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Human Factors Performance Data for Future Foward Area Air Defense Systems (FAADS)

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This research documents the collection, organization, and analysis of MANPRINT-related data from the 1985 Sgt York Follow-On Evaluation I. In 1985, an extensive follow-on evaluation was conducted of the Sgt York system. Due to the use of an automated digital data bus, a large quantity of objective system and subsystem data was recorded. Included in these data was a substantial amount of previously uninvestigated individual and crew performance data. The data yielded findings on many issues relevant to the design of FAADS. The report provides suggestions on applying the performance data to future soldier-system performance models. Such models can be remarkably helpful in making decisions about future FAADS. Recommendations are also given on how to improve future follow-on evaluations.

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FOREWORD

The Fort Hood Field Unit of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) conducts research and development to promote the effective combat use of the soldier and to improve soldier-machine interfaces in future system designs. Data are reported here from the Sgt York Follow-On Evaluation I (FOE I), which generated objective performance measures on individual soldier, team, and system performance in the execution of the target engagement sequence. The implications of these data for developing future air defense systems are discussed for such areas as system and subsystem performance, tactical performance, individual and crew performance, personnel factors, and training.

The primary objective of this effort was to structure the data into a human performance data base that could be incorporated into computer models of human and system performance in future Forward Area Air Defense Systems (FAADS). Further, the data, the analyses, and the recommendations in this report provide information directly relevant to consideration of the soldier into future FAADS design.

The participation of ARI in the Sgt York FOE I was in accordance with a Letter of Agreement between ARI and the U.S. Operational Test and Evaluation Agency (OTEA) dated 15 June 1983. The preparation of this report was funded under Research Task 114, Air Defense Crew and Operator Performance, sponsored by the Air Defense School. The effort was in accordance with a Letter of Agreement between ARI and the U.S. Army Air Defense Artillery School dated 20 September 1986. The data and analyses presented in this report have been provided to OTEA and the U.S. Army Air Defense School.

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Mr. Richard W. Obermayer, Vreuls Research Corporation, built the computer data base and a data processing and analysis system as described in Appendix A. The data distributions in Chapter III and the statistical analysis of research findings in Chapter IV were executed by Mr. Obermayer and refined jointly with the present authors. We are grateful to Mr. Obermayer for his skill, patience, and enthusiasm.

HUMAN FACTORS PERFORMANCE DATA FOR FUTURE FORWARD AREA AIR DEFENSE SYSTEMS (FAADS)

EXECUTIVE SUMMARY

Requirement:

Considerable data were collected during the Sgt York Follow-On Evaluation I. When system acquisition was cancelled by the Secretary of Defense, much of the processing of the collected data was also cancelled or brought to a hasty conclusion. The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) proposed that additional analyses be performed and reported. This document reports the findings of this effort. It documents the collection and analysis of man-system performance events during 271 target engagement sequences and answers the requirement to develop information of use in the design of future forward area air defense systems.

Procedure:

The principal data for this analysis was produced by an automated digital data bus during the Sgt York force-on-force trials (nonlive fire) that took place at Fort Hunter-Liggett in 1985. Printouts were examined and a criterion was developed for usable engagements (events that proceeded all the way through to a trigger pull). Using this criterion, data from 271 target engagement sequences occurring during 15 of the 29 valid trials were included in the analysis. Collateral data were assembled relating to the independent variables associated with the engagements.

Findings:

The data yielded findings on many issues related to the design of FAADS. Objective performance data are examined with respect to fourteen issues:

- Actual system performance compared with system performance requirements
- The negative impact of some semi-automation
- Variations in fire unit performance
- The impact of various tactical scenarios on performance
- The effect of hostile rotary-wing tactics on system performance
- The effect of various electronic countermeasure (ECM) conditions
- Varying performance levels as a function of the time of day
- Reaction to first target appearance at various ranges
- Specific task performance of gunner and squad leaders
- The effect of wearing mission-oriented protective posture gear

- Varying target workloads on the operator
- Characteristics of crewmen related to individual performance
- The influence of "mental category" on crew mix and crew performance
- Crew member training, past experience, and performance

Utilization of Findings:

This report provides suggestions for application of the performance data to soldier-performance models that will impact on decisions relating to future FAADS. Recommendations are also made for improvement of future FAADS evaluations.

HUMAN FACTORS PERFORMANCE DATA FOR FUTURE FORWARD AREA AIR DEFENSE SYSTEMS (FAADS)

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HUMAN FACTORS PERFORMANCE DATA FOR FUTURE FORWARD AREA AIR DEFENSE SYSTEMS (FAADS)

Introduction

Future FAADS

Whatever the future of specific forward area air defense artillery systems, it would appear to be a safe prediction that many new systems are going to be developed and evaluated. Whether the systems are soldier-portable (e.g., Stinger and AAWS-M) or multi-crew self-propelled vehicles (e.g., ADATS, Shahine, or the advanced Rapier), some combination of air defense artillery systems will emerge in the future to meet the continuing and increasing threat that hostile fixed-wing and rotary aircraft bring to the battlefield. While some of these may be non-developmental items, it appears safe to predict that much new (and better) design will be needed for future FAADS.

Estimates of the requirements from the battlefield continue to increase in severity. Effective weapon ranges seem to expand constantly, perhaps up to 10 kilometers. The most important requirement, however, is response time. We are dealing with system response times of less than 10 seconds. Both in speed and in tactics, hostile fixed-wing and rotary aircraft will be directed to provide decreased exposure which in turn will require air defense artillery response times to decrease.

Role of the Human Operator

With very short system response times required, the role of the human operator in FAADS must be questioned. While there are many potential uses for the human operator in air defense systems, there may not be time for the human to react. Or, if he is in the control loop, his actions must be very simple ones.

For some years this problem has been increasingly evident in the design of air defense systems, and there have been more and more attempts to introduce system and subsystem automation. Briefly, the trend has been first to change manual tasks into semi-automatic tasks and then to provide support with automatic decision-aiding systems. An example of the first is manual computer-assisted firing; an example of the second is automated Identification Friend or Foe (IFF). Some data from the SGT York testing suggests that the particular automation introduced may not have helped system performance. The particular technique of automation may have reduced system capability by increasing the system's response time.

Operational tests over the past five years have suggested that the soldier has been used in less than optimal ways in air defense systems. Beyond poor basic human engineering design for the crew stations (Babbitt, 1987), some of the fundamental tasks being performed, for example, by the gunner and squad leader appear to be badly designed, particularly when various levels of automation are introduced.

Computer Simulation for Design

Part of the problem appears to be that operational tasks and roles for the soldier are inadequately tested in development. Insufficient time and resources are applied to verify the feasibility and timeliness of required human task performance. It is to be hoped that in the future more attention is given by system design teams to physical simulation and empirical check of man's roles before system designs are frozen.

There is another method that could be used effectively to predict and design human operator tasks in air defense systems. That method is the development of quantitative human performance models through computer simulation (Chubb, Laughery, & Pritsker, 1987). Briefly, a number of extensively developed and proven models are available for simulating human-system performance and predicting quantitatively (and accurately) expected levels of human performance in complex systems.

Such simulations have been widely and successfully used in Army weapon systems design. For example, the ARI Crew Performance Model (Schwalm, Crumley, Coke, & Sachs, 1981) has recently been used to predict soldier-system performance in advanced concepts for the Howitzer Improvement Program. These models have also been developed specifically for man-machine problems in air defense. One specific example was MOPADS (Models of Operator Performance in Air Defense Systems) based on the SAINT modeling language and tested on the AN/TSQ-73 system and the IHAWK (Polito & Laughery, 1984). The technical methodology is well developed and tested (Rouse, 1980).

In essence, if a specific model is not available for the particular system, the following steps have to be taken for a quantitative man-machine model:

- The proposed system and alternatives must be described at a sufficient level of detail so that all critical system tasks are identified.

- An appropriate computer model framework is selected to represent the system and its functions. This is a simulation of the system, and will be successful to the degree to which the simulation maps into the system. Many models and flexible simulation languages are available for use. Extreme precision, incidentally, is not necessarily mandatory depending upon, among other things, what level of accuracy is required in quantitative predictions. For design feasibility studies, it is often sufficient to identify that a design alternative is an acceptable candidate for advanced development.

- Data estimates have to be available to simulate predicted performance values that might be expected for each system and subsystem parameter in the model. These may be data distributions or they may be single data points depending upon the particular model framework. These are the data that the model will use to compute predicted performance levels.

Performance Data For Modeling

Data for the model may be generated in a number of ways. First, for some parameters there are very substantial data in the literature. In fast response time systems where operator reaction time is critical, thousands of published data points are available for human reaction time data distributions. Second, no known data may exist, and estimation techniques (some of which are quite satisfactory) must be used.

Third, data may come from empirical situations which have another objective. For example, developmental and operational tests of specific systems can provide data that go beyond the particular and can be used in far more general or other specific contexts. This report supplies data from just such a source. In 1985, a very extensive operational test was conducted with the Sgt York air defense system. Very large amounts of performance data were collected from air defense tasks performed by the crews in the Sgt York. Of particular importance was data on target engagement events during 271 operational trials. From this, the human and system performance data base presented in this report was developed. These data are applicable beyond the Sgt York, and are analyzed in depth in this report.

Purpose of this Report

Building from the Sgt York target engagement sequence data base and the objective human and system performance data there, the following objectives are the purpose of this report:

- Developing specific recommendations for the use of the human operator in future FAADS with particular emphasis on future automation.

- Generating data on a wide variety of potential air defense systems variables in such areas as system and subsystem performance, tactical performance variations, individual and crew performance, personnel quality, and training. The present findings suggest which variables are important and which might not be important.

- Generating significant parameters and data for computer models of human performance in future FAADS design.

- Providing data, concepts, and awareness for the critical role of the soldier in air defense systems and his better utilization in future FAADS.

The FAADS Target Engagement Sequence (TES)

The target engagement sequence is at the heart of the air defense mission. A generic model is presented in this chapter to describe the target engagement sequence which would apply to any forward area air defense weapon system. The generic model is then expanded and refined so that it applies to specific FAAD systems for ADATS, Liberty (Shahine), Tracked Rapier, and Paladin (Roland). Further amplification of the target engagement sequence includes a model specific to the Divisional Air Defense Gun System (DIVAD), and its several acquisition system modes of operation. Integration of the specific target engagement sequences with the generic model will be discussed.

Generic Target Engagement Sequence

In the simplest terms, target engagement involves detecting, identifying, and firing on a target. That last segment has long been machine supported, whether such support means firing a bullet, a shell, or a missile. More recently, machines have helped system operators to aim at the target, to lead the target appropriately, and to track and identify the target.

Now, in a variety of FAADS applications, many of the target engagement tasks are machine aided. Radar systems can help to detect targets as well as to discriminate friends from foes. The type of weapon system used against a target has an impact on the actions that must be taken by human operators and the help that machine systems will provide. Attacking a plane using a shoulder-fired Stinger weapon places very different demands on an operator than does using a weapon system such as the Sgt York, which is capable of performing more functions automatically.

The FAADS Target Engagement Sequence (TES) will vary in its particulars from one weapon system to another, but there will also be important parallels within the various systems. Whatever the system, a target must be detected, it must be acquired by the weapon, and it must be fired at. A possible sequence of steps leading from target appearance through cease fire is indicated below:

1. Target appears.
2. Target is detected.
3. Target is identified as foe.
4. Target is tracked.
5. Target elevation, azimuth, and range are determined.
6. Aiming point is determined, i.e., firing solution is calculated.
7. Weapons system is aimed at target.
8. Decision to fire is made.
9. Firing begins.
10. Firing ceases.

Some variation may occur among systems as to the order in which the steps of the target engagement sequence must be taken; still, some steps must be accomplished before other steps are taken. For example, the target must be detected before any of the rest of the sequence can proceed. It is important to classify the target as foe before firing on it, but that classification can precede or follow the determination of the exact location of the target.

The information obtained from the fifth step is needed for the sixth step, and certainly the weapon system should be aimed (Step 7) before firing begins (Step 9). In other words, although there is some interdependence among the steps in the target engagement sequence, variations in the order of occurrence are possible. These variations are dependent on (1) the specific total weapon system and the way the tasks are allocated between human operator and machine components for that system, and also on (2) the particular way that a given target engagement sequence develops.

To locate a target precisely enough to be able to hit it, elevation, azimuth, and range information is needed and should be obtained before the target is fired on. A human operator can establish elevation and azimuth by superimposing some sighting element (cross hairs, reticle, etc.) over the target. Range information is less easily obtained. Radar and laser are two ways of getting range data. A moving target presents special difficulties because its position is constantly changing. To hit it, its position must not only be determined but predicted so that the weapon system can intercept it.

To provide an overview for this discussion, a model is presented which illustrates the FAADS generic target engagement sequence functions (see Figure 1). As will be seen with the description, function, and flow diagrams for specific systems, each system will be different as weapon systems, yet will be subsumed under the generic target engagement sequence.

The U.S. Army's comprehensive FAAD plan consists of five different elements: Line-of-Sight, Forward-Heavy (LOS-FH); Line-of-Sight, Rear (LOS-R); Non-Line-of-Sight; Combined Arms; and Command-Control Information (C2I) ("After DIVAD, an $11-billion plan,"). LOS-FH is considered the Sgt York replacement. An interim system of European design will be fielded for the line-of-sight forward defense of heavy divisions. LOS-FH is to be a combined missile and gun system. LOS-FH armored vehicles are to travel along with tanks and other armored vehicles in the forward half of the Army's heavy divisions. Under congressional mandate, a LOS-FH replacement for Sgt York was to be selected by November, 1987, with a prior shoot off. An existing system currently in production was to be selected in November, and fielded by 1990. The competitors for LOS-FH were: (1) ADATS system from Martin-Marietta Orlando Aerospace and Oerlekon Aerospace of Canada; (2) Liberty (evolved from the French-made Shahine system) from LTV Missile and Electronics Group's Missile Division and Thomson-CSF of France; (3) Rapier from United Technologies, FMC Corp., and British Aerospace; and (4) Paladin (a renamed version of the Roland) from Hughes Aircraft, Messerschmitt-Boeoklu-Blohm of West Germany, and SNI Aerospatiale of France (Adams, 1987). All four systems have self-contained radars for locating targets and missiles with a range of at least 6 km.

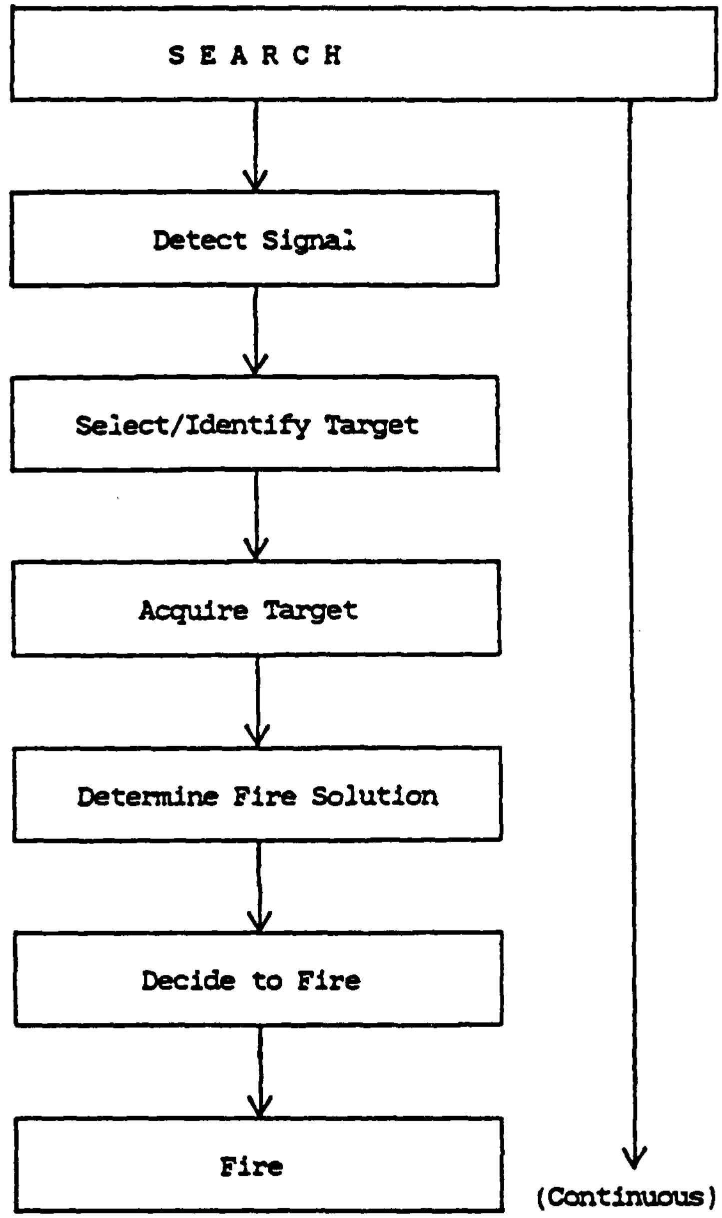


Figure 1. Forward Area Air Defense Systems (FAADS) generic target engagement sequence functions.

Air Defense, Anti-Tank Systems - ADATS. ADATS is a day/night and adverse weather missile system capable of engaging air targets or tanks. Each fire unit is self-contained, and uses its own radar for early detection of targets. The fire unit can be incorporated into a network of layer radars for command and control. The target engagement sequence used for ADATS is shown in Figure 2. Characteristics of the ADATS are presented in Table 1.

Liberty (Evolution of the Shahine). The Liberty originally evolved from the Crotale air defense system which was a forerunner of the Shahine air defense system. The system is configured with 2, 3, or 4 fire units, and one or two acquisition and coordination units. The modular system can be mounted on a tank chassis, wheeled armored vehicle, or air transportable shelters. Liberty is a surface-to-air defense system designed for all-weather interception of targets. The target engagement sequence used for the Liberty is presented in Figure 3. Characteristics of the Liberty are provided in Table 1 from a description of the Shahine air defense system. Liberty is an evolution of the French-made Shahine system used in Saudi Arabia (the system consists of a 25 mm gun and 12 missiles on an Abrams chassis) (Adams, 1987).

Tracked Rapier. An armored version of a cargo carrier is being used as the launch vehicle for Tracked Rapier. The weapon system is highly mobile and is able to defend mobile forces against low-flying fixed-wing and rotary-wing aircraft. The system carries eight missiles, four on each side. The missiles can be fired and guided at low elevations over the cab. The armored cab is designed to be operated by crew members in MOPP gear. The Tracked Rapier has day/night capability. Optical tracking facilities are combined with thermal imaging. The system may operate in a passive mode, and has automatic passive search when the radar is switched off. The operator may select optical or IR tracking. The target engagement sequence for the Tracked Rapier is presented in Figure 4. Characteristics of the Tracked Rapier are identified in Table 1.

Paladin (Renamed Version of the Roland II). Paladin is an all-weather/clear-weather surface-to-air weapon system. It was designed for defence against very low, low, and medium altitude fixed-wing and rotary-wing targets. The weapon system can be incorporated into various armored vehicles, and is able to function as an independent unit. The fire unit can be mounted on a tracked vehicle or on a truck. The Roland (Paladin) is in its third updated version, and has increased range, speed, and uses a heavier warhead than in previous versions. A new launcher system was designed, and the weapon system is able to carry 12 missiles, whereas previously it carried 10 missiles. Nine countries have adopted the weapon system. The target engagement sequence for the Paladin is flowcharted in Figure 5. Characteristics of the Paladin are identified in Table 1 from a description of the Roland II Mobile Anti-Aircraft Weapon System. The French-German Euromissile Consortium developed the Roland system.

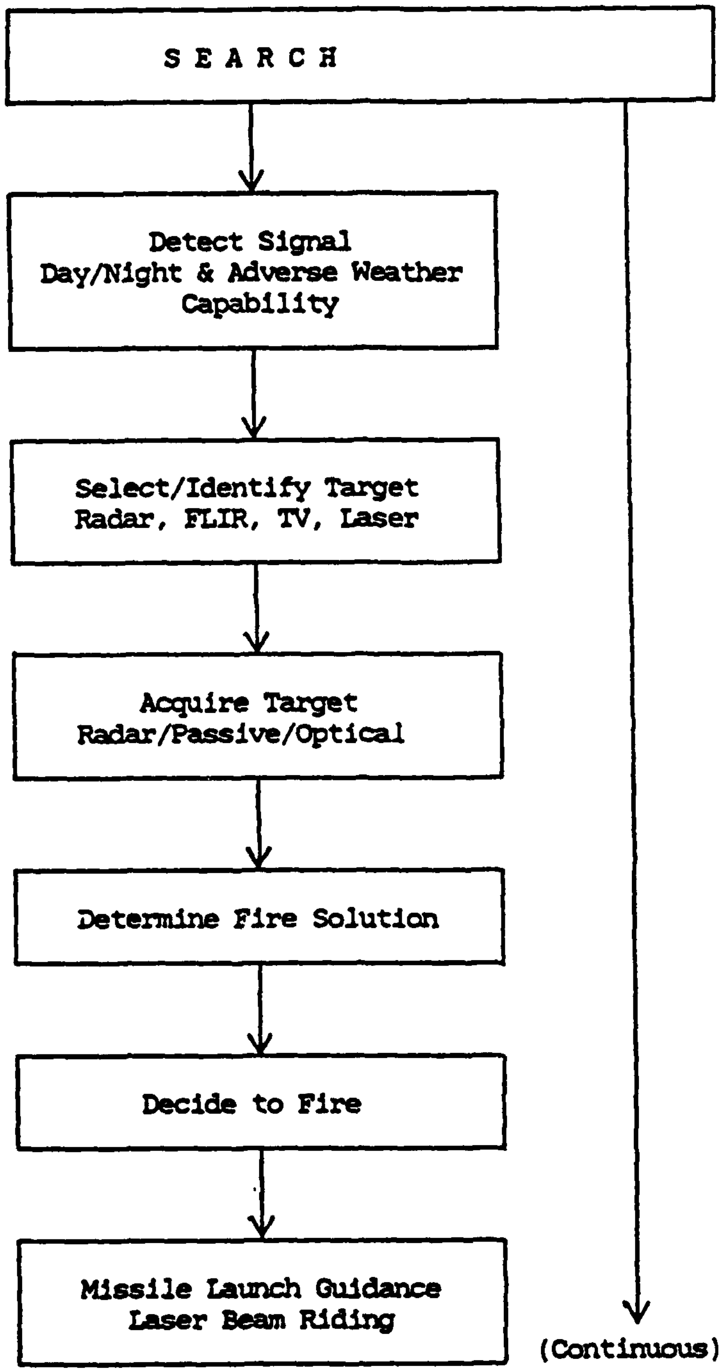


Figure 2. Air Defense, Anti-Tank System (ADATS) target engagement sequence functions.

Table 1

Weapon System Characteristics (Jane's Weapon Systems, 1986-87; and Aviation Week & Space Technology, 1987)

Air Defense Anti-Tank System (ADATS)	8 Ready-to-Fire Missiles Air Targets Anti-Tank Defense Autonomous Fire Unit Propulsion Solid, Smokeless Rocket Motor Range 8+ km Search Range 20 km 1 Cannon 25 mm Machine Gun .50 Caliber Bradley Chassis
Liberty (evolution of the Shahine)	6 Ready-to-Fire Missiles (12 Missiles, Production Version) 40 Targets on Display Threat Evaluation & Tracking 18 Targets 1 or 2 Acquisition & Coordination Units, & 2, 3, or 4 Fire Units Acquisition Range 19.5 km Tracking Range 17 km Tracked Vehicle or Heavy-Duty Wheeled Reaction Time 6 seconds AMX-30 Tank Chassis (M1A1 Tank Chassis & 2 Cannons 25 mm, Production Version)
Tracked Rapier	8 Ready-to-Fire Missiles Air Targets Anti-Tank Defense Autonomous Fire Unit Propulsion Integral 2-Stage Solid Propellent Motor Range 7 km Amphibious Cab Design for NBC Gear 2 Machine Guns .50 Caliber FMC/RCM 748 Tracked Vehicle (Bradley Chassis, 1 Cannon 25 mm, Production Version)
Paladin (renamed version of Roland II)	10 Ready-to-Fire Missiles Air Targets Missile Tracking IR Autonomous Fire Unit Range 16 km M933 Tracked Vehicle (M1A1 Tank Chassis & 1 Cannon 25 mm, Production Version)

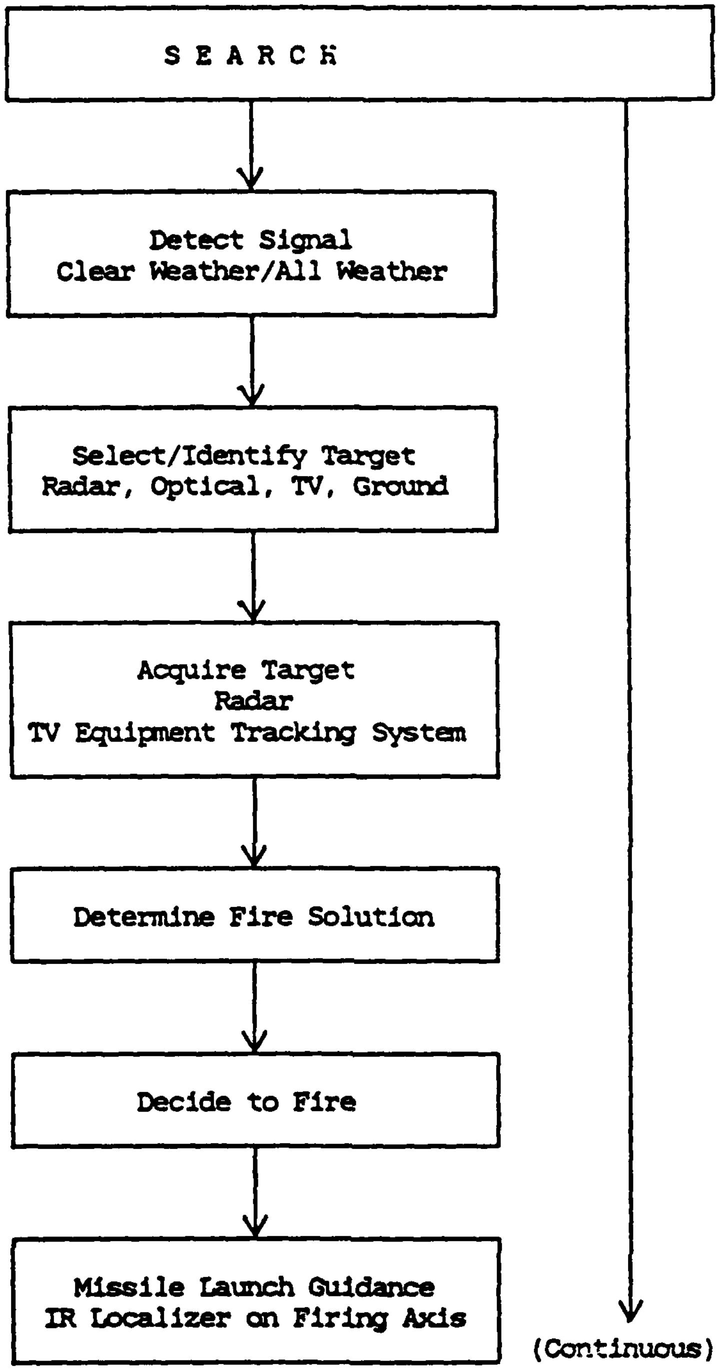


Figure 3. Liberty (evolution of the Shahine) target engagement sequence functions.

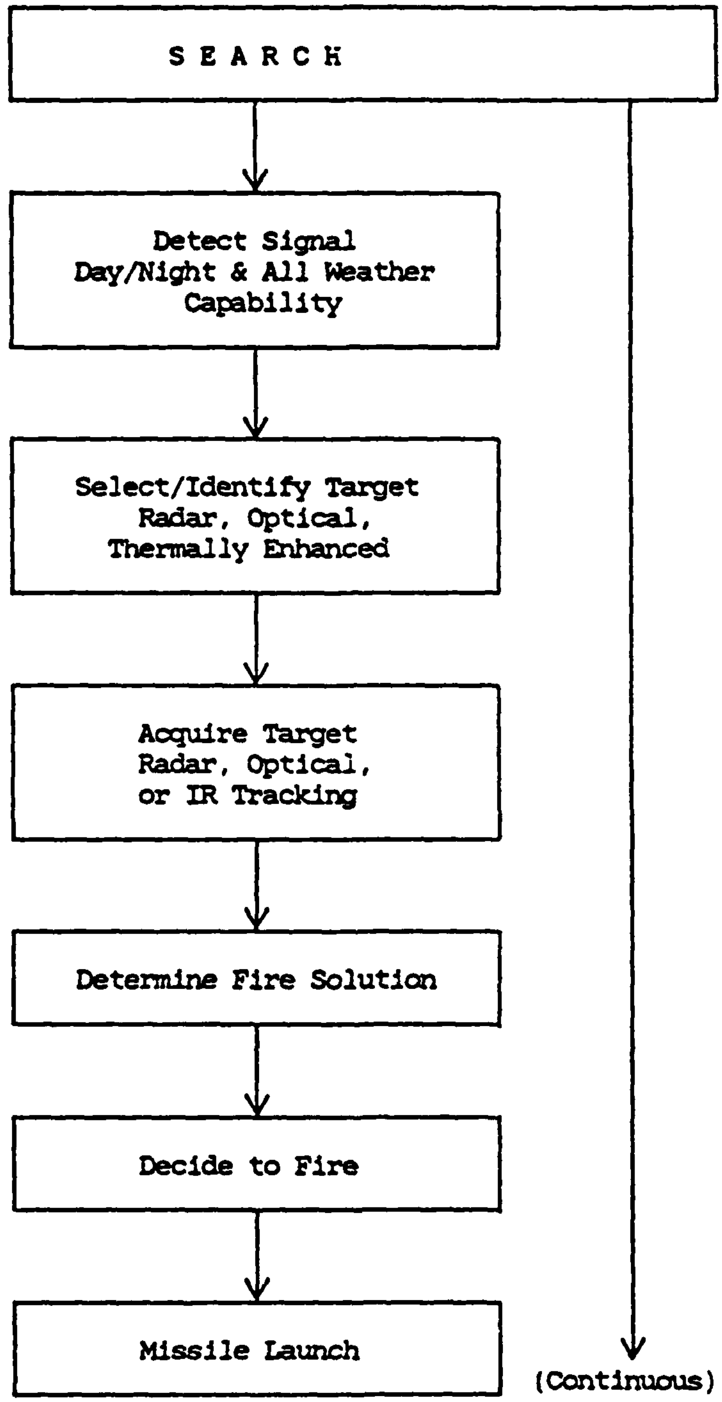


Figure 4. Tracked Rapier target engagement sequence functions.

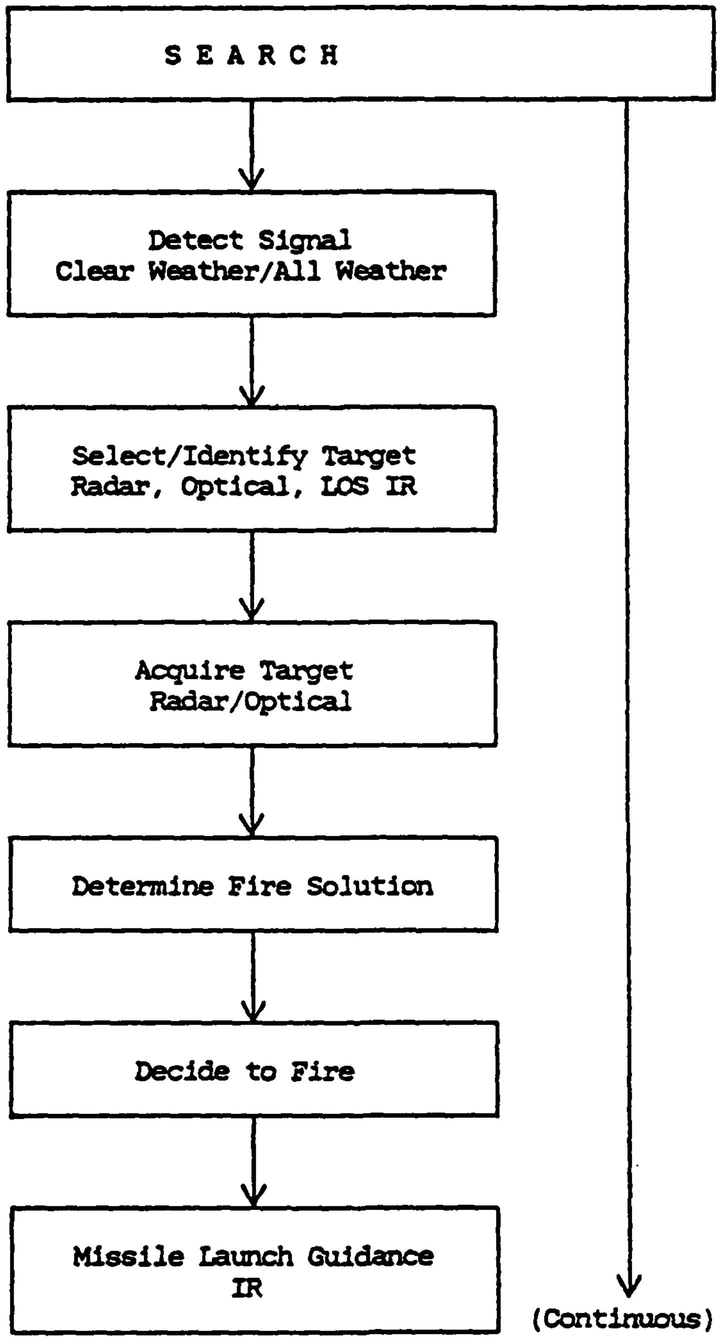


Figure 5. Paladin (renamed version of the Roland II) target engagement sequence functions.

FAADS TES Specific to the Sgt York Fire Unit

The content of the FAADS data base described in this report came from the first Follow-on Evaluation of the Sgt York system. Therefore, it is appropriate at this time to look at the procedures for conducting the target engagement sequence as they were structured for the Sgt York crews. The amplification of procedures will be important to understanding and interpreting research findings regarding crew decisions, crew activities, and weapon system processing. The concept of "system modes" is key and pervasive to learning and understanding Sgt York target engagement procedures.

System Modes of Operation

The Sgt York gun system had over a dozen modes of system operation. In addition, there were off-line modes to prepare for operations. Modes of operation were identified and clustered differently in different documents, such as the Operator's Manual (Crew) Volumes I-III, and the 1553 Serial Data Bus.

Mode Performance Data Included in Data Base. During FOE I Force-on-Force, not all system modes of operation were tested. Human and system performance data (target engagement event times) was collected and inserted into the FAADS data base only for System Acquisition Modes 8, 9, A, B, and C. These are all that this report (e.g., the data base) provides data for. (There is another acquisition mode, mode 7, for which, unfortunately, no data was obtained.) So, in the most important respect, having entries in the performance data base, only these acquisition modes are addressed by this document.

However, to provide the reader with some idea of the other modes, they will also be listed or briefly described in the next several pages.

Radar Auto mode. Radar Auto mode was the fastest target engagement method. In Radar Auto, the system pointed to a top priority target when it was within a predetermined range. Automatic calculation was performed for gun lead and superelevation angles. The system was directed to the greatest threat when more than one engageable target appeared. When the RDR switch was set to AUTO, the PALM SWITCH was enabled; and when the TURRET-GUN switch was set to ENABLE, the turret could slew with little or no warning. The gunner watched the target in the gunsight, and the squad leader watched the display for target data or searched for additional targets.

Radar Pointer mode. The second radar method used to acquire targets was termed the Radar Pointer mode. The operator could designate with a cursor a target of any priority during Radar Pointer mode. Only one target could be designated with the pointer symbol on the display. Once the target had been pointed, the target was watched by search radar. While the radar was tracking the pointer-designated target, other targets could also be engaged. While in the Radar Pointer mode, it was possible to acquire targets even though they may have been beyond the recommended firing range. Crew members could acquire a designated target under Radar Pointer mode at any time.

Radar Jammer mode. Radar Jammer mode was designed to acquire on-board radar jammers, and was considered a variation of Radar Pointer method. If a sector was affected by jamming, the radar automatically indicated the sector on the display. The display indicated the calculated center of the jammed sector (see Figure 6). Gunner and Squad Leader were to designate jammer cues as though they were targets.

System Laser. The laser could be combined with any radar engagement method (Radar Auto, Radar Pointer, Radar Jammer), or it could be used alone for the optical/laser mode. A more accurate fire control solution was produced when the laser mode was combined with a radar mode (see Figure 7).

Laser with any radar mode. When the laser mode was combined with a radar mode, laser data was added to the track radar data to establish a combined firing solution. If the crewmen were tracking in the radar mode, they were to lase when the target could be seen in the gunsight. Actually, the determining factor as to whether radar and lase modes should be combined was contingent on whether there was additional time to supplement the radar solution with greater accuracy to the radar-based fire control solution. If a firing solution for radar only was blinking instead of solid, then if time allowed, the crew could lase. Since a blinking center firing cue indicated that a firing solution had been achieved yet was out of recommended range, use of the laser could promote an improved fire solution and hopefully a solid firing cue indicating that the target was in recommended range.

System optical/laser. It was possible to use the laser range-finder alone during optical/laser engagements. The laser rangefinder consisted of a transmitter. receiver, and an electronics unit. Lasing was the only way to provide target range and speed information to the fire control computer in the optical mode. Lasing a target in the optical mode, using the laser rangefinder, resulted in the display of only the target lased. Ground and air were the two submodes of optical/laser operation. These modes were selected using a GROUND-AIR switch on the gunner's control panel. Ground targets were displayed with a ground target symbol only. Air targets were differentially displayed as slow or fast targets. Slow targets were represented by a helicopter symbol, and fast targets were represented by a fixed-wing aircraft symbol. Targets that were in range were displayed as larger symbols than for targets out of range (see Figure 8).

Point-detonating ammunition was automatically selected in the laser ground mode unless it was not available or the crew member overrode the automatic selection of ammunition. The narrow laser beam (0.5 mils) associated with the ground mode corresponded to the gunsight inner reticle. Live ammunition was not used during the Force-on-Force trials.

In laser air mode, ammunition was selected automatically by the fire control computer according to its evaluation of the target. The wider laser beam (3.0 mils) used during air mode allowed for easier tracking of a dodging air target. The air mode laser beam corresponded to the coverage of the periscope inner reticle circle and the gunsight outer reticle circle.

Laser effectiveness was degraded by conditions such as fog, clouds, and smoke. In addition, since laser firing generates heat, the laser would automatically stop firing when the laser transmitter temperature reached a pre-set level.

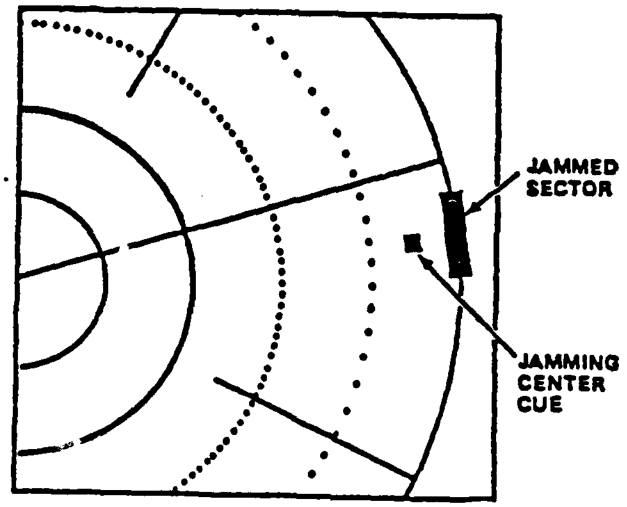


Figure 6. Display indicates jammed sector and jamming center cue.

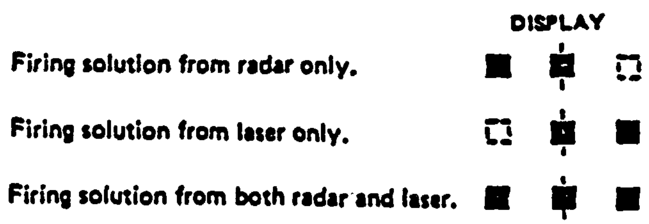


Figure 7. Firing solution cues for radar and laser.

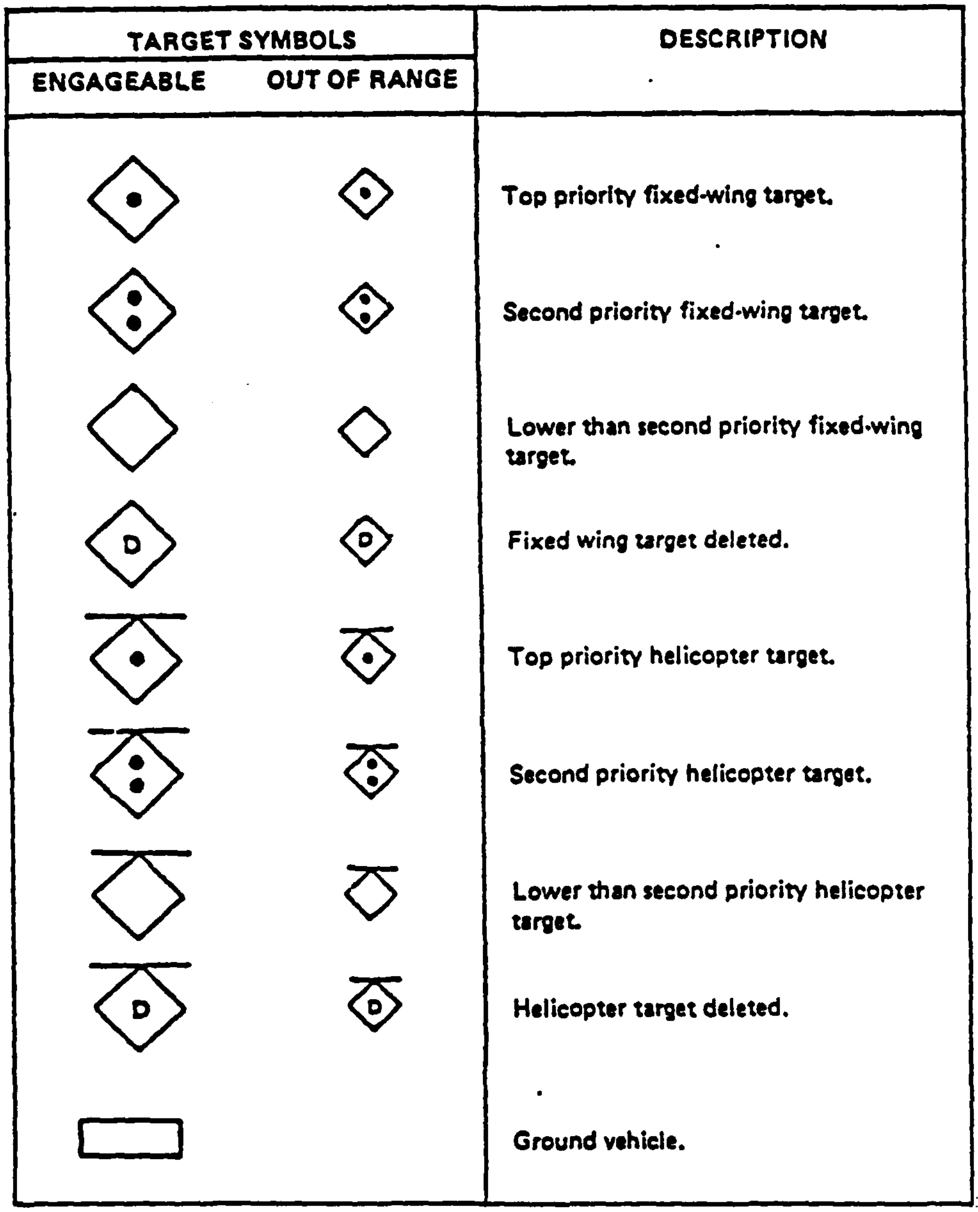


Figure 8. Target symbols for fixed-wing, helicopter, and ground vehicle.

Gun Slaving Modes. Particular subsystem failures could occur during which normal fire control solutions were not produced by the fire control computer. Instead the data were entered by the operator who was moving the gunsight. In the slave mode, guns were pointed where the gunsight was pointed (sights were scoped to gunline). Gun superelevation and lead angle were entered by the operator. The fire control computer could not make automatic ammunition selection or burst length in the slave mode. Therefore, the operator had the additional task of selecting both ammunition type and burst length.

Operators were alerted to the occurence of the slave mode condition by a SYSTEMS STATUS (SST) NO GO lamp on the gunner's control panel (see Figure 9). Failures of the attitude reference unit (ARU) or the fire control computer could result in a SST message which specifies slave mode.

System Firing on the Move. System firing on the move included the optical/laser system mode and all radar system modes. All laser and radar systems were stabilized to allow for engagements while traversing terrain or on road march conditions. However, a slight loss of accuracy would be anticipated when firing on the move versus firing from a stationary position.

Battle Quick Start procedures. Fire unit preparation required preliminary procedures to be conducted prior to target engagement. Preliminary procedures included, but were not limited to, system operational checks, magazine loading, calibration firing, pre-engagement checks, radar preparation, setting search-sector limit, setting primary target line, selecting radar channel, setting symbols switch, antenna deployment, etc. Battle Quick Start procedures could be used in an emergency to achieve operational readiness for the fire unit in less time. However, when Battle Quick Start procedures were used, there was some degradation of system capabilities and performance.

System Mode Radar Silent. During Radar Silent mode, power was supplied by vehicle batteries only. Silent mode was used for periods of observation and surveillance or after loss of high voltage AC power. Since radar did not operate without system AC power, Radar Silent mode consisted of a limited version of the optical/laser engagement. Two 12-volt batteries were used for silent mode, and four 12-volt batteries were held in reserve to start the fire unit. Gun firing and turret movement were performed manually. Either gunsight or periscope could be used to manually aim the 40-mm guns. There were limitations in using Radar Silent mode. For example, the attitude reference unit (ARU) and the laser were cooled by AC power. The ARU and the laser could have led to automatic shutdown without cooling.

For purposes of the Force-on-Force FOE I, modes of operation were primarily radar pointer or radar supported by laser. Crew members usually maintained control over the turret by tracking each target manually. Using this approach, they avoided the sudden and hazardous slewing of the turret that could occur when in the Radar auto mode.

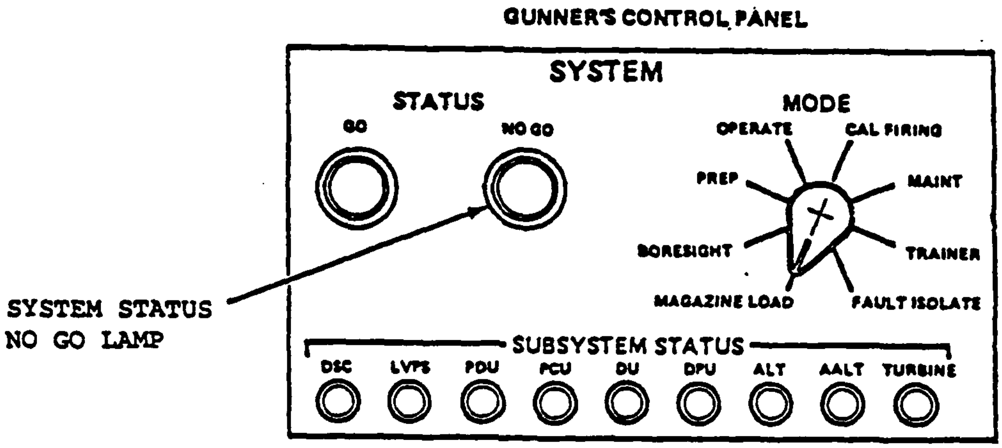


Figure 9. System status NO GO lamp indicates slave mode.

System Mode Non-Operative. In addition to system modes of operation, several non-operative modes (off-line, preparatory modes) were available to the crew. They were special non-tactical modes which crew members were not to select when involved in an engagement sequence. The seven non-operative modes were to be used for: (1) magazine loading and down-loading, (2) checking and setting boresights, (3) preparatory procedures, (4) calibration firing, (5) maintenance operations, (6) proficiency trainer, and (7) fault isolation.

System Modes of Operation and the 1553 Data Bus. The 1553 Serial Data Bus carried system event data between the Data System Controller, the Fire Control Computer, and the Radar Computer. Switch actions by the Sgt York crew were recorded on the 1553 Data Bus. The Data Bus recorded to the nearest one-thousandth of a minute when a fire unit entered each system mode and the onset time of various activities as well (see Table 2).

Non-Acquisition Modes. There were six non-acquisition modes. The non-acquisition modes were to be used during activities such as searching, detecting, identifying and classifying, acquiring, tracking, and lasing targets. However, it was not possible to engage a target while functioning in any of the six non-acquisition modes. (The label of Non-Engagement Modes seems more appropriate.) For this reason, the times at which the FU entered a non-acquisition mode were not extracted for entry into the FAADS Target Engagement Sequence data base. The six non-acquisition modes were as follows:

1 = Gunner Slave, Radar, Optical
2 = Gunner Slave, Radar Auto
3 = SL Slave, Radar, Optical
4 = SL Slave, Radar Auto
5 = Gunner Free, Radar, Optical
6 = Gunner Free, Radar Auto

Because they involve the Radar Auto mode, non-acquisition modes 2, 4, and 6 are at a higher level of automation than modes 1, 3, or 5. Non-acquisition modes 1, 3, and 5 all included the optical component which required more time to engage than the radar auto system mode.

Non-acquisition modes 1 and 2 both used Gunner Slave, and modes 3 and 4 both used Squad Leader Slave procedures. The four non-acquisition modes using gunner and squad leader slave are not to be associated with the System Mode Slave where subsystem failure precluded a normal fire control solution.

During Gunner Slave (modes 1 and 2), the squad leader retained control of the periscope to maintain search capability. However, since the gunner was in control, the gunner maintained control of guns and gunsight. The guns moved to gunsight line of sight. The gunner's triggers were enabled, and the squad leader's triggers were not enabled. The Operator's Manual (Crew) (Volume I of III, Gun, Air Defense Artillery, Self-Propelled: 40 mm, M247, Sgt York, July 1984) defined the slave mode as follows: "To lock either guns, gunsight, or periscope to certain position and then bringing remaining two to the same azimuth and elevation."

In Squad Leader Slave, the squad leader maintained control of the guns, turret, and gunsight. The guns and gunsight both moved to the periscope line of sight (LOS). The gunner had no grip control. The squad leader's triggers were enabled, but the gunner's triggers were not enabled.

As seems evident from the name, there was no slaving of the guns to the gunsight during the Gunner Free modes (5 and 6). System designers provided an abundance of system modes. The reasons for distinguishing between these two modes and for prohibiting firing when in an otherwise aggressive "non-acquisition" mode are not expressed in the Operator's Manual. Provision of redundancy does not seem a sufficient reason.

Acquisition Modes. There were six Acquisition modes. Any of them could be used throughout the engagement sequence. The 1553 Data Bus indicated the time at which a system mode was changed by a crew member, and what system mode the Fire Unit was in throughout the engagement sequence. The six acquisition modes were as follows:

7 = Gunner/SL, Laser Track, Radar Auto
8 = Gunner/SL, Radar Auto
9 = Gunner/SL, Laser Track, Radar Pointer
A = Gunner/SL, Radar Pointer
B = Gunner/SL, Laser Track, Radar, Optical
C = Gunner/SL, Radar, Optical

Modes 7 and 8 represented the highest level of automation during a target engagement sequence, since they both used a form of Radar Auto. Modes 9 and A represented a medium level of automation with the use of Radar Pointer. Modes B and C were indicative of the lowest level of automation based on the functions required to perform an optical engagement. In the optical mode, the squad leader detected and located a target visually by either using the periscope or by operating with head out of the turret. In the optical mode, all targets had to be identified visually by one of the crew members. Mode 7 was not employed during the Force-on-Force Target Engagement Sequences that were entered into the Data Base created by this research effort.

1553 Data Bus. The 1553 Data Bus documented the system modes that were used during the engagement sequence. Of some interest was the sequence of system modes used during each engagement. The number of acquisition modes selected, the number of non-acquisition modes selected, and the mode applying at time of trigger pull were retrieved and are shown in Table 5. Table 2 depicts the chronology of a portion of Trial 1035 as printed by the 1553 Data Bus listing. The listing indicates that System Mode 9 (Laser Track, Radar Pointer) was the system mode of operation throughout the firing sequence. The Fs running down the F column indicate continuous firing during the time sequence represented on the table. The sequence depicted has a total duration of 3.93 seconds.

For a better understanding of the relationship between the system modes and the 1553 Data Bus, knowledge of the procedures required to initiate target acquisition and engagement sequence using radar, laser, or both would be beneficial. The target acquisition and engagement sequence for Sgt York consisted of eight categories as shown in Figure 10.

Searching - The acquisition and engagement process was initiated by having the crew search for targets. Detecting is to find a potential target.

Table 2

1553 Data Bus, Trial 1035

TIME	SYSTEM MODE		FIRING		ACTIVITY
9 43.053	221.220	9 A G L R P	4 S B B F	D	LASER ON, WIDE BEA
9 43.075	221.242	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 43.121	221.288	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 43.143	221.310	9 A G L R P	4 S B B F		GUNSIGHT BORESIGHT NC
9 43.348	221.515	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 43.393	221.560	9 A G L . P	4 B B B F	R	RADAR CUE BLINKING
9 43.621	221.788	9 A G L . P	4 B B B F	R	FCC CLAIMS RADAR BROK
9 43.666	221.833	9 A G L . P	4 B B B F	R	FCC CLAIMS RADAR LOCK
9 43.757	221.924	9 A G L R P	4 S B B F	R	RADAR CUE SOLID
9 43.893	222.060	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 44.030	222.197	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 44.166	222.333	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 44.212	222.379	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 44.256	222.423	9 A G L R P	4 S B B F		IFF NOT FRIEND, TARGE
9 44.302	222.469	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 44.439	222.606	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 44.484	222.651	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 44.530	222.697	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 44.575	222.742	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 44.666	222.833	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 44.712	222.879	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 44.757	222.924	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 44.848	223.015	9 A G L . P	4 B B B F	R	RADAR CUE BLINKING
9 44.893	223.060	9 A G L . P	4 B B B F	R	FCC CLAIMS RADAR BROK
9 44.939	223.106	9 A G L . P	4 B B B F	R	FCC CLAIMS RADAR LOCK
9 45.075	223.242	9 A G L . P	4 B B B F	R	FCC CLAIMS RADAR BROK
9 45.121	223.288	9 A G L . P	4 B B B F	R	FCC CLAIMS RADAR LOCK
9 45.211	223.378	9 A G L R P	4 S B B F	R	RADAR CUE SOLID
9 45.393	223.560	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 45.439	223.606	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 45.575	223.742	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 45.666	223.833	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 45.757	223.924	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 45.802	223.969	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 45.848	224.015	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 45.984	224.151	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 46.029	224.196	9 A G L R P	4 S B B F		IFF NOT FRIEND, TARGE
9 46.302	224.469	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 46.348	224.515	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 46.529	224.696	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 46.757	224.924	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK
9 46.847	225.014	9 A G L R P	4 S B B F		IFF NOT FRIEND, TARGE
9 46.893	225.060	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR BROK
9 46.984	225.151	9 A G L R P	4 S B B F	R	FCC CLAIMS RADAR LOCK

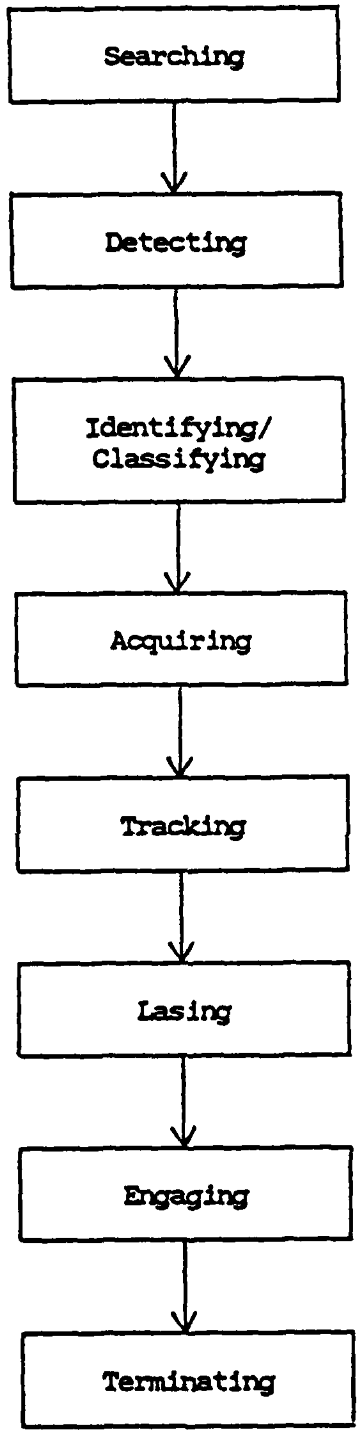


Figure 10. Target acquisition and engagement sequence for Sgt York.

Identifying is to determine whether the target is a friend or a foe. Classifying is to determine what type of vehicle or aircraft the foe is; and to determine, for multiple threats, which target possesses the greatest degree of threat. Acquiring - Acquiring the target required directing the tracking system to the target. In the case of the Sgt York, the tracking system could have been the radar, laser, or a combination of both. Lasing - Actually, lasing was a subset of acquisition and tracking, since it could have been used optionally in either of these categories. During tracking, the acquired target was followed by radar and/or laser. Engaging is to fire the system's guns at the target. Terminating is the ending of the engagement sequence, and this could happen in either of two ways. One, the crew member firing could stop pulling the trigger. Two, the fire control system could terminate the firing even though the crew member continued to pull the trigger. This was another aspect of the automatic functioning of the fire units.

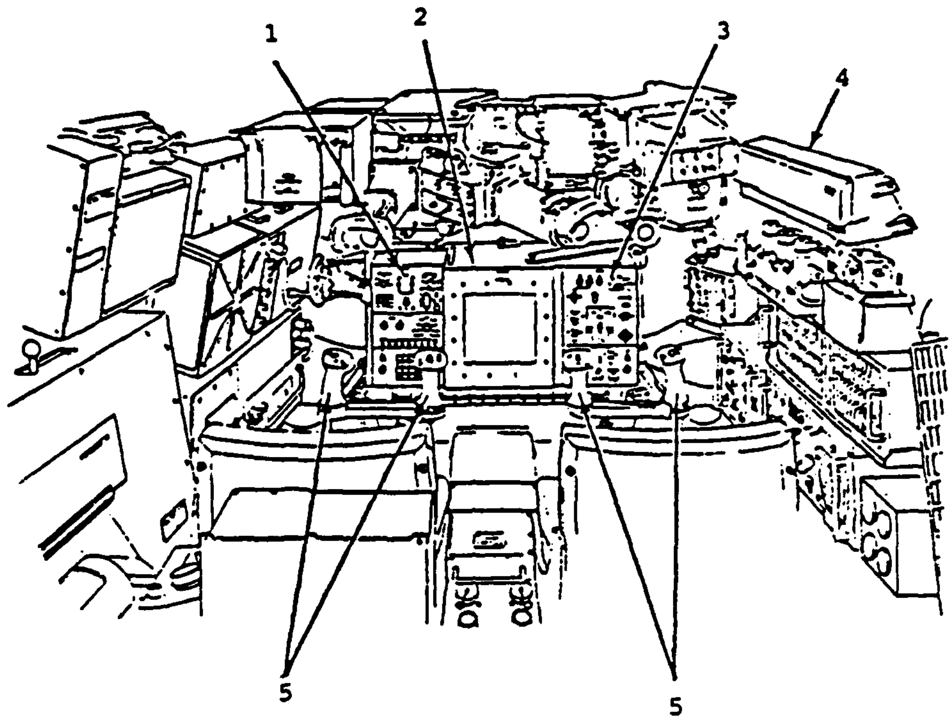
For an overview of the layout within the crew stations, see Figure 11. This illustrates the location of the gunner and squad leader control panels, the display, and the control grips.

Radar Auto. In the Radar Auto system mode, either the squad leader or the gunner activated the palm switch, and the turret gun switch was set to enable. The RDR switch was set to AUTO. The fire control computer directed the system to the target when the target was in the recommended range. The system was directed to the target of highest priority, e.g., greatest threat. A solid radar cue meant the target had been acquired by the radar. In the Radar Auto mode, the crew decision time was reduced more than in the other system modes. In the Radar Auto mode, once the auto mode had been set up by the crew, the only decision for the crew member to make was to pull the trigger when there was a solid fire cue. The Radar Auto procedures are illustrated in Figure 12.

The squad leader and the gunner each had identical right control grips. The right control grip had a toggle switch which placed the system in Radar Auto or Radar Pointer acquisition mode (see Figure 13).

Radar Pointer. Using the Radar Pointer acquisition mode, it was possible to designate one target with the pointer symbol on the display. Once the target was pointed, it was watched by search radar. It was possible to engage other targets while the radar watched the designated target. The squad leader or the gunner could designate the target using the Radar Pointer method. Radar pointer designation was performed by selecting a target on the display and holding the pointer on button down. At the same time, the thumb tracker was used to direct the pointer symbol to the designated target. When the pointer on symbol touched the target symbol, the POINTER ON button was released. The pointer locked on the target and moved with the target on the display. The flow of the sequence for the radar pointer activity is shown in Figure 14.

As in the Radar Auto acquisition mode, either the squad leader or the gunner used his right control grip for radar pointing. In this procedure, the toggle switch was moved to the pointer position. The left control grip was used to push and hold down the POINTER ON button. Concurrently, the THUMB TRACKER was used to direct the pointer to the target symbol on the display (see Figures 15 and 16).



1. GUNNER'S CONTROL PANEL: Contains controls for gun and ammunition setup, laser mode selection and arming, system mode selection, and 16-button keyboard for entering commands and data. Also contains indicator lamps to show status of systems.

2. DISPLAY: Shows target situation, vehicle coordinates, system status, operating menus, and fault isolation data, depending upon mode selected.

3. SQUAD LEADER'S CONTROL PANEL: Contains controls for selecting radar mode and search sector, arming guns, adjusting status of display symbols, and selecting power on-line status of major systems. Also contains indicator lamps to show status of different systems.

4. POWER DISTRIBUTION UNIT (PDU): Contains circuit breakers for electrical circuits in turret systems. Includes BATTLE SHORT S1 and TUR INTLK OVERRIDE S2 switches.

5. CONTROL GRIPS: Control turret and gun movement and target engagement functions.

Figure 11. Crew compartment components.

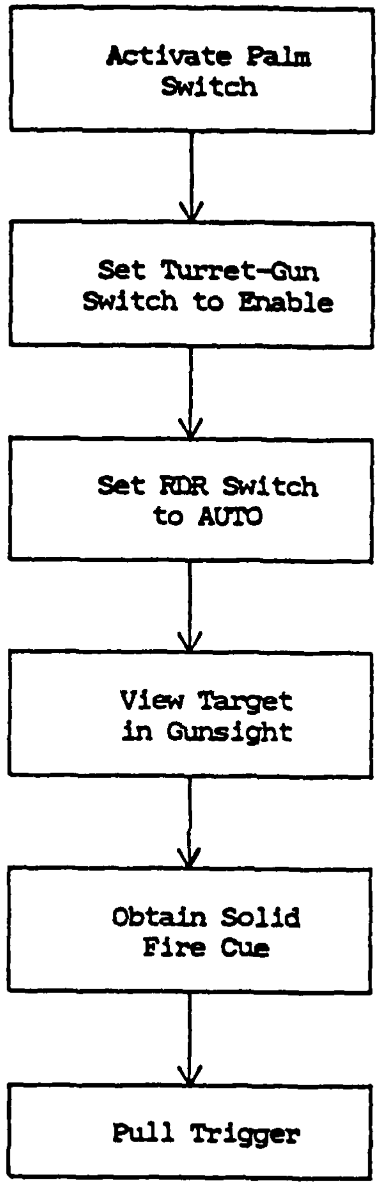


Figure 12. Radar Auto procedures.

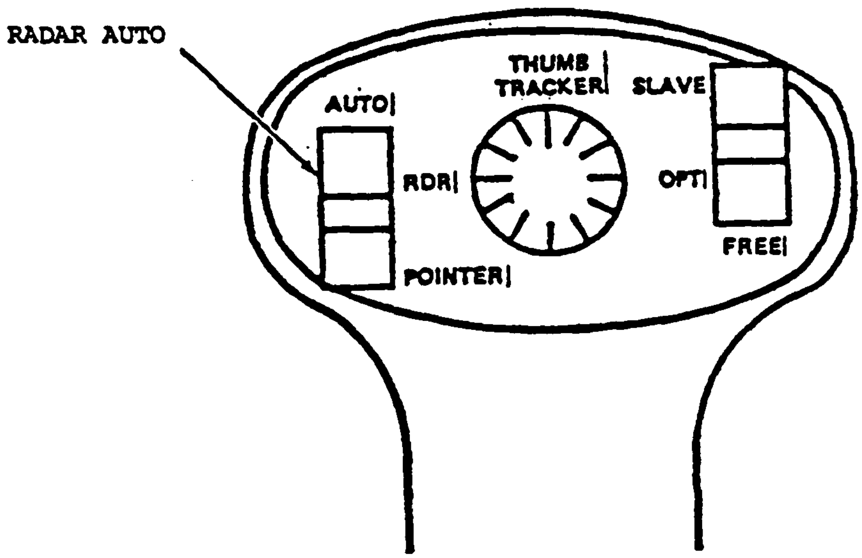


Figure 13. Right control grip, Radar Auto.

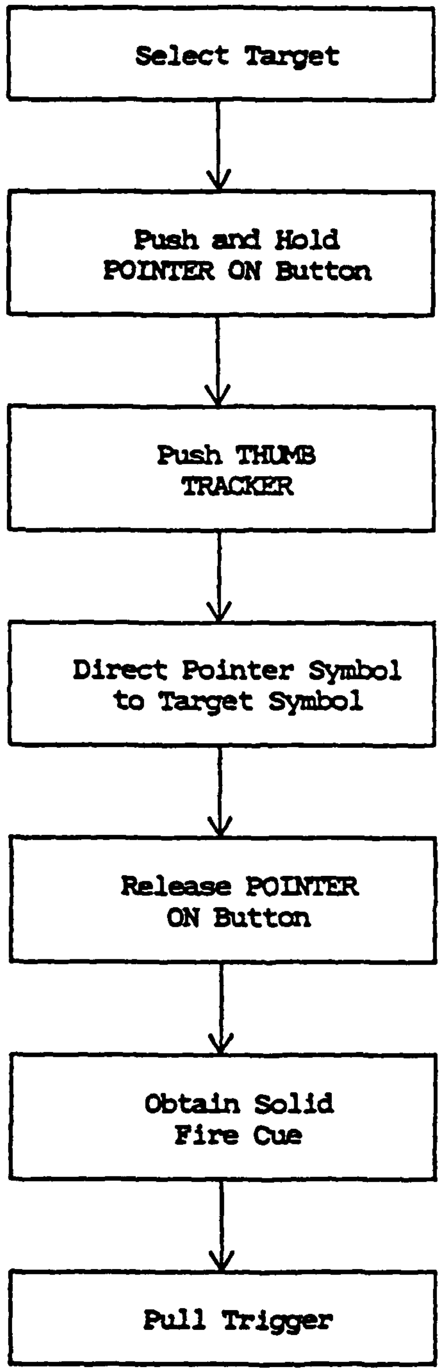


Figure 14. Radar Pointer procedures.

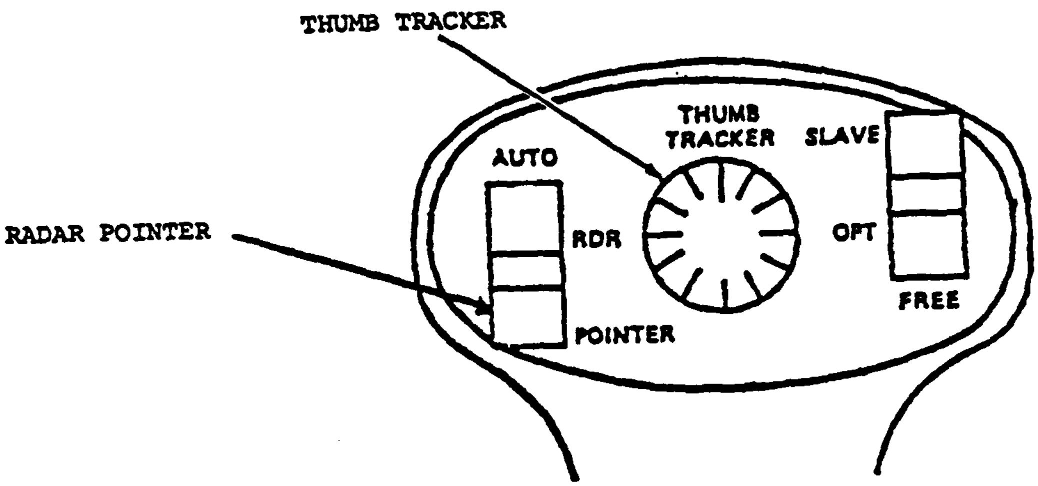


Figure 15. Right control grip, radar pointer and thumb tracker.

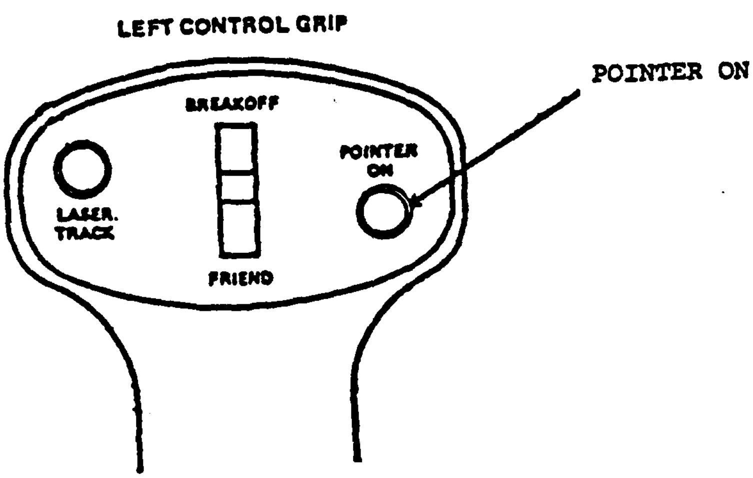


Figure 16. Left control grip.

Lasing Targets. There were two primary modes used for lasing a target. There was the Optical/Laser acquisition mode previously described as engaging targets without the support of radar capability. In the Optical/Laser mode, the IFF did not identify targets so that targets had to be visually identified during tracking. In the Optical mode, the only way to give target range and speed data to the fire control computer (FCC) was by lasing.

When added to either the Radar Auto mode or the Radar Pointer mode, lasing a target could provide greater accuracy to the radar-based fire control solution. Provided that the target could be seen in the gunsight and that there was time to arm the laser, greater accuracy was possible. A flow diagram of the lase procedure is presented in Figure 17.

To initiate the lase procedure, the GROUND-AIR switch was set for target type by the gunner. The switch was located on the gunner's control panel. In ground mode, the narrow laser beam matched coverage of the gunsight inner reticle circle, and point detonating ammunition was automatically selected. After the GROUND-AIR switch had been set, the laser switch was set to ARM by the gunner. The ARMED indicator lamp indicated the laser armed condition. See Figure 18 depicting the gunner's control panel for laser.

If the crew decided to lase a target without radar, then the gunner was to set the OPT switch to slave and release. This would place the gunner in gunner slave condition. The gunner was then in control. The guns moved to gunsight LOS, and the gunner's trigger was enabled. Concurrently, the squad leader was free to move the periscope for search activities, and the squad leader's trigger was not enabled. The squad leader's OPT switch was set to free, while the gunner's switch was set to slave. See Figure 19 for a line drawing of the gunner's right control grip which indicates the OPT toggle switch.

After the laser had been armed, the laser track button was pushed. Pushing the laser track button erased any earlier target range data. Gunsight control was given to the gunner, and the laser was prepared for firing. Figure 20 represents the gunner's left control grip and the location of the laser track button.

The thumb tracker (right control grip) was used to move the center of the small reticle circle to the selected target area (see Figure 19). As soon as the circle was moving at the same rate as the lased spot, the laser track button was released. There were laser cues on the display. The thumb tracker was used to continue to make small corrections as the target was tracked. Periscope and gunsight eye pieces blinked until the range data was received. When the range data was accepted, the laser cue came on steady. The target would now be considered in laser acquisition, and could be engaged.

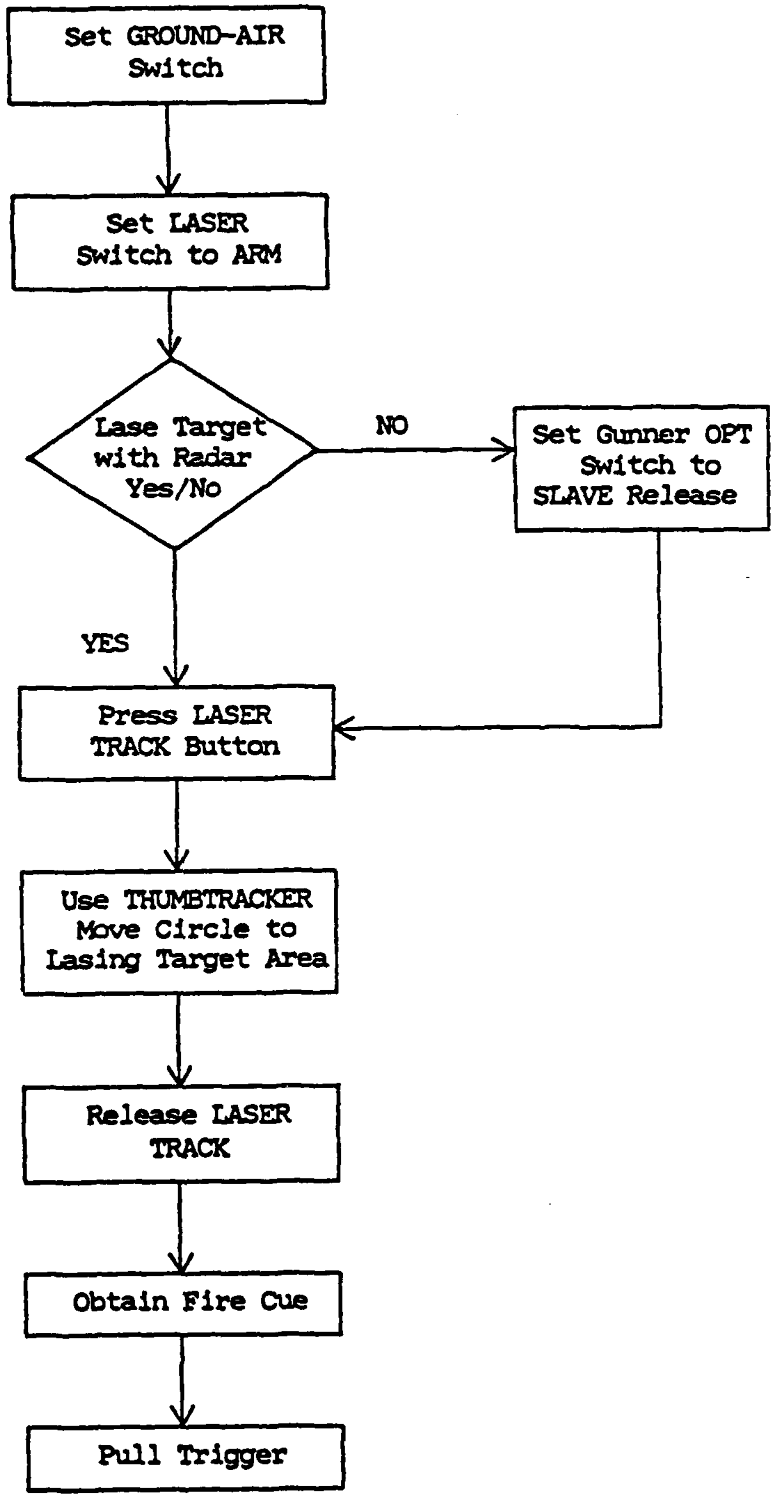


Figure 17. Lase procedures.

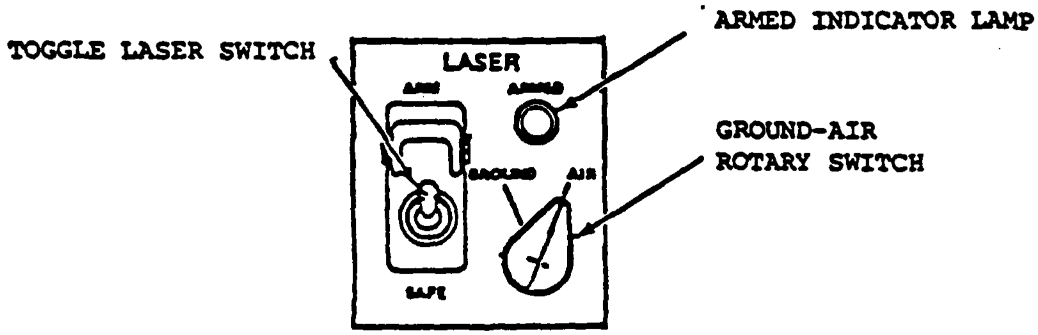


Figure 18. Gunner's control panel, laser.

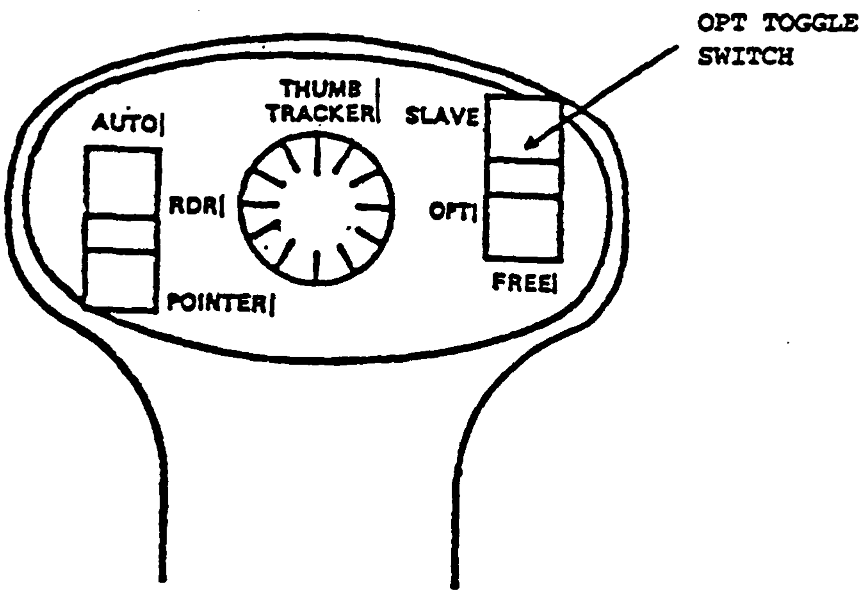


Figure 19. Gunner's right control grip, OPT switch and thumb tracker.

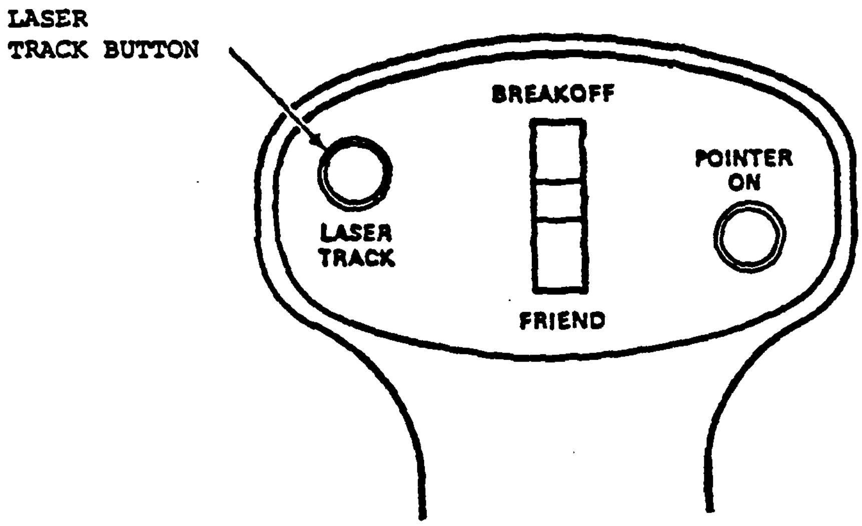


Figure 20. Gunner's left control grip showing laser track button.

A TES Performance Data Base

During the first half of 1985, follow-on evaluation tests (FOE I) were conducted to evaluate the performance of the Sgt York Air Defense Gun. FOE I for Sgt York had two phases, Force-on-Force and Live Fire. The Force-on-Force phase included 29 test trials in which Sgt York fire units were involved and which met pre-established criteria for validity. As described in the preceding section, a 1553 Data Bus was connected to each Sgt York fire unit taking part in the Force-on-Force trials. Consequently, it was possible to monitor the actions of the crew members as indicated by their button-pushing and switch actions. For example, records of switch actions showed when the radar pointer control was pressed or released, when the laser was turned on and off, and when the trigger was engaged and released. From the printout of the data bus information (See sample in Table 2), it was possible to tell what was done, when it was done, and by whose controls, the squad leader's or the gunner's.

By extracting data from the data bus record of activity during the Force-on-Force trials, an extensive body of data was compiled on the target engagement sequences that occured during Force-on-Force test trials. A total of 15 complete trials was analyzed. In selecting the trials to be analyzed, trial variables were considered and trials chosen so that all test conditions were represented within the selected trials. To make the effort manageable, while maximizing the usefulness of the obtained data distributions, only actions which led to complete target engagement sequences were extracted. That is, for an action or series of actions to appear in the data base that is presented and discussed in this report, it had to culminate in firing on a target. Each target that was actually fired on during the 15 trials selected for analysis was tracked back to its initial appearance. Action pertaining to that target then was identified and recorded for the period from time of appearance (the start of an engagement) to the time that firing on that target ceased (the end of an engagement). A total of 271 such target engagements were identified and analyzed for this report.

From start to end of a target engagement sequence, a number of tasks had to be carried out. The target had to be identified, selected, and classified; it had to be tracked and a Fire Solution calculated to make interception possible. A firing decision had to be made and implemented. The fire units' computers were available to aid the operators throughout the target engagement sequence. As has been explained in the preceding section, several operational modes were available to the Sgt York crewmen so that they could choose appropriate levels of automation.

The conditions and parameters of the Sgt York FOE I tests are described briefly below to provide a context for later discussions of variables used in the categorization and presentation of data. Following the test description, the final and major portion of this chapter presents the actual data obtained for the FOE I tests.

The Sgt York FOE I Tests

During the Sgt York FOE I Force-on-Force trials which were conducted at the Combat Development Experimentation Center (CDEC) at Fort Hunter-Liggett, CA, there were a total of 52 valid trials conducted. Of this total, 12 were

Vulcan baseline trials, 11 others were combined Chaparral and Vulcan trials, and 29 included Sgt York fire units. It was from this group of 29 trials that the subset of 15 was selected for analysis.

The Blue Force portrayed the friendly force and the Red Force simulated the enemy. In an attempt to have test conditions represent the variety of situations that might be encountered in an actual battlefield, the Blue battalion task force was assigned to a series of scenarios to be conducted against enemy vehicles and aircraft under various electronic warfare conditions with simulated enemy aircraft employing a variety of tactics, and with crews wearing nuclear, biological, and chemical (NBC) gear (i.e., Mission-Oriented Protective Posture (MOPP)).

During each of the Sgt York trials, from three to five Stinger crews were present for the Blue Force. In addition, two Chaparral fire units were deployed to the rear of the battalion task force. The Blue Force also had from 21 to 26 M-1 tanks, from 10 to 13 M-3s (infantry fighting vehicles), and usually an AH-1 (attack helicopter), although on Trial 1026 an OH-58 (observation helicopter) was used as a substitute.

The Red Force included two A-10s (fixed-wing aircraft) representing Frogfoot aircraft, two A-7s (fixed-wing aircraft) representing FITTERs, and from two to four AH-64s (attack helicopters) acting as HAVOC or HIND helicopters depending on the particular test conditions to be met. In addition, there were other support elements, including at least 16 M-60 tanks representing T-80 tanks.

Each Sgt York FOE I trial had originally been planned to have a duration of 72 hours. However, due to the constraints of instrumentation, data collection for each trial was limited to approximately 20 to 30 minutes. Even so, the Sgt York crew members were in their crew compartments for at least 2 to 3 hours for each trial.

Each trial was assigned a sequential trial number and each trial was assigned to one of three scenarios, to one of three helicopter tactical conditions, to one of three ECM levels, to day or night time, and to one of two MOPP levels. These conditions are described briefly below.

Scenario Conditions. Three different scenarios were used for the Force-on-Force trials: (1) Delay, (2) Attack, and (3) Road March. Each scenario differed by the technical mission assigned to the Blue Force. Two versions of each scenario type were implemented. The chief difference between the two versions was in the direction of orientation and thus the specifics of the terrain conditions encountered.

Valid Sgt York trials included 10 Delay scenario trials, 14 Attack scenario trials, and 5 Road March scenario trials. Four Delay scenario descriptions used site 1, Gabilan Valley, southeast, and six Delay scenarios used site 2, San Miguelito Loop, northwest. Six Attack trials used the San Miguelito Loop terrain site, southwest, designated as site 3. An additional eight Attack scenario descriptions used terrain site 4, Gabilan Valley, northwest. Only one Road March scenario trial used terrain site 5, San Miguelito Loop, southeast. Road March terrain site 6, Gabilan Valley, was used in four different trials.

Helicopter Tactics. Another of the variables introduced into the Sgt York FOE I trials concerned the tactics used by the simulated enemy rotary-wing aircraft. Two different types of threat were represented, Havoc and Hind aircraft. That is, in a given trial, threat rotary-wing aircraft represented either the Hind or the Havoc.

Two tactical variations were introduced when the Hind was the helicopter simulated. In some trials, the Hind used the tactic of hovering, and in other trials it used the tactic of running. The simulations of the Havoc only used the tactic of hovering. Thus, there were three combinations of helicopter-plus-tactical variations, one of which was assigned to each trial. Each trial was either a Havoc/hover, a Hind/hover, or a Hind/running trial.

ECM Conditions. The countermeasure types were termed Benign, Design, and Initial Operational Capability (IOC). In those trials assigned to the Benign ECM conditions, no electronic countermeasures were introduced. The Design condition was defined as electronic countermeasures consistent with Sgt York design specifications; it was the level originally intended to be used in Sgt York trials. The Initial Operating Capability (IOC) condition represented an advanced ECM environment, consistent with the level of electronic countermeasures that Sgt York was expected to encounter when fielded. Thus, it was the most stringent ECM condition used during Sgt York FOE I trials.

Time-of-Day. FOE I was initially seen as an opportunity to evaluate the ability of the Sgt York to function under both day and night conditions. Both road march scenarios were scheduled to be run at night and in the day, but operational difficulties and safety hazards encountered in the first nighttime trial (Trial 1040, Road March 6) led to a decision prior to the second night road march to deploy the fire units along the route of march during the pre-dusk hours while light was still available so that they did not have to be repositioned in the dark. Thus, the second night road march was only nominally a night trial. Because the operational conditions of the Road March 5 trial differed from those of the earlier night road march, only the early trial was used in the Day-Night comparison.

MOPP Level. Two levels of MOPP equipment were introduced as a variable in the FOE I trials. Two trials were conducted with the crews wearing MOPP Level 4. All other Force-on-Force trials were conducted at MOPP Level 1. The crew members started the trial by wearing MOPP gear around their lower legs with overboots on. The tactical operating procedure was to suit up partially before entering a vehicle. Crew members wore the MOPP overgarments around their lower legs for Level 1 MOPP. For the two MOPP 4 trials, the MOPP overgarments were pulled up and masks/hoods and gloves were donned (Babbitt, 1987).

The Sgt York FOE I Data Base

This section presents the data base compiled by extracting data from the Sgt York FOE I Force-on-Force test trials. First, Table 3 presents the performance data base, showing trial by trial mean times for each of 11 segments of the sequence. Table 4 summarizes the mean times, segment by segment, and includes the standard deviation and N for each measure. Table 5 presents data on the number of targets displayed when the selected target first appeared, the range at which the selected target first appeared, and information on system modes applicable to each engagement. It is organized, as was Table 3, by trial number and by fire unit and engagement number within each trial. The elements of Table 3 are discussed below in detail.

Table 3 presents the data extracted from the records of the actual performance of crew members and fire units as they took part in the Sgt York FOE I Force-on-Force test. As noted earlier, 15 of the 29 valid Sgt York trials were the focus of detailed analysis. All completed target engagement sequences (i.e., those in which a target was actually fired on) in those 15 trials, a total of 271 target engagement sequences, were analyzed. In Table 3, data on those 271 engagements are ordered by trial number, the first trial presented being Trial 1020 and the last trial presented being Trial 1048. A new page is started with each change of trial number, and some trials run over a single page of description.

Within each trial, the data are ordered by fire unit number, from 1 to 5, and within fire unit by engagement number. Fire unit number and engagement number are shown in the first column of Table 3. If a fire unit number is missing from the record of a given trial, it indicates that the fire unit either did not take part in that trial or did not finish any complete target engagements during that trial.

For each engagement detailed in Table 3, times are shown for 11 different time intervals. These 11 intervals represent four separate classes of data: Crew decision times, crew action times, system processing times, and summary measures. These classes are named in the top line of Table 3. In the second line, the column headings name the 11 time intervals. These 11 intervals, which are dependent variables, are defined and described below. In each case, the event or action that began the interval and the one that ended it are identified.

<u>Select/Classify Target</u>. The selection interval began when a target appeared on the plasma display. This event was indicated on a plot of the targets displayed that was taken from the 1553 data bus. It showed targets by number or letter with range (0-10 km) shown across the top of the plot and time along the left margin. The selection interval ended when the operator (squad leader or gunner) depressed either the radar pointer or the laser switch to begin target acquisition. The mean time taken to select a target was 7.9 seconds, for 221 engagements.

<u>Point Target</u>. This column records the time it took a crew member to get a target pointed; i.e., the interval between pointer depressed and pointer release, so long as the release was followed by the appearance on the 1553 data printout of a target number under "Target Pointed." To point a target, a crew member had to track the target while holding the pointer switch depressed. The mean time it took to point a target was 2.3 seconds, for 155 engagements.

<u>Lase Target</u>. This column records the time it took a crew member to indicate a target by lasing it. The time entered represents the interval between laser depression and laser release, if that release was followed by the appearance on the 1553 data printout of a target number under "Target Engaged." The mean time that the laser switch was depressed was 1.1 seconds, for 66 engagements.

Acquisition of Target. Once the tracking radar had locked onto the target selected and was able to follow it, the Radar Pointer Button or the Laser Button was released by computer signal. Later, the 1553 data bus indicated that a radar cue or a laser cue was on. The interval between the time that the crew action (pointing or lasing) terminated and the time that the radar or laser cue came on was recorded as the acquisition interval. The mean acquisition time for the 221 engagements involving Point Target and Lase Target was 3.5 seconds. The mean acquisition time for the 271 engagements recorded in Table 3 was 4.2 seconds.

Fire Solution by Computer: Blinking Cue. Once the target had been acquired by the tracking radar and had range as well as elevation and azimuth information, the fire control computer was able to calculate a fire control solution. When that solution had been obtained, the firing cue came on in the Sgt York crew compartment. A firing cue light might blink on and off, or it might simply come on and stay on. The former case was referred to as a "blinking" firing cue and the latter case was referred to as a "solid" firing cue. A blinking cue indicated a less certain solution than did a solid cue. The interval between the appearance of the radar or laser cue and the subsequent appearance of the blinking firing cue was entered as the time it took for Fire Solution by Computer: Blinking Cue. Whether or not to fire on a blinking firing cue rather than waiting for a solid cue (that might or might not appear) was left to the discretion of the operator. If the firing cue light stopped blinking and became a solid firing cue before the trigger was activated, "NA" was entered in the blinking cue column for that engagement. On 65 of the 271 engagements, firing began on a blinking fire cue. For those 65 cases, the mean time taken by the computer to produce a firing solution was 4.0 seconds.

Fire Solution by Computer: Solid Cue. If the firing cue light came on and stayed on, the time between Target Acquisition (indicated by the appearance of a radar cue or a laser cue light) and the onset of the solid firing cue was entered as Fire Solution by Computer: Solid Cue. A blinking fire cue might or might not precede a solid fire cue, but the time entered under "solid cue" was always calculated from the end of acquisition. Thus, the time to obtain a solid firing solution was not affected by whether or not a blinking fire cue occurred, and the time to solid firing cue could be compared across engagements. If a solid firing cue came on after a blinking firing cue and after firing had already begun, the time to onset of a solid cue is shown in parenthesis in Table 3 and is not taken into account in calculating the mean time. If the firing cue did not stop blinking, "NA" was entered under "Solid Cue." For the 206 engagements for which there was a solid fire cue presented prior to trigger depression, the mean time to onset of the solid fire cue was 2.6 seconds.

Comparing the mean time for Fire Solution: Blinking (4.0 seconds) with mean time for Fire Solution: Solid (2.6 seconds) suggests that the crew members may have had some informal criterion for how long they should wait for a fire cue to become solid, and, if the fire cue continued to blink after that time interval had passed, the operator decided not to wait longer but to fire on the blinking cue. Had he waited, perhaps there would have been a time for "fire cue solid" instead of "NA" in that column. It appears that it takes less time to achieve a solid fire cue than to achieve a blinking fire cue, it may be that for some engagements the solution was more difficult or tenuous and on such engagements the solution not only took longer but only reached the "blinking cue" stage.

Decision to Fire: After Blinking Cue. The time interval between the appearance of a firing cue and trigger depression by a crew member was recorded as decision-to-fire time. As noted earlier, although a solid firing cue indicated a higher probability of a successful engagement, a crew member could decide to fire on a blinking cue. Firing began a mean of 1.7 seconds following the onset of a blinking fire cue and 1.3 seconds after a solid fire cue. If there is an entry in the column headed "After Blinking Cue," it indicates that on that engagement, the operator fired on a blinking cue. The number entered indicates the delay in seconds from time of onset of blinking fire cue to time of trigger activation. If the trigger was not depressed while the fire cue was blinking, "NA" is entered.

Decision to Fire: After Solid Cue. The time between onset of a solid fire cue and trigger depression is entered in this column. If the operator fired before the solid firing cue appeared, "NA" is entered. On one engagement (Trial 1046, Fire Unit 2, Engagement 6), a negative number, -0.1, is entered under "After Solid Cue." On this occasion, the gunner activated the trigger just prior to the appearance of the firing cue. In this case when the fire cue came on, it was solid from the onset.

Time to Fire. This column represents a summary of the preceding steps of the TES. It tells how long it took after target presentation for firing to begin. The overall mean Time to Fire for all 271 engagements was 16.5 seconds, except for times enclosed in parentheses; those steps are not included in the Time-to-Fire total because they occurred simultaneously with other steps.

Fire Duration. This column indicates how long firing continued for each engagement. That is, it records the time interval from the beginning of trigger pull to the end of the engagement. Some engagements were ended when the gunner released the trigger. In other instances, the weapon system ended the engagement (stopped firing) when radar lock-on was lost. According to Sgt York operating manuals, firing was to continue for 3 to 7 seconds when firing in burst select mode. The mean Fire Duration for the 271 engagements was 8.0 seconds.

Total Engagement Duration. This column summarizes the time interval from the appearance of the target to the cessation of firing. The mean Engagement Duration across all 271 trials was 24.6 seconds.

Table 3

Performance Data Base. Target engagement time durations for Sgt York FOE I <u>Trial 1020</u> (4 Fire Units; 32 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	62.1	NA	01.0	00.1	NA	03.3	NA	01.1	67.6	11.8	79.4
Engmt. 2	35.7	NA	00.8	00.0	04.8	NA	00.8	NA	42.1	01.2	43.3
Engmt. 3	14.5	NA	01.0	00.1	03.0	NA	01.5	NA	20.1	01.1	21.2
Engmt. 4	0*	00.3	NA	04.7	NA	04.0	NA	00.8	09.8	05.0	14.8
Engmt. 5	29.6	NA	01.1	00.1	03.2	NA	02.0	NA	36.0	04.1	40.1
Engmt. 6	0*	02.2	NA	03.4	NA	02.2	NA	00.4	08.2	09.6	17.8
Engmt. 7	05.7	NA	00.9	00.0	NA	02.3	NA	00.5	09.4	09.3	18.7
Fire Unit 3											
Engmt. 1	18.8	NA	02.0	00.0	NA	06.6	NA	00.7	28.1	12.5	40.6
Engmt. 2	05.6	NA	00.8	00.1	NA	06.5	NA	00.4	13.4	03.6	17.0
Engmt. 3	00.4	02.0	NA	07.1	NA	05.4	NA	00.9	15.8	11.8	27.6
Engmt. 4	01.6	03.0	NA	02.5	NA	25.3	NA	04.4	36.8	01.8	38.6
Engmt. 5	01.8	01.3	NA	07.2	NA	01.2	NA	01.0	12.5	03.4	15.9

*Crew action was first indicator of target appearance.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1020 (4 Fire Units; 32 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 4											
Engmt. 1	06.3	06.4	NA	02.1	NA	01.6	NA	00.6	17.0	06.9	23.9
Engmt. 2	18.8	02.7	NA	03.6	NA	01.5	NA	04.7	31.3	10.9	42.2
Engmt. 3	06.8	02.0	NA	04.1	NA	01.3	NA	00.4	14.6	11.6	26.2
Engmt. 4	04.2	06.9	NA	10.3	NA	01.8	NA	15.3	38.5	02.0	40.5
Engmt. 5	04.0	01.1	NA	10.8	NA	01.3	NA	08.4	25.6	02.7	28.3
Engmt. 6	14.0	03.4	NA	03.5	NA	01.3	NA	02.9	25.1	04.9	30.0
Engmt. 7	01.9	00.0	NA	02.2	NA	01.3	NA	00.5	05.9	02.3	08.2
Engmt. 8	**	**	**	29.1	NA	00.0	NA	00.0	29.1	04.7	33.8
Engmt. 9	**	**	**	08.2	00.0	NA	00.0	NA	08.2	05.6	13.8
Engmt. 10	18.5	03.0	NA	03.5	NA	01.4	NA	00.3	26.7	21.3	48.0
Engmt. 11	0*	NA	01.1	00.2	04.1	(10.8)	00.9	NA	06.3	11.4	17.7
Engmt. 12	**	**	**	00.0	NA	00.0	NA	00.0	00.0	07.9	07.9
Engmt. 13	**	**	**	02.0	NA	00.0	NA	00.0	02.0	11.2	13.2
Engmt. 14	**	**	**	14.8	NA	00.0	NA	00.0	14.8	15.9	30.7
Engmt. 15	09.3	03.6	NA	02.8	01.9	NA	01.0	NA	18.6	03.5	22.1
Engmt. 16	10.2	00.8	NA	05.6	NA	00.8	NA	01.2	18.6	22.8	41.4
Engmt. 17	02.4	01.3	NA	04.1	NA	03.4	NA	00.6	11.8	08.8	20.6
Engmt. 18	**	**	**	08.4	NA	00.0	NA	00.0	08.4	03.4	11.8
Engmt. 19	63.1	03.6	NA	03.8	NA	01.2	NA	02.9	74.6	19.1	93.7
Fire Unit 5											
Engmt. 1	**	**	**	02.6	NA	00.0	NA	00.2	02.8	11.9	14.7

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1021 (3 Fire Units; 14 Engagements). (All times in seconds.)

TASK CATEGORY——>	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function——>	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	03.0	02.0	NA	06.0	NA	01.2	NA	00.8	13.0	03.9	16.9
Fire Unit 3											
Engmt. 1	0*	03.3	NA	05.2	NA	01.3	NA	01.6	11.4	09.0	20.4
Engmt. 2	**	**	**	10.9	NA	02.1	NA	00.0	13.0	04.3	17.3
Engmt. 3	**	**	**	04.5	00.0	NA	00.0	NA	04.5	03.0	07.5
Engmt. 4	0*	NA	00.5	00.0	NA	02.3	NA	01.6	04.4	05.1	09.5
Engmt. 5	13.0	02.9	NA	05.3	NA	01.3	NA	02.2	24.7	13.1	37.8
Engmt. 6	**	**	**	01.8	NA	00.0	NA	04.7	06.5	03.2	09.7
Fire Unit 5											
Engmt. 1	0*	NA	00.2	00.1	NA	03.1	NA	00.5	03.9	01.8	05.7
Engmt. 2	18.8	01.6	NA	05.4	02.4	(05.8)	01.6	NA	29.8	16.7	46.5
Engmt. 3	00.9	00.2	NA	05.9	NA	00.3	NA	03.0	10.3	00.5	10.8
Engmt. 4	09.6	01.5	NA	04.2	03.5	(17.5)	12.6	NA	31.4	05.9	37.3
Engmt. 5	**	**	**	00.6	NA	00.0	NA	00.0	00.6	05.2	05.8
Engmt. 6	**	**	**	00.0	NA	00.0	NA	00.0	00.0	14.6	14.6
Engmt. 7	**	**	**	05.8	00.0	NA	00.0	NA	05.8	06.4	12.2

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1022 (4 Fire Units; 34 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	0*	NA	02.4	00.2	NA	02.6	NA	00.8	06.0	07.5	13.5
Engmt. 2	0*	03.1	(01.8)	02.6	NA	03.0	NA	00.7	09.4	14.9	24.3
Fire Unit 3											
Engmt. 1	05.2	02.6	NA	03.1	03.9	NA	02.2	NA	17.0	02.1	19.1
Engmt. 2	04.2	01.1	NA	06.0	(03.8)	03.8	(00.6)	00.6	15.7	12.3	28.0
Engmt. 3	06.9	NA	00.7	00.1	NA	03.0	NA	01.2	11.9	00.3	12.2
Engmt. 4	**	**	**	03.0	(00.9)	01.1	(01.1)	00.9	05.0	02.9	07.9
Engmt. 5	**	**	**	15.9	00.0	NA	00.0	NA	15.9	02.2	18.1
Engmt. 6	08.9	02.5	NA	02.4	NA	02.9	NA	00.5	17.2	10.5	27.7
Engmt. 7	06.6	01.0	NA	03.7	NA	02.1	NA	00.6	14.0	04.9	18.9
Engmt. 8	**	**	**	09.3	NA	00.0	NA	00.0	09.3	06.1	15.4
Engmt. 9	25.8	NA	00.9	00.1	NA	02.8	NA	00.7	30.3	16.7	47.0
Engmt. 10	01.9	03.1	NA	05.6	NA	01.9	NA	00.9	13.4	11.7	25.1
Engmt. 11	04.6	01.7	NA	04.3	NA	02.3	NA	00.5	13.4	06.1	19.5
Engmt. 12	0*	NA	03.7	00.1	NA	07.4	NA	04.3	15.5	07.5	23.0
Engmt. 13	18.2	03.5	NA	10.9	(01.5)	01.3	(00.4)	00.6	34.5	01.4	35.9
Engmt. 14	19.1	03.3	NA	04.5	NA	01.3	NA	00.7	28.9	05.8	34.7
Engmt. 15	02.0	01.4	NA	04.1	NA	01.2	NA	01.1	09.8	16.7	26.5
Engmt. 16	**	**	**	05.3	NA	00.0	NA	00.0	05.3	13.1	18.4
Engmt. 17	**	**	**	17.6	NA	00.0	NA	00.0	17.6	01.1	18.7
Engmt. 18	19.1	01.5	NA	07.4	NA	01.2	NA	00.8	30.0	00.9	30.9

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1022 (4 Fire Units; 34 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 4											
Engmt. 1	07.3	07.3	(01.6)	10.4	14.3	NA	00.7	NA	40.0	11.5	51.5
Engmt. 2	0*	NA	00.6	00.1	(03.3)	03.2	(00.4)	00.5	04.4	14.1	18.5
Engmt. 3	23.1	NA	00.7	00.1	NA	03.2	NA	00.8	27.9	09.8	37.7
Engmt. 4	0*	NA	00.3	00.2	04.3	(07.1)	00.9	NA	05.7	04.3	10.0
Fire Unit 5											
Engmt. 1	0*	NA	01.3	00.1	NA	02.4	NA	03.0	06.8	17.1	23.9
Engmt. 2	0*	NA	00.4	00.1	03.5	NA	04.8	NA	08.8	29.5	38.3
Engmt. 3	**	**	**	00.0	00.1	NA	00.1	NA	00.2	13.2	13.4
Engmt. 4	0*	NA	01.5	00.0	NA	02.3	NA	00.5	04.3	25.6	29.9
Engmt. 5	0*	NA	02.0	00.0	NA	02.8	NA	00.6	05.4	15.7	21.1
Engmt. 6	0*	NA	03.9	00.1	NA	04.3	NA	01.9	10.2	02.2	12.4
Engmt. 7	0*	NA	00.9	00.0	NA	02.3	NA	00.5	03.7	29.3	33.0
Engmt. 8	0*	NA	01.4	00.1	NA	04.1	NA	00.3	05.9	02.6	08.5
Engmt. 9	0*	NA	04.4	00.2	NA	02.7	NA	00.4	07.7	24.0	31.7
Engmt. 10	0*	NA	03.3	00.2	NA	02.5	NA	00.5	06.5	23.2	29.7

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1023 (3 Fire Units; 13 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	11.2	01.9	NA	04.0	NA	01.5	NA	00.8	19.4	14.8	34.2
Engmt. 2	00.4	06.7	NA	06.7	(04.8)	04.6	(01.1)	01.3	19.7	01.6	21.3
Engmt. 3	0*	NA	01.9	00.1	NA	03.6	NA	00.7	06.3	23.2	29.5
Engmt. 4	00.8	00.7	NA	01.9	NA	01.3	NA	00.7	05.4	09.7	15.1
Engmt. 5	35.2	05.3	(03.2)	02.7	05.4	NA	05.5	NA	54.1	52.8	106.9
Engmt. 6	0*	NA	00.4	00.1	02.9	NA	01.3	NA	04.7	30.7	35.4
Fire Unit 3											
Engmt. 1	17.9	02.6	(01.4)	05.1	03.5	NA	02.5	NA	31.6	07.0	38.6
Engmt. 2	0*	NA	01.3	00.0	NA	02.3	NA	00.8	04.4	51.3	55.7
Engmt. 3	04.9	NA	01.0	00.2	NA	03.7	NA	00.6	10.4	06.7	17.1
Fire Unit 4											
Engmt. 1	19.2	01.6	NA	02.7	NA	02.6	NA	01.9	28.0	06.2	34.2
Engmt. 2	27.6	00.9	NA	03.3	NA	02.9	NA	00.6	35.3	15.1	50.4
Engmt. 3	**	**	**	00.0	(06.5)	09.9	(05.5)	02.1	12.0	17.9	29.9
Engmt. 4	06.6	01.5	NA	03.6	NA	02.7	NA	00.5	14.9	03.3	18.2

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1026</u> (4 Fire Units; 12 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	01.8	01.7	(04.8)	04.5	03.8	(13.3)	01.8	NA	13.6	08.5	22.1
Engmt. 2	**	**	**	00.0	NA	00.0	NA	00.0	00.0	08.3	08.3
Engmt. 3	09.6	NA	00.6	00.1	NA	03.0	NA	00.3	13.6	08.9	22.5
Fire Unit 3											
Engmt. 1	13.8	NA	00.4	00.2	NA	03.1	NA	00.7	18.2	05.0	23.2
Fire Unit 4											
Engmt. 1	00.4	NA	01.0	00.1	03.0	NA	00.8	NA	05.3	11.5	16.8
Fire Unit 5											
Engmt. 1	0*	NA	01.0	00.2	NA	03.5	NA	00.7	05.4	00.1	05.5
Engmt. 2	15.9	NA	01.2	00.1	04.2	(10.9)	01.3	NA	22.7	14.5	37.2
Engmt. 3	(07.7)	NA	(01.5)	06.3‡	(05.5)	01.3	(00.1)	04.3	11.9	02.8	14.7
Engmt. 4	**	**	**	15.1	02.5	(09.0)	00.1	NA	17.7	19.1	36.8
Engmt. 5	06.6	01.2	(01.6)	06.5	(04.0)	09.0	(06.3)	01.3	24.6	14.2	38.8
Engmt. 6	04.4	NA	00.6	00.1	03.2	NA	00.1	NA	08.4	02.7	11.1
Engmt. 7	(33.5)	(02.1)	NA	31.7‡	06.2	NA	02.7	NA	40.6	03.7	44.3

*Crew action was *first indicator of* target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.
‡System acquired target prior to crew action.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1027 (4 Fire Units; 25 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	**	**	**	14.7	NA	00.0	NA	00.5	15.2	12.9	28.1
Fire Unit 3											
Engmt. 1	13.3	00.2	NA	02.5	03.2	NA	01.5	NA	20.7	00.6	21.3
Engmt. 2	0*	07.0	NA	02.5	NA	01.5	NA	00.9	11.9	05.3	·17.2
Engmt. 3	12.1	02.8	NA	06.6	NA	01.4	NA	01.8	24.7	03.9	28.6
Engmt. 4	02.1	00.3	NA	04.4	NA	01.3	NA	01.6	09.7	04.1	13.8
Engmt. 5	03.6	01.3	NA	07.3	NA	01.2	NA	00.9	14.3	07.0	21.3
Engmt. 6	04.7	NA	00.3	00.1	NA	03.1	NA	00.0	08.2	05.2	13.4
Engmt. 7	**	**	**	09.4	(00.0)	00.2	(12.0)	11.8	21.4	01.3	22.7
Engmt. 8	**	**	**	09.9	NA	04.7	NA	02.6	17.2	10.3	27.5
Fire Unit 4											
Engmt. 1	02.0	01.9	NA	04.4	04.6	NA	03.5	NA	16.4	01.2	17.6
Engmt. 2	00.4	01.1	NA	02.0	NA	01.6	NA	01.2	06.3	08.1	14.4
Engmt. 3	0*	01.5	NA	03.0	NA	01.6	NA	01.4	07.5	03.1	10.6
Engmt. 4	00.2	02.0	NA	08.6	03.8	(09.5)	02.9	NA	17.5	10.7	28.2
Engmt. 5	06.0	01.9	NA	04.6	NA	04.1	NA	00.7	17.3	08.0	25.3
Engmt. 6	09.3	02.4	NA	12.0	NA	00.3	NA	01.2	25.2	07.6	32.8
Engmt. 7	01.3	02.9	NA	05.3	NA	01.5	NA	01.1	12.1	06.4	18.5
Engmt. 8	14.5	01.9	NA	03.0	NA	02.6	NA	00.5	22.5	00.1	22.6
Engmt. 9	**	**	**	00.0	NA	00.0	NA	00.0	00.0	07.7	07.7
Engmt. 10	05.7	06.2	NA	03.1	NA	01.3	NA	00.4	16.7	02.9	19.6

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1027</u> (4 Fire Units; 25 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 5											
Engmt. 1	05.2	02.8	(02.8)	03.0	NA	04.0	NA	01.8	16.8	13.2	30.0
Engmt. 2	**	**	**	06.5	NA	00.0	NA	03.4	09.9	02.0	11.9
Engmt. 3	16.3	01.0	(02.1)	01.7	03.7	NA	04.2	NA	26.9	01.0	27.9
Engmt. 4	15.0	00.6	(00.7)	05.1	NA	02.5	NA	01.1	24.3	04.3	28.6
Engmt. 5	03.0	02.6	(01.7)	03.4	NA	01.7	NA	03.6	14.3	04.4	18.7
Engmt. 6	07.7	(01.5)	00.7	00.1	NA	01.3	NA	01.8	11.6	02.5	14.1

**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1029 (3 Fire Units; 12 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 2											
Engmt. 1	00.6	04.0	(01.0)	02.6	NA	01.5	NA	01.6	10.3	15.1	25.4
Engmt. 2	17.8	01.5	(02.0)	02.7	NA	09.8	NA	01.4	33.2	06.5	39.7
Engmt. 3	00.6	02.2	NA	04.9	NA	02.7	NA	00.9	11.3	02.7	14.0
Engmt. 4	**	**	**	07.6	NA	00.0	NA	00.0	07.6	09.4	17.0
Engmt. 5	04.5	02.9	(01.0)	05.4	NA	02.7	NA	02.0	17.5	23.3	40.8
Fire Unit 4											
Engmt. 1	06.2	01.8	NA	03.4	NA	02.2	NA	01.0	14.6	09.7	24.3
Engmt. 2	0*	01.9	NA	03.8	NA	01.4	NA	00.4	07.5	07.4	14.9
Engmt. 3	27.1	01.3	NA	01.9	03.2	NA	02.6	NA	36.1	08.4	44.5
Fire Unit 5											
Engmt. 1	Radar Auto --------->			06.5	01.4	(07.0)	01.3	NA	09.2	05.8	15.0
Engmt. 2	07.1	00.7	NA	06.4	NA	00.3	NA	00.9	15.4	00.2	15.6
Engmt. 3	**	**	**	10.8	NA	00.0	NA	00.0	10.8	00.1	10.9
Engmt. 4	05.2	00.7	(00.9)	08.3	NA	02.4	NA	01.1	17.7	12.9	30.6

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1035</u> (4 Fire Units; 21 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer: Blinking Cue	Fire Solution by Computer: Solid Cue	Decision to Fire: After Blinking Cue	Decision to Fire: After Solid Cue	Time to Fire	Fire Duration	Total Engmt. Duration
Fire Unit 1											
Engmt. 1	0*	NA	00.1	00.2	NA	04.3	NA	01.3	05.9	23.4	29.3
Engmt. 2	(18.6)	NA	(00.1)	14.6‡	07.5	NA	00.9	NA	23.0	25.1	48.1
Engmt. 3	03.7	NA	00.1	00.1	06.8	NA	01.5	NA	12.2	11.7	23.9
Engmt. 4	02.2	02.4	(00.4)	02.3	04.0	NA	02.2	NA	13.1	39.5	52.6
Engmt. 5	0*	NA	00.9	00.0	NA	03.0	NA	00.4	04.3	10.7	15.0
Engmt. 6	00.6	02.2	(00.6)	04.0	NA	01.8	NA	00.6	09.2	10.4	19.6
Engmt. 7	01.6	03.5	(02.3)	02.8	NA	01.8	NA	03.9	13.6	12.1	25.7
Engmt. 8	41.0	NA	01.1	00.1	NA	08.3	NA	00.5	51.0	02.8	53.8
Fire Unit 2											
Engmt. 1	0*	NA	01.1	00.1	NA	02.1	NA	01.2	04.5	06.1	10.6
Engmt. 2	19.3	NA	01.0	00.0	NA	02.4	NA	00.2	22.9	05.0	27.9
Engmt. 3	**	**	**	16.7	NA	00.0	NA	00.0	16.7	00.8	17.5
Engmt. 4	08.8	01.6	NA	03.4	10.4	NA	01.1	NA	25.3	05.0	30.3
Engmt. 5	(18.6)	NA	(03.9)	18.9‡	07.0	NA	00.9	NA	26.8	42.9	69.7

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.
‡System acquired target independent of crew action.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1035 (4 Fire Units; 21 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 3											
Engmt. 1	0*	02.5	NA	04.1	NA	03.0	NA	01.6	11.2	27.3	38.5
Engmt. 2	0*	02.3	NA	06.5	NA	00.3	NA	00.8	09.9	00.2	10.1
Engmt. 3	00.2	01.7	NA	05.6	NA	03.6	NA	01.3	12.4	03.2	15.6
Engmt. 4	01.6	03.4	(05.4)	11.1	NA	00.4	NA	32.3	48.8	05.7	54.5
Engmt. 5	21.7	02.2	NA	05.1	NA	01.2	NA	00.1	30.3	00.2	30.5
Fire Unit 4											
Engmt. 1	0*	04.6	NA	03.6	NA	02.1	NA	01.0	11.3	04.5	15.8
Engmt. 2	**	**	**	01.6	NA	00.0	NA	00.0	01.6	06.7	08.3
Engmt. 3	00.7	03.9	NA	07.7	NA	01.5	NA	01.1	14.9	04.0	18.9

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1036 (4 Fire Units; 13 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer: Blinking Cue	Fire Solution by Computer: Solid Cue	Decision to Fire: After Blinking Cue	Decision to Fire: After Solid Cue	Time to Fire	Fire Duration	Total Engmt. Duration
Fire Unit 1											
Engmt. 1	25.3	02.7	(01.0)	05.3	NA	01.5	NA	00.9	35.7	01.1	36.8
Engmt. 2	**	**	**	11.1	NA	00.0	NA	00.0	11.1	05.1	16.2
Engmt. 3	25.3	NA	01.9	00.0	03.0	NA	00.9	NA	31.1	04.8	35.9
Engmt. 4	08.5	02.1	(01.1)	03.9	NA	02.1	NA	01.7	18.3	19.0	37.3
Fire Unit 2											
Engmt. 1	46.0	00.7	(00.3)	07.2	(01.6)	04.6	(03.6)	00.6	59.1	02.7	61.8
Fire Unit 3											
Engmt. 1	04.4	01.6	NA	03.7	NA	01.4	NA	00.7	11.8	11.1	22.9
Engmt. 2	03.6	00.2	(01.7)	19.6	NA	27.1	NA	00.5	51.0	10.6	61.6
Fire Unit 4											
Engmt. 1	01.6	02.0	NA	03.6	NA	03.6	NA	00.4	11.2	03.5	14.7
Engmt. 2	05.1	00.7	NA	03.5	NA	01.6	NA	00.6	11.5	03.6	15.1
Engmt. 3	0*	01.0	NA	03.6	NA	05.3	NA	01.5	11.4	04.0	15.4
Engmt. 4	20.9	01.0	NA	02.3	01.3	(02.0)	00.5	NA	26.0	03.3	29.3
Engmt. 5	07.4	01.0	NA	05.5	NA	01.2	NA	00.4	15.5	06.3	21.8
Engmt. 6	02.0	01.8	NA	03.5	NA	01.2	NA	00.5	09.0	01.7	10.7

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1039 (4 Fire Units; 18 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	02.4	01.1	NA	04.7	NA	02.9	NA	00.4	11.5	02.2	13.7
Engmt. 2	08.0	00.9	NA	03.7	07.0	NA	01.1	NA	20.7	02.5	23.2
Engmt. 3	13.6	00.4	(00.6)	10.8	NA	05.6	NA	00.7	31.1	09.8	40.9
Engmt. 4	00.3	01.5	(00.7)	22.1	(01.5)	01.5	(00.9)	00.9	26.3	00.1	26.4
Fire Unit 2											
Engmt. 1	01.6	03.6	(01.4)	02.8	03.5	(07.7)	01.8	NA	13.3	10.9	24.2
Engmt. 2	13.7	01.8	NA	02.8	NA	01.2	NA	02.6	22.1	00.8	22.9
Engmt. 3	09.6	02.5	(02.8)	06.7	NA	15.4	NA	00.5	34.7	03.5	38.2
Engmt. 4	03.8	01.0	NA	03.0	NA	01.2	NA	00.5	09.5	10.9	20.4
Fire Unit 3											
Engmt. 1	05.8	01.6	(01.3)	11.4	NA	03.4	NA	01.3	23.5	05.9	29.4
Engmt. 2	34.3	00.6	(00.9)	02.6	NA	05.4	NA	01.0	43.9	01.2	45.1
Engmt. 3	16.2	(00.2)	00.6	00.0	NA	02.0	NA	00.3	19.1	02.0	21.1
Engmt. 4	09.9	NA	00.3	00.1	NA	02.2	NA	00.4	12.9	04.7	17.6
Engmt. 5	07.6	02.0	NA	03.0	NA	02.4	NA	00.5	15.5	05.4	20.9

( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1039 (4 Fire Units; 18 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 4											
Engmt. 1	08.7	03.4	NA	06.3	NA	01.3	NA	00.7	20.4	00.2	20.6
Engmt. 2	18.1	00.7	NA	02.7	01.9	NA	00.7	NA	24.1	03.8	27.9
Engmt. 3	03.0	02.2	(00.6)	10.6	08.3	(13.7)	00.7	NA	24.8	09.9	34.7
Engmt. 4	01.4	NA	00.5	00.1	(02.5)	04.4	(02.1)	00.2	06.6	10.4	17.0
Engmt. 5	0*	NA	00.2	00.1	NA	01.6	NA	00.5	02.4	08.2	10.6

*Crew action was first indicator of target appearance.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1040</u> (2 Fire Units; 7 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->					Fire Solution by Computer		Decision to Fire				
	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue	Time to Fire	Fire Duration	Total Engmt. Duration
Fire Unit 2											
Engmt. 1	09.4	04.3	NA	03.9	04.3	NA	01.2	NA	23.1	06.0	29.1
Engmt. 2	02.8	01.0	NA	07.4	06.8	NA	00.6	NA	18.6	00.8	19.4
Engmt. 3	07.2	01.9	NA	02.7	NA	03.5	NA	00.6	15.9	09.3	25.2
Fire Unit 4											
Engmt. 1	00.3	00.8	NA	02.9	07.2	NA	01.5	NA	12.7	00.2	12.9
Engmt. 2	18.1	06.2	NA	02.9	04.2	NA	00.8	NA	32.2	09.4	41.6
Engmt. 3	02.0	00.9	NA	02.9	NA	13.2	NA	00.4	19.4	01.7	21.1
Engmt. 4	05.9	06.3	NA	01.9	NA	04.3	NA	00.5	18.9	06.5	25.4

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1041</u> (3 Fire Units; 16 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	03.7	02.5	NA	02.7	NA	01.6	NA	00.9	11.4	00.9	12.3
Engmt. 2	32.6	NA	00.2	00.2	NA	02.3	NA	00.4	35.7	00.9	36.6
Fire Unit 3											
Engmt. 1	27.9	01.5	NA	03.9	NA	01.4	NA	00.5	35.2	11.0	46.2
Engmt. 2	01.6	02.8	NA	04.0	03.3	(11.3)	00.7	NA	12.4	07.4	19.8
Fire Unit 5											
Engmt. 1	0*	NA	00.9	00.1	NA	02.2	NA	06.0	09.2	26.8	36.0
Engmt. 2	00.7	02.0	NA	04.9	NA	01.1	NA	00.9	09.6	08.2	17.8
Engmt. 3	**	**	**	03.0	NA	00.0	NA	00.0+	03.0	06.6	09.6
Engmt. 4	**	**	**	01.7	00.0	NA	00.0+	NA	01.7	01.1	02.8
Engmt. 5	0*	NA	01.7	00.2	04.9	NA	01.9	NA	08.7	02.0	10.7
Engmt. 6	06.7	02.4	NA	03.1	NA	02.9	NA	02.0	17.1	32.2	49.3
Engmt. 7	25.2	01.0	(00.8)	04.1	NA	02.4	NA	00.0+	32.7	03.5	36.2
Engmt. 8	01.9	02.1	(01.1)	04.3	03.2	NA	01.5	NA	13.0	01.2	14.2
Engmt. 9	0*	04.5	NA	02.2	NA	01.5	NA	00.6	08.8	09.0	17.8
Engmt. 10	04.1	00.6	NA	00.4	NA	00.0	NA	01.3	06.4	02.6	09.0
Engmt. 11	**	**	**	05.2	NA	03.0	NA	00.4	08.6	02.8	11.4
Engmt. 12	**	**	**	02.9	NA	00.0	NA	00.0+	02.9	14.2	17.1

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.
+No trigger release between targets.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1042</u> (4 Fire Units; 14 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	21.9	01.8	NA	02.6	04.0	NA	01.1	NA	31.4	13.0	44.4
Engmt. 2	09.6	00.7	NA	02.4	10.8	NA	00.8	NA	24.3	04.9	29.2
Fire Unit 2											
Engmt. 1	00.6	NA	00.8	00.1	10.9	NA	01.3	NA	13.7	05.4	19.1
Engmt. 2	01.1	20.4	NA	04.2	NA	01.2	NA	01.0	27.9	07.6	35.5
Fire Unit 4											
Engmt. 1	14.0	01.3	NA	03.7	NA	01.3	NA	00.5	20.8	01.4	22.2
Engmt. 2	**	**	**	08.9	NA	00.0	NA	00.0	08.9	08.9	17.8
Engmt. 3	01.0	02.5	NA	03.2	NA	02.7	NA	00.3	09.7	05.2	14.9
Engmt. 4	21.0	01.9	NA	05.0	06.0	NA	03.6	NA	37.5	08.8	46.3
Engmt. 5	0*	02.5	NA	05.0	NA	02.7	NA	00.6	10.8	04.8	15.6
Engmt. 6	**	**	**	00.2	NA	00.0	NA	00.0	00.2	00.6	00.8
Fire Unit 5											
Engmt. 1	03.9	01.7	NA	20.9	NA	01.2	NA	01.0	28.7	02.3	31.0
Engmt. 2	01.8	02.0	NA	02.3	NA	03.8	NA	00.4	10.3	18.1	28.4
Engmt. 3	00.4	01.1	NA	07.6	NA	01.2	NA	00.5	10.8	03.2	14.0
Engmt. 4	**	**	**	01.0	00.2	NA	02.3	NA	03.5	05.8	09.3

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1046 (4 Fire Units; 29 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 1											
Engmt. 1	05.9	NA	00.5	00.2	NA	03.7	NA	00.9	11.2	16.0	27.2
Engmt. 2	00.9	00.9	NA	03.7	NA	02.4	NA	01.6	09.5	06.5	16.0
Engmt. 3	0*	01.1	NA	03.6	NA	01.2	NA	00.5	06.4	04.8	11.2
Engmt. 4	14.0	01.5	NA	02.9	03.5	NA	01.5	NA	23.4	02.8	26.2
Engmt. 5	06.0	01.4	NA	02.0	12.7	NA	01.3	NA	23.4	00.5	23.9
Engmt. 6	**	**	**	00.0	00.0	NA	00.0	NA	00.0	02.7	02.7
Fire Unit 2											
Engmt. 1	00.7	03.8	NA	06.0	NA	02.9	NA	01.0	14.4	02.6	17.0
Engmt. 2	05.7	01.5	NA	12.9	NA	01.4	NA	00.6	22.1	07.4	29.5
Engmt. 3	09.8	00.9	NA	05.8	NA	01.2	NA	00.5	18.2	04.6	22.8
Engmt. 4	02.2	09.5	NA	04.3	NA	02.2	NA	00.0	18.2	00.4	18.6
Engmt. 5	**	**	**	10.0	NA	00.0	NA	00.0	10.0	05.3	15.3
Engmt. 6	02.6	NA	01.6	00.0	NA	01.6	NA	-00.1	05.7	06.8	12.5
Engmt. 7	29.3	NA	01.0	00.1	NA	03.9	NA	00.2	34.5	07.8	42.3
Engmt. 8	20.4	NA	01.5	00.1	03.9	NA	16.0	NA	41.9	15.4	57.3

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I Trial 1046 (4 Fire Units; 29 Engagements). (All times in seconds.)

TASK CATEGORY——>	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function——>	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 3											
Engmt. 1	0*	01.0	NA	04.0	(02.7)	01.6	(01.5)	02.6	09.2	07.3	16.5
Engmt. 2	11.2	01.5	NA	05.5	NA	01.3	NA	01.6	21.1	02.1	23.2
Engmt. 3	**	**	**	02.4	NA	00.0	NA	00.0	02.4	09.3	11.7
Fire Unit 5											
Engmt. 1	02.6	01.0	NA	03.1	03.7	(05.4)	00.7	NA	11.1	10.7	21.8
Engmt. 2	0*	NA	02.1	00.1	NA	02.4	NA	01.4	06.0	03.5	09.5
Engmt. 3	03.5	00.7	NA	03.3	NA	01.3	NA	00.5	09.3	01.9	11.2
Engmt. 4	**	**	**	06.7	NA	00.1	NA	00.0	06.8	04.4	11.2
Engmt. 5	05.3	NA	01.0	00.0	NA	01.6	NA	00.5	08.4	00.9	09.3
Engmt. 6	15.7	NA	01.3	00.0	NA	02.4	NA	01.5	20.9	00.9	21.8
Engmt. 7	01.4	02.4	NA	04.2	01.9	NA	00.5	NA	10.4	02.6	13.0
Engmt. 8	00.3	00.9	NA	09.0	NA	02.8	NA	02.5	15.5	11.0	26.5
Engmt. 9	01.1	00.5	NA	08.0	NA	02.1	NA	00.5	12.2	09.9	22.1
Engmt. 10	05.2	(01.2)	01.1	00.0	NA	03.5	NA	00.6	10.4	08.4	18.8
Engmt. 11	17.6	00.3	NA	03.1	02.1	NA	00.9	NA	24.0	03.4	27.4
Engmt. 12	0*	NA	00.5	00.2	NA	07.2	NA	02.3	10.2	01.8	12.0

*Crew action was first indicator of target appearance.
**No crew action indicated in 1553 data base.
( )Action occurred simultaneously with other events/functions.

Table 3

Performance Data Base (Cont'd.). Target engagement time durations for Sgt York FOE I <u>Trial 1048</u> (3 Fire Units; 11 Engagements). (All times in seconds.)

TASK CATEGORY--->	CREW DECISION	CREW ACTION		SYSTEM PROCESSING			CREW DECISION		SUMMARY	CREW ACTION	SUMMARY
Function--->	Select/ Classify Target	Point Target	Lase Target	Acquisition of Target	Fire Solution by Computer		Decision to Fire		Time to Fire	Fire Duration	Total Engmt. Duration
					Blinking Cue	Solid Cue	After Blinking Cue	After Solid Cue			
Fire Unit 3											
Engmt. 1	Radar Auto ———>			02.5	NA	01.3	NA	00.7	04.5	03.0	07.5
Engmt. 2	Radar Auto ———>			06.5	NA	00.0	NA	00.0+	06.5	06.7	13.2
Fire Unit 4											
Engmt. 1	01.2	NA	00.6	00.2	02.8	NA	01.2	NA	07.1	00.4	07.5
Engmt. 2	0*	NA	01.2	00.1	NA	03.3	NA	01.0	05.6	00.6	06.2
Engmt. 3	06.5	NA	01.0	00.1	NA	07.7	NA	02.3	17.6	06.0	23.6
Engmt. 4	04.7	01.9	NA	02.9	NA	01.8	NA	00.8	12.1	10.4	22.5
Fire Unit 5											
Engmt. 1	07.6	02.3	NA	03.9	NA	01.2	NA	00.9	15.9	11.5	27.4
Engmt. 2	05.8	NA	00.2	00.2	NA	01.9	NA	00.7	08.8	10.0	18.8
Engmt. 3	05.9	00.3	NA	02.3	NA	01.3	NA	00.8	10.6	01.6	12.2
Engmt. 4	16.7	NA	02.4	00.1	NA	08.8	NA	00.6	28.6	04.4	33.0
Engmt. 5	00.2	03.2	NA	02.3	NA	03.3	NA	00.7	09.7	09.4	19.1

*Crew action was first indicator of target appearance.
+No trigger release between targets.

Table 4

Mean Durations of the Component Intervals of the Target Engagement Sequence (plus standard deviation and N = number of engagements)

TES Interval	Mean Duration (secs)	Standard Deviation (secs)	N
Select Target	7.9	10.4	221
with Radar Pointing	7.7	9.4	155
with Lasing	8.3	12.4	66
Pointing or Lasing Target	1.9	1.8	221
Duration of Pointing	2.3	2.2	155
Duration of Lasing	1.1	0.9	66
Target Acquisition	4.2	4.7	271
Via Radar Pointing	4.9	3.3	155
Via Lasing	0.1	0.07	66
Via Radar Auto	5.2	2.3	3
System Preempts	6.6	6.4	43
System, then Crew	17.9	10.6	4
Fire Solution: Blinking	4.0	3.1	65
Fire Solution: Solid	2.6	3.2	206
Fire Solution: B + S	2.9	3.2	271
Fire Decision: Blinking	1.7	2.5	65
Fire Decision: Solid	1.3	2.8	206
Fire Decision: B + S	1.4	2.7	271
Time to Fire	16.5	11.9	271
with Radar Pointing	19.8	11.1	155
with Lasing	14.3	13.0	66
with Radar Auto	6.7	2.4	3
with System Preempts	7.9	6.9	43
with System Tgt Acqu	25.6	11.8	4
Fire Duration	8.0	8.0	271
Total Engagement Duration	24.6	14.3	271

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action

TRIAL 1020	TARGETS Scenario: Attack Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 1</u>							
Engmt. 1	67.6	5	2.5	1	3	B	G
Engmt. 2	42.1	7	4.0	2	5	B	G
Engmt. 3	20.1	4	3.0	1	1	B	G
Engmt. 4	9.8	3	4.0	1	0	A	SL
Engmt. 5	36.0	3	4.0	3	6	B	G
Engmt. 6	8.2	2	4.5	1	1	A	SL
Engmt. 7	9.4	7	2.0	1	3	B	G
<u>Fire Unit 3</u>							
Engmt. 1	28.1	16	8.5	2	1	B	G
Engmt. 2	13.4	13	2.0	2	1	B	G
Engmt. 3	15.8	2	7.0	1	1	A	G
Engmt. 4	36.8	4	4.5	3	1	A	G
Engmt. 5	12.5	3	2.5	1	0	A	G
<u>Fire Unit 4</u>							
Engmt. 1	17.0	5	5.5	2	1	A	SL
Engmt. 2	31.3	10	2.5	1	2	A	SL
Engmt. 3	14.6	7	3.0	2	1	A	SL
Engmt. 4	38.5	10	6.0	1	1	A	G
Engmt. 5	25.6	15	1.0	1	1	A	SL
Engmt. 6	25.1	16	0.5	1	1	A	SL
Engmt. 7	5.9	7	2.0	1	1	A	SL
Engmt. 8	29.1	8	1.0	1	0	A	NA
Engmt. 9	8.2	16	0.5	1	0	A	NA
Engmt. 10	26.7	7	6.5	1	1	A	G
Engmt. 11	6.3	8	6.5	2	1	C	G
Engmt. 12	0.0	11	4.0	1	0	C	NA
Engmt. 13	2.0	12	3.0	1	0	C	NA
Engmt. 14	14.8	11	1.0	1	0	C	NA
Engmt. 15	18.6	17	1.5	2	1	A	SL
Engmt. 16	18.6	6	3.5	2	4	B	G
Engmt. 17	11.8	5	6.0	1	1	A	G
Engmt. 18	8.4	11	4.0	1	0	A	NA
Engmt. 19	74.6	3	3.0	7	7	A	SL
<u>Fire Unit 5</u>							
Engmt. 1	2.8	10	0.5	2	0	B	NA

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1021	TARGETS Scenario: Attack Sce. Tactic: Hind/Running			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
Fire Unit 2							
Engmt. 1	13.0	5	2.0	1	0	A	G
Fire Unit 3							
Engmt. 1	11.4	9	4.0	1	1	A	G
Engmt. 2	13.0	5	1.0	1	0	A	NA
Engmt. 3	4.5	7	1.0	1	0	A	NA
Engmt. 4	4.4	1	0.0	1	0	B	G
Engmt. 5	24.7	3	0.5	1	1	A	G
Engmt. 6	6.5	6	1.0	1	0	A	NA
Fire Unit 5							
Engmt. 1	3.9	6	1.0	1	0	B	G
Engmt. 2	29.8	2	2.0	2	2	A	G
Engmt. 3	10.3	6	2.0	1	1	A	SL
Engmt. 4	31.4	4	8.0	1	1	A	G
Engmt. 5	0.6	4	4.0	1	0	A	NA
Engmt. 6	0.0	2	3.5	1	0	A	NA
Engmt. 7	5.8	3	3.5	1	0	A	NA

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1022	TARGETS Scenario: Attack Sce. Tactic: Hind/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 2</u>							
Engmt. 1	6.0	1	0.0	1	0	B	G
Engmt. 2	9.4	12	5.0	3	1	9	SL
<u>Fire Unit 3</u>							
Engmt. 1	17.0	2	5.0	1	1	A	G
Engmt. 2	15.7	4	8.0	1	0	A	SL
Engmt. 3	11.9	5	3.0	1	0	B	G
Engmt. 4	5.0	10	1.5	1	0	B	NA
Engmt. 5	15.9	7	1.5	1	0	B	NA
Engmt. 6	17.2	11	7.5	2	2	A	SL
Engmt. 7	14.0	5	3.5	1	1	A	G
Engmt. 8	9.3	7	3.0	1	1	A	NA
Engmt. 9	30.3	5	2.0	1	3	B	G
Engmt. 10	13.4	16	5.0	1	2	A	G
Engmt. 11	13.4	17	5.5	1	2	A	G
Engmt. 12	15.5	8	0.0	1	1	B	G
Engmt. 13	34.5	7	5.5	1	1	A	G
Engmt. 14	28.9	8	2.0	1	1	A	G
Engmt. 15	9.8	9	3.0	1	1	A	G
Engmt. 16	5.3	17	1.0	1	0	A	NA
Engmt. 17	17.6	17	0.0	1	0	A	NA
Engmt. 18	30.0	12	2.0	2	1	A	G
<u>Fire Unit 4</u>							
Engmt. 1	40.0	7	5.0	3	2	B	SL
Engmt. 2	4.4	1	0.0	1	1	B	G
Engmt. 3	27.9	3	5.5	2	4	B	G
Engmt. 4	5.7	3	3.0	1	0	B	G
<u>Fire Unit 5</u>							
Engmt. 1	6.8	1	0.0	1	0	B	G
Engmt. 2	8.8	1	0.0	3	0	B	G
Engmt. 3	0.2	18	6.0	1	0	B	NA
Engmt. 4	4.3	1	0.0	2	0	B	G
Engmt. 5	5.4	1	0.0	1	0	B	G
Engmt. 6	10.2	1	0.0	1	0	B	G
Engmt. 7	3.7	1	0.0	1	0	B	G
Engmt. 8	5.9	1	0.0	1	0	B	G
Engmt. 9	7.7	1	0.0	1	0	B	G
Engmt. 10	6.5	1	0.0	1	0	B	G

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1023	TARGETS Scenario: Delay Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 2</u>							
Engmt. 1	19.4	2	0.5	1	1	A	G
Engmt. 2	19.7	4	1.0	1	1	A	G
Engmt. 3	6.3	9	0.0	1	1	B	G
Engmt. 4	5.4	4	3.0	1	1	A	SL
Engmt. 5	54.1	9	4.0	10	4	9	SL
Engmt. 6	4.7	1	0.0	2	1	B	G
<u>Fire Unit 3</u>							
Engmt. 1	31.6	3	10.1	4	2	9	SL
Engmt. 2	4.4	3	0.0	1	0	B	G
Engmt. 3	10.4	8	1.0	2	1	B	G
<u>Fire Unit 4</u>							
Engmt. 1	28.0	6	6.5	2	1	A	SL
Engmt. 2	35.3	10	8.0	4	3	A	SL
Engmt. 3	12.0	4	6.0	1	0	A	NA
Engmt. 4	14.9	3	5.0	2	2	A	SL

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1026	TARGETS Scenario: Road March Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 1</u>							
Engmt. 1	13.6	1	7.0	2	1	A	SL
Engmt. 2	0.0	4	5.0	2	0	A	NA
Engmt. 3	13.6	3	1.0	2	2	B	G
<u>Fire Unit 3</u>							
Engmt. 1	18.2	8	2.5	1	3	B	G
<u>Fire Unit 4</u>							
Engmt. 1	5.3	5	4.5	1	1	B	G
<u>Fire Unit 5</u>							
Engmt. 1	5.4	4	0.0	1	0	B	G
Engmt. 2	22.7	6	10.0	2	5	B	G
Engmt. 3	11.9	3	7.0	3	0	9	NA
Engmt. 4	17.7	3	3.0	1	2	B	NA
Engmt. 5	24.6	3	5.0	3	2	9	G
Engmt. 6	8.4	8	4.0	1	3	B	G
Engmt. 7	40.6	4	5.0	2	0	9	NA

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1027	TARGETS Scenario: Delay Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 1</u>							
Engmt. 1	15.2	8	2.0	1	1	A	NA
<u>Fire Unit 3</u>							
Engmt. 1	20.7	5	8.0	1	1	A	SL
Engmt. 2	11.9	2	3.0	1	1	A	G
Engmt. 3	24.7	8	3.0	1	1	A	SL
Engmt. 4	9.7	4	2.0	1	1	A	SL
Engmt. 5	14.3	3	3.5	1	1	A	SL
Engmt. 6	8.2	9	0.5	2	1	C	SL
Engmt. 7	21.4	9	7.0	1	1	A	NA
Engmt. 8	17.2	6	7.0	4	0	9	NA
<u>Fire Unit 4</u>							
Engmt. 1	16.4	3	7.0	1	1	A	G
Engmt. 2	6.3	1	2.0	1	1	A	SL
Engmt. 3	7.5	4	4.0	1	1	A	G
Engmt. 4	17.5	4	4.0	1	1	A	SL
Engmt. 5	17.3	7	8.0	1	1	A	SL
Engmt. 6	25.2	4	2.0	1	3	A	G
Engmt. 7	12.1	3	5.0	1	1	A	G
Engmt. 8	22.5	4	5.0	2	2	A	SL
Engmt. 9	00.0	5	3.0	1	0	A	NA
Engmt. 10	16.7	7	1.0	1	1	A	G
<u>Fire Unit 5</u>							
Engmt. 1	16.8	5	5.0	4	1	9	SL
Engmt. 2	9.9	10	1.5	2	0	A	NA
Engmt. 3	26.9	5	0.0	3	1	A	G
Engmt. 4	24.3	7	9.0	4	4	9	SL
Engmt. 5	14.3	5	4.5	3	1	9	SL
Engmt. 6	11.6	5	2.5	3	1	9	SL

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1029	TARGETS Scenario: Delay Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 2</u>							
Engmt. 1	10.3	9	3.5	3	1	A	SL
Engmt. 2	33.2	5	3.5	2	1	9	SL
Engmt. 3	11.3	4	5.0	1	0	A	SL
Engmt. 4	7.6	10	4.5	1	0	A	NA
Engmt. 5	17.5	2	6.0	3	1	A	G
<u>Fire Unit 4</u>							
Engmt. 1	14.6	10	2.0	1	1	A	SL
Engmt. 2	7.5	6	2.0	1	1	A	SL
Engmt. 3	36.1	1	8.5	1	1	A	SL
<u>Fire Unit 5</u>							
Engmt. 1	9.2	6	4.0	1	0	8	NA
Engmt. 2	15.4	8	3.5	4	1	A	SL
Engmt. 3	10.8	8	5.0	2	1	A	NA
Engmt. 4	17.7	4	6.0	5	1	9	SL

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1035	TARGETS Scenario: Delay Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
Fire Unit 1							
Engmt. 1	5.9	1	0.0	1	0	B	G
Engmt. 2	23.0	5	5.0	2	1	9	NA
Engmt. 3	12.2	4	5.5	1	1	B	G
Engmt. 4	13.1	4	5.5	3	1	A	SL
Engmt. 5	4.3	11	3.0	1	1	B	G
Engmt. 6	9.2	7	3.5	2	1	A	SL
Engmt. 7	13.6	11	5.0	2	1	A	SL
Engmt. 8	51.0	8	4.0	1	3	B	G
Fire Unit 2							
Engmt. 1	4.5	1	0.0	1	0	B	G
Engmt. 2	22.9	6	3.5	5	4	B	G
Engmt. 3	16.7	4	5.0	3	2	C	NA
Engmt. 4	25.3	7	5.0	1	1	A	G
Engmt. 5	26.8	3	6.0	2	1	9	NA
Fire Unit 3							
Engmt. 1	11.2	4	6.0	1	1	A	G
Engmt. 2	9.9	2	2.0	1	1	A	G
Engmt. 3	12.4	3	2.0	1	1	A	SL
Engmt. 4	48.8	2	2.0	4	2	9	SL
Engmt. 5	30.3	3	4.5	4	4	A	G
Fire Unit 4							
Engmt. 1	11.3	4	5.0	1	1	A	SL
Engmt. 2	1.6	12	3.0	2	0	A	NA
Engmt. 3	14.9	2	4.0	1	1	A	G

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1036	TARGETS Scenario: Attack Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
Fire Unit 1							
Engmt. 1	35.7	2	9.0	2	2	A	G
Engmt. 2	11.1	4	3.0	2	2	A	NA
Engmt. 3	31.1	4	3.0	3	2	B	G
Engmt. 4	18.3	2	0.0	3	1	9	G
Fire Unit 2							
Engmt. 1	59.1	1	1.0	1	4	B	G
Fire Unit 3							
Engmt. 1	11.8	2	4.5	1	1	A	G
Engmt. 2	51.0	1	4.0	2	1	9	G
Fire Unit 4							
Engmt. 1	11.2	2	7.0	1	1	A	G
Engmt. 2	11.5	7	2.0	1	1	A	G
Engmt. 3	11.4	4	5.5	1	1	A	G
Engmt. 4	26.0	7	4.5	2	2	A	SL
Engmt. 5	15.5	7	1.0	2	1	A	SL
Engmt. 6	9.0	6	1.0	1	1	A	SL

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1039	TARGETS Scenario: Attack Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 1</u>							
Engmt. 1	11.5	4	7.0	1	1	A	G
Engmt. 2	20.7	3	5.0	1	1	A	SL
Engmt. 3	31.1	1	2.5	3	4	B	SL
Engmt. 4	26.3	2	3.5	4	5	A	G
<u>Fire Unit 2</u>							
Engmt. 1	13.3	4	9.0	2	1	9	G
Engmt. 2	22.1	7	3.5	3	2	A	SL
Engmt. 3	34.7	4	8.5	3	4	9	SL
Engmt. 4	9.5	8	1.0	2	1	A	SL
<u>Fire Unit 3</u>							
Engmt. 1	23.5	5	10.0	3	1	9	SL
Engmt. 2	43.9	1	7.5	2	1	9	SL
Engmt. 3	19.1	3	4.0	5	2	B	G
Engmt. 4	12.9	3	1.5	3	2	B	G
Engmt. 5	15.5	5	6.0	3	3	A	SL
<u>Fire Unit 4</u>							
Engmt. 1	20.4	1	4.0	1	2	A	G
Engmt. 2	24.1	3	3.5	2	2	A	SL
Engmt. 3	24.8	1	4.0	2	2	B	G
Engmt. 4	6.6	3	3.5	1	1	B	G
Engmt. 5	2.4	2	0.0	1	0	B	G

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1040	TARGETS Scenario: Road March Sce. Tactic: Hind/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 2</u>							
Engmt. 1	23.1	4	5.0	1	1	A	G
Engmt. 2	18.6	4	4.0	1	0	A	SL
Engmt. 3	15.9	4	4.0	1	1	A	G
<u>Fire Unit 4</u>							
Engmt. 1	12.7	1	5.0	1	1	A	G
Engmt. 2	32.2	1	4.5	2	2	A	SL
Engmt. 3	19.4	2	4.0	3	2	A	G
Engmt. 4	18.9	1	3.5	2	1	A	SL

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1041	TARGETS Scenario: Attack. Sce. Tactic: Hind/Running			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
Fire Unit 1							
Engmt. 1	11.4	2	4.0	1	1	A	SL
Engmt. 2	35.7	5	4.0	1	3	B	G
Fire Unit 3							
Engmt. 1	35.2	4	6.5	2	2	A	SL
Engmt. 2	12.4	2	5.5	1	1	A	G
Fire Unit 5							
Engmt. 1	9.2	1	0.0	1	1	B	G
Engmt. 2	9.6	7	1.0	1	1	A	SL
Engmt. 3	3.0	6	3.0	1	0	9	NA
Engmt. 4	1.7	7	3.0	1	0	9	NA
Engmt. 5	8.7	5	5.5	1	0	B	G
Engmt. 6	17.1	6	6.5	4	0	A	G
Engmt. 7	32.7	2	3.5	4	3	9	SL
Engmt. 8	13.0	2	4.0	3	1	9	SL
Engmt. 9	8.8	6	3.0	1	1	A	G
Engmt. 10	6.4	4	4.0	1	0	A	SL
Engmt. 11	8.6	2	6.0	1	1	A	NA
Engmt. 12	2.9	3	4.0	1	0	A	NA

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1042	TARGETS Scenario: Delay Sce. Tactic: Hind/Running			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
Fire Unit 1							
Engmt. 1	31.4	1	6.0	3	2	A	SL
Engmt. 2	24.3	4	6.0	1	1	A	SL
Fire Unit 2							
Engmt. 1	13.7	2	1.0	1	1	B	G
Engmt. 2	27.9	1	2.0	2	2	A	SL
Fire Unit 4							
Engmt. 1	20.8	1	2.0	1	1	A	G
Engmt. 2	8.9	2	2.0	1	1	A	NA
Engmt. 3	9.7	5	6.0	1	1	A	G
Engmt. 4	37.5	1	8.0	1	1	A	G
Engmt. 5	10.8	1	5.5	1	1	A	G
Engmt. 6	0.2	3	3.5	1	0	A	NA
Fire Unit 5							
Engmt. 1	28.7	1	3.5	1	3	A	G
Engmt. 2	10.3	2	6.5	1	1	A	G
Engmt. 3	10.8	3	2.0	1	1	A	G
Engmt. 4	3.5	3	5.5	1	0	A	NA

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1046	TARGETS Scenario: Attack Sce. Tactic: Hind/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
Fire Unit 1							
Engmt. 1	11.2	2	1.0	1	3	B	G
Engmt. 2	9.5	3	4.5	1	2	A	SL
Engmt. 3	6.4	11	3.5	1	1	A	SL
Engmt. 4	23.4	1	3.0	2	2	A	SL
Engmt. 5	23.4	1	5.5	1	1	A	SL
Engmt. 6	0.0	3	5.5	1	0	A	NA
Fire Unit 2							
Engmt. 1	14.4	1	6.0	1	1	A	G
Engmt. 2	22.1	4	2.0	2	2	A	G
Engmt. 3	18.2	7	2.5	1	1	A	G
Engmt. 4	18.2	3	4.0	1	2	A	G
Engmt. 5	10.0	6	4.0	1	2	A	NA
Engmt. 6	5.7	5	1.0	2	1	B	G
Engmt. 7	34.5	17	10.0	3	2	B	G
Engmt. 8	41.9	6	6.0	2	4	B	G
Fire Unit 3							
Engmt. 1	9.2	5	1.5	1	1	A	SL
Engmt. 2	21.1	6	2.0	1	0	A	G
Engmt. 3	2.4	3	1.0	1	0	A	NA
Fire Unit 5							
Engmt. 1	11.1	5	7.0	1	1	A	SL
Engmt. 2	6.0	5	0.0	1	1	B	G
Engmt. 3	9.3	2	2.0	1	1	A	SL
Engmt. 4	6.8	4	2.0	1	1	A	NA
Engmt. 5	8.4	5	2.0	1	2	B	G
Engmt. 6	20.9	6	3.0	3	4	C	G
Engmt. 7	10.4	2	4.0	1	1	A	G
Engmt. 8	15.5	3	6.5	1	0	A	SL
Engmt. 9	12.2	9	4.0	1	0	A	SL
Engmt. 10	10.4	5	1.5	2	3	B	G
Engmt. 11	24.0	6	1.0	4	3	A	SL
Engmt. 12	10.2	6	0.0	2	0	B	G

Table 5

Target Engagement Tasks Showing Targets Displayed and Range, System Modes, and Crew Action (Cont'd.)

TRIAL 1048	TARGETS Scenario: Attack Sce. Tactic: Havoc/Hover			SYSTEM MODE			CREW ACTION
	Time to Fire (s)	Targets Displayed	Target Range (km)	# of Acq. Mode	# of Non-Acq. Mode	Mode at Trigger Pull	1st Action
<u>Fire Unit 3</u>							
Engmt. 1	4.5	5	2.0	1	0	8	NA
Engmt. 2	6.5	4	3.0	2	0	8	NA
<u>Fire Unit 4</u>							
Engmt. 1	7.1	8	2.5	2	2	C	G
Engmt. 2	5.6	1	0.0	1	0	B	G
Engmt. 3	17.6	1	0.0	3	0	B	G
Engmt. 4	12.1	5	5.5	1	1	A	SL
<u>Fire Unit 5</u>							
Engmt. 1	15.9	7	4.0	2	4	A	SL
Engmt. 2	8.8	6	1.0	1	3	B	G
Engmt. 3	10.6	9	3.5	2	1	A	SL
Engmt. 4	28.6	8	3.5	2	1	B	G
Engmt. 5	9.7	2	7.0	1	1	A	SL

Missing Data Analyses

The approach taken in compiling the data base presented in the preceding section represents one of many possible ways of looking at the data available on system (man and machine) performance during the Sgt York FOE I test. The choice was made to analyze only target engagements that included firing, the terminal task of the target engagement sequence.

As the data on completed engagement sequences were extracted, it became apparent that many engagement sequences had been interrupted before firing occurred. It would have been possible to collect data on such interrupted sequences for each trial, and each fire unit, and to categorize each one by the stage at which the interruption or break-off occurred. That is, it would have been possible to do a great deal of what might be considered error analysis. As noted earlier, a blinking fire cue did not constitute a mandatory firing situation, but a solid fire cue was a clear indication that a target should be fired on. A crew member might have chosen not to fire if, for example, his visual check of the target disconfirmed the IFF classification of the target as a foe. In such a case, the operator could have used the break-off switch and indicated that the target was a friend.

Without such a legitimizing explanation, not firing on a solid fire cue could be considered an error. The information provided by such analyses would constitute an alternative and additional view of operator and crew performance. For example, an exploratory error analysis of a single trial (Trial 1036) revealed that Fire Unit 1 fired on all solid firing cues throughout the trial. Fire Units 2 and 3 each had one solid fire cue and in each case the respective crews failed to fire on the target. Fire Unit 4, the only other fire unit involved in Trial 1036, had solid fire cues presented in two separate instances and in neither case did the crew fire. The crew did point and engage the target but did not take the final step of pressing the trigger.

One possible explanation for a failure to activate the trigger and fire on a target is that the time available was too brief. As explained above, error analysis was not the focus of this study, and once it was determined that an emphasis on complete target engagement sequences would provide more useful data in terms of applicability to future FAADS modeling efforts, the consideration of incomplete engagements was put aside. Preliminary as they are, the data from three trials showing by trial and by fire unit how long solid fire cues were displayed to the crews as part of engagements that were never carried through to trigger pull are presented in Table 6. An early, a midterm, and a late trial were chosen to see if there was evidence of change in number of fire cues to which crews did not respond as FOE I progressed. There does seem to be some evidence of improvement. Whether or not Fire Unit 4 in Trial 1036 had Time to Fire on the target in the two instances noted above, the fact remains that they did not. Despite this non-firing, Fire Unit 4 in each of the two instances received feedback that the target was presumed to have been damaged.

Being able to damage a target without firing on it raises some questions of validity that deserve attention. In contrast to battlefield conditions, the Force-on-Force trials provided no actual target destruction to provide knowledge of results and to signal that firing could/should cease. The theoretical success of an engagement for these Force-on-Force trials was

Table 6

Total Number of Seconds Solid Firing Cues Were Displayed for Targets on Which No Firing Occurred

TRIAL 1020

Fire Unit 1	Fire Unit 2	Fire Unit 3	Fire Unit 4	Fire Unit 5
1.8	N/A	1.1	35.3	N/A
10.9		2.7	12.1	
4.3		2.7	7.1	
1.1		0.0	1.4	
			1.1	
			3.2	

TRIAL 1036

Fire Unit 1	Fire Unit 2	Fire Unit 3	Fire Unit 4	Fire Unit 5
0.0	10.1	3.3	1.0	N/A
			1.7	

TRIAL 1048

Fire Unit 1	Fire Unit 2	Fire Unit 3	Fire Unit 4	Fire Unit 5
0.0	N/A	0.2	4.5	0.7
			0.7	3.3

determined by a Monte Carlo model available to CDEC. Evidently in the case of the Sgt York FOE I, either trigger pull was not an element required for successful engagement according to the model used, or in instances such as the ones cited above for Fire Unit 4 in Trial 1036, some error occurred. That it was not an isolated or uncommon occurrence was evident from an examination of the 1553 printouts.

The results of the Monte Carlo damage assessment were supposed to be relayed to crew members, but the information transmission was often delayed and sometimes never occured. In addition, problems of credibility arose when a crew was told it had damaged a target it had not fired on (and conversely that it had failed to damage a target that the crew believed "killed").

More often than not, no record of the outcome was included as part of the printout of the 1553 data bus; thus, no outcome information was available for this data analysis. Had such information been available, something in addition to a simple time-to-perform measure could have been developed, something that would make it possible to judge whether or not the fastest engagements were the most effective. Any engagement to be effective must reach Time to Fire before the hostile target destroys the defense, but if the firing does not actually damage the target, the engagement should not be judged a success no matter how quickly the trigger was pulled.

The preceding discussions suggest the richness of the unexplored data. The next chapter will illustrate the variety of what was explored. In that chapter, fourteen topics are discussed. The discussions are based on analyses of the data contained in Tables 3 and 5. They deal with tactical and system parameters and their relationship to individual, crew, and system performance. The analyses presented do not begin to exhaust the possibilities that exist. Many additional comparisons could be made. It is our intent in providing these data to give interested designers and researchers real numbers based on the actual performance of crews using an operating system in a field test environment.

Research Findings

The data presented in Tables 3 and 5 are an indication of the quantity of raw performance data available for analysis and interpretation. In order to bring some structure to these data and the areas they represent, five categories were established as follows:

- System and Subsystem performance,
- Tactical performance variations,
- Individual and crew performance,
- Personnel quality, and
- Training.

In the discussions that follow in this chapter, each of these major areas will be addressed with appropriate supporting data.

System and Subsystem Performance. Three topics are covered under this general area:

- System and subsystem response times
- System modes and levels of automation
- Fire unit comparisons

Two themes of major importance are (1) what levels of systems and subsystem performance were achieved and (2) the impact of manual and semi-automated system modes of operation.

Tactical performance variations. Forward area air defense offers a very rich environment for performance variations as a function of different scenario and battle conditions. Data are provided here for a number of variables:

- Varying scenario types
- Rotary-wing tactics
- ECM conditions
- Time of day, and
- Target range at first appearance.

These data provide a rich source of information for the interaction of tactics, crew performance, and subsystem performance.

Individual and crew performance. An unusual quanitity of data is available for the performance of individuals and two-man crews. Three topics are discussed here:

- Crew action and decision response times
- Mission-oriented protective posture (MOPP)
- Target workload

Detailed information is available about many of the actions the individuals and crews took, as well as how they used the system.

Personnel quality. In this specific test case, much was known about the personnel who participated in the test. This information is related to performance and presented in two parts:

- Personnel characteristics and individual performance
- Crew mix, mental categories, and crew performance

It may be expected that in future FAADS design much more attention will be given to the relationship between predicted personnel quality and appropriate design features, due to the MANPRINT initiative (Army Regulation 602-2, 1987).

Training. Although the data are limited, some comparisons can be made with respect to such factors as previous system experience or the lack of it, individual training scores, collective training outcomes, and mean performance times for such operator activities as selecting and classifying targets, pointing targets, and lasing targets.

Data files and analysis. It would not have been feasible to process these data without computer assistance. Appendix A provides a description of the data files and the data processing method. The data files were structured redundantly, so they can be processed by either dBase II or III. The data base is available on floppy disc for MS-DOS and IBM-cinoatubke personal computers. The statistical analysis software package was SYSTAT. The correlations among parameter measures may be of some psychometric technical interest. The correlation matrix is shown and discussed in Appendix B.

System and Subsystem Performance

System/Subsystem Response Times

In 1976 the Army established a Required Operational Capability (ROC) for a new air defense gun (USA-TRADOC ACN22087). The system would be required to be able to fire within 7 seconds at any target following its detection and establishment as a hostile target.

So, one of the most important aspects of the Sgt York's performance during the Force-on-Force trials is the length of time it took to start firing at hostile targets; i.e., how long was the system Time to Fire? Does the observed Time to Fire meet the 7 second requirement?

Figure 21 shows the overall means of segments of system performance derived from the engagements selected for purposes of this study/analysis. From these data, it can be noted that the overall mean Time to Fire, based on 271 target engagement sequences, was 16.5 seconds. This does not meet the operational requirement of 7 seconds; it is more than twice that amount of time.

1. Target Appearance

    1 to 2: 7.9 secs. (N = 221)

    6.4 secs. if N = 271

2. Crew pushes
Radar or Laser Button

    2 to 3: 1.9 secs. (N = 221)

3. Computer releases
Radar or Laser Button

    3 to 4: 3.5 secs. (N = 221)

    1 to 2 to 3 to 4: 13.3 secs. (N = 221)

    1 to 4: 7.4 secs. (N = 50)

4. Radar or Laser Cue Appears

    4 to 5: 4.0 secs. (N = 271)

5. Fire Solution Cue(s) Appear(s)

    5 to 6: 1.4 secs. (N = 271)

6. Crew pulls Trigger

Time To Fire (no steps 2 & 3)	13.1 secs. (N = 50 & 271)
Time To Fire (N = 271 for each step)	16.5 secs.
Time To Fire (all steps included)	19.0 secs. (N = 221 or 271)

Note. The Required Operational Capability is a Time To Fire of 7 seconds

Figure 21. System and subsystem performance times for indicated numbers of engagements.

It is also worthwhile to look within the target engagement sequence at component subsystem response times as shown in Figure 21:

1. It took a mean of 6.4 seconds (computed for 271 engagements) to acquire and identify the target. This step was a combined manual-computer function which included the essential IFF function as a principally automated mode and a variety of manual and semi-automatic control modes. This component mean alone consumes almost all of the prescribed system Time to Fire. Perhaps worse, the above mean included 50 enagagements for which there was no event #2 because of system program intervention. For the 221 engagements wherein the crew's action ended the Target Acquisition interval, the mean time required was 7.9 seconds.

2. In 221 engagements, the crew member either used Radar pointing or lased the target for an input to enable the display-computer system to compute a fire solution. This step measures the length of time it took the operator to get the computer to accept his designation-location of the target. The mean pointing/lasing time was 1.9 seconds for N = 221. (Computed for N = 271, the mean was 1.6 seconds.)

3. Automated decision support was provided by a fire control computer subsystem, coupled with an automatic tracking system. Figure 21 shows that the mean time consumed by automated decision support at this point in the target engagement sequence was 7.4 seconds (Steps 1 to 4, n = 50). This also is more than the required system Time to Fire of 7 seconds.

4. There had to be a manual (crew) decision to fire. For n = 271, the mean time to make the decision to fire was 1.4 seconds.

In short, the system was not able to achieve on the average, over a large sample of engagements, the required system performance response time. Some of the variations or modes of system operation took less time than others, and these variations are presented in later paragraphs.

In the evolving design of semi-automated systems, there have been several occasions where automating has imposed greater burdens on the system and impeded both load processing (such as number of targets processed) and timeliness (such as Time to Fire). This probably was inevitable as technology was developed in a piece-meal fashion to transform subsystem functions from manual to semi-automatic and automatic. It is important in each case to estimate closely how well a subsystem will perform as a part of the total system. "Optimal" subsystems, even if achieved, do not necessarily induce optimum system performance.

The results shown in Figure 21 are illustrative of many past and present systems where manual and automated functions have either been joined or integrated. The results are indicative of at least four continuing technology problems:

1. However good a subsystem function "solution" may be technically, total system performance effectiveness may not necessarily be enhanced. Thus, during design, there is an urgent need for a system engineering approach to make sure that the parts add up to an acceptable, effective whole. In the

very short response times required by air defense, careful attention must be given to each subsystem to insure acceptable system response times.

2. It is important that sufficient simulation and developmental testing be performed before prototype operational testing occurs. In developmental testing, assurance can be reached, or correction can be made, so that required system and subsystem response times can be achieved before design freeze and actual hardware development. It is simply too late to find out in operational test that the system did not meet operational requirements.

3. Allocation of function to man and machine is still an uncertain art (Price, 1985; Kantowitz & Sorkin, 1987). The allocations in this system seemed appropriate, yet the combined human-automatic target analysis step consumed virtually the entire response time requirement. The automated decision support subsystem processing time exceeded the required Time to Fire. However appealing automated decision aids may be, they must meet system performance requirements.

4. The required Time to Fire for this battlefield system is short, yet reflects the demands of the modern battlefield. But, as a technical and operational standard, the simple number of 7 seconds leaves something to be desired. It is probable that a set of performance requirements varying as a function of battlefield scenarios and conditions would be more useful for design and should be available from the operational analysis of future battlefield scenarios.

It may be of value to consider the potential consequences of a response time such as that shown in Figure 21. If the system can only respond on the average within 16-17 seconds, one question could be: What would be the predicted consequences of such a response time? It may be that there are some battlefield conditions where such response times might be acceptable. A study of this could be done by using the data of this report in a computer model of future FAAD systems.

System Modes and Levels of Automation

To evaluate the effect of the use of the different system modes available to Sgt York, several different comparisons were made. For the first comparison, three nominal system modes were used: Radar Auto, Radar Pointer, and (Radar) Optical. For the first comparison, laser capability was disregarded; that is, all engagements using radar pointer, whether with or without laser, were combined, as were all nominally optical engagements. For the second comparison, the modes were broken down, as far as possible, into five individual modes; that is, radar pointer engagements with laser capability were separated from radar pointer engagements without laser capability. For the third comparison, all laser modes were combined and contrasted with non-laser modes. For the fourth and final comparison, a new structure was created based on the way system events occured during some of the Force-on-Force trials; i.e., in ways not described in pre-FOE documents.

For each of the comparisons, the target engagement sequences were broken down by acquisition mode into the mean durations of the eleven component intervals discussed earlier: Select, Pointer On, Laser On, Acquisition Time, Fire Solution Blink, Fire Solution Solid, Fire Duration Blink, Fire Duration

Solid, Time to Fire, Fire Duration, and Engagement Time (not a component, of course). Throughout this report, in evaluating differences in mean times, a probability level of .05 has been adopted as the criterion for significance of the differences.

To implement making the comparisons discussed above, the data were configured into the following combinations:

1. Modes Comparison - Nominal System Modes

    a. Mode 8 - Radar Auto
    b. Modes 9 & A - Radar Pointer
    c. Modes B & C - (Radar) Optical

2. Modes Comparison - Individual Modes

    a. Mode 8 - Radar Auto
    b. Mode 9 - Laser Track, Radar Pointer
    c. Mode A - Radar Pointer
    d. Mode B - Laser Track, Radar, Optical
    e. Mode C - Radar, Optical

3. Modes Comparison - Effect of Laser

    a. With Laser
    b. Without Laser

4. Levels of Automation Comparisons

    a. Radar Auto
    b. System Preempts
    c. Radar Pointer Primary
    d. Lase Primary

In comparison 1, of nominal system modes, the category of Radar Auto included only Mode 8. The second category combined Mode 9, Radar Pointer with Laser Track, with Mode A, Radar Pointer without Laser. Category three included both optical modes (Modes B & C). This comparison of nominal system modes found two components of the engagement sequence to be significantly different, Target Acquisition time ($p<.001$) and Fire Duration time ($p=.028$).

As Table 7 shows, for Target Acquisition time, the Optical Mode, with a mean of 1.5, had a significantly shorter mean than the Radar Pointer Modes' mean of 5.4 seconds and the Radar Auto Mode mean of 5.2 seconds. In this context, it is important to note the difference in what acquisition time represents in the various modes. Ordinarily, acquisition time represented the interval between the time when the radar or laser button was released (i.e., the target had been pointed or lased) and the time when the radar or laser cue came on. However, in the Auto mode, there was no crew pointing or lasing; for that mode, acquisition was measured as the interval from target appearance time to the onset of the radar cue. (This is also the case for the category of System Preempts, discussed later.) For the Radar Pointer and Lase categories, Target Acquisition is the interval from the computer's release of the Radar or Laser buttons until the Radar or Laser cue appears on the display.

Table 7

Modes Comparison, Nominal System Modes, Target Acquisition

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Radar Auto: Mode 8	3	5.2	2.3
Radar Pointer (with or without laser): Modes 9 & A	188	5.4	4.5
Optical (with or without laser): Modes B & C	80	1.5	4.0

As Table 8 shows, Fire Duration was longest for the Optical Modes at 10.0 seconds, next longest for the Radar Pointer Modes at 7.3 seconds, and briefest for the Radar Auto mode, at 5.2 seconds. Frequently, regardless of operational mode, the weapon system automatically ended the engagement. Rather than define Fire Duration as the interval from trigger pull to trigger release, it has been defined as the interval from trigger pull to computer termination of firing. The data bus contained 34 cases where no data was given for trigger release, 116 cases where trigger release and computer termination times were identical, and 121 cases where the trigger release time was greater than the computer termination time. For these 121 cases, the mean trigger release time was 1.7 seconds longer than the computer termination time. Over 271 engagements, this way of defining Fire Duration shortened the mean Fire Duration by 0.8 seconds compared to the alternate (and expected) way of defining Fire Duration.

The Sgt York operator manuals recommended that firing continue for 3 to 7 seconds. Eighty-two of the 271 (= 30 %) Fire Duration values (measured to computer termination) were in this range. Seventy-seven of the 237 (= 32%) Fire Duration values (measured to trigger release) were in this range.

Table 8

Modes Comparison, Nominal System Modes, Fire Duration

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Radar Auto: Mode 8	3	5.2	1.9
Radar Pointer (with or without laser): Modes 9 & A	188	7.3	7.3
Optical (with or without laser): Modes B & C	80	10.0	9.2

Modes Comparison, Individual Modes. The five individual acquisition modes were compared to determine if there were any differences among modes for engagement sequence component times. The five system modes compared were (1) Mode 8, Radar Auto; (2) Mode 9, Laser Track, Radar Pointer; (3) Mode A, Radar Pointer; (4) Mode B, Laser Track, Radar, Optical; and (5) Mode C, Radar Optical. For these five modes, statistical significance tests were possible on only six of the eleven components of the target engagement sequence because of missing variances for the other components. The individual acquisition modes were significantly different on all six of the comparisons made: (1) Target Acquisition ($p<.001$), (2) Fire Solution: Solid ($p<.001$), (3) Fire Decision: Solid ($p=.035$), (4) Time to Fire ($p=.001$), (5) Fire Duration ($p=.003$), and (6) Engagement Duration ($p<.001$). Each comparison is discussed in turn below.

The amount of time it took for the weapon system to acquire the target was influenced by the individual system mode being used. Acquisition of the target was actually a system processing function, and should not be confused with how long it would take to perform crew actions. As Table 9 shows, in those engagements using Optical Mode B (a mode with laser available), acquisition time was only 1.2 seconds, while Mode C's (the Optical Mode without laser) mean acquisition time was 4.2 seconds. Mode 9, laser track with radar pointer, had the longest acquisition mean time, 7.6 seconds.

Table 9

Modes Comparison, Individual Modes, Target Acquisition

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Mode 8, Radar Auto	3	5.2	2.3
Mode 9, Laser Track, Radar Pointer	26	7.6	6.9
Mode A, Radar Pointer	162	5.0	3.9
Mode B, Laser Track, Radar, Optical	72	1.2	3.4
Mode C, Radar, Optical	8	4.2	7.2

As indicated in Table 10, the time required for the weapon system to generate a solid cue fire solution varied significantly among the five individual modes. Fire solutions, whether indicated by solid or blinking cues, represented a weapon system processing function carried out by the fire solution computer. When in Optical Mode C and Radar Auto Mode 8, the weapon system achieved the shortest time durations for system processing functions which culminated in a fire solution solid fire cue. Again, this does not represent crew action or crew decision times. As with acquisition time, Mode 9, radar pointer with laser track, had the longest mean time.

Table 10

Modes Comparison, Individual Modes, Fire Solution Solid Cue

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Mode 8, Radar Auto	3	0.6	0.9
Mode 9, Laser Track, Radar Pointer	26	5.3	6.7
Mode A, Radar Pointer	162	1.9	2.7
Mode B, Laser Track, Radar, Optical	72	3.4	1.9
Mode C, Radar, Optical	8	0.9	1.4

Differences in crew mean fire decision times following a solid fire cue are shown in Table 11. Fire decision time, solid cue, is defined as the amount of time that it takes a crew member to pull the trigger after a solid fire cue appears on the display. Again, Modes C and 8 had the shortest mean time durations. Mode 9, radar pointer with laser, required the longest fire decision time of the five modes following a solid fire cue.

Table 11

Modes Comparison, Individual Modes, Fire Decision Following Solid Cue

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Mode 8, Radar Auto	3	0.4	0.5
Mode 9, Laser Track, Radar Pointer	26	3.2	7.4
Mode A, Radar Pointer	162	1.2	2.0
Mode B, Laser Track, Radar, Optical	72	1.0	1.0
Mode C, Radar, Optical	8	0.2	0.6

Table 12 indicates that mean Time to Fire varied significantly ($p=.001$) among the five system modes. Time to Fire was a combined man-machine system function since it covered the target engagement sequence from the time of target appearance until the time a crew member depressed the trigger. Thus, Time to Fire incorporated the first five intervals of the target engagement sequence (Select/Classify, Point/Lase, Acquisition, Fire Solution, Fire Decision). The shortest mean Time to Fire was Mode 8's 6.7 seconds, based on only three cases. Next came Mode C, with 9.5 seconds. Mode 9 had the longest mean Time to Fire, 24.6 seconds.

Table 12

Modes Comparison, Individual Modes, Time to Fire

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Mode 8, Radar Auto	3	6.7	2.4
Mode 9, Laser Track, Radar Pointer	26	24.6	14.4
Mode A, Radar Pointer	162	16.1	9.9
Mode B, Laser Track, Radar, Optical	72	15.7	14.1
Mode C, Radar, Optical	8	9.5	7.3

Table 13 indicates that mean Fire Duration varied significantly ($p = .003$) among the five individual modes. Mode 8, Radar Auto, had the shortest Fire Duration time, 5.2 seconds, and Mode 9 the longest, 11.0 seconds. Fire Duration may be considered a crew action time in most instances. It is defined for the purpose of this report as the amount of time the firing continued for each engagement. Specifically, Fire Duration was measured by the time interval from the beginning of the trigger pull to the end of the engagement. The engagement was considered terminated when the gunner released the trigger, or when the weapon system ended the engagement, usually when radar lock was lost.

Table 13

Modes Comparison, Individual Modes, Fire Duration

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Mode 8, Radar Auto	3	5.2	1.9
Mode 9, Laser Track, Radar Pointer	26	11.0	12.4
Mode A, Radar Pointer	162	6.6	5.9
Mode B, Laser Track, Radar, Optical	72	10.4	8.4
Mode C, Radar, Optical	8	6.7	5.8

Table 14 shows the results of comparing mean Engagement Duration among the five individual modes. Mean Engagement Duration is the total length of the target engagement from the appearance of the target to the cessation of firing. Differences in the Total Engagement Duration time were found to be significant across the five system modes.

Table 14

Modes Comparison, Individual Modes, Engagement Duration

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Mode 8, Radar Auto	3	11.9	3.9
Mode 9, Laser Track, Radar Pointer	26	35.7	21.5
Mode A, Radar Pointer	162	22.8	11.7
Mode B, Laser Track, Radar, Optical	72	26.1	15.2
Mode C, Radar, Optical	8	16.2	7.6

As discussed in an earlier chapter, the Total Engagement Duration included three components associated with system processing. These components are Acquisition of the Target, and Fire Solution by the Computer (Blinking Cue and Solid Cue). A fourth component, Fire Duration Time, might sometimes have incorporated an aspect of system processing, for engagements were terminated by the weapon system in some instances.

The shortest mean Total Engagement Duration was associated with the system mode that had the highest level of automation, Mode 8, Radar Auto, with a mean of 11.9 seconds; but with only three cases, the reliability of this mean is somewhat suspect. Another finding appears relevant to the concept of levels of automation. Mode 9, which included both the Laser Tracking and Radar Pointing functions, had a longer Total Engagement Duration than the other system modes. The mean engagement time for Mode 9 was 35.7 seconds, almost three times the mean for Mode 8. In Mode 9, the crews are required to perform a greater number of procedures in order to activate the radar pointer and arm and point the laser. Even though the Radar Auto, Mode 8, appeared to be the most viable system mode to use for reducing Engagement Duration time, the combination modes using pointer and/or laser were the more frequently employed modes of operation during the Force-on-Force phase of FOE I.

Modes Comparison, With and Without Laser. To evaluate the impact of the laser, another modes comparison was carried out. Based on the use of the laser, engagements were configured into two groups. One group represented system modes where the crewmembers used the laser; the other group represented system modes where no laser was used. Summary statistics for Modes Comparison, With or Without Laser, were analyzed. Laser versus non-laser system modes of operation were found to be significantly different for Acquisition, Fire Solution Solid, Fire Duration, and Engagement Duration. Conversely, the two groups were not significantly different with regard to Target Selection/Classification, Pointing/Lasing, Fire Decision, and Time to Fire.

The acquisition interval was the time between when the target had been pointed and when there was an indication that a laser or radar cue was on the display. In the system modes where lasing had been enabled, laser data could be added to the track radar data to establish a firing solution. Where no radar was used during the target engagement, lasing provided target range and speed data to the fire control computer. When the laser was armed and the target was tracked by the laser, a laser cue would be indicated on the display. For target engagements where no laser was used, a radar cue would be indicated on the display as soon as the tracking radar locked on the target. When system modes using both radar and laser were combined, both radar and laser cues would be indicated on the display when tracking commenced.

The time to acquire a target was significantly shorter for laser than for non-laser modes ($p=.001$). As Table 15 shows, the mean acquisition time for lasing modes was 2.9 seconds; it was 5.0 seconds for the non-lasing modes, more than 2 seconds longer.

Table 15

Modes Comparison, With or Without Laser, Acquisition

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
With Laser	98	2.9	5.4
Non-Laser	173	5.0	3.6

Fire solution with a solid cue was a system processing function requiring information on range, elevation, and azimuth. Fire solution solid cue time is defined as the interval between the appearance of the radar cue or the laser cue, and the subsequent appearance of the firing cue. It represents the time it took the fire control computer to obtain a solution. Table 16 indicates that the mean time to produce a solid cue fire solution differed significantly ($p < .001$) from lasing modes to non-lasing modes. The solid firing cue was produced 2.0 seconds faster when non-laser modes were used than when laser modes were used. This finding contrasts with that for the acquisition system processing time, where the laser mode was 2.0 seconds faster than the non-laser mode. The acquisition time gained by using the laser was lost by the longer fire solution solid cue system processing time for laser modes.

Table 16

Modes Comparison, With or Without Laser, Fire Solution Solid

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
With Laser	98	3.9	3.8
Non-Laser	173	1.9	2.7

Table 17 indicates that Fire Duration varied significantly between lasing and non-lasing modes ($p < .001$). The mean Fire Duration time for non-laser modes (6.6 secs) was within the 3 to 7 seconds mandated by the Sgt York operator manuals. Since the mean Fire Duration for laser modes, at 10.6 seconds, was well above the prescribed time period, a smaller proportion of the laser modes' Fire Durations fell within the 3 to 7 seconds range. No reason for the difference in Fire Duration means is readily discernable.

Table 17

Modes Comparison, With or Without Laser, Fire Duration

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
With Laser	98	10.6	10.2
Non-Laser	173	6.6	5.9

Laser and non-laser acquisition modes were also significantly different ($p<.001$) with respect to Total Engagement Duration time, as is shown in Table 18. Laser engagements' mean duration was 6.3 seconds longer than non-laser engagements, but the blame cannot be put on the use of the laser itself; for, as Table 4 indicates, the Laser On time was but 1.1 seconds compared to the Pointer On time of 2.3 seconds. Other components, such as Fire Duration, are responsible for the longer Laser Total Engagement Duration.

Table 18

Modes Comparison, With or Without Laser, Engagement Duration

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
With Laser	98	28.6	17.5
Non-Laser	173	22.3	11.6

Levels of Automation Comparisons. As has been observed throughout this section, the times associated with the Radar Auto mode, Mode 8, show that engagements conducted using this mode were briefer than engagements in which other modes were used. The Radar Auto mode represented the highest level of automation available with the Sgt York system. It should be remembered that in all engagements the fire decision (implemented by pulling the trigger) was to be made by one of the crew members, not by the automatic system.

A close inspection of the 1553 data bus record revealed that the crew members' decision role was preempted by the automatic system in two ways on some engagements. One type of preemption concerned the firing decision. On some occasions while the trigger was being pressed and a target was being fired on, the target being engaged would change without any action by the crew members to occasion such a change. If the gunner was not extremely alert, he would continue firing but on a different target than the one he had selected. When the system switched targets, Fire Duration for the operator-selected target was terminated automatically (and perhaps prematurely). Often, after a brief trigger release for confirmation of the foe classification of the new target, the gunner would reengage the new target and fire purposefully on the new target.

Another preemption by the system occurred earlier in the target engagement sequence. Sometimes without any recorded crew action to select a target, whether by pointing or lasing, a target would suddenly be engaged by the system. This action was clearly indicated on the 1553 record by a notation showing "target number" under the 1553 column headed target engaged. Both of these preemptions share the characteristic that the system has established a radar or laser cue relating to a new target. The next system step will be to determine a firing solution. These steps also occur when the system is in the Radar Auto Mode. System preempts did not exhibit the Radar Auto property of controlling the gun turret's movement.

To ascertain what effect such system-initiated engagements might have had on the times for the various segments of the target engagement sequence, another comparison was carried out with the "system-preempts" forming a separate category, or after-the-fact mode. Information would be sought on how similar the system preempt mean intervals would be to the Radar Auto mode and the other modes as well. Radar Auto engagements were considered the highest level of automation, able to perform the engagement functions most quickly of the designed modes. The four categories to be compared were:

(1) Radar Auto,

(2) All system preempt engagements (coded in Table 3 as ** engagements), whatever the nominal mode appearing on the data bus,

(3) All engagements in which radar pointing was the primary way used to select a target, and

(4) All engagements in which the laser was used as the primary way of selecting a target.

As indicated in Table 19, these four levels of automation were found to be significantly different ($p<.001$) with respect to four parts of the target engagement sequence: Target Acquisition, Fire Solution, Time to Fire, and Total Engagement Duration.

Table 19 shows system Target Acquisition time as a function of automation level. In comparing acquisition times, it must be remembered that, for both Radar Auto engagements and system-preempt engagements, no crew action preceded acquisition, so the 5.2 seconds for acquisition in the Radar Auto mode and the 6.6 seconds for acquisition during system preempt engagements represents the total time for the engagement up to the onset of the radar or laser cue. For Radar Pointer engagements, another 10.0 seconds of crew decision and action time had preceded the 4.9 seconds attributable to acquisition, bringing the Radar Pointer total time to acquisition to 14.9 seconds (for which see Table 20). For Laser engagements, 9.4 seconds of crew decision and action time had preceded the 0.10 acquisition time, bringing the Laser engagement total time to acquisition to 9.5 seconds.

Table 19

Levels of Automation Comparisons, Acquisition

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Radar Auto	3	5.2	2.3
System Preempts	43	6.6	6.4
Radar Pointer Primary	155	4.9	3.3
Lase Primary/Optical	66	0.10	0.07

Table 20 shows the mean total time it took to achieve Target Acquisition as a function of level of automation. Again, this is the interval from target appearance to radar or laser cue onset. No radar/laser buttons are depressed or released by the computer for the Radar Auto or System Preempts; so, for these two categories, the first three time intervals of the engagement sequence are not measurable - or one may consider their values to equal zero. A new interval, called Total Time to Acquisition, is defined and shown in Table 20. It appears that the system preempts level of automation falls between Radar Auto engagements and crew-initiated engagements as regards Total Time to Acquisition.

Table 20

Levels of Automation Comparisons, Total Time to Acquisition

Level	Mean Total Time (s)
Radar Auto	5.2
System Preempts	6.6
Radar Pointer Primary	14.9
Lase Primary/Optical	9.5

The mean times for fire solution solid as a function of the defined levels of automation are shown in Table 21. The shortest mean times of 0.6 seconds were found for both the system-preempt engagements and Radar Auto fire engagements. Mean times for the other two categories, Radar Pointer and Laser engagements, are more than 2 seconds longer. Perhaps some unapparent parallel processing was possible in the first two types of engagements but not in the latter two. On this variable, system preempts perform at the same level as Radar Auto.

Table 21

Levels of Automation Comparisons, Fire Solution Solid

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Radar Auto	3	0.6	0.9
System Preempts	43	0.6	1.7
Radar Pointer Primary	155	2.8	3.7
Lase Primary/Optical	50	3.5	1.8

Table 22 shows the mean Time to Fire for the four levels of automation comparison. The mean for the three engagements in the Radar Auto mode was 6.7 seconds. The individual engagement values were 4.5, 6.5, and 9.2 seconds, meaning that two of the three times were under 7 seconds. The mean Time to Fire for each of the other three categories of engagements exceeded 7 seconds. The mean for the 43 system preempt engagements exceeded it by 0.9 seconds. Examination of the individual times revealed that 51% (22 of 43) System Preempt Time to Fire scores were under 7 seconds. The mean Time to Fire for the 66 Laser and/or optical engagements was 14.5 seconds, exceeding the system operational requirement by 7.5 seconds. Surprisingly, perhaps, 46% of 50 examined laser engagements took less than seven seconds. The mean Time to Fire for the 155 Radar Pointer engagements was 19.8 seconds, 12.8 seconds over the requirement. Only 2% (3 of 155) of the individual scores were less than seven seconds.

Table 22

Levels of Automation Comparisons, Time to Fire

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Radar Auto	3	6.7	2.4
System Preempts	43	7.9	6.9
Radar Pointer Primary	155	19.8	11.1
Lase Primary/Optical	66	14.5	13.0

As Table 23 shows, the relationship among the four mean Total Engagement Duration times was similar to the relationship for Time to Fire means in that the Radar Auto mean was shortest and Radar Pointer mean was longest. Laser engagements were again shorter than Radar Pointer ones, but whether that advantage was related to previous operator experience with laser systems or to some aspect of the Sgt York system is unclear. The system preempts mean is close to the Radar Auto mean, as it was for the Time to Fire variable.

Table 23

Levels of Automation Comparisons, Engagement Duration

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Radar Auto	3	11.9	3.9
System Preempts	43	14.8	8.2
Radar Pointer Primary	155	27.0	14.0
Lase Primary/Optical	66	24.8	14.5

One other comparison is worthy of comment. Radar Auto engagements and system-initiated engagements were compared with gunner-initiated engagements and squad leader-initiated engagements. The breakdown used earlier in Figure 21 was used for this comparison. As noted earlier, only the mean for the Radar Auto engagements is less than seven seconds. System initiated engagements were next fastest, but gunner-initiated engagements were more than 2 seconds faster, with respect to Time to Fire, than were squad leader-initiated engagements. Since squad leader-initiated engagements required coordination between the two crew members and gunner-initiated ones did not, this coordination time may account for the 2.4 seconds shorter mean Time to Fire taken by the gunners.

Table 24

System and Subsystem Performing Times as a Function of Engagement Initiator

Initiator Subystem Component	Radar Auto (s)	System Initiated (s)	Gunner Initiated (s)	Squad Leader Initiated (s)
Crew Target Analysis	0	0	7.6	8.4
Crew Target Action	0	0	1.8	2.2
Automated Decision Support	6.1	6.6	6.8	7.3
Crew Decision to Fire	0.7	0.7	1.3	1.9
Time to Fire	6.7	7.9	17.3	19.7

In Figure 22, the target engagement sequence is broken down into five components: crew target analysis, crew target action, system target analysis, automated decision support, and crew decision to fire. Figure 22 parallels data in Table 24, except that what is shown as "automated decision support" in Table 24 is further droken down into "system target analysis" and "automated decision support" in the figure. Vertical bars are included in Figure 22 to represent the four levels of automation discussed here, as well as for gunner initiated and squad leader-initiated engagements. As the figure makes apparent, integrating human operators into the target engagment sequence in the case of the Sgt York not only added additional steps to the sequence (crew action and crew decision steps), but lengthened the time required to perform the remaining steps, the steps common to automated and crew-involved engagements. That is, if man is to be in the loop, his influence may extend beyond the steps he performs and in this system may have lengthened the other steps as well.

Fire Unit Comparisons

Five Sgt York fire units were involved in the FOE I Force-on-Force trials. Times for each component of the target engagement sequence were broken out separately by fire unit in order to identify any differences that might exist between fire units. Note, however, that crew identity is extensively confounded with fire unit identity. As Table 25 shows, a given crew (i.e., a specific squad leader paired with a specific gunner) usually stayed with a given fire unit. Fire Units 1 and 2 had no crew changes for the trials analyzed. Fire Unit 4 had the same crew for trials 1-14, and a completely different crew for trial 15. Fire Units 3 and 5 had the same squad leader throughout, but changed gunners as indicated. For this analysis, only fire unit identity is specified, despite its confounding with crew identity. Crew composition will be treated later in this chapter.

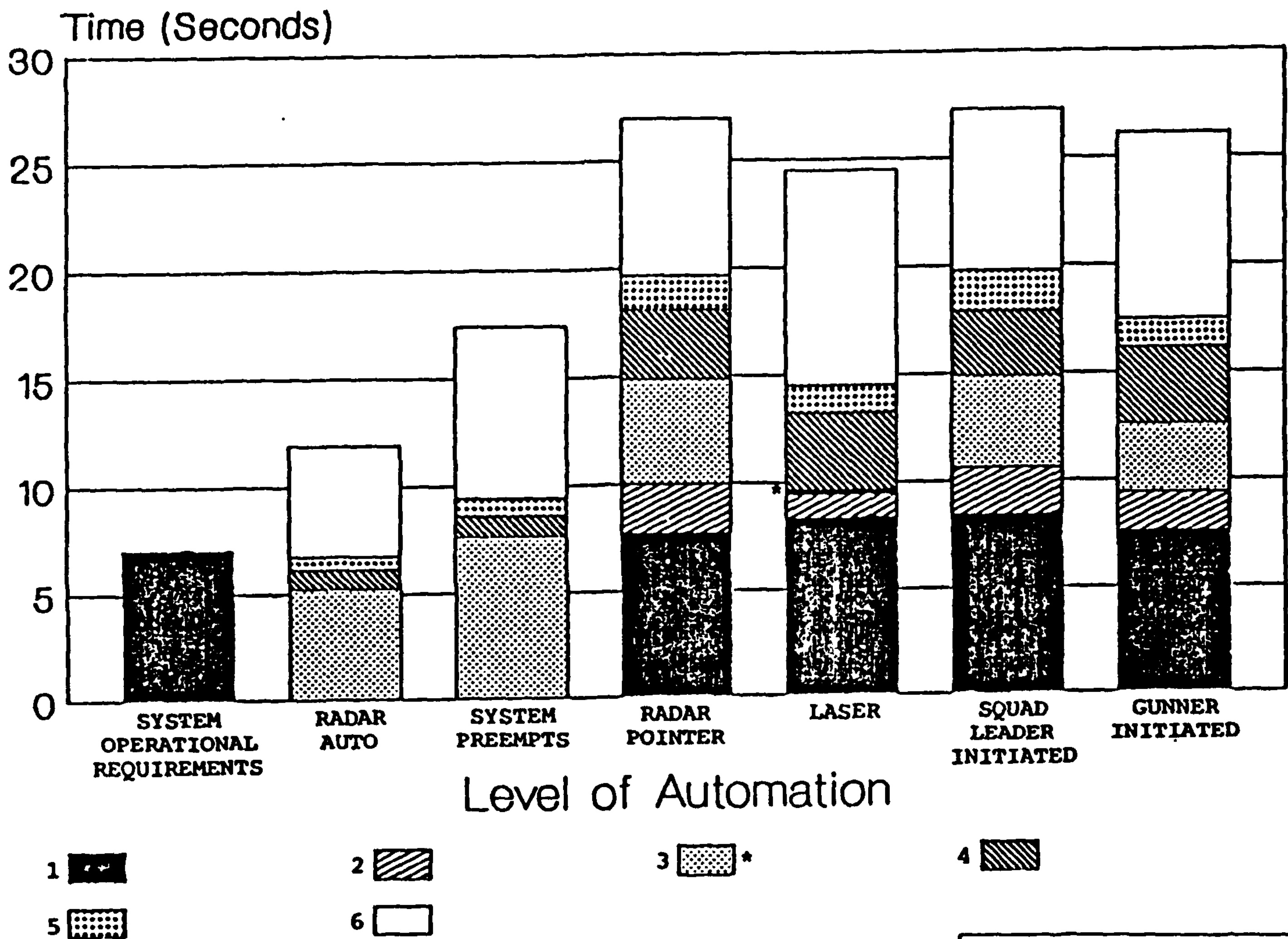


Figure 22. Components of target engagement sequence by levels of automation and by sequence initiator.

KEY:

1 - Crew Target Analysis
2 - Crew Target Action
3 - System Target Analysis
4 - Automated Decision Support
5 - Crew Decision to Fire
6 - Firing Action

Table 25

Crews and Fire Units by Trial

Trial Number	Fire Unit 1	Fire Unit 2	Fire Unit 3	Fire Unit 4	Fire Unit 5
1020	A		E	C	B
1021		D	H	C	B
1022		D	H	C	B
1023	A	D	G	C	
1026	A		E	C	B
1027	A		E	C	B
1029	A	D		C	B
1035	A	D	G	C	
1036	A	D	G	C	
1039	A	D	G	C	
1040	A	D	G	C	
1041	A	D	F		B
1042	A	D		C	B
1046	A	D	G		I
1048	A		F	D	B

Key:

Crew	Squad Leader ID	Gunner ID
A	9089	6111
B	4343	0240
C	1746	9843
D	6640	5197
E	3753	5197
F	3753	9843
G	3753	0240
H	3753	6111
I	4343	9843

Table 26 presents a comparison of the target engagement sequence times for the different fire units. Fire Unit 5 had shorter mean times than did the other fire units for both of the summary measures, e.g., Time to Fire and Total Engagement Duration. Fire Unit 5 began firing more than 4.5 seconds sooner than Fire Unit 4, the second fastest fire unit. The Time to Fire differences were significant ($p=.005$).

Fire Unit 5 also had the shortest mean Total Engagement Duration. The difference was not as great as the Time to Fire difference, since Engagement Duration included Fire Duration and the mean Fire Duration for Fire Unit 5 was relatively long (8.6 seconds). The differences in Fire Durations were not significant, but only Fire Unit 2 had a longer mean Fire Duration.

Table 26

Mean Times by Fire Unit for Target Engagement Components

	Mean Times (s)					Significance Level
	FU1	FU2	FU3	FU4	FU5	
Select	12.1	8.1	8.1	7.9	4.7	.040
Pointer On	1.6	3.5	2.1	2.5	1.5	.005
Laser On	0.8	1.3	1.0	0.7	1.5	NS
Acquisition	3.6	4.5	5.0	4.2	3.7	NS
Fire Solution Blinking	5.3	6.1	2.3	4.2	2.4	.005
Fire Solution Solid	2.6	2.8	3.0	2.6	2.3	NS
Fire Decision Blinking	1.2	3.3	1.2	1.4	1.7	NS
Fire Decision Solid	0.8	0.8	1.8	1.2	1.3	NS
Time to Fire	19.7	19.4	17.5	16.7	12.2	.005
Fire Duration	8.5	10.4	6.8	7.1	8.6	NS
Engagement Duration	28.2	29.8	24.4	23.8	20.8	.014

Despite its relatively long Fire Duration mean, Fire Unit 5 still had a mean Engagement Duration more than 3 seconds shorter than Fire Unit 4, the next fastest engagement mean. Engagement Duration differences were significant ($p=.014$).

Times for the remaining eight components are also presented in Table 26. On five of the eight components, there were no significant differences among the fire units. However, for Select Time, Pointer on Time, and Fire Solution Blinking time, there were significant differences. On the first two, both involving crew functions, Fire Unit 5 was the fastest. On the third, a system processing time, Fire Unit 5 was the second fastest, but it was only 0.1 slower than the fastest Fire Unit, unit 3. There was a spread of 3.8 seconds from the fastest to the slowest Fire Solution blinking time (2.3 to 6.1 seconds). The spread of Fire Solution Solid mean times was much narrower, 0.7 seconds (2.3 to 3.0 seconds), and those differences were not significant.

In summary, it appears that the shorter overall times achieved by Fire Unit 5 represented both quicker crew response times (Select and Pointer On times) and quicker hardware-software function (Acquisition and Fire Solution times). However, the system processing times for Fire Unit 5 were not significantly shorter; so it does not appear that Fire Unit 5 was faster or consistently different from the other fire units.

Tactical Performance Variations

Forward area air defense offers a very rich environment for performance variations as a function of different scenario/battle conditions. Data are provided here for the following variables: one, Scenario type; two, Rotary-wing tactics; three, ECM condition; four, Time of day; five, Target range at first appearance.

Scenario Type

Scenario Descriptions. Three different scenarios were used for the Force-on-Force trials: (1) Delay, (2) Attack, and (3) Road March. Each scenario differed in terms of the tactical mission assigned to the Blue Force. In addition to the Blue force which portrayed the friendly force, there was the Red Force which simulated the enemy. Two versions of each scenario type were implemented.

Delay scenarios had the Blue Force performing a defensive mission. Two terrain sites were used for the two Delay scenarios: (1) Gabilan Valley with the Blue Force oriented toward the southeast, and (2) San Miguelito Loop with the Blue Force oriented toward the northwest. Ten valid Sgt York trials were run using delay scenarios. Six of them were analyzed, three of them with the Gabilan Valley site and southeast orientation (1021, 1023, and 1027) and three of them with the San Miguelito Loop site and the northwest orientation (1029, 1035, and 1042). The relationship of scenario to terrain site and orientation is shown in Table 27.

Table 27

Terrain Site and Orientation

Scenario Type	Gabilan Valley	San Miguel-ito Loop	Southeast	Northwest
Delay (1)	X		X	
Delay (2)		X		X
Attack (3)		X	X	
Attack (4)	X			X
Road March (5)		X	X	
Road March (6)	X			X

Attack scenarios represented the Blue Force exercising an offensive mission. There were 14 valid Attack trials and 7 of them were analyzed (1020, 1022, 1036, 1039, 1041, 1046, and 1048). The Attack scenarios used the same two basic terrain sites: (1) San Miguelito Loop with the Blue Force oriented toward the southeast, and (2) Gabilan Valley with the Blue Force oriented toward the northwest.

The Road March scenario consisted of the Blue Force on tactical road march moving from the rear toward the Forward Edge of the Battle Area (FEBA). Sgt York valid trials included five Road March scenarios; two of the them were analyzed (1026 and 1040). During the Road March, the same two terrain sites were used: (1) San Miguelito Loop with the Blue Force oriented toward the southeast, and (2) Gabilan Valley with the Blue Force oriented toward the northwest. Trial 1040 was a night road march and Trial 1054 was planned as a second night road march, but test changes were made during its execution. The second night road march was run with the Blue Force (including the Fire Units) deployed along the march route prior to trial start time. This operational change was made to avoid safety problems. There was concern for the safety of the crews if they had to manuever the Sgt York in the dark. Because of this difference with Trial 1040, this trial was not analyzed.

Fifteen trials are identified in Table 28 according to trial number, date conducted, scenario type, scenario number, day/night conditions, end of trial time, rotary wing tactics, level of Mission Oriented Protective Posture (MOPP), Electronic Countermeasures (ECM) condition, replication, and order in day. The term "replication" indicates how many times the trial was initiated until it was completed successfully. For example, Trial 1020 was completed successfully on its first initiation (this is noted by the symbol "A" in the replication column). Trial 1048 was completed successfully on its third initiation which is noted by a "C." The second field is termed "Order in Day" and indicates whether the trial was being run as the first, second, or third trial of the day.

Scenario Comparisons. To analyze the effects of the three basic scenario types, the two Delay scenarios were combined, the two Attack scenarios were combined, and the two Road March scenarios were combined. In the dBase III data base created for this study, there were 7 Attack trials, 6 Delay trials, and 2 Road March trials. Within the 29 valid Sgt York FOE I trials, there were 14 Attack scenario trials, 10 Delay scenario trials, and 5 Road March scenario trials.

Scenario type came close to the statistical significance criterion for only one of the target engagement sequence components, reaching it for none. Mean times for Fire Solution Solid Cue were found to be very close ($p = .051$) to the criterion for rejecting the hypothesis of no difference when the three scenario types were compared using analysis of variance (see Table 29). Did something about the fire unit's moving during the road march increase the computer's time to process a fire solution?

During the Road March condition, it did take longer for the fire control computer to obtain a solid firing cue. The Road March represents firing on the move (known as shoot on the move capability), and the fire units were designed for such conditions. It was indicated in the Operator's Manual that there would be a loss of accuracy when firing on the move. According to the operational and organization plan, Sgt Yorks were to provide convoy/escort defense for maneuver elements during road marches when they were not in contact with enemy forces. Even though Sgt Yorks had shoot on the move capability, firing on the move was considered particularly difficult for the gunner (the difficulty associated with his keeping his eye in the gunsight). It should be kept in mind that in situations requiring a tactical road march, the purpose of the road march is for relocation and not for enemy contact. Tactical road marches are conducted at prescribed rates of speed with prescribed intervals between vehicles. Findings for scenario differences, including Road March, indicate that there was no significant difference for

Table 28

Scenarios Carried Out During Sgt York FOE I Tests, Detailed in Order of Their Occurrence

Trial No.	Date Conducted	Scenario Type	Scenario No.	Day Night	End of Trial Time	Rotary Wing Tactics	MOPP Yes/No	ECM Condition	Repli-cation	Order in Day
1020	17-04-85	Attack (4)	14	D	1713	Havoc/Hover	No	IOC	A	2
1021	18-04-85	Delay (1)	42	D	1205	Hind/Running	No	IOC	A	1
1022	18-04-85	Attack (3)	01	D	1530	Hind/Hover	No	Benign	A	2
1023	19-04-85	Delay (1)	19	D	1116	Havoc/Hover	No	IOC	A	1
1026	22-04-85	Roadmarch (6)	20	D	1547	Havoc/Hover	No	IOC	A	2
1027	23-04-85	Delay (1)	18	D	1140	Havoc/Hover	Yes	IOC	A	1
1029	24-04-85	Delay (2)	16	D	1049	Havoc/Hover	Yes	IOC	A	1
1035	28-04-85	Delay (2)	17	D	1336	Havoc/Hover	No	IOC	B	2
1036	28-04-85	Attack (4)	14	D	1800	Havoc/Hover	No	IOC	B	2
1039	30-04-85	Attack (3)	11	D	1759	Havoc/Hover	No	Benign	A	2
1040	30-04-85	Roadmarch (6)	04	N	2207	Hind/Hover	No	Design	A	3
1041	01-05-85	Attack (4)	07	D	1259	Hind/Running	No	Design	A	1
1042	01-05-85	Delay (2)	41	D	1732	Hind/Running	No	Benign	A	2
1046	07-05-85	Attack (3)	43	D	1544	Hind/Hover	No	Design	A	2
1048	08-05-85	Attack (4)	39	D	1420	Havoc/Hover	No	Design	C	2

crew decision time and crew action time among scenario conditions. Even under Road March conditions, crews were able to maintain approximate levels of functioning for target engagement sequences. For future FAADS designs, examining performance while moving would appear to be a more reasonable concern even at the expense of some scenario differences.

Table 29

Scenario Comparisons for Time for Three Scenario Types - Fire Solution Solid

Scenario Type	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Delay	77	2.0	1.9
Attack	153	2.8	3.7
Road March	19	4.5	1.6

Table 30

Scenario Comparisons for Delay 1 & 2, Attack 1 & 2, Road March 1 - Fire Solution Blinking

Scenario Type	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Delay 1	52	2.9	1.8
Delay 2	47	6.0	3.6
Attack 3	73	2.5	1.6
Attack 4	80	4.4	4.1
Road March 5	19	4.5	1.6

A further comparison of the scenarios was performed. As described earlier, the performance data base included data on two variations of the Delay and Attack scenarios and one variation of the Road March. Thus, there were five separate scenario subtypes available for this further scenario comparison. Analysis of variance revealed that there was a significant difference among these five scenarios ($p=.023$) for Fire Solution Blinking (see Table 30). In scenario Attack 3 and scenario Delay 1, a fire solution blinking cue was obtained more quickly than in the other three scenarios. These two scenarios (Attack 3 and Delay 1) had different terrain sites and a different geographic orientation so that location during scenario does not appear to account for the magnitude of their blinking fire solution cue means. The blinking cue does not reflect crew decision time or crew action time, rather it is a weapon system processing time that represents the fire control computer's time to calculate a fire control solution. As noted earlier, the blinking cue indicated a less certain solution than a solid cue. Why there should have been more than a 3-second difference between Delay (1) and Delay (2) trials, or a 1.9-second difference between Attack (3) and Attack (4) trials, is unclear.

In this five scenario comparison, no crew decision or crew action times were significantly different among the scenarios. Apparently, crew decision and action times were comparable within the scenario variations.

Rotary-Wing Tactics

One of the variables employed during the Sgt York FOE I Force-on-Force trials concerned the tactics used by the rotary-wing aircraft involved in these tests. Two different hostile helicopters, the Havoc and the Hind, were simulated during these tests by AH-64s. In the case of the Havoc, the AH-64 employed a hover tactic. In the case of the Hind, two different tactics were used, a hover tactic, as with the Havoc, and a running tactic. Thus, there were three helicopter/tactic mixes: Havoc/Hover, Hind/Hover, and Hind/Running. One of these three mixes was assigned to each Sgt York trial. That is, for a given trial, the AH-64s simulated either Havoc or Hind helicopter; if Havoc, they used a hover tactic; and if Hind, either a hover or a running tactic. The type of helicopter simulated did not vary within a single trial, nor did the tactic used vary within the trial.

Table 31 shows the mean times for all components of the target engagement sequence, presented separately for the three rotary-wing tactics discussed above. There are significant differences on only three of the measures, Laser On Time, Time to Fire, and Engagement Duration. For all three of these categories, the time was shortest for Hind/Running. Both Time to Fire and total engagement time suggest that the Havoc/Hover tactic was the most difficult of the three presented for the system to handle. However, laser on time was longest for Hind/Hover.

Table 31

A Comparison of Mean Times for Target Engagement Sequence Tasks According to Rotary-Wing Tactic Used

Tasks	Rotary-Wing Tactic			Significance Level
	Havoc/ Hover (s)	Hind/ Hover (s)	Hind/ Running (s)	
Select	8.9	6.0	7.3	NS
Pointer On	2.1	2.4	2.7	NS
Laser On	0.9	1.6	0.7	.007
Acquisition	4.7	3.5	3.8	NS
Fire Solution: Blinking	4.0	4.5	3.5	NS
Fire Solution: Solid	2.8	2.6	1.4	NS
Fire Decision: Blinking	1.5	2.0	1.8	NS
Fire Decision: Solid	1.5	0.8	1.1	NS
Time to Fire	18.1	14.6	14.0	.040
Fire Duration	8.4	7.9	7.1	NS
Engagement Time	26.4	22.5	21.1	.035

It is tempting to try to derive hypotheses about the effect of tactics on operator and machine performance by noting the differences in mean times entered in Table 31. The FOE trials analyzed here do not resolve the question of whether or not the tactics used by enemy aircraft affect the speed with which human operators handle such targets or influence the speed of the hardware/software system's operations. There are differences, but since they did not reach the designated level of significance, they should not be considered real or reliable differences.

An additional factor should be considered in comparing the times associated with the three rotary-wing tactic conditions. As noted earlier in this chapter in the discussion of levels of automation and system modes, engagements which were initiated independent of crew action, including those run in the Radar Auto mode, had shorter Time to Fire times and total engagement times than did the other engagements. Of the engagements run in the Hind/Running condition, which had the shortest Time to Fire and Engagement Times of the three tactical conditions, 70% were initiated by crew members. In the Hind/Hover condition, 87% were crew initiated, and in the Havoc/Hover, 82%. So the system-preempt engagements contributed their quickness more to the Hind/Running condition than to the other two helicopter-tactic mixes, thus apparently contaminating the comparison. Whether or not the relationship between tactical condition and proportion of crew-initiated engagements is anything other than chance remains an open question.

ECM Conditions

The Sgt York FOE I Force-on-Force trials were run under three different electronic countermeasure (ECM) conditions. That is, each trial was assigned to one of three conditions with respect to ECM: Benign, Design, and IOC. In the benign condition, enemy forces did not employ ECM. In the design condition, the ECM conditions faced were as described in the design specifications. Finally, the third ECM condition attempted to simulate the ECM environment that it was anticipated the Sgt York would encounter when actually fielded; that is, the initial operating conditions (IOC). Thus, the three treatment conditions presented increasingly difficult challenges for the weapon system.

For the two conditions in which ECM was encountered (Design and IOC), one of three different versions (designated ECM suites) was introduced during each trial. That is, each Design trial employed Suite 1, 2, or 3 and each IOC trial likewise was assigned to one of three suites. To implement the Design level of ECM, A-10s and A-7s dropped flares. To implement the IOC level of ECM, A-10s dropped flares and chaff and AH-64s dropped chaff only.

Table 32 presents a comparison of mean times for the 11 measures or segments of the target engagement sequence for each of the three ECM conditions represented during Sgt York FOE I. Differences in engagement time were significant, and differences among acqusition times were close to the signficance criterion. For acquisition time, the mean was shortest for the Design ECM condition and longest for the IOC condition. For total Engagement Time, the Design ECM condition had the shortest mean, and the IOC condition produced the longest total Engagement Time.

Table 32

Comparison of Target Engagement Task Times as a Function of ECM Condition

Target Engagement Task	Benign ECM (s)	Design ECM (s)	IOC ECM (s)	Significance Level
Select	6.8	6.8	8.9	NS
Pointer On	2.5	2.2	2.2	NS
Laser On	1.5	1.1	0.9	NS
Acquisition	4.2	3.0	4.7	.051
Fire Solution: Blinking	5.2	3.8	3.6	NS
Fire Solution: Solid	2.6	2.5	2.6	NS
Fire Decision: Blinking	1.5	1.8	1.8	NS
Fire Decision: Solid	0.8	0.9	1.7	NS
Time to Fire	16.2	14.3	17.6	NS
Fire Duration	8.2	6.2	8.8	NS
Engagement Time	24.4	20.5	26.4	.022

Time of Day Comparisons

The 15 trials that have been included in the data base were identified according to the time of day at the conclusion of each trial. Fourteen of the trials involving 264 engagements were conducted during the day. Only one trial, which involved seven engagements, was conducted at night. The night trial was No. 1040, and the scenario was Road March. Recall that a second Road March trial was included among the 15 trials and then found to be lacking in the movement characteristic. In order to analyze whether there were any significant differences associated with time of day, two comparisons were made. The first comparison was between the 14 day trials and the one night trials. The second comparison in effect redefined the independent variable. This was done by dividing the trials into three time clusters which represented (1) early morning, (2) midday, and (3) afternoon trial times.

Time of Day Comparison - Day Versus Night. The night trial concluded at 2207 hrs., and the day trials ended between 1049 hrs. and 1800 hrs. When these trials were compared, the day and night trials were found to be significantly different with respect to number of targets ($p=.047$) and fire solution solid cue ($p = .016$).

As Table 33 indicates, an average of 5.2 targets were observed on the plasma display at the initiation of the engagement sequence during day conditions. A mean of 2.5 targets was observed on the plasma display for the night trial at the initiation of the engagement sequence. It should be noted that the sample size for number of engagements during the night condition was extremely small in comparison to daytime engagements.

Table 33

Time of Day Comparisons - Day Versus Night - Number of Targets

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Day Trials	264	5.22	3.69
Night Trials	7	2.48	1.51

Day trials also differed from night trials ($p=.016$) with respect to time to obtain a solid fire cue. The fire solution solid time is associated with system processing functions, not with crew actions or crew decisions. Radar Pointer was the primary system mode used during Trial 1040.

During the night condition, it took the fire control computer 4.5 seconds longer than during the day condition to calculate a fire solution that produced a solid cue (see Table 34). This weapon system processing time is not indicative of crew action or crew decision times.

Table 34

Time of Day Comparisons - Day Versus Night - Fire Solution Solid

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Day Trials	264	2.5	3.2
Night Trials	7	7.0	5.4

The fundamentals of operations should have been the same during the day versus night trials, but certain techniques would vary for night operations. The Sgt York was designed to acquire, track, and engage targets at night as well as in adverse weather conditions. The weapon system's radar and data processors should not have been affected by night visibility conditions. The weapon system was designed to detect and classify all targets at extended ranges during night conditions in radar system modes. Optically tracking and engaging the target requires the weapon system to use a passive image intensification system. The optical system mode is dependent upon ambient light, and limited visibility could degrade the capability of the passive image intensification system (optical mode). Such a degradation of the ability to engage targets during night operations should not have affected weapon system processing (as indicated by time for fire solution solid cues) since acquisition system modes used incorporated radar. Ability to engage targets might have been influenced by the number of targets available. As noted earlier in this section, day and night trials differed in the number of targets displayed; more than twice as many targets (5.2 versus 2.5) appeared on the plasma display at the initiation of day engagements as at the initiation of night engagements.

One other difference between the day and night trials is the range-at-first-appearance for targets that were subsequently fired on. For day trials, this distance varied from 0 to 10 km; but for the night trial, the range was only from 3.5 to 5.0 km.

Time of Day Comparisons - Early Morning, Midday, and Late Day. In order to compare whether the time of day impacted on differences among the trials, the trials were divided and clustered into three categories. The first category was termed the early morning trials. Early trials commenced with Trial 1029 which concluded at 1049 hrs. The early trials consisted of Trials 1027, 1023, and 1029, and ranged in time between 1049 hrs. and 1140 hrs. for their completion. The second category was termed midday, and represented trials conducted in the early afternoon. Early afternoon trials included 1022, 1035, and 1040, and ranged in time at completion of trial between 1336 hrs. and 1530 hrs. The third category was termed late afternoon. Late afternoon trials consisted of Trials 1036, 1039, and 1042, and ranged in time between 1732 hrs. and 1800 hrs. for the completion of the trials. When time of day was defined as early morning, early afternoon, and late afternoon, an analysis of variance showed that time of day made a significant difference ($p=.040$) for Time to Fire and Fire Duration ($p=.032$).

Time to Fire is a cumulative measure of operator and machine functions; it represents target engagement time from target appearance up to the time at which a crew member depressed the trigger. This could be in response to a solid or a blinking firing cue. Even though a solid cue indicated a higher probability of successful engagement, it was acceptable for a crew member to fire on a blinking cue.

For the late day trials, the mean Time to Fire was 5.5 seconds longer than for the midday trials (see Table 35). Consider fatigue as a factor in the increase in seconds between midday and late day engagements. Since the midday trials' mean Time to Fire was 1.9 seconds less time than the mean for the early trials, it becomes difficult to invoke fatigue as an explanation because of this inconsistent effect. As noted below, Fire Duration was also influenced by the time of day, but the total engagement time was not.

Table 35

Time of Day Comparisons - Early Morning, Midday, and Late Day - Time to Fire

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Early Morning Trials	50	16.5	9.9
Midday Trials	65	14.6	10.8
Late Day Trials	45	20.1	12.6

The Fire Duration differences shown in Table 36 were significant ($p=.032$) among the three time-of-day periods. Fire Duration is the time interval from the beginning of the trigger pull until the end of the engagement; i.e., when either the operator released the trigger or the weapon system stopped firing due to the loss of a radar lock on.

Table 36

Time of Day Comparisons - Early Morning, Midday, and Late Day - Fire Duration

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Early Morning Trials	50	9.5	10.8
Midday Trials	65	10.2	9.6
Late Day Trials	45	5.8	4.4

The mean Fire Duration for the Late day trials was shortest at 5.8 seconds. Clearly, more of these late day trials conformed to the recommended range of firing durations (3 - 7 seconds) than did the Early morning or Midday trials.

Crews did not receive feedback as to whether or not they had hit the target during the FOE I Force-on-Force trials. The fire units were credited for target kills by a Monte Carlo method. Nor was the quantity of ammunition expended or remaining revealed to the crews. This lack of feedback may have encouraged longer Fire Duration times. Perhaps both the longer overall Time to Fire and the briefer Fire Durations typical of the late day trials were the result of fatigue.

Target Range at First Appearance

In these trials, a number of different scenarios and tactics were used, as has been discussed in the preceding pages. It is consistent with this that targets would appear at a variety of ranges. This in fact was the case. Table 37 shows the variation in range of target at first target appearance. It may be seen that targets could appear at immediate proximity to the fire unit or they could appear as far as 10 km away. The mean, median, and mode values tend to approximate distances of 3-4 km.

Table 37

Variations in Range at First Target Appearance

Parameters	Number
Number of engagements	271
Minimum range (km)	0
Maximum range (km)	10
Mean (km)	3.6
Median (km)	3
Mode (km)	4
Standard Deviation of Mean (km)	2.4

However, recalling the actual frequency distributions of range at first appearance that were shown in Figure 23, it is apparent that there were great variations in target distance on first appearance. It was, for example, highly probable that the target would appear anywhere within 4 km distance from the fire unit.

It is to be expected that the distance of the target should have had some effect on performance times. It seems reasonable, for example, that the closer the target, the more urgent the response should have been from the fire unit. And the data confirm that expectation. Table 38 shows that the range of target first appearance is correlated with the target selection, Time to Fire, and Total Engagement Times. While the correlations are not large, they are significant. It could be predicted that the closer the target when it first appears, the faster would be the response time of the fire unit. And, for those functions in which the operator was involved, it did appear that faster response times occured.

Table 38

Correlation of Target Range and Subsystem Tasks

Task Functions	r = Range of Target First Appearance
Select	.202 *
Acquire	.101
Time to Fire	.280 *
Fire Duration	-0.036
Engagement Time	.202 *

* Statistically significant $p<.01$

For example, Figure 24 shows Time to Fire in seconds as a function of the range of the targets in kilometers up to distances of 4.0 km. It may be seen that there is an increase in Time to Fire as the range increases. It appears that there might be a linear increasing function.

Perhaps the most alarming number in Figure 24 is that associated with a zero target range. This assumes that the target is on the fire unit and presumably most threatening. But, the mean Time to Fire was almost 9 seconds. This is beyond the system response time standard (7 seconds) and, perhaps, was beyond a comfortable firing response time for a hostile target so close to the unit.

In system models, range can be expressed in ways other than distance. For example, range could be translated into time for the unit to deal with the threat. If this is done, these data suggest that subsystem and task response times should be linked with that distance-time relationship. But, clearly, other considerations may be paramount; target priorities may not be directly correlated to distance from the fire unit, for example.

It should also be noted that the only measure of target range used for this analysis was range-at-first-appearance. It is unlikely that crew members always noted a target immediately; other measures, such as range-at-first-crew-action, might show a stronger relationship to Time to Fire. Range at first sighting (by an operator) might be one of the more revealing measures, but to have such a measure available would require data collection techniques designed to indicate when the operator first noted the target.

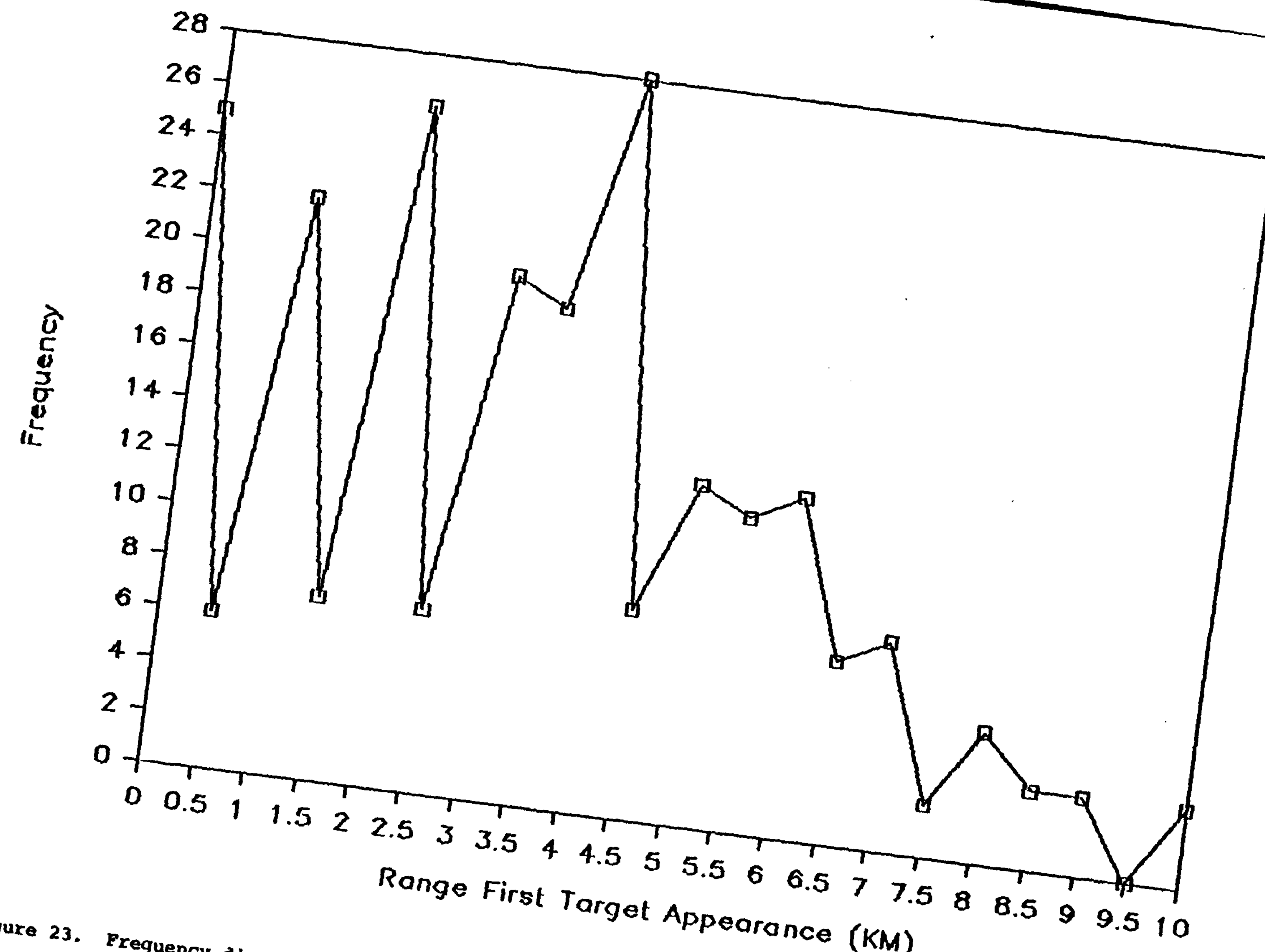


Figure 23. Frequency distribution of target range in kilometers at first appearance based on 271 target engagement sequences.

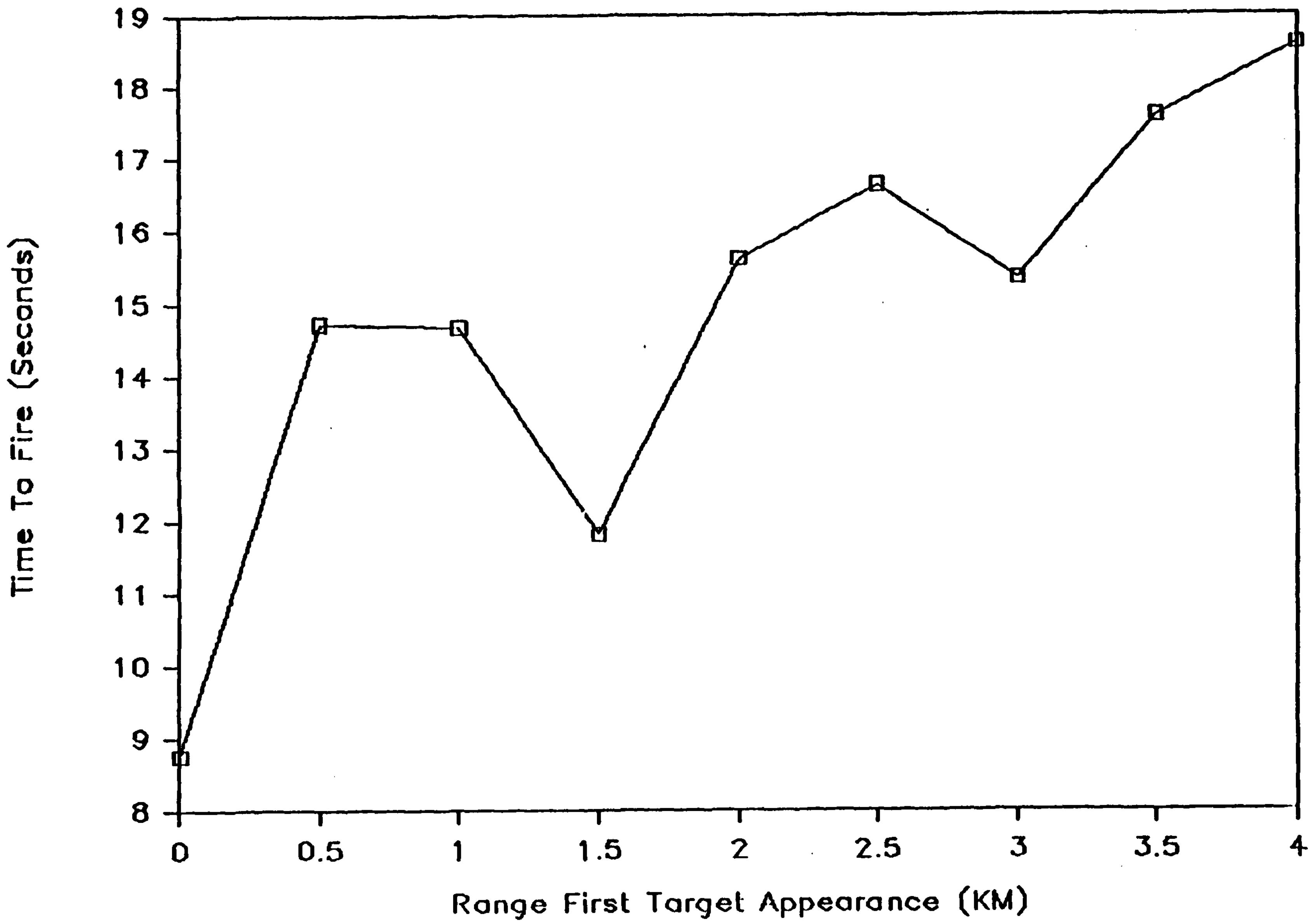


Figure 24. Time to fire in seconds as a function of the range of target at first appearance in kilometers.

Individual and Crew Performance

Crew Action/Decision Response Times

The Sgt York target engagement sequence (TES) provides an opportunity to look at some specific measures of operator and crew performance. Note that the representativeness of the data is limited in that it was generated by four Gunners, and five Squad Leaders. Table 39 shows the crew performance mean times both overall and separately by crew position. Included are three measures of operator action, i.e., Pointer On time, Laser On time, and Fire Duration. There are also three measures of operator decision-making time: (1) the time it takes to select and classify a target, or Select time; (2) the time it takes to decide to fire on a target after a blinking fire cue is presented, or Fire Decision: Blinking time; and (3) the time it takes to fire on a target after a solid fire cue is presented, or Fire Decision Solid time. There are also two summary measures that necessarily include components both of operator performance, and of hardware or software functioning; they are Time to Fire and Total Engagement Duration.

With respect to the initial action of selecting a target, the squad leaders as a group showed a strong preference for using the radar pointer rather than the laser. Of the 90 target selections performed by squad leaders, all but one selection used the radar pointer. The gunners showed no similar preference. Of the 131 target selections carried out by gunners, 68 were by radar pointer and 63 by lasing, a nearly even split. For the three measures of crew action time, pointer on, laser on, and fire duration, the squad leader's times are on the average shorter than the gunner's, but these differences are not statistically significant. The difference in the times used by the squad leader and the gunner in making the target selection decision was also not statistically significant.

The only difference that did reach statistical significance was the length of time it took to respond to a solid firing cue. In all the engagements, it was the gunner who fired, but if he had also taken the initial action, whether pointing or lasing the target, he fired more quickly than if the squad leader had taken the initial action. On gunner-initiated engagements, trigger pull occurred a mean of 1.0 seconds after the onset of the solid firing cue. For squad leader-initiated engagements, it took 2.0 seconds after a solid fire cue appeared for a firing decision to be made and implemented. Thus, the delay between the onset of a solid firing cue and trigger pull was about one second greater for engagements initiated by a squad leader than for engagements initiated by a gunner. Evidently, taking the responsibility for both operator aspects of the engagement (selecting the target and firing on it) facilitated rather than interfered with the process, as evidenced by a savings of almost a full second.

The reaction to a blinking fire cue did not show the same effect. As Table 39 indicates, the delay in responding to a blinking fire cue was greater (rather than smaller) on gunner-initiated engagements than it was on squad leader-initiated ones, but the difference was not statistically significant. That is, who initiated the engagement had no real (reliable) effect on time taken to respond to a blinking fire cue.

Table 39

Crew Action/Decision Response Times Shown as a Function of Position

		Over All (s)	Squad Leader (s)	Gunner (s)	Difference Between SL and G
Crew Action	Pointer On	2.3	2.2	2.4	NS
	Laser On	1.1	0.3	1.2	NS
	Fire Duration	8.0	7.5	8.8	NS
Crew Decision	Select	7.9	8.4	7.6	NS
	Fire Decision: Blinking	1.7	1.5	2.3	NS
	Fire Decision: Solid	1.3	2.0	1.0	.032
	Time to Fire	16.5	19.7	17.3	NS
	Engagement Duration	24.6	27.2	26.1	NS

Note 1. The gunner's Fire Decision Solid time is signficantly shorter than the squad leader's time.

In further comparing times for gunner-initiated engagements with those for engagements initiated by squad leaders, only one other difference was significant. System acquisition time was significantly shorter ($p=.035$) for gunner-initiated engagements. Table 40 shows acquisition mean time as a function of which crew member took the first action. There is no evident reason why what is essentially a hardware/software function should be sensitive to which operator initiated the engagement.

Table 40

System Acquisition Time as a Function of Engagement Initiator

Initiator	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Squad Leader	90	4.3	2.5
Gunner	131	3.2	4.3

As Table 39 shows, on all of the crew action/decision measures discussed so far, the mean for all engagements falls somewhere between the squad leader's and the gunner's means. For the summary measures, Time to Fire and Engagement Duration, this relation does not hold true. The mean times for all engagements are briefer than the times for either squad leader or the gunner-initiated engagements. This difference occurred because the overall means include system-initiated engagements (Radar Auto engagements and engagements in which the automatic system preempts the target selection even when the auto mode has not been chosen by the crew) as well as operator-initiated engagements.

As discussed earlier in this chapter (see Levels of Automation/System Modes), such system-initiated engagements have shorter Engagement Durations than those involving crew actions. The effect on the overall mean of these shorter engagements is reflected in the times entered in Table 39. That is, the overall mean Time to Fire and overall engagement time were both shorter than comparable measures for squad leader and gunner-initiated engagements.

Mission Oriented Protective Posture (MOPP)

As part of the FOE I test plan, levels of MOPP clothing requirements were included to reflect the conduct of combat operations in a threat environment consisting of conventional firing and air attacks along with nuclear weapons used with chemical and biological agents (NBC threat) in the Airland Battle 2000. The selection of a protective posture against a NBC threat is dependent on the threat, terrain, mission, weather, etc. The mission oriented protective posture (MOPP) prescribes how and when protective clothing and equipment should be worn.

The 15 trials under analysis for this study included 13 of the trials where crew members were operating at MOPP Level 1. Two of the trials (1027 and 1029) were conducted under MOPP Level 4 conditions. For purposes of analysis, MOPP Level 1 trials were compared to MOPP Level 4 trials. Clothing requirements for MOPP Level 1 specify that overgarments may be worn open or closed according to the temperature. Overboots, mask/hood, and gloves are to be carried. At MOPP Level 4, overgarments, overboots, masks/ hoods, and gloves are all to be worn in closed configuration. Maximum protection is achieved at MOPP Level 4. (Levels 2 and 3 are considered intermediate stages of protection.) Table 28 shows that MOPP Level 4 applied during Trials 1027 and 1029. All other Force-on-Force trials were conducted with crew members starting the trial wearing MOPP gear around their lower legs with overboots on. The tactical operating procedure was to suit up partially before entering a vehicle. Crew members wore the MOPP overgarments around their legs for a low-order MOPP. During Trials 1027 and 1029, the MOPP overgarments were pulled up and masks/hoods and gloves were donned.

When MOPP Level 1 was compared with MOPP Level 4, there were no significant differences among any of the dependent variables. The 11 DVs are: Select, Pointer On, Laser On, Acquire, Fire Solution Blinking, Fire Solution Solid, Fire Decision Blinking, Fire Decision Solid, Time to Fire, Fire Duration, and Engagement Duration.

The lack of significant differences may have been influenced by the limited duration of the trial periods, and by the primary system mode used during Trials 1027 and 1029. FOE I had originally been planned for trials lasting between 16 to 20 hours. Trials were required to be shortened into 30-minute periods instead of up to 20 hours because of limits in the data recording system. Thirty-minute trials do not produce the fatigue that would occur in a 20-hour trial conducted in MOPP Level 4. FM 44-11 indicates that "...extended periods in high MOPP will result in decreased efficiency due to physiological and psychological effects." Actually, the crews were in the fire units for period of 2 to 3 hours for each scenario even though the trials were confined to approximately 30 minutes. Extended trials such as those originally planned would probably have led to significant differences between MOPP Level 1 and MOPP Level 4.

If more engagements had been conducted under the system acquisition mode had of optical/laser, the opportunity for MOPP 4 to influence performance would have been greater. In this mode, the only way to provide target range and speed data to the fire control computer is by lasing. The optical/laser mode required a greater number of steps to follow as well as more demands on dexterity. When the engagements were combined for Trials 1027 and 1029, there were 36 engagements in total. Of the combined total, 75% of the engagements took place during system mode A, 19% in system mode 9, 3% in system mode C, and 3% in system mode 8. System modes A and 9 are both variations on radar pointer. They are not representative of an optical/laser with no radar condition.

Due to the constraints of the FOE I, it is not possible to evaluate the potential degradation in performance that would have been expected during extended trial durations. A trial which compares MOPP clothing requirements over 30-minute intervals does not adequately compare fatigue levels for extended field operations conducted under MOPP 1-4 conditions.

Target Workload

During target engagements, the operators frequently encountered multiple targets on the display. Table 41 shows some of the target statistics per trial. It can be seen in the table that from 1 to 18 targets were displayed simultaneously. The values of the mean, median, and mode as well as the standard deviation of the mean indicate that there was much variability in the number of targets the operator might see during a given engagement sequence.

Table 41

Target Workload Data

Parameters	Number
Number of engagements	271
Minimum targets per trial	1
Maximum targets per trial	18
Mean	5.1
Median	4
Mode	1
Standard Deviation of Mean	3.67

Another way of showing the target workload is illustrated in Figure 25 which gives the frequency distribution of targets per trial extracted from all 15 trials analyzed. As the table shows, the most frequent target workload was indeed one target, but it was very probable that more than one target would be on the display at any time. For future modeling, target workload should be a relevant model parameter, and it is to be expected that the operator will be presented with more than one target at a time. It is difficult to envision a display system and operational scenario for air defense that would not require a variable target workload for the operator.

It may also be reasonably assumed that variable target workload would differentially affect operator performance. The data here fail to show any statistically significant performance result. Table 42 lists the correlations among target workload and the five major subsystem tasks. As may be seen in that table, the relationship is very limited and may be chance since none of the correlations are statistically significant.

Another way of looking at potential performance effects is shown in Figure 26 which shows ttime to ffire in seconds as a function of target workload up to 10 simultaneous targets. Supporting the correlation result from the Table 42 (Time to Fire, $r = -0.030$), the figure shows there is very little apparent effect on Time to Fire as target workload increases.

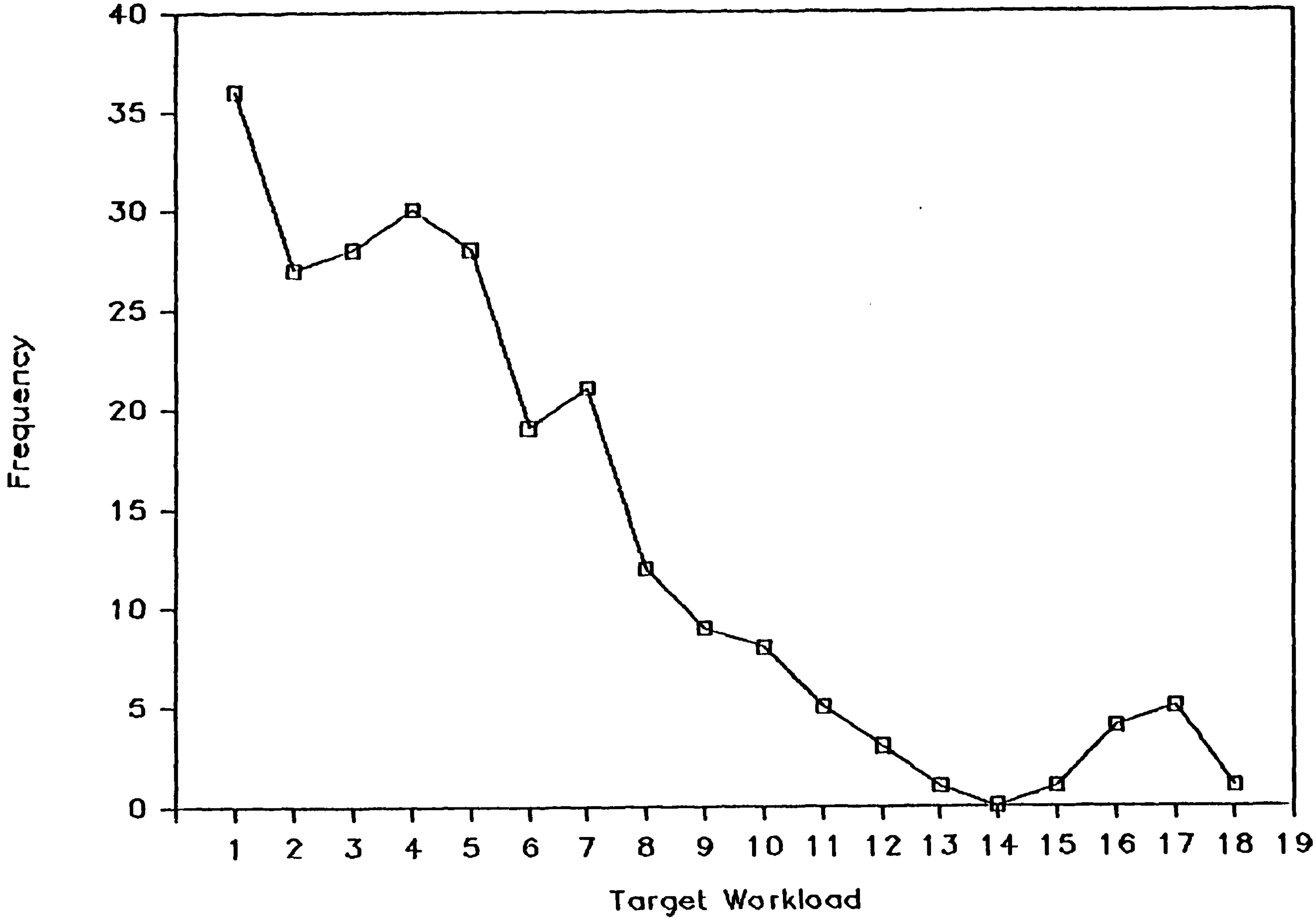


Figure 25. Distribution of target workloads per trial based on 271 target engagement sequences.

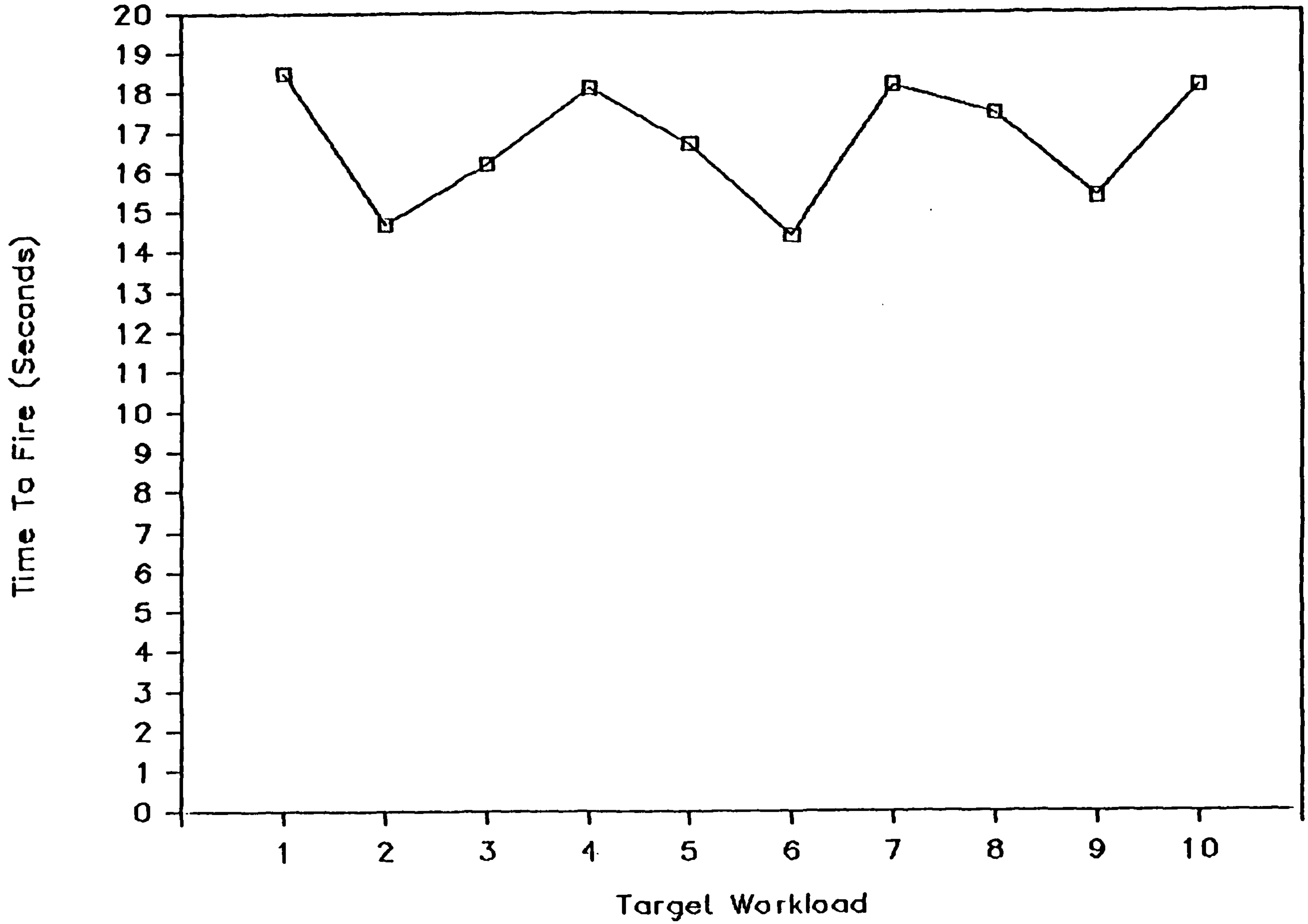


Figure 26. Time to fire as a function of target workload.

Table 42

Correlation of Target Workload and Subsystem Tasks

Task Functions	r = Target Workload
Select	0.113
Acquire	0.047
Time to Fire	-0.030
Fire Duration	-0.055
Engagement Time	-0.056

Note. No correlations are statistically significant.

Further consideration of the particular circumstances for this system suggests that one must be careful not to assume a target "workload" variable just because there are multiple targets displayed. In looking at the display configurations, from the actual sequences, the multiple targets were often distributed all over the display and did not particularly clutter the actual active target. A measure of target volume more meaningful with respect to workload might be definable. For example, in addition to counting all the targets on the display at a given moment (i.e., all those from 0 to 10 km range), it might be revealing to count only those targets within a kilometer of the target of interest. Such a measure might reveal an underlying workload phenomenon with respect to crew action or decision times that was obscured in the present analysis by disregarding distance from the active target.

Further, the display system designated target priorities which in effect directed the operator to the high-priority target. The system often said: "Look at and deal with target X and don't worry about all those other targets." If that is the case for the operator, he is not dealing with multiple equally probable targets and he is certainly not required to deal with all of them. "Workload" is a term that applies to the response of the operator and not necessarily the independent variables; it may well have been in this system that, despite many displayed targets, there were not many "workload" problems for the gunner or squad leader. All of this argues for much care in the definition of "target workload." It is possible to have multiple targets and no apparent workload problem - at least so the present data suggest.

Although these results show little evidence of a workload phenomenon, recall that the 15 trials analyzed were selected because they included the presence of firing at a target. Heavier target workloads would delay or prevent operators from firing - and the 14 trials that did not involve firing at targets were excluded from this analysis. The sample of trials analyzed has a very probable bias against showing the effects of heavier target workloads.

Personnel Quality

Personnel Characteristics and Individual Performance

As part of the MANPRINT initiative, those assessing operational tests have been directed to look more closely at the characteristics of test players and at how operator performances are related to individual characteristics. In the Sgt York FOE I tests, as in almost all such operational tests, the number of individuals participating as operators was very small. It is not appropriate or reasonable to use elaborate statistics with data of this type to relate personal variables to operational outcomes when so few individuals are involved. The Sgt York test provided quantitative data on the performance of five Squad Leaders and four Gunners. It would be as inappropriate to neglect it as it would be to make too much of it.

Personnel Characteristics. In the Force-on-Force phase of the tests, there were 14 players: 5 squad leaders, 4 gunners, and 5 drivers. Excluding the drivers, there were 9 crew members who had roles as weapon system operators and whose performance was individually reflected in the data base. Those nine players are identified in Table 43 and some general descriptive data are provided.

Table 43

Sgt York Player Personnel: Identification, Description, and Experience

Player ID#	Player Rank	MOS	Time in MOS (yr/mo)	Position S=Sqd Ldr G=Gunner	Time in Service (yr/mo)	Height (in)	Weight (lb)	Age (yr/mo)
0240	E5	16L20	1/6	G	5/2	69	161	25/6
1746	E6			S		70	150	
3753	E7	16L3H	1/7	S	10/10	72	195	28/11
4343	E6	16L	0/6	S	11/2	73	196	29/2
5197	E5	16L	0/7	G	9/6	69	130	27/7
6111	E5	16L	6/10	G	6/10	73	210	24/9
6640	E6	16L30	0/7	S	9/11	69	169	27/1
9089	E7	16L4H	1/6	S	14/3	69	130	33/8
9843	E6	16L30	0/7	G	10/0	74	215	28/6

Table 43 identifies each crewman by player identification number in Column 1 and by military rank in Column 2. Columns 3 and 4 represent Military Occupational Specialty (MOS) and time in MOS by year and month. MOS 16L was identified as the Sgt York Air Defense Gun System Crew Member.

Prerequisite experience and background were required for the test participant 16L MOS personnel. Specifically, 16L10-OSUT prerequisite was Active Army, Grade E4 and below, with Operator/Foodhandler (OF) score 95 or above, and Electrical (EL) score 90 or above; and 16L/20/30/40-T prerequisite was Active

Army, Grade E5 and above, related Air Defense Artillery (ADA) MOS, OF score 95 or above, and EL score 90 or above.

Column 5 of the table specifies the crew member's position within the fire unit. Column 6 identifies the total amount of time each crew member was in the service by year and by month at the time of FOE I. Columns 7 and 8 give the height and weight of each crew member. Performance and selection implications are associated with height and weight measures since personnel above the 60th percentile did not have adequate space within the M48 tank chassis (Korean War era tank chassis). Column 9 describes each crew member according to age by year and by month.

Individual Performance. Because of the instrumentation available on the Sgt York, Select and Classify time, pointer on time, and laser on time were measurable and also could be attributed to a specific crew member. A comparison of individual crew member performance was conducted for gunners and squad leaders regarding Select and Classify target times and pointer on times. Laser on times were not available for all crew members, so no statistical comparison was made on that measure.

Select Target time. Select and Classify target was defined as the amount of time it took a crew member to detect and begin to respond to a target from the time the target appeared on the display to the time the pointer was depressed. This period of time was considered crew decision making. An analysis of variance was performed comparing Select and Classify target times for individual crew members. Findings indicated that there was a significant difference ($p=.007$) among individual crew members. Individual select scores are presented in Table 44.

Table 44

Select and Classify Target Scores for Individual Crew Members

	ENGAGEMENTS (n)	Mean (s)
Gunner, #0240	36	5.0
Gunner, #5197	33	7.3
Gunner, #6111	31	13.7
Gunner, #9843	35	4.7
Squad Leader, #1746	26	12.0
Squad Leader, #3753	15	9.6
Squad Leader, #4343	19	5.6
Squad Leader, #6640	12	7.6
Squad Leader, #9089	15	5.6

Two gunners (#9843 & #0240) were faster at selecting and classifying targets than were the other crew members. Their select and classify times averaged 4.7 seconds and 5.0 seconds, respectively.

Pointer on time. Another comparison of individual crew member performance was conducted for gunners and squad leaders and the time in seconds it took them to get a target pointed. Pointing the target was considered a crew action time. The activity consisted of the crew member tracking the target while holding the pointer switch depressed during the radar pointer mode. The crew member designated the target on the display with a cursor. When the pointer on symbol touched the target symbol, the pointer on button was released by the computer. Pointer on time represents the amount of time it took a crew member to get a target pointed. Individual pointer on mean times are shown in Table 45. Analysis of variance comparing gunners and squad leaders by pointer on time indicated that the differences were significant. ($p=.003$).

Table 45

Pointer On Scores for Individual Crew Members

	ENGAGEMENTS (n)	Mean (s)
Gunner, #0240	15	1.8
Gunner, #5197	17	3.2
Gunner, #6111	14	2.3
Gunner, #9843	23	2.4
Squad Leader, #1746	26	2.3
Squad Leader, #3753	14	1.6
Squad Leader, #4343	19	1.3
Squad Leader, #6640	12	3.8
Squad Leader, #9089	15	1.6

In the Pointer On crew activity, four of the crewmen had mean pointer on times that were under 2 seconds. The highest mean of 3.8 seconds was almost three times the shortest mean of 1.3 seconds.

Having individual performance measures and discovering that there are significant differences in performance scores are only the beginning. The next step is to search for individual characteristics, ratings, or experience that vary with the performance measures, and thereby enable prediction of the performance from the characteristic, etc. The pre-established selection criteria for attendance in the MOS 16L transition course, discussed at the beginning of this section, included (1) Active Army, (2) Grade E5 and above, (3) related ADA MOS, (4) OF score of at least 95, and (5) EL score of at least 90. The first two criteria were not variables. The third criterion was translated into time in MOS, but there was no apparent relationship between the time crew members had been in their MOS and mean Select or Pointer times.

The other individual descriptors included in Table 43 were inspected, but these descriptors do not seem to be related to performance patterns. Perhaps if the sample had been larger, there might have been some descriptors that would have proven useful in selecting crew members with potential for better performance on target engagement tasks.

Additional data were available for most of the Sgt York player personnel, including level of education, OF and EL scores on the Armed Services Vocational Aptitude Battery (ASVAB), Armed Forces Qualification Test (AFQT) scores, mental category, and GT scores. Although, as noted earlier, no elaborate statistical analyses are appropriate with such limited data, Table 46 was constructed to facilitate inspection of the relationship between the various descriptive scores listed above and individual performance during the operational tests. Thus, Table 46 includes select time, pointer on time, and laser on time.

Table 46

Sgt York Player Personnel: Characteristics and Performance Scores

Player ID#	Level of Education	ASVAB		AFQT Score	Mental Category	GT Score	Select/ Classify x (s)	Pointer On x (s)	Laser On x (s)
		OF	EL						
0240	GED	98	103	35	IIIB	80	5.0	1.8	1.5
1746	---	---	---	65	II	109	12.0	2.3	---
3753	C2	112	113	65	II	118	9.6	1.6	0.3
4343	C1	105	109	—	IIIA	99	5.6	1.3	---
5197	HSD	95	109	59	IIIA	96	7.3	3.2	1.2
6111	HSD	105	93	19	IV	87	13.7	2.3	0.9
6640	HSD	114	76	25	IV	84	7.6	3.8	---
9089	HSD	118	106	23	IV	108	5.6	1.6	---
9843	GED	119	120	65	II	110	4.7	2.4	0.9

Note. The abbreviations used in this table have the following meanings:

ASVAB = Armed Services Vocational Aptitude Battery
OF = Operator/Foodhandler
EL = Electronics
AFQT = Armed Forces Qualification Test
GT = General Test
GED = General Education Diploma
C2 = College, two years
C1 = College, one year
HSD = High School Diploma

Level of education. For all but one crew member, level of education is indicated in Table 46. Level of education was graphed against mean Select time for eight crew members (Figure 27). The figure indicates that the mean select time did not go down as education went up. Indeed, the two operators who had a General Education Diploma (GED), which was considered the lowest level of education represented in the sample of eight, had the shortest select/classify mean times. Short select times were achieved by operators in each category (GED, High School Diploma (HSD), and College (C)).

Level of education was also plotted against mean Point time. As Figure 28 shows, fast Point times were found among individuals representing all levels of education (GED, HSD, and C). As a group, high school graduates seemed to be slowest at pointing, but more data would be needed to substantiate the curvilinear relationship suggested. Amount of formal education does not indicate how well a crew member will perform the tasks that contribute to tracking a target.

ASVAB scores. Crew members scores on the OF and EL scales of the Armed Services Vocational Aptitude Battery (ASVAB) are included in Table 46. To look at the effect of these remaining two selection criteria (OF score and EL score), mean Select time was plotted against individual OF scores (Figure 29) and against individual EL scores (Figure 30). Note that one squad leader (Player #6640) was below the EL cutoff of 90 (discussed earlier). Neither ASVAB OF nor ASVAB EL scores demonstrated a consistent relationship between higher ASVAB scores and lower Select times.

Mean Pointer On times were similarly plotted against ASVAB OF scores (Figure 31) and ASVAB EL scores (Figure 32). Individual differences in OF and EL scores did not appear to account for differences in point time. When the four crew members with the best mean times for pointing a target were compared on ASVAB OF scores, the scores ranged between 98 and 118. If all crew members were included in the range of scores, the scores ranged between 95 and 119. That is, the OF scores for the best performers covered almost the full range.

The ASVAB Operator/Foodhandler (OF) consists of two subtests from the Armed Services Vocational Aptitude Battery. These subtests were used to select Vulcan crewmen. Average ASVAB OF scores for Vulcan crewmen (N=1281) was 100. The average for the Sgt York sample of eight crew members for whom scores were available was 108. As noted earlier, prerequisite scores had been established for future 16L MOS personnel which included an Operator/Foodhandler (OF) score of 95 or above.

EL scores for the four crew members with the best mean times for pointing a target ranged between 103 and 113. When all the EL scores were taken into account for the crew members, the scores ranged between 76 and 120.

From this small sample, it does not appear that ASVAB OF or EL scores are useful in predicting performance. For a discussion of the ASVAB scores and observations related to training, see Seven (1987). Whether the ASVAB cutoff scores were too high or did not indicate enough about individual ability was not resolved.

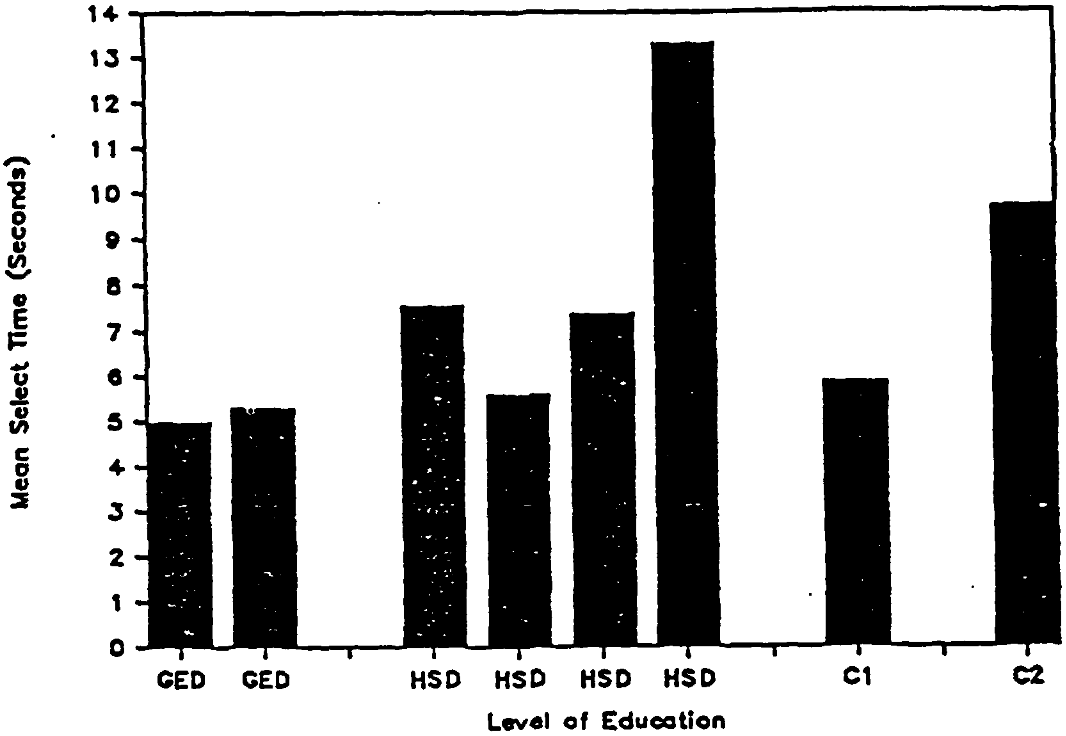


Figure 27. Mean select time in seconds by level of education.

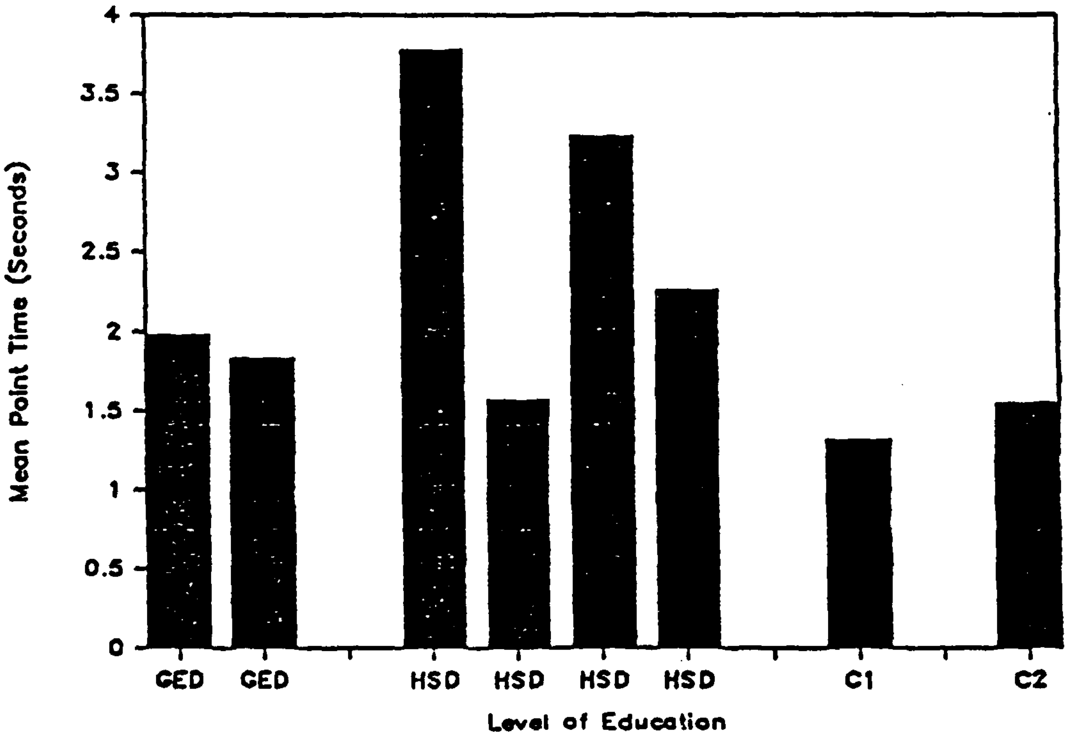


Figure 28. Mean point time in seconds by level of education.

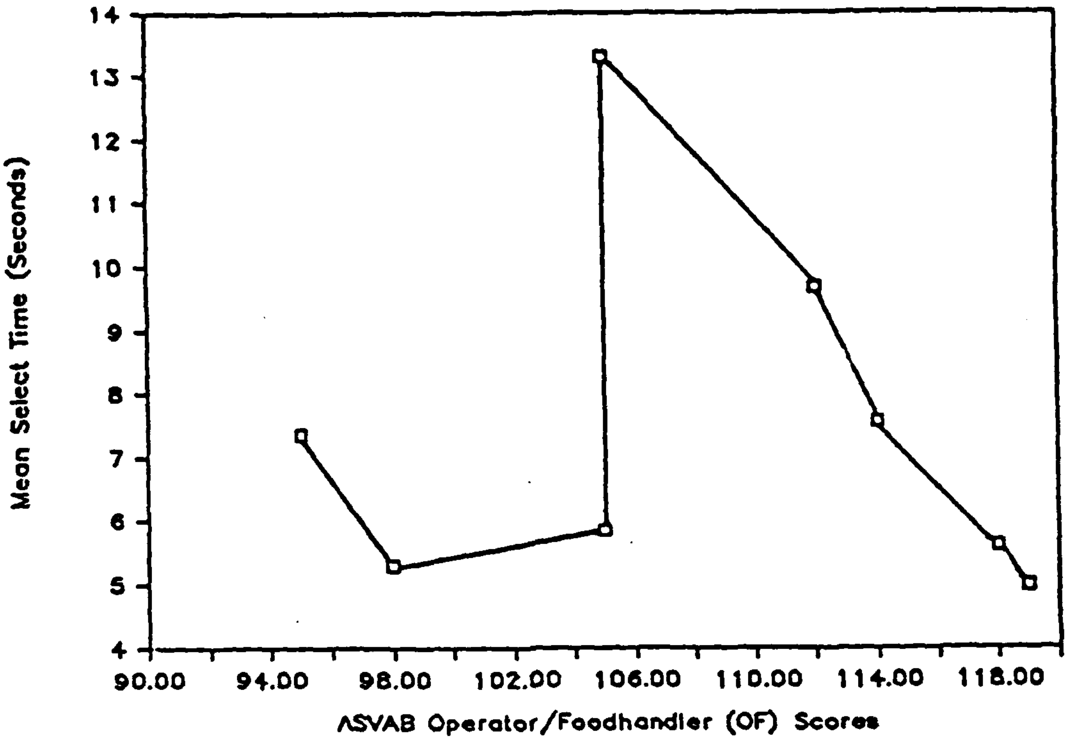


Figure 29. Individual OF scores plotted against mean select times.

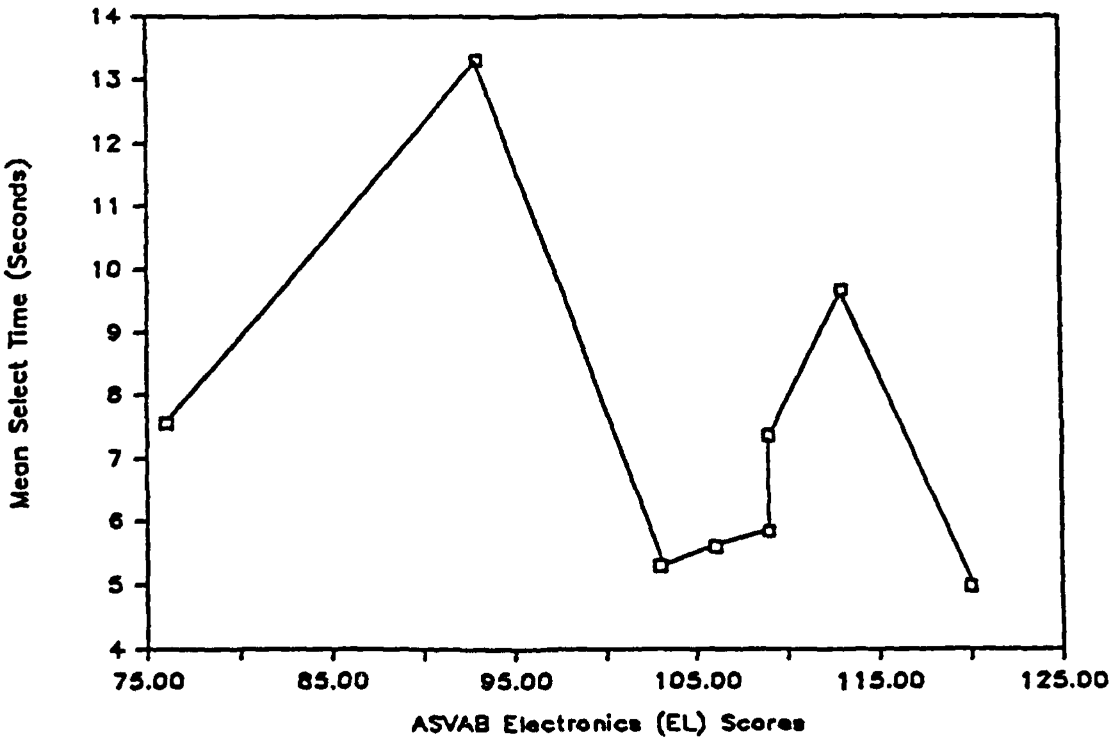


Figure 30. Individual EL scores plotted against mean select times.

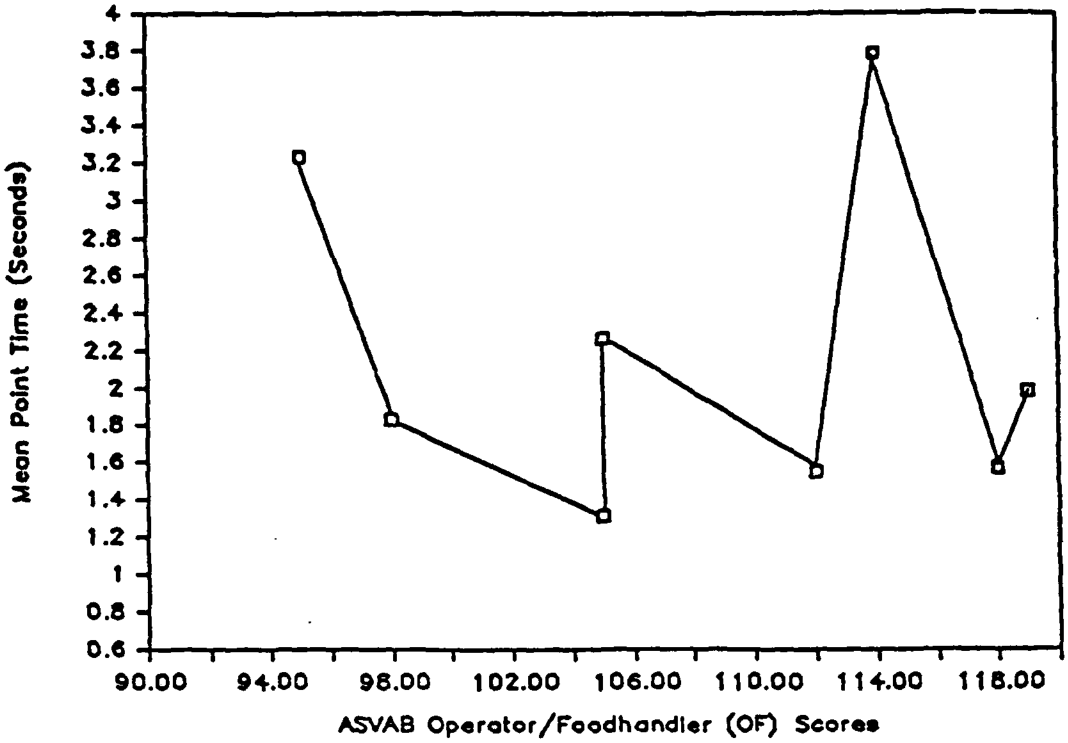


Figure 31. Individual OF scores plotted against mean point time.

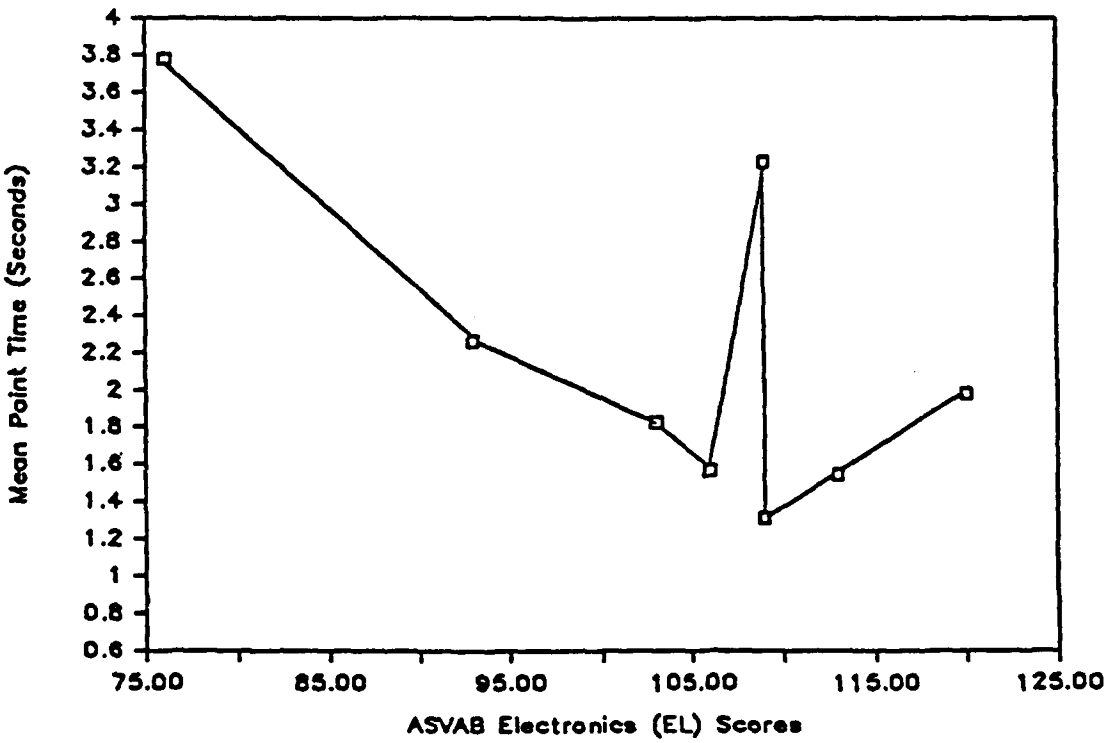


Figure 32. Individual EL scores plotted against mean point time.

AFQT scores. No prerequisites had been established with respect to AFQT score. When individual crew member AFQT scores were plotted by mean Select time, the distribution indicated that higher AFQT scores may not necessarily be associated with lower performance time as indicated by time to classify and select a target. There was a difference of 30 points between crew members #0240 and #9843 on AFQT score, even though their mean Select and Classify target times were similar. As Figure 33 illustrates, there does not appear to be a simple relationship between AFQT score and performance as indicated by Select time.

AFQT scores of Sgt York operators were plotted against crew member mean Point time. As Figure 34 shows, the resulting graph indicated that there was no relationship between AFQT score and the time it took a crew member to point a target. The findings suggest that AFQT scores may not be useful in selecting crew members for activities that focus on pointing a target.

Note (see Table 46) that the lowest AFQT score (19) for this sample was obtained by a Sgt York gunner. This individual also had the highest individual training score. This observation supports the conclusion that soldiers with low AFQT scores, or some subset of them, are capable of satisfactorily completing individual and collective training, as well as being capable of operating a complex weapons system during a field test situation.

AFQT scores were also related to crew member mean performance time in seconds for pointing a target. The range in AFQT scores for crew members with a high level of performance in mean time to point a target ranged between scores of 23 and 65. All of the crew members used in the sample in this study had AFQT scores ranging from 19 through 65. An average AFQT score had been obtained on the population of 16R (Vulcan) crewmen. The Vulcan average AFQT score was 45.4 (N=1281). The average AFQT score for the eight Sgt York crew members for whom scores were available was 44.5, suggesting that on this measure, at test, the Sgt York operators were fairly representative.

Mental Category classification. A Mental Category histogram was constructed to explore whether a relationship existed between Mental Category classification and individual crew member mean select and classify target time. As Figure 35 shows, individual performance times were quite similar, and rapid selection was achieved by individuals in Mental Categories II, IIIA, IIIB, and IV. Knowledge of Mental Category does not appear to be important in the selection of personnel for this task. Results based on the small sample of nine crew members would allow for the participation of crew members with a Mental Category IV classification. Such an outcome could broaden the pool for candidate crew members.

Mental Category classification was also plotted against Pointer On time for each individual crew member. The four crew members who had pointer on times under 2 seconds had Mental Category classifications of IIIA, II, IV, and IIIB, respectively. When mean pointer on time in seconds was plotted by Mental Category for the crew members in this study, as shown in Figure 36, it became apparent that the slower performers on the crew activity of pointing the target were found in Mental Categories IIIA and IV. However, superior performance for mean time in seconds (i.e., quick performance) regarding the pointer on task was found in Mental Categories II, IIIA, IIIB, and IV. The

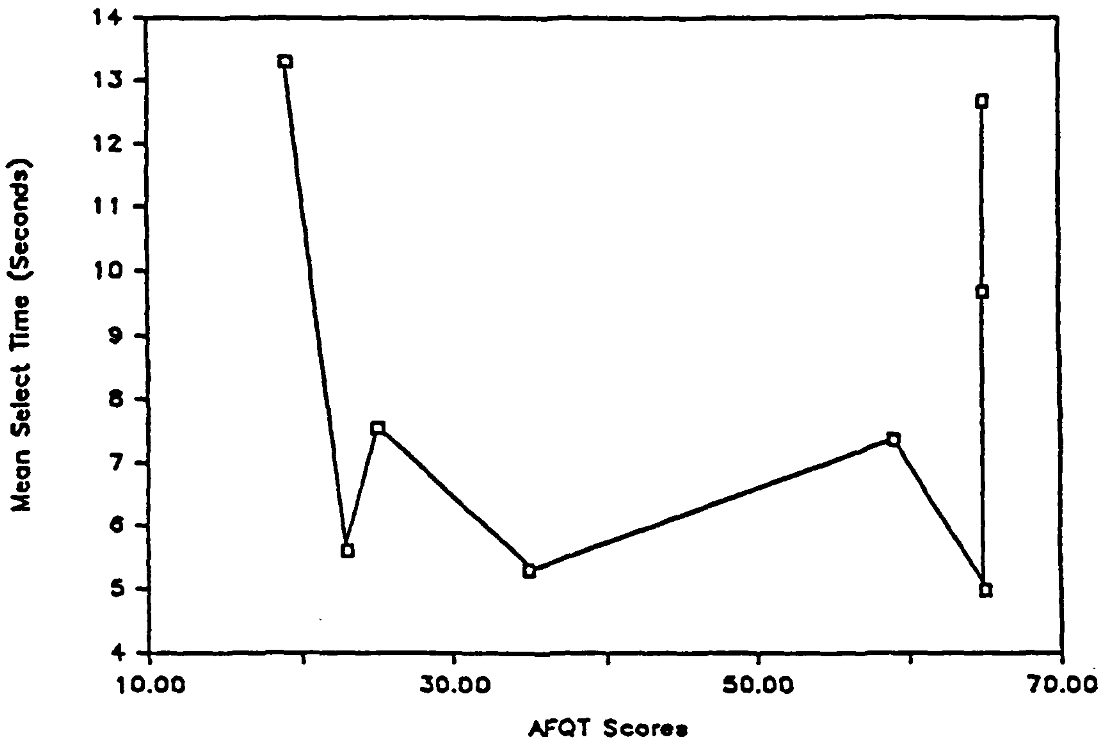


Figure 33. AFQT scores plotted against mean select time.

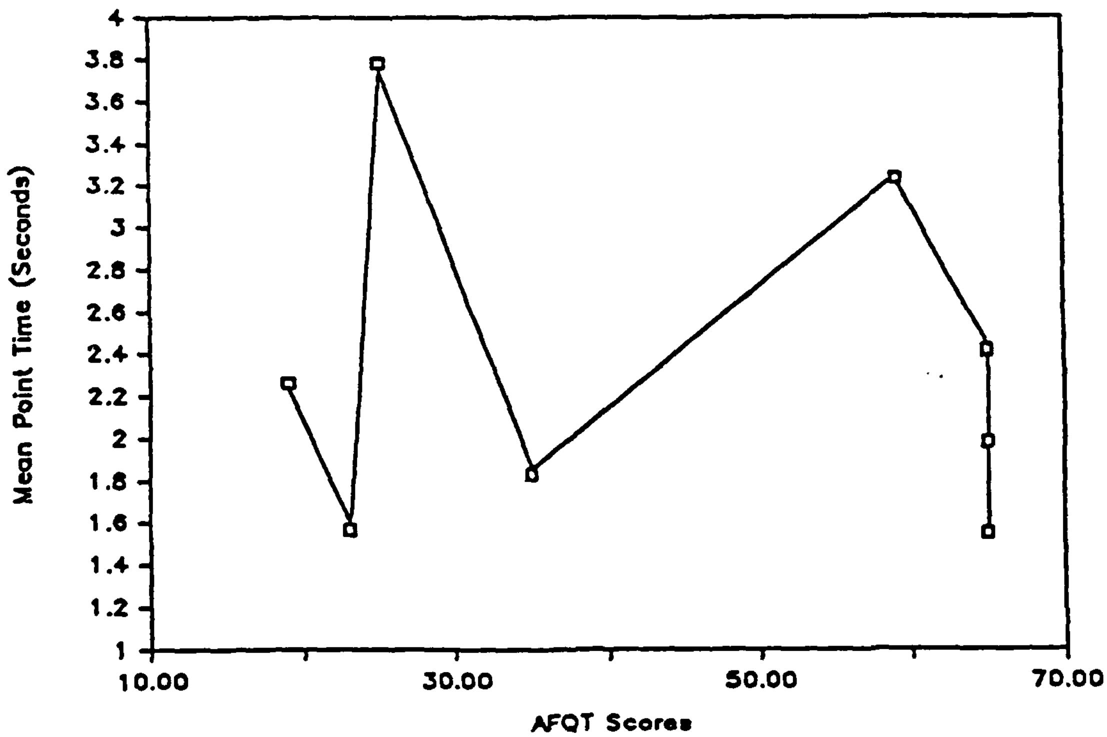


Figure 34. AFQT scores plotted against mean point time.

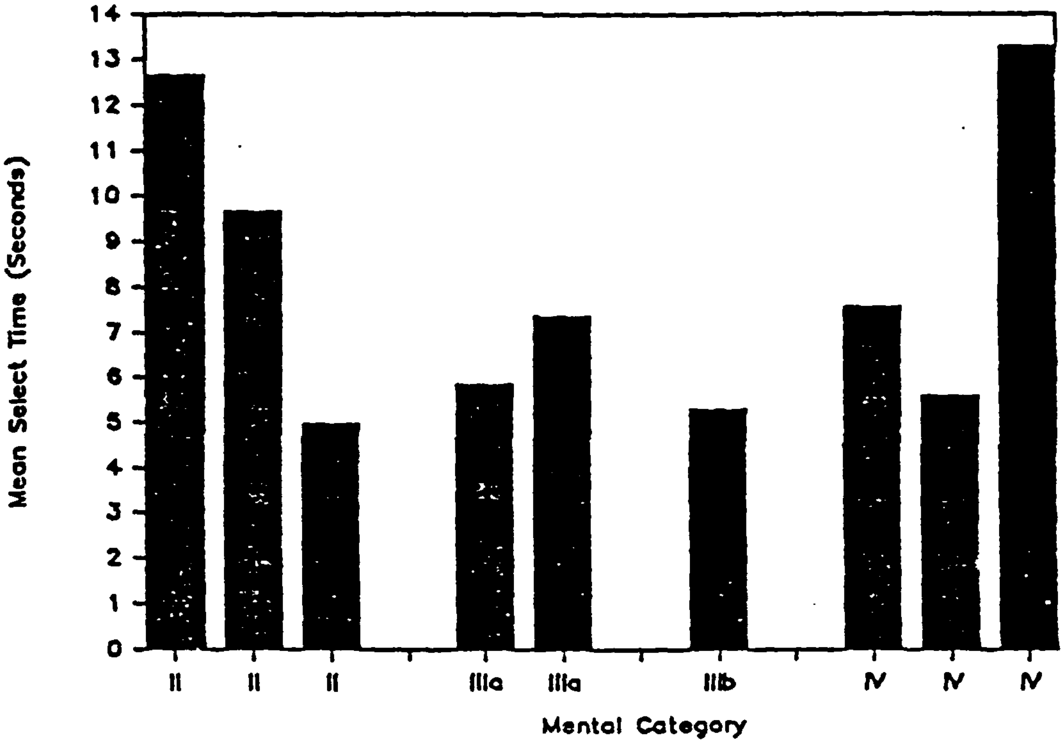


Figure 35. Mean select time in seconds by Mental Category.

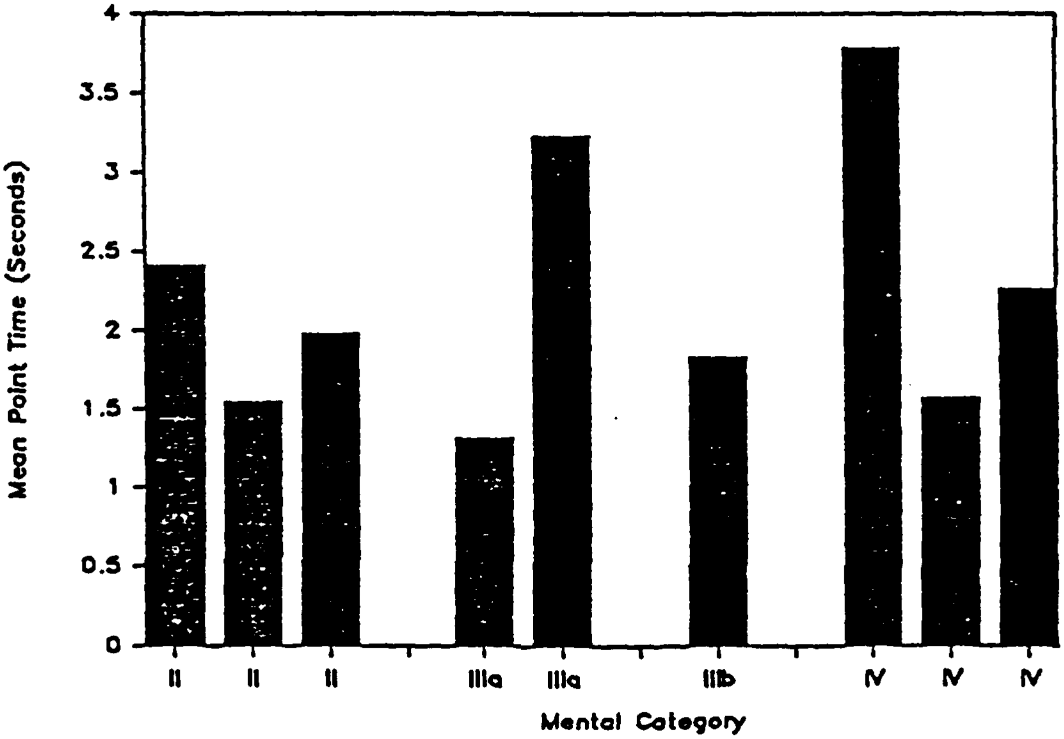


Figure 36. Mean point time in seconds by Meantal Category.

histogram indicates that Mental Category was not useful for selecting individuals who would exhibit greater skill in pointing a target. Perhaps if more subjects had been included, Mental Category might have proven valuable in selecting crew members. The current findings suggest that it may be appropriate to select future crew members for complex weapon systems such as Sgt York from Mental Categories II, III, and IV.

General Test scores. As with AFQT scores, crew members #0240 and #9843 represent the bottom and the top of the distribution. Also, as with AFQT scores, General Test (GT) scores showed a difference of 30 points between crew members #0240 and #9843. A graph was constructed to display the spread of GT scores for individual crew members by the mean time to select and classify a target. As Figure 37 shows, a high GT score was not necessarily associated with quick select/classify performance time.

General Test scores also were assessed for their relationship to the crew activity of pointing a target. Crew members #0240, #3753, #4343, and #9089 had GT scores ranging from 80 to 118. These crew members were all able to point a target in less than 2 seconds. When all crewmen were identified by GT score, scores ranged between 80 through 118. Even though both ranges are identical, a graph of GT scores by mean point time in seconds indicated that there may be a slight trend (and a bimodal distribution) toward higher GT scores being associated with a higher level of performance as reflected in mean time in seconds to point a target (see Figure 38). Further research would be warranted in developing selection criteria that include GT scores for crew activities based on mean performance times. The limited sample size does not allow for generalizing this finding with any confidence.

Summary. The evidence supports the contention that performance time in seconds to select and classify a target is not related to available crew descriptors or selection scores. Possibly, other selection scores could be developed which would have an element of predictability. At the present time, these descriptors and selection scores will not be of great use regarding select/classify tasks. The most important finding for performance time on the selection and classification of the target was associated with Mental Category classification, but it dealt not with a difference but the lack of a difference. Since Mental Categories II, IIIA, IIIB, and IV had similar performance times on select/classify tasks, further MANPRINT studies will be needed to assess the potential for increasing the use of Mental Category IV individuals. Data presented in this section are not sufficient to assess personnel selection criteria, but they do indicate that personnel selection criteria should be reevaluated.

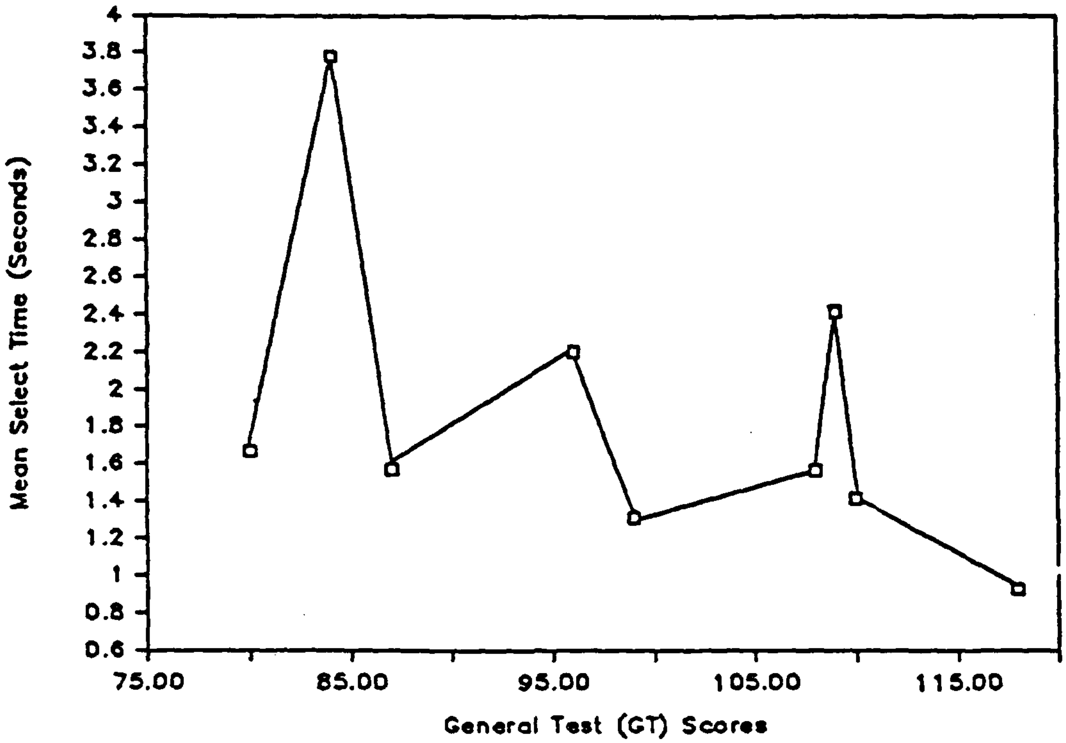


Figure 37. General Test scores plotted against mean select time.

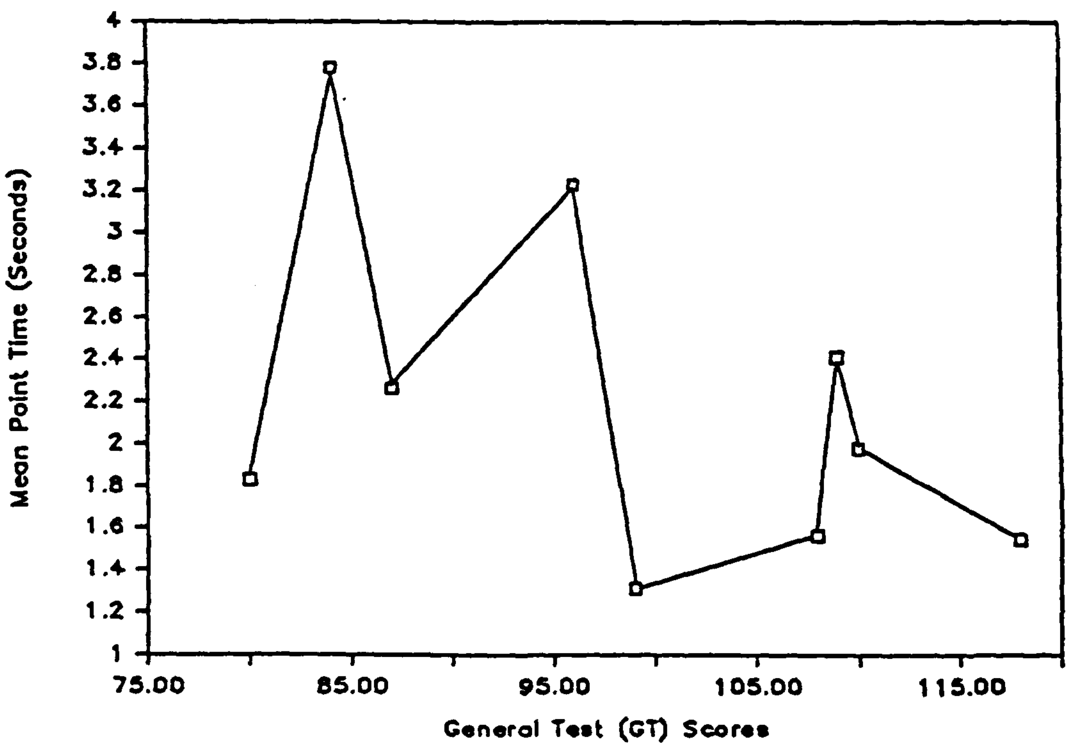


Figure 38. General Test scores plotted against mean point time.

Crew Mix/Mental Category

During the Sgt York FOE I Force-on-Force trials, five different squad leaders and four different gunners served as Sgt York crew members. An additional gunner was selected and trained, but for some unrecorded reason failed to take part in the test trials. Since there were five fire units taking part in the tests, the four gunners were moved about among the fire units, creating a variety of squad leader/gunner mixes.

As noted earlier in this chapter (see Fire Unit Comparisons), nine unique crews, or squad leader/gunner mixes, were created. The performance of these crews was reviewed and compared. The one significant difference found among crews was on mean Time to Fire. Time to Fire means and standard deviations for each of the crews are presented in Table 47; the nine unique crews are designated A through I and the number of trials in which they took part, the number of complete engagements which they carried out, and the percentage of the engagements initiated by the crew are indicated in the same table.

Table 47

Mean Time to Fire for Nine Unique Crews (Squad Leader/Gunner Mixes)

Crew Designation	Time to Fire Mean (s)	S.D. (s)	Number of Trials	Number of Engagements	% Crew-Initiated
A	19.7	14.4	13	37	86%
B	12.2	9.2	9	56	71%
C	17.1	12.5	12	65	83%
D	18.5	12.7	12	41	90%
E	17.2	8.2	3	15	80%
F	14.6	14.1	2	4	50%
G	20.5	14.8	6	18	94%
H	15.8	8.6	2	23	70%
I	12.1	5.5	1	12	92%

Note.

Crew	Squad Leader ID	Gunner ID
A	9089	6111
B	4343	0240
C	1746	9843
D	6640	5197
E	3753	5197
F	3753	9843
G	3753	0240
H	3753	6111
I	4343	9843

Since crew-initiated engagements took longer on the average, the shortest mean times to fire might be expected to have been associated with the lowest proportion of crew initiations. Crew I had the shortest mean Time to Fire

(12.10 seconds); Crew G had the longest (20.52 seconds). Both had approximately the same proportion of crew-initiated engagements (92% and 94%, respectively), above the average for the 271 total engagements (82%). Whether or not the quicker automatic engagements artificially lowered the average mean Time to Fire for some crews, it is unlikely that they accounted for the difference between the performance of Crews G and I, the slowest and the fastest crews.

The assignment of individuals to fire units and hence to crews was detailed earlier (see Fire Units) and is further discussed below. (The individual crew members were characterized and their differences discussed in the preceding section of this report.) It should be noted that the squad leader was the same for the two crews with the fastest Time to Fire scores. That squad leader belonged to Mental Category III. In Crew I, he was paired with a Category II gunner; in Crew B the gunner belonged to Category IIIB. Crew G, the one with the slowest mean Time to Fire score, had the same Category IIIB gunner, but in Crew G he was paired with a Category II squad leader. An attempt to assess the overall impact of the Mental Category of crew members on system performance was made earlier in this section. Mental Category (a nomenclature changed to "Test Score Category" as of 31 October 1987) is sometimes presumed to be related to an individual's ability to function as part of a complex, highly sophisticated man-machine system. Hence, the Mental Category was one variable considered in viewing performance scores.

Table 48 shows how crew members were assigned to fire units trial by trial. As the table indicates, with one exception, each squad leader stayed with a given fire unit throughout the trials analyzed. The one exception was on Trial 1048; the crew that had operated Fire Unit 2 on eleven earlier trials, operated Fire Unit 4 on the final trial analyzed. Three of the squad leaders were paired with only one gunner each. Another squad leader worked with a second gunner on one trial only. The fifth squad leader worked with all four gunners, each for at least two trials.

That circumstance provided an unusual opportunity to compare the performance of individuals belonging to different Mental Categories. There were gunners belonging to Categories II, IIIA, IIIB, and IV, and all four had worked with a single squad leader and, although in different trials, on the same fire unit. The results of this comparison are presented in Table 49. As the table indicates, none of the differences were significant. In other words, in this context and with these individuals, Mental Category was not a factor in speed of performance; Categories II, III, and IV gunners performed equivalently.

The data from Sgt York FOE I provide an additional opportunity to look at the effect of Mental Category on performance. Categories II, III, and IV were represented by squad leaders as well as by gunners. Furthermore, there were crews in which both members were Category II, another in which both members were Category III, and yet another in which both members were Category IV. Isolating the performance of these crews made possible the comparison presented in Table 50. Here there were significant differences in performance times. As the table shows, select time, pointer and laser on times, and Time to Fire all showed significant differences.

Table 48

Assignment of Squad Leaders and Gunners to Fire Units by Trial

Trial	Fire Unit 1 SL 9089	Fire Unit 2 SL 6640	Fire Unit 3 SL 3753	Fire Unit 4 SL 1746	Fire Unit 5 SL 4343
1020	G 6111		G 5197	G 9843	G 0240
1021		G 5197	G 6111	G 9843	G 0240
1022		G 5197	G 6111	G 9843	G 0240
1023	G 6111	G 5197	G 0240	G 9843	
1026	G 6111		G 5197	G 9843	G 0240
1027	G 6111		G 5197	G 9843	G 0240
1029	G 6111	G 5197		G 9843	G 0240
1035	G 6111	G 5197	G 0240	G 9843	
1036	G 6111	G 5197	G 0240	G 9843	
1039	G 6111	G 5197	G 0240	G 9843	
1040	G 6111	G 5197	G 0240	G 9843	
1041	G 6111	G 5197	G 9843		G 0240
1042	G 6111	G 5197		G 9843	G 0240
1046	G 6111		G 0240		G 9843
1048	G 6111		G 9843	SL 6640	G 0240
		G 5197			

Table 49

Mean Times for Target Engagement Sequence Tasks as a Function of Gunners from Different Mental Categories (II, IIIA, IIIB,IV), All Paired with the Same Squad Leader

Category of Gunner	II (s)	IIIA (s)	IIIB (s)	IV (s)	Significance Level
Select	14.8	6.5	8.2	8.5	NS
Pointer On	2.2	2.2	1.8	2.3	NS
Laser On	---	0.9	0.8	1.4	--
Acquisition	4.2	4.2	5.0	5.6	NS
Fire Solution: B	3.3	3.2	3.5	1.3	--
Fire Solution: S	0.9	4.5	3.6	1.9	NS
Fire Decision: B	0.7	1.5	2.5	0.7	--
Fire Decision: S	0.4	2.0	2.7	1.1	NS
Time to Fire	14.6	17.2	20.5	15.8	NS
Fire Duration	7.0	5.2	9.0	6.2	NS
Engagement Time	21.7	22.4	29.5	22.0	NS
No. of Engagements	4	15	18	23	

Table 50

Mean Times for Target Engagement Tasks Presented by Mental Category Level of Crew Members

Task	Category II Crew (s)	Category III Crew (s)	Category IV Crew (s)	Significance Level
Select	8.3	4.7	12.1	.021
Pointer On	2.5	1.6	1.6	.027
Laser On	0.6	1.6	0.8	.022
Acquisition	4.4	3.9	3.6	NS
Fire Solution: B	4.3	2.4	5.3	.032
Fire Solution: S	2.1	2.2	2.6	NS
Fire Decision: B	1.3	1.9	1.2	NS
Fire Decision: S	1.2	1.4	0.8	NS
Time to Fire	17.1	12.2	19.7	.008
Fire Duration	7.2	9.4	8.5	NS
Engagement Time	24.3	21.5	28.2	NS

All of these measures represent or include times for crew actions. With respect to select time, the Category III crew was significantly faster: 3.6 seconds faster than the Category II crew and 7.4 seconds faster than the Category IV crew. For pointer on time, the Category III and Category IV crews were only 0.01 seconds apart, but the Category II crew was significantly slower. For Time to Fire as with select time, it was the Category III crew which was fastest. Laser on time was the only significantly different measure on which the Category II crew was fastest.

Fire Solution blinking times were also significantly different as a function of crew Mental Category. Mean times for the Category III crew were shorter than those of either the Category II crews or the Category IV crew, but it is not clear how a hardware/software function such as that would be influenced by crew Mental Category.

These data do not show the disadvantage for Mental Category IV operators that would be expected on the basis of earlier studies. Although "those in the higher AFQT categories ...are more likely to qualify for specialized training in a greater number of occupational areas and perform better on the job than their low scoring peers" (Army Field Circular FC21-451, p. 2-5), there is no evidence on the basis of the Sgt York FOE I data to show that Category II crews are superior to average crews. Only with respect to laser-on time was the Category II crew superior and there the difference was less than a second: The Category II crew was 1.0 second faster than the Category III crew and 0.15 second faster than the Category IV crew. For all other measures on which there was a significant difference, either the Category III crew or both the Category III and the Category IV crews were quicker than the Category II crew.

There were two unique squad leader/gunner pairings in which both crew members belonged to Mental Category II. The gunner was the same in both crews, but the squad leader was not. The performance of these two crews was compared and found to be very similar. None of the differences was significant.

The comparisons just presented looked at crews on which the Mental Category of the squad leader and the gunner matched. There was also a variety of mixed category crews, that is, crews in which the Mental Category of the squad leader and the gunner differed. As a result, it was possible to compare the performance of crews in which the squad leader was of a higher Mental Category than the gunner (i.e., Crews E, G, and H) with the performance of crews in which the squad leader was of a lower Mental Category than the gunner (i.e., Crews D and I). In a comparison of all eleven segments of the target engagement sequence, from select time through total engagement time, no significant differences were found. In other words, crew performance was essentially the same whether the squad leader belonged to a higher or a lower Mental Category than did the gunner. As an example, Time to Fire was 17.7 seconds if the squad leader was higher in Mental Category and it was 17.1 if the gunner was higher in Mental Category. Apparently, at least with the crew members who took part in Sgt York FOE I, the relative Mental Categories of crew members did not affect performance.

Two other comparisons of note were made. In one, the crews which remained together in stable working relationships were compared to the crews in which the members were frequently interchanged. The so called stable crews might be expected to have an advantage over the less stable crews, but there were no significant differences among them.

Finally, crews in which the squad leader had previous Sgt York experience were compared with crews in which the squad leaders had no such previous experience. None of the gunners who took part in the Force-on-Force Sgt York tests had previous experience with Sgt York. There were significant differences on three measures as Table 51 shows. Crews in which squad leaders were experienced had significantly shorter laser-on times, but crews with inexperienced squad leaders had shorter select and Time to Fire times. It may be that previous experience not just with Sgt York but with other similar systems (in which laser operation was an important component) accounts both for the quicker lase times found for experienced squad leaders and for slower times on those operations unique to Sgt York.

Table 52 presents a summary of the differences observed in crew performance. That some crews were faster than others is neither surprising nor very informative, but the observation that crews which stayed together throughout the Force-on-Force trials did not outperform the crews which worked together only occasionally is interesting. Furthermore, the fact that crews whose members belonged to Mental Category II did not consistently or significantly outperform Category III or Category IV crews and that the overall performance of Category III crews was the fastest is informative. Even in view of the limited sample of crews represented and the nature of the test environment, these outcomes are worth noting.

Table 51

Mean Times for Target Engagement Tasks as a Function of Experience of Squad Leader

Task	Inexperienced SL (s)	Experienced SL (s)	Significance Level
Select	5.9	9.1	.025
Pointer On	2.4	2.2	NS
Laser On	1.4	0.8	.010
Acquisition	3.9	4.4	NS
Fire Solution: B	3.6	4.4	NS
Fire Solution: S	2.5	2.6	NS
Fire Decision: B	2.2	1.3	NS
Fire Decision: S	1.1	1.4	NS
Time-to-Fire	14.6	17.9	.024
Fire Duration	9.0	7.4	NS
Engagement Time	23.6	25.2	NS

Table 52

Summary of Crew Comparisons

Comparison	Significant Differences	Fastest
Unique Crews (A through I)	Time-to-Fire	Crews B & I
Gunner Mental Category (II, IIIA, IIIB, IV)	No Significant Differences	
Composite Crew Mental Category (II, III, IV)	Select Time	Category IIICrew
	Pointer On Time	Category IV Crew
	Laser On Time	Category II Crew
	Fire Solution: B Time	Category IIICrew
	Time to Fire	Category IIICrew
Two Different Category II Crews	No Significant Differences	
Stable vs. Changing Crews	No Significant Differences	
Experience of Squad Leaders	Select Time	Inexperienced SL
	Laser On Time	Experienced SL
	Time to Fire	Inexperienced SL

Training

Training and Target Decisions

This section presents information on individual crew member mean performance times as they relate to previous Sgt York experience, individual training scores, and collective training outcomes. Additional analyses include crews with experienced squad leaders versus crews with inexperienced squad leaders. Keep in mind the small number of individuals involved.

Table 53 identifies each crew member in the sample according to whether or not he had previous Sgt York experience, individual training scores, collective training outcomes, and mean performance time in seconds for three crew performance measures that could be associated with specific individuals: selecting/classifying targets, pointing targets, and lasing targets.

Table 53

Sgt York Player Personnel: Previous Experience and Training

Player ID#	Previous Sgt York Experience	Training		Performance Times		
		Ind.	Col.	Select/ Classify x (s)	Pointer On x (s)	Laser On x (s)
0240	No	94.9	Sat.	5.0	1.8	1.5
1746	Yes	NA	Sat.	12.0	2.3	---
3753	Yes	NA	Sat.	9.6	1.6	0.3
4343	No	96.7	Sat.	5.6	1.3	---
5197	No	Fail	Sat.	7.3	3.2	1.2
6111	No	97.6	Sat.	13.7	2.3	0.9
6640	No	91.3	Sat.	7.6	3.8	---
9089	Yes	NA	Sat.	5.6	1.6	---
9843	No	97.2	Sat.	4.7	2.4	0.9

Note. Ind. = Individual
Col. = Collective
Sat. = Satisfactory
NA = Not Applicable; players with previous Sgt York experience were not included in pre-FOE I individual training.

Previous Sgt York Experience. Column 2 of Table 53 reflects whether or not individuals had previous experience with the Sgt York fire unit. Individual crew members who had been involved with the Early Production Unit Test (EPUT) and the Limited Test (LT) were classified as having previous Sgt York experience. Of the 30 crew members who participated in FOE I, six crew members had previous Sgt York experience. During the Force-on-Force phase of FOE I, 3 of the 9 operators had previous Sgt York experience. These persons were all squad leaders. Soldiers who had previous Sgt York experience did not participate in the individual training course that preceded FOE I. Crew members identified in this table participated in the trials and engagements from which the performance data base presented earlier (Tables 3, 4, and 5) was generated.

Previous Sgt York experience and mean Select and Classify times. Gunner and squad leader individual mean select times were compared for the first crew activity, Select and Classify targets. Results indicated that there was a significant difference ($p=.007$). The two crew members who had the fastest performance were Gunner #0240 (5.0 seconds mean), and Squad Leader #9843 (4.7 seconds mean). Neither crew member had previous experience. For this limited sample, having no previous experience with the fire unit was found to be advantageous in selecting (and pointing) a target. Experienced crew members did not take part in FOE I individual training. The performance times of the inexperienced crew members for Select and Classify targets may have been enhanced by their recent individual training.

Previous Sgt York experience and mean Pointer On times. Another comparison of crew mean performance times, for crew members doing the pointer on task, was made. Crew members varied significantly on the amount of time it took them to point a target ($p=.003$). Four crew members had mean pointer on times of under two seconds (Gunner #0240, 1.8 seconds; Squad Leader #3753, 1.6 seconds; Squad Leader #4343, 1.3 seconds; and Squad Leader #9089, 1.6 seconds). Two of these four crew members had previous Sgt York experience. Crewmen's speed in pointing a target was not associated with previous experience or lack of experience with the fire unit.

Crews with experienced squad leaders versus crews with inexperienced squad leaders. Crew members were sorted into those with experienced squad leaders and those with inexperienced squad leaders to see if this factor made a signficant difference in performance. These two groups of crews were compared on mean times for Select and Classify, Pointer On, Laser On, Acquire, Fire Solution Blinking, Fire Solution Solid, Fire Decision Blinking, Fire Decision Solid, Time to Fire, Fire Duration, and Engagement Time. Significant differences were found for Select and Classify, Laser On, and Time to Fire.

Crews with experienced squad leaders were found to be significantly different from crews with inexperienced squad leaders ($p=.025$) in performing the Select and Classify activity. The mean time it took a crew with an inexperienced squad leader to select and classify a target was 3.2 seconds less than for a crew who had an experienced squad leader (see Table 54).

Table 54

Crews With Experienced Versus Crews With Inexperienced Squad Leaders, Select and Classify Target

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Crews With Experienced Squad Leader	133	9.1	11.4
Crews With Inexperienced Squad Leader	88	5.9	8.5

Ordinarily, significantly quicker mean performance times would not be expected from novice squad leaders without previous fire unit experience. Perhaps the more recent individual training given to inexperienced squad leaders improved their performance in selecting and classifying targets, and they may have coached the gunner. Lack of recent individual training for experienced squad leaders in this content area may have contributed to their relatively poorer performance.

Laser on was found to be significantly different ($p=.010$) between crews with experienced and crews with inexperienced squad leaders. The finding indicates that crews with experienced squad leaders lased targets about a half second more quickly than crews with inexperienced squad leaders (See Table 55). Apparently, previous squad leader experience with the fire unit was beneficial in reducing mean time to perform the laser pointing task. Since all but one lasing was performed by gunners, it was particularly notable that squad leader experience made a difference in performance. Previous experience with laser-using systems may also have reduced mean lase times.

Table 55

Crews With Experienced Versus Crews With Inexperienced Squad Leaders, Laser On

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Crews With Experienced Squad Leader	32	0.8	0.7
Crews With Inexperienced Squad Leader	34	1.4	1.0

Time to Fire was found to be significantly different ($p=.024$) between crews with experienced versus crews with inexperienced squad leaders. The crew decision function, Time to Fire, represents the amount of time it took a gunner to depress the trigger after a firing cue appeared. Gunners with inexperienced squad leaders were able to fire 3.3 seconds more quickly (mean performance time) than gunners with experienced squad leaders (see Table 56). It is difficult to understand why a gunner with an experienced squad leader would fire less quickly than a crew with an inexperienced squad leader. As previously mentioned, crewmen with previous Sgt York experience did not receive individual training. Perhaps the additional training and the experience combined would have reversed these findings, or perhaps recent training was more successful at overcoming negative transfer from experience with systems other than Sgt York.

Table 56

Crews With Experienced Versus Crews With Inexperienced Squad Leaders, Time to Fire

	ENGAGEMENTS (n)	MEAN (s)	S.D. (s)
Crews With Experienced Squad Leaders	162	17.9	12.4
Crews With Inexperienced Squad Leaders	109	14.6	10.8

Individual Training. Individual and collective training scores and ratings have been included in Column 3 (individual training) and Column 4 (collective training) of Table 53.

Individual training was conducted at Fort Bliss, TX, between 15 October and 21 December 1984. The Program of Instruction (POI) was six weeks and three days. The POI had been modified and reduced from an original 11 weeks and two days to its shorter length. Limited training days were available before the initiation of FOE I, and this prompted the modification to the POI.

As previously mentioned pertaining to the column "Previous Sgt York Experience," not all crewmen received individual training. Six crewmen had previous Sgt York experience and had been trained by Ford Aerospace and Communications Corporation (FACC). Three of these individuals participated in the Force-on-Force trials and are identified in Column 3 by "Not Applicable" because they were not included in the pre-FOE I individual training.

Individual training scores and mean Select and Classify times. Gunner and squad leader mean performance times were compared for Select and Classify targets, a crew activity. There was a significant difference ($p=.007$); the two crew members having the highest level of performance were Gunner #0240, 5.0 seconds mean; and Squad Leader #9843, 4.7 seconds mean. When these two crew members were compared on individual training scores, there was a difference of 2.3 points in scoring between the crewmen. Figure 39 shows the individual training scores by the mean select/classify times for individual crew members. Higher individual training scores are not necessarily associated with higher performance (quicker times) in selecting and classifying a target.

Individual training scores and mean Pointer On times. Crew members were compared on their mean performance times in pointing targets (pointer on). Mean times on this task were found to be significantly different ($p=.003$). The fastest performing crew members with mean time under 2.0 seconds were Gunner #0240, 1.8 seconds; Squad Leader #3753, 1.6 seconds; Squad Leader #4343, 1.3 seconds; and Squad Leader #9089, 1.6 seconds. Two of these crewmen had individual training scores of 94.9 and 96.7. The other two crewmen did not receive pre-FOE I individual training since they had previous Sgt York experience. This is an indication that the task of pointing a target may be taught in the classroom or during on-the-job training (OJT). Both methods of instruction were just as proficient in allowing the four crewmen to achieve a high level of performance for the pointer on task. Crew members used in this sample were compared for mean pointer on performance times by individual training scores. Figure 40 illustrates that a higher individual training score does not indicate that the crew member will have a faster pointer on performance.

Collective Training. Collective training was conducted at Fort Bliss between 31 December 1984 and 15 February 1985. Those individuals who were certified as satisfactorily completing collective training were identified with a "Sat." in Table 53. It was not possible to differentiate among crew members regarding their certification or lack of certification for the completion of collective training since all crew members in the sample received a designation of satisfactory. Collective training, as well as individual training, did not seem to influence the ability of any crew member to perform the laser on task more quickly.

Trends among training scores, previous Sgt York experience, designations, and performance times were not found. This may have been due to the limited sample size. With a larger sample, it might have been possible to establish trends. However, it is not unusual to find a lack of supporting data for transfer of training from the classroom to the field. Data presented on experience and training are not sufficient to assess selection criteria for training cutoff scores, collective training designation, or amount of training.

Training cutoff scores used as a criterion for selection or other established criteria for collective training were not appropriate for selecting crew members due to the contingencies of the training environment. Because of the accelerated fielding schedule, the fire units were retrofitted for software and hardware during training and testing. Crew members were not familiar with the changes, and the impact of the retrofitting was not taken into account for training scoring and designation purposes.

Other factors which influenced the reliability of the training are associated with a transfer of training from the VULCAN to the Sgt York fire unit. Squad leaders previously trained and experienced with the VULCAN were found to use the laser/optics instead of the radar during training sessions. The preference for laser/optics was identified for situations where there was no tactical necessity for the use of that system mode. Since Radar Auto mode had the highest level of automation and was the most efficient mode in the completion of a target engagement sequence, it would be counterproductive to use laser/optics when they were not needed. Overall, squad leaders with previous VULCAN training and experience distrusted the Sgt York fire unit. Previous VULCAN training may have been detrimental to Sgt York crew member performance and appeared to have negatively impacted the Sgt York training.

Use of Initiative. Squad leaders were taught how to read maps, but they had a difficult time generalizing this knowledge into terrain reading. This skill was required at Hunter-Liggett in order to execute the decentralized mission of the autonomous fire units. The resulting behavior appeared to be due to a lack of confidence to execute a decentralized mission. However, on the airland battlefield, crew members would be required to show initiative and use common sense to achieve their commander's objectives. To operate as independent elements would be necessary (Babbitt, Seven, Lyons, & Sparks, 1986).

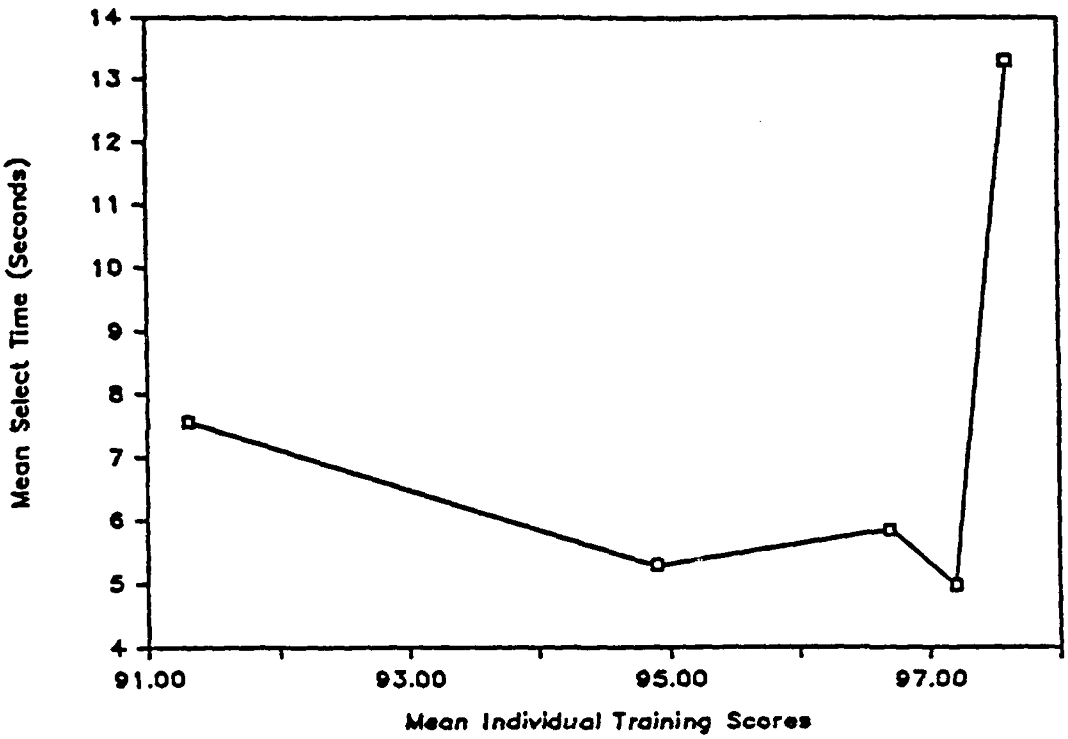


Figure 39. Mean select time in seconds by individual training scores.

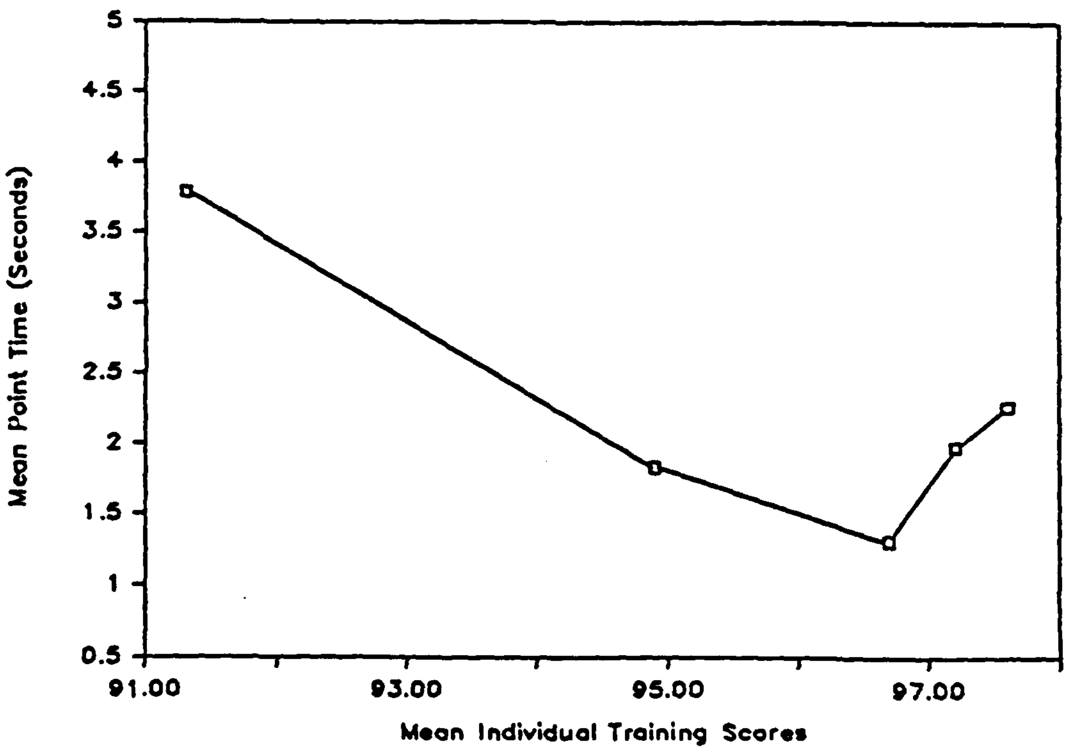


Figure 40. Mean point time in seconds by individual training scores.

Quantitative Prediction Models

In the Introduction, the point was made that a desirable tool for the future design of FAADS is quantitative system-human performance computer simulation models. One major purpose of this report is to provide concepts and data that might be useful for that goal. The purpose of this chapter is to see what concepts and data presented in the chapters on human performance data and on research findings could be applied to future FAADS soldier-system performance models.

In the Introduction, some fundamental requirements for modeling were noted. They include at least three sequential areas:

- The FAADS to be modeled must be described including major system functions and tasks both with respect to the system, subsystems, crew and human operator tasks.
- For system functions and tasks, parameter identification must be made to insure that appropriate parameters are included in the model.
- For the model parameters, performance data must be available either from existing empirical sources or data estimation.

A fourth general requirement, selection of the best computer language and software, will not be discussed here because that is more of a problem of specific choice of <u>how</u> the soldier-system is to be simulated rather than <u>what</u> is to be simulated.

System Description

The chapter on human performance data opened with a detailed discussion of the FAADS target engagement sequence first in the most generic sense, then with examples of variations expressed by the ADATS, Liberty, Rapier, Paladin, and Sgt York systems. It is this kind of system description that must form the basis for quantitative prediction models.

Further, there will always be a question as to the appropriate level of detail to which the system description must be taken. One deciding factor in determining the appropriate level always is the kind of design question being asked. If, for example, there is some question about target designation, then the model must be able to focus on that task in sufficient detail. This was the area of interest in the MOPADS model (Polito & Laughery, 1984), as noted in the Introduction. On the other hand, if the question is to predict if system response times are being achieved, a much different and far more global level of system description must be simulated and modeled.

It is hoped that the analysis presented in the chapter on human performance data will be helpful in any specific future FAADS modeling effort. While there may be many specific subsystem differences, the sequences shown in the chapter on human performance data must be represented in the model in some form unless, of course, some radically new technology appears to solve forward area air defense problems.

For many purposes in design - and not just for the development of performance models - traditional systems engineering functional flow analyses can serve at several levels as the basis for the development of simulated system descriptions. In some system designs, these analyses are performed, but in many cases they are not. It is critically important to specify at several levels of detail what functions the system must perform apart from the question of how the functions are done (i.e., the actual mechanization). It is impossible to develop an acceptable quantitative prediction model without that kind of analysis as the foundation for the model.

Parameter Identification

The chapter on research findings offers a number of suggestions for necessary variables and parameters that might be included in a future FAADS soldier-system performance model. One of the purposes of the analyses in that chapter was to investigate what some of the critical parameters might be. That is, what conditions in forward area air defense might be expected to influence individual, crew, subsystem, and system performance? It is important to note that the findings are suggestive only. The fact that a variable was not shown to be effective in these data does not automatically exclude it from consideration in future model development.

In summary of the research findings, the following comments could be made with respect to model development:

- It is useful to have some quantitative estimate of how closely the system reaches, or falls short of, system response time requirements. Periodic checks can be made with the model as design progresses and subsystems are revised and/or changed.

- If the proposed system has multiple modes of operation, it seems imperative that quantitative predictions be available on how well those modes will be used and above all how fast performance is predicted to be. Multiple modes may in fact impede successful system performance.

- Where multiple fire units are involved, there may be important differences in performance among them. Potential variability should be investigated in the model. Whether the fire units are operating independently or in a command and control network will also be a critical modeling consideration.

- The model should be sufficiently rich so as to explore possible variations in tactical performance. For example, the results found here suggest that processing times change when the unit is fixed or mobile. But the changes may only be of interest in subsystem tasks. On the other hand, for a critical system measure - Time to Fire - significant differences were found for rotary-wing tactics, ECM condition, time of day, and target range at first appearance.

Some of the variables and parameters looked at here did not seem to make much difference in performance. This was true of (1) scenario type, (2) comparisons of gunner and squad leader performance, (3) the use of MOPP gear, and (4) target workload. But they are not necessarily to be ignored in future models because:

- The particular scenarios exercised may have not been different enough to make any particular impact.
- In crew performance models, it is to be expected that distributions of performance data will be used for different crew members.
- In this instance, the MOPP gear simply was not worn long enough to have an effect upon performance.
- Target workload had no apparent impact because target prioritization was performed by automatic decision aids.

In previous model developments, it has been difficult to include certain parameters associated with crew characteristics. An example of one such variable is "mental category" or, using the new terminology, "test score category." With respect to this variable and crew mix, the Chapter IV finding was that Time to Fire was influenced by various crew mixes. Related to this parameter is the impact of past crew member experience. Here, one finds the odd result that crews with experienced squad leaders were slower on Time to Fire than crews with inexperienced squad leaders. Whatever direction, crew mix and individual crew member experience are variables for modeling.

Finally, it seems very reasonable that training parameters should somehow be candidates for inclusion in performance models. It is probable, however, that "training" variables per se are not of direct model use, but rather must be translated to levels of performance produced by training. This would mean, for example, using different soldier performance data distributions to reflect various stages of human learning.

Data Distributions

One of the major purposes of this report was to extract and present performance data distributions over a wide variety of conditions appropriate to the forward area air defense problems. These data could be used for a variety of design purposes, but one purpose in particular is for performance models for future FAADS. Such data and their distributions have been presented in the discussions of the individual research findings; means and standard deviations, as well as actual frequency distributions where appropriate, have been presented.

The principal data distributions, however, were shown in Tables 3 and 5. For 271 complete target engagement sequences, time data are given for 11 basic system and task functions by each individual TES. Where similar subsystem functions appear in future FAADS and a system model is developed, the data presented in this report may be considered for model data distributions. It is hoped that such data will find extensive use as human performance models are developed for future FAADS.

Follow-On Evaluation Procedures

Follow-on evaluation procedures for operational test and evaluation (OT&E) are viewed from a perspective of opportunities and possibilities of what could be accomplished if MANPRINT methodology actually had been applied during FOE I. The specific objectives of this chapter are multidimensional, and are designed to heighten awareness of lessons relearned, to improve the weapon system acquisition process and system designs of the future, and to suggest what could be accomplished for future OT&E. Discussion of follow-on evaluation procedures covers topic areas for MANPRINT implications, test planning with an emphasis on preplanning activities, data analyses and interpretation, realistic test environment, personnel characteristics and training and performance measures, and dissemination of information from OT&E.

MANPRINT Implications

The integration of MANPRINT procedures into OT&E, as the next iteration from the previous manpower, personnel, and training OT&E used by human factors engineers in operational testing, will be considered. The total MANPRINT methodology for an integrated approach to the design of equipment which includes procedures for imposing manpower and personnel integration within the full acquisition process (AR 602-2, 1987) will not be dealt with here.

Because the complexity of Army systems has been increasing over time, soldiers are now required to be capable of performing tasks with significantly higher cognitive demands. Complex tasking for complex systems has compromised soldier-system performance and force effectiveness. For example, complex tasks in the Sgt York fire unit were identified for operators for tasks associated with selection and use of the multiple system modes during the target engagement sequence. Other complex tasks were identified during FOE I for the maintainers regarding bit isolation. Responsibility for resolving the problem of complex tasking for complex systems should be a joint effort between the Army Materiel Command and the private sector. They should perform analyses which illuminate tradeoffs between design alternatives, manpower, personnel, and training.

MANPRINT involves a higher level, and more integrated level, of analyses than previously performed during OT&E. There are no standard methods for applying MANPRINT, yet former OT&E test planning and implementation will no longer be viable because of the MANPRINT initiative. Structurally sound MANPRINT methodology should include task analyses that are performed to identify critical tasks for overall system performance. These critical tasks must be viewed in terms of overall system performance as it relates to ergonomic and cognitive skills for the population of soldiers who are available, and who are projected to be available over the life cycle of the weapon system. Outcomes from the measurement are then designed to answer questions such as: What is the quality of the personnel, will there be potential changes in the quality and quantity of the personnel, how can training and system design reduce stress on the soldier and help to attain system performance goals?

Test design plans of the future will not be able to get away from the requirement for more and more measurement. In order to investigate the MANPRINT areas, HFE personnel activities associated with data collection, analyses, and dissemination of information will be expanded. To illustrate the type of expansion required for the implementation of MANPRINT data collection techniques, critical task measurement has been refined. In a previous test where MANPRINT techniques were applied (Remotely Piloted Vehicle), critical task crew performance measures were established through critical task assessment interviews, on-site observation, structured interviews covering the test data requirements, and comment and opinion data from test participants. Critical tasks identified and integrated into the multiple data collection techniques all had timed crew performance measures amenable to timed data collection conditions which were tied into the test instrumentation. Criteria were applied to the selection and retention of critical crew performance tasks. Without criteria, it would have been impossible to assess the tasks and interpret the data with any assurance of validity. During Sgt York FOE I, the test plan did not identify critical tasks (Babbitt, 1987; Seven, 1987). Criteria were not established prior to or during analyses of the test results. The measurement process was constrained and forced into a format of describing the data, but the element of prediction based on critical tasks and criteria had no solid methodological foundation. Generalization of the test results was, therefore, tenuous.

The design of the test plan has increased in importance due to the MANPRINT requirements. In order to develop a test plan with multiple measures to provide answers for the six MANPRINT areas (human factors, manpower, training, personnel, system safety, and health hazards), time allotted for preplanning of the test must be expanded. To provide an example of the level of effort that is now needed to address MANPRINT in preplanning and conducting the test, and post-test activities, a task listing was developed as a guide for implementing the MANPRINT initiative, as shown in Table 57 (Krohn, 1986).

Resulting documentation from the accomplishments of the task listing are identified in Table 57. As can be seen by a review of the pretest activities, test conduct activities, and post-test activities, more technical manpower loading is required for test personnel to complete the pretest activities than to conduct the test or the post-test activities. There is a profound labor shift among OT&E test activities and professional labor hours to plan and conduct tests now compared to previous years. MANPRINT OT&E has become a more labor-intensive endeavor than in previous years. The shift in pretest activities, the increased data collection and analyses, and the new approaches to reporting and disseminating information have had a significant impact on budget preparation activities and funding requirements. Allocating resources within the test plan, and obtaining funding necessary to achieve acceptable integration of data and outcomes promised by MANPRINT efforts have the potential to become productive efforts. OT&E planning and implementation of tests conducted using new and evolving techniques have been found to increase test budgets by more than 90% over what would have been incurred prior to the MANPRINT initiative. In the name of the soldier-machine interface, where all the test community effort counts, the question still remains as to whether the federal government has the resources to fund MANPRINT OT&E. Obviously, without adherence to administrative procedures already in place, and without appropriate funding, the OT&E-MANPRINT marriage could easily become unhinged. Adherence to MANPRINT would retain checkpoints embedded throughout the weapon

Table 57

Major Operational Test and Evaluation Tasks for the MANPRINT Assessment of Systems

TASK LISTING	RESULTING DOCUMENTATION (Comments)
PRETEST	
1. Coordination meetings with OTEA POC and Test Directorate.	1. None (May require more than one meeting.)
2. Develop MANPRINT test issues and criteria.	2. List of test issues and criteria in OTEA format for inclusion in draft Test Design Plan.
3. Review previous test documentation and findings.	3. a. List of MANPRINT areas requiring full investigation or additional data. b. Summary included in ARI MANPRINT test report.
4. Plan human performance measures side tests and critical task assessment (CTA).	4. Draft experimental or quasi-experimental design plans for inclusion in draft Detail Test Design Plan.
5. Plan training assessment.	5. Training Assessment Plan.
6. Meet with OTEA to integrate human performance measures and automated data processing efforts.	6. Final draft of MANPRINT sections of the Test Design Plan and Detail Test Plan. (May require more than one meeting.)
7. Conduct test system familiarization: a. Visit ongoing testing (e.g., developmental testing), b. Visit pretest player training, c. Visit predecessor systems operations, d. Visit system's manufacturing facility.	7. Site visit report: a. Interview data, b. Photo documentation.

Table 57

Major Operational Test and Evaluation Tasks for the MANPRINT Assessment of Systems (Cont'd.)

TASK LISTING	RESULTING DOCUMENTATION (Comments)
PRETEST (cont'd)	
8. Conduct pretest training evaluation at player training site: a. Attend classroom sessions, b. Attend field demonstrations, c. Review training documentation, d. Administer interviews, e. Administer questionnaires and pretest training test.	8. Site visit report and later the final ARI training assessment report or sections in the final ARI MANPRINT test report.
9. Validate selection of critical tasks for CTA: a. Visit and review player training, b. Visit and review ongoing testing, c. Interview test system subject matter experts.	9. List of critical tasks for which performance measures will be collected.
10. Prepare Detail MANPRINT Data Collection Plan: a. Overview of plan, b. MANPRINT tasks, c. Test data requirements, d. Schedules, e. Detail data collection plans, f. Staffing, g. ADP requirements.	10. Draft MANPRINT human factors assessment plan and data collection materials.
11. Prepare detail data collection materials: a. Interviews, b. Checklists, c. Observations log, d. Daily debrief and comments log, e. Comment code taxonomy.	11. Draft MANPRINT human factors assessment plan and data collection materials.
12. Review with ARI OTEA designates the detailed MANPRINT data collection plan and data collection materials.	12. Final MANPRINT human factors assessment plan and data collection materials.

Table 57

Major Operational Test and Evaluation Tasks for the MANPRINT Assessment of Systems (Cont'd.)

TASK LISTING	RESULTING DOCUMENTATION (Comments)
PRETEST (cont'd)	
13. Integrate MANPRINT data collection plan and human performance measures into automated data base.	13. Draft ADP requirements, input output formats, and review of system performance measures.
14. Prepare detail experimental, quasi-experimental, and/or critial task assessment methodology.	14. Experimental design and CTA performance measure worksheets.
15. Demonstrate ADP integration.	15. Fictitious data files for ADP operations check.
16. Attend operational test readiness reviews (OTRR).	16. None. (May require more than one meeting.)
17. Prepare test data collector training for MANPRINT effort. Give data collector training related to MANPRINT.	17. a. List data collection items to be collected by data collectors. b. Lists of operational definitions for performance measures to be collected by data collectors. c. Examples of MANPRINT data requirements and crew behaviors regarding the beginning and ending of the operational definitions.
18. Obtain test player demographic, experience, training, and aptitude data from the soldier support center or other sources as appropriate.	
19. Manage MANPRINT specialist staffing. Prepare budget and expense data.	19. Budget and expense data.
*20. Prepare MANPRINT system baseline prediction assessment plan.	20. MANPRINT system baseline predictions validation plan.

*Potential new area of investigation. During the design phase of new system development, MANPRINT MPT predictions will be made concerning manpower quantity and quality. During operational testing the predictions for each MOS assigned to the system should be validated.

Table 57

Major Operational Test and Evaluation Tasks for the MANPRINT Assessment of Systems (Cont'd.)

TASK LISTING	RESULTING DOCUMENTATION (Comments)
TEST CONDUCT	
1. Attend test site collective training.	1. None.
2. Attend pilot testing:	2. a. Completed data collection forms and comment listing.
a. Verify data collection procedures for performance measures,	b. Preliminary ADP output.
b. Collect interview data,	c. Revisions to data collection materials if necessary.
c. Collect daily debrief and comment data,	
d. Observe field operations,	
e. Attend daily data analysis group DAG meetings,	
f. Refine data collection materials.	
3. Attend full test:	3. a. Completed data collection forms.
a. Insure proper CTA performance measure data collection,	b. Preliminary ADP raw data output.
b. Administer data collection materials, (1) Interviews (2) Checklists (3) Questionnaires	c. Preliminary safety and health hazards assessment report as necessary.
c. Perform safety assessment of safety/health hazard problem areas as necessary,	d. Data file output summary formats for findings to date.
d. Observe field operations,	e. Preliminary listing and description of MANPRINT findings.
e. Attend daily player debriefs,	
f. Attend RAM, SYSTEM PERFORMANCE, and MANPRINT DAG.	f. Outlines for OTEA test report sections and the ARI MANPRINT report.

Table 57

Major Operational Test and Evaluation Tasks for the MANPRINT Assessment of Systems (Cont'd.)

TASK LISTING	RESULTING DOCUMENTATION (Comments)
TEST CONDUCT (cont'd)	
g. Collect and categorize opinion and comment data,	g. Budget and expense data.
h. Collect manpower requirements data from field observations and RAM incident data forms,	h. Video recording of major MANPRINT findings.
i. Administer training retention tests and obtain comments and opinions from players concerning training,	
j. Insure proper ADP data file development. Review cumulative data to date.	
k. Collect instrumented measures of environmental factors (e.g., noise, vibration, illumination, temperature, humdity, toxic fumes/gases) as appropriate based on findings of previous testing,	
l. Prepare listing and descriptions of preliminary findings for scoring conference,	
m. Prepare outlines of OTEA test report sections and ARI MANPRINT report,	
n. Conduct preliminary MANPRINT findings scoring conference,	
o. Manage MANPRINT specialist manpower staffing. Prepare budget and expense data,	
p. Video tape record major MANPRINT findings.	

Table 57

Major Operational Test and Evaluation Tasks for the MANPRINT Assessment of Systems (Cont'd.)

TASK LISTING	RESULTING DOCUMENTATION (Comments)
TEST CONDUCT (cont'd)	
4. Attend side tests and demonstrations:	4. a. Completed data collection forms and comment listings.
a. Attend system side test and demonstrations, (1) Observe (2) Interview	b. Videotape recordings of MANPRINT experimentation and findings.
b. Conduct human performance side tests, (1) Implement experimental designs (2) Coordinate activities with test directorate (3) Direct field experimentation, (4) Collect data, (5) Submit data to ADP or analyze data, (6) Videotape record side tests.	
POSTTEST	
1. Analyze and statistically summarize data.	1. The OTEA test report sections.
2. Prepare output formats for all reports.	2. The ARI MANPRINT test assessment report(s):
3. Present MANPRINT findings at a formal scoring conference.	a. Human engineering, b. Safety/health hazards, c. Training,
4. Attend end of test RAM, system performance, and MANPRINT DAG meetings.	d. Manpower, e. Soldier characteristics, f. C^2E baseline prediction assessment and validation.
5. Prepare data for C^2E data base.	g. MANPRINT baseline prediction assessment and validation.
6. Write report sections and full reports.	

system acquisition process to insure that problems are resolved and do not continue into a subsequent phase (Tragesser, 1985).

Since MANPRINT-style OT&E is more labor intensive, and has more pretest planning, there is a need for an earlier preplanning start-up time. The very need for more pretest time runs counter to the tendency of the weapon system acquisition process to become accelerated. The impact of the acceleration can be seen throughout OT&E, and has had an adverse effect on the quality of the resulting products.

The Test Plan

The Sgt York test plan was spontaneous. The test plan was changed, modified, and reshaped on a daily basis throughout the Force-on-Force phase of FOE I. The inability to establish and fix a test plan prior to the conduct of FOE I was a significant limitation. Instrumentation used during the test introduced unmeasured and uncontrolled variables (Seven, 1987). Integration of the Combat Development Experimentation Center (CDEC) and 1553 data bus was a major problem, as well as the problem to convert Real Time Casualty Assessment (RTCA), Multiple Integrated Laser Engagement System (MILES), and 1553 data bus recordings from digital to analog form. Of considerable concern were the instrumentation and data collection instruments which were not designed for human factors evaluation, but had to be used for the human factors evaluation. The instrumentation constrained each trial to approximately a 30-minute window of data collection. The instrumentation played a major role in warping the test plan. From this experience, it becomes clear that test personnel must be knowledgeable of the instrumentation to be used prior to the development of the test plan (note Table 57), and that the test director should not start the test without resolution of the types of problems encountered during FOE I.

The instrumentation testing constraints limited trials to approximately 30-minute durations and signified a departure from the originally planned trials of longer duration. The resulting short trial periods created a "snapshot" view of the operation. Even if the instrumentation would have accommodated trials of 24-hour duration, the manning and staffing of such trials would not have been feasible. Trials of limited duration were found to distort measurements, e.g., those for Mission Oriented Protective Posture (MOPP). Realistic trial times would establish a more reliable data base for system evaluation. Instrumentation requires modification to accommodate longer trial times.

Other pretest planning activities that have proven valuable have been the integration of the human factors data base into the overall (OTEA) data base. For example, the critical task analysis data base for timed measures should be designed as part of the pretest activities. Worksheets should be prepared that identify the purpose of the measure, the desired data elements, the data element operational definition, and a description of the planned analyses. The pretest activities should also include integrating the critical task measures into the OTEA test data base along with data collection requirements. Computer specification worksheets should include descriptions of data elements, data display matrices for review, program format and output requirements, and examples of graphic displays. Critical task measures can be incorporated in the system performance and reliability, availability, and maintainability (RAM) data collection.

During the Force-on-Force phase of FOE I, safety limitations impinged on the day to day conduct of the test. Units were forced to modify safety procedures throughout data collection. Policy positions regarding safety procedures were frequently reversed. An illustration of this problem was the issue of operating in the heads-out position. The policy on heads-out was revised and reversed on various occasions. The issue of laser safety was not clearly evaluated or ever resolved. Follow-on evaluation procedures which do not take into account and do not resolve known safety issues prior to test conduct can easily confound the established measurement plan, the data collection, and the results.

Many more examples could be provided regarding contaminated measurements resulting from test plans. For example, the frequency of data collection in some test plans other than the Sgt York test plan indicated that some measurements were to be taken so often that the measurements would add no new knowledge, and would inhibit participants from providing useful responses throughout the data collection period. Other problems were encountered during FOE I where repetitious scenarios were found to allow crews to respond to previously learned terrain. Scenarios that did not truly differentiate among delay, attack, and road march due to their overly familiar features were not of great diagnostic value.

Some of the potential problems encountered in the test planning phase may be induced by the need for test personnel to excel. The objective is to design a test plan that measures and integrates the MANPRINT data, yet avoids establishing an unrealistic and overambitious test plan. Accomplishing both objectives simultaneously is not an easy task.

Data Analyses and Interpretation

Hard data were accumulated from many sources during FOE I. The thru-sight and crew compartment videos were of special interest for data analysis. The collection of data which included video had been anticipated as leading to a richer data base for further data analyses at end of test. These two sources of video documentation proved to be a disappointment. Because of the customary time constraints to generate an OT&E report within a short period of time, it was not feasible to review or analyze the thru-sight or crew compartment video recordings at that time. It was anticipated that the videos would be useful during the present study. Subsequent review of the video recordings was accomplished by comparing Time to Fire on the 1553 data bus along with the video recordings, and the audio transcripts. The comparison revealed that the audio transcripts were deficient in reporting out complete conversations that were observed on the crew compartment videos. However, observation of the crew communication on the videos did not provide enough information or insight into why certain crew actions were or were not taken. When video recordings were compared to the 1553 data base, it was discovered that the 1553 data base was far superior and more precise than the videos in reporting crew activities. The videos did not provide enough information for analysis. There were also many technical problems with the resulting videos where the picture was so poor that it could not be deciphered. In many instances, the video's footage was blank.

Video techniques for measuring and analyzing crew performance currently have serious limitations. The analyses are expensive and lead to a paucity of interpretable data. If video capability is to be used, and it is recommended as a useful technique for certain types of recording and reporting, it better serves the test community by documenting and supporting test findings. In our evolving electronic age, individuals are being shaped by television and video to expect a visual executive summary of current events. The video OT&E report provides a "quick" overview of problems and solutions identified during OT&E. It is a most useful technique for disseminating information on design flaws to design engineers. The test community could benefit by producing OT&E video reports. Video reports should be budgeted and integrated into the preplanning test activities, and into the test budget.

Realistic Test Environment

Since test personnel try to present a realistic picture of system performance, limitations should not be placed on crew members that result in crew inefficiency. Some examples of the limitations placed on the Sgt York crew members which resulted in crew inefficiency were associated with: (1) Instrumentation and data collection requirements which introduced uncontrollable and unmeasurable variables into the test design, (2) the continual effort during FOE I to retrofit and upgrade fire units to full production standards, and (3) limiting crews to operating in abnormal conditions which do not reflect realistic operation of the weapon system.

During pretest planning, problems with experimental and unproven instrumentation should be resolved prior to conducting valid test trials. Instrumentation which constrains the test to the point of impacting data collection and subsequent interpretation of the data may generate ambiguous findings. To illustrate this point, Sgt York crew members were required to continue expending rounds at dead targets because aircraft which the fire units engaged displayed no realistic signature. Measurements for crew activity performance times would be affected by this type of constraint. It follows that performance times for Fire Duration and Total Engagement Duration would be needlessly extended. Trigger pull times associated with the lack of ammunition depletion feedback did not represent the actual crew capability. It is doubtful that the data reduction process incorporated methods for crediting crews with reduced performance times for Fire Duration and Total Engagement Duration.

Accelerated weapon acquisition programs may tend to field equipment before the equipment is actually ready to go to test. Retrofitting weapon systems during training and testing creates a situation where the measurement and interpretation of the performance data is questionable. For example, during FOE I, contractor retrofit changes were made to both hardware and software. The changes impacted on the Sgt York crews, RAM, performance measures, and training. The objective was to upgrade the equipment to full production standards, but retrofitting prior to training and testing would have been preferable. The adaptability of crew members to adjust to on-going retrofit is an admirable trait. However, retrofitting during training invalidates training measures. Retrofitting during testing invalidates testing results. Depending on the nature of the retrofit, it could modify crew action and decision times, as well as system processing times. There is a potential for the retrofit to modify the performance times anywhere along the target engagement sequence continuum. Performance times may have been distorted each time a retrofit occurred. Retrofitting contaminated the data.

Artificial limits placed on the operation of the equipment during testing represents a serious threat to the test design, measures, and interpretation of the data. Artificial limits run counter to the design of OT&E plans which strive to establish a realistic portrayal of system performance. Yet artificial limits have been known to exist where crews were requested to perform under adverse conditions. To illustrate an artificial limitation during the FOE I, Sgt York crews were forced to operate the fire unit under constraints that would run counter to crew training, and counter to the design and function of the fire unit. The fire unit was designed to have multiple system mode options during the target engagement sequence for acquisition of the target. However, during a FOE I trial, Sgt York crews were required to obscure their gunsights with covers in order to simulate a night environment. Subsequently, lasers were declared non-operational so that only radar acquisition modes could be used in parts of the test.

OT&E is supposed to measure performance under conditions of maximum fidelity to the operational environment as much as possible. According to Meister (1987), the goal of testing is to simulate the operational system and environment, not to distort the operational environment. Continual efforts should be made to strive for fidelity in the test environment.

Personnel Characteristics/Training/Performance Measures

Requirements for military personnel serving as subjects during OT&E most frequently involve the need for subjects to have both training and experience. During FOE I, not all subjects received individual training. Those subjects who did not receive Sgt York individual training were considered experienced Sgt York crew members, in that they had previous experience with fire units. The decision to equate the individuals with previous Sgt York experience with those who completed individual training was perhaps driven by the need to increase the pool of candidate subjects. Those individuals who did receive individual training found that the training schedule was abbreviated. When the two groups of individuals were compared, it was not possible to differentiate the effect of training. For that matter, it was not possible to relate performance measures to subject characteristics, and selection scores such as height, weight, age, level of education, ASVAB scores, etc.

Although the subjects were representative of the individuals who were supposed to operate the fire units eventually, the number of subjects was small. Working under the constraint of a small sample size precludes statistical analyses to correlate individual characteristics and selection scores to performance measures.

Dissemination of Information from OT&E

In a list of behavioral questions associated with system development suggested by Meister (1987), the last item was "Evaluate and recommend system improvement modifications." Once improvements have been identified and specified in report form, other methods for dissemination of the identified improvements should be sought. For example, how can OT&E personnel disseminate testing results in an effective way so that the data can be applied effectively to modify a current system or improve future systems? How can the data be made accessible and useful for design engineers? To illustrate this problem, the Sgt York fire unit incorporated the M48 chassis as part of the weapon system. The M48 chassis is a Korean vintage chassis with previously documented deficiencies. There are many examples in OT&E where equipment deficiencies have been identified, and where design engineers continue to replicate their mistakes in new designs. There does not seem to be a corporate history or military record or a data repository where individuals may seek information and learn from previous mistakes.

Innovative attempts are being made to assist in alleviating the problem of "repeated design failures." MANPRINT is one such attempt where the acquisition process is to be halted at each review stage until identifiable problems are resolved. Another attempt to influence the design stage is being undertaken by the U.S. Air Force, as the lead service for the Department of Defense. The proposed project is commonly known as CSERIAC or Crew Station Ergonomic Information Analysis Center. At the present time, this is a concept, but not an implemented program. CSERIAC has the potential to establish a center that will allow designers the opportunity to access data which is technically sound and will improve future systems prior to the production of prototypes. The OT&E video reports previously discussed would also be quite useful to design engineers to assist in alleviating the problem of repeating mistakes. Questions of dissemination concern who should receive the OT&E information, in what format, and using what administrative vehicle.

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Appendix A

Description of Data Files

The purpose of this appendix is to describe the data files and data processing for the analyses in this study. The data files and their relationships are shown in Figure A-1. Each of these data files are available on computer disk suitable for MSDOS and IBM-compatible personal computers.*

The primary files include an engagement data base (ENG2), a crew composition data base (CREWCOMP), a personnel description data base (PERSDESC), and a scenario description data base (SCENDESC). These were created using the Ashton-Tate dBASE data base management software (Ashton-Tate, 1985). The distribution disk includes files for both dBASE II and dBASE III versions of this software (with file extensions .db2 and .db3 respectively; the appropriate version must be renamed to .dbf before use with dBASE). The structure and content of these files are defined in Tables A-1 through A-4. The tables show the field name, type of data (C=character, N=numeric), the number of decimal places if numeric data, and a full-text version of the field name.

The ENG2 data base is a corrected version of the initial data entry file (not included on the distribution disk). The dBASE software can operate under program control, as well as with on-line interactive operator inputs. For example, COMPUTE.PRG is a program which computes the quantities shown in Table 3 of the main report. These results were later stored as TOTAL.DAT for subsequent statistical analyses.

The dBASE software permits using these data bases in combination, relating the appropriate data in one file to that in another. For example, the data in the CREWCOMP file can be used to identify the specific crew member who took action in the ENG2 file, compute performance measures, and create a file of individual performance (INDPERF, structure shown in Table A-5). This was accomplished using the COMBINE.PRG and COMPUTE2.PRG programs. Although the information can be derived whenever desired from the basic data base files, it was more efficient to create a permanent INDPERF file for subsequent repeated use. A file named INDPERF.DAT is an ASCII format file used for input to statistical analysis software.

The TOTAL and INDPERF files were converted to a form required for statistical analysis. The statistical package used is SYSTAT (Wilkinson, 1987). The files needed are simply ASCII files which are transformed by the DATA module to files which are used by the remaining SYSTAT modules. These files are included in the distribution disk with the extension .SYS. If the ASCII files are to be used for a statistical package other than SYSTAT, it should be noted that missing data are coded in the dBASE files with the value 999. No other data have values this large. Under the SYSTAT system, missing data are recoded as ".".

*This appendix was prepared by Richard W. Obermayer, Vreuls Research Corporation.

```
+----------+    +------------+    +------------+    +------------+
! ENG2.DB2 !    !CREWCOMP.DB2!    !PERSDESC.DB2!    !SCENDESC.DB2!
! ENG2.DB3 !    !CREWCOMP.DB3!    !PERSDESC.DB3!    !SCENDESC.DB3!
+----------+    +------------+    +------------+    +------------+
     ! !              !                 !                   !
     ! +--------------+                 !                   !
     !                !                 V                   V
     V                V
+------------+  +------------+
! COMPUTE.DAT !  ! COMBINE.PRG  !
+------------+  ! COMPUTE2.PRG !
     !          +------------+          DBASE II OR DBASE III
     !                !                 DATA BASE MANAGEMENT
     V                V                 SYSTEM SOFTWARE
+------------+  +------------+
! TOTAL.DAT   !  ! INDPERF.DBF  !
+------------+  ! INAT  !
     !          +------------+
     !                !
     V                V
======================================================================
     !                !
     V                V
+------------+  +------------+
! MISDAT.CMD  !  ! MISDAT2.CMD !
+------------+  +------------+
     !                !
     !                !             SYSTAT
     V                V             STATISTICAL
+------------+  +------------+      ANALYSIS
! TOTALS.SYS  !  ! INDPERF.SYS !      SOFTWARE
+------------+  +------------+
     !                !
     V                V
+-----------------------------+
!    STATISTICAL ANALYSIS      !
!    (DESCRIPTIVE STATISTICS,  !
!     BOX-AND-WHISKER DIAGRAMS, !
!     CORRELATION, ANOVA,      !
!     MULTIPLE REGRESSION)     !
+-----------------------------+
```

Figure A-1. Data processing flow diagram.

Table A-1

STRUCTURE FOR FILE: A:ENG2.DBF
NUMBER OF RECORDS: 00271

FLD	NAME	TYPE	WIDTH	DEC	REMARKS
001	TRIAL	C	004		TRIAL NUMBER
002	FU	C	001		FIRE UNIT
003	ENGAGE	C	002		ENGAGEMENT
004	HR	N	002		HOUR
005	MIN	N	002		MINUTE
006	TPRES	N	005	001	PRESENTATION TIME
007	TGTID	C	012		TARGET IDENTIFICATION
008	RANGE	N	004	001	TGT RANGE (KILOMETERS)
009	NUMTGT	N	002		NUMBER OF TGTS PRESENTED
010	TGTTYPE	C	002		TARGET TYPE (FIXED/ROTARY)
011	SYSMODE	C	036		SEQUENCE OF SYSTEM MODES
012	USEMODE	C	001		MODE USED
013	PCREW	C	002		CREWMEMBER POINTING
014	PDEP	N	005	001	POINTER DEPRESS TIME
015	PREL	N	005	001	POINTER RELEASE TIME
016	LDEP	N	005	001	LAZER DEPRESS TIME
017	LREL	N	005	001	LAZER RELEASE TIME
018	RCON	N	005	001	RADAR CUE ON TIME
019	LCON	N	005	001	LAZER CUE ON TIME
020	FCBLINK	N	005	001	FIRE CUE BLINKING
021	FCSOLID	N	005	001	FIRE CUE SOLID
022	TRIGON	N	005	001	TRIGGER ON TIME
023	TCREW	C	002		CREWMEMBER FIRING
024	TSWITCH	C	001		TRIGGER SWITCH (L/R)
025	TRIGOFF	N	005	001	TRIGGER OFF TIME
026	TERM	N	005	001	TERMINATE TIME

Note. HR and MIN are starting time hour and minute; other times are entered as the number of seconds after HR and MIN.

Table A-2

STRUCTURE FOR FILE: A:CREWCOMP.DBF
NUMBER OF RECORDS: 00113

FLD	NAME	TYPE	WIDTH	DEC	REMARKS
001	TRIAL	C	004		TRIAL NUMBER
002	DATE	C	008		DATE
003	SCEN	C	002		SCENARIO
004	FU	C	001		FIRE UNIT
005	GNO	C	004		GUNNER ID
006	SNO	C	004		SQUAD LEADER ID
007	DNO	C	004		DRIVER ID

Table A-3

STRUCTURE FOR FILE: A:PERSDESC.DBF
NUMBER OF RECORDS: 00015

FLD	NAME	TYPE	WIDTH	DEC	REMARKS
001	IDNO	C	004		IDENTIFICATION NR.
002	RANK	C	002		RANK
003	POS	C	001		POSITION (S,G,D)
004	HT	N	002		HEIGHT
005	WT	N	003		WEIGHT
006	OF	N	003		OF SCORE
007	EL	N	003		EL SCORE
008	AFQT	N	002		AFQT SCORE
009	CAT	C	004		AFQT CATEGORY
010	GT	N	003		GT SCORE
011	SYEXP	C	003		SGT YORK EXPERIENCE
012	INDTRNG	N	004	001	INDIVID. TRAINING
013	COLTRNG	C	003		COLLECTIVE TRAINING

Table A-4

STRUCTURE FOR FILE: A:SCENDESC.DBF
NUMBER OF RECORDS: 00029

FLD	NAME	TYPE	WIDTH	DEC	REMARKS
001	TRIAL	C	004		TRIAL NUMBER
002	DATE	C	008		DATE
003	TYPE	C	013		SCENARIO TYPE
004	NO	C	002		SCENARIO NUMBER
005	DorN	C	001		DAY OR NIGHT
006	ENDTIME	N	004		ENDING TIME
007	TACTICS	C	012		TACTICS
008	MOPP	C	003		MOPP (YES/NO)
009	ECM	C	006		ECM CONDITION

Table A-5

STRUCTURE FOR FILE: A:INDPERF.DBF
NUMBER OF RECORDS: 00271

FLD	NAME	TYPE	WIDTH	DEC	REMARKS
001	TRIAL	C	004		TRIAL NUMBER
002	FU	C	001		FIRE UNIT
003	ENGAGE	C	002		ENGAGEMENT
004	HR	N	002		HOUR (START)
005	MIN	N	002		MINUTE (START)
006	TPRES	N	005	001	PRESENTATION TIME
007	PCREW	C	002		CREWMEMBER POINTING
008	PDEP	N	005	001	POINTER DEPRESS TIME
009	PREL	N	005	001	POINTER RELEASE TIME
010	LDEP	N	005	001	LAZER DEPRESS TIME
011	LREL	N	005	001	LAZER RELEASE TIME
012	TCREW	C	002		CREWMEMBER FIRING
013	IDNO	C	004		CREWMEMBER TAKING FIRST ACTION
014	SELCT	N	005	001	SELECT TIME MEASURE
015	PTRON	N	005	001	POINTER TIME MEASURE
016	LZRON	N	005	001	LAZER TIME MEASURE

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Appendix B

Correlations Among Parameter Measures

As may be seen throughout the discussions on research findings, five basic parameters form the essence of the measurement system. These parameters are:

- o Target Selection
- o Target Acquisition
- o Time to Fire
- o Fire Duration
- o Engagement Time

These parameters have been discussed and defined in the chapter on human performance data. Further, some of the parameters have been decomposed to lower levels of the process as shown in Table 3.

It is of some interest to look at the correlations among the basic five measures. These correlations are shown in Table 63 as Pearson product moment correlations.

Table B-1

Pearson Correlation Among Parameters

Parameters	Select	Acquire	Time to Fire	Fire Duration	Engagement Time
Select	1.000				
Acquire	-0.079	1.000			
Time to Fire	0.843	0.276	1.000		
Fire Duration	0.000	-0.071	0.007	1.000	
Engagement Time	0.707	0.189	0.832	0.560	1.000

The patterns seen in Table B-1 are exactly as might be expected from a close examination of the actual processes as they were performed. At first look, one might predict a high and growing correlation among all these measures since they are sequentially dependent combining to form a target engagement sequence. But, as Table 63 shows, this is not necessarily the case. So, for example, acquisition times, based so strongly on automatic data processing, show little variation with respect to Fire Duration and Engagement Time. This subfunction is relatively fixed with regard to the process.

Target Selection Times, on the other hand, vary considerably and have a very strong effect on subsequent Time to Fire (r = .843) and Total Engagement Time (r = .707). Fire Duration presents a different kind of pattern - strongly influencing engagement time (r = .560) but not related to Selection, Acquisition, or Time to Fire.

A technical problem in most models is the degree of orthogonality among various system parameters. With complex multi-level systems involving the human operator in a variety of ways from total immersion to exclusion, the correlations among parameters and their measures will vary as do those in Table 63. In short, some parameters are independent of the other process parameters and many others are not. This fact, of course, will complicate model development as well as data interpretation.