy one of the cockpits during the engagement, the score (no breakpoint information) could be displayed on an unused cockpit instrument (e.g., tachometer). Means must be provided so that the IP can select between relative advantage, technique score, or tactics score as the information indicated on the thermometer-type display.

Note that information is to be displayed for each of the participants in the ACM engagement, and there are two Real-Time Displays and two Summary Displays.

TABLE B-4. TRANSFORMATIONS

$$\text{AVG} = \frac{\sum_{n=1}^{N} X_n}{N}$$

$$\text{RMS} = \left[\frac{\sum_{n=1}^{N} (X_n)^2}{N}\right]^{1/2}$$

$$\text{S.D.} = \left[\frac{\sum_{n=1}^{N} (X_n)^2 - \frac{\left(\sum_{n=1}^{N} X_n\right)^2}{N}}{N-1}\right]^{1/2}$$

Range = (Maximum Value) - (Minimum Value)

TABLE B-5. DISCRIMINANT SCORE COMPUTATIONS

PARAMETRIC

$$Y = b_1X_1 + b_2X_2 + \ldots\ldots + b_mX_m$$

where Xm = the m^{th} performance score

NONPARAMETRIC

$$Y = \frac{1}{M} \sum_{m=1}^{M} \frac{Xm - MIN\ (Xm)}{Range_m}$$

where Xm = occupancy count of m^{th} TACSPACE cell

APPENDIX C

DATA FOR DISCRIMINANT MODELS

TABLE C-1. MULTIVARIATE DISCRIMINANT SEGMENT SUMMARY MODEL FOR WHOLE ENGAGEMENT

Measure	Coefficient	Communality
1	.001	.159
2	- .013	.395
6	- .549	.154
8	- .571	.281
10	- .001	.169
11	.010	.647
12	- .002	.014
15	.006	.033
16	-1.291	.390
23	2.436	.473
24	-1.875	.715
25	.029	.025
27	- .010	.044

(BP = 9.3935)

R^2	.636
Chi^2	199.700
ndf1	13.000
ndf2	192.000
F-ratio	25.800

TABLE C-2. UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT

Measure	Pooled Minimum	Pooled Range	t
1	0.000000E+00	0.662651E-01	1.192460
2	0.000000E+00	0.272109E-01	2.305340
3	0.000000E+00	0.854430E-01	2.049840
4	0.000000E+00	0.328638E-01	1.515000
5	0.000000E+00	0.1732280000	1.926380
7	0.000000E+00	0.100503E-01	1.450320
9	0.000000E+00	0.691244E-02	1.732510
10	0.000000E+00	0.388350E-01	1.326970
15	0.000000E+00	-0.540541E-02	1.000000
16	0.000000E+00	-0.196629E-01	1.134310
17	0.000000E+00	-0.370370E-01	1.191370
22	0.000000E+00	0.186916E-01	1.024820
23	0.000000E+00	0.231214E-01	0.934007
26	0.000000E+00	0.222222E-01	2.647820
27	0.000000E+00	0.325087E-01	3.218350
28	0.000000E+00	0.373832E-01	3.900644
29	0.000000E+00	0.289855E-01	2.996200
30	0.000000E+00	0.833333E-01	2.561460
31	0.000000E+00	0.612245E-01	2.611930
32	0.000000E+00	0.1168830000	4.949560
33	0.000000E+00	0.1227440000	5.375510
34	0.000000E+00	0.2698410000	2.797950
35	0.000000E+00	0.925926E-01	4.153550
36	0.000000E+00	0.1285710000	1.640080
37	0.000000E+00	0.1093750000	4.967260
38	0.000000E+00	0.949367E-01	3.875140
39	0.000000E+00	0.1568630000	2.999280
40	0.000000E+00	0.1851850000	2.567570
42	0.000000E+00	0.510204E-01	2.181170
44	0.000000E+00	0.373134E-02	1.000000
45	0.000000E+00	0.787412E-01	1.809680
47	0.000000E+00	0.230415E-01	1.230790
48	0.000000E+00	0.126263E-01	1.362320
49	0.000000E+00	0.261194E-01	1.173550
50	0.000000E+00	0.106667E-01	1.000000
53	0.000000E+00	-0.270270E-02	1.000000
54	0.000000E+00	-0.699301E-02	0.979979
55	0.000000E+00	-0.209790E-01	1.000000
56	0.000000E+00	-0.173410E-01	0.980201
59	0.000000E+00	-0.188088E-01	0.863446
61	0.000000E+00	0.108225E-01	1.115250
62	0.000000E+00	0.235294E-01	2.261550
63	0.000000E+00	0.203046E-01	1.791810

TABLE C-2. UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
65	0.000000E+00	0.228571E-01	1.293170
66	0.000000E+00	0.272832E-01	3.614670
67	0.000000E+00	0.297297E-01	3.134380
68	0.000000E+00	0.648148E-01	2.834160
69	0.000000E+00	0.486726E-01	1.872840
70	0.000000E+00	0.659898E-01	2.322070
71	0.000000E+00	0.1070500000	4.038680
72	0.000000E+00	0.976864E-01	5.286390
73	0.000000E+00	0.2040820000	3.593440
74	0.000000E+00	0.609137E-01	4.116740
75	0.000000E+00	0.942249E-01	3.457710
76	0.000000E+00	0.1829650000	1.773990
77	0.000000E+00	0.1867090000	3.755990
78	0.000000E+00	0.1992570000	3.245790
79	0.000000E+00	0.5490200000	1.242580
80	0.000000E+00	0.688775E-01	2.035980
82	0.000000E+00	0.800000E-02	1.295260
86	0.000000E+00	-0.271318E-01	1.171810
94	0.000000E+00	-0.421053E-02	1.000000
95	0.000000E+00	-0.133333E-01	1.000000
96	0.000000E+00	-0.923077E-02	1.894050
98	0.000000E+00	0.2000000000	0.952906
99	0.000000E+00	-0.980392E-02	1.399210
100	0.000000E+00	0.170316E-01	0.833277
101	0.000000E+00	-0.243902E-01	1.737460
103	0.000000E+00	0.2500000000	0.961926
104	0.000000E+00	-0.230415E-02	1.420290
110	0.000000E+00	-0.153846E-01	1.157400
111	0.000000E+00	-0.278552E-01	1.013720
113	0.000000E+00	0.342857E-01	0.388799
114	0.000000E+00	-0.371179E-01	0.946205
117	0.000000E+00	0.288809E-01	1.835570
118	0.000000E+00	0.204678E-01	2.423290
119	0.000000E+00	0.351351E-01	1.512430
120	0.000000E+00	0.692308E-01	1.168450
121	0.000000E+00	-0.539084E-02	1.897960
123	0.000000E+00	0.135136E-01	1.523570
124	0.000000E+00	0.135135E-01	1.918210
126	0.000000E+00	-0.108303E-01	2.090000
128	0.000000E+00	0.973236E-02	1.000000
129	0.000000E+00	-0.520833E-02	1.000000
130	0.000000E+00	-0.295699E-01	1.421050
132	0.000000E+00	-0.584795E-01	1.338130

TABLE C-2. UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
134	0.000000E+00	-0.294840E-01	1.380090
136	0.000000E+00	-0.662651E-01	1.697400
137	0.000000E+00	-0.238663E-01	1.797220
138	0.000000E+00	-0.1000000000	1.954460
139	0.000000E+00	-0.328638E-01	2.224590
140	0.000000E+00	-0.1732280000	2.061410
141	0.000000E+00	-0.144092E-01	2.574020
142	0.000000E+00	-0.481651E-01	1.473960
143	0.000000E+00	-0.628931E-01	2.445190
144	0.000000E+00	-0.1023620000	1.409430
145	0.000000E+00	-0.831461E-01	1.656470
146	0.000000E+00	-0.409836E-01	2.557190
147	0.000000E+00	-0.1562500000	1.516250
148	0.000000E+00	-0.397112E-01	1.636910
149	0.000000E+00	-0.314961E-01	2.563050
150	0.000000E+00	-0.299539E-01	1.465420
151	0.000000E+00	-0.176471E-01	2.406820
152	0.000000E+00	-0.462963E-01	1.003530
153	0.000000E+00	-0.308483E-01	1.732880
154	0.000000E+00	-0.266667E-01	2.119370
156	0.000000E+00	-0.123457E-01	3.063530
159	0.000000E+00	-0.329670E-01	1.812480
160	0.000000E+00	0.242718E-01	0.987333
162	0.000000E+00	0.229885E-01	1.584690
166	0.000000E+00	-0.262467E-01	2.785560
170	0.000000E+00	-0.410557E-01	1.588110
171	0.000000E+00	-0.909091E-01	2.557680
172	0.000000E+00	-0.1677220000	2.483330
173	0.000000E+00	-0.1020410000	2.078050
174	0.000000E+00	-0.404762E-01	1.273370
175	0.000000E+00	-0.685358E-01	1.930070
176	0.000000E+00	-0.1482650000	3.223770
177	0.000000E+00	-0.1588540000	4.067170
178	0.000000E+00	-0.1107590000	3.994700
179	0.000000E+00	-0.1012660000	2.886000
180	0.000000E+00	-0.817610E-01	2.508030
181	0.000000E+00	-0.1924290000	3.113800
182	0.000000E+00	-0.1458330000	3.338890
183	0.000000E+00	-0.960000E-01	3.598130
184	0.000000E+00	-0.1026600000	3.469570
185	0.000000E+00	-0.2350600000	2.192770
186	0.000000E+00	-0.2357720000	3.846880
187	0.000000E+00	-0.2514620000	3.153610
188	0.000000E+00	-0.1159870000	3.416800

TABLE C-2. UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
189	0.000000E+00	-0.432857E-01	4.000370
190	0.000000E+00	-0.907080E-01	1.930440
191	0.000000E+00	-0.696379E-01	3.512450
192	0.000000E+00	-0.607287E-01	6.534390
193	0.000000E+00	-0.740741E-01	6.012550
194	0.000000E+00	-0.760369E-01	5.037820
195	0.000000E+00	-0.505319E-01	2.934480
199	0.000000E+00	0.434783E-01	1.843870
200	0.000000E+00	0.370370E-01	2.044970
201	0.000000E+00	0.231959E-01	0.916142
202	0.000000E+00	0.306122E-01	2.918280
203	0.000000E+00	0.327869E-01	1.446650
204	0.000000E+00	0.573770E-01	2.330670
206	0.000000E+00	-0.486111E-01	1.500170
210	0.000000E+00	0.317919E-01	0.835193
211	0.000000E+00	-0.966057E-01	4.558730
212	0.000000E+00	-0.901639E-01	4.703440
213	0.000000E+00	-0.1938780000	2.398920
214	0.000000E+00	-0.567823E-01	1.550460
215	0.000000E+00	-0.444444E-01	1.964600
216	0.000000E+00	-0.1263160000	4.791010
217	0.000000E+00	-0.886076E-01	5.919510
218	0.000000E+00	-0.1263540000	5.498320
219	0.000000E+00	-0.370370E-01	4.433560
220	0.000000E+00	-0.648148E-01	3.726890
221	0.000000E+00	-0.1376520000	4.006640
222	0.000000E+00	-0.1562500000	4.358340
223	0.000000E+00	-0.1525420000	3.878210
224	0.000000E+00	-0.1638842000	2.993600
225	0.000000E+00	-0.882353E-01	3.720680
226	0.000000E+00	-0.1463410000	5.402070
227	0.000000E+00	-0.3089430000	4.515350
228	0.000000E+00	-0.1971500000	3.872550
229	0.000000E+00	-0.1500000000	2.902900
230	0.000000E+00	-0.1445090000	3.568100
231	0.000000E+00	-0.1365830000	2.496220
235	0.000000E+00	0.2013420000	1.982690
236	0.000000E+00	0.668524E-01	1.630550
237	0.000000E+00	0.625000E-01	5.240630
238	0.000000E+00	0.724638E-01	6.476230
239	0.000000E+00	0.668693E-01	6.625570
240	0.000000E+00	0.851064E-01	6.004000
242	0.000000E+00	0.1562500000	1.871870
243	0.000000E+00	0.397112E-01	2.573760

TABLE C-2. UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
244	0.000000E+00	0.393701E-01	2.098250
245	0.000000E+00	0.370370E-01	3.226240
246	0.000000E+00	-0.439189E-01	2.002400
249	0.000000E+00	0.153061E-01	1.278990
250	0.000000E+00	0.287611E-01	2.120450
251	0.000000E+00	-0.280374E-01	3.777210
252	0.000000E+00	-0.470588E-01	3.011510
253	0.000000E+00	-0.136054E-01	2.679620
254	0.000000E+00	-0.180723E-01	1.081240
255	0.000000E+00	-0.609137E-01	0.864099
256	0.000000E+00	-0.590551E-01	4.697820
257	0.000000E+00	-0.555556E-01	3.995210
258	0.000000E+00	-0.740741E-01	3.583430
259	0.000000E+00	-0.856269E-01	3.086350
260	0.000000E+00	-0.795107E-01	2.519810
261	0.000000E+00	-0.469799E-01	2.152660
262	0.000000E+00	-0.469799E-01	2.195070
263	0.000000E+00	-0.641711E-01	3.521490
267	0.000000E+00	-0.1230770000	0.909937
268	0.000000E+00	-0.925926E-01	1.587930
270	0.000000E+00	0.1127170000	2.340800
271	0.000000E+00	0.2031250000	0.913597
272	0.000000E+00	0.1812870000	2.655800
273	0.000000E+00	0.4971750000	4.325500
274	0.000000E+00	0.2000000000	3.635730
275	0.000000E+00	0.3188410000	5.237690
276	0.000000E+00	0.1013510000	2.573460
277	0.000000E+00	0.2397660000	4.229800
278	0.000000E+00	0.1653540000	5.481220
279	0.000000E+00	0.1818180000	4.021820
280	0.000000E+00	0.774336E-01	3.906600
282	0.000000E+00	0.251572E-01	1.039920
283	0.000000E+00	0.628931E-01	2.251730
284	0.000000E+00	0.178571E-01	1.565400
285	0.000000E+00	0.329114E-01	1.138990
287	0.000000E+00	-0.250000E-02	1.415320
288	0.000000E+00	-0.1500000000	0.824839
289	0.000000E+00	0.101266E-01	1.723120
290	0.000000E+00	0.505051E-01	1.955280
292	0.000000E+00	-0.952381E-01	1.414920
293	0.000000E+00	-0.203046E-01	1.442380
294	0.000000E+00	0.643087E-02	1.251690
296	0.000000E+00	-0.173410E-01	2.221770
297	0.000000E+00	-0.246914E-01	1.788460

TABLE C-2. UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
298	0.000000E+00	-0.194175E-01	1.192740
299	0.000000E+00	-0.806452E-02	1.565653
300	0.000000E+00	0.156740E-01	1.416410
306	0.000000E+00	0.140602E-01	0.961804
307	0.000000E+00	0.467290E-01	1.946150
308	0.000000E+00	0.294118E-01	2.016890
309	0.000000E+00	0.496183E-01	0.829617
310	0.000000E+00	0.1086960000	1.268270
311	0.000000E+00	0.358127E-01	3.482630
312	0.000000E+00	0.795455E-01	2.874940
313	0.000000E+00	0.1266150000	3.529930
314	0.000000E+00	0.1428570000	3.423670
315	0.000000E+00	0.1111110000	3.976850
316	0.000000E+00	0.993976E-01	2.500960
317	0.000000E+00	0.1176470000	3.972590
318	0.000000E+00	0.1417910000	3.129040
319	0.000000E+00	0.793651E-01	2.727830
320	0.000000E+00	0.2350600000	2.791920

	Mean	Std Dev
Grp1	4.66188	4.67598
Grp2	-5.12831	4.35224
Pooled	-0.23322	6.66188

Break Point = -1.0450

F1: 275.996
F2: 32153.000

SSB: 5607.10
SSW: 4733.59
SST: 10340.70

Wilkes-Lambda: 0.457764
S-Omega: 0.539212
R-Squared: 0.542236

Predicted Min. Percent Error = 15.81

TABLE C-3. MULTIVARIATE DISCRIMINANT SEGMENT SUMMARY MODEL FOR NEUTRAL SEGMENT (WITH REDUCED ACMRI/TACTS MEASURE SET)

Measure	Coefficient	Communality
1	.009	.081
2	.001	.076
3	- .010	.080
4	.388	.011
5	- .005	.001
8	.005	.002
9	.018	.007
25	.095	.009
27	-2.089	.989
R^2	.915	
Chi^2	1226.770	
ndf1	13.000	
ndf2	492.000	
F-Ratio	407.7	

Simulated Percent Misses 16.25

TABLE C-4. UNIT SCALED TACSPACE DISCRIMINANT MODEL
FOR NEUTRAL SEGMENT
GROUP 1 TERMINATED DEFENSIVE GROUP 2 TERMINATED OFFENSIVE

Measure	Pooled Minimum	Pooled Range	t
8	0.000000E+00	-0.2962960000	1.0000000000
9	0.000000E+00	-0.1111110000	1.0000000000
31	0.000000E+00	-0.8000000000	2.3860200000
32	0.000000E+00	-1.0000000000	3.5964700000
33	0.000000E+00	-0.5000000000	2.7625400000
34	0.000000E+00	-0.1458330000	1.7251900000
35	0.000000E+00	-0.5000000000	1.2138100000
47	0.000000E+00	-0.2857140000	0.8853400000
48	0.000000E+00	-0.1111110000	0.3813100000
49	0.000000E+00	0.000000E+00	0.000000E+00
50	0.000000E+00	-1.0000000000	1.0000000000
71	0.000000E+00	-0.6842110000	4.2756000000
72	0.000000E+00	-1.0000000000	4.5592300000
73	0.000000E+00	-0.5714290000	2.6475600000
74	0.000000E+00	-0.2250000000	0.7822400000
75	0.000000E+00	-0.1875000000	1.0000000000
82	0.000000E+00	-0.156250E-01	1.0000000000
91	0.000000E+00	0.1056230000	1.3727900000
92	0.000000E+00	0.1142860000	0.7008300000
93	0.000000E+00	-0.625000E-01	1.0000000000
94	0.000000E+00	0.000000E+00	0.000000E+00
95	0.000000E+00	0.8333330000	1.0000000000
96	0.000000E+00	0.5000000000	1.0000000000
97	0.000000E+00	0.000000E+00	0.000000E+00
98	0.000000E+00	0.4074070000	1.0000000000
99	0.000000E+00	0.1132080000	1.4169700000
101	0.000000E+00	0.5000000000	1.6747500000
102	0.000000E+00	0.000000E+00	0.000000E+00
103	0.000000E+00	0.3571430000	1.2533300000
104	0.000000E+00	1.0000000000	1.0364800000
105	0.000000E+00	1.0000000000	1.0000000000
106	0.000000E+00	1.0000000000	2.1143200000
107	0.000000E+00	0.6363640000	1.1925900000
108	0.000000E+00	0.5714290000	1.4621200000
109	0.000000E+00	0.1951220000	1.0000000000
110	0.000000E+00	0.3333330000	1.4167300000
111	0.000000E+00	0.1052630000	0.5770000000
112	0.000000E+00	0.1538460000	0.6080800000
113	0.000000E+00	0.2500000000	0.8500800000
114	0.000000E+00	0.2195120000	1.0000000000
115	0.000000E+00	0.6363640000	1.6625800000
117	0.000000E+00	-0.781250E-01	0.462845E-01
118	0.000000E+00	0.1904760000	1.0000000000
119	0.000000E+00	0.1600000000	1.0000000000

TABLE C-4. UNIT SCALED TACSPACE DISCRIMINANT MODEL
FOR NEUTRAL SEGMENT (Continued)
GROUP 1 TERMINATED DEFENSIVE GROUP 2 TERMINATED OFFENSIVE

Measure	Pooled Minimum	Pooled Range	t
127	0.000000E+00	-0.169492E-01	0.574409E-01
151	0.000000E+00	0.2000000000	2.0988100000
152	0.000000E+00	0.8571430000	3.1160000000
153	0.000000E+00	1.0000000000	2.7207600000
154	0.000000E+00	0.6000000000	3.5540000000
155	0.000000E+00	0.7142860000	3.4343400000
166	0.000000E+00	0.1052630000	1.0000000000
167	0.000000E+00	0.2500000000	0.9384840000
168	0.000000E+00	-0.1219510000	1.0000000000
169	0.000000E+00	-0.1600000000	1.0000000000
170	0.000000E+00	-0.2000000000	0.3179990000
191	0.000000E+00	0.1578950000	1.8822400000
192	0.000000E+00	1.0000000000	5.7481300000
193	0.000000E+00	1.0000000000	5.9166000000
194	0.000000E+00	1.0000000000	5.4109700000
195	0.000000E+00	1.0000000000	5.9662100000
201	0.000000E+00	-0.1428570000	1.1151800000
202	0.000000E+00	-0.8571430000	1.5666600000
203	0.000000E+00	-1.0000000000	1.5640100000
204	0.000000E+00	-0.6000000000	2.0986200000
205	0.000000E+00	-0.5555560000	1.4384500000
206	0.000000E+00	0.4000000000	1.7214400000
207	0.000000E+00	-0.769231E-01	0.3186420000
208	0.000000E+00	0.2105260000	0.3987230000
209	0.000000E+00	-0.1951220000	1.0000000000
210	0.000000E+00	-0.6111110000	1.2574600000
211	0.000000E+00	0.5789470000	4.0343700000
212	0.000000E+00	1.0000000000	4.2231000000
213	0.000000E+00	0.1250000000	1.4560000000
214	0.000000E+00	0.750000E-01	0.1280370000
215	0.000000E+00	0.000000E+00	0.000000E+00
216	0.000000E+00	1.0000000000	5.8410200000
217	0.000000E+00	1.0000000000	5.8369600000
218	0.000000E+00	0.5714290000	4.0051300000
219	0.000000E+00	0.2708330000	1.8372700000
220	0.000000E+00	0.5000000000	1.7378500000
221	0.000000E+00	1.0000000000	5.5753100000
222	0.000000E+00	1.0000000000	4.8800700000
223	0.000000E+00	0.6521740000	3.9919100000
224	0.000000E+00	0.2881360000	2.2592000000
225	0.000000E+00	0.3750000000	1.9596100000
226	0.000000E+00	1.0000000000	4.4994000000
227	0.000000E+00	1.0000000000	5.3406700000
228	0.000000E+00	0.5000000000	4.0873900000

TABLE C-4. UNIT SCALED TACSPACE DISCRIMINANT MODEL
FOR NEUTRAL SEGMENT (Continued)
GROUP 1 TERMINATED DEFENSIVE GROUP 2 TERMINATED OFFENSIVE

Measure	Pooled Minimum	Pooled Range	t
229	0.000000E+00	1.0000000000	2.0815400000
230	0.000000E+00	0.7368420000	1.8814000000
231	0.000000E+00	0.4545450000	0.5751260000
232	0.000000E+00	-0.6250000000	0.8496060000
233	0.000000E+00	0.4736840000	0.526746E-01
234	0.000000E+00	-0.7222220000	0.6590380000
235	0.000000E+00	-0.5454550000	1.0138200000
236	0.000000E+00	-0.4210530000	2.2726500000
237	0.000000E+00	-1.0000000000	6.3317300000
238	0.000000E+00	-1.0000000000	6.3152400000
239	0.000000E+00	-1.0000000000	5.6427700000
240	0.000000E+00	-1.0000000000	6.4517700000
246	0.000000E+00	-1.0000000000	1.1922000000
247	0.000000E+00	-0.5909090000	1.1001000000
248	0.000000E+00	-0.5714290000	1.3618900000
249	0.000000E+00	-0.2195120000	1.0000000000
250	0.000000E+00	-0.2777780000	1.4132400000
271	0.000000E+00	-1.0000000000	6.7717600000
272	0.000000E+00	-1.0000000000	5.9074300000
273	0.000000E+00	-0.5277780000	4.3266000000
274	0.000000E+00	-1.0000000000	2.2978400000
275	0.000000E+00	-0.7368420000	1.6528000000
311	0.000000E+00	-1.0000000000	4.5341700000
312	0.000000E+00	-1.0000000000	4.2763400000
313	0.000000E+00	-0.4090910000	3.5539200000
314	0.000000E+00	-0.3846150000	2.0246800000
315	0.000000E+00	-0.3750000000	1.3867900000

TABLE C-4. UNIT SCALED DISCRIMINANT TACSPACE MODEL FOR NEUTRAL SEGMENT (Continued)
GROUP 1 TERM, DEFENSIVE GROUP 2 TERM, OFFENSIVE

Statistics on new variable:

	Mean	Std Dev
Grp1	1.03775	0.48227
Grp2	-1.09743	0.44078
Pooled	-0.02984	1.16405

Break Point = -0.0709

F1: 2707.40
F2: 683616.

SSB: 576.712
SSW: 107.572
SST: 684.284

Wilkes-Lambda: 0.157203
S-Omega: 0.842223
R-Squared: 0.842797

Predicted Min. Percent Error = 1.98

TABLE C-5. UNIT-SCALED SEGMENT SUMMARY MODEL FOR OFFENSIVE SEGMENT GROUP 1 LOST ADVANTAGE GROUP 2 FIRED

Measure	Pooled Minimum	Pooled Range	t
3	153.9490000000	578.126000	0.829626
5	0.1246130000	- 72.111800	1.134830
6	0.289449E-02	0.277239	1.228660
8	0.6108200000	- 66.762400	1.060230
11	1.0979200000	- 88.582000	1.278420
12	0.1838210000	30.022300	1.541350
13	-298.4940000000	-1003.250000	0.984364
14	20.5588000000	- 707.104000	2.270160
15	15.5030000000	- 690.250000	1.774900
17	0.1650960000	- 76.044100	1.069080
23	0.5399630000	- 77.899700	0.891716
24	0.7207590000	- 69.519000	0.838816
28	- 37.1925000000	- 68.427500	1.267460
30	0.5666530000	47.060700	0.889184

Statistics on new variable:

	Mean	Std Dev
Grp1	-1.99588	1.34911
Grp2	-2.47057	1.49429
Pooled	-2.27971	1.45296

Break Point = 0.3970

F1: 5.10985
F2: 748.09200

SSB: 10.5092
SSW: 396.9340
SST: 407.4430

Wilkes-Lambda: 0.974207
S-Omega: 0.206411E-01
R-Squared: 0.257930E-01

Predicted Min. Percent Error = 39.18

TABLE C-6. UNIT SCALED TACSPACE DISCRIMINANT MODEL
FOR OFFENSIVE SEGMENT
GROUP 1 LOST ADVANTAGE GROUP 2 FIRED

Measure	Pooled Minimum	Pooled Range	t
171	0.000000E+00	1.000000	1.886750
172	0.000000E+00	0.125000	1.000000
175	0.000000E+00	-0.875000	1.000000
177	0.000000E+00	-1.000000	0.961937
178	0.000000E+00	-1.000000	1.335630
180	0.000000E+00	-1.000000	1.117510
182	0.000000E+00	1.000000	1.696880
185	0.000000E+00	-1.000000	1.225960
188	0.000000E+00	1.000000	0.934416
189	0.000000E+00	-1.000000	1.627500
190	0.000000E+00	1.000000	1.000000

Statistics on new variable:

	Mean	Std Dev
Grp1	0.56263	0.75822
Grp2	-0.08227	0.85078
Pooled	0.17326	0.87134

Break Point = 1.0000

F1: 33.7700
F2: 4309.0400

SSB: 19.3998
SSW: 60.3190
SST: 79.7188

Wilkes-Lambda: 0.756648
S-Omega: 0.234457
R-Squared: 0.243352

Predicted Min. Percent Error = 17.92

TABLE ·7. UNIT SCALED SEGMENT SUMMARY MODEL
FOR DEFENSIVE SEGMENT
GROUP 1 ESCAPED GROUP 2 WAS FIRED AT

Measure	Pooled Minimum	Pooled Range	t
12	126.617000	52.5588	0.959819
13	-298.494000	-1003.2500	0.998035
14	23.055000	- 756.6720	2.051270
15	15.503000	- 690.2500	1.787550
16	1.000000	3.0000	1.409040
18	1.000000	3.0000	1.396640
20	4.615220	-1352.1500	0.995522
21	0.206214	- 430.6020	0.826603
22	- 71.965900	- 148.8110	0.976289
23	0.620147	- 85.1120	1.141590
28	- 51.981600	218.7470	0.849673
29	0.732483	- 251.6340	2.006210

Statistics on new variable:

	Mean	Std Dev
Grp1	1.23982	0.50624
Grp2	0.90457	0.78061
Pooled	1.03936	0.70178

Break Point = 1.5475

F1: 11.2650
F2: 1747.1300

SSB: 5.24198
SSW: 89.80950
SST: 95.05140

Wilkes-Lambda: 0.944851
S-Omega: 0.500085E-01
R-Squared: 0.551489E-01

Predicted Min. Percent Error > 50.0

TABLE C-8. UNIT SCALED TACSPACE DISCRIMINANT MODEL FOR DEFENSIVE SEGMENT GROUP 1 ESCAPED GROUP 2 WAS FIRED AT

Measure	Pooled Minimum	Pooled Range	t
76	0.000000E+00	1.000000	2.512900
79	0.000000E+00	-0.875000	0.926216
80	0.000000E+00	-0.875000	1.239090
279	0.000000E+00	-1.000000	1.605180
317	0.000000E+00	1.000000	1.863580
318	0.000000E+00	-1.000000	1.225570
320	0.000000E+00	-1.000000	1.377280

Statistics on new variable:

	Mean	Std Dev
Grp1	0.36811	0.60342
Grp2	-0.23634	0.63795
Pooled	0.01299	0.68857

Break Point = 0.6250

F1: 65.9900
F2: 6375.6300

SSB: 17.0476
SSW: 20.4086
SST: 37.4562

Wilkes-Lambda: 0.544865
S-Omega: 0.445167
R-Squared: 0.455135

Predicted Min. Percent Error = 26.25

TABLE C-9. DISSIMILAR AIRCRAFT, UNIT-SCALED SUMMARY SEGMENT MODEL FOR REDUCED ACMI/TACTS WHOLE ENGAGMENT

Measure	Pooled Minimum	Pooled Range	t
1	256.0700000000	-409.744000	3.35441
2	369.7940000000	-450.905000	5.55015
3	262.5890000000	-417.787000	3.59137
6	0.940246E-02	0.195849	4.65563
7	- 5.6554900000	5.655490	1.97343
9	1.0310700000	- 4.632270	3.04957
10	-124.5940000000	-242.841000	1.19951
11	131.3440000000	-228.627000	1.79246
12	19.1357000000	-152.309000	9.00980
25	0.000000E+00	0.883333	4.28832
26	0.000000E+00	- 1.000000	7.95391
29	17.4137000000	935.399000	2.34531
30	3.3577100000	82.197200	4.06604

	Mean	Std Dev
Grp1	-1.29783	1.07531
Grp2	-4.02234	0.85623
Pooled	-2.61143	1.67997

F1: 110.976
F2: 2864.000

Break Point = -3.3424

SSB: 103.7890
SSW: 51.4378
SST: 155.2260

Wilkes-Lambda: 0.331373
S-Omega: 0.658634
R-Squared: 0.668627

Predicted Min. Precent Error = 7.14

TABLE C-10. DISSIMILAR AIRCRAFT, UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT

Measure	Pooled Minimum	Pooled Range	t
1	0.000000E+00	-0.145455E-01	1.362060
2	0.000000E+00	-0.176991E-01	0.861799
3	0.000000E+00	-0.221239E-02	1.430230
4	0.000000E+00	-0.199115E-01	1.512840
5	0.000000E+00	-0.1552630000	3.661780
7	0.000000E+00	0.248756E-02	1.795020
11	0.000000E+00	-0.110497E-01	0.984895
14	0.000000E+00	0.442478E-02	1.726860
15	0.000000E+00	0.116279E-01	1.563640
18	0.000000E+00	0.118694E-01	1.303780
21	0.000000E+00	0.101010E-01	1.377550
22	0.000000E+00	-0.141509E-01	1.579220
23	0.000000E+00	-0.110497E-01	1.840810
24	0.000000E+00	-0.524194E-01	1.292090
25	0.000000E+00	-0.297619E-01	2.128630
28	0.000000E+00	-0.298507E-01	1.825160
29	0.000000E+00	-0.221811E-01	3.316770
30	0.000000E+00	-0.578778E-01	4.076410
31	0.000000E+00	-0.436364E-01	1.403670
32	0.000000E+00	-0.545455E-01	1.488550
33	0.000000E+00	-0.301370E-01	1.857840
34	0.000000E+00	0.468384E-02	1.000000
35	0.000000E+00	-0.2611940000	2.970870
36	0.000000E+00	-0.377907E-01	1.131160
37	0.000000E+00	-0.763636E-01	1.773720
39	0.000000E+00	-0.316456E-01	1.835830
40	0.000000E+00	-0.1740330000	5.451510
42	0.000000E+00	0.497512E-02	1.000000
45	0.000000E+00	-0.307329E-01	2.692280
48	0.000000E+00	0.467290E-02	1.000000
51	0.000000E+00	0.890208E-02	1.044950
52	0.000000E+00	0.234192E-02	1.000000
53	0.000000E+00	0.290698E-02	1.000000
55	0.000000E+00	0.290698E-02	1.000000
57	0.000000E+00	-0.118694E-01	1.549500
58	0.000000E+00	-0.118694E-01	1.707160
59	0.000000E+00	-0.145349E-01	1.958310
63	0.000000E+00	-0.943396E-02	2.895700
64	0.000000E+00	-0.936768E-02	2.943990
65	0.000000E+00	-0.712166E-01	2.017270
66	0.000000E+00	-0.298507E-01	1.932420
67	0.000000E+00	-0.149254E-01	1.219140

TABLE C-10. DISSIMILAR AIRCRAFT, UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
69	0.000000E+00	-0.376569E-01	1.904930
70	0.000000E+00	-0.763158E-01	3.249170
71	0.000000E+00	-0.547945E-01	2.251530
72	0.000000E+00	-0.526316E-01	2.215990
73	0.000000E+00	-0.491400E-01	1.338260
74	0.000000E+00	0.210773E-01	1.000000
75	0.000000E+00	-0.2698410000	1.859450
76	0.000000E+00	-0.872093E-01	1.555110
77	0.000000E+00	-0.690909E-01	1.251520
78	0.000000E+00	0.2833330000	0.934640
79	0.000000E+00	-0.278638E-01	1.000000
80	0.000000E+00	-0.1546960000	1.796790
82	0.000000E+00	-0.593472E-02	1.000000
84	0.000000E+00	-0.148368E-01	1.000000
85	0.000000E+00	-0.278638E-01	1.960050
87	0.000000E+00	0.316456E-02	1.000000
96	0.000000E+00	-0.483092E-02	1.000000
97	0.000000E+00	-0.700935E-02	1.762300
101	0.000000E+00	-0.221239E-02	1.000000
103	0.000000E+00	-0.143369E-01	1.000000
106	0.000000E+00	-0.148368E-01	2.005910
107	0.000000E+00	-0.373134E-01	0.974081
113	0.000000E+00	-0.234192E-02	1.000000
114	0.000000E+00	0.327103E-01	1.000000
115	0.000000E+00	0.267009E-01	1.480820
116	0.000000E+00	0.793651E-02	0.892433
117	0.000000E+00	-0.136986E-01	1.000000
118	0.000000E+00	0.1666670000	1.073950
119	0.000000E+00	0.666667E-01	0.961215
121	0.000000E+00	0.390208E-02	1.054590
126	0.000000E+00	-0.298736E-02	1.436230
127	0.000000E+00	0.890208E-02	1.000000
129	0.000000E+00	0.148368E-01	1.000000
130	0.000000E+00	0.247678E-01	1.969020
135	0.000000E+00	0.165485E-01	1.918430
136	0.000000E+00	0.436364E-01	1.157010
138	0.000000E+00	0.516351E-02	1.330330
139	0.000000E+00	0.943396E-02	1.741510
140	0.000000E+00	0.1552630000	3.868050
141	0.000000E+00	0.218182E-01	1.000000
142	0.000000E+00	0.232558E-01	1.347900
143	0.000000E+00	0.166667E-01	2.166330
144	0.000000E+00	0.333333E-01	2.211800

TABLE C-10. DISSIMILAR AIRCRAFT, UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
145	0.000000E+00	0.1548120000	3.727300
148	0.000000E+00	0.184211E-01	1.821710
149	0.000000E+00	0.171990E-01	2.199110
150	0.000000E+00	0.1088710000	3.268250
152	0.000000E+00	0.890208E-02	2.861320
153	0.000000E+00	0.144928E-01	3.459250
154	0.000000E+00	0.298507E-01	4.012070
155	0.000000E+00	0.604839E-01	3.316720
156	0.000000E+00	0.158720E-01	3.635970
157	0.000000E+00	0.122850E-01	3.676340
158	0.000000E+00	0.283019E-01	2.439130
159	0.000000E+00	0.201613E-01	1.149540
161	0.000000E+00	-0.890208E-02	3.346460
162	0.000000E+00	-0.148368E-01	3.506700
163	0.000000E+00	-0.283019E-01	2.697070
164	0.000000E+00	-0.201613E-01	1.890800
165	0.000000E+00	-0.425139E-01	0.928661
166	0.000000E+00	-0.793651E-02	1.267300
167	0.000000E+00	0.136986E-01	1.000000
168	0.000000E+00	0.1166670000	0.923342
169	0.000000E+00	0.666667E-01	1.070940
170	0.000000E+00	0.1333330000	1.289450
171	0.000000E+00	0.821918E-02	1.000000
172	0.000000E+00	0.654545E-01	1.594730
173	0.000000E+00	0.3333300000	1.041230
176	0.000000E+00	0.545455E-01	1.239410
177	0.000000E+00	0.1236360000	1.653630
178	0.000000E+00	0.333333E-01	1.609960
179	0.000000E+00	0.315456E-01	1.910290
180	0.000000E+00	0.2170420000	5.396040
181	0.000000E+00	0.1598840000	1.457170
182	0.000000E+00	0.1135270000	1.854460
183	0.000000E+00	0.557276E-01	2.069100
184	0.000000E+00	0.2333330000	1.234460
185	0.000000E+00	0.2364560000	5.346410
186	0.000000E+00	0.967742E-01	1.422590
187	0.000000E+00	0.522388E-01	0.991641
189	0.000000E+00	0.101010E-01	0.826201
190	0.000000E+00	0.949367E-01	3.377030
191	0.000000E+00	0.301370E-01	1.377610
192	0.000000E+00	0.303030E-01	1.463430
195	0.000000E+00	0.467290E-01	3.077560
202	0.000000E+00	-0.828729E-02	2.968820

TABLE C-10. DISSIMILAR AIRCRAFT, UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
203	0.000000E+00	-0.165094E-01	3.593380
204	0.000000E+00	-0.298507E-01	3.699120
205	0.000000E+00	-0.685484E-01	3.116920
208	0.000000E+00	0.468384E-01	1.000000
209	0.000000E+00	-0.327103E-01	1.000000
210	0.000000E+00	-0.257009E-01	1.483170
211	0.000000E+00	0.298507E-01	2.583640
212	0.000000E+00	0.712074E-01	1.959790
213	0.000000E+00	0.540541E-01	1.165020
215	0.000000E+00	0.873016E-01	1.851930
216	0.000000E+00	0.690990E-01	1.443600
217	0.000000E+00	0.552326E-01	1.131820
218	0.000000E+00	0.309598E-01	1.643460
219	0.000000E+00	-0.936768E-02	1.000000
220	0.000000E+00	0.2611940000	3.510130
223	0.000000E+00	0.588235E-01	0.925768
225	0.000000E+00	0.1194030000	3.383010
229	0.000000E+00	0.199115E-01	1.869030
234	0.000000E+00	0.1111110000	0.920598
236	0.000000E+00	-0.438356E-01	2.194160
237	0.000000E+00	-0.348259E-01	1.045500
239	0.000000E+00	-0.298507E-01	1.594810
240	0.000000E+00	-0.476190E-01	2.979440
241	0.000000E+00	-0.789474E-01	1.763550
242	0.000000E+00	-0.203488E-01	1.996620
243	0.000000E+00	-0.184211E-01	1.900640
244	0.000000E+00	-0.171990E-01	2.707050
245	0.000000E+00	-0.1088710000	3.829900
246	0.000000E+00	0.148368E-01	1.646118
248	0.000000E+00	0.296736E-02	1.000000
251	0.000000E+00	0.298507E-01	1.424150
252	0.000000E+00	0.149254E-01	2.294820
253	0.000000E+00	0.118694E-01	2.125970
254	0.000000E+00	0.358423E-01	1.181680
255	0.000000E+00	0.605263E-01	2.223940
256	0.000000E+00	-0.238095E-01	1.150700
258	0.000000E+00	0.298507E-01	2.260850
259	0.000000E+00	0.377358E-01	3.309420
260	0.000000E+00	0.660377E-01	5.041140
261	0.000000E+00	0.110619E-01	0.871105
262	0.000000E+00	0.158730E-01	0.938214
267	0.000000E+00	0.597015E-01	0.983142
269	0.000000E+00	-0.277778E-01	1.184920

TABLE C-10. DISSIMILAR AIRCRAFT, UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

Measure	Pooled Minimum	Pooled Range	t
274	0.000000E+00	-0.187354E-01	1.120110
275	0.000000E+00	-0.1615040000	2.583730
276	0.000000E+00	-0.967742E-01	1.874110
277	0.000000E+00	-0.581818E-01	2.048410
278	0.000000E+00	-0.464396E-01	1.220330
279	0.000000E+00	-0.757576E-02	1.532650
280	0.000000E+00	-0.1061090000	3.916170
281	0.000000E+00	-0.218182E-01	1.240110
285	0.000000E+00	-0.1507940000	3.296420
287	0.000000E+00	0.442478E-02	1.000000
288	0.000000E+00	0.358423E-02	1.000000
289	0.000000E+00	0.358423E-02	1.000000
293	0.000000E+00	0.234192E-02	1.000000
294	0.000000E+00	0.716846E-02	1.327210
295	0.000000E+00	0.265700E-01	1,827730
296	0.000000E+00	-0.101010E-01	2.279550
298	0.000000E+00	0.892857E-02	1.266240
299	0.000000E+00	0.362903E-01	1.255140
300	0.000000E+00	0.766129E-01	2.079070
305	0.000000E+00	-0.483871E-01	1.656470
306	0.000000E+00	-0.165746E-01	1.198810
309	0.000000E+00	0.257009E-01	0.870949
311	0.000000E+00	-0.1018180000	1.192970
312	0.000000E+00	-0.1236360000	0.977326
314	0.000000E+00	0.234192E-02	1.000000
315	0.000000E+00	-0.1194030000	3.389600
316	0.000000E+00	-0.472727E-01	1.804900
317	0.000000E+00	-0.1236360000	1.932730
318	0.000000E+00	-0.465396E-01	0.932289
320	0.000000E+00	-0.3417720000	5.888210

TABLE C-10. DISSIMILAR AIRCRAFT, UNIT-SCALED TACSPACE DISCRIMINANT MODEL FOR WHOLE ENGAGEMENT (Continued)

	Mean	Std Dev
Grp1	4.66188	4.67598
Grp2	-5.12831	4.35224
Pooled	-0.23322	6.66188

Break Point = -1.0450

F1: 275.996
F2: 32153.000

SSB: 5607.10
SSW: 4733.59
SST: 10340.70

Wilkes-Lambda: 0.457764
S-Omega: 0.539212
R-Squared: 0.542236

Predicted Min. Percent Error = 15.81

APPENDIX D

NORMATIVE DATA

TABLE D-1. NEUTRAL SEGMENT SUMMARY MEASURES: MEANS AND STANDARD DEVIATION

	Group 1 with 253 obs		Group 2 with 253 obs		Pooled with 506 obs	
Measure	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	298.2120000000	60.0973000000	337.0400000000	75.5404000000	317.6260000000	70.9044000000
2	334.3810000000	80.7711000000	382.4050000000	93.3212000000	358.3930000000	90.4380000000
3	302.5260000000	59.0801000000	340.3730000000	74.4519000000	321.4500000000	69.7612000000
4	- 0.751629E-02	0.711789E-01	0.245910E-02	0.863203E-01	- 0.252859E-02	0.791919E-01
5	22.8847000000	19.1798000000	24.3361000000	19.8122000000	23.6104000000	19.4928000000
6	0.870881E-01	0.550774E-01	0.976143E-01	0.949080E-01	0.923512E-01	0.776940E-01
7	- 3.4368900000	1.2813100000	- 3.4677100000	1.5965500000	- 3.4523000000	1.4461900000
8	23.3016000000	18.5069000000	25.0816000000	18.9398000000	24.1916000000	18.7272000000
9	3.5481100000	1.2495800000	3.7536400000	1.4219800000	3.6508800000	1.3411900000
10	- 0.8522670000	43.5363000000	1.2078900000	101.4910000000	0.1778120000	78.0183000000
11	107.3240000000	95.4528000000	256.0900000000	96.3600000000	181.7070000000	121.3420000000
12	46.0609000000	37.5284000000	132.5950000000	30.0444000000	89.3280000000	55.0362000000
13	172.2290000000	441.4080000000	171.9670000000	446.8060000000	172.0980000000	443.6750000000
14	791.4000000000	413.5100000000	795.3110000000	412.7970000000	793.3560000000	412.7490000000
15	473.0430000000	245.4940000000	475.2860000000	246.2500000000	474.1650000000	245.6320000000
16	3.5678700000	0.6718220000	3.8161900000	0.5080590000	3.6920300000	0.6078470000
17	23.4022000000	19.3809000000	25.1731000000	20.4062000000	24.2877000000	19.9002000000
18	3.6530800000	0.6718220000	3.8569500000	0.4665470000	3.7550200000	0.5530090000
19	- 0.3629240000	18.7359000000	- 0.1251710000	19.1149000000	- 0.2440480000	18.9080000000
20	199.2940000000	323.0190000000	171.9050000000	274.6330000000	185.5990000000	299.8200000000
21	42.1692000000	62.4619000000	38.3461000000	54.4773000000	40.2577000000	58.5790000000
22	- 6.7718900000	26.7473000000	- 8.9218700000	24.3986000000	- 7.8468800000	25.5972000000
23	37.1113000000	26.9027000000	37.9898000000	30.2608000000	37.5505000000	28.6060000000
24	26.1376000000	17.1760000000	26.0091000000	15.7960000000	26.0733000000	16.48420000000
25	0.2016240000	0.3008220000	0.1377400000	0.2693380000	0.1696820000	0.28701800000
26	0.432770E-01	0.1399730000	0.9416140000	0.1457600000	0.4924450000	0.47173100000
27	0.9338470000	0.1444390000	0.439083E-01	0.1426760000	0.4888780000	0.46792900000
28	2.6923100000	11.2223000000	2.1372600000	18.1124000000	2.4147900000	15.0542000000
29	38.6878000000	54.0113000000	62.5975000000	90.4882000000	50.6426000000	75.3981000000
30	13.7392000000	15.1969000000	21.1207000000	27.6920000000	17.4300000000	22.6176000000

TABLE D-2. OFFENSIVE SEGMENT SUMMARY MEASURES: MEANS AND STANDARD DEVIATIONS

Measure	Group 1 with 78 obs Mean	Group 1 with 78 obs Std Dev	Group 2 with 116 obs Mean	Group 2 with 116 obs Std Dev	Pooled with 194 obs Mean	Pooled with 194 obs Std Dev
1	345.7670000000	87.8369000000	336.0880000000	85.6145000000	339.9800000000	86.4193000000
2	380.6140000000	95.8683000000	369.1070000000	96.7271000000	373.7340000000	96.2998000000
3	348.4380000000	87.1014000000	337.9930000000	84.3016000000	342.1930000000	85.3683000000
4	- 0.673757E-02	0.648505E-01	- 0.966371E-03	0.506175E-01	- 0.328675E-02	0.566797E-01
5	20.4892000000	15.8982000000	23.2273000000	17.3041000000	22.1264000000	16.7651000000
6	0.668525E-01	0.497172E-01	0.584132E-01	0.423879E-01	0.618063E-01	0.455408E-01
7	- 3.4743400000	1.2357000000	- 3.3410200000	1.4802300000	- 3.3946200000	1.3853100000
8	20.1050000000	14.7676000000	22.4803000000	16.0589000000	21.4243000000	15.5574000000
9	3.5770100000	1.2145600000	3.4266200000	1.4390100000	3.4870800000	1.3519800000
10	- 1.4921700000	9.7711900000	- 0.8927300000	6.8424700000	- 1.1337400000	8.1287100000
11	27.1023000000	15.6581000000	30.2385000000	18.2611000000	28.9776000000	17.2885000000
12	8.1466100000	7.6945800000	6.6209800000	5.0591800000	7.2343800000	6.2797200000
13	123.0020000000	127.4150000000	143.1900000000	156.9930000000	135.0730000000	145.8130000000
14	216.6750000000	112.2090000000	260.1390000000	154.2570000000	242.6640000000	140.2080000000
15	155.9390000000	96.2521000000	184.0470000000	123.7490000000	172.7460000000	114.0700000000
16	3.6789900000	0.6805340000	3.6356700000	0.6793410000	3.6530900000	0.6783910000
17	22.1703000000	16.8149000000	24.8944000000	18.2392000000	23.7991000000	17.6867000000
18	3.7271500000	0.6398800000	3.6855100000	0.6321210000	3.7022500000	0.6339280000
19	0.6581770000	18.8885000000	- 1.6148800000	22.0882000000	- 0.7009720000	20.8399000000
20	85.1207000000	192.6110000000	75.6994000000	131.0390000000	79.4873000000	158.2850000000
21	27.6373000000	52.4961000000	23.9470000000	46.2508000000	25.4307000000	48.7585000000
22	- 22.7788000000	23.5070000000	- 12.7823000000	25.5568000000	-12.7809000000	24.6910000000
23	15.9795000000	14.3026000000	17.9312000000	15.8585000000	17.1465000000	15.2443000000
24	22.3950000000	16.3386000000	24.4333000000	16.9705000000	23.6138000000	16.7067000000
25	0.3851700000	0.4070320000	0.3507690000	0.3907090000	0.3646010000	0.3966660000
26	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
27	0.9862660000	0.443073E-01	0.9890840000	0.447899E-01	0.9879510000	0.445035E-01
28	- 1.2224100000	11.6190000000	0.7910160000	9.5892000000	- 0.185060E-01	10.4705000000
29	27.7148000000	27.7536000000	26.0218000000	20.8719000000	26.7025000000	23.8238000000
30	13.1074000000	9.7680200000	11.9185000000	7.2650500000	12.3816000000	8.3568700000

TABLE D-3. DEFENSIVE SEGMENT SUMMARY MEASURES: MEANS AND STANDARD DEVIATION

	Group 1 with 78 obs		Group 2 with 116 obs		Pooled with 194 obs	
Measure	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
1	384.6100000000	110.6110000000	391.8020000000	107.8350000000	388.9110000000	108.7320000000
2	421.0120000000	120.7210000000	427.0120000000	124.0840000000	424.5990000000	122.4640000000
3	387.9040000000	109.4230000000	395.6490000000	106.9790000000	392.5350000000	107.7530000000
4	0.898674E-03	0.881439E-01	0.625625E-03	0.848601E-01	0.735408E-03	0.859686E-01
5	24.1441000000	20.7332000000	25.3768000000	20.4871000000	24.8812000000	20.5417000000
6	0.835146E-01	0.806258E-01	0.802749E-01	0.758398E-01	0.815775E-01	0.776091E-01
7	- 3.7956700000	1.5313700000	- 3.8565000000	1.5809000000	- 3.8320400000	1.5575100000
8	23.9479000000	19.3663000000	25.4637000000	19.3512000000	24.8543000000	19.3214000000
9	4.0035300000	1.4832600000	4.0429000000	1.5275200000	4.0270700000	1.5061300000
10	- 15.4785000000	133.8080000000	-17.9901000000	133.4320000000	-16.9803000000	133.2420000000
11	254.7740000000	99.8965000000	244.3400000000	96.0438000000	248.5360000000	97.4889000000
12	167.9120000000	8.4359700000	166.6660000000	9.4754800000	167.1670000000	9.0699600000
13	123.5740000000	125.5040000000	143.9490000000	157.8500000000	135.7570000000	145.7100000000
14	219.8670000000	116.6240000000	260.0120000000	155.5690000000	243.8710000000	142.2550000000
15	155.5790000000	96.1068000000	184.0080000000	124.9220000000	172.5780000000	114.8000000000
16	3.8489100000	0.4018560000	3.7472900000	0.6025720000	3.8392100000	0.5322350000
17	25.7710000000	21.8768000000	26.8309000000	20.8421000000	26.4047000000	21.2143000000
18	3.8914600000	0.3307290000	3.8040700000	0.5398400000	3.8392100000	0.4681170000
19	25.7710000000	23.0386000000	- 1.1168800000	22.9107000000	- 1.8883400000	22.9219000000
20	3.8914600000	134.6260000000	109.8870000000	198.1020000000	100.3250000000	175.3610000000
21	86.1049000000	45.2613000000	33.7364000000	62.8852000000	31.1545000000	56.4235000000
22	- 11.0639000000	24.9520000000	- 7.3801700000	26.9362000000	- 8.8612500000	26.1534000000
23	15.7380000000	13.8931000000	18.1559000000	15.2749000000	17.1838000000	14.7461000000
24	21.8237000000	18.0943000000	23.1810000000	17.7615000000	22.6353000000	17.8617000000
25	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
26	0.9822170000	0.503137E-01	0.9815920000	0.514819E-01	0.9818430000	0.508839E-01
27	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
28	4.7938700000	23.2462000000	2.2694800000	14.8417000000	3.2844400000	18.6651000000
29	32.1983000000	24.7397000000	41.4547000000	39.4864000000	37.7330000000	34.5534000000
30	17.4576000000	20.6738000000	18.7265000000	13.8407000000	18.2163000000	16.8835000000

TABLE D-4. OFFENSIVE CELL OCCUPANCY: MEANS AND STANDARD DEVIATIONS

	Group 1 with 78 obs		Group 2 with 116 obs		Pooled with 194 obs	
Measure	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
171	0.405907E-01	0.1828370000	0.143678E-02	0.154746E-01	0.171791E-01	0.1176870000
172	0.160256E-02	0.141535E-01	0.000000E+00	0.000000E+00	0.644330E-03	0.897448E-02
173	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
174	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00	0.000000E+00
175	0.000000E+00	0.000000E+00	0.754310E-02	0.812417E-01	0.451031E-02	0.628213E-01
176	0.395615E-01	0.1750860000	0.244253E-01	0.1510900000	0.305110E-01	0.1608970000
177	0.256410E-01	0.1590850000	0.508553E-01	0.2050900000	0.407176E-01	0.1879190000
178	0.128205E-01	0.1132280000	0.420259E-01	0.1907820000	0.302835E-01	0.1643440000
179	0.480769E-02	0.424604E-01	0.517241E-02	0.557086E-01	0.502577E-02	0.506806E-01
180	0.000000E+00	0.000000E+00	0.969828E-02	0.9347956000	0.579897E-02	0.723084E-01
181	0.796754E-01	0.2542920000	0.839807E-01	0.2699810000	0.822497E-01	0.2631125000
182	0.2231570000	0.4034610000	0.1308570000	0.3179940000	0.1679670000	0.3567290000
183	0.1248740000	0.3193020000	0.1628490000	0.3479560000	0.1475800000	0.3364030000
184	0.566434E-01	0.2132430000	0.834898E-01	0.2491640000	0.726959E-01	0.2351770000
185	0.384615E-01	0.1935520000	0.783559E-01	0.2590830000	0.623159E-01	0.2352170000
186	0.688645E-01	0.2443290000	0.645971E-01	0.2346370000	0.663128E-01	0.2379620000
187	0.1277930000	0.3221220000	0.1124100000	0.2997860000	0.1185950000	0.3082290000
188	0.1097220000	0.3027160000	0.716313E-01	0.2376590000	0.869462E-01	0.2656410000
189	0.192308E-01	0.1217380000	0.597571E-01	0.2233520000	0.434630E-01	0.1898270000
190	0.128205E-01	0.1132280000	0.000000E+00	0.000000E+00	0.515464E-02	0.717958E-01

TABLE D-5. DEFENSIVE CELL OCCUPANCY: MEANS AND STANDARD DEVIATIONS

	Group 1 with 78 obs		Group 2 with 116 obs		Pooled with 194 obs	
Measure	Mean	Std Dev	Mean	Std Dev	Mean	Std Dev
36	0.595583E-01	0.2056190000	0.645748E-01	0.2223490000	0.625578E-01	0.2152500000
37	0.770322E-01	0.2300150000	0.769069E-01	0.2338200000	0.769573E-01	0.2316990000
38	0.662393E-01	0.2227560000	0.911697E-01	0.2718230000	0.811462E-01	0.2529290000
39	0.323503E-01	0.1321040000	0.415684E-01	0.1586190000	0.378621E-01	0.1482390000
40	1.276341E-01	0.1559290000	0.457512E-01	0.1908660000	0.384670E-01	0.1774440000
76	0.861569E-01	0.2588580000	0.112227E-01	0.591425E-01	0.413509E-01	0.1737080000
77	0.943732E-02	0.717159E-01	0.129370E-01	0.926599E-01	0.115299E-01	0.846807E-01
78	0.211538E-01	0.1342410000	0.178528E-01	0.1308190000	0.191800E-01	0.1318690000
79	0.384615E-02	0.339683E-01	0.132902E-01	0.1017060000	0.949313E-02	0.815201E-01
80	0.000000E+00	0.000000E+00	0.969829E-02	0.842984E-01	0.579897E-02	0.652457E-01
276	0.716700E-01	0.2436920000	0.687500E-01	0.2325430000	0.699240E-01	0.2364670000
277	0.1739750000	0.3625160000	0.1345730000	0.3260810000	0.1504150000	0.3408260000
278	0.1110040000	0.3060850000	0.1135450000	0.3079570000	0.1125230000	0.3064130000
279	0.256410E-01	0.1590850000	0.7088[illegible]1E-01	0.2334600000	0.526918E-01	0.2075280000
280	0.128205E-01	0.1132280000	0.172[illegible]14E-01	0.1307340000	0.154639E-01	0.1237080000
316	0.217900E-01	0.864560E-01	0.345384E-01	0.1318090000	0.294128E-01	0.1156440000
317	0.1286900000	0.2888250000	0.594408E-01	0.1900310000	0.872831E-01	0.2365540000
318	0.290723E-01	0.1026300000	0.554749E-01	0.1953750000	0.448594E-01	0.1646680000
319	0.241453E-01	0.1165470000	0.283828E-01	0.1040390000	0.266790E-01	0.1089640000
320	0.000000E+00	0.000000E+00	0.137931E-01	0.1078620000	0.824742E-02	0.835360E-01