METHODOLOGY TO ASSESS IN-FLIGHT

PERFORMANCE FOR AIR-TO-AIR

COMBAT TRAINING

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ABSTRACT

The Navy's Tactical Aircrew Combat Training System (TACTS) provides the instrumentation necessary to record in-flight performance of aircrews during air-to-air combat training. Data recorded on TACTS has been an important source of information for the development of objective flight performance criteria. This paper discusses research related to the development and application of in-flight measures of air combat performance. Procedures for systematic development of aircrew performance measures are identified and discussed. A generic methodology is proposed which will eventually lead to a prescriptive model for performance measurement system development. Some of the many applications of objective flight performance criteria include training progress evaluation, training methodology and effectiveness studies, and learning acquisition and transfer studies.

INTRODUCTION

Instrumentation

The Navy's Tactical Aircrew Combat Training System (TACTS) enables aircrews to monitor in real time various air combat exercises, and through its replay capability, provides the opportunity to debrief and evaluate pilot tactics, maneuvers, and weapon delivery accuracy. The U.S. Air Force second-generation version of this system is referred to as Air Combat Maneuvering Instrumentation (ACMI). Four major subsystems comprise the TACTS/ACMI System:

- **Airborne Instrumentation Subsystem (AIS)** - Uses a pod attached to the aircraft which measures flight dynamics information, senses weapon firing signals, and transmits data to the ground through the TIS.

- **Tracking Instrumentation Subsystem (TIS)** - Uses a series of unmanned remote tracking stations communicating with a master tracking station in order to monitor aircraft in a specified airspace.

- **Control and Computation Subsystem (CCS)** - Converts data received from the TIS into suitable form for display. Uses a pod attached to the aircraft which measures flight dynamics information and senses weapon firing.

- **Display and Debriefing Subsystem (DDS)** - Serves as a control center and display station.

Figures 1 and 2 illustrate the major TACTS/ACMI subsystems and their interrelationships. Some of the more important training features of TACTS/ACMI follow:

- Real-time tracking including position, velocity, acceleration, altitude, and angular rate measurement of aircraft engaged in air combat training

- Tape playback of flight history data, complete with pictorial display of the air-to-air engagement and voice transmissions

- Both digital and graphic hardcopy printouts of flight data, aircraft state vector positions, cockpit view of engaged aircraft, and mission summary data

- Computer-generated estimates of the results of weapon firing.

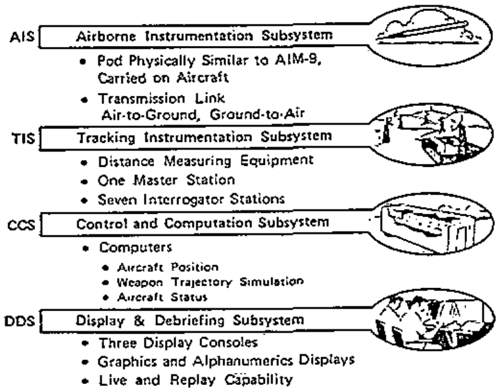

Figure 1 Tactical Aircrew Combat Training System (TACTS)

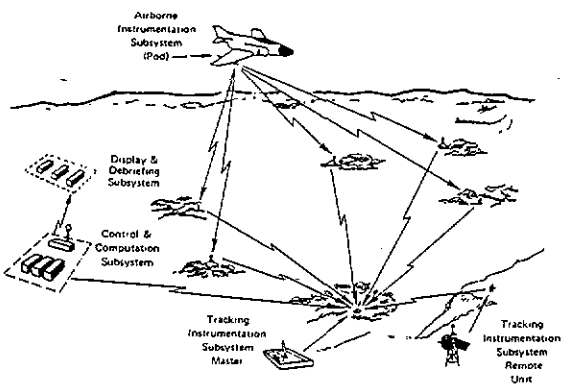

Figure 2 General Configuration of TACTS Subsystems

Recent engineering advances on TACTS have incorporated instrumentation required for training aircrews in ground attack missions as well. Some of the added capabilities include No-Drop Bomb Scoring, electronic warfare, and mine laying. This research paper, however, will concentrate on the traditional role of TACTS/ACMI in assessing performance of aircrews during air combat training.

Need for a Performance Measurement System

The Navy developed TACTS in response to lessons learned in Viet Nam indicating that U.S. pilot performance in air combat was below acceptable standards. A plausible reason for poor performance was thought to be inadequate pilot training in the use of proper weapon fire boundaries.[1] It was then suggested that aircrew training could be substantially improved by providing an instrumented range able to monitor and record air combat engagements and to simulate weapon firing results. TACTS was designed to meet these urgent demands for training instrumentation, so engineering emphasis was necessarily placed on real-time tracking of air-to-air engagements, weapon envelope simulation, and enhanced aircrew debrief via the DDS.

Present range instrumentation capabilities of TACTS provide a unique opportunity for aircrews to practice both flying and shooting tasks under realistic flight conditions and within an information-rich training environment. It is important to realize, however, that since TACTS is designed primarily to enhance debriefing of individual air combat engagements, the resulting system design does not include a capability to collect and analyze cumulative performance results or to depict statistical trends. Analysis of trend data and application of other performance assessment methods are needed for:

- Training progress evaluation by:
  - operational aircrews
  - training officers
- Combat readiness estimation by:
  - fleet commanders
  - DoD analysis groups
- Tactics development by:
  - fleet squadrons
  - operational test and evaluation squadrons
- Research Development Test and Evaluation (RDT&E) by:
  - weapon system developers
  - Government research centers.

Performance assessment is appropriately referred to by instructional system designers as the best means to determine that learning has occurred following training. Without performance measurement there can be no assurance that any training system, including TACTS, is meeting its design objectives.[2] Application of performance assessment procedures will enable aircrews undergoing training on TACTS to:

- Evaluate progress toward completing specific instructional objectives
- Estimate combat readiness of individual aircrew members and operational units
- Diagnose training deficiencies and provide corrective feedback, and in general, to remove redundancy and inefficiency in training through application of performance-based feedback.

Research Background

Since early research related to the development of air combat performance measures was discussed in several technical reports and previously published articles, it will not be treated in great detail here.

The first technical report was written in 1977 for the Naval Aerospace Research Laboratory, and this report described an analytic framework for conducting performance criterion research.[3] This analytic framework described the TACTS as a system which includes *aircrews, instructors, aircraft, weapons, missions* and *operating environment.* The technical approach used calls for obtaining performance measures within a system framework which identifies the above TACTS elements, defines the training mission and the operational environment, and provides measurement methods sensitive to the influence of variables identified in the total TACTS system. Each set of performance data collected on TACTS is described and referenced using this system framework (i.e., training mission, system elements and operating environment). Thus performance variations can be related back to specific elements and operating conditions. If desirable, the combination of elements (aircraft, weapons, aircrews, etc.) and the training mission can be systematically controlled to assess their influence on system performance.[4]

A second research report presented measurement criteria and assessment methods for evaluating Navy aircrew missile envelope recognition performance.[5] Two generic measurement methods were used to assess aircrew performance in missile firing accuracy.

First, a criterion-referenced assessment method was applied to score missile launch success (percent hits) and to compute task accuracy measures (error from prescribed missile launch boundary). A pilot must fire his weapon within this prescribed boundary to obtain a hit, and the distance from a proper launch window can be used to compute task accuracy (error scored) measures.

Second, norm-referenced measures, based on empirical data (mean ± one standard deviation), were used to evaluate performance related to group standards. A combination of norm-referenced and criterion-referenced measures has been proposed for other specific air combat tasks, i.e., radar search and acquisition, visual search and acquisition, tactics and maneuvers, etc.[6]

Another report presented a synthesis and application of the above measurement methods. In addition, preliminary measurement validation tests were presented.[7] Results of these preliminary validation tests showed statistical support for selection of task-based measures used to assess aircrew performance in air-to-air combat.

Finally, more extensive statistical validation tests were conducted using multiple linear regression analysis in a double cross-validation design.[8] Measures related to successful completion of various air combat tasks have reliably predicted 45 percent of the variance in final engagement outcome scores. These tasks include early visual identification of an opponent, missile fire accuracy, shooter-to-target pointing accuracy, and maneuvering to obtain a first-shot advantage.

PERFORMANCE MEASUREMENT SYSTEM DEVELOPMENT

Research Strategy

Meister (1978) has summarized characteristics which distinguish measurement approaches based upon controlled experimentation and those measurement approaches related to complex systems.[9] An important distinction made by Meister is that measures obtained in complex systems are taken in reference to the entire task, or job, which is performed in the context of the actual (uncontrolled) work environment.

In contrast, laboratory experimental research is conducted under highly controlled conditions. Isolated or synthetic tasks are performed while selected variables are systematically manipulated. Measures obtained in the laboratory are usually directly related to experimental hypotheses which guide the measurement selection process, data collection, and analysis procedures used to evaluate experimental results. In complex systems, measures are typically obtained while the system is in operation. It is difficult to measure the performance of individuals under these circumstances because each individual's effort is embedded within a system framework. Meister proposes to measure performance at the individual, team and systems levels. This will help us to understand the relative contribution of each level in meeting overall system performance requirements.

Another major difficulty encountered with aircrew performance measurement in complex systems is the determination of exactly what measures to use out of the total available. While there are many studies of aircrew performance in the literature, no widely accepted research strategy has evolved which specifically outlines the steps or procedures required to select and validate aircrew performance measures and assessment methods.

Vreuls and Wooldridge (1977) have discussed in broad outline many important aspects of performance measurement research.[10] These authors propose a systems-oriented, statistically based approach to develop aircrew performance measurement methods. Some of the more important ideas discussed by Vreuls and Wooldridge in their article are briefly summarized below:

- **Systems Orientation** – Aircrew performance is embedded in a complex system and is influenced by such factors as tactical doctrine, mission plan, weather, weapon availability, aircraft subsystem capabilities, and operating status.

- **Task Analysis** – The measurement specialist must devise a means to sample aircrew tasks that are most important to measure (i.e., tasks and measures that are best for describing, predicting, and understanding aircrew and system performance).

- **Statistical Approach** – A multi-variate statistical approach is proposed as the "only method powerful enough to deal with the complexity of the real world" (i.e., in which many variables interact to influence performance measures obtained).

- **Measurement Selection** – Measures should be selected which satisfy statistical requirements for validity and reliability and which are accepted by the operational user.

The above researchers have identified some key principles to consider during the development of aircrew performance criteria. Application of such principles forms the basis of a systems approach to performance measurement specification which emphasizes generic methods and test procedures.

System Development Model

Figure 3 presents a proposed model for Performance Measurement System (PMS) development. The model specifies a four-phase research and development program which begins by defining the training mission and operational task structure and ends with implementation of a PMS. The four phases of PMS development (analysis, description, validation and implementation) are briefly described below.

- **Analysis** – During the analysis phase of research, *information related to the mission and its associated* operational tasks is collected. Operational task data are brought to a level of analysis required to specify performance-based training objectives and to select a preliminary measurement set. (11).

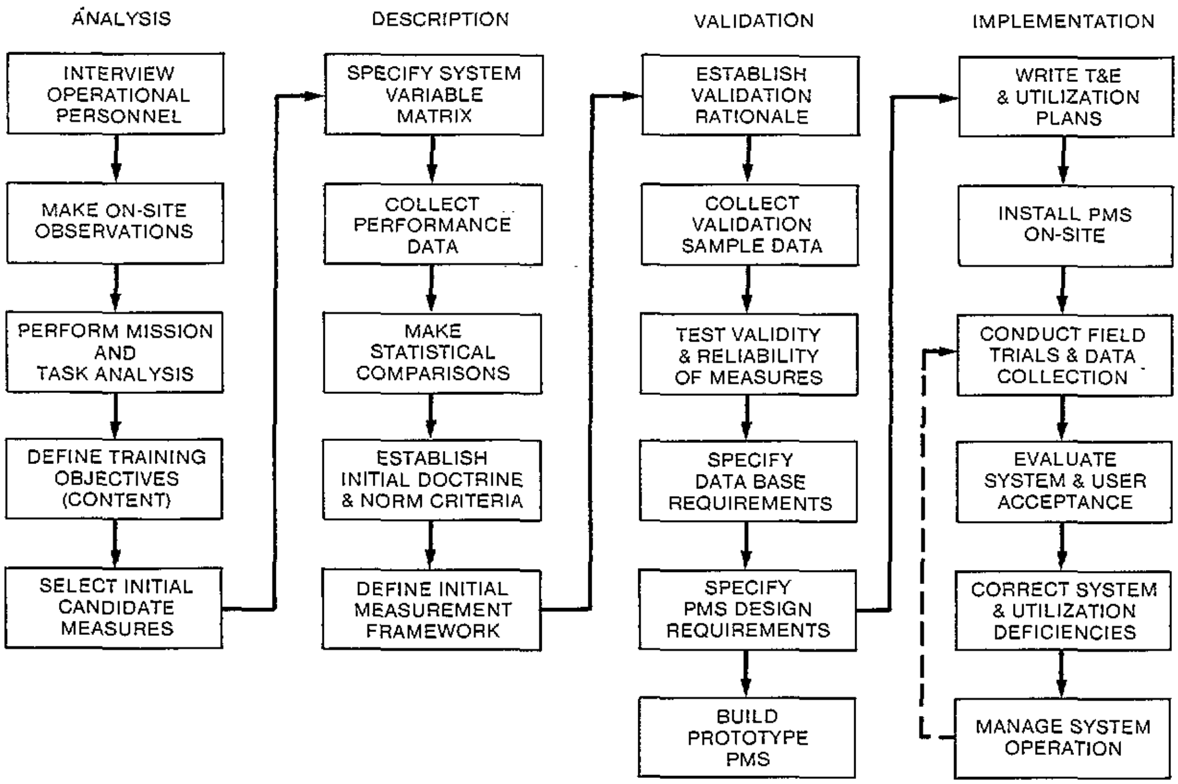

Figure 3 Performance Measurement System (PMS) Development Flow Chart

- **Description** – A variable matrix which identifies training or operational system elements, in this case aircrews aircraft, weapons and mission factors. The variable matrix serves as an initial systems framework for guiding performance data collection and analysis. Data collected on the training system can be categorized for later analysis with respect to the key operating elements as potential sources of variance of the training system. In other words, statistical sample comparisons are made between various aircraft types, weapon types, mission characteristics, aircrew changes, etc. These initial descriptive statistical comparisons provide the measurement specialist with initial information regarding the sensitivity of measures to discriminate expected performance differences at the system level. Table 1 presents an example of a variable matrix which was used in air combat performance measurement development. (See Ref. (11).)

- **Validation** – Information from task analysis and descriptive statistical comparisons (i.e., from analysis and descriptive phases) is used as a foundation to establish a preliminary measurement framework. The measurement framework represents a hypothetical position regarding operational tasks, their associated performance measures, and the potential influence of system-level variables on overall performance in the operational training system. Since the initial measurement framework is based on the researcher's *a priori* judgments about key variables and their relationships to the operating system, the resulting framework represents a theoretical structure requiring empirical validation. (See Ref. (4).)

The validation phase of performance measurement research is concerned with establishing an objective rationale to verify and support initial selection of candidate performance measures. The validation rationale usually is based on the following considerations:

(a) The degree to which candidate measures correlate with overall (terminal) system performance
(b) The ability of the measures to discriminate variations in operator (aircrew) skill level
(c) The reliability of performance measures obtained over repeated applications
(d) User acceptability and ease of implementation.

Once a rationale for validation has been established and successfully demonstrated, then data base requirements and functional design features can be specified for hardware and software engineering development of a prototype PMS.

- **Implementation** – An important part of PMS implementation should be preparation of a Test and Evaluation (T&E) plan. The T&E plan should:

(a) Include guidelines for applying the PMS as an integral part of an overall training system
(b) Specify Training Effectiveness Evaluation (TEE) procedures for PMS application.

Procedures outlined above need to be amplified in certain areas and refined in others to formulate a more complete prescriptive model for performance measurement system development. Even at this early stage of their development, such procedural guidelines were a useful aid in the specification of a measurement framework for air combat performance assessment.

Table 1. TACTS Training System Components and Variable Matrix

Personnel		Equipment		Mission	
Instructors*	Aircrews	Aircraft	Weapons	Mission	Environment
Experience and training	Adversary and fighter aircrews	Adversary and fighter type	Type	Type (e.g., single or multiple aircraft)	Weather
In-flight and debrief procedures and techniques	Perceptual/ motor skills	Performance characteristics and limitations	Design characteristics and limitations	Specific training objectives	Visibility
Content and quality of directive commentary (related to RTOs)	Training and education	Specific design features	Delivery parameters	Tactics and maneuvers specified and/or used	Terrain
Training function and tasks	Flight experience (total, type, crew, section)	Particular weapon and sensor complement	Procedures	Range operating constraints	Traffic
Training aids	ACM experience	System/subsystem operating status	Specific weapon load and selection options	Participating aircraft (mission mix)	Sun
					Miscellaneous

*Including Range Training Officer (RTO) and Flight Leader.

Air Combat Measurement Framework

Figure 4 shows a simplified Air Combat Maneuvering (ACM) sequence. ACM *mission phases* are written at the top of the figure, while points of measurement related to key aircrew training objectives are indicated in boxes. The solid boxes represent points for which measures are now available, and dotted boxes represent recommended additions to this overall measurement scheme. For example, ACM engagement state models[12] and algorithms for measuring energy maneuverability performance[13] are two essential additions in the final formation of an overall ACM measurement system.

Measures for engagement state are based on obtaining a position advantage, i.e., by measuring an aircraft's proximity to the lethal zone of an adversary aircraft. Measures for energy maneuverability are related to optimizing airspeed for efficient air combat maneuvering, i.e., flying an aircraft to its aerodynamic ideal. Addition of energy-related and maneuvering information to the building blocks model presented in Figure 4 would complete a technical approach that is based on a multi-task, multi-measure method. Table 2 shows short-form definitions of ACM training objectives and also indicates the corresponding candidate performance measures for these objectives. More detailed definitions for training objectives and candidate measures are reported elsewhere. (See Ref. (11).)

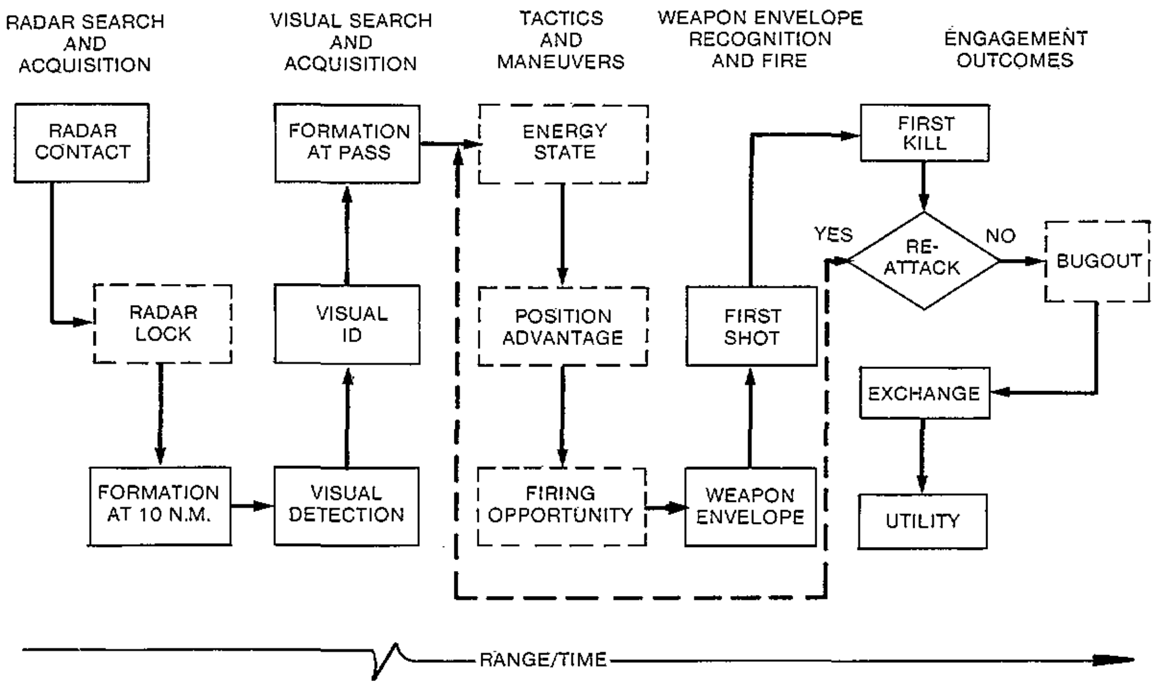

Figure 4 Simplified Air Combat Sequence: Shows Engagement Phases and Measurement Points

Table 2. Air Combat Engagement Analysis

Training Objective	Performance Measure
1. Obtain early radar contact and lock-on.	Interaircraft range and success rate (%) over engagements flown
2. Determine adversary attack formation at 10 n.m.	Quantity and position of enemy aircraft.
3. Obtain early visual detection of adversary aircraft.	Interaircraft range and success rate (%) over engagements flown.
4. Obtain early visual identification of adversary aircraft.	Interaircraft range and success rate (%) over engagements flown.
5. Determine attack formation at initial pass.	Quantity and position of enemy aircraft.
6. Maintain high energy state.	Indicated air speed and altitude (energy package).
7. Gain/maintain position advantage.	% or proportion of engagement in offensive, defensive states.
8. Gain firing opportunity.	Time and/or % in envelope or fatal offensive state.
9. Obtain first shot of engagement.	Elapsed time and % first shots.
10. Fire weapon in weapon envelope.	Interaircraft range, angle-off-tail, pointing angle, airspeed and acceleration parameters.
11. Obtain first kill of engagement.	Elapsed time and % first kills.
12. Execute successful re-attack.	Iterate 6-11 above.
13. Execute successful bugout by staying neutral, maintaining energy, and completing disengagement with no friendly loss.	% neutral, indicated airspeed and altitude, % loss at bugout.
14. Obtain favorable exchange (Exch) rate.	Ratio of fighter to adversary kills.
15. Satisfy mission (utility) requirements.	Neutralize threat aircraft and survive or minimize losses.

Results of the measurement research program have been directly applied to operational training. A computer-based, air combat debrief system was designed and developed as a prototype to test the feasibility of adding a PMS to TACTS (14,15). The resulting debrief system, currently undergoing further development by NAVTRAEQUIPCEN, is referred to as the Performance Assessment and Appraisal System (PAAS). PAAS design is based on the previously described measurement framework which has been partially validated. (See Ref. (8).)

The debrief system can display numerous graphs depicting statistically summarized performance results from TACTS training sessions. (See Ref. (15).) Data are provided to aircrews in an understandable format for review and diagnostic evaluation of air combat training progress. Figures 5 and 6 present examples of computer-generated graphics used by aircrews to assess their performance in key air combat tasks using PAAS.

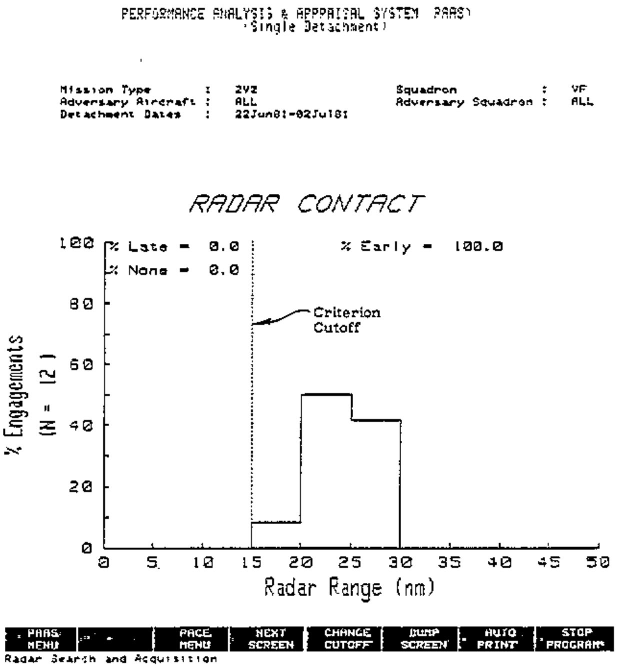

Figure 5 PAAS Graphic Format Used to Evaluate Radar Contact Performance for a Single Training Detachment

It is important to note that the present PAAS provides performance-based feedback *only on non-maneuvering* portions of an air-to-air engagement. Inclusion of measures related to air combat maneuvering is considered necessary to complete the proposed measurement framework (presented in Figure 4). Obtaining air combat *maneuvering* measures, however, will require use of an automated data retrieval system that is tied directly to TACTS/ACMI in order to capture the time history data necessary for analyzing maneuvers. No automated retrieval system is available on TACTS/ACMI today, and would have to be developed.

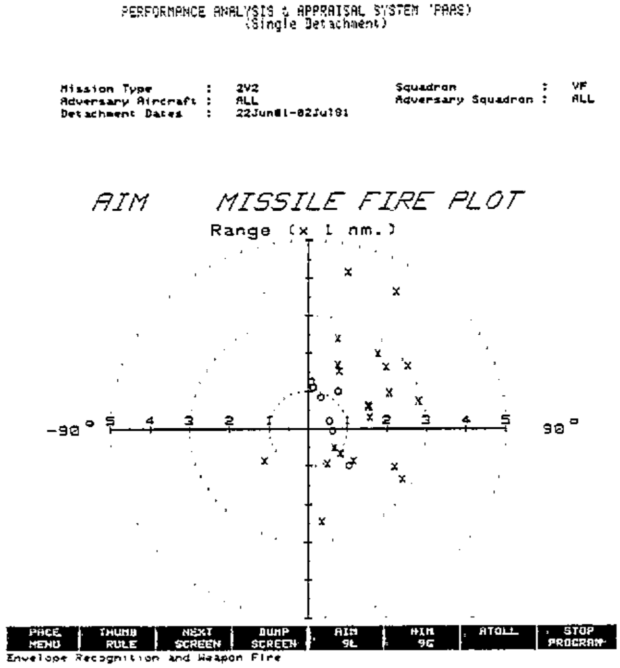

Figure 6 PAAS Graphic Format Used to Evaluate AIM Missile Fire Accuracy (envelope recognition) for a Single Training Detachment

DISCUSSION AND CONCLUSIONS

Performance measurement is an important ingredient to effective training. It is only by measuring performance that we can know if learning has occurred, and whether or not our instruction has succeeded.

Until recently, aircrew training instructors had to rely upon their subjective estimates of student training progress and instructional effectiveness. With the development of instrumented ranges like TACTS, we can now record in-flight performance. Such a capability provides the training community with an opportunity to apply objective performance criteria during the instructional process.

Caution should be raised, however, concerning the advent of instrumented ranges like TACTS, and advanced flight simulators which incorporate recording capabilities. The mere capability to record outputs from these training systems does not necessarily guarantee that such recorded data are valid and reliable measures or that they are appropriately applied. As should be apparent from the contents of this paper and previous publications, much analysis and testing preceded the selection and application of performance measures. Such analysis and testing is an essential precaution against merely adding a PMS as a possible extraneous feature to a training device. Addition of a PMS can enhance training, but it also can conceivably result in *decreased* training value if a PMS is poorly designed and/or inappropriately applied.

This paper discussed application of a task-based measurement approach which capitalized on the availability of TACTS data for *developing, validating,* and *applying* air combat performance measures. The proposed PMS development model represents a hopeful first step toward a more refined prescriptive model, or generic methodology, for incorporating systematically developed and validated performance criteria as an integral part of training system design.

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