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ABSTRACT

This research investigated the feasibility of predicting a pilot's workload in a single-seat aircraft. A model was developed which combined discrete event simulation output with an existing workload methodology to predict workload. The methodology used was the Subjective Workload Assessment Technique (SWAT), which recognizes three dimensions of workload: time load, mental effort load, and psychological stress load. Discrete event simulation output provided estimators for the time load dimension while pilots' subjective estimates were used for the other two SWAT dimensions.

Using a queueing analogy with the pilot modeled as the server and the pilot's tasks as customers, several modeling options were investigated in the discrete event simulation. The main issue examined was whether processing tasks in series or parallel produced more accurate work load predictions. Two distinct simulation models were developed, each employing a priority system with preemption. In the parallel model, the number of tasks that could be processed simultaneously was dependent on the particular combination of tasks currently requiring pilot resources. With each task demanding specified resources, the availability of pilot resources was determined by reference to the Multiple Resource Model. Three different measures from the simulation model were evaluated as surrogates for the SWAT time load dimension: pilot idle time, task interruption rate, and simultaneous task rate. Four different definitions of task interruption rate were also considered.

The predictions of the work load model were validated by comparison to SWAT work load measurements taken under identical conditions in a high-fidelity flight simulator. This analysis was accomplished using a multivariate comparison of means and a profile analysis. Both techniques produced similar results. From a model viewpoint, little difference in prediction accuracy between the serial and parallel simulation models was found when pilot idle time was used as the surrogate predictor. When evaluating predictors, the most accurate results were produced using pilot idle time and the simultaneous task rate predictors.

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One critical concern in each case is the workload imposed on the human by the design of the system. In this research, workload refers to the mental or cognitive load on a human rather than the physical load that might be imposed in some situations. Workload is a concern as a new machine is designed and steps are taken to alleviate, minimize, or balance the workload imposed on the human. Workload may be identified through several methods, but ultimately, at the present time, this must involve the use of a mock-up, prototype, or simulation of the real system to measure the workload imposed on the human operator.

A problem may arise because any hardware which reasonably replicates the final system is usually not available until late in the development process of that system. Problems discovered while testing hardware may cause expensive redesign and considerable production delays for that system. Clearly, what is needed is some means of assessing workload early in the design phase of system development.

Specific Aims

In order to pursue this goal, this research is limited to the problem of assessing a pilot's workload while flying an aircraft. The intent is to develop and validate a model which predicts pilot workload. This effort will show the feasibility of such a model and show that the model's

predictions relate reasonably well to measured workload levels. This study focuses on pilot workload in a single-seat, fighter aircraft. While the methods employed are generally applicable to other human-machine systems, it is not known if any derived conclusions can also be applied to other systems. This research is unique in that it employs a model significantly different from other existing models. This model combines predictions from discrete-event simulation with subjective predictions, while other models generally rely on a single method. In addition, this model employs the structure of an existing measurement methodology to provide a framework for these predictions. This model may be useful in early aircraft design stages to assess the impact of a particular aircraft configuration on pilot workload. Keywords: Radar Aided Mission / [illegible], Digital Simulation, SWAT

Significance

The prediction of pilot workload is an emerging area that goes beyond simply defining or measuring pilot workload. In itself, workload is something of a fuzzy, intuitive concept. Several popular definitions exist, but these definitions do not necessarily agree with one another. In spite of not having a common definition, workload measurement efforts have been on-going for a number of years. Several measurement techniques have shown reasonable success in discriminating between different

A METHODOLOGY FOR PREDICTING PILOT WORKLOAD

DISSERTATION

Presented in Partial Fulfillment of the Requirement for the Degree Doctor of Philosophy in the Graduate School of the Ohio State University

By

Thomas Frederick Schuppe, B.S., M.S.

* * * * *

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Dissertation Committee:

R. A. Miller

P. J. Smith

B. L. Nelson

Approved by

R A Miller

Adviser
Department of Industrial
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To My Wife, Mary

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VITA

August 24, 1944	Born, Fond du Lac, Wis.
1967	B.S., Univ. of Wisconsin
1967 - 1968	Project Engineer, McDonnell Aircraft, St. Louis, Missouri
1968 - Present	Officer, United States Air Force
1976	M.S., Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio

FIELDS OF STUDY

Major Field: Operations Research

Studies in stochastic processes, mathematical programming, and statistics

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CHAPTER I

INTRODUCTION

Humans are increasingly being placed in more demanding situations in a variety of human-machine environments. This condition is especially true in situations where the human acts as a controller or operator of the human-machine system. In order to function properly, the human must be able to properly receive a wide variety of inputs, both visual and aural, process these inputs in a timely manner, and respond in such a way that the human-machine system efficiently achieves its intended purpose. This process is complicated by many factors, especially as the interactions between the two elements of this system, human and machine, increase in number and complexity.

Several common examples of such systems exist: a pilot flying an aircraft, an air traffic controller directing air traffic, a nuclear power plant operator controlling his/her system. Although all of these systems function in different domains, the interactions between the human and the machine in each case are similar in several ways.

levels of workload. However, workload measurement requires that some physical system (aircraft, flight simulator, or laboratory apparatus) be available to measure the workload of a human pilot or subject. This approach may be acceptable for some purposes, but, it is not an acceptable method to predict pilot workload during the early design phases of a new aircraft when actual hardware is physically non-existent.

To address this problem, a workload modeling technique would be helpful. Several methods used to predict pilot workload do exist. Some are based on modeling techniques such as simulation or time-line analysis. These are adequate to account for timing, sequencing, and rate change issues, but are generally insensitive to human-oriented, psychological issues (32). Attempts have been made, for example, to include the effects of stress on performance within a simulation model, but these are often without a theoretical basis and their accuracy must be questioned.

Other predictive techniques rely on the subjective opinions of "expert" pilots to assess workload. Battiste and Hart (2) and Reid, et al, (31) each describe a separate method that will predict workload. Theoretically, a pilot skilled in a particular type of aircraft should be able to extrapolate an estimate of workload to a new, non-existent system similar to the system with which he is familiar. While pilots have been able to assess the impact of mental

and psychological factors on workload, Battiste and Hart (2) have found inaccuracies in estimating the impact of complex or unfamiliar timing elements. This suggests a need for some other method to assess the impact of task timing and rate changes on workload.

Developing a predictive model which will overcome these deficiencies will help reduce system cost and pilot workload in future aircraft systems. If pilot workload can be predicted with reasonable accuracy early in the design process, unacceptable levels of workload can be identified and design changes can be made with relative ease. As systems are now developed, the measurement of pilot workload occurs only after hardware is produced and then design changes are both difficult and expensive. A validated predictive methodology would both save the cost of hardware design changes and expedite the design process.

Overview

The next chapter provides the background for this study. It begins with a discussion of the concept of workload and then reviews recent efforts to measure and predict workload. Special emphasis is given to the Radar Aided Mission/Aircrew Capability Exploration (RAM/ACE) (13 and 27) experiment since it bears directly on this research.

The next chapter describes the general method used in

this research, beginning with a discussion of specific definitions and assumptions. The general workload model is described next, with the exception of the simulation model, which is deferred to the following chapter. However, the interface between the workload model and the simulation model is described. A replication of the original RAM/ACE experiment is described and used to illustrate the use of the workload model. Finally, the experimental design and data analysis methods are described.

The next chapter describes the simulation models developed in this research. These simulation models form only a part of the workload model but are described separately to allow those readers specifically interested in simulation to direct their attention to this chapter. Both versions of the model (single server and parallel server) are described in detail. A discussion of input data modeling is then presented, followed by a description of how the input data was adjusted for each model version and each aircraft cockpit configuration. This is followed by a description of the process used to verify the simulation model and a brief description of important model outputs.

The next chapter is devoted to the specific results derived from this study. The output from simulation-based production runs is described and the procedure used to convert these output values to the general workload model

terminology is described. The workload estimates derived from several different predictors are then presented. Finally, the results of a sensitivity analysis performed to assess the criticality of several assumptions are presented.

The last chapter presents conclusions and recommendations based on the results of this study effort. Also included are several appendices which provide supporting evidence and additional detail. Of special interest is Appendix C which includes the instructions and cockpit equipment description for the RAM/ACE experiment and its replication. It is included here to illustrate the degree of detail available in the experiment and provide a reference since it is not otherwise readily available.

CHAPTER II

BACKGROUND

An important design issue for an aircraft cockpit is the amount of workload that design will impose upon a pilot or crewmember. Recent advances in computers and automation have attempted to alleviate a pilot's workload, but in many cases, have simply refocussed it. Formerly, a pilot functioned primarily as an active controller in the aircraft system, but more recently has assumed a less active role, becoming more of a monitor and decision maker. This led to a shift in a pilot's workload from physical to mental workload. Recognition of this change is important and is the first step in attempting to define, measure, predict, or alleviate a pilot's workload.

Workload Definition

Unfortunately, there is little agreement on a definition of workload, either in a general sense, or specifically related to mental workload. Several authors have proposed definitions, but a great deal of variety is evident in these proposals. Senders (36) defines workload

as a non-accessible, hypothetical, unidimensional, internal variable over the range of 0.0 - 1.0 in any human operator. In his view, workload may be considered the ratio of demand to capacity with respect to any action. He further suggests that workload is a meaningful concept only in the context of a well-defined task which must be performed to a stipulated criteria.

Rouse (33) proposes that mental workload has two dimensions: fraction of attention and intensity of effort. He further suggests that the product of these two might be a reasonable composite definition of workload. While this definition is intuitively appealing, measuring workload in both of these dimensions may be a problem.

Sheridan and Simpson (38) view mental workload as primarily concerned with information processing and decision making. They suggest that mental workload, which can only be inferred and not directly measured, is some combination of mental effort, information processing, and emotion in response to task demand. This leads to three category descriptors: task time constraints, task uncertainty and complexity of planning, and task-induced psychological stress.

Wickens (46) defines workload in terms of the relation between resource supply and task demand. As long as resources are available, workload is inversely related to reserve capacity. Once all resources are occupied,

workload is inversely related to the level of task performance. Wickens agrees with Senders that workload involves a relation between task demand and the operator's capacity. However, Senders uses a single dimension model while Wickens emphasizes a multiple resource model. This leads to a multi-dimensional concept for workload. Wickens also states that workload can be affected by changes in operator capacity and changes in task resource demands.

Johannsen (14) suggests that workload is an umbrella concept which includes input load and operator effort. Input load, which is influenced by the environment, the system design, and operating procedures, impacts operator effort and ultimately affects operator performance. Johannsen, et al, (15) claim workload is multi-dimensional but do not specify what those dimensions are. They do suggest that it would be intuitively appealing if these dimensions could be combined into a single number. This would allow comparisons between different measurements, but at a loss of some of the dimensionality information.

It is difficult to establish a concensus definition from all of these definitions. It does appear that workload is multi-dimensional in nature and involves the relation of task demands to operator capacity. The workload dimensions proposed by Sheridan and Simpson (mental effort, information processing, and emotion) seem to be representative of the various dimensions discussed by other authors.

Operator capacity may also be multi-dimensional and is a variable influenced by many factors. Further details of this concensus definition of workload will be provided in the next chapter.

Workload Measurement

Once a definition of workload is established, the next step is finding some means to measure workload. With the number of different definitions available for workload, it is not surprising that there are even more measurement techniques. In fact, Moray (21) states that there is no agreed-upon definition of mental workload and no agreement on how to measure it. The very complexity of workload has resulted in its measurement by many methods, but the relationships among these methods is not clearly established.

Several authors have provided summaries and overviews of the most well-known measurement methods. Williges and Wierwille (51) provide a comprehensive review of fourteen specific classes of behavioral workload measures grouped into three general categories: Subjective opinion, spare mental capacity, and primary task metrics. They conclude that, due to the multi-dimensionality of workload, no single metric can be recommended as the definitive measure of mental workload. Rather, they suggest that the most promising assessment procedure should include multiple

measures of subjective opinions, spare mental capacity, and primary task measures.

Wierwille, Rahimi, and Casali (50) evaluated 16 measures of mental workload using a simulated flight task emphasizing mediational (cognitive) activity. Their results indicate that two primary task measures, two subjective measures, one spare mental capacity measure, and two physiological measures were reliably sensitive to mediational loading. In a similar study, Wierwille and Connor (49) evaluated 20 workload measures using a psychomotor task in a moving-base aircraft simulator. They showed that two subjective measures and one primary task measure demonstrated sensitivity to all levels of load. None of the measures considered showed any intrusion on the primary task.

Casali and Wierwille (4) performed a sensitivity/intrusion comparison of eight mental workload estimation techniques using a flight task emphasizing perceptual piloting activities. They found no evidence of intrusion and six of the eight measures proved sensitive to the load. The sensitive measures included two subjective rating measures, two secondary task measures, one primary task measure, and one physiological measure. They also concluded that primary task measures are quite task-specific and should be used cautiously.

Rahimi and Wierwille (28) looked at the sensitivity and intrusion of eight workload estimation techniques in piloting tasks emphasizing mediational activity. The mediational activity employed in this aircraft simulator experiment was a variety of navigation problems sorted into three load levels based on the number and complexity of the calculations required to solve them. They found one primary task measure, one subjective opinion measure, and one secondary task measure to be sensitive to the load. However, the secondary task measure was considered to be intrusive on other pilot activities.

Bortolussi, Kantowitz, and Hart (3) compared four widely used methods developed to predict and measure pilot workload. These measures were reaction time, time production (secondary task), inflight verbal estimates, and retrospective rating scales (subjective opinion). Using a flight simulator, the authors found all four techniques were able to distinguish among levels of scenario complexity. Both secondary task methods and the in-flight workload ratings were able to distinguish among levels of difficulty for different segments within the scenarios.

All of these studies demonstrate the diversity of available workload measurement techniques and provide evidence of their relative merits. To summarize, it appears that primary task measures produce reliable results if the task selected is closely related to the dimension of

interest. However, in a complex flight scenario, it may be difficult to identify a single task which reflects the wide variety of potential sources of operator load. Secondary tasks, designed to reflect spare mental capacity, are often sensitive to load but can intrude on the prime task of flying the aircraft. Secondary task measures may also lose their sensitivity as the operator becomes fully loaded due to prime task activity. Subjective measures appear to be sensitive to a wide range of pilot tasks. However, there is some concern that a subjective measure, taken at the conclusion of a flight, may not accurately represent the workload over the entire flight. Other means have been proposed to collect the subjective information during a flight, but this collection process itself may intrude on the primary flight task. Physiological workload measures appear to be very task-specific. That is, for certain narrowly-defined tasks, physiological measures appear to be sensitive. But for a complex situation consisting of a wide variety of diverse tasks, no single physiological measure appears to be appropriate.

Of all the workload measures discussed, the most widely accepted type appears to be subjective measures. Several authors have also come to this conclusion. Johannsen, et al, (15) state that despite all the well-known difficulties in the use of rating scales, these must be regarded as central to any investigation. Rouse (33)

states that some form of subjective measurement is inevitable if mental workload is to be assessed. Williges and Wierwille (51) concluded that no single technique can be recommended as the definitive behavioral measure of operator workload, but probably the strongest research support exists for using subjective opinions and task analytic methods involving task component/time summation. Finally, Wierwille and Connor (49) suggest that well-designed subjective rating scales are among the best techniques for evaluating psychomotor load.

Three subjective measurement techniques have shown success in previous studies: a modified Cooper-Harper (5) scale, the Subjective Workload Assessment Technique (SWAT), and the NASA Bi-Polar technique. The first of these is derived from the successful Cooper-Harper scale used to evaluate aircraft handling qualities. It uses a decision tree format and asks the pilot a sequence of questions to lead him to a logical evaluation of handling qualities. Sheridan and Simpson (38) have modified this scale to address pilot workload and have suggested that three separate scales be created with each scale addressing a different dimension of workload. The dimensions they suggest are time load, uncertainty and planning load, and mental stress load.

Stein and Rosenberg (40) have developed a one-dimensional version of this scale designed to be used at

one-minute intervals during a specific task. At the sound of a tone, an operator is asked to press one of ten buttons relating to how hard the operator feels he is working at that time. A "1" would indicate essentially no effort is required and a "10" would indicate that the workload is overwhelming even when maximum effort is used. This method collects a large amount of data by sampling at one-minute intervals and strives to eliminate error caused by the delay between workloading and the assessment of that workload after a flight is complete. However, requiring an operator to respond with a workload estimate once each minute is somewhat intrusive on his primary task and may itself contribute to total workload. This technique is fairly new and, while initial test results appear to accurately measure workload, further testing is required for full acceptance.

The Subjective Workload Assessment Technique (SWAT) developed by Reid, et al, (29) is also based on concepts proposed by Sheridan and Simpson (38). However, their three dimensions of workload have been modified to time load, mental effort load, and psychological stress load. Each dimension is considered to have three levels: high, medium, or low. This leads to a total of 27 (3 x 3 x 3) possible workload ratings for a given test. The method itself requires two stages. In the first stage, prior to any actual workload assessment, a subject is asked to order

the 27 possible workload states from easiest to most difficult. This order is subsequently used to provide an ordinal scale for combined workload ratings through a technique called conjoint measurement (25). In the second stage a subject performs some task or operation and, at its completion, provides a rating of low, medium, or high in each of the three SWAT dimensions. These three ratings are then combined through the conjoint measurement technique to yield a single workload measure. This technique has been tested extensively and has been accepted as a reasonable measurement device for mental workload (13, 27, 42).

The NASA Bi-Polar measurement technique [Hart, et al, (12) and Kantowitz, et al, (18)] has also demonstrated reasonable accuracy as a subjective workload assessment technique. This technique requires an operator to complete bi-polar rating scales for ten items after a set of tasks is complete. Each operator is also required to complete a pairwise ranking of all ten items to establish weights for each item. By combining bi-polar workload ratings with their appropriate weights, a single metric of workload is determined.

Vidulich and Tsang (42) found in a laboratory experiment that the NASA Bi-Polar method was successful in measuring the differences in task difficulty as indicated by a multivariate analysis of performance. They also found a remarkably similar workload assessment when the SWAT

technique was used in the same laboratory test. Vidulich and Tsang concluded that the subjective experience of workload is sufficiently robust to be resistant to variations in the measuring technique.

Workload Prediction

As a general concept, workload prediction involves using some method or technique to forecast what an operator's workload will be in a "real" environment. These predictive techniques may vary from a sophisticated flight simulator, used to predict pilot workload for an almost identical aircraft, to a simple "back-of-the-envelope" method used for the same purpose. In this study, a distinction will be drawn between workload prediction and workload measurement. Measurement will denote any laboratory or flight simulator experiments in which the performance of a human subject is actually measured. Prediction will denote all other methods of estimating actual workload, including discrete event simulation, time-line analysis, and human estimates. This study will primarily attempt to develop a predictive technique and will use an accepted measurement technique as a tool to validate predictions.

Rouse (33) makes this same distinction in discussing models and measures. In his view, a model of mental workload is some procedure for predicting workload based on

a priori conditions. On the other hand, a measure of mental workload is some measurable quantity that allows one to determine the presence of some specific level of workload. From a system design perspective, a model is used to predict how (usually physically non-existent) alternate designs will perform while measures are used to evaluate designs once they have resulted in a particular system being produced. Thus, a measure of mental workload would be useful to validate the predictive ability of a model of mental workload.

Several models used to predict mental workload already exist. Senders (37) uses an information theory model to predict workload in monitoring and controlling situations. His model, which assumes that a pilot always works to full capacity, yields fraction of attention metrics in a direct manner. Where this model has been applied to relatively simple situations, it has had reasonable success. However, due to its rigid structure, it cannot be applied readily to more realistic, complex tasks.

Control theory models have been used to model tasks involving dynamic systems. However, this is only a small subset of the tasks for which workload predictions are of interest, so this model is rather limited in application.

Queueing theory overcomes some of the problems of the other two models. It ignores many details of a task and instead concentrates on the time involved in performing the

task. This allows a greater variety of tasks to be addressed. Queueing models usually assume that task demands occur randomly and each task is accomplished perfectly. Therefore, levels of performance are not usually considered, performance is usually assumed to be perfect. This assumption may be the major disadvantage of these models. Queueing models inherently produce predictions of server utilization.

Battiste and Hart (2) describe a laboratory experiment in which a workload measurement technique was used to derive predictions. Each experimental subject was presented a basic scenario which involved the simulated processing of five different task types. After an hour of practice at the basic scenario, each subject rated his workload using the NASA Bi-Polar rating method. Following this practice session, fifteen additional scenarios of increasing levels of difficulty were presented. Prior to each scenario, a description of that scenario and a schedule of task arrival times were provided to each subject. Operators predicted the expected workload after studying this information, again using the bi-polar method. They also rated their experiences at the end of each scenario.

From this experiment, Battiste and Hart found that in low workload scenarios, operators tended to overestimate the workload of unfamiliar task elements by a large margin.

In more complex scenarios (which also imposed more workload), operators predicted workload with greater accuracy. The authors concluded that operators could predict the workload of realistically complex tasks if: (a) they are familiar with the basic system, and (b) the design, functional requirements, and operational procedures of the proposed modifications are described clearly. Operators are less able to predict unfamiliar rate or schedule complexity manipulations, for which timing is an important element. While this method was not entirely successful in predicting workload, their recognition of the problem of operators having difficulty predicting the timing of events was significant.

Reid, et al, (31) developed a predictive workload technique based on his SWAT measurement technique. In this method, each of a group of experts is given a detailed description of a scenario, aircraft equipment, and flight requirements. Based on this information, each expert provides workload estimates in each of the three SWAT dimensions. These ratings are then combined using the usual conjoint measurement process to reach a single workload metric. In one study, this metric was found to have a correlation of greater than 0.75 with SWAT ratings given after flight simulator missions reflecting identical flight conditions. Although relatively new and not thoroughly validated, this predictive technique shows

promise. Additional work must be done to validate this technique over a wide variety of workload situations.

Eggleston and Quinn (7) did a more detailed study of this projective SWAT technique. They used three variations of the technique and compared the results against SWAT measurements of the same systems and scenarios. The results of all analyses showed correlation coefficients of 0.55 to 0.85 between SWAT projections and measurements. The authors considered this strong support for the technique, but suggest further effort is required for validation. Furthermore, they provided suggestions for developing adequate descriptive material, selecting an appropriate definition of an event, and determining the desired knowledge base of a rater. Since they bear directly on this research, Eggleston and Quinn's efforts are discussed in much greater detail in Chapter III.

Based on the predictive techniques described here, it appears that workload prediction is possible. However, these techniques are all relatively unproven and will require further work for validation. The next section proposes a predictive technique that combines certain elements of these techniques with several other concepts. A proposed method of validating this technique will also be described.

Pilot Models

A number of models do exist which attempt to represent a pilot accomplishing normal tasks in a cockpit. These models often differ in purpose so it is not surprising that differences can be found in their assumptions, structure, and implementation. Wickens (48) provides an excellent overview of these models and summarizes their strengths and weaknesses. Because his findings are so germane to this analysis, they will be discussed in some detail.

Wickens divides these models into two basic categories: those that assume a serial mode of processing and those that assume some form of time sharing or parallel processing of tasks. Each of these categories of models can be further subdivided into a model class addressing allocation of resources and another class referring to the sources of variance in competition between tasks. The former refers to the selection aspects of attention while the latter addresses the scarcity of resources.

Several serial processing models are pertinent to this research. These models assume that tasks are accomplished one at a time. When two or more tasks compete simultaneously for an operator's attention, some rule determines which task receives priority and which task must wait. These rules vary between models. For example, the Human Operator Simulator (HOS) is based on user-defined priorities (43).

The SAINT (52) network programming language has been applied only to discrete tasks. This is also true of the human operator model developed by Siegel and Wolf (39). While most serial models recognize task conflict by the delay induced until a task reaches the head of a queue, Siegel and Wolf take a different approach. They determine a workload estimate, based on the ratio of time for task completion to time available, to determine a mean completion time for tasks and the task's probability of errorless completion.

Wickens (48) notes that all of these models share a common concern for the role of time. Time becomes the only resource of concern and completion time, or task length, defines the difficulty of a task. Early versions of these models generally do not recognize intensive aspects of task demand or degrees of similarity between tasks. Therefore, these serial models choose to ignore evidence of parallel processing (45). It is not immediately apparent if this is a serious drawback to this class of models. However, it is intuitively disconcerting. One of the objectives of this research is to examine several serial models and see if there appears to be any general problem with this approach.

Several parallel processing models also exist. Wickens (48) states that these models assume parallel processing between tasks is ongoing and interference effects result from competition for something more than

time. This additional aspect of competition is related to intensity. A revised version of HOS allows parallel processing. However, there is no mechanism for specifying interaction between parallel tasks, so all parallel processing is assumed to be perfect processing.

A revised version of SAINT called MICROSAINT (20) recognizes eight demand levels in addition to task time requirements. It also recognizes four channels (visual, auditory, cognitive, and psychomotor) for task demands in which interference may occur. The A^3I model by Corker, et al (6) makes similar assumptions about the four channels. However, both of these last two models are limited. First, both fail to acknowledge difficulty variation of tasks within a level. Second, the assumption of parallel processing <u>between</u> channels appears to be unwarranted. Wickens (45) shows there is clear evidence that auditory and visual tasks interfere, as do perceptual (both auditory and visual) and cognitive ones. In general, there appears to be little effort to validate these models, so some caution must be exercised in their use.

Wickens (48) suggests that models developed in psychological laboratories may be useful to improve the simulation models described earlier. He suggests his multiple resources model (46) has received a great deal of validation and may be appropriate for such a purpose. This model, which is explained in greater detail later, assumes

that two tasks will interfere to the degree that component tasks are more difficult (demand more resources) and that components compete for overlapping resources. North (23) has developed a conflict matrix which estimates the degree of task interference based on the degree of overlap of the resource requirements of both tasks. Use of this matrix allows a model to more accurately assess the degree of task interference between both similar and dissimilar tasks. Wickens (48) recommends that the logic of North's conflict matrix be incorporated into any model used.

To develop an improved pilot model, Wickens (48) recommends three possible approaches. First, more quantitative elements could be built into a multiple resources model. Second, a class of models known as multichannel detection and recognition could be extended. Finally, attempts should be made to determine how accurately complex performance can be predicted by serial models with assumptions of single task neglect. As a final note, Wickens suggests that it may be necessary to accept adequate, rather than precise fits when modeling in this complex domain.

Summary

This chapter reviewed information pertinent to this research in the areas of workload measurement and prediction, as well as existing pilot models. In the

following chapter, a method will be described which employs Wickens' multiple resource model in a parallel processing computer simulation. A second model is also described which employs serial processing to model the same scenario. The outputs of these two models are then used with the SWAT methodology to predict workload. This workload prediction technique will be found to be useful in itself, as well as providing validation for the pilot simulation models.

CHAPTER III

METHODOLOGY

Introduction

This chapter describes the methodology used to conduct this research. Specific definitions and assumptions used in this study are presented and discussed. Two candidate models are described in detail and the derivation of specific predictors is also described. Model and predictor accuracy are determined by comparing model-based predictions of pilot workload with workload ratings determined from a flight simulator. This comparison process forms the basis of a validation procedure for these models. Finally, the experimental design and plan for data analysis is presented.

Definitions and Assumptions

This research effort will assume the workload concept proposed by Sheridan and Simpson (38) and used by Reid, et al, (29) in their Subjective Workload Assessment Technique, is an acceptable definition of mental workload. Recall that Reid defined workload as the demand on a pilot's resources induced by a combination of task time load,

mental effort load, and psychological stress load. According to Potter and Acton (26) time load refers to the degree of task overlap or interruption. Mental effort load refers to the amount of attention or concentration required for task performance. Finally, psychological stress load refers to the combined emotional and physical factors, such as anxiety or confusion, which can otherwise affect subjective load.

Other definitions and workload concepts were discussed in Chapter II. The obvious question is: Why choose this three-dimensional definition of workload over the others? Rouse (33) described workload as having two dimensions and Hart's Bi-Polar technique (12) employs nine dimensions. While these may seem to be radically different definitions, they appear to be relatable as shown in Figure 1. Essentially, this figure shows that the Reid definition corresponds to a breakdown of Rouse's definition. Hart's definition appears to be a further breakdown of Reid's.

As Figure 1 suggests, adding additional dimensions did not add another aspect to mental workload, it simply subdivided those dimensions already identified. This may add some clarity, but it does not add new dimensions to the workload concept. Rouse's two-dimensional concept differs from Reid's three-dimensional concept by dividing Intensity of Effort into Mental Effort Load and Psychological Stress Load. This enables a somewhat clearer understanding of

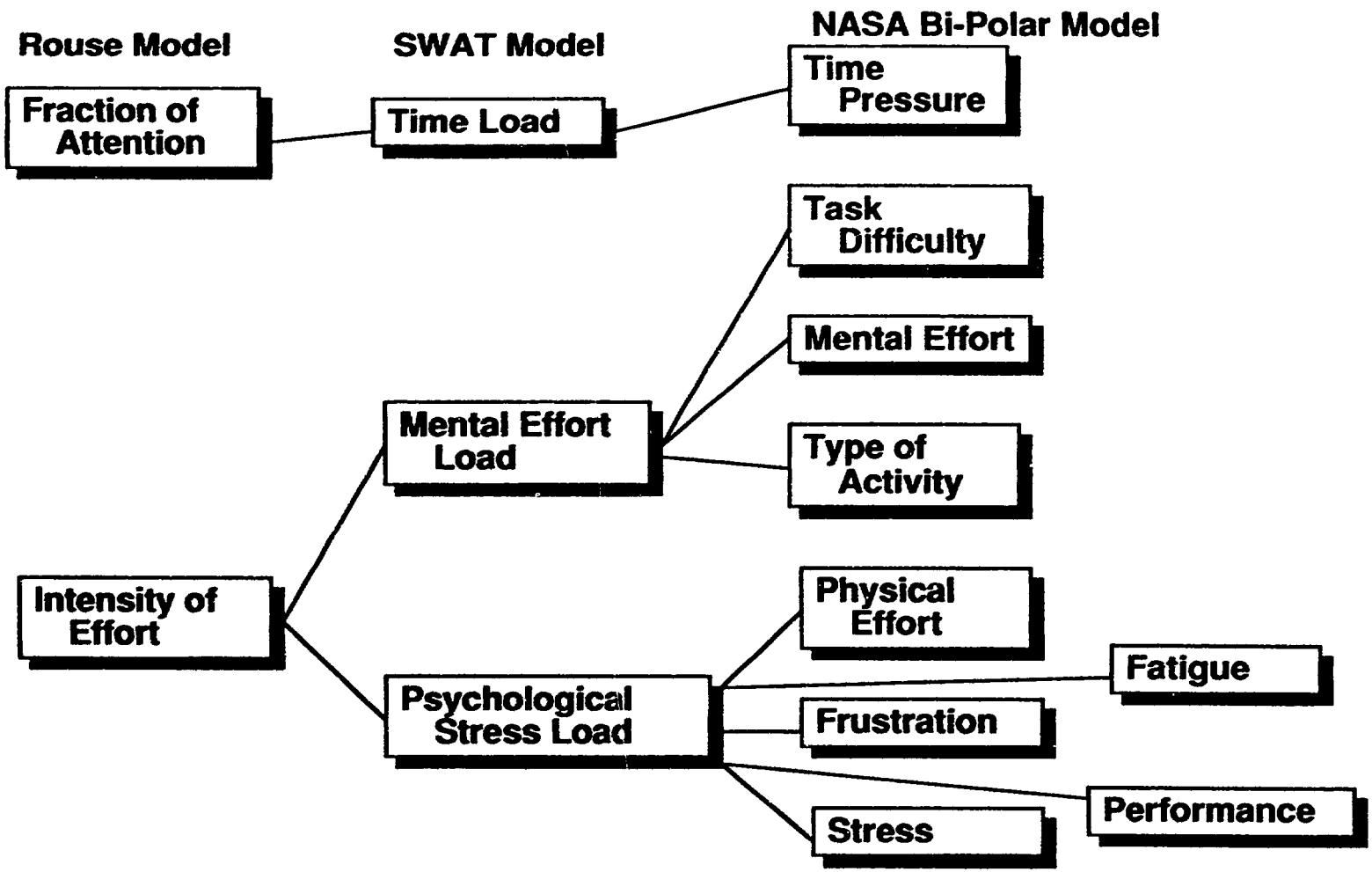


Figure 1 Workload Dimensional Comparison

Rouse's dimension of Intensity of Effort. Furthermore, the substantial amount of evidence supporting SWAT provides justification for using this definition over Rouse's definition.

Expanding the three-dimensional definition to nine dimensions also adds some clarity, but its benefits must be questioned. Vidulich and Tsang (42) showed that SWAT and the NASA Bi-Polar technique produced equally valid results and only cited ease-of-use differences as reasons for choosing one over the other. Potter and Acton (26) also found differential sensitivity between the three SWAT subscales, supporting the assumption that the three dimensions of SWAT represent separate dimensions of subjective load.

For these reasons, this research will use the three-dimensional concept of workload proposed by Sheridan and Simpson (38), and refined in the development of the SWAT measurement technique by Reid, et al (29).

The Workload Model

The model proposed for this research effort will be patterned on the three-dimensional workload definition just described. Separate predictions will be made in each dimension and their combined effect determined using the conjoint measurement technique employed in SWAT. This

combined metric will constitute the primary prediction of the model.

A study by Battiste and Hart (2), previously described in Chapter II, concluded that operators are less able to predict unfamiliar rate or schedule complexity manipulations for which timing is an important element. This suggests that a purely subjective prediction of time load may be inaccurate and some alternate means should be found to predict workload in the time load dimension. To accomplish this, workload in the time load dimension will be predicted using a discrete event simulation model.

The development of such a model requires that many assumptions be made. A major assumption of this work is that a queueing model is a reasonable representation of a pilot in this environment. This model views the pilot as a server in a queueing system and the tasks he accomplishes as customers that arrive and queue for service. This basic structure is employed in this research with several variations. One of these variations addresses the question of whether the pilot should be viewed as a single server processing tasks one at a time in series, or as a parallel processor, capable of accomplishing more than one task at a time.

Much discussion appears in the literature regarding the concept of serial and parallel processing of tasks by humans. It is not the intent of this research to determine

whether such tasks are actually processed in series or parallel. Rather, its purpose is to determine which model, a single server queueing model or a parallel server queueing model, is more accurate for such a situation.

The choice of simulation as a means of predicting workload in this situation has several advantages. Prediction of workload involves modeling a complex human-machine system. Ideally, a set of analytic equations could be developed and solved to provide such a prediction. However, it is extremely difficult, if not impossible, to find analytic solutions for systems with complex sets of inputs and outputs such as those associated with a pilot/aircraft system. Rouse (31) recognizes this complexity and suggests that it is often necessary to resort to simulation to solve these equations.

Additional support for the use of simulation comes from the ease with which simulation employs queueing models. As stated in the Introduction, a queueing analogy would be used as the basic means of addressing this man-machine problem. Rouse (31) supports this idea and states that:

> "Queueing theory models of human-machine systems view the human as a time-shared computer, allocating attention and resources among a variety of tasks. . . . In multitask situations, the human must allocate attention among tasks. Adding differing priorities among tasks as well as different inter-arrival time and service time distributions results in a multitask situation particularly amenable to queueing theory formulation."

This statement exactly describes the situation addressed in this research. It further suggests that a queueing model implemented in a simulation would satisfy many of the modeling constraints of this complex man-machine system.

While use of a queueing model in this manner will yield information regarding how long a task must wait for service, how busy the server is, or how long each task is serviced, such a model will not tell how well such a task is performed. In fact, there is an inherent assumption that each task is performed correctly or acceptably at all times. A modeler may add features to a simulation which recognize errors and require incorrectly performed tasks to be reaccomplished, but this is not inherent in the model.

In the simulation model developed in this research, the pilot will be represented as a server and will accomplish tasks normally associated with pilot duties (11, 19, 41). Tasks will arrive for service with inter-arrival times specified by probability distributions and will wait in a queue if the pilot is occupied with another task of equal or higher priority. For the purpose of this model, a task is defined as an action required of the pilot to maintain flight and accomplish a mission, resulting from information received by the pilot.

Two basic versions of this simulation model will be developed. The first will model the pilot as a single

channel server, processing tasks in series. The second version will view the pilot as a multi-channel server, using Wickens' (46) multiple resource concept to define the available channels. This multiple resource model allows the possibility of more than one task being accomplished at any one time. The model assumes that each task requires specific pilot resources for completion. As long as the resource demands of two separate tasks do not overlap too severely, they may be accomplished simultaneously, but with an increase in service times compared to accomplishing these tasks individually. If some of the same resources are required, then service times for each task are increased even more. Chapter IV contains a detailed description of this simulation model.

The method used to determine the availability of resources will be Wickens' (46 and 47) multiple resource model. This model postulates that humans possess several different capacities with resource properties. Task interference will occur if resources are shared, but little interference will occur if different tasks require different resources. Wickens' model describes three resource dimensions with binary properties: input modality (visual or auditory), processing stages (encoding and central processing or responding), and processing codes (spatial or verbal). This results in eight (2 x 2 x 2) possible combinations that may be demanded by a task.

In each version (single channel server or parallel processing model) of this simulation model, a priority system controlled which tasks were serviced first. Sheridan and Simpson (172) and Katz (93) define a pre-emptive priority system that categorizes pilot tasks into three groups:

1. Operating tasks - those concerned directly with the operation of the aircraft which must be handled immediately. Examples include aircraft maneuvering and control, and monitoring radio communications.

2. Monitoring tasks - those that may be delayed for a short period of time while operating tasks are being performed. Examples include systems monitoring, out-the-window visual scan, and instrument cross-checking.

3. Planning tasks - tasks deferrable into idle periods of time. Examples include retrieving weather forecasts, planning approaches, and computing landing data.

This preemptive priority system was employed in the simulation model of this research. The primary output of this simulation model was a workload prediction in the time load dimension. Reid, et al, (28) suggest that time load is characterized by the number of task interruptions, the number of times tasks are performed simultaneously, or the amount of pilot spare time. Each of these represents a slightly different aspect of time load. Since it was impossible to determine beforehand which is more

appropriate, all three were computed and tested in a validation process to determine which was the better predictor. In the case of the single-channel model, simultaneous performance of tasks was not considered, nor was task interruption rate considered for the parallel processing model. Chapter IV describes these predictors in greater detail.

The purpose of developing these three simulation-based predictors was to use them as surrogates, or replacements for a subjective prediction in the Time Load dimension. This prediction, along with subjective predictions in the Mental Effort Load and Psychological Stress Load dimension, were obtained in two separate experiments. The first of these was accomplished in 1982 as part of the Radar Aided Mission/Aircrew Capability Exploration (RAM/ACE) project conducted by the Aerospace Medical Research Laboratory at Wright-Patterson Air Force Base (7, 13, and 27). The second set of subjective predictions were gathered in 1986 as part of this research. Both of these experiments are described later in this chapter.

By using several combinations of subjective predictions and discrete-event, simulation-based predictors, it is possible to develop seven different workload model predictors for each set of experimental measurements taken. Since two sets of workload measurements were taken (1982 and 1986), this would result

in two sets of workload measurements for each scenario. The details of each of the seven predictors and the methods used in comparing these predictors to the workload measurements are presented later in this chapter in a section entitled Experimental Design.

The Radar-Aided Mission/Aircrew Capability Exploration (RAM/ACE) Experiment

This study effort was sponsored by the Air Force Aerospace Medical Research Laboratory (7, 13, and 27). Its purpose was to explore several technological enhancements for application in a post-1995 time frame to improve the effectiveness of fighter aircraft in a tactical, air-to-ground environment. Using an advanced version of an F-15C flight simulator, each of several enhancements were evaluated over a multitude of mission and scenario combinations by highly experienced Tactical Air Command F-15 pilots. Each of these enhancements was evaluated according to several different measures of merit: survivability, target kills, cost, and pilot workload. An analysis based on these measures was then used to recommend promising enhancements for future development of air-to-ground aircraft systems.

To determine aircrew workload, the RAM/ACE study used the Subjective Workload Assessment Technique (SWAT), which was previously described. The RAM/ACE program utilized

this technique in two ways. Prior to a pilot entering a flight simulator to fly a specific mission, each pilot made a subjective estimate of his expected workload using the SWAT methodology. This estimate was based entirely on a written description of the mission requirements, scenario, and particular enhancement being considered. With his extensive knowledge and accumulated experience, each pilot was asked to integrate all pertinent factors to develop an accurate "prediction" of his own workload under a specific set of conditions.

After completing this predictive exercise, the pilot flew the same mission scenario in a flight simulator, which also was modified to have an operable version of the enhancement being considered. At the conclusion of the flight simulator exercise, each pilot made a second set of SWAT workload ratings based on his perceived workload while flying the flight simulator. Because SWAT is widely accepted as a validated workload measurement technique, these simulator-based workload ratings were accepted as accurate measures of pilot workload for the particular mission, scenario, and equipment enhancement combination considered.

Eggleston and Quinn (7) describe how they compared the SWAT predictions, which they called PRO-SWAT, with the SWAT measurements. Although they expressed some cautions about using the PRO-SWAT method, they did find that the actual

correlation between PRO-SWAT predictions and SWAT measurements ranged from 0.55 to 0.85. While these results seemed encouraging, it was difficult to assess the reliability and validity of the PRO-SWAT procedure. This was due, in part, to workload assessment being contingent upon both the structure of the materials used and the relevant characteristics of the rater. As a first effort, however, the PRO-SWAT technique did show promise as a tool to predict pilot workload without having to construct an operable version of a proposed system.

RAM/ACE Replication

Since much of the raw data from the original RAM/ACE program was initially unavailable, an attempt was made to replicate the PRO-SWAT portion of this experiment. This replication effort, under the author's direction, took place in 1986, approximately four years after the initial PRO-SWAT effort. The original written descriptive material of the enhanced F-15 cockpit configuration was available and was used with only minor changes. The revised version appears in Appendix C of this document, which contains the entire workload prediction survey used in the experiment replication. After completion of this replication, the original PRO-SWAT raw data was found, so both sets of data were used in the analysis discussed in Chapter V.

The workload prediction survey (Appendix C) was administered to eight A-7 pilots and five F-4 pilots. Both sets of pilots were well-experienced in the type of air-to-ground mission used in the original RAM/ACE study. The A-7 pilots were members of the 166 and 162 Tactical Fighter Squadrons, Ohio Air National Guard and the F-4 pilots were members of the 89 Tactical Fighter Squadron, U.S. Air Force Reserve. The A-7 is a single seat (pilot only) aircraft designed for the air-to-ground mission only. The F-4 carries two crew members, a pilot and a weapon systems operator. The F-4 can accomplish both air-to-ground and air-to-air missions. Each pilot was asked to answer the survey as if he were performing duties in a manner he was accustomed to. That is, A-7 pilots answered as if they were the only crew member and F-4 pilots answered as if they had the assistance of a weapon system operator. This is the same manner in which the original RAM/ACE measurements were taken.

Even though both sets of workload estimates were developed, only the A-7 estimates were used in the remainder of this research. The F-4 workload estimates were not included because the simulation model developed to modify workload estimates did not model a pilot working with another crewmember. This is a much more complex situation since it requires consideration of the sharing of tasks and the required coordination to accurately model

such a situation. In general, this process is not well understood, so no attempt was made to include it in the simulation model. The intent of this research was to explore various pilot modeling options. Since this was not possible for a two-man cockpit, no attempt was made to include F-4 data.

The workload survey (Appendix C) was introduced by the author to the pilots in groups of three to five on normal training days. All pilot subjects were volunteers and received no compensation for their participation other than their normal duty pay. After a short introduction on the purpose of this survey, the subjects were given an overview of the concept of workload and the SWAT measurement technique. Demographic data, including flying experience, was requested and recorded for each subject. This was followed by a SWAT card sort by each subject. A copy of the SWAT cards and accompanying instructions are contained in Appendix A. The purpose of this card sort is to establish a linear, calibrated scale on which each individual's SWAT ratings could be placed. This process is described in detail by Reid, Shingledecker, and Eggemeier (30). The results of the SWAT card sorting exercise are contained in Appendix B.

After all pilots completed the SWAT card sort they were given a copy of the workload survey (Appendix C). They were asked to complete this survey on their own time

and mail the three data sheets back to the author.

Ideally, it would have been better to have conducted this survey in a more controlled environment. That is, each pilot should have completed this survey under the supervision of the author so that questions could have been answered and some assurances made that each pilot gave sufficient time and attention to his answers. However, this was not possible due to time constraints set by each flying squadron. As a result, each pilot was simply asked to complete the survey on their own within the following two weeks.

All pilots involved in this research returned their surveys. After receiving all these surveys, the data was reviewed and summarized. These summaries were returned to each pilot along with copies of that pilot's original ratings. Each pilot was then asked to compare his original ratings to the summarized ratings, modify his own ratings if desired, and return the revised ratings to the author. The purpose of this review and revision effort was to determine if knowledge of the group's ratings would affect the individual ratings of each pilot. It was planned that, if there were any significant changes after the first review and revision process, the process would be repeated until the revisions essentially ceased, that is, a stable estimate was achieved. The final set of revised estimates would become the set of data for the 1986 experiment which

would be compared to the RAM/ACE flight simulator data. In this research only one iteration was required since none of the workload estimates was changed after the first iteration. This 1986 data would also be used, in conjunction with the data from the discrete event simulation, to form a set of predictors to compare with the RAM/ACE data. The details of this are described in the next section.

Experimental Design and Data Analysis

The general purpose of this research is to determine if the use of a simulation model of a pilot can improve workload predictions for that pilot. To accomplish this purpose, a computer simulation model was built, two sets of workload predictions were made, and workload measurement data from a flight simulator exercise was used. This section describes how the data from each of these tasks was used to draw conclusions about the value of using a simulation model to predict workload.

The primary output of the computer simulation models was three metrics: pilot idle time (or spare time), task interruption rate, and simultaneous task rate. All three of these parameters are measured as a per cent or, equivalently, a number between zero and one. On the other hand, the primary output of both the predictions and the SWAT flight simulator workload measurement exercise is a

set of workload metrics in three dimensions (Time Load, Mental Effort Load, and Psychological Stress Load) rated as LOW, MEDIUM, or HIGH. Since the ultimate goal is to use all of this information together, it is necessary to develop a transformation from one set of metrics to the other.

Since the SWAT methodology was used throughout this research, the decision was made to continue with that structure and transform the simulation model metrics into the SWAT domain. In essence, the three metrics, derived from the computer simulation model, become surrogates or replacements for the Time Load dimension of the SWAT methodology. This requires that a method be found to transform the three metrics (all in the range 0.0 - 1.0) to ratings of LOW, MEDIUM, and HIGH. The method used to develop this transformation was to ask a wide variety of people, via a brief survey, to estimate these metrics for each potential SWAT workload rating (L, M, H). The survey and the detailed results are presented in Appendix G and discussed in Chapter V.

After completion of this transformation, all required information was contained entirely within the SWAT structure and terminology. At this point it was possible to construct seven candidate predictors for evaluation as model-augmented improvements to the totally subjective PRO-SWAT predictions. In addition, the PRO-SWAT ratings

themselves were used as an eighth predictor and as a baseline estimate of workload by which to compare the other four predictors. Five of these candidate predictors were based on a single-channel, serial-processing model of a pilot, as described in Chapter IV. These five candidate predictors used pilot idle time and four different definitions of task interruption rate, determined from the single channel pilot model, as estimates of workload in the Time Load dimension. The remaining two candidate predictors were derived from the multiple-channel, parallel processing model of a pilot, which is also described in Chapter IV. These two predictors used pilot idle time and simultaneous task rate as estimates of workload in the Time Load dimension. Figure 2 displays the structure and relationships of these terms and measures.

By using pilot idle time derived from both the single channel model and the multiple channel model, conclusions can be drawn about the appropriateness of each model. Pilot idle time or spare time is simply a measure of the proportion of time the pilot is not occupied performing a required task. It does not recognize other factors which may impact in the Time Load dimension. These factors would include the influence of tasks interrupting one-another or the influence of tasks being accomplished simultaneously.

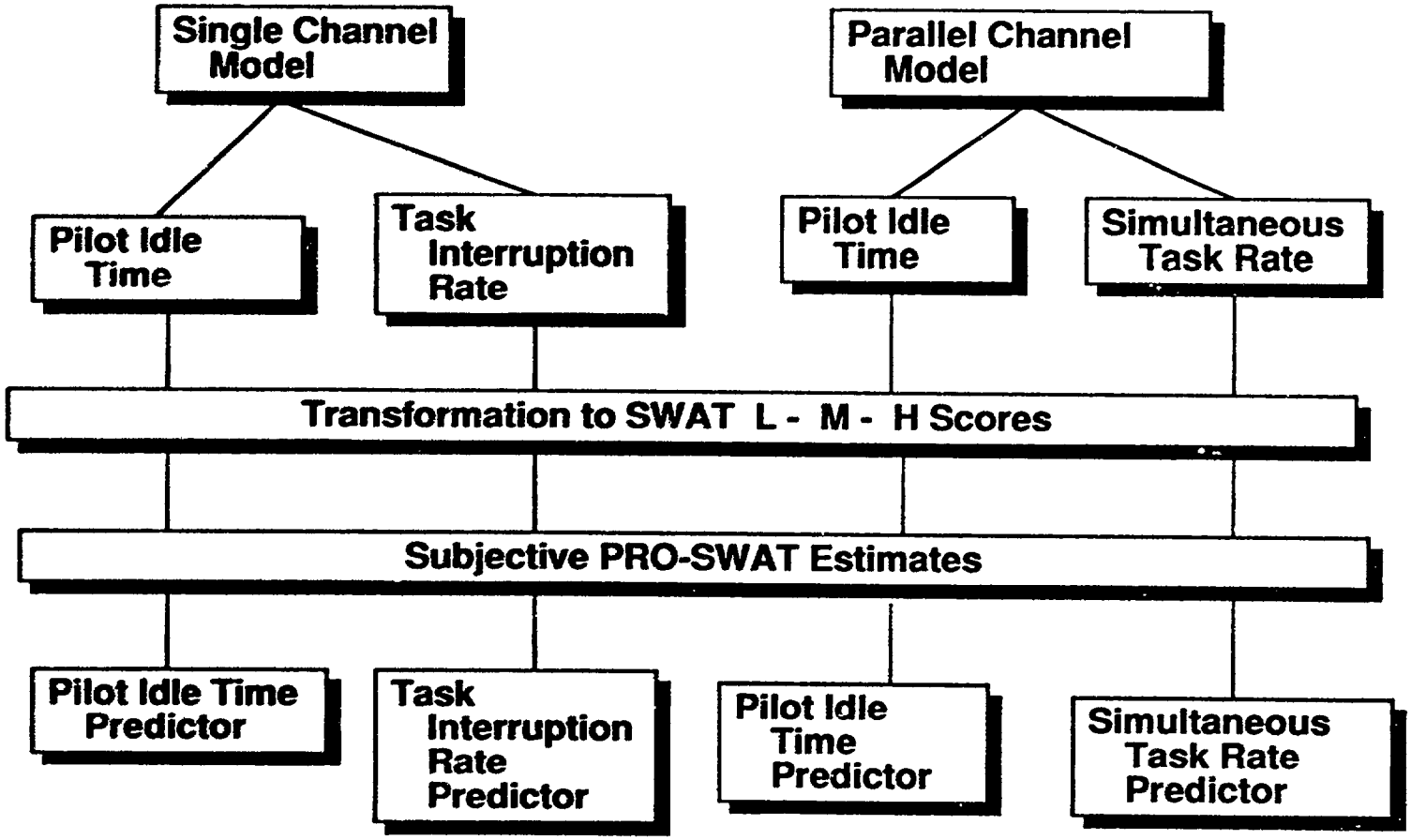


Figure 2 Derivation of Time Load Predictors

In this single-channel model, only one task can be accomplished at a time, with higher priority tasks interrupting lower priority tasks. Therefore, the relative rate at which this happens, the task interruption rate, measures the effect of this phenomena on the Time Load dimension. A single channel model does not allow for simultaneous processing of more than one task, so a simultaneous task rate would be irrelevant for the single channel model and is, in fact, always equal to zero for this model.

Although it appears to be a simple concept, it is not entirely clear what constitutes a task interruption, or how interruptions should be measured. One possible means of quantifying interruptions is to count only the number of times tasks are preempted by higher priority tasks and normalize by dividing by the total number of task arrivals. This approach would yield the percent of tasks interrupted by preemption. One possible problem with this method is that low priority tasks could be preempted many times, yielding a ratio of interrupts to arrivals greater than one. This value is not intuitively appealing and may present problems in converting task interrupt rates to SWAT workload ratings of LOW, MEDIUM, and HIGH. This problem can be overcome by increasing the number of arrivals by one each time a preempted task re-enters service.

Another possible view of what constitutes a task interruption is to ignore task preemptions and simply count the number of times a task arrives while the pilot is busy with another task. Perhaps the pilot's recognition of the arrival of a second task constitutes an interruption and adds to the pilot's workload. The arrival of this second task could involve additional workload on the pilot's part to recognize and classify the task, make a priority determination for the two tasks involved, and either effect the preemption, or mentally recognize that another task awaits his attention if preemption is not possible. In this case task interruption rate could be computed by counting the number of times that tasks arrive while the pilot is busy, normalized by dividing by the total number of arrivals. Although arrival of an additional task could cause workload, no special provision for this was provided in the simulation model.

In this research, each of these possible interpretations of task interruption will be considered. The relative worth of each interpretation will be determined in the validation process of comparing PRO-SWAT predictions to SWAT measurements.

For the multiple channel model, tasks are not often interrupted, but additional tasks may be added to a task currently being worked and processed simultaneously. By measuring the rate at which tasks are completed

simultaneously, it is possible to capture this aspect of the Time Load dimension. In a sense, this measure goes beyond the concept of idleness or, conversely, "busy-ness". Simultaneous task rate suggests that the pilot is not only busy, but is occupied with a given number of parallel tasks, on the average. Although some tasks may be interrupted in a multiple channel model, the effect of these interruptions is assumed to be insignificant compared to the number of tasks completed simultaneously.

The original RAM/ACE flight simulator exercise was conducted under a wide variety of equipment enhancements, mission scenarios, crew size, and both day and night conditions. A subset of these conditions was selected to provide the basis for comparing the five predictors previously mentioned. Three cockpit equipment configurations were selected. These were the F-15C Advanced Baseline (ABL), the ABL plus Terrain Following/Terrain Avoidance (TF/TA), and the ABL plus Terrain/Threat Avoidance (TTA). This eliminated four other possible enhancements from consideration, but the three selected appeared to span the range of possible pilot workload. The ABL represents the enhancement with the fewest automatic features and suggests the possibility of high workload. The TF/TA system automates the problem of avoiding contact with the ground, somewhat alleviating the pilot's workload. The TTA system automates both the

terrain avoidance problem and the hostile threat avoidance problem. By examining all three of these, situations of high, medium, and low workload were be examined, respectively.

Data was available for both day and night missions in the RAM/ACE study. However, to reduce the work involved, only data from day missions was used. This was something of an arbitrary decision. Night-time scenarios could have been modeled in the computer simulation, but this would have required modifying some of the input data since it was based on day-time pilot performance. This modification would have added some additional uncertainty since this transformation is undefined. RAM/ACE data was available for both one-man and two-man crews, but only the data for one-man crews was used. It was not the intent of this study to attempt to model the complex interaction process that occurs in a two-man cockpit. Several mission scenarios were also defined for each equipment enhancement. The primary difference in these scenarios was the final course flown to the target and the relative location of turn points along the route of flight. Since it was felt that different inbound courses and turn-points approaching a target would have no impact on workload, these differences in scenarios were ignored. That is, the data for different scenarios was combined and treated as being

homogeneous. This provided more RAM/ACE data for comparison purposes.

Summary

This chapter describes the overall model developed to predict workload. This model begins with the SWAT methodology and incorporates surrogate Time Load predictors from simulation models. These predictors are changed from the values of the computer simulation output to the SWAT ratings of LOW, MEDIUM, and HIGH by means of a transformation developed in this research.

The workload predictions of this research are compared to the workload measurement of the RAM/ACE study. This study is discussed and a replication of the workload portion of that study is also discussed. Finally, the experimental design and plan for data analysis is also discussed. The details of the actual statistical analysis are discussed in Chapter V. For the interested reader, details of the computer simulation are presented in the next chapter and additional information is found in Appendix E. Listings of each computer model, the serial server model and the parallel server model, can be found in Appendix F.

CHAPTER IV

SIMULATION MODEL

This chapter describes a discrete-event simulation model developed to estimate pilot workload in the Time Load dimension of the SWAT methodology. The Time Load estimates derived from this model will be combined with subjective estimates in the other two dimensions. This will provide a workload predictor which will be compared to SWAT ratings of simulator flights using the same scenarios. Two basic versions of this simulation model were developed. The first model assumed that the pilot is a serial processor, i.e., he could accomplish only one task at a time. The second version allowed parallel processing of tasks, but computed a service time penalty when more than one task was processed at a time.

Some similarities exist in both versions. In each case, the basic structure of a queueing model is used. In this model, the pilot is the server and the tasks he accomplishes are his customers. Customers are served according to a priority system. Higher priority tasks preempt lower priority tasks. Within a priority class, a

first-come, first-served discipline is employed. Three task priority classes are used: operating tasks, monitoring tasks, and planning tasks. Operating tasks are those required for aircraft control and subsystem operation. This class has the highest priority and can tolerate very little delay. Monitoring tasks are those which require the pilot to scan inside and outside the cockpit to update his knowledge of the aircraft's status and situation. This second class can accept short delays without serious consequences. The lowest priority class, planning tasks, can be deferred into idle periods for completion. Some tasks, such as aircraft control, are recurrent and are modeled as repeat customers. Other tasks, such as passing a navigation turn point, occur only at specified points in a flight and are modeled as non-repeating customers.

This simulation model is written in SIMSCRIPT II.5 and was run on both an IBM 3081 and a VAX 11/785. Run times on the IBM were approximately 15 CPU seconds for the serial processing model and 21 CPU seconds for the parallel processing model. On the VAX, the times were 14 CPU seconds and 41 CPU seconds, respectively. The model consists of twelve separate event routines which create tasks to be accomplished by the pilot. Of these twelve discrete event routines, seven are repetitive while the remainder occur only once. The inter-arrival time for each

repetitive task is random and is determined by Monte Carlo sampling from predetermined probability distributions. The time required for the pilot to complete each task is also random and is determined by Monte Carlo sampling from another appropriate probability distribution. The specific tasks, distributions, and parameters used in this model are documented in Appendix E. Other routines also exist to accomplish specific computations or to print intermediate and final results. Figure 3 shows the generic network structure employed in both the single channel and parallel processing models.

Single Channel Model

This version of the model assumes that a pilot processes all tasks sequentially. That is, he can process only one task at a time and cannot begin a second task until the first is completed or preempted. Any task which arrives while the pilot is working on another task must have a higher priority for service to preempt the working task. If it is unable to preempt, the newly arrived task must wait until the old task is completed and the pilot is free to begin service. All tasks waiting for service are ranked by priority. Once a task has been preempted, it returns to the waiting line to await another chance for service. Preempted tasks do not use their original service time for subsequent service, but resample to determine a

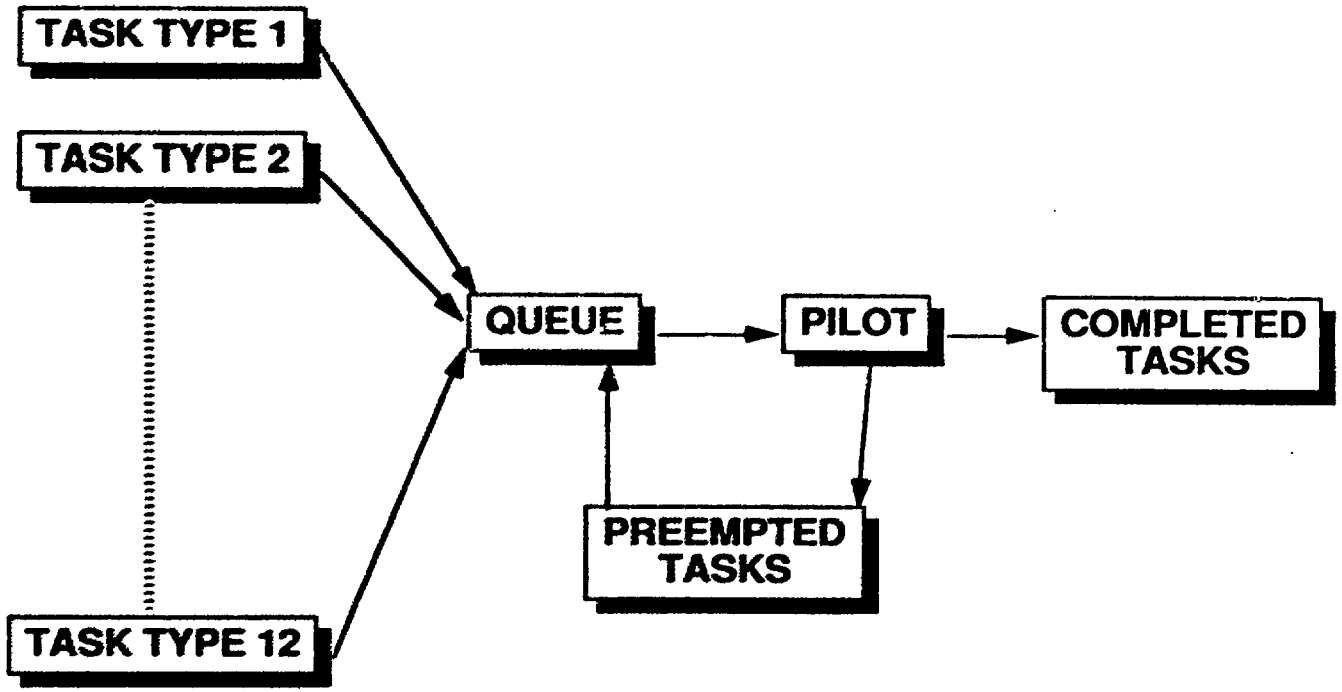


Figure 3 Queueing Network Structure, Serial and Parallel Models

new service time. Resampling is done to reflect the changed aircraft state when the task re-enters service. It is assumed that previously accomplished portions of tasks have to be repeated, changed, or corrected.

The primary estimators of Time Load produced by the single channel model are pilot idle time and the ratio of interrupted tasks to task arrivals. These estimators are described in Chapter III and are used to predict pilot workload. Figures 4 and 5 display the task arrival and service completion processes respectively for the single server model.

Parallel Processing Model

The second version of this model assumes that a pilot can process more than one task at a time. This is accomplished by processing tasks in parallel. The number of parallel channels available is not fixed, but is dependent on the pilot resources required by the tasks demanding service. Wickens' (46) multiple resource model is used to define available pilot resources.

When a new task arrives and the pilot is idle, the pilot will immediately begin work on that task. If the pilot is not idle, but sufficient pilot resources are available, the pilot will also begin work on the second task immediately. If resources are not available, the model will preempt a lower-priority task, if possible. If

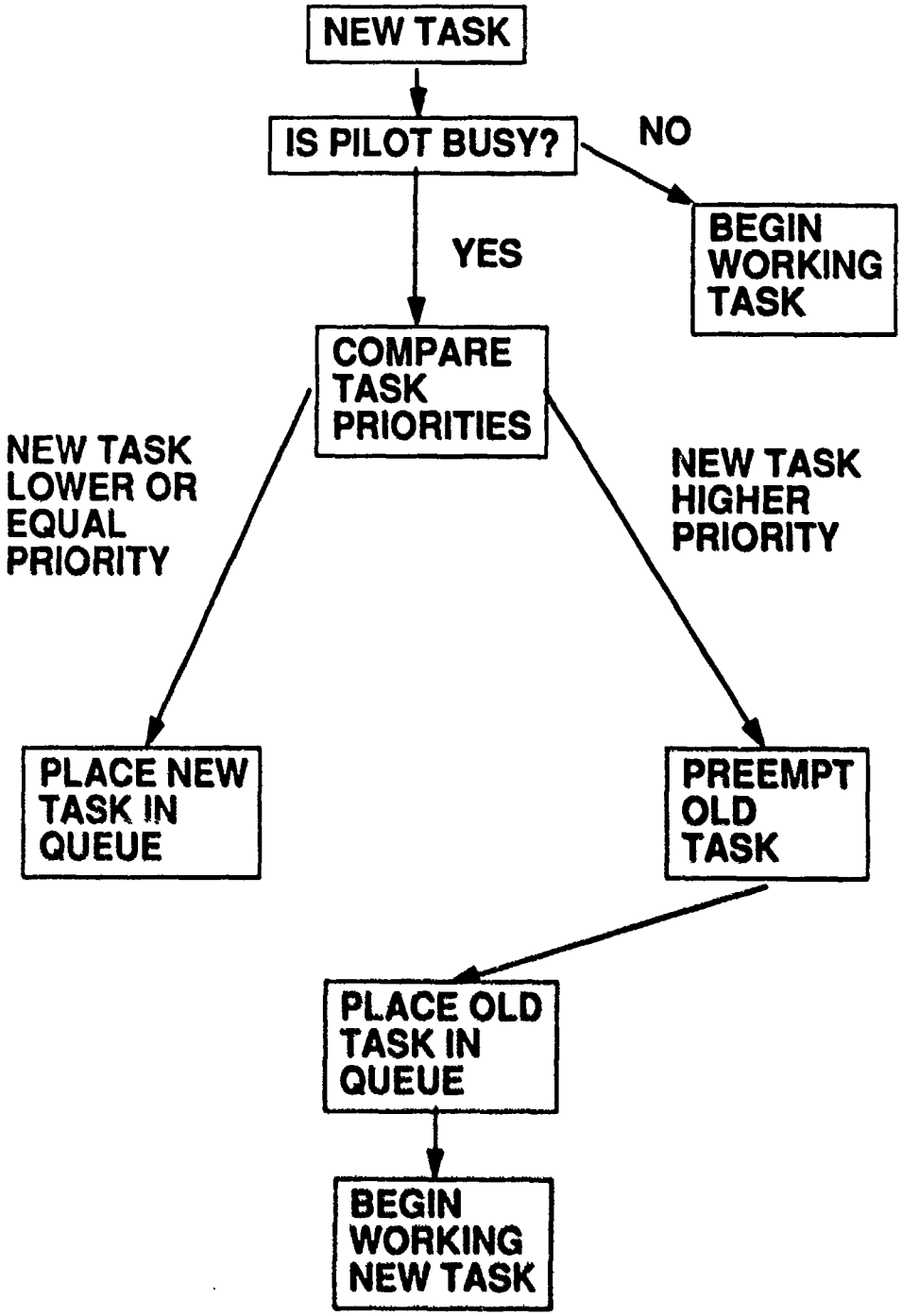


Figure 4 Task Arrival Process, Single Server Model

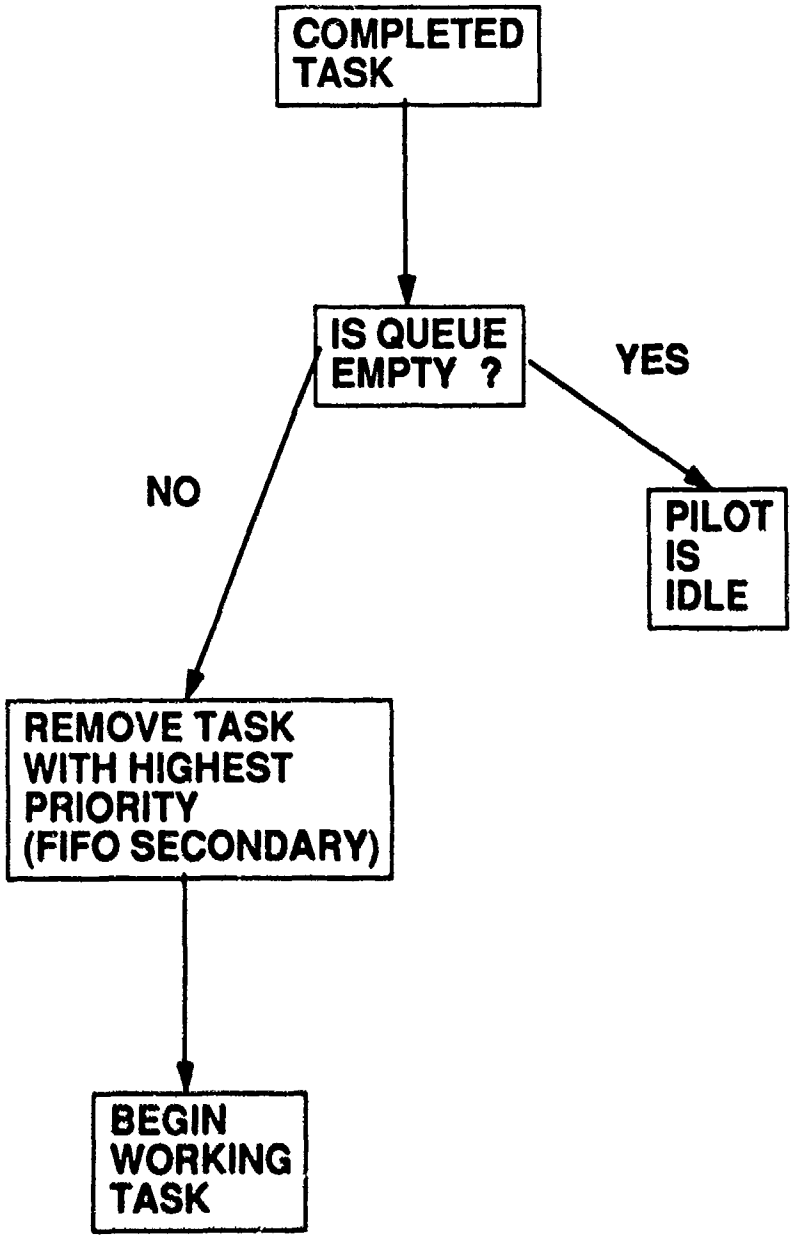


Figure 5 Service Completion Process, Single Server Model

preemption is not possible, the new task waits until resources become available so that the pilot can begin work on this new task.

Within the simulation, the availability of resources is determined in the following manner. A 2 x 3 matrix maintains a listing of resources currently required by tasks on which the pilot is working. This matrix is shown in Table 1. All values in this matrix are initially set equal to zero. When the first task arrives, the

Table 1 Multiple Resource Model Matrix.

MODALITY	CODE	STAGE
Auditory	Spatial	Responding
Visual	Verbal	Encode/ entral Processing

resource requirements of that task are used to change corresponding matrix cell values to equal one, while the others remain equal to zero. If a second task arrives prior to the completion of the first, the resource requirements of the new task are temporarily added to those of the old task. If this results in no more than two resources being used simultaneously, the second task is assigned to the pilot to work. If three resources are required simultaneously, a further computation is required

to determine if both tasks can be accomplished simultaneously. This computation is the determination of a Degradation Factor. It is based on the number of overlapping task resource requirements. The scheme used to determine this is shown in Table 2. The values in this table are derived from the conflict matrix developed by North (23). This Degradation Factor is used both for determining if an additional task can be assigned to the pilot and computing the amount of service time degradation resulting from that assignment.

Table 2 Degradation Factors.

NUMBER OF OVERLAPPING RESOURCES	DEGRADATION FACTOR
0 (With 2 tasks)	Uniform (0.1, 0.3)
1	Uniform (0.3, 0.6)
2	Uniform (0.6, 0.9)
3	Uniform (0.9, 1.1)
4 (Or more)	1.1

Whenever a new task is assigned to the pilot, resulting in the pilot working on more than one task (parallel processing), the service times for all tasks being worked are increased. This reflects the performance degradation resulting from parallel processing, as compared

to serial processing [Norman & Bobrow (22) and Wickens, Mountford, & Schreiner (44)]. Service times are increased by computing a Degradation Factor. This factor, normally between 0 and 1, is multiplied by the single-task service time and the product added to that service time. For example, if a degradation factor of 0.5 were computed, all affected task service times would be multiplied by a factor of 1.5, or effectively increased by 50%. If preemption is not possible and the Degradation Factor exceeds 1.0, then the new task would be assigned to wait until resources are available. A Degradation Factor limit of 1.0 is a subjective, arbitrary limit. It represents doubling a service time and assumes that it is better to defer a task to an idle period than to double the current service times of all tasks being worked at that time. Each time the pilot begins work on a new task, the resources being used to work on all tasks are updated. Similarly, when a task is preempted or completed, resource status is also updated. Figures 6 and 7 display the task arrival and service completion processes respectively for the parallel processing model.

The method used to degrade service times is based on simply counting the number of required resource "overlaps" and computing a Degradation Factor based on this count. This procedure is a modeling simplification since it ignores existing evidence [Norman and Bobrow (22) and

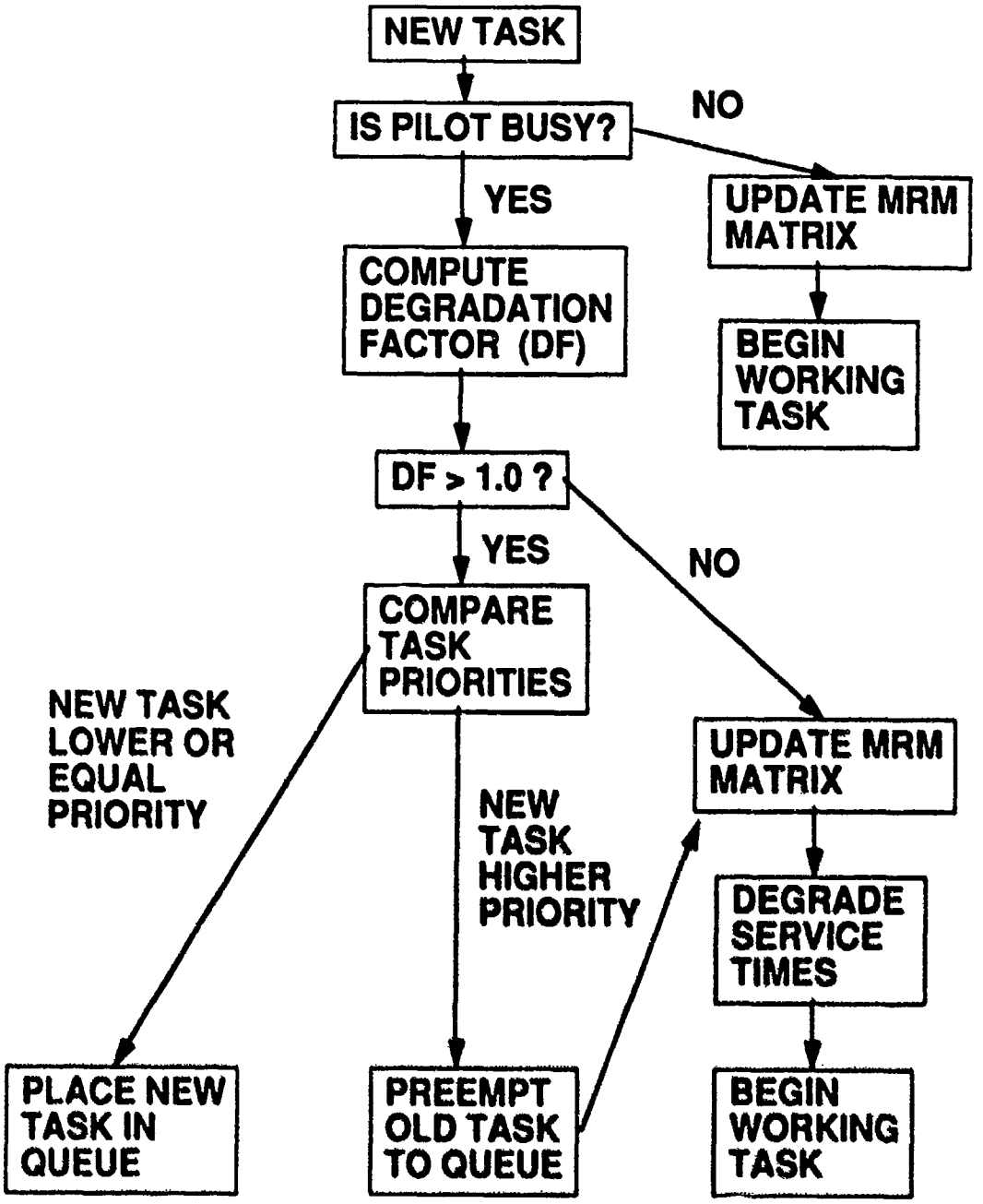


Figure 6 Task Arrival Process, Parallel Processing Model

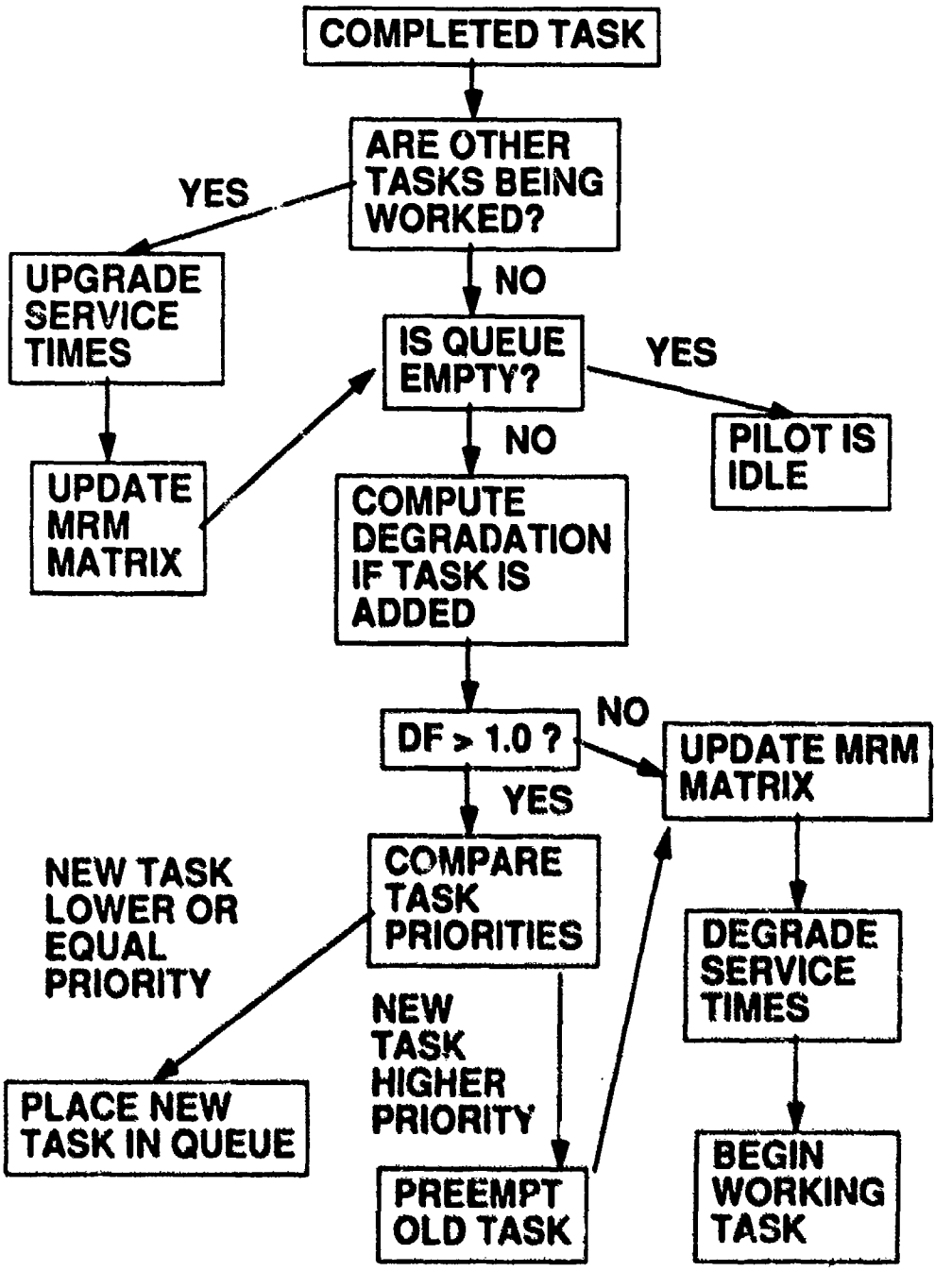


Figure 7 Service Completion Process, Parallel Processing Model

Wickens, Mountford, and Schreiner (44)] that the type of resource overlap is important in determining the actual degradation of service times for dual task performance over single task performance. Very little data exists to accurately determine these degradations for specific task combinations if resource type were considered. However, the degradations used were based on North's work (24) and agree with the degradation factors he presented. Therefore, since data for specific resource overlaps was not available, an assumption was made that simply counting the number of required resource overlaps was a reasonable modeling approach.

Task Inter-Arrival and Service Time Development

All times were first determined for the ABL configuration in the Penetration Segment and then adjusted for other segments and configurations. These are presented in Table 30. For the ABL, service times in the Penetration Segment are based on experimental results or handbook data. The service rate for flight control inputs involved in the FLY AIRCRAFT task are based on a flight simulator experiment done by Groves and Kaercher (11). Service times are assumed to be distributed exponentially since the mean and standard deviation determined experimentally (1.509 and 1.414) are approximately equal and the cumulative distribution function presented by Groves and Kaercher

strongly resembles an exponential distribution. However, insufficient data is presented by Groves and Kaercher to determine the statistical confidence in this assumption.

All other tasks in the Penetration Segment derive their service times from standard values as described by Siegel and Wolf (39). These service times are assumed to be normally distributed. This seems to be a logical assumption since the tasks are procedurally oriented and should require approximately the same amount of time to accomplish on each repetition.

Inter-arrival times for the FLY AIRCRAFT task are again derived from experimental results by Groves and Kaercher. These authors assumed this data to be normally distributed, although they do not provide sufficient data to verify this. Their assumption was used in this research since it worked well in their research. All other inter-arrival times are estimates based on the author's experience. In addition, these estimates compared favorably to those of Groves and Kaercher (11). Those tasks labeled with an "R" in Table 31 are repetitive and are assumed to be distributed normally. Tasks labeled "N" are non-repetitive and occur only once.

The mean inter-arrival and service times of tasks accomplished during the Target Acquisition Segment are derived from those of the Penetration Segment. All service times remain unchanged, but the mean of seven of the twelve

inter-arrival times are changed. One of these, the FLY AIRCRAFT task, is increased slightly to recognize the decreased rate of flight control input required of the pilot while executing a "POP-UP" maneuver rather than continuing to fly a terrain following profile. The other six tasks (NAVIGATE, ASSESS ENVIRONMENT, ASSESS MISSION PLAN, MONITOR/ASSESS AIRCRAFT SYSTEMS, CONFIGURE AIRCRAFT SYSTEMS, and DEFENSIVE MANEUVER) all have decreased inter-arrival times to reflect increased activity in these areas. A pilot's primary concern in this phase is to detect and identify the target. Precise altitude, heading, or airspeed control is not required.

The same philosophy is used in determining parameters for the tasks of the Weapon Delivery Segment. The mean of the FLY AIRCRAFT inter-arrival time distribution is the same as that used during the terrain-following Penetration Segment since precise heading, airspeed, and altitude are required for accurate weapon release. All other task parameters remain unchanged from the Target Acquisition segment.

The inter-arrival and service time distributions developed for the ABL configuration were used as a basis for both the TF/TA and TTA configurations. The fundamental difference between the TF/TA and ABL configurations is that the former automatically controls pitch and bank to provide for terrain following and terrain avoidance. The latter

only provides commands for terrain following which require a manual pilot response. This difference is accounted for by increasing the mean inter-arrival time for the FLY AIRCRAFT task in the Penetration Segment for the TF/TA configuration. The amount of increase is based on the author's judgment and reflects the possibility that, even though TF/TA is fully automatic, the pilot may manually override the system periodically.

All service and inter-arrival distribution parameters for the Target Acquisition Segment, with the TF/TA configuration, are identical to the ABL configuration. In this segment, terrain-following and avoidance are not being accomplished so the benefits of the automatic system are not obtained. In the Weapon Delivery Segment for the TF/TA configuration, the pilot is again using TF/TA to maintain terrain separation. However, now he must integrate this information with information related to his target location. Therefore, he will require additional manual inputs compared to the Penetration Segment, but not as frequently as would be required by the ABL configuration. All other parameters remain unchanged from the ABL configuration.

In addition to providing automatic terrain avoidance, the TTA configuration also provides automatic threat avoidance. This impacts the inter-arrival time distribution parameters in three ways. First, the inter-

arrival mean for the FLY AIRCRAFT task, for the Penetration Segment, is equal to the mean for the TF/TA configuration. This reflects the fact that the same automatic terrain avoidance is available, so the load on the pilot from this task is the same as the TF/TA configuration. Second, since automatic threat avoidance is provided, the frequency of a DEFENSIVE MANEUVER task is decreased. Therefore, the mean inter-arrival time for this task is assumed to double. Third, this configuration requires that two different displays be monitored, the Head-Down Display and the Threat Display. This requires that the mean inter-arrival time for the MONITOR/ASSESS AIRCRAFT SYSTEMS task be decreased to reflect the increase in pilot activity.

In the Target Acquisition Segment, the enhanced features of the TTA configuration provide no benefit to the pilot. As a result, the inter-arrival and service rate parameters are the same as those used for the ABL and TF/TA configurations.

For the Weapon Delivery Segment, the inter-arrival time distribution parameters for the TTA configuration differ from the TF/TA configuration in three ways. First, monitoring two displays for the TTA configuration requires a decreased mean inter-arrival time for the MONITOR/ASSESS AIRCRAFT SYSTEMS task compared to the TF/TA configuration. Second, the mean inter-arrival time for the DEFENSIVE MANEUVER task was increased due to the automatic features

of the TTA system. Finally, the mean inter-arrival time for the FLY AIRCRAFT task was decreased due to the increase in control inputs required in this segment.

Parallel Server Model Calibration

The previous section described how the single server model was developed. Once this was complete, it was necessary to calibrate the parallel server model to assure that at some point it matched the performance of the single server model. One of the goals of this research was to compare the performance of a single server model and a parallel server model. To accomplish this goal, it was necessary to provide a common starting point for both models where the output performance measures were as closely matched as possible. Once this baseline was established, any subsequent disparity in performance would be attributable to the model, not the starting point.

Since the input parameters for the single server model had already been determined, the parallel server model was calibrated to it for the ABL configuration. This was done by adjusting the mean service rates for the parallel server model to find the point which approximately resulted in the same utilization rate as the single server model. For this model, changes to the service rate were examined so that the same task arrival rates used in the single server model were also employed in the parallel processing model. The

results of these adjustments in service rates are shown in Figure 8. In this figure, the solid line represents the parallel model performance as a function of service rate changes. The dashed line is the idle time ratio for the serial model. The point at which the lines cross represent the service rate at which the idle time ratio from both models was equal.

From Figure 8 it was apparent that no single service rate yielded identical performance between the single server model and parallel server model. Therefore, it was noted that the total minimum squared error for all three flight phases occurred at an increase of 2% in service rates, as shown in Table 3. However, the mean squared error at a 0% change in service rate was only slightly higher, so the parallel server model was evaluated with the same arrival rates and service rates as used in the single server model.

Model Verification

Both versions of this model are relatively complex in their final versions. Because of this complexity, it is difficult to verify that each version is an accurate representation of a queueing system model. To overcome this problem, steps were taken during model development to verify the proper functioning of each version, as it was developed.

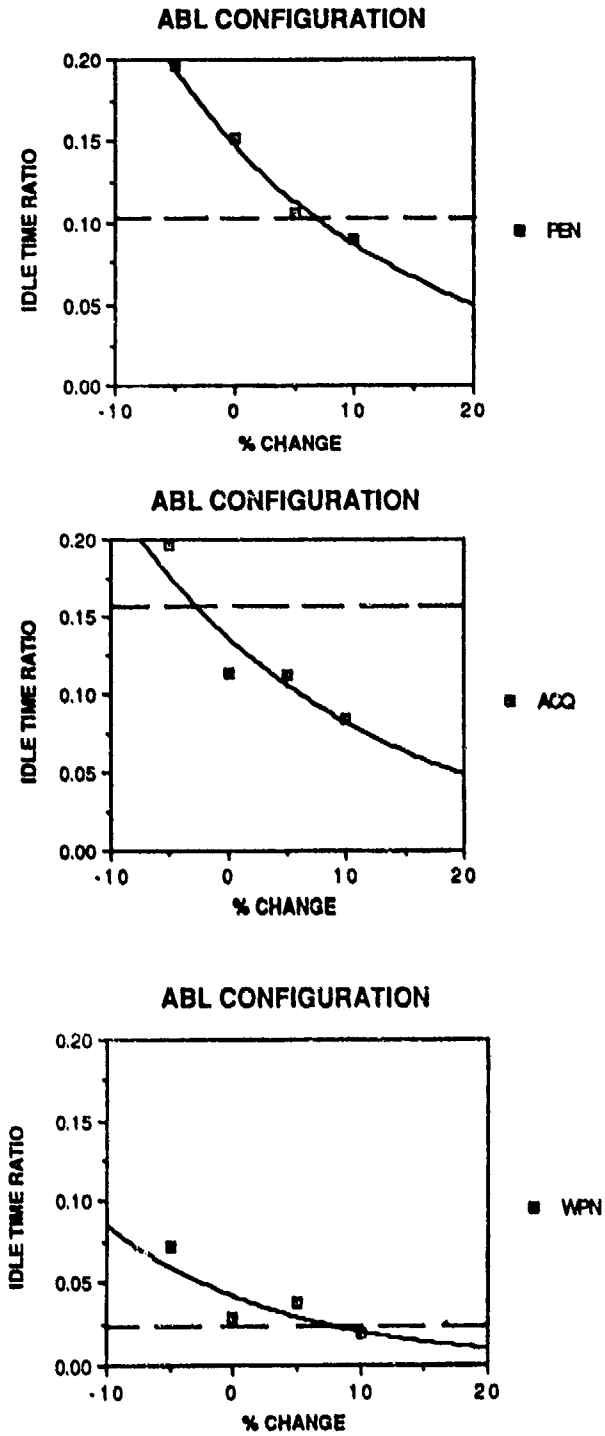


Figure 8 Parallel Server Model Calibration

Table 3 Utilization Rate Squared Error: Parallel Server Model

SERVICE RATE CHANGES	SQUARED DIFFERENCES			
	PEN	ACQ	WPN	TOTAL
0 %	.00238	.00203	.00000	.00441
1 %	.00174	.00265	.00000	.00439
2 %	.00120	.00314	.00002	.00436
3 %	.00071	.00360	.00005	.00437
4 %	.00039	.00397	.00006	.00442
5 %	.00016	.00436	.00008	.00460

For the single channel model, an initial version was created with a single task source and exponentially distributed inter-arrival and service times. Using this simplified model, it was possible to compare steady-state output parameters (mean waiting time, mean system time, etc.) for the simulation model with known analytical, steady-state results. This essentially verified that the arrival and servicing of customers were handled properly and output statistics were computed properly.

Once this was verified, it was possible to add additional tasks and a priority system. Giffin (9) shows that analytic results are available for a preemptive priority system with a single server and any number of priority classes, each having a common mean service rate. Using his formulation, it was also possible to compare

simulation results with analytic, steady-state results. These results compared favorably and indicated that the simulation model describing a multiple-task priority system, in a simplified form, was accurate. The change from this form to the final form was relatively simple in that it required modifying only the appropriate rates and distributions, not the structure of the model. This procedure lends confidence that the single channel model reasonably represents one version of a pilot accomplishing tasks in a cockpit environment.

Verification of the parallel processing model was accomplished in a similar manner. A simplified version of the model was developed which allowed parallel processing in two channels simultaneously. A single customer source was provided and the arrival rate and service rates were selected to load the system at a 0.75 utilization rate. Identical service rates were used in each parallel channel. Steady-state simulation results were compared to analytic results. The procedure was then repeated with three and four channels. These comparisons showed that the model was accurately representing a multiple-channel system.

Verification of this model by comparing steady-state simulation results to analytically-derived values for any added complexity was virtually impossible since analysis was not possible for more complex systems. Therefore, the following procedure was used to give some confidence in the

final model. Starting with the simplified version of the parallel processing model previously described, several features were added. These included a priority system, degraded and upgraded service rates, and a logic system to determine if an additional channel would be available to service another task in parallel. These features were added one at a time and resulting performance parameters closely monitored to assure that they were reasonable. For example, when the priority system was first tested, the average system time for each class of customers was computed. Logically, a higher priority class should have a lower average system time than a lower priority class. This result was verified, as well as other, similar logical conclusions.

When the final version of the parallel processing simulation model was completed, several runs were made which provided a trace of each customer arrival and service event completion. This allowed a manual reconstruction of the events and statistics of each run to be made. While this was tedious, it verified that the simulation of the parallel processing model was performing as expected and could be used with some degree of confidence.

Model Output

Both versions of this simulation model produce estimates of pilot idle time. In this context, idle time

is defined as the ratio of time spent not working on any task to total time. In the single channel version, it is a simple matter to compute idle time; the pilot is either working on a task (busy) or not working on a task (idle). The same concept is used in the multiple resource model. The pilot is idle if he is not working on any task. He is considered busy if he is working on at least one task. The number of tasks being worked does not influence idle-time computations for this version. There is no such thing as degrees of "busy-ness"; the pilot is either busy or idle. If a pilot is working on multiple tasks simultaneously his workload will be greater than if he is only working on a single task. Idle Time is not intended to measure this, rather an alternative measure, Simultaneous Task Rate, will be used to account for multiple tasks being completed simultaneously.

The single channel model also produces another Time Load estimator, the ratio of task interruptions to total arrivals. Several possible definitions and interpretations of a task interruption are possible. One possible interpretation would be to count an interruption only when one task is preempted by another. Another view might be that an interruption occurs anytime a new task arrives while the pilot is working on another task, regardless of whether a preemption occurs. This suggests that the pilot's simple recognition of a task arriving constitutes

an interruption. Since it is desired that any task interruption measure be normalized between 0 and 1, a task interruption measure can be computed by dividing total interruptions by total task arrivals, for either definition. However, total task arrivals is open to interpretation. It is obvious that the original arrival of each task should be counted, but should subsequent arrivals of previously preempted tasks be counted? Since there was no obvious answer to this, it was decided to consider both counting and not counting preempted tasks as arrivals.

This led to a total of four possible definitions of task interruption rate, as shown in Table 4.

The parallel processing model also determines the average number of tasks being worked by the pilot. This is used as an estimator of Time Load. In this version, the pilot can work on more than one task at a time so the number of task interruptions is not a pertinent measure of Time Load. Instead, the average number of tasks being worked on simultaneously is a more accurate measure of Time Load. In the model, this is computed by maintaining a time-weighted average of the number of tasks being worked by the pilot. The method used to combine these estimators of Time Load with other subjective estimators was presented in Chapter III.

Table 4 Task Interruption Predictor Definitions

Predictor	Interruption Defined By:	Subsequent Arrival of Preempted Tasks:
A	Preemption	Counted
B	Preemption	Not Counted
C	Arrival of New Task	Counted
D	Arrival of New Task	Not Counted

Summary

This chapter described two discrete event simulation models developed to provide surrogate predictors for the Time Load dimension of the SWAT methodology. One of these models assumed tasks were completed serially and the other model assumed that tasks could be processed in parallel. The number of tasks processed in parallel was determined by embedding Wickens' multiple resource model in the simulation model.

Also described in this chapter is the development of task inter-arrival and service time distributions. Further details can be found in Appendix E. Task inter-arrival times and service times were first developed for the serial model. Inter-arrival times were identical for the parallel model. Service times for the parallel model were

calibrated to the serial model to replicate performance for the ABL configuration.

Finally, the process used to verify these models was discussed. Model validation will be considered in the overall process of validating the entire workload prediction model. The next chapter describes the results produced by these models and leads into a discussion of the workload prediction model validation.

CHAPTER V

RESULTS

Introduction

Three basic sets of workload data were used in this study. One of these was the workload ratings derived from the flight simulator experiment of the RAM/ACE program. The other two sets were workload predictions, one derived as part of the RAM/ACE study and the other accomplished during this research. The value of these predictions can only be determined by comparing them to the RAM/ACE workload ratings. A complete listing of the basic predictions and ratings is found in Appendix I. For comparison purposes, the mean values of these observations are shown in Table 5. SWAT workload ratings are scaled between 0 and 100, where 0 represents no workload and 100 represents the highest possible level of workload. Other, intermediate workload levels are scales between 0 and 100 by the SWAT methodology (29).

In addition to comparing the basic predictions to the workload ratings, other predictions were developed and compared also. These additional predictions were developed

Table 5 Workload Ratings and Predictions Summary

METHOD	CONFIGURATION	FLIGHT PHASE		
		PEN	ACQ	WPN
SWAT	ABL	31.5	63.1	68.1
RATINGS	TF/TA	28.3	40.1	65.4
	TTA	21.4	36.1	57.3
PRO-SWAT	ABL	46.8	52.5	82.3
(1982)	TF/TA	29.0	38.9	41.3
PREDICTIONS	TTA	22.1	32.8	57.8
PRO-SWAT	ABL	51.7	56.6	50.1
(1986)	TF/TA	54.2	38.3	35.2
PREDICTIONS	TTA	39.9	42.8	39.3

by modifying both basic sets of predictions with output from the computer simulation described in Chapter IV. This resulted in fourteen additional predictor sets. Ultimately, each of these predictor sets was compared to the workload ratings to evaluate the accuracy of each predictor. This chapter describes that process and details the results of the comparison. These results lead to the conclusions drawn in the next chapter concerning the accuracy of the predictors. Since some assumptions were made in accomplishing this research, the sensitivity of the results to these assumptions is examined in the final portion of this chapter.

Computer Simulation Results

As described in Chapter IV, two basic simulation models were built to augment the workload predictions. One model assumed the pilot could accomplish only one task at a time while the second model assumed the pilot could process more than one task in parallel. The former model estimated pilot idle time and task interruption rate as surrogates for the Time Load Dimension of workload. The latter model developed estimates for pilot idle time and simultaneous task rate as workload surrogates. Each model was run for 25 replications to more accurately estimate mean values and to determine the variance of the estimators.

The results of these computer runs are summarized in Tables 6 and 7. These results show the mean values computed over the 25 replications as well as the standard error. In all cases, the error deviation was considered to be small enough to disregard the use of variance reduction techniques. This small standard error also suggested that it was unnecessary to make additional runs beyond 25. As will be shown in the next section, it will be necessary to convert these mean predictor values to ratings of 1, 2, or 3 (LOW, MEDIUM, or HIGH) to use with the SWAT methodology. The relatively low standard error shown in these tables generally has no effect on this conversion process.

Table 6 Predictor Values, Single Server Model

PREDIC-TOR	CONFIG-URATION	FLIGHT PHASE					
		PEN		ACQ		WPN	
		MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
SS-PIR	ABL	.389	.007	.166	.020	.037	.010
	TF/TA	.609	.006	.317	.025	.124	.017
	TTA	.588	.006	.286	.028	.124	.019
SS-TI(A)	ABL	.131	.004	.141	.017	.087	.011
	TF/TA	.070	.006	.130	.016	.118	.015
	TTA	.072	.006	.146	.015	.114	.016
SS-TI(B)	ABL	.152	.006	.177	.024	.100	.014
	TF/TA	.077	.007	.159	.021	.142	.021
	TTA	.079	.007	.180	.021	.139	.021
SS-TI(C)	ABL	.538	.010	.738	.025	.944	.016
	TF/TA	.309	.009	.528	.031	.813	.029
	TTA	.297	.009	.476	.025	.705	.028
SS-TI(D)	ABL	.467	.008	.631	.022	.861	.015
	TF/TA	.287	.008	.453	.022	.714	.025
	TTA	.321	.010	.566	.034	.801	.032

Table 7 Predictor Values, Parallel Server Model

PREDIC-TOR	CONFIG-URATION	FLIGHT PHASE					
		PEN		ACQ		WPN	
		MEAN	S.E.	MEAN	S.E.	MEAN	S.E.
PS-PIR	ABL	.570	.007	.324	.020	.181	.016
	TF/TA	.677	.004	.449	.018	.335	.019
	TTA	.663	.004	.440	.021	.320	.018
PS-STR	ABL	.352	.009	.548	.022	.758	.020
	TF/TA	.255	.009	.410	.022	.561	.028
	TTA	.241	.007	.404	.025	.577	.020

SWAT Score Conversion

The purpose of developing the two simulation models was to modify the workload estimate in the Time Load dimension of the SWAT methodology. The results of the computer simulation, as described in the previous section, were all scaled between 0 and 1. To make these compatible with the SWAT methodology, it was necessary to develop a transformation for these simulation-derived estimates.

Several methods were considered for developing this transformation, but the method used was to develop a survey and simply ask subjects to estimate this transformation. The survey form used, and detailed results, are found in Appendix G. Final results are summarized in Table 8. These results are derived from 82 subjects who completed the survey. Of these, 46 were pilots and 36 were non-pilots. Four of the subjects were also recognized experts in workload measurement, while the other 78 were not.

Using a MANOVA procedure in SAS (35) the null hypothesis of no overall pilot effect was tested and not rejected ($F = 0.30$, $P > F = 0.93$). The hypothesis of no overall expert effect was also tested and not rejected ($F = 1.34$, $P > F = 0.25$). When each of the break points for the simulation output parameters was tested individually, only the experts' estimate of the break point between LOW and MEDIUM levels of workload, as estimated by Pilot Idle Time, was found to be significant ($F = 5.13$, $P > F = 0.026$). All

Table 8 Simulation Output, SWAT Score Transformations

SIMULATION OUTPUT PARAMETER	PARAMETER RANGES	SWAT CONVERSION
PILOT IDLE RATE (PIR)	0% ≤ PIR ≤ 12.3%	HIGH (3)
	12.3% ≤ PIR ≤ 44.1%	MEDIUM (2)
	44.1% ≤ PIR ≤ 100%	LOW (1)
TASK INTERRUPT RATE (TIR)	69.3% ≤ TIR ≤ 100%	HIGH (3)
	28.9% ≤ TIR ≤ 69.3%	MEDIUM (2)
	0% ≤ TIR ≤ 28.9%	LOW (1)
SIMULTANEOUS TASK RATE (STR)	65.5% ≤ STR ≤ 100%	HIGH (3)
	26.2% ≤ STR ≤ 65.5%	MEDIUM (2)
	0% ≤ STR ≤ 26.2%	LOW (1)

other individual hypothesis tests proved to be non-significant at the 5% level.

Because the experts constituted a relatively small group and because the hypothesis of no overall expert effect was not rejected, it was decided to use all survey responses to define this transformation. Therefore, the transformation presented in Table 8 represents the average values provided by all 82 survey respondents. These transformations were then used to convert the simulation output, found in Tables 6 and 7, to SWAT workload predictions. The process used to compare these modified predictions to the RAM/ACE SWAT ratings is described in the next section.

Predictor Comparisons

The fundamental question to be addressed in this section was how accurately did the various predictors match the SWAT simulator workload ratings of the RAM/ACE experiment. When Eggleston and Quinn (7) compared their predicted results to the RAM/ACE workload measurements, they used simple correlation. This was possible because they could compare predictions versus ratings for specific pilots, since the same pilots were used in each case. However, in this research a totally different group of pilots was used to predict workload. Therefore, another approach was needed which allowed comparison of predictions and measurements on a grouped, rather than an individual, basis.

This comparison was accomplished by viewing the predictions and measurements as two multivariate sets in a two-way experiment. This is shown in Table 9. This table shows that the workload predictions from one of the PRO-SWAT data sets is compared against SWAT measurements for all three cockpit configurations (ABL, TF/TA, and TTA). The data points themselves are triplets, i.e., workload values for the Penetration (P), Target Acquisition (A), and Weapon Delivery (W) segments for each combination of cockpit configuration and method. When viewed this way, the multivariate nature of the data is more obvious.

Table 9 Multivariate Comparison Process

METHOD	COCKPIT CONFIGURATION		
	ABL	TF/TA	TTA
PRO-SWAT (1 or 2)	P/A/W	P/A/W	P/A/W
SWAT	P/A/W	P/A/W	P/A/W

A table of information such as this could be formed for each predictor and each PRO-SWAT data set. The SWAT workload measurements have five sets of pilot ratings in each cell of the matrix above. The PRO-SWAT estimates made in 1982 also have five sets of estimates in each cell, while those completed in 1986 have eight sets in each cell.

In order to deal with this data using multivariate techniques, it is common to assume that the data has a multivariate normal distribution. Johnson and Wichern (16) suggest that one method of supporting this assumption is to test the marginal, univariate distributions for normality. This can be done by developing a plot of the ordered original values and their standard normal quantiles. If these plotted values form a straight line, the assumption of normality is supported. However, this requires subjective judgment as to the "straightness" of the resulting line. Filliben (8) describes a probability plot correlation coefficient test for normality. This test takes the subjective element out of the process. By

determining a correlation coefficient between the ordered data and their standard normal quantiles, and comparing this against a critical value, a powerful test of normality results. This test was done for each univariate data set of workload predictions and measurements. Of the 153 sets checked, only six sets did not pass this univariate normality check. This result was viewed as strong support for the assumption of multivariate normality.

Multivariate Comparison of Means

Two possible methods for comparing workload predictions to workload measurements were identified. The first of these methods is a comparison of multivariate means, implemented via a hypothesis test:

$$H_0: \ \underline{\mu}_1 = \underline{\mu}_2 \tag{1}$$

where $\underline{\mu}_1$ is a 3 x 3 matrix of mean values of SWAT workload measurements. $\underline{\mu}_2$ is a similar 3 x 3 matrix of PRO-SWAT workload predictions. This comparison was made by comparing one predictor (e.g., pilot idle time from the serial processing model) at a time against the SWAT workload measurements. Since there are a total of eight different predictors for two different PRO-SWAT sets, there are a total of sixteen hypothesis tests.

There are three basic assumptions which must be satisfied for this analysis to be valid. The first is that the random samples from different populations are independent. This independence requirement between the SWAT measurements and the second set of PRO-SWAT estimates is easily satisfied since the estimates and measurements were accomplished by two completely distinct groups of pilots approximately four years apart. The original PRO-SWAT estimates and the SWAT ratings were made by the same pilots so there might be a suspicion that these data sets are not independent. However, each pilot rated workload (SWAT) over eight different simulator flights and estimated workload (PRO-SWAT) over the same number of missions. These were mixed in a random fashion for each pilot, so an assumption of independence seems reasonable.

The second assumption is that the covariance matrix (Σ) for each data set was equal. Johnson and Wichern (16) suggest that any discrepancy of the order of $\sigma_{1,ii} = 4\sigma_{2,ii}$ is probably serious and should cause concern. There were no values with this large a difference; in fact, most values were of the order of $\sigma_{1,ii} = 2\sigma_{2,ii}$ or less. Bartlett (1) presents a formal test to statistically verify that the covariance matricies are equal.

Bartlett's test, as described by Green (10), tests the equivalence of covariance matricies by computing a test

statistic which has an appropriate chi square distribution. This test statistic is computed by the formula:

$$B = (m-G) \ln |C_w| - \sum_{g=1}^{G} (m_g - 1) \ln |C_g| \tag{2}$$

where: $$m = \sum_{g=1}^{G} m_g \tag{3}$$

$$G = \text{number of covariance matricies} \tag{4}$$

$$m_g = \text{number of observations in group } g \tag{5}$$

$$C_w = \text{pooled covariance matrix} \tag{6}$$

$$\text{d.f.} = 1/2[(G-1)(p)(p+1)] \tag{7}$$

and p is the number of dependent variables.

The null hypothesis, that the covariance matricies are equal, would be rejected if the test statistic, B, exceeds the appropriate chi square value at confidence level α. Bartlett's test was implemented by using the SAS IML procedure (Interactive Matrix Language) (34). All covariance matricies passed Bartlett's test, so it is reasonable to assume that corresponding covariance matricies are equal.

The final assumption was that each population is multivariate normal. This assumption was satisfied, as described earlier in this chapter.

With these three assumptions satisfied, it is possible to conduct this hypothesis test with confidence. Table 10 shows the results of this hypothesis test, implemented with

Table 10 Multivariate Comparison of Means

PREDICTOR	PRO-SWAT (1982)		PRO-SWAT (1986)	
	F	P > F	F	P > F
PRO-SWAT	0.33	0.81	1.26	0.29
SS-PIR	0.32	0.81	2.03	0.13
SS-TI(A)	1.27	0.31	7.40	0.0006
SS-TI(B)	1.49	0.24	7.52	0.0006
SS-TI(C)	1.06	0.38	3.29	0.03
SS-TI(D)	1.28	0.30	2.32	0.09
PS-PIR	0.44	0.73	2.34	0.09
PS-STR	0.32	0.81	2.21	0.11

the SAS General Linear Models Procedure (35).

In this table the predictor, PRO-SWAT, refers to the purely subjective workload estimates, not modified by any output from the simulation. All predictors beginning with SS were derived from the single server model and those beginning with PS from the parallel server model. PIR refers to pilot idle time rate and TI refers to one of the task interrupt rate predictors. Finally, STR refers to the simultaneous task rate.

From Table 10, it is apparent that the basic PRO-SWAT data from 1982 very closely matches the SWAT measurements. The 1986 data matches the SWAT measurements, but not nearly as well. This is not surprising and the reasons for this

will be discussed in the next chapter. However, the data shows that when the 1982 predictions are modified with simulation output, the F statistic generally grows but the difference between means never becomes significant. Note that the pilot idle rate (PIR) predictor for the single server model and the simultaneous task rate (STR) actually improve the basic predictor (PRO-SWAT) slightly. The unmodified 1986 data does not match the SWAT data as well as the 1982 data, but is not significantly different. None of the predictors improve the 1986 data, but several result in differences that are non-significant. The next chapter will present some conclusions from this table.

The results of the previous table were derived by comparing the output for a given predictor, over all three cockpit configurations, to the SWAT measurement data. A similar analysis was also made by considering each cockpit configuration individually. However, this method of analysis provided no discrimination between predictors and did not reject any hypotheses that the mean predictor values matched the SWAT data. This apparent inconsistency is attributed to the fewer number of data points available when the hypothesis was tested separately for each cockpit configuration. When all three cockpit configurations were considered simultaneously, there was enough information not to reject the hypothesis for some and reject for others.

Profile Analysis

The second multivariate technique used to evaluate the predictors was profile analysis, as described by Johnson and Wichern (16). This technique tests the same hypothesis:

$$H_0: \ \mu_1 = \mu_2 \tag{8}$$

This test is accomplished in a stagewise fashion. The first stage asks the question, "Are the profiles parallel?" An auxiliary hypothesis could be formed:

$$H_{01}: \ \underline{C}\,\mu_1 = \underline{C}\,\mu_2 \tag{9}$$

where $\underline{C}$ is the contrast matrix:

$$\underline{C} = \begin{bmatrix} -1 & 1 & 0 & 0 & - & - & - & - & 0 & 0 \\ 0 & -1 & 1 & 0 & - & - & - & - & 0 & 0 \\ . & . & . & . & - & - & - & - & . & . \\ . & . & . & . & - & - & - & - & . & . \\ 0 & 0 & 0 & 0 & - & - & - & - & -1 & 1 \end{bmatrix} \tag{10}$$

and $\underline{C}$ is a (p-1) x p matrix. In this case, p is the number of treatments (flight segments) for each population. Basically, this hypothesis asks if a plot of the means of each population, when connected by straight lines, are

parallel. This still allows differences in mean values, but accepts the hypothesis if the profiles are parallel. Hypothesis H_{01} should be rejected at level α if:

$$T^2 = (\underline{X}_1 - \underline{X}_2)' \underline{C}' [(1/n_1 + 1/n_2) \underline{C} \underline{S}_p \underline{C}']^{-1} \underline{C} (\underline{X}_1 - \underline{X}_2) > c^2 \qquad (11)$$

where $\underline{X}_1$ and $\underline{X}_2$ are the sample mean vectors, $\underline{S}_p$ is the pooled covariance matrix, and:

$$c^2 = \frac{(n_1 + n_2 - 2)(p - 1)}{n_1 + n_2 - p} F_{p-1, n1+n2-p}(\alpha) \qquad (12)$$

The second stage asks the question, "Assuming the profiles are parallel, are they coincident?" Another auxiliary hypothesis could be formed:

$$H_{02}: \ \underline{1}\, \mu_1 = \underline{1}\, \mu_2 \qquad (13)$$

$$\text{where } \underline{1}' = [1\ 1\ - - - -\ 1\ 1] \qquad (14)$$

Stated another way, given that the profiles are parallel, do they lie on top of one another? These two hypotheses are germane to this research since they test how closely the means of the two populations agree. Hypothesis H_{02} should be rejected at level α if:

$$T^2 = \underline{1}'(\underline{X}_1 - \underline{X}_2)[(1/n_1 + 1/n_2) \underline{1}' \underline{S}_p \underline{1}]^{-1} \underline{1}'(\underline{X}_1 - \underline{X}_2) > F_{1, n1+n2-2}(\alpha) \qquad (15)$$

The third stage of the profile analysis asks the question, "Assuming the profiles are coincident, are the profiles level?" Stated as a third auxiliary hypothesis:

$$H_{03}: \ \underline{C}(\mu_1 + \mu_2) = \underline{0} \tag{16}$$

Hypothesis H_{03} should be rejected at level α if:

$$(n_1+n_2)\underline{X}'\underline{C}'[\underline{C}\underline{S}_p\underline{C}']^{-1}\underline{C}\underline{X} > F_{p-1,\ n1+n2-p}(\alpha) \tag{17}$$

$$\text{where } \underline{X} = n_1/(n_1 + n_2)\ \underline{X}_1 + n_2/(n_1 + n_2)\ \underline{X}_2 \tag{18}$$

While this third test may be important in some domains, it was not considered important in this research. There is no reason to suspect, for example, that workload in all three flight phases, or all three cockpit configurations, should be the same. In fact, there are many reasons to expect just the opposite is true.

The first attempt at conducting a profile analysis considered each predictor over all cockpit configurations. However, this proved impossible. To compute the appropriate test statistic required a 9 x 9 covariance matrix (three flight phases for three cockpit configurations). The data available for this was limited to only five data points for both the SWAT and 1982 PRO-SWAT data, and eight data points for the 1986 data. This

led to covariance matricies of less than full rank. Therefore, it was impossible to test the hypothesis on this basis. The second attempt at a profile analysis was conducted separately for each cockpit configuration. This resulted in a 3 x 3 covariance matrix. Since there were a minimum of five data points in each cell, the resulting covariance matrix was of full rank and the analysis could be conducted. Sample profiles are shown in Figures 9 and 10 for the PRO-SWAT 1986 data and the 1982 data, respectively. The results of this profile analysis are shown in Table 11 for the 1982 PRO-SWAT data and Table 12 for the 1986 PRO-SWAT data.

The predictors in both of these tables are defined in the same way as they were for Table 10. The entries in the tables are the values of the test statistics computed by Equations 11 (H_{01}), 15 (H_{02}), and 17 (H_{03}). Also shown are the critical values, which can be compared to the test statistics. Where the test statistic exceeds the critical value, the corresponding hypothesis should be rejected for that predictor. As shown in Table 11, neither the hypothesis for parallel profiles nor the hypothesis for coincident profiles is rejected for the basic data (PRO-SWAT) or any of the predictors. The last column of Table 11 shows Bartlett's test statistic and its corresponding critical value. As discussed earlier, Bartlett's test was used to determine if the covariance matricies of the

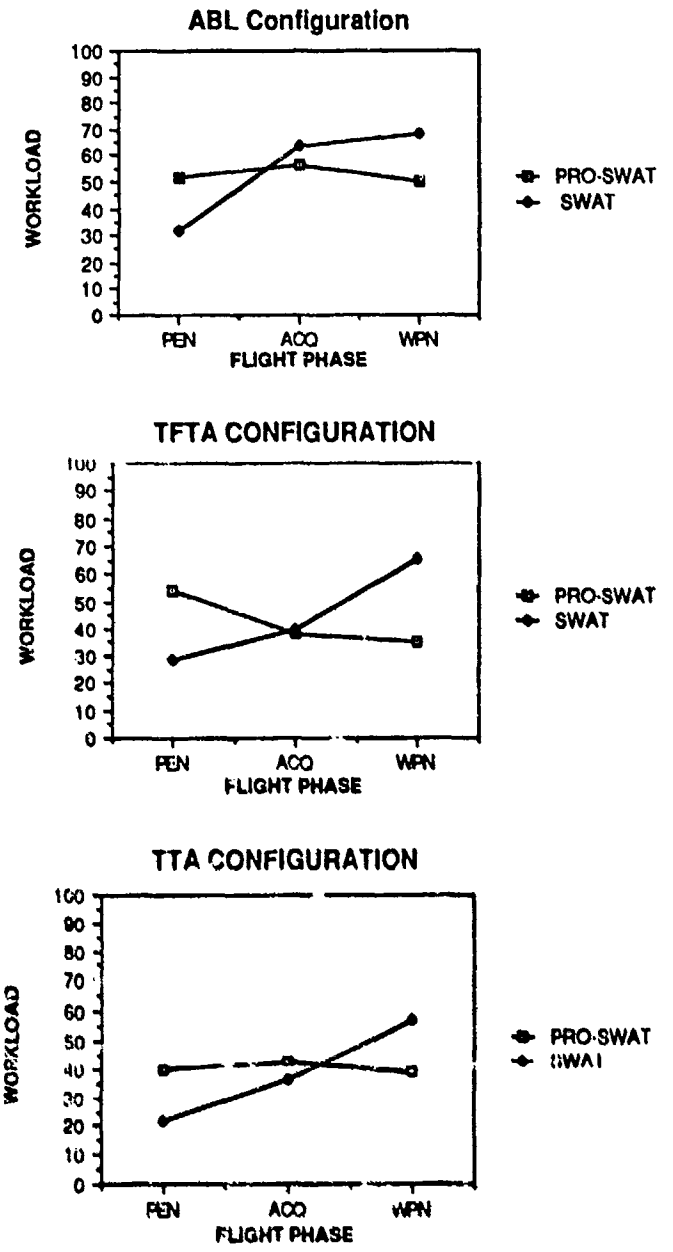


Figure 9 Workload Profiles. SWAT and PRO-SWAT (1986)
(Predictor = PRO-SWAT)

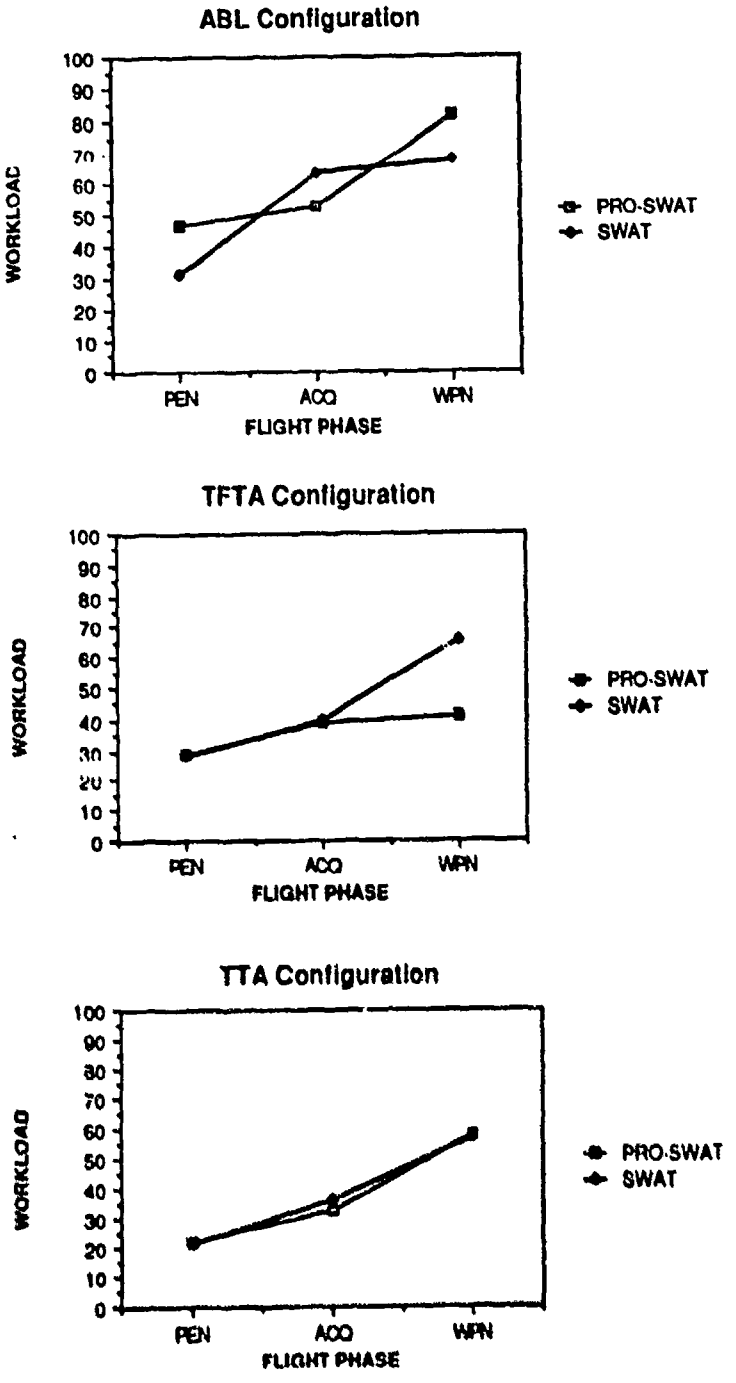


Figure 10 Workload Profiles, SWAT and PRO-SWAT (1982)
(Predictor = PRO-SWAT)

Table 11 Profile Analysis Results, 1982 Data

CONFIG-URATION	PREDIC-TOR	PARALLEL H_{01}	COINCIDENT H_{02}	EQUAL H_{03}	BARTLETT STATISTIC
ABL	PRO-SWAT	2.35	0.20	8.06	4.07
	SS-PIR	4.63	0.58	10.46	11.33
	SS-TI(A)	1.96	0.06	6.75	12.54
	SS-TI(B)	2.79	0.14	6.41	11.71
	SS-TI(C)	1.38	1.27	10.21	10.91
	SS-TI(D)	4.53	0.54	10.30	10.62
	PS-PIR	1.77	0.02	8.67	10.67
	PS-STR	4.63	0.58	10.46	11.33
TF/TA	PRO-SWAT	3.84	0.42	7.10	11.71
	SS-PIR	1.99	0.79	8.71	3.75
	SS-TI(A)	2.32	1.97	7.51	4.13
	SS-TI(B)	2.32	1.97	7.51	4.13
	SS-TI(C)	0.18	0.06	15.38	3.82
	SS-TI(D)	0.06	0.24	16.44	3.80
	PS-PIR	0.65	1.29	11.29	4.05
	PS-STR	1.99	0.79	8.71	3.75
TTA	PRO-SWAT	0.11	0.01	9.42	1.85
	SS-PIR	0.08	0.24	8.66	1.26
	SS-TI(A)	0.26	2.97	6.98	1.22
	SS-TI(B)	0.26	2.98	6.98	1.22
	SS-TI(C)	1.35	1.07	11.19	1.03
	SS-TI(D)	1.35	1.07	11.19	1.03
	PS-PIR	0.08	0.24	8.66	1.26
	PS-STR	0.08	0.24	8.66	1.26
CRITICAL VALUE		10.83	5.32	4.74	12.59

predictor data and the corresponding SWAT data were equal. In all cases, the equality of covariance matricies was established. This equality satisfies one of the three assumptions mentioned earlier and is a critical assumption when sample sizes are small, as they are in this research.

Some additional comments are in order regarding the data in Table 11. Note that the original PRO-SWAT predictions, over all three cockpit configurations, are excellent. In fact, there are relatively few predictors which improve the predictions in terms of being both parallel and coincident. There appears to be no discernable pattern as to which predictor consistently improved or worsened the estimates over the three cockpit configurations. Perhaps even more important, none of the predictors changed the original PRO-SWAT estimates so much that they were rejected by the parallel or coincident hypothesis tests. Also note that all predictors were rejected by H_{03}, testing whether the profiles were level. In essence, this suggests that workload levels over the three flight segments were different and this difference was recognized by the statistical test.

In general, the 1986 PRO-SWAT data does not predict the SWAT measurements as accurately as the 1982 PRO-SWAT data. This is shown in Table 12, which depicts results of the profile analysis on this data. The hypothesis of parallel profiles (H_{01}) is rejected for two of the task

Table 12 Profile Analysis Results, 1986 Data

CONFIG-URATION	PREDIC-TOR	PARALLEL H_{01}	COINCIDENT H_{02}	EQUAL H_{03}	BARTLETT STATISTIC
ABL	PRO-SWAT	2.82	0.02	2.07	4.34
	SS-PIR	2.11	0.35	8.17	8.51
	SS-TI(A)	3.84	3.02	3.31	6.38
	SS-TI(B)	3.84	3.02	3.31	6.38
	SS-TI(C)	0.68	1.98	13.17	9.32
	SS-TI(D)	2.11	0.35	8.17	8.51
	PS-PIR	1.23	0.55	7.08	5.18
	PS-STR	2.17	0.20	7.37	9.14
TF/TA	PRO-SWAT	8.07	0.04	0.94	4.10
	SS-PIR	5.50	0.13	1.84	6.61
	SS-TI(A)	9.40	1.84	1.23	6.45
	SS-TI(B)	9.40	1.84	1.23	6.45
	SS-TI(C)	4.22	0.74	6.89	4.38
	SS-TI(D)	1.31	0.19	9.02	6.55
	PS-PIR	5.83	0.76	4.08	6.48
	PS-STR	5.50	0.13	1.84	6.61
TTA	PRO-SWAT	3.66	0.14	2.45	7.49
	SS-PIR	1.62	0.04	6.89	3.65
	SS-TI(A)	3.80	2.46	2.41	5.36
	SS-TI(B)	3.87	3.15	2.29	5.51
	SS-TI(C)	1.43	4.10	8.48	7.62
	SS-TI(D)	1.43	4.10	8.48	7.62
	PS-PIR	1.62	0.04	6.89	3.65
	PS-STR	1.62	0.04	6.89	3.65
CRITICAL VALUE		9.02	4.84	4.10	12.59

interrupt predictors (SS-TI(A) and SS-TI(B)) for the TF/TA configuration. This result is consistent with the results shown in Table 10, Multivariate Comparison of Means, which also shows these predictors to produce results different than the SWAT measurements at the .0006 level of significance.

For the remaining predictors, the hypotheses of parallel and coincident profiles could not be rejected for the 1986 PRO-SWAT data at $\alpha = 0.05$. This result is apparently contradictory to the results obtained from the multivariate comparison of means, Table 10. That table also showed that the PRO-SWAT, SS-TI(D), and PS-STR predictors were significantly different at an $\alpha = 0.05$. Once again, the inconsistency between these tables should be attributed to differences in the amount of data available for each test. The multivariate comparison of means had more data available and was more discriminating.

The profile analysis of the 1986 PRO-SWAT data also showed that the hypothesis of equal workload levels (H_{03}) was not rejected in 9 of 22 cases considered. This result does not include the SS-TI(A) and SS-TI(B) predictors in the TF/TA configuration since they had already been rejected by the parallel profile hypothesis. Recall that profile analysis is a stagewise succession of tests that determine if multivariate means are equal. Failure of the first stage automatically causes failure of subsequent

stages because each test is conditional on passing the previous test. The fact that 9 of 22 cases were identified as having equal levels of workload is alarming since it is known that the workload at each of these levels was, in fact, different. This indicates that, while the hypotheses of being parallel and coincident could not be rejected, the 1986 PRO-SWAT data was, in some cases, relatively flat over the three flight phases. This can be seen graphically in Figure 9.

Sensitivity of Results

The final segment of this chapter looks at the sensitivity of results to some of the assumptions made in conducting this research. Three basic assumptions are discussed. The first of these relates to the definition of a task interruption, as described by the three task interrupt predictors. The second assumption tested is that of ignoring a significant difference of workload experts' estimate of the transformation of simulation output results to SWAT scores. The third assumption tested is the decision to require non-preempting tasks to queue for service if the service time degradation factor exceeds an arbitrary value of 1.0. This assumption applies only to the parallel processing model.

Task Interruption Definition

This research considered the concept of task interruption in the serial processing model as a surrogate for the Time Load dimension of the SWAT methodology. Four different definitions of task interruption were provided and measured. Table 4 defined each of these predictors. Predictors A and B were similar in that a task interruption occurred when a task was preempted by another. Predictors C and D recognized a task interruption when a new task arrived and the pilot was already occupied with another, regardless of whether a preemption occurred. Predictors A and C counted subsequent arrivals of preempted tasks as additional arrivals, while predictors B and D did not.

From Table 6 it is evident that there is little difference between simulation output for predictors A and B. The same results can be drawn from Table 6 about the difference between C and D. This suggests that counting or not counting the subsequent arrival of preempted tasks had little effect on the predictors. However, there does appear to be significant differences between predictors A and C as shown by Table 6. A similar observation can be made about predictors B and D. In both cases, counting preemptions as task interruptions produced significantly lower estimates of the task interruption rate than did counting arrivals of new tasks while another task was

already being worked. This is logical and intuitively appealing.

The obvious question is which of these two options provides the more accurate prediction. Using the multivariate comparison of means technique, as presented in Table 10, significant differences are shown for the 1986 PRO-SWAT data. Predictors A and B show the most significant differences from the SWAT measurements and strongly suggest that using the notion of task preemption as a definition of a task interruption is inappropriate. Predictor D shows non-significant differences (at the 5% level) from the SWAT measurement data. Predictor C shows significant differences at the 5% level. This result suggests that counting task arrivals while another task is being worked is a better definition of task interruption. However, this result is mixed and perhaps the better predictor is achieved when Predictor D is used. That is, count task arrivals when another task is being worked as an interrupt but do not count subsequent arrivals of preempted tasks as new arrivals.

The 1982 PRO-SWAT data provides very little evidence about the definition of task interruptions as shown in Table 10. Since none of these predictors are rejected and all statistics have about the same value, little can be said about the predictors.

The profile analysis of the 1986 PRO-SWAT data, as shown in Table 12, partially confirms the results of the previous two paragraphs. For the TF/TA configuration, Predictors A and B are shown to produce profiles non-parallel to the SWAT measurement data. The results for Predictors C and D were mixed in this table, although both were not rejected by either the parallel or coincident hypothesis test.

The 1982 PRO-SWAT data, as shown in Table 11, did not reject any of the predictors. In fact, it provided only mixed results regarding the relative accuracy of the four predictor definitions.

Workload Expert's Transformation

As described earlier in this chapter, a transformation was developed to convert simulation output to SWAT 1-2-3 ratings. As was noted, a significant difference in the expert's estimate of the dividing line between LOW and MEDIUM levels of workload, as estimated by Pilot Idle Time, was ignored. However, had the experts' opinion been used, only two transformations would have changed. These transformations are for the single server model, Pilot Idle Time predictor, Penetration flight phase, and for the TF/TA and TTA cockpit configurations. In both cases, a LOW Time Load workload estimate was changed to a MEDIUM estimate. All other predictor transformations remained unchanged.

The effect of these changes was measured by reaccomplishing both the multivariate comparison of means and the profile analysis. The results of the former method are shown in Table 13. Although the numbers change for the 1982 PRO-SWAT data, the conclusion is the same. However, for the 1986 PRO-SWAT estimates, using the experts' transformation leads to a significant difference for this predictor.

Table 13 Transformation Sensitivity, Multivariate Comparison of Means (Predictor = SS-PIR)

Transformation	PRO-SWAT (1982)		PRO-SWAT (1986)	
	F	P > F	F	P > F
Original	0.32	0.81	2.03	0.13
Expert	0.64	0.60	4.09	0.01

Table 14 shows the result of using the expert's transformation for the profile analysis. With the expert's transformation, the parallel profile hypothesis is rejected at the 0.05 level for the 1986 TF/TA data. Once again, this is for the Pilot Idle Time predictor. This is consistent with the result of the multivariate comparison of means findings, just discussed, and shown in Table 13. In general, this method is not sensitive to not using the experts' transformation. However, it is apparent that use of this transformation did cause the rejection of a

Table 14 Transformation Sensitivity, Profile Analysis (Predictor = SS-PIK)

Transformation	Method/ Config	Parallel H_{01}	Coincident H_{02}	Equal H_{03}	Bartlett Statistic
Original	82/TF/TA	1.99	0.79	8.71	3.75
	82/TTA	0.08	0.24	8.66	1.26
	86/TF/TA	5.50	0.13	1.84	6.61
	86/TTA	1.62	0.04	6.89	3.65
Expert	82/TF/TA	2.15	0.43	7.67	3.73
	82/TTA	0.20	0.001	7.02	1.06
	86/TF/TA	9.40	0.01	1.23	4.52
	86/TTA	3.88	0.68	2.28	7.02

predictor which had not been rejected by the original transformation.

Service Time Degradation Factor

The parallel processing model allows simultaneous processing of tasks up to a limit. However, as each new task is added to any tasks already being worked, the remaining service times of all involved tasks were increased. The amount of this increase was determined by computing a degradation factor based on North's conflict matrix (23). This conflict matrix was based on the number of resource demands caused by the tasks involved. When the degradation factor exceeded an arbitrary limit of 1.0, the new task was placed in a queue to wait for service if it could not preempt another task. The 1.0 limit represented a doubling of service times, so it was arbitrarily selected

as the upper limit of the degradation factor.

To examine the sensitivity of this arbitrary decision, the degradation limit was varied and the parallel processing model was rerun for all three flight configurations. The results are shown in Table 15. Several conclusions are obvious from this table. First, pilot idle time ratio is relatively insensitive to changes in the degradation limit over all three cockpit configurations and three flight phases. This is not surprising. Changing the degradation limit does not change the number of tasks that arrive, only the number that can be processed simultaneously. Decreasing the degradation limit places more tasks in the queue for later processing, which would tend to decrease pilot idle time. However, this is compensated for by the lower service times for those tasks actually being worked. Hence, pilot idle time ratio is relatively insensitive to changes in the degradation limit.

Table 15 shows that the simultaneous task rate is more sensitive to changes in the degradation limit. This is not surprising because, as the degradation limit is decreased, fewer tasks are worked simultaneously. Therefore, the simultaneous task rate will decrease as the degradation limit decreases. Except for minor variations due to random effects, this trend was shown consistently over all cockpit configurations and flight phases.

TABLE 15 Service Time Degradation Limit Sensitivity

CONFIG-URATION	DEG LIMIT	IDLE TIME RATIO			SIMULTANEOUS TASK RATE		
		PEN	ACQ	WPN	PEN	ACQ	WPN
ABL	0.6	0.55	0.25	0.11	0.19	0.23	0.37
	0.8	0.57	0.32	0.15	0.26	0.42	0.59
	1.0	0.57	0.32	0.18	0.35	0.55	0.76
	1.1	0.55	0.30	0.14	0.38	0.58	0.84
	1.3	0.55	0.30	0.14	0.38	0.58	0.84
TF/TA	0.6	0.68	0.40	0.32	0.18	0.16	0.39
	0.8	0.68	0.42	0.33	0.21	0.27	0.49
	1.0	0.68	0.45	0.33	0.26	0.41	0.56
	1.1	0.68	0.45	0.31	0.26	0.41	0.58
	1.3	0.68	0.44	0.31	0.25	0.41	0.58
TTA	0.6	0.66	0.39	0.30	0.19	0.16	0.36
	0.8	0.66	0.41	0.32	0.20	0.30	0.48
	1.0	0.66	0.44	0.32	0.24	0.40	0.58
	1.1	0.66	0.45	0.28	0.25	0.42	0.60
	1.3	0.66	0.45	0.28	0.25	0.42	0.60

The service time degradation limits shown in Table 15 were also translated to SWAT workload scores for both the 1982 and 1986 prediction sets. These predictions were then compared to the SWAT workload measurements. Using the multivariate comparison of means, the results of this comparison are shown in Table 16. Note that degradation limits above 1.0 are not reported since both predictors produced results equal to those of a degradation factor of 1.0 for all values greater than 1.0. This is not surprising since North's conflict matrix (22), as shown in Table 2, produces very few degradation factors greater than 1.0 and none greater than 1.1.

The results shown in Table 16 indicate that, for the simultaneous task rate predictor, a degradation factor of

1.0 produced the most accurate predictions. For the pilot idle time predictor and 1982 PRO-SWAT data, there was no significant change in results over the range of degradation factors. However, for the 1986 PRO-SWAT data, workload predictions more closely matched measurements as the degradation limit decreased. This was exactly opposite to the trend for the Simultaneous Task Rate predictor discussed previously.

Table 16 Degradation Limit Sensitivity, Multivariate Comparison of Means

PREDICTOR	DEG. LIMIT	1982		1986	
		F	P > F	F	P > F
PS-PIR	0.6	0.49	0.70	1.50	0.23
	0.8	0.49	0.70	2.40	0.09
	1.0	0.44	0.73	2.34	0.09
PS-STR	0.6	1.29	0.30	3.77	0.02
	0.8	0.44	0.72	2.47	0.08
	1.0	0.32	0.81	2.21	0.11

When degradation limit sensitivity is assessed using profile analysis, the results are inconclusive. Tables 17 and 18 show these results and there appears to be no consistent trend over both 1982 and 1986 PRO-SWAT data sets. Once again, the test statistics displayed under the PARALLEL and COINCIDENT columns are the ones most critical to determining how well SWAT predictions match measurements.

Table 17 Degradation Limit Sensitivity, Profile Analysis 1982 Data

CONFIG-URATION	PREDIC-TOR	DEG LIMIT	PARALLEL H_{01}	COIN. H_{02}	EQUAL H_{03}	BARTLETT STATISTIC
ABL	PS-PIR	0.6	1.77	0.02	8.67	10.67
		0.8	1.77	0.02	8.67	10.67
		1.0	1.77	0.02	8.67	10.67
	PS-STR	0.6	3.88	0.01	8.75	11.05
		0.8	1.77	0.02	8.67	10.67
		1.0	4.63	0.58	10.46	11.33
TF/TA	PS-PIR	0.6	0.65	1.29	11.99	4.05
		0.8	0.65	1.29	11.99	4.05
		1.0	0.65	1.29	11.99	4.05
	PS-STR	0.6	0.65	1.29	11.99	4.05
		0.8	1.99	0.79	8.71	3.75
		1.0	1.99	0.79	8.71	3.75
TTA	PS-PIR	0.6	0.14	1.26	7.01	1.21
		0.8	0.14	1.26	7.01	1.21
		1.0	0.08	0.24	8.66	1.26
	PS-STR	0.6	0.83	1.15	9.19	1.27
		0.8	0.83	1.15	9.19	1.27
		1.0	0.08	0.24	8.66	1.26
CRITICAL VALUE			10.83	5.32	4.74	12.59

Table 18 Degradation Limit Sensitivity, Profile Analysis 1986 Data

CONFIG-URATION	PREDIC-TOR	DEG LIMIT	PARALLEL H_{01}	COIN. H_{02}	EQUAL H_{03}	BARTLETT STATISTIC
ABL	PS-PIR	0.6	0.54	0.003	11.03	5.50
		0.8	1.32	0.60	7.06	5.34
		1.0	1.23	0.55	7.08	5.18
	PS-STR	0.6	2.33	1.66	4.98	5.86
		0.8	1.32	0.59	7.07	5.30
		1.0	2.17	0.20	7.37	9.14
TF/TA	PS-PIR	0.6	5.83	0.76	4.08	6.48
		0.8	5.83	0.76	4.08	6.48
		1.0	5.83	0.76	4.08	6.48
	PS-STR	0.6	5.83	0.76	4.08	6.48
		0.8	5.50	0.13	1.84	6.61
		1.0	5.50	0.13	1.84	6.61
TTA	PS-PIR	0.6	1.62	0.04	6.89	3.65
		0.8	1.62	0.04	6.89	3.65
		1.0	1.62	0.04	6.89	3.65
	PS-STR	0.6	2.00	0.50	4.82	5.37
		0.8	2.00	0.50	4.82	5.37
		1.0	1.62	0.04	6.89	3.65
CRITICAL VALUE			9.02	4.84	4.10	12.59

Summary

This chapter presented the results of this research, comparing two predictor data sets to SWAT measurements and modifying these predictor sets to develop additional predictors. These modifications were based on the output from computer simulation models. The process which transformed the simulation output to SWAT scores was also described.

Using two means of evaluation, a multivariate comparison of means and profile analysis, all predictors were compared to SWAT measurements. Some predictors were found to improve the unmodified predictors and others did not. In general, the predictor values matched SWAT measurements reasonably well.

Based on the multivariate comparison of means, the most accurate predictors are Pilot Idle Time, using the single server model, and Simultaneous Task Rate, using the parallel processing model. Almost as accurate is Pilot Idle Time, using the parallel processing model. Although the results are not as obvious, profile analysis generally identifies the same three predictors as producing the most accurate predictions over all cockpit configurations and both predictor data sets. Since both the single server model and the parallel processing model produced a predictor with approximately equal accuracy, it is not possible to state that one model is more accurate than

another. It does appear that the parallel processing model may be more consistent, since both parallel processing predictors are relatively accurate. The single server model produced mixed results, a relatively accurate Pilot Idle Rate predictor and an inaccurate Task Interruption Rate predictor.

The sensitivity of several assumptions was also investigated. First, several different definitions for task interruptions were tested. It was found that defining a task interruption as the arrival of a new task which occurred while the pilot was busy produced the most accurate prediction for this predictor. The second assumption tested was the validity of ignoring a different estimate of idle time categories posed by workload experts. It was shown that using the experts' estimate actually worsened the prediction.

The third assumption tested was the sensitivity to an arbitrary service time degradation limit of 1.0 in the parallel processing model. It was shown that the Pilot Idle Time predictor was insensitive to this, but the Simultaneous Task Rate was somewhat sensitive to this.

The next chapter reviews these results and draws conclusions about this research. Following these, some recommendations are made for additional work which will improve the methods described.

Chapter VI

CONCLUSIONS AND RECOMMENDATIONS

Introduction

The first chapter stated that the intent of this research was to develop and validate a model which predicts pilot workload. Chapters II through IV discussed the development of this model and Chapter V presented the model's predictions. This chapter will summarize these results and draw conclusions. These conclusions will be about the modeling process as a whole, as well as about specific predictors and assumptions of the model. Finally, some recommendations for further study will be presented.

Conclusions

In general, it appears that the model developed in this research predicts workload reasonably well. However, some of the assumptions and techniques used produced more accurate results than other options. Furthermore, all predictions were measured against a single set of measurements. Before full acceptance of this method, predictions should also be compared against other sets of workload measurement data.

Before presenting specific conclusions, a brief discussion of the basic PRO-SWAT workload estimates is in order. Two sets of workload predictions were used in this research: one set developed in 1982 and one set in 1986. Although every attempt was made to derive accurate predictions, it appears that those developed in 1986 were not as accurate as the 1982 set. There are several reasons for this. First, the administrators of the 1982 experiment were experienced in the SWAT measurement technique. This was not true for the 1986 predictions. The 1986 predictions were administered by the author on his first and only experience with developing SWAT predictions. In both cases, however, the same materials were used by the pilots and the same instructions given to the pilots.

The second major reason for differences in the two sets of predictions concerns the pilots used in each exercise. The pilots making predictions in 1982 were qualified F-15 pilots who were asked to estimate workload in an advanced version of the F-15. Furthermore, these pilots were active duty Air Force pilots who were assigned to participate in this exercise for several weeks. Therefore, the pilots were able to dedicate time and attention to accomplishing this. The predictions developed in 1986 were accomplished by Air National Guard pilots, qualified in the A-7 aircraft. They did not fly, nor had

they ever flown the F-15. These pilots volunteered to participate in the study, but did so in their spare time. In other words, they were not freed of other duties to work on this study. The A-7 pilots made all workload estimates on their own, without any means of monitoring their effort or any chance of asking questions.

The accuracy of the results could have been predicted. The 1982 PRO-SWAT estimates were more accurate than the 1986 estimates. However, from the perspective of this research, that may have been beneficial. One of the purposes of this research was to explore various modeling options and techniques. By starting with two different data sets, it was possible to examine these modeling options when used with both a more accurate and a less accurate set of data. This resulted in a richer set of data comparisons and more interesting results.

Workload Predictors

Several workload predictors were developed by combining output from the computer simulation models and the basic PRO-SWAT predictions. Using the multivariate comparison of means, as shown in Table 10, it appears that the most accurate predictions resulted when Pilot Idle Time (single server model) was used as the Time Load dimension surrogate. The Pilot Idle Time predictor (parallel server

model) also produced reasonably accurate predictions, but not as accurate as the single server model. The predictions derived by using the Simultaneous Task Rate predictor were also as accurate as those produced by Pilot Idle Time (single server model). For the 1986 data, three predictors (SS-TI(A), SS-TI(B), and SS-TI(C)) produced results that were significantly different from the SWAT data at the 5% level. These three predictors also produced less accurate predictions for the 1982 data. The last predictor, SS-TI(D), yielded non-significant differences, but less accurate predictions than the basic PRO-SWAT predictor for both the 1982 and 1986 data.

When the predictors are evaluated using profile analysis, as shown in Tables 11 and 12, some of the same conclusions can be drawn. For the 1982 data, none of the predictors could be rejected. Some predictors yielded greater accuracy than others, but the results were mixed when viewed over three cockpit configurations. Statements about the accuracy of predictors were also difficult because the parallel and coincident hypothesis tests may show different trends for a given predictor. The 1986 data did have two predictors (SS-TI(A) and SS-TI(B)) rejected by the parallel hypothesis test for the TF/TA configuration. This was consistent with the multivariate comparison of means results previously discussed. For the 1986 data,

both predictors using pilot idle time generally show more accurate results in terms of being parallel and coincident. Again, this is consistent with earlier conclusions.

Serial vs Parallel Models

A fundamental issue addressed in this research is the relative merits of a serial processing model versus a parallel processing model. A serial model is simpler, easier to develop and run, and conceptually easier to understand. Yet the serial model ignores evidence of actual parallel processing. If one is only interested in the most accurate model, which of these two models is better?

Perhaps the best way to answer that is by comparing the accuracy of the two Pilot Idle Time predictors (SS-PIR and PS-PIR). Both of these have been identified as providing accurate predictions and they were computed using identical methods in each model. Therefore, it seems logical that differences in accuracy of these predictors should reflect on the models themselves, rather than other factors.

The results of the multivariate comparison of means, as repeated in Table 19, show the serial model predictor produced essentially the same results for the 1982 data and less accurate results for the 1986 data. The

Table 19 Multivariate Comparison of Means, Idle Time Predictor Only

Predictor	PRO-SWAT (1982) F	P > F	PRO-SWAT (1986) F	P > F
PRO-SWAT	0.33	0.81	1.26	0.29
SS-PIR	0.32	0.81	2.03	0.13
PS-PIR	0.44	0.73	2.34	0.09

parallel model produced slightly worse results for the 1982 data and worse results for the 1986 data. Ideally, the better model should have produced predictions at least as accurate as the basic PRO-SWAT data. One would expect that the 1986 PRO-SWAT predictions should be improved by either pilot idle time predictor since the 1986 predictions were not as accurate as the 1982 predictions. In fact, the 1982 predictions were changed only a small amount by incorporating the pilot idle time surrogate predictor. If a choice is to be made, Table 19 suggests that the serial processing model, using pilot idle time as a surrogate, produces slightly more accurate predictions than the parallel processing model. However, it does not appear that this increase in accuracy is statistically significant.

Results from the profile analysis show no trends regarding parallel versus serial models. Table 20 repeats pertinent profile analysis data from Tables 11 and 12.

Table 20 Profile Analysis, Idle Time Predictor

DATA SET	CONFIG-URATION	PREDIC-TOR	PARALLEL H_{01}	COINCIDENT H_{02}	EQUAL H_{03}
1982	ABL	PRO-SWAT	2.35	0.20	8.06
		SS-PIR	4.63	0.58	10.46
		PS-PIR	1.77	0.02	8.67
	TF/TA	PRO-SWAT	3.84	0.42	7.10
		SS-PIR	1.99	0.79	8.71
		PS-PIR	0.65	1.29	11.29
	TTA	PRO-SWAT	0.11	0.01	9.42
		SS-PIR	0.08	0.24	8.66
		PS-PIR	0.08	0.24	8.66
1986	ABL	PRO-SWAT	2.82	0.02	2.07
		SS-PIR	2.11	0.35	8.17
		PS-PIR	1.23	0.55	7.08
	TF/TA	PRO-SWAT	8.07	0.04	0.94
		SS-PIR	5.50	0.13	1.84
		PS-PIR	5.83	0.76	4.08
	TTA	PRO-SWAT	3.66	0.14	2.45
		SS-PIR	1.62	0.04	6.89
		PS-PIR	1.62	0.04	6.89

Examination of this data shows no evidence that either model is more accurate over both data sets and all three flight configurations in terms of being both parallel and coincident.

The general conclusion to be drawn from the two analysis methods just described is that the serial processing model is perhaps, slightly more accurate. However, this should be viewed with caution because the results were not totally conclusive and probably not

statistically significant. The multivariate comparison of means suggested that the serial processing model was slightly more accurate. However, the profile analysis shows mixed results and no clear trend. Based on this evidence, no strong statement can be made suggesting that either model consistently produces more accurate results.

Expert versus Non-expert Pilot Subjects

Two predictor data sets were used in this research. The 1982 set was based on workload estimates made by F-15 pilots predicting workload in an advanced version of the F-15. The 1986 set of predictions were made by A-7 pilots estimating workload for the same advanced F-15 cockpit. It is reasonable to question the wisdom of using A-7 pilots for this task since they were less than experts in the F-15.

To address this, several issues must be raised. The mission scenarios evaluated in the RAM/ACE experiments were all air-to-ground missions. As the F-15 currently exists, it is exclusively an air-to-air mission aircraft. This implies that all F-15 pilots used in the 1982 experiment were trained in the air-to-air mission, not the air-to-ground mission being evaluated. While the F-15 pilots may have been knowledgeable in basic F-15 systems, they were not especially knowledgeable in the air-to-ground mission.

On the other hand, the A-7 pilots used in the 1986 RAM/ACE experiment replication were skilled in the air-to-ground mission, since that is the primary mission of the A-7 aircraft. As stated previously, the A-7 pilots were not skilled in the F-15 aircraft.

It is not at all clear which factor was more important: knowledge of the F-15 or knowledge of the air-to-ground mission. One might expect the F-15 pilots to provide more accurate predictions, but there is no way to prove this assumption in this research. Not only were there experience differences in the pilots used in both experiments, but there were also differences in the way the experiments were administered. Much tighter experimental control was possible in the 1982 experiment, as described in Chapter III, than in the 1986 replication. Lack of tight control in this replication may have contributed to the relative inaccuracy of the 1986 data. However, it is not possible to separate inaccuracies resulting from lack of experimental control and those resulting from lack of F-15 expertise.

In summary, the pilots used to develop each predictor data set were experts, but in different facets of the mission scenario being evaluated. Ideally, expert pilots in both facets should have been used, but this was not possible. It is not clear that F-15 experience was more

important than air-to-ground experience since different levels of experimental control were used in each case. However, it is clear that the 1982 predictions were more accurate than the 1986 predictions and this did have an impact on the accuracy of all derived predictors.

Sensitivity Issues

Chapter V examined several assumptions and evaluated the sensitivity of the models to these assumptions. The first considered four alternative definitions for task interruption rate. Both the multivariate comparison of means and the profile analysis recognized problems with predictors A and B. This suggests that task preemption is not an adequate definition for a task interruption. Of the two remaining predictors, both based on the arrival of a new task when at least one other task is already being worked, only one (D) showed non-significant differences from the SWAT data. This occurred when this latter definition of task interrupts was used and subsequent arrivals of preempted tasks are not counted as new arrivals. It should be pointed out, however, that all predictors based on task interrupt rate yielded predictions less accurate than the basic PRO-SWAT data or the predictors based on pilot idle time or simultaneous task rate.

Another assumption examined was the decision to ignore workload experts' significantly different estimate of one of the transformation limits. Tables 13 and 14 show that using the experts' transformation yielded less accurate results than those provided by the original transformation. Given the inherent limits of this transformation, it is acceptable to ignore this expert opinion and accept the combined inputs of all subjects as defining the transformation most accurately.

The third assumption examined in Chapter V was the arbitrary decision to use 1.0 as the degradation limit for increasing service times. This only applied to the parallel processing model when a new task was being considered for parallel processing. The sensitivity of this assumption was examined and it was found that the simultaneous task rate predictor (PS-STR) was sensitive to this limit, while the pilot idle time predictor was relatively insensitive. When predictor accuracy was determined for several levels of the degradation limit, results were mixed using both profile analysis and multivariate comparison of means, as shown in Tables 16, 17, and 18.

Perhaps the definition of simultaneous task rate as used in this research is the reason for these mixed results. This rate was computed as the percent of time a

pilot was occupied with two or more tasks simultaneously. As defined, it ignored differences between working two tasks simultaneously and three tasks simultaneously. One would expect higher workload for the latter case than for the former case. This definition will not recognize this. In a sense, the simultaneous task rate definition is the complement to pilot idle rate, if working on a single task is viewed as being "idle". This suggests that this definition of simultaneous task rate was, in a sense, measuring almost the same underlying concept as pilot idle rate. Since pilot idle rate was found to be a relatively accurate predictor, changing the definition slightly will most likely result in a similar level of accuracy. This conclusion is consistent with the results.

General Conclusion

The previous sections discussed the accuracy of this model when predicting pilot workload in a specific situation. The evidence cited generally supports the validity of this modeling approach. Of all the predictors evaluated, it appears that the Pilot Idle Time predictors and the Simultaneous Task Rate predictor produce the most accurate results. As described in the previous section, simultaneous task rate may be measuring the same underlying concept as pilot idle rate. Therefore it is not surprising

that these three predictors should produce similar results. As good as these results were, they should be viewed only as preliminary indicators of the technique's validity. Further research should be conducted to increase confidence in this modeling methodology.

Recommendations

At the completion of this research, several suggestions can be made regarding ways in which this modeling methodology can be improved or further investigated. The first and most obvious would be to reaccomplish the predictions against another set of workload measurements. By comparing predictor accuracy against an independent set of measurements, it would be possible to further validate the model. If this is done, care should be taken to insure that a large number of data samples are taken. This should provide more discrimination between predictors and greater confidence in the results.

The transformation developed in this research to convert simulation output to workload measurements was adequate, but could be improved. As mentioned previously, the survey used transformed in the reverse direction and assumed that this transformation was reversible. Since the transformation was based on a survey, it is subject to all the problems of a survey. For example, statements and

questions can be misunderstood, wrong answers recorded, or unintentional biases included. Furthermore, opinions recorded as numerical ratings may not correspond to "true" results. A possible improvement would be to conduct an experiment in a flight simulator. SWAT workload measurements could be taken and some method developed to assess pilot idle time, task interruption rate, and simultaneous task rate. With these data points recorded over a large number of pilots, a more direct transformation could be made.

The degradation factors used in the parallel processing model apparently worked well enough. The factors were determined by computing the number of resource overlaps using the multiple resource model. This is a modeling simplification because it only counts overlaps and ignores the types of resource overlaps occurring. A possible model refinement would be to consider overlap types and combinations of resources demanded. This may result in more accurate predictions.

It may also be possible to convert directly from the resources used, as defined by Wickens' multiple resource model (44, 46, and 47), to SWAT scores without going through a surrogate predictor and transformation. If the multiple resource model is a reasonably accurate representation of the fundamental capacities of a pilot and

the demands on those capacities, it should also recognize varying levels of pilot workload. Workload is a construct that describes the demand on fundamental pilot capacities. If the multiple resource model reflects these capacities, it should also reflect demand on these capacities, or workload. To derive SWAT workload measures, it would be necessary to convert task demands on the 2 x 3 multiple resource model matrix to SWAT scores. If the assumption is made that the multiple resource model only reflects the Time Load dimension of the SWAT methodology, a method to convert resource demands to LOW, MEDIUM, and HIGH ratings must be developed. Perhaps this could be accomplished through another flight simulator experiment.

The final recommendation concerns the possibility of using the existing predictors in another way. Instead of evaluating each predictor individually, it may be possible to find some combination of predictors which produces more accurate predictions. The SWAT methodology assumes that workload is characterized by pilot idle rate, task interruption rate, and simultaneous task rate. Perhaps some combination of these three predictors could provide more accurate predictions.

Contributions

At the conclusion of this research, it is possible to identify specific contributions as follows:

- Two simulation models have been developed which emulate a pilot working on certain tasks in a cockpit. From these models it is possible to determine surrogate workload predictors. The validity of these models as predictors of the Time Load dimension of the SWAT methodology has been supported.

- Various definitions of Time Load surrogate predictors have been investigated and the most promising have been identified.

- The parallel processing model developed incorporates Wickens' multiple resource model to determine pilot resources available to accomplish a task. This has not been done before and only recently was suggested by Wickens' (48).

- Proper use of this workload model could provide a tool for accurately estimating pilot workload. A potential exists to extend this to other domains. Furthermore, the model could be used to cross-check or validate other workload prediction techniques.

- Areas for possible future research have been identified and suggestions made toward initiating that research.

APPENDIX A

SWAT CARDS AND SORTING INSTRUCTIONS

This appendix contains a copy of the SWAT Card Sort Instructions given to each subject before the SWAT card sort was begun. This card sort was completed prior to making any SWAT estimates and was used to establish a unique, linear scale for each subject. The exact procedures used are described in Chapter III.

The instructions begin on the next page and these are followed by copies of the SWAT cards themselves.

SWAT CARD SORT INSTRUCTIONS FOR SUBJECTS

During the course of this experiment, you will be asked to quantify the mental workload required to complete the tasks you will be performing. Mental Workload refers to how hard you work to accomplish some task, groups of tasks, or an entire job. The workload imposed on you at any one time consists of a combination of various dimensions which contribute to the subjective feeling of workload. The Subjective Workload Assessment Technique (SWAT) defines these dimensions as (1) Time Load, (2) Mental Effort Load, and (3) Psychological Stress Load.

For the purpose of SWAT, the three dimensions have been assigned three levels. The dimensions and their levels are described in the following paragraphs.

Time Load

Time Load refers to the fraction of the total time that you are busy. When time load is low, sufficient time is available to complete all of your mental work with some time to spare. As time load increases, spare time drops out and some aspects of performance overlap and interrupt one another. This overlap and interruption can come from performing more than one task or from different aspects of performing the same task. At higher levels of time load, several aspects of performance often occur simultaneously, you are busy, and interruptions are very frequent.

Time load may be rated on the three point scale below.

1. Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

2. Occasionally have spare time. Interruptions or overlap among activities are very frequent.

3. Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Mental Effort Load

As described above, time load refers to the amount of time one has available to perform a task or tasks. In contrast, mental effort load is an index of the amount of attention or mental effort required by a task regardless of the number of tasks to be performed or any time limitations. When mental effort load is low, the concentration and attention required by a task is minimal and performance is nearly automatic. As the demand for mental effort increases, due to task complexity or the amount of information which must be dealt with in order to perform adequately, the degree of concentration and attention required increases. High mental effort load demands total attention or concentration due to task complexity or the amount of information that must be processed.

Mental effort load may be rated using the three point scale below.

1. Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

2. Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

Psychological Stress Load

Stress load refers to the contribution to total workload of any conditions that produce anxiety, frustration, or confusion while performing a task or tasks. At low levels of stress, one feels relatively relaxed. As stress increases, confusion, anxiety, or frustration increase and greater concentration and determination are required to maintain control of the situation.

Psychological stress load may be rated on the three point scale below.

1. Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

2. Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

3. High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Each of the three dimensions just described contribute to workload during performance of a task or group of tasks. Note that although all three factors may be correlated, they need not be. For example, one can have many tasks to perform in the time available (high time load) but the tasks may require little concentration (low mental effort). Likewise, one can be anxious and frustrated (high stress) and have plenty of spare time between relatively simple tasks. Since the three dimensions contributing to workload are not necessarily correlated, please treat each dimension individually and give independent assessments of the time load, mental effort load, and stress load that you experience in performing the following tasks.

One of the most important features of SWAT is its unique scoring system. SWAT uses a procedure to find separate scoring weights for each level of the dimension. Then, it determines a distinctive workload scale for each person. The scaling system greatly improves the precision of the workload ratings you will give later.

In order to develop your individual scale, we need information from you regarding the amount of workload you feel is imposed by various combinations of the dimensions described above. We get this information by having you rank order the workload associated with each of the combinations.

In order for you to rank order the workload for each of the combinations, you have been given a set of 27 cards with the combinations from each of the three dimensions. Each card contains a different combination of levels of Time Load, Mental Effort, and Psychological Stress. Your job is to sort the cards so that they are rank ordered according to the level of workload represented on each.

In completing your card sorts, please consider the workload imposed on a person by the combination represented in each card. Arrange the cards from the lowest workload condition through the highest condition. You may use any strategy you choose in rank ordering the cards. One strategy that proves useful is to arrange the cards into a number of preliminary stacks representing "High", "Moderate", and "Low" workload. Individual cards can be exchanged between stacks, if necessary, and then rank ordered within stacks. Stacks can then be recombined and checked to be sure that they represent your ranking of lowest to highest workload. However, the choice of strategy is up to you and you should choose the one that

works best for you.

There is no "school solution" to this problem. There is no correct order. The correct order is what, in your judgment, best describes the progression of workload from lowest to highest for a general case rather than any specific event. That judgment differs for each of us. The letters you see on the back of the cards are to allow us to arrange the cards in a previously randomized sequence so that everyone gets the same order. If you examine your deck you will see the order on the back runs from A through Z and then ZZ.

Please remember:

1. The card sort is being done so a workload scale may be developed for you. This scale will have a distinct workload value for each possible combination of Time Load, Mental Effort Load, and Psychological Stress Load.

Time	Effort	Stress	Workload Scale
1	1	1	0
.	.	.	.
.	.	.	.
.	.	.	.
3	3	3	100

2. When performing the card sorts, use the descriptors printed on the cards. Please remember <u>not</u> to

sort the cards based on a particular task (such as flying an airplane). Sort the cards according to your general view of workload and how important you consider the dimensions of time, mental effort, and psychological stress load to be.

3. During the actual experiment, you will read a description of the desired tasks. Then, you will provide a SWAT score based on your opinion of the mental workload required to perform the task. This SWAT score will consist of one number from each of the three dimensions. For example, a possible SWAT score is 1 - 2 - 2. This represents a 1 for Time Load, a 2 for Mental Effort Load, and a 2 for Psychological Stress Load.

4. We are not asking for your preference concerning Time, Mental Effort, and Psychological Stress Load. Some people may prefer to be "busy" rather than "idle" in either the Time Load, Mental Effort Load or Psychological Stress Load dimension. We are not concerned with this preference. We need information on how the three dimensions and the three levels of each one will affect the level of workload as you see it. You may prefer a 2 - 2 - 2 situation instead of a 1 - 1 - 1 situation. But, you should still realize that the 1 - 1 - 1 situation imposes less workload on you and leaves a greater reserve capacity.

From this point until you have completed the sorting

will probably take 30 minutes to an hour. Please feel free to ask questions at any time. Thank you for your cooperation.

Card A

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card B

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card C

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Card D

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Card E

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card F

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card G

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card H

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card I

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Card J

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card K

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card L

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card M

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Card N

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card O

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Card P

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card Q

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card R

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Card S

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card T

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.

Card U

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card V

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card W

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Card X

Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.

Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card Y

Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.

Card Z

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

Card ZZ

Occasionally have spare time. Interruptions or overlap among activities are very frequent.

Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

APPENDIX B

SWAT CARD SORT RESULTS

A total of thirteen subjects participated in the workload prediction experiment conducted by the author. All subjects were experienced Air Force pilots. The first eight flew the single-seat A-7 aircraft and the remaining five flew the two-seat F-4 aircraft. After receiving initial instructions, each pilot was asked to review the 27 cards shown in Appendix A and arrange them in ascending order from lowest workload to highest workload. The results of this sorting process are shown in Table 21. This table shows the ordered position for each card, from 1 to 27, by subject, for each possible combination of Time Load, Mental Effort Load, and Psychological Stress Load.

This data was then processed by a conjoint measurement, computer-implemented algorithm to translate the raw data to an ordinal scale. This algorithm also identified the dominant group to which each subject belonged. That is, experience has shown that individual subjects typically view one dimension (time, mental effort, or psychological stress) as dominant. The algorithm determines this and computes a scale for each dominant group as well as a scale for the entire group. These scales are shown in Tables 22 through 25. These scales are used to convey subsequent low, medium, and high ratings (i.e., 1, 2, 3) in the three SWAT dimensions to an ordinal scale. These linearized scores are then used as estimates

of pilot workload.

Table 21 CARD SORT DATA

(T,M,P)	ORIGINAL ORDER	SUBJECT 1	2	3	4	5	6	7	8	9	10	11	12	13
(1,1,1)	N	1	1	1	1	1	1	1	1	1	1	1	1	1
(1,1,2)	B	5	3	4	5	3	16	7	11	2	7	4	4	3
(1,1,3)	W	3	4	5	11	6	15	16	16	6	13	11	8	18
(1,2,1)	F	12	2	8	3	2	12	2	4	5	2	3	3	4
(1,2,2)	J	14	5	11	9	7	10	9	13	8	15	13	13	13
(1,2,3)	C	15	6	21	18	12	23	18	20	12	20	14	15	21
(1,3,1)	X	8	7	16	6	5	5	5	7	10	5	8	6	20
(1,3,2)	S	17	8	18	15	11	21	11	14	18	12	15	14	16
(1,3,3)	M	16	9	22	24	18	25	20	24	20	22	23	20	24
(2,1,1)	U	2	10	2	2	4	2	3	2	3	3	2	2	2
(2,1,3)	G	18	12	6	8	9	7	8	9	4	11	7	9	9
(2,1,3)	Z	4	11	7	16	16	14	17	17	7	18	12	17	6
(2,2,1)	V	6	13	9	7	8	8	4	5	9	4	5	5	10
(2,2,2)	Q	9	14	12	13	17	11	10	15	11	17	10	16	11
(2,2,3)	ZZ	7	15	15	23	23	19	19	22	15	23	22	19	8
(2,3,1)	K	19	16	19	12	13	4	6	10	17	8	9	10	19
(2,3,2)	E	20	17	23	21	21	24	12	23	21	16	21	21	14
(2,3,3)	R	22	18	24	25	26	26	21	25	22	25	24	22	26
(3,1,1)	H	10	19	3	4	10	3	13	3	13	6	6	7	5
(3,1,2)	P	11	21	10	14	15	17	22	12	14	14	18	12	12
(3,1,3)	D	25	20	14	19	20	18	25	21	16	21	20	23	17
(3,2,1)	Y	13	22	13	10	14	9	14	6	19	10	16	11	7
(3,2,2)	A	23	24	17	20	22	13	23	19	23	19	19	24	22
(3,2,3)	O	26	23	25	26	24	22	26	26	24	26	26	26	15
(3,3,1)	L	21	25	20	17	19	6	15	8	25	9	17	18	23
(3,3,2)	T	24	26	26	22	25	20	24	18	26	24	25	25	25
(3,3,3)	I	27	27	27	27	27	27	27	27	27	27	27	27	27

(T,M,P): T - Time Load Rating
M - Mental Effort Load Rating
P - Psychological Stress Load Rating

Table 22 SWAT WORKLOAD RATINGS, Time Load Emphasis Group

LEVEL (T,M,P)	WORKLOAD
(1,1,1)	0.0
(1,1,2)	14.2
(1,1,3)	20.1
(1,2,1)	15.7
(1,2,2)	29.9
(1,2,3)	35.7
(1,3,1)	26.2
(1,3,2)	40.4
(1,3,3)	46.3
(2,1,1)	30.0
(2,1,2)	44.2
(2,1,3)	50.1
(2,2,1)	45.7
(2,2,2)	59.9
(2,2,3)	65.7
(2,3,1)	56.2
(2,3,2)	70.4
(2,3,3)	76.3
(3,1,1)	53.7
(3,1,2)	67.9
(3,1,3)	73.8
(3,2,1)	69.4
(3,2,2)	83.6
(3,2,3)	89.5
(3,3,1)	79.9
(3,3,2)	94.1
(3,3,3)	100.0

(T,M,P): T - Time Load Rating
M - Mental Effort Load Rating
P - Psychological Stress Load Rating

Table 23 SWAT WORKLOAD RATINGS, Mental Effort Load Emphasis Group

LEVEL (T,M,P)	WORKLOAD
(1,1,1)	0.0
(1,1,2)	14.6
(1,1,3)	19.5
(1,2,1)	24.7
(1,2,2)	39.3
(1,2,3)	44.2
(1,3,1)	49.9
(1,3,2)	64.5
(1,3,3)	69.4
(2,1,1)	1.4
(2,1,2)	16.0
(2,1,3)	20.9
(2,2,1)	26.2
(2,2,2)	40.8
(2,2,3)	45.7
(2,3,1)	51.3
(2,3,2)	65.9
(2,3,3)	70.8
(3,1,1)	30.6
(3,1,2)	45.2
(3,1,3)	50.1
(3,2,1)	55.4
(3,2,2)	70.0
(3,2,3)	74.8
(3,3,1)	80.5
(3,3,2)	95.1
(3,3,3)	100.0

(T,M,P): T - Time Load Rating
M - Mental Effort Load Rating
P - Psychological Stress Load Rating

Table 24 SWAT WORKLOAD RATINGS, Psychological Stress Load Emphasis Group

LEVEL (T,M,P)	WORKLOAD
(1,1,1)	0.0
(1,1,2)	28.8
(1,1,3)	48.5
(1,2,1)	13.0
(1,2,2)	41.8
(1,2,3)	61.5
(1,3,1)	23.9
(1,3,2)	52.6
(1,3,3)	72.4
(2,1,1)	10.4
(2,1,2)	39.2
(2,1,3)	59.0
(2,2,1)	23.5
(2,2,2)	52.2
(2,2,3)	72.0
(2,3,1)	34.3
(2,3,2)	63.1
(2,3,3)	82.8
(3,1,1)	27.6
(3,1,2)	56.4
(3,1,3)	76.1
(3,2,1)	40.6
(3,2,2)	69.4
(3,2,3)	89.2
(3,3,1)	51.5
(3,3,2)	80.2
(3,3,3)	100.0

(T,M,P): T - Time Load Rating
M - Mental Effort Load Rating
P - Psychological Stress Load Rating

Table 25 SWAT WORKLOAD RATINGS, Composite Group Solution

LEVEL (T,M,P)	WORKLOAD
(1,1,1)	0.0
(1,1,2)	23.7
(1,1,3)	37.5
(1,2,1)	16.2
(1,2,2)	39.9
(1,2,3)	53.7
(1,3,1)	33.3
(1,3,2)	57.0
(1,3,3)	70.8
(2,1,1)	9.8
(2,1,2)	33.5
(2,1,3)	47.3
(2,2,1)	26.1
(2,2,2)	49.8
(2,2,3)	63.5
(2,3,1)	43.2
(2,3,2)	66.9
(2,3,3)	80.6
(3,1,1)	29.2
(3,1,2)	52.9
(3,1,3)	66.7
(3,2,1)	45.4
(3,2,2)	69.1
(3,2,3)	82.9
(3,3,1)	62.5
(3,3,2)	86.2
(3,3,3)	100.0

(T,M,P): T - Time Load Rating
M - Mental Effort Load Rating
P - Psychological Stress Load Rating

APPENDIX C

WORKLOAD SURVEY

This appendix includes the workload prediction survey instructions and cockpit equipment description for the RAM/ACE experiment and its replication. This appendix was not created by the author, but was modified slightly and used in the RAM/ACE experiment replication. It is included here to illustrate the degree of detail available in the experiment and to provide a reference since this information is not otherwise readily available.

PILOT WORKLOAD PREDICTIONS

Instructions and Description

LTC Tom Schuppe

Department of Industrial and Systems Engineering

The Ohio State University

1971 Neil Avenue

Columbus, Ohio 43210

Introduction

This exercise is being conducted to determine a pilot's ability to predict his workload in a proposed aircraft system. You have been asked to participate in this study so that we can use your unique experience and insight in the air-to-ground combat environment. You will be provided a detailed description of an aircraft, its subsystems, and a mission scenario. Using this information and your own flying experience, you will be asked to predict pilot workload. The information you provide will form an essential part of an Air Force-sponsored research effort. The goal of this effort is to develop a technique to accurately estimate pilot workload in a new aircraft system prior to the development of hardware. This will provide two distinct benefits: more effective systems will be built and development costs will be reduced.

The aircraft considered in this exercise is an advanced version of the F-15 C/D. It will have several enhancements designed to improve its performance as an air-to-ground weapon delivery system. This configuration will be designated as an Advanced Baseline (ABL). After reading a detailed description, you will be asked to provide three sets of workload estimates: one for the ABL and two other sets for more enhanced versions. The first of these two enhanced versions, using an automatic Terrain Following/ Terrain Avoidance (TF/TA) subsystem, will be described and

you will again estimate pilot workload. Your final workload estimates will be for the second enhanced version, using an automatic Terrain/Threat Avoidance (TTA) subsystem added to the ABL. Consider each of these two enhancements to be added separately and independently to the ABL.

This document contains a combination of descriptive material and directions to lead you through this exercise. It should take approximately 90 minutes to complete this exercise. If possible, try to do the entire exercise in one sitting. This should minimize your time commitment and also increase the consistency of your answers. Everything you are being asked to do should be explained in detail. However, if you have any questions, please contact me at any time. (LTC Tom Schuppe, 513-879-0616 or 614-292-4567)

Workload

Pilot workload is an important consideration in the design of any new aircraft system. Several methods have been developed to measure pilot workload. One of these is known as SWAT (Subjective Workload Assessment Technique). SWAT relies on a pilot's ability to subjectively assess the workload he experienced in a given situation after it has occurred. It has been widely tested, validated, and accepted as a meaningful measure of pilot workload. In the past it has been used exclusively with a pilot in a flight simulator or aircraft to measure his perceived workload.

In this exercise, we are now attempting to use it to predict workload rather than measure it.

SWAT assumes there are three independent dimensions to workload: Time Load, Mental Effort Load, and Psychological Stress Load. Each of these dimensions may assume one of three levels: low, medium, or high. These ratings are entirely subjective and reflect each rater's judgment concerning pilot workload. A complete description of the ratings in each dimension is found on the next page.

You will be asked to provide ratings in each dimension for various mission and equipment combinations. One word of caution, there are no "right" answers. Each pilot accomplishing this task may rate workload differently. Final workload predictions are based on a combination of these ratings and your previous ranking of 27 cards containing workload descriptions. Therefore, it is not important how your answers might compare with someone else's answers. However, it is important that you are consistent in rating workload and ranking the 27 card descriptions of workload.

If you normally fly a single-seat aircraft, your workload estimates should be made on that basis. Likewise, if you fly an aircraft with a second crewmember, your workload estimates should reflect only your own workload as you now accomplish it. This may require you to ignore some tasks described as pilot tasks since your second crewmember

normally accomplishes these.

Mission Description

The mission used in all of these evaluations will be a battlefield interdiction (BI) mission. We are mainly concerned about the Penetration, Target Acquisition, and Weapon Delivery segments, as shown in Figure 11. The Penetration segment is flown at 200 feet AGL, at 600 knots and lasts approximately 5 minutes. It includes penetration of the FEBA and its associated threats. The next segment is Target Acquisition and consists of a 4 G pullup so that sensors may locate and designate the target. This segment is Weapon Delivery and involves all pilot actions required to obtain an accurate weapon release. Consider this segment to last 30 seconds. Once again, hostile threats must be considered in this segment.

Assume that the entire mission is conducted during the day and the weather is 3000 feet overcast with 3 miles visibility. The terrain for your mission is gently rolling with maximum hilltops 500 feet above your nominal flight path. Your target is a tank column on a road and the weapon you will use is an IIR Maverick. You have recent information on your target's position and are certain of its location within one-half mile. Also assume that your

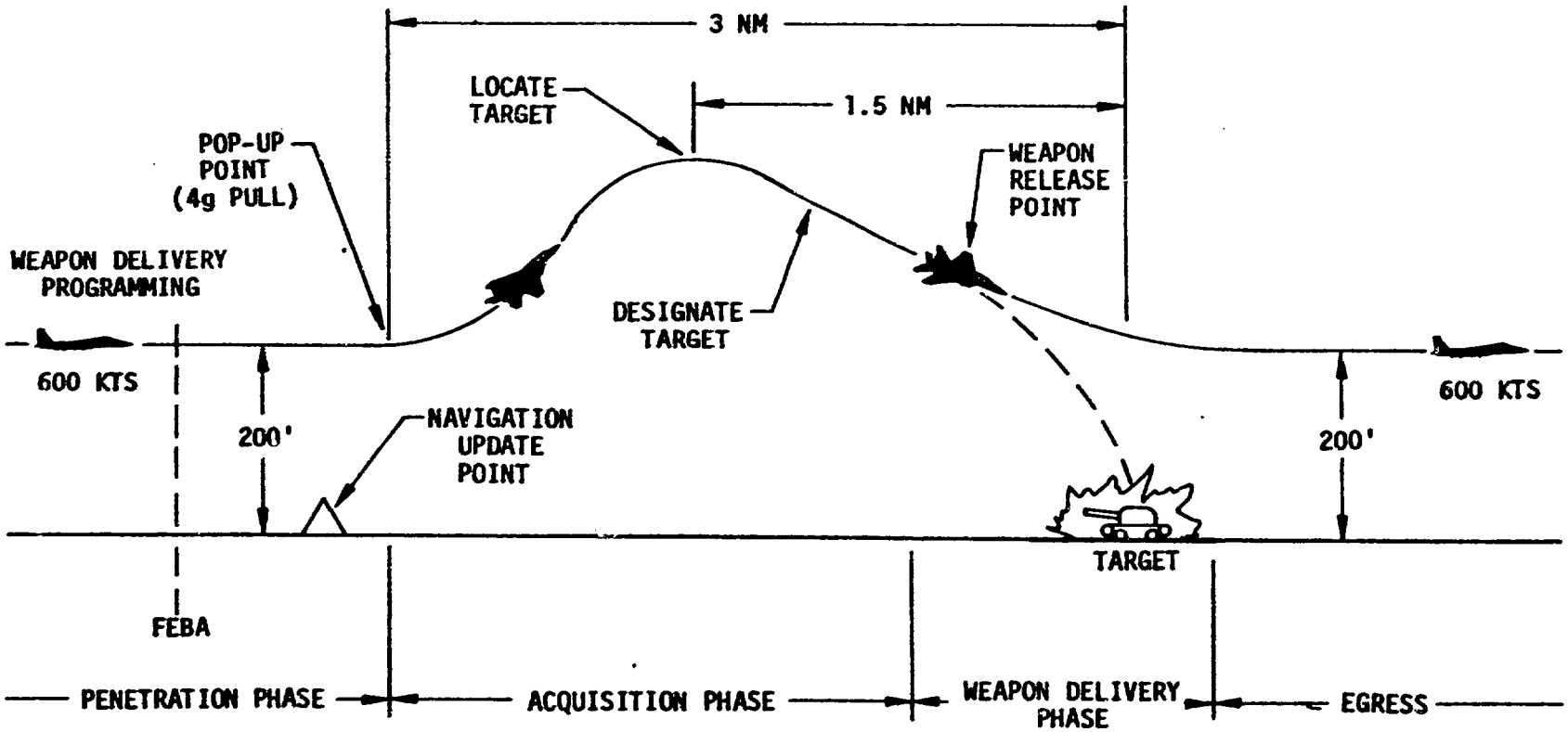


Figure 11 Generic Air-To-Ground Weapon Delivery Profile

aircraft is fully operational at the start of the penetration segment and that your fuel is adequate to complete the mission.

SWAT RATING VALUE DESCRIPTIONS

Rating values and descriptions of each are provided below for the three workload factors we are interested in for this study. Please refer to these descriptions whenever necessary during any enhancement rating.

TIME LOAD (TL)

VALUE	DESCRIPTION
1.	Often have spare time. Interruptions or overlap among activities occur infrequently or not at all.
2.	Occasionally have spare time. Interruptions or overlap among activities are very frequent.
3.	Almost never have spare time. Interruptions or overlap among activities are very frequent, or occur all the time.

MENTAL EFFORT LOAD (ML)

VALUE	DESCRIPTION
1.	Very little conscious mental effort or concentration required. Activity is almost automatic, requiring little or no attention.
2.	Moderate conscious mental effort or concentration required. Complexity of activity is moderately high due to

uncertainty, unpredictability, or unfamiliarity. Considerable attention required.

3. Extensive mental effort and concentration are necessary. Very complex activity requiring total attention.

PSYCHOLOGICAL STRESS LOAD (SL)

VALUE	DESCRIPTION
1.	Little confusion, risk, frustration, or anxiety exists and can be easily accommodated.
2.	Moderate stress due to confusion, frustration, or anxiety noticeably adds to workload. Significant compensation is required to maintain adequate performance.
3.	High to very intense stress due to confusion, frustration, or anxiety. High to extreme determination and self-control required.

ABL Instructions

A detailed description of the F-15 Advanced Baseline (ABL) is presented in the next section. Read this, keeping in mind the mission scenario just presented, and then make your best estimate of pilot workload. Estimates will be required for each segment (Penetration, Target Acquisition, and Weapon Delivery) in each dimension (Time Load, Mental Effort Load, and Psychological Stress Load).

ADVANCED BASELINE

To bring the RAM/ACE baseline F-15C/D up to a configuration consistent with its expected capabilities for the study time period, an advanced baseline (ABL) fighter/attack system was created. The ABL utilizes the same basic airframe and engine capabilities demonstrated by the F-15C/D with the exception of its avionics suite which will include the following:

a) A "glass" cockpit to include multipurpose displays, a Head-Up Display (HUD), and an up-front control panel.

b) A more sophisticated radar system which includes Synthetic Aperture Radar (SAR).

c) Manual Terrain Following (TF).

d) Carriage capability for the Imaging Infrared (IIR) Maverick and WASP anti-armor munition.

All of these capabilities being added do not affect the basic air-to-air capabilities of the existing F-15C/D. However, since the thrust of RAM/ACE is air-to-ground tactical attack, the air-to-air capabilities will not be exercised during these simulations.

The system enhancements derived during this study will be added to the ABL configuration and evaluated in this simulation.

Aircraft Parameters

The Advanced Baseline (ABL) is based on the F-15D airframe with many avionics and crew station changes. The aircraft is powered by two advanced turbofan engines, has a high mounted sweptback wing and two vertical stabilizers. The airframe parameters are:

- o Wingspan - 43 feet
- o Length - 64 feet
- o Height - top of vertical tail - 19 feet
  top of closed canopy - 12 feet
- o Distance between main landing gear - 9 feet
- o Takeoff gross weight - full internal fuel, armament: 70,000 pounds

Avionics/Sensor Description

The Advanced Baseline aircraft is configured with an avionics system which includes a large memory, high speed digital computer, redundant multiplexed digital data buses, multifunction programmable displays and display processors, a wide field-of-view HUD and an Up Front Control (UFC) Panel. The onboard sensors include a high resolution Forward Looking Infrared (FLIR) sensor. The operation of the multifunction displays and up front control are described later.

The following list provides some of the important features of the ABL avionics systems.

o Fire Control System - Consists of the radar system, the FLIR, the lead computing gyro and the armament control system. This provides an effective all-weather air-to-surface weapon delivery.

o Threat Warning System - Provides full spherical coverage to warn of air-to-air and surface-to-surface threats.

o Navigation System - Consists of very accurate Inertial Navigation System (INS), with accuracies approaching .5 NM per hour, and a Global Positioning System. The two systems provide virtually error free navigation.

o Communication, RF Navigation and Identification - Provides for voice and data communications and identification of self and other aircraft, as well as compatibility with existing navigation facilities.

o Digital Computation - Consists of a large memory, high speed digital computer and associated redundant digital multiplexed data buses.

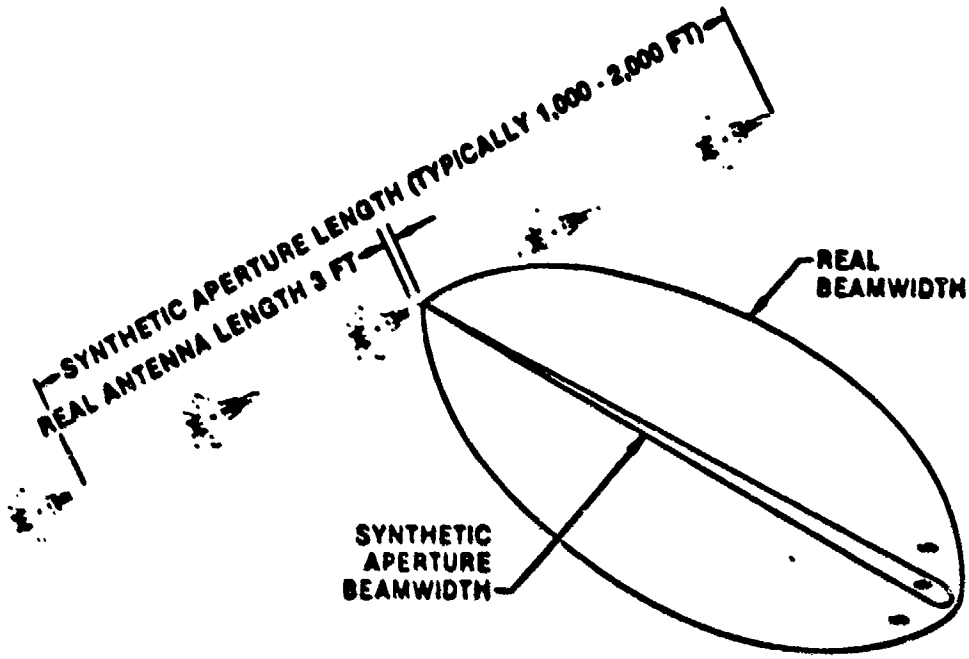
o Controls and Displays - Consists of multiple programmable CRT displays in both front and rear cockpits, multiple display generators, a wide field of view HUD (front only), and up front controls.

o Flight Controls - Quadruple redundant fail operate, fail safe flight control system.

ADVANCED BASELINE RADAR

The resolution and quality of imagery the operator views is primarily determined by the antenna beamwidth; the narrower the beamwidth the better the resolution and image quality. Two factors determine the beamwidth, (1) the size of the radar antenna and (2) the operating frequency. The larger the antenna and/or the higher the frequency, the narrower the beamwidth, and hence the better the resolution. Most contemporary fighter and attack aircraft do not have space available for large antennas, and operating frequencies are determined by other system performance requirements such as missile compatibility, in weather operation, etc.

If the radar antenna were directed to stop scanning and look at a fixed point on the ground, and the target return data sampled and processed as the aircraft moved over the ground (Figure 12) it would in effect synthetically generate an antenna as big as the distance the aircraft traveled during the sampling period. This effect produces a very narrow beamwidth and hence very high resolution and image quality. The high resolution map mode, referred to as synthetic aperture radar, produces near optical quality imagery. Because of the generation techniques employed, i.e., aircraft motion, 2 to 10 seconds (frame time) are generally required to form the map images and squint angles off of ground track are required.



SAR	REAL ANTENNA BEAMWIDTH
• AZIMUTH RESOLUTION DETERMINED BY SYNTHETIC APERTURE LENGTH	• AZIMUTH RESOLUTION DETERMINED BY REAL ANTENNA LENGTH
• SYNTHETIC APERTURE LENGTH ACHIEVED BY COHERENT DIGITAL PROCESSING	• LONGER ANTENNA LENGTH PROVIDES BETTER AZIMUTH RESOLUTION

Figure 12 Synthetic Aperture Radar

Since operation of this mode relies on doppler effect processing, the mode is not operable for targets along the aircraft ground track or so near to it that the frequency shift is too small for processing. In the ABL this unusable portion is approximately +/- 10^0 from ground track as shown in Figure 13.

Forward Looking Infrared Sensor (FLIR) - The FLIR used on the advanced baseline aircraft is a pod mounted sensor with two fields of view, 12^0 x 12^0 wide field of view and 3^0 x 3^0 narrow field of view. It has a field of regard of $+30^0$, -150^0 elevation and $+/-540^0$ roll. The FLIR can be cued to a line of sight as designated by the radar or navigation system, and has an inertial tracking mode.

COCKPIT LAYOUT

The forward and aft cockpits of the ABL have been modified to accommodate added systems and capabilities. The forward crew station incorporates the addition of three Cathode Ray Tubes (CRT) that are Multipurpose Displays (MPD's) with 20 pushbuttons around the periphery. The left and right MPD's are 6" monochromatics and the center is a 5" monochromatic. Any display can be called up on the left and right MPD's and used for systems management. The lower center MPD can be used to display the Electronic Horizontal Situation Indicator (EHSI) and the Head Down Display (HDD).

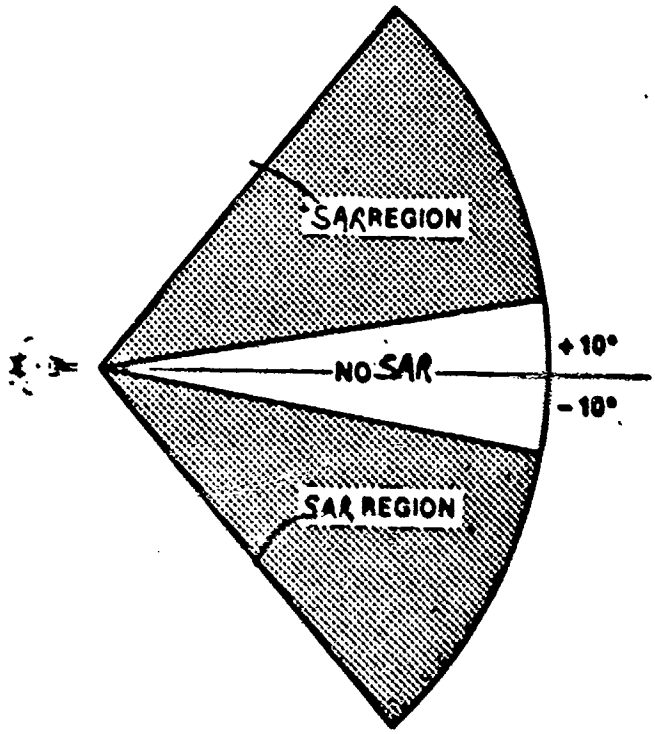


Figure 13 DBS Ground Plan

The forward crew station configuration is shown in Figure 14.

While most of the F-15C/D sensor console control panels are retained, the majority of these panels are backup controls. This is accomplished by extending the capabilities of the hands-on control concept of performing moding and subsystem control utilizing displayed options on the CRT display and selecting these options via display mounted pushbuttons, or by using a cursor controlled from the throttle grips. Cursor control is assigned to a particular display using an added switch on the flight

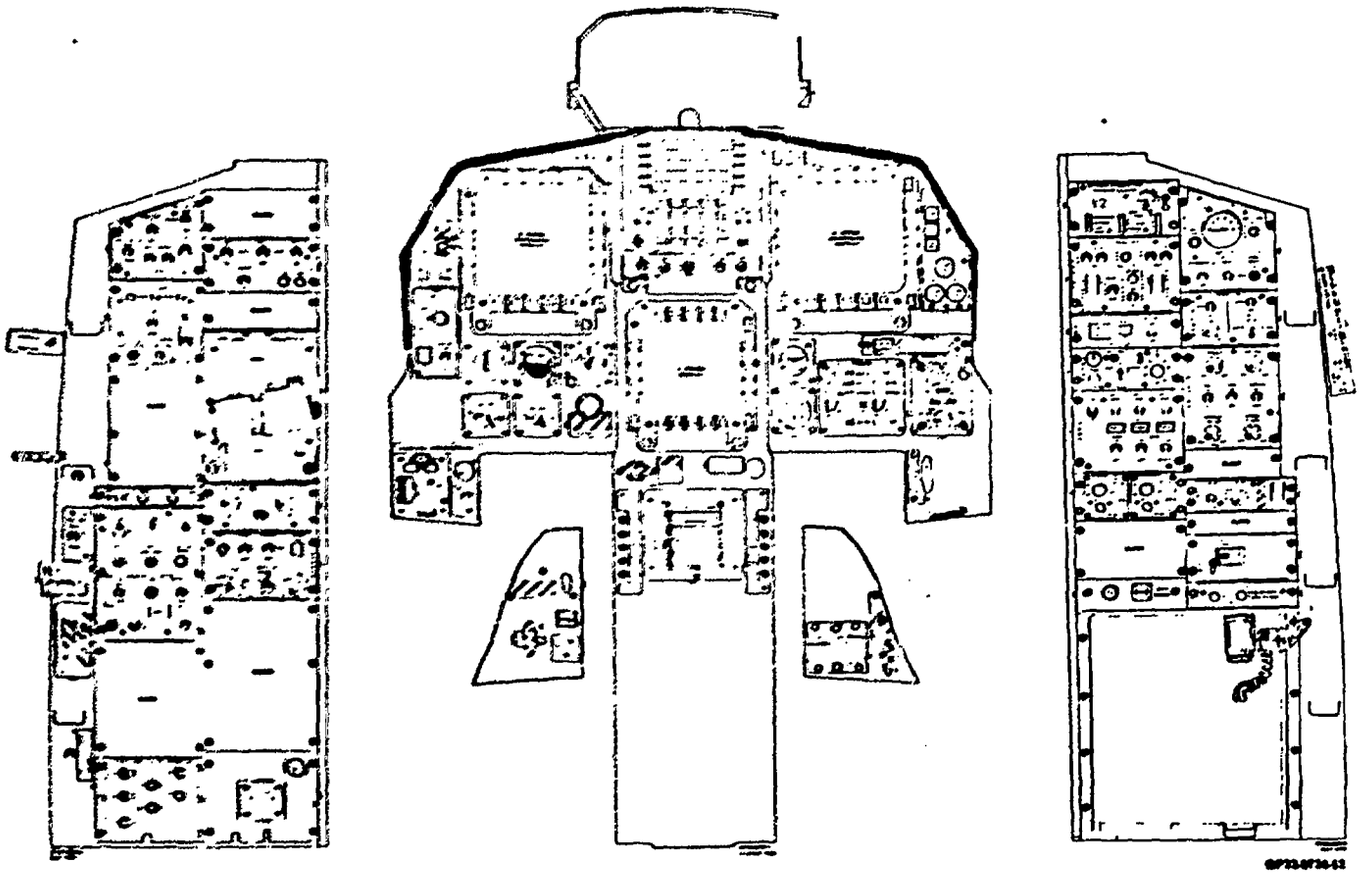


Figure 14 RAM/ACE Advanced Baseline Forward Crew Station

control stick grip. Cursor slewing and option selection is done with the Target Designator Controller (TDC) on the throttle.

The forward and aft crew stations also incorporate an Up-Front Control (UFC) panel. The UFC features a keyboard for data entries associated with communications, navigation, and identification functions on the aircraft. The onboard radios and Identification, Friend or Foe (IFF) functions are also integral to the UFC.

The aft crew station consists of two 6" monochromatic MPD's in the center and two 5" monochromatic MPD's on either end. Display control in the aft crew station is totally independent from that of the front cockpit and vice versa. Two stationary hand controllers located on left and right side consoles give the weapon system officer (WSO) control of all aft seat functions.

Primary subsystem control is via control menus or lists, presented on the MPD's. The WSO can either use associated pushbuttons or displayed cursors, controlled from the hand controls, to select the operating modes for each subsystem. He also has full control of the setup of the four display units. He can quickly change the display of any subsystem from one MPD to another or change which subsystems are being presented. The aft crew station is illustrated in Figure 15.

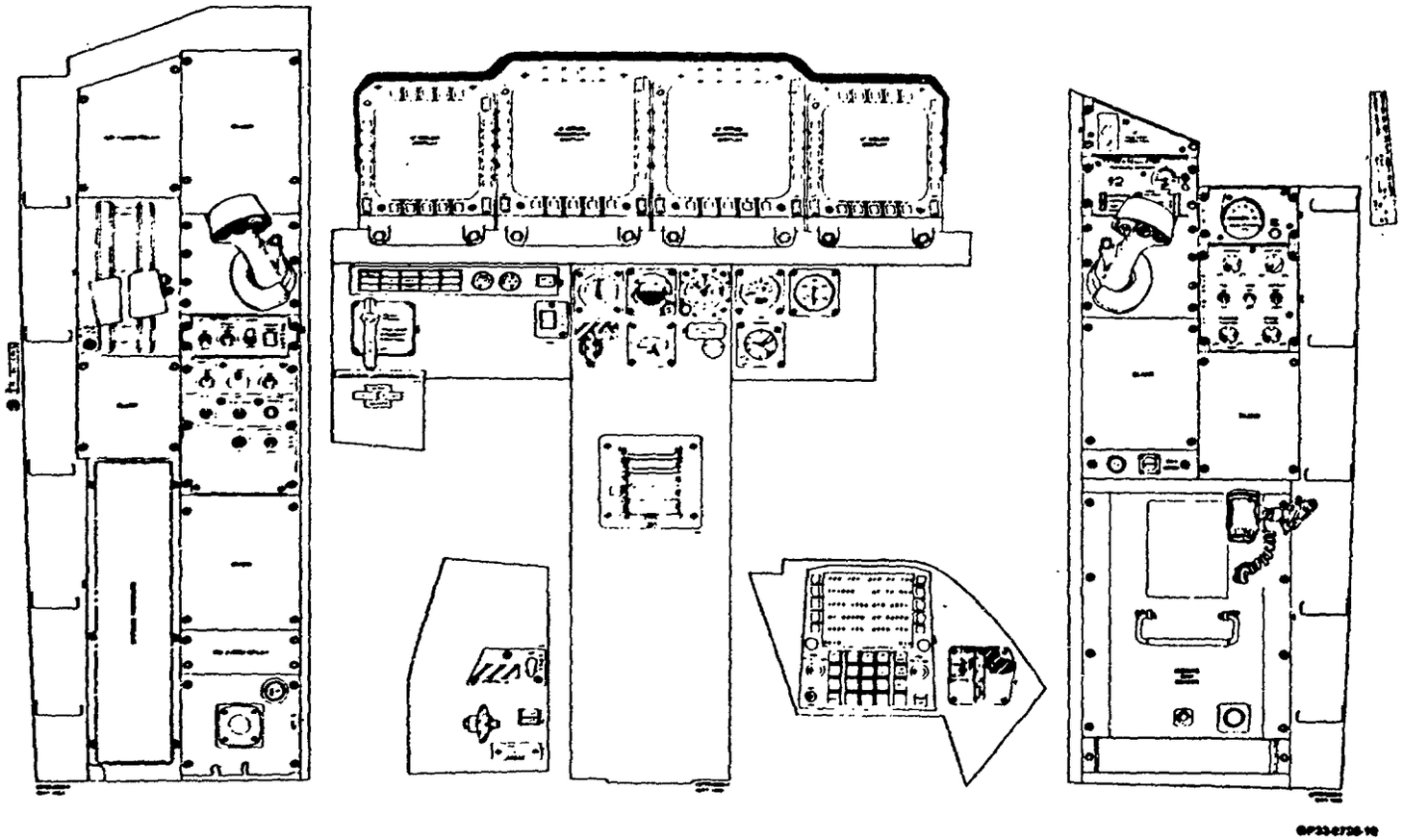


Figure 15 RAM/ACE Advanced Baseline Aft Crew Station

CONTROLS OPERATION

Forward Cockpit Stick and Throttle Functions:

In order to allow rapid weapon system control in time critical situations, the RAM/ACE ABL crew stations were designed with many weapon system control functions on the stick and throttle in the forward crew station and on the two stationary hand controllers in the aft crew station. These functions are outlined below and in Figures 16 through 19.

Stick Functions:

Pickle Button - When Maverick is the selected weapon, each depression releases one AGM-65D Imaging Infrared (IIR) Maverick. When WASP is the selected weapon, holding the pickle button depressed will ripple off WASP missiles until weapon count goes to zero.

TDC Assignment Switch - The TDC assignment switch is a 4-position momentary action, return to center switch. The forward position assigns TDC functions to a HUD cursor for the purpose of visual designations or designation updates. The left position assigns TDC functions to the left MPD and its cursor for the purpose of sensor control and designation. The right position assigns TDC functions to the right MPD and its cursor. The aft position assigns TDC functions to the lower center MPD and its cursor.

Trim Switch - Activates aileron and elevator trim functions.

Maverick/FLIR Switch - This is a three position switch:

Forward - Subsequent depressions alternates FLIR Field-of-View (FOV) between wide and narrow.

Down - Alternates between the FLIR and Maverick display on the same MPD.

Aft - Steps between Maverick Weapon stations in lieu of using the armament control display. When the boresight correlator option is selected on the FLIR display, activation of this switch steps the priority target between those selected by the FLIR.

Undesignate Switch - Activation cancels a previously accomplished designation.

Paddle Switch - Disengages all autopilot and terrain following functions.

Throttle Functions:

UHF Comm Switch - To transmit on UHF1 depress and hold this switch aft.

Speed Brake Switch - Depressing and holding this switch aft extends the speed brake. Depressing and holding this switch forward retracts the speed brake.

Voice Recognition Command (VRC) Switch - Depressing and holding this switch forward keys the voice recognition system enhancement.

Coordinate Transmit Switch - During the multi-ship operations enhancement, activation of this switch

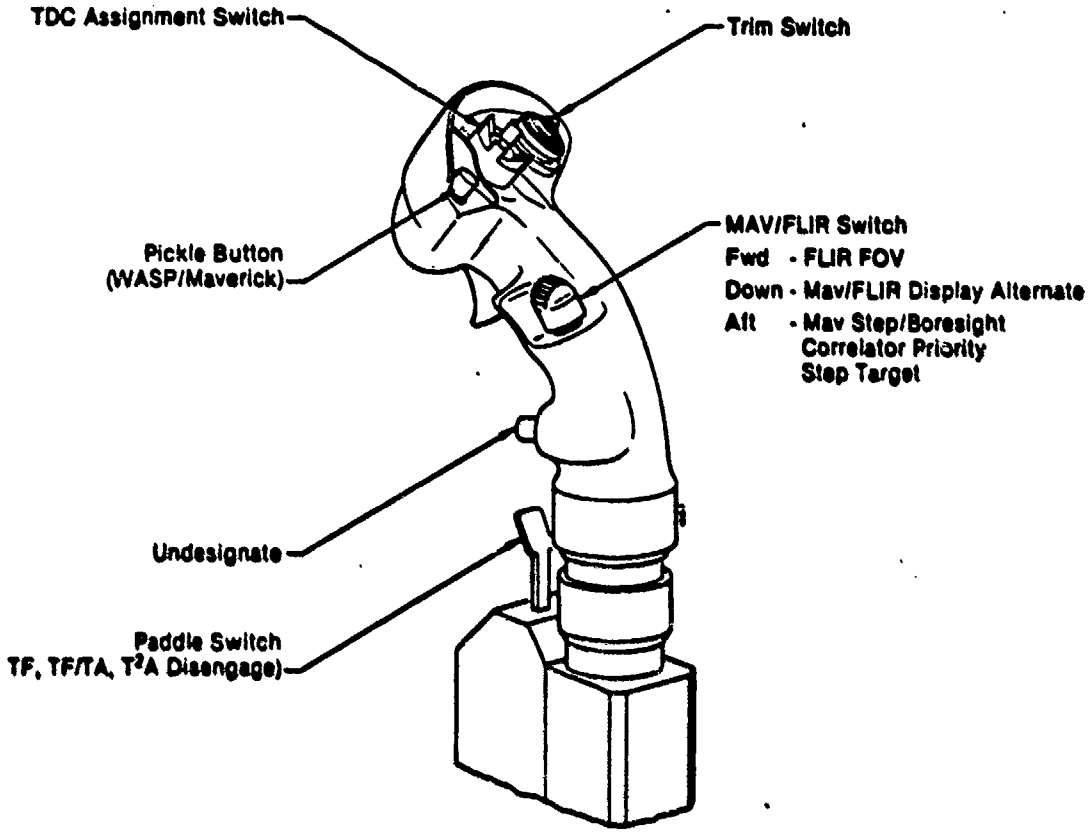


Figure 16 RAM/ACE Forward Crew Stick Functions

transmits target coordinates to the wingman.

Pop-Up Command Switch - Moving the switch up commands the pop-up mode HUD cueing and cancels terrain following HUD commands. Pushing the switch down cancels the pop-up cueing.

Target Designator Controller (TDC) - In the non-depressed (no action) position, the TDC slews display

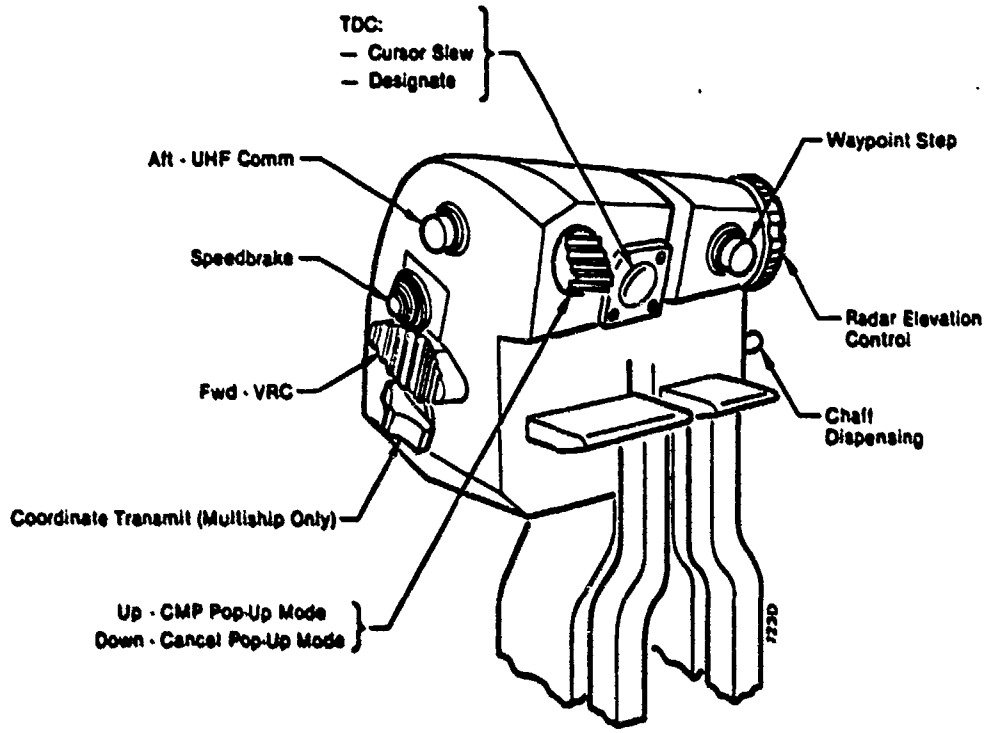


Figure 17 RAM/ACE Forward Crew Station Throttle Functions

cursors, sensors or the Maverick head depending on the TDC assignment. When depressed and released, the TDC commands designation Maverick lock-on, or MPD display option.

Waypoint Step Button - Each depression increments to the next prestored waypoint data for steering information.

Radar Elevation Control - A potentiometer that moves the radar scan in elevation up or down.

Chaff Dispensing Switch - Each activation of the

switch deploys one chaff bundle.

Aft Crew Station Controls

Although the switches used on the hand controllers, Figures 18 and 19, in the aft crew station are different from the front seat, the functions are identical.

The left and right hand controller functions are identical and mirror images of one another. The exception to the rule are the TDC assignment switches. Because there are four MPD's in the aft crew station, the TDC assignment switch on the left hand controller assigns TDC fucntions between the two left MPD's and the TDC assignment switch on the right hand controller assigns TDC functions between the two right MPD's.

The WSO can release weapons from the aft seat using the weapon release button on the stick. The remainder of the stick switches in the aft crew station are non-functional. The UHF comm switch on the aft crew station throttle is also operational. Again, this is the only aft cockpit throttle switch used.

Up-Front Control (UFC) Operation

The UFC used in RAM/ACE is illustrated in Figure 20 along with the top level functions. Four systems are controlled via the UFC. They are Identification Friend or Foe (IFF), waypoint data entry and control, the three terrain following modes, and UHF radios (both numeric and

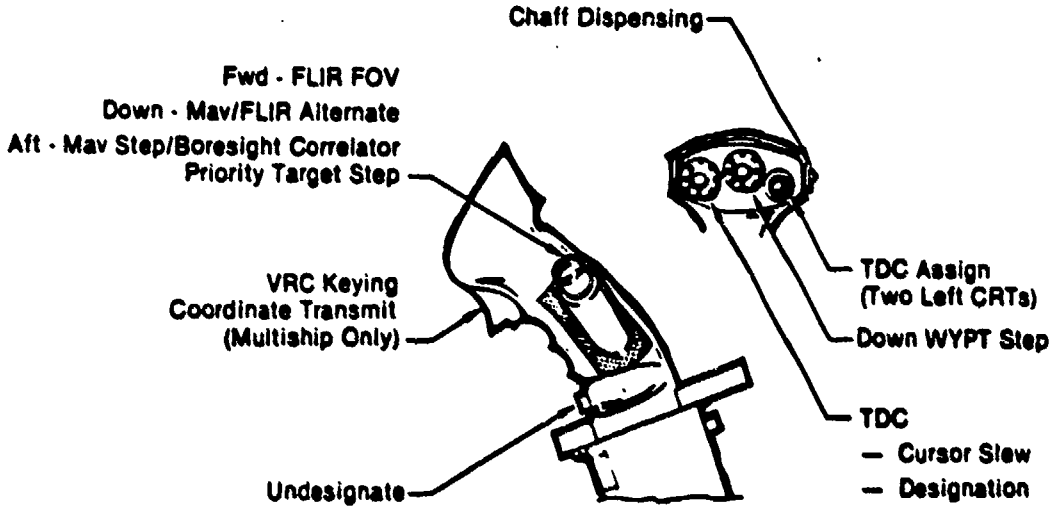


Figure 18 RAM/ACE Aft Crew Station Left Hand Controller Functions

preset channels). The center numeric keyboard is operational along with:

CLR	- Clear scratchpad data
MENU	- Return to top level UFC format from sublevel format
SHF	- Allows use of the N, S, E, W and decimal point functions on the UFC keyboard
N, S	- Latitude coordinate prefixes
E, W	- Longitude coordinate prefixes
.	- Decimal point for frequency entries

One UHF radio is available in the ABL: UHF 1 (left side). Ten (10) preset radio channels (1-10) are available for the radio. To change a UHF frequency, rotate the radio

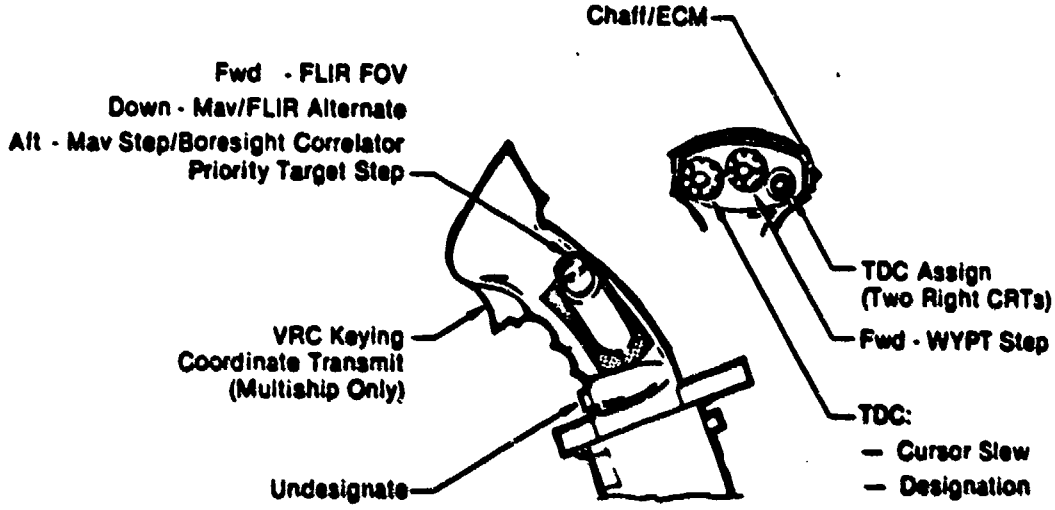


Figure 19 RAM/ACE Aft Crew Station Right Hand Controller Functions

channel select knob to the desired channel. Enter the frequency of choice in the scratchpad (225.000 to 399.975). Once the frequency is correct, depress "ENTER". That frequency is now entered into that preset channel.

When the IFF pushbutton is selected on the top level UFC format, the IFF sublevel appears as shown in Figure 21. The IFF modes available in this study are modes "3", "4", and "C". Mode 3 is automatically enabled in the scratchpad for data entry. To change the mode 3 squawk, simply type in the four number code and depress enter. The new code will appear in the mode 3 row. Mode 4 has two allowable codes: 4A and 4B. Each time the associated option select switch is depressed, the mode 4 code scrolls

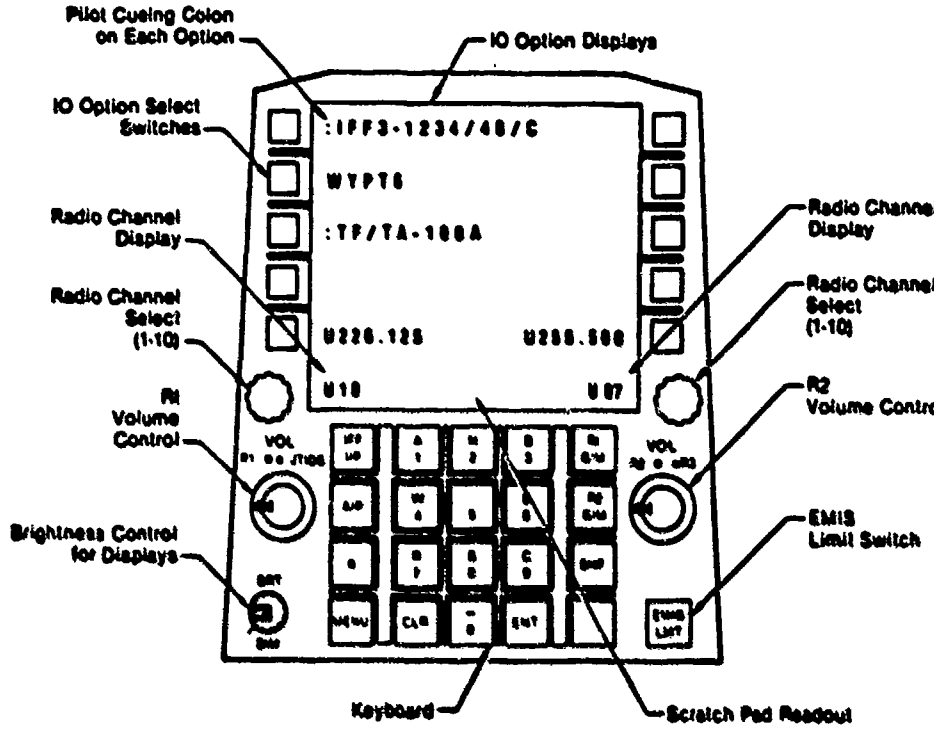


Figure 20 RAM/ACE Up-Front Control

from:

4A	:4A	4B	:4B	4A
(4A-OFF)	(4A-ON)	(4B-OFF)	(4B-ON)	(4A-OFF)

Mode C is either on (:) or off. The option select switch works as an alternate action button. To return to the top level display, simply depress the "MENU" button and the selected IFF modes are displayed.

Upon selecting the "WYPT" option select button or the UFC button on the EHSI WYPT sublevel, the UFC waypoint

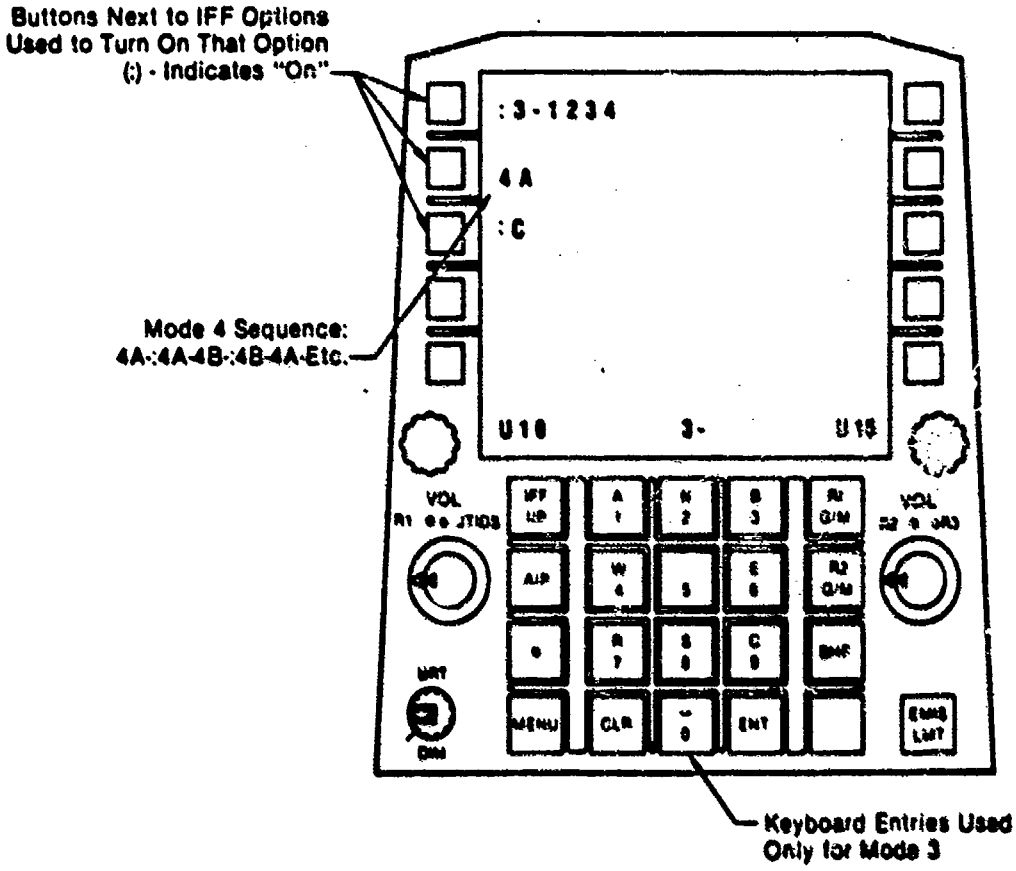


Figure 21 RAN/ACE UFC IFF Sublevel

sublevel display appears as shown in Figure 22. This format shows the current latitude and longitude for the selected waypoint coordinates can be entered by depressing the "POSN" option select button (a colon appears) which enables the scratchpad for data entry. For a latitude the coordinates must be prefaced by a SHF "N" or SHF "S" and for a longitude the coordinates must be prefaced by a SHF "E" or SHF "W". The coordinate entry format must follow the illustrated example of Figure 23.

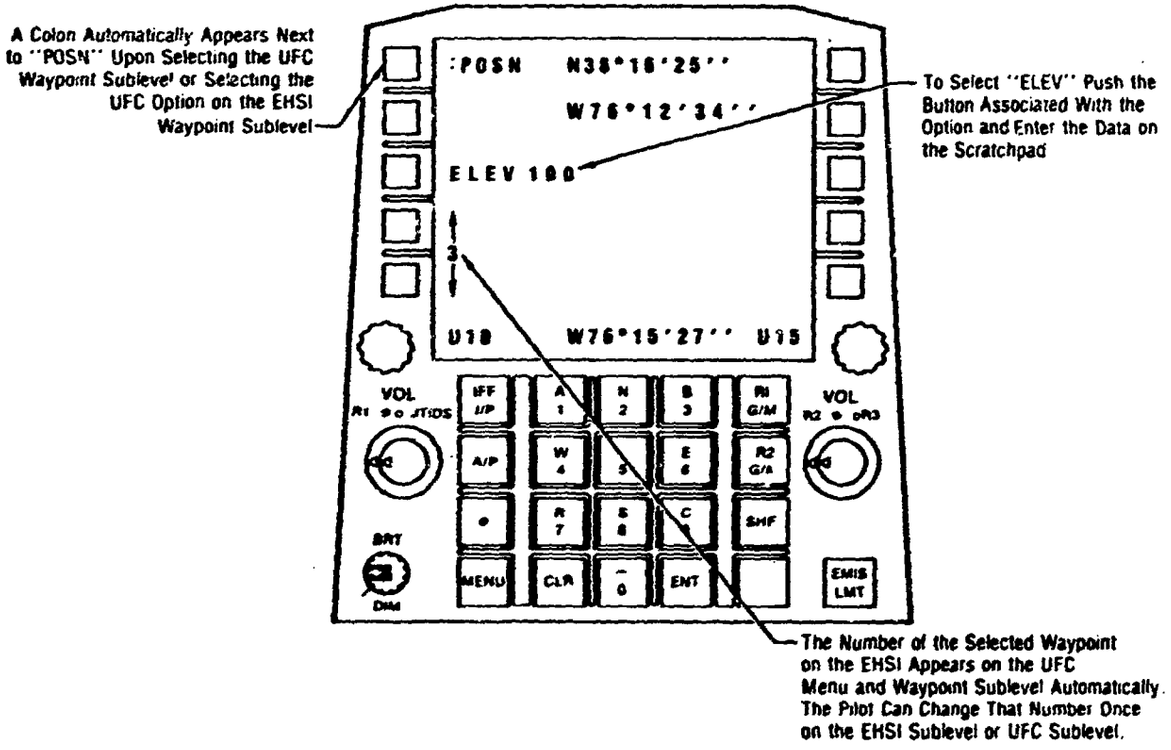


Figure 22 RAM/ACE UFC Waypoint Sublevel

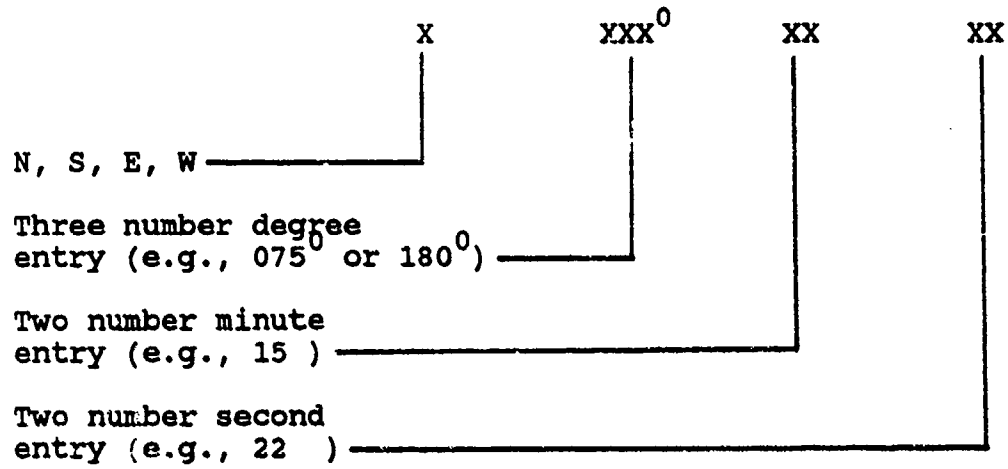
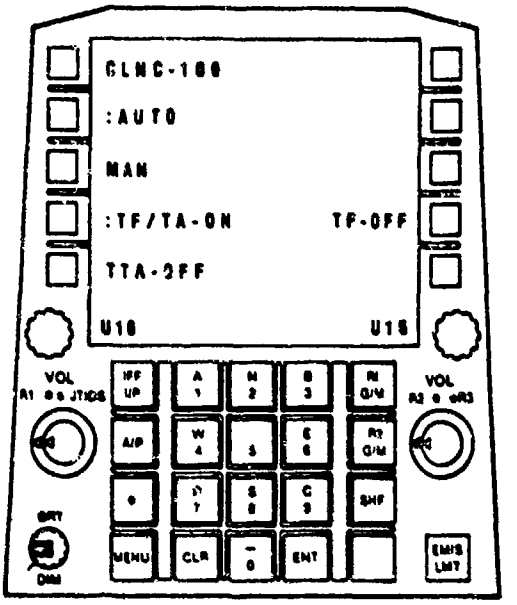


Figure 23 RAM/ACE Waypoint Data Entry Format

Once the pilot is satisfied with the scratchpad entry, he depresses "ENTER" and the new position is entered and displayed. The pilot can enter the elevation for each waypoint in a similar manner. Valid entries are from 0 feet to 999 feet.

The pilot can also sequence through each waypoint using the up and/or down arrows on the UFC waypoint sublevel display or EHSI sublevel or top level displays. However, changing waypoint numbers on either the EHSI or UFC sublevel displays will not change the waypoint number selected on either top level format. To return to the UFC top level format, the pilot selects "MENU".

If the option select button for one of the terrain following modes is depressed when in the UFC top level format, the terrain following sublevel becomes available as shown in Figure 24.



— Auto/Manual is Applicable to TF/TA and TTA
— TF is Always Manual
— CLNC is the Only Keyboard Entry

Figure 24 RAM/ACE UFC-TF/TA Sublevel

The options are:

CLNC - Allows the operator to select the terrain clearance plane for TF operations.

AUTO - Automatic terrain following mode applicable to TF/TA or TTA and mutually exclusive with MANUAL mode.

MAN - Manual terrain following mode available with TF/TA, TTA, and TF. Mutually exclusive with Automatic mode.

TF - Terrain following mode. The only terrain following mode available on the ABL. It offers elevation commands only.

TF/TA - Terrain following and terrain avoidance mode.

Both pitch and roll commands for terrain avoidance are provided. This option will only be operational with the TF/TA enhancement.

TTA - Terrain and threat avoidance mode. Both pitch and roll real-time commands for the best path between both terrain and detected threats is given. This option will only be available when the TTA enhancement is run. NOTE: TF, TF/TA, and TTA are all mutually exclusive.

To return to the top level UFC format, select "MENU".

ADVANCED BASELINE DISPLAYS

Head-Up Display (HUD):

The ABL Head-Up Display is a Wide Field-Of-View (WFOV) diffractive optics HUD that yields a total FOV of 30° in azimuth and approximately 20° in elevation. An illustration of the HUD is shown in Figure 25. The basic symbology used on the HUD is shown in Figure 26. In the following paragraphs, the number refers to the callouts in Figure 26.

1. Heading - The aircraft's magnetic heading is indicated by the moving 360° heading scale. The actual aircraft heading is directly above the caret. The moving heading scale provides trend information during turns. As the aircraft turns right, the scale moves from right to left.

2. Air Speed - Calibrated air speed from the air data

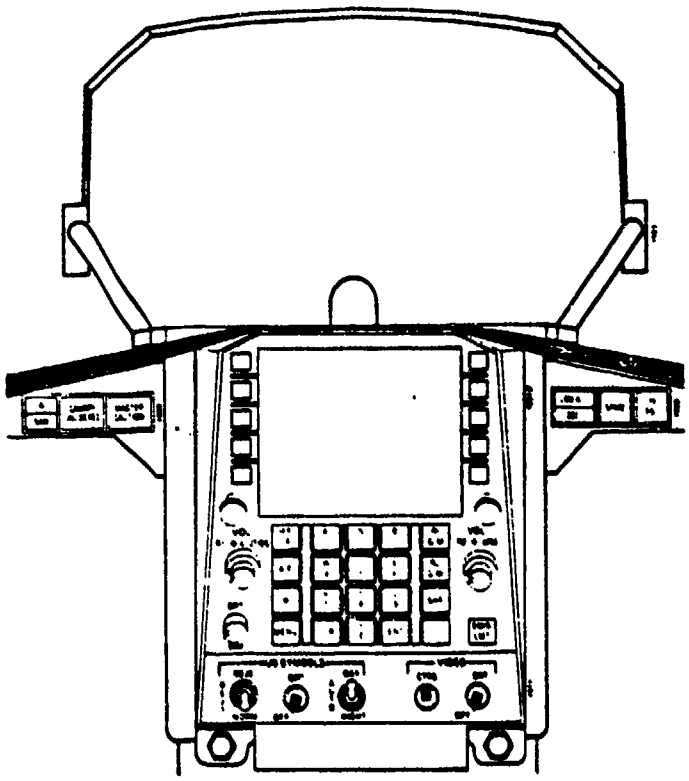


Figure 25 RAM/ACE Wide Field-of-View HUD

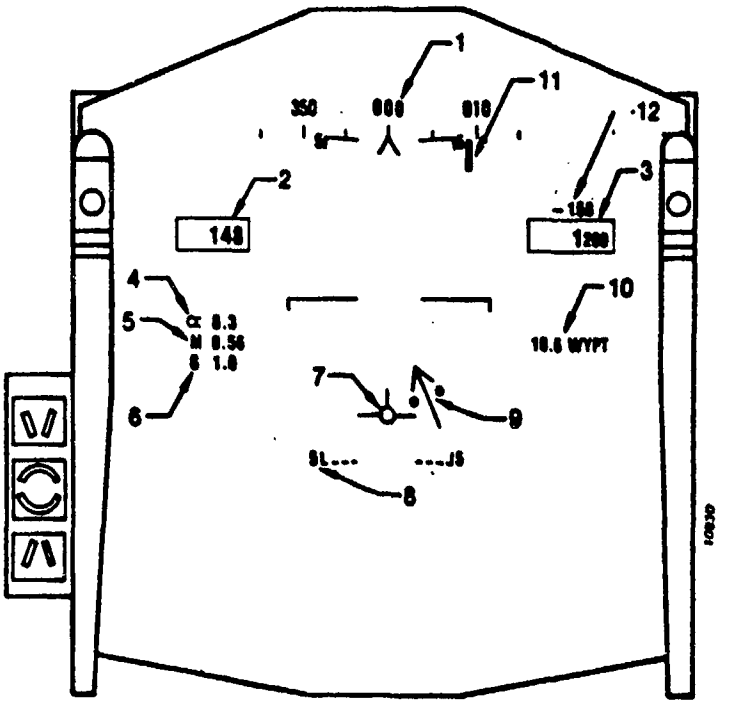
computer is provided in the box on the left side of the HUD. The tops of the airspeed and altitude boxes are positioned at the aircraft waterline (4° up from the optical center of the HUD).

3. Altitude

4. Angle of Attack - True angle of attack in degrees is displayed at the left center of the HUD.

5. Mach Number - The aircraft Mach number is displayed immediately below the digital angle of attack.

6. Aircraft G's - Normal acceleration of the aircraft



1. Heading
2. Airspeed
3. Altitude
4. Angle-of-attack
5. Mach number
6. Aircraft g
7. Velocity vector
8. Flight path ladder
9. Waypoint course arrow
10. Nav range
11. Command heading bug
12. Vertical velocity

Figure 26 RAM/ACE HUD Symbology

is displayed immediately below the Mach number.

7. Velocity Vector - The velocity vector provides the pilot with an outside world reference with regard to actual aircraft flight path. The velocity vector represents the point towards which the aircraft is flying (aircraft flight path). The position of the velocity vector is limited to an 8°-radius circle centered at the HUD optical center. If

the velocity vector reaches this limit during high angle of attack flight or large yaw and/or drift angles, then it will flash rapidly (2.5 times per second) to indicate that it does not accurately indicate flight path.

8. Flight Path Ladder - The vertical flight path angle of the aircraft is indicated by the position of the velocity vector on the flight path/pitch ladder. The horizon and flight path/pitch angle lines represent the horizon and each 5° of angle between the horizon line. Negative pitch lines are dashed and are below the horizon line. The outer segments of the lines point toward the horizon. Each line is numbered to aid in determining flight path angle when it is changing rapidly. The pitch lines are angled toward the horizon at an angle half that of the flight path angle. For example, in a 48° climb, the pitch lines are angled 24° toward the horizon. In level flight, the pitch lines are not angled. The zenith is indicated by a circle and the nadir is indicated by a circle with an X in it. Aircraft pitch angle can be determined by comparing the tops of the altitude and airspeed boxes (which represent the aircraft waterline) with the pitch ladder when the wings are level. However, since the flight path/pitch ladder normally rotates about the velocity vector, determination of pitch angle may be difficult at high roll angles.

Because of the large amount of data that can be

displayed on the HUD at any one time, there are two levels of clutter reject provided for pilot selection via the clutter reject switch located at the bottom-left of the HUD control panel. The clutter reject levels provide the pilot the option to remove symbology from the HUD display that he considers unessential for mission completion or to reduce interference light output. The symbology that is removed from the display is:

Clutter Reject No. 1	Clutter Reject No. 2
Aircraft Mach Number	Clutter Reject No. 1 Symbology
Aircraft G's	
Peak Positive G's	Boxes Around Altitude and Airspeed
Heading Scale	Nav Range

9. Waypoint Course Arrow - When waypoint steering is selected on the EHSI and a waypoint course is set, the waypoint course arrow appears on the HUD showing a course depiction similar to that on the EHSI.

10. NAV Range - When waypoint steering is selected on the EHSI, the range to waypoint is displayed on the HUD. Upon designation of a target, this waypoint range changes to target range which illustrates distance to weapon release point.

11. Command Heading Bug - When waypoint steering is selected on the EHSI, great circle steering is supplied via

the command heading bug on the heading scale.

12. Vertical Velocity - Vertical velocity in feet per minute is displayed above current altitude on the HUD.

The WFOV HUD used on the ABL is also video raster capable. As a result, FLIR imagery can be displayed on the HUD to aid navigation.

After a target designation (as a result of using any sensor or the HUD), has been performed, the HUD display changes as shown in Figure 27. The target designation diamond should overlay the target (if not, it can be updated visually or with a designation sensor or weapon). The pilot should steer to put the velocity vector over the azimuth steering line (ASL) to null out any azimuth errors. Range to target, time to weapon release and delivery mode are also displayed on the designated HUD.

Multipurpose Display Logic

The left and right 6" monochromatic MPD's in the front cockpit can be used to display any of the ABL's formats. The center 5" monochromatic MPD in the front seat can only display the EHSI and the HUD if selected from the EHSI. An illustration of the display logic is shown in Figure 28.

In the aft crew station all four displays are MPD's and can be used to project any format that is desired. On the MPD's the operator can call up any display format via the MENU. The MENU option is always the center button on

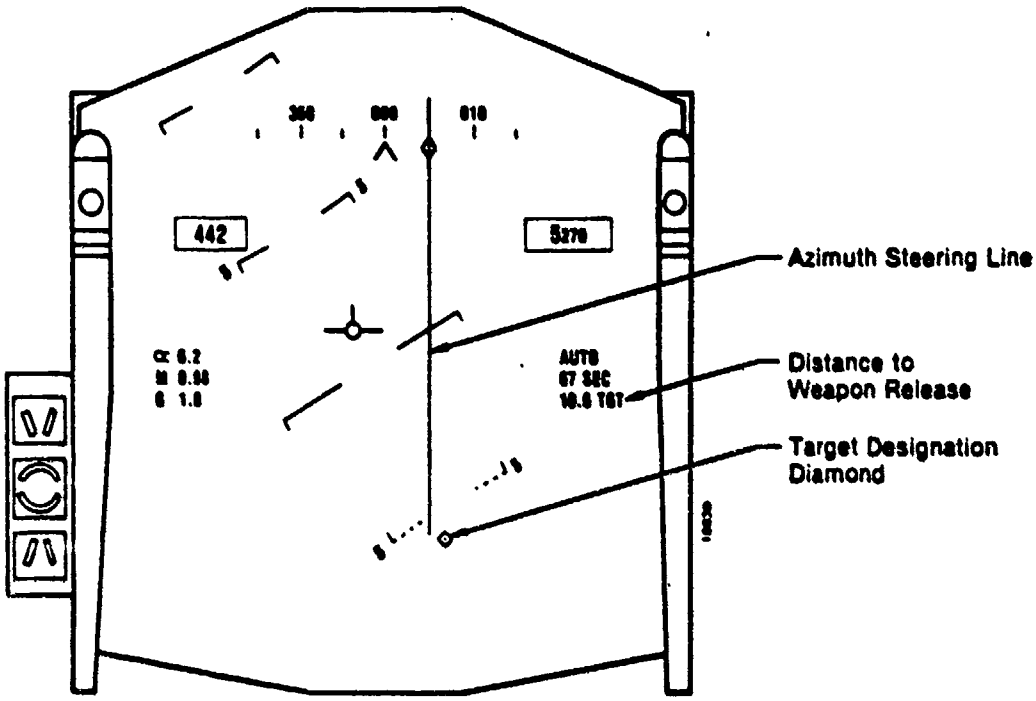


Figure 27 RAM/ACE Basic HUD Display Designated

the lower row of buttons. The MENU format displays all available system format options for pilot selection as shown in Figure 29.

Upon selecting a format using the option buttons, the MENU format is replaced with the selected format. It's important to note that a given format cannot be displayed on two MPD's simultaneously in the same crew station. However, since the front and rear cockpit display logic is independent, the same format can be displayed simultaneously in both the front and rear crew stations.

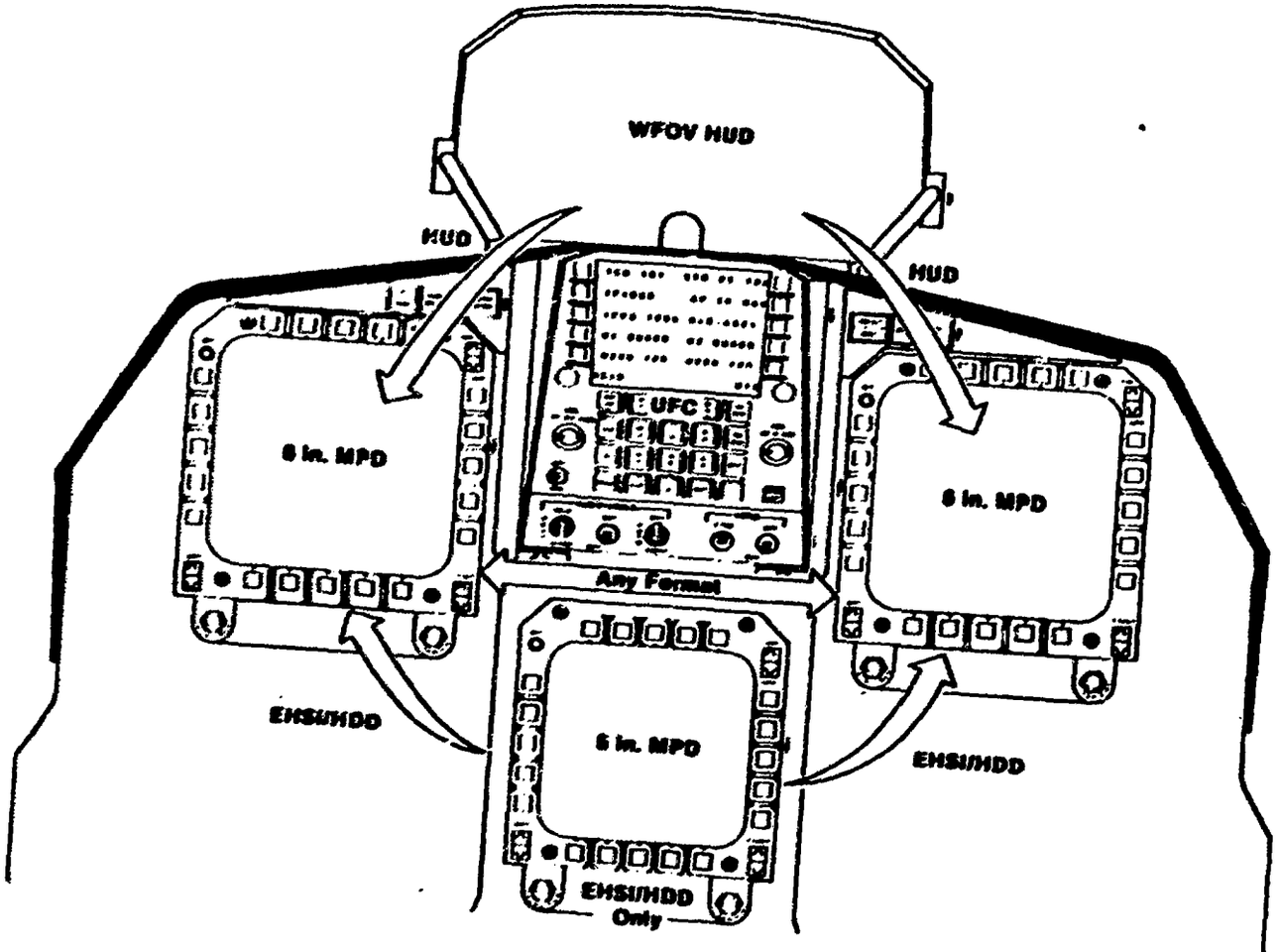


Figure 28 RAM/ACE Display Logic

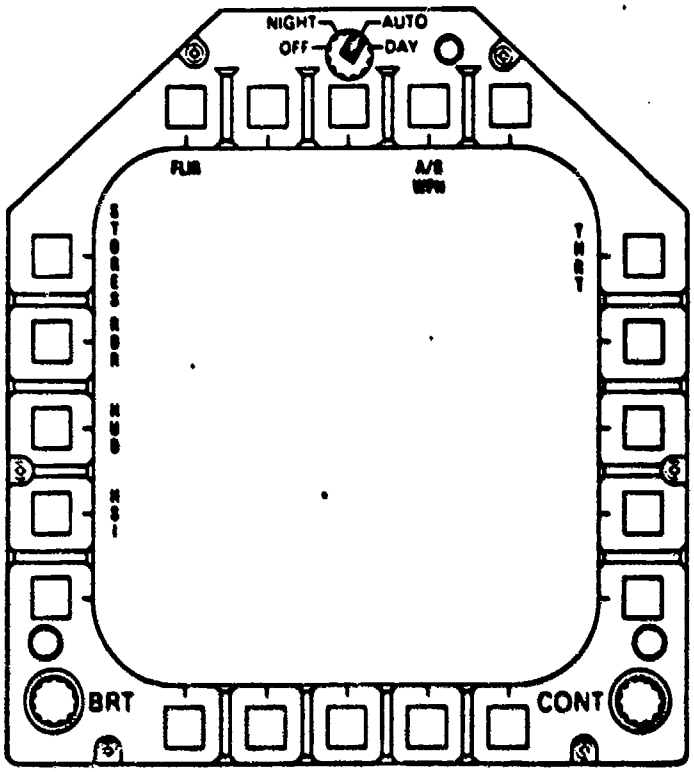


Figure 29 RAM/ACE Menu Format

The available display formats will now be discussed along with their associated control logic.

Head Down Display (HDD)

The HDD represents a futuristic combination of the contemporary E-scope terrain following display, as in the F-111, and the newer PPI formatted terrain avoidance display as used in the F/A-18A. The HDD is depicted in Figure 30. The display can only be selected via a button option on the EHSI format and represents a 5.6 mile X 5.6 mile area.

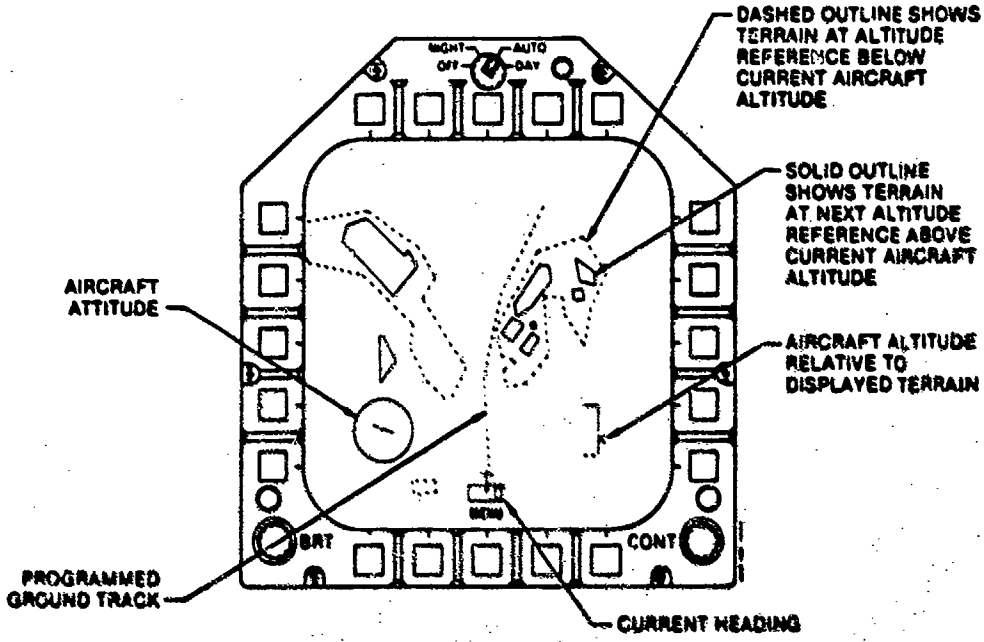


Figure 30 RAM/ACE Head-Down Display (HDD)

The HDD depicts ownships position at the lower center of the display just above the aircraft's current heading. The aircraft's computed path is shown by a dashed line while the great circle direct path between waypoints is shown by the solid line. Terrain contours are shown at 500 feet in increments of terrain elevation and are shown on the HDD as follows:

Dashed line - represents terrain contour <u>below</u> the aircraft's present altitude

1st solid line - represents terrain contour <u>above</u> the aircraft's present altitude

At the lower left of the HDD is an attitude format referenced to a fixed aircraft symbol in the center of the circle. At the lower right of the display is a relative altitude reference illustrating the aircraft's present altitude with respect to the next level of terrain above and below the aircraft. To return to the EHSI simply depress the "HSI" option on the lower right. Or, if return to the menu display is desired, the "MENU" option should be selected.

Armament Control System (ACS) Display

The ACS format represents an aircraft wing-form with the available weapons and sensors being displayed on their respective stations. On stations 1 and 9, AIM-9 Sidewinders are always shown, even though they cannot be accessed or fired in the RAM/ACE simulation. The FLIR pod is always loaded on station 4. The master arm status is shown at the center of the format as either "ARM" or "SAFE". There are two different weapon loads used on the ABL in RAM/ACE: the first is an IIR Maverick where missiles are on stations 2, 3, 7, and 8, as shown in Figure 31. To get a weapon ready, the following functions must be accomplished.

a) The Maverick weapon option (MAV) must be selected on the upper row, far left button. When this is accomplished, the simulated ACS will automatically select a

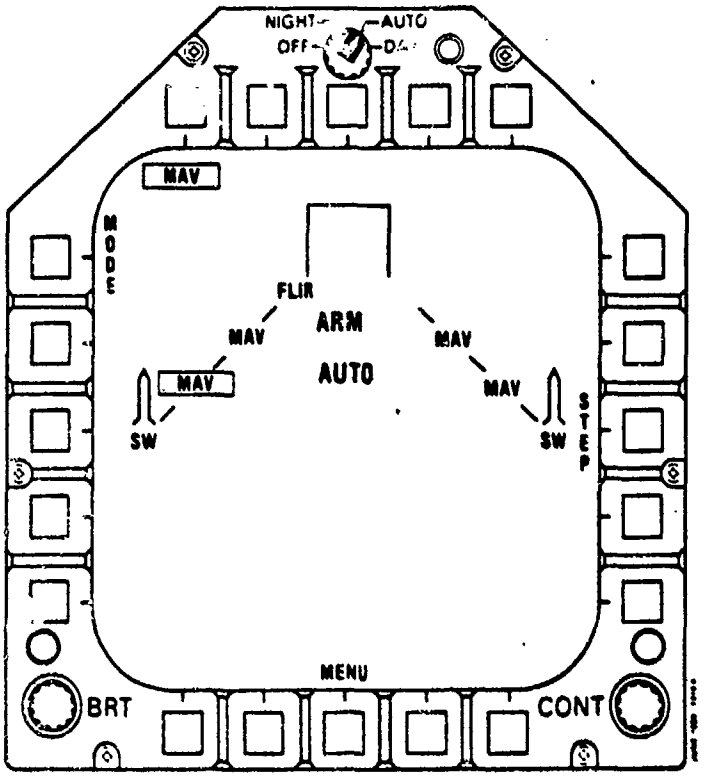


Figure 31 RAM/ACE ACS Format, Maverick Weapon Load

weapon station for first launch, indicated by a box around the weapon acronym. The operator can change that station by depressing the step option as many times as is necessary.

b) The "MODE" option must be selected so that the system will enable the automatic firing mode.

c) The air-to-ground master mode must be selected on the main instrument panel.

d) The Master Arm must be placed in "ARM".

e) In the case of the Maverick, the "cage" button must be depressed on the Maverick display to uncage the

weapon. For the Boresight correlator enhancement, the weapon uncaging is automatically accomplished without pilot action.

After all of these steps have been accomplished, the X through the weapon type will be removed from the ACS display, the HUD, and the Maverick display, and the weapon release button becomes hot. The second ACS weapon load used in RAM/ACE is 2 WASP pods containing 8 missiles each, as shown in Figure 32. The WASP pods are loaded on stations 2 and 8. To enable the weapons for launch, the same steps must be followed as for Maverick except no weapon uncaging is required.

Threat Display

To use the threat display, select the "THRT" option on the menu format. The threat display is shown in Figure 33. It is a range azimuth format that depicts ownship position in the center with 15 and 30 NM range rings. It is assumed that accurate azimuth and range is determinable for detected threats. A threat's centroid is shown on the display by placing one of the symbols shown in Figure 34 at the appropriate range and azimuth. Symbols are placed on the display for all threats which have you in detection range. In addition to a threat's centroid, a lethal radius that decreases with decreasing ownship altitude is depicted. The lethal radius can be made to disappear by

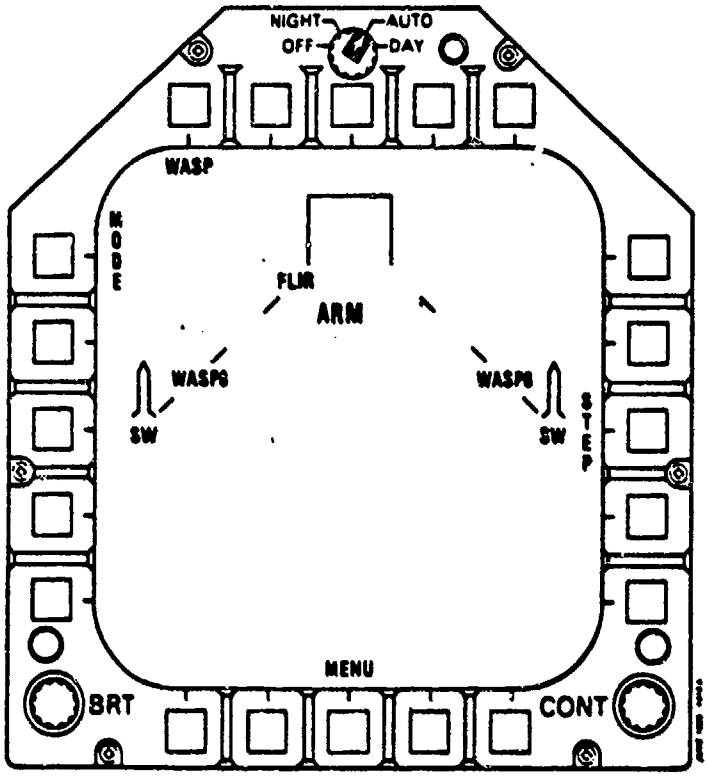


Figure 32 RAM/ACE ACS Format, WASP Weapon Load

flying very low. This is a simple method of simulating the effects of terrain masking. However, masking due to specific topographic features is not included. There are three threat states depicted. These are:

o Active (non-tracking); 1 second status change tone and the threat symbol with it lethal radius is displayed.

o Tracking (radar tracking ownship), ownship is within threat detection range (not displayed); continuous tracking tone.

o Launch; ownship is within lethal range; continuous launch tone. Threat symbol and lethal range circle flash

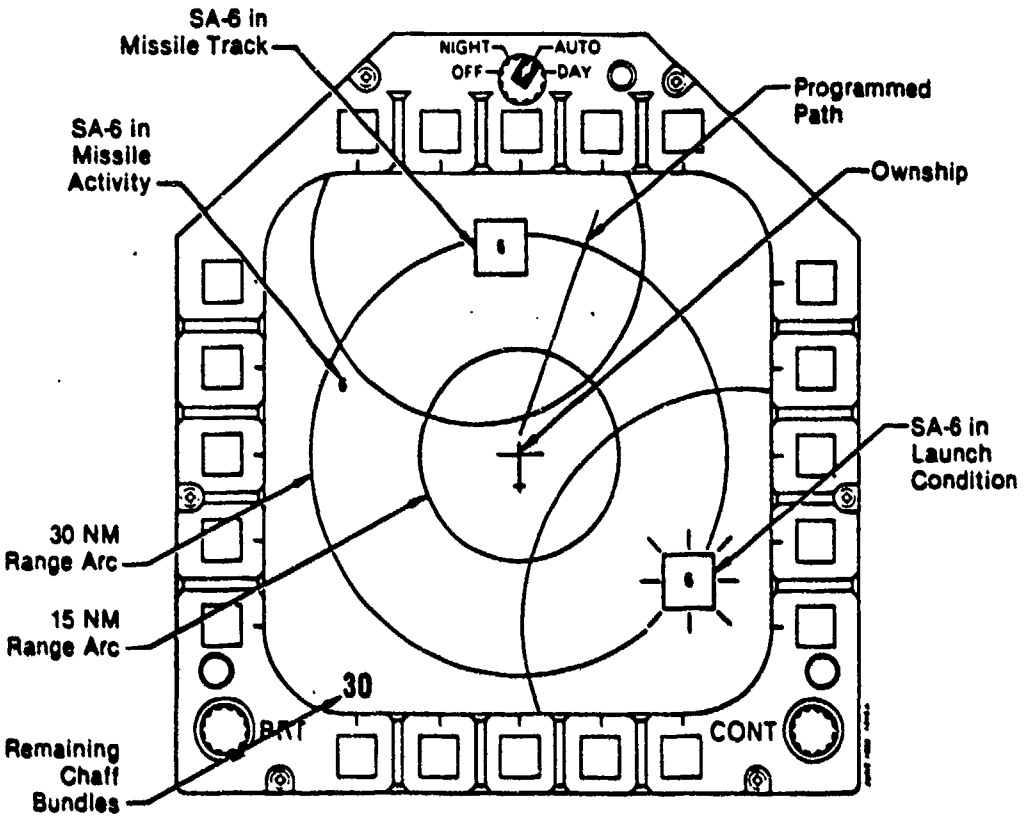


Figure 33 RAM/ACE Threat Display

indicate missile launch (or gunfire).

Forward Looking Infrared (FLIR) Display

The FLIR display can be selected via the MENU format. It is illustrated in Figure 34. When the FLIR is on and operating correctly, it is indicated by an "OPR" in the upper left corner of the display. In the center of the display, a velocity vector, horizon line and a field of view reticle is depicted. The azimuth and elevation position of the FLIR head are shown at top center and left

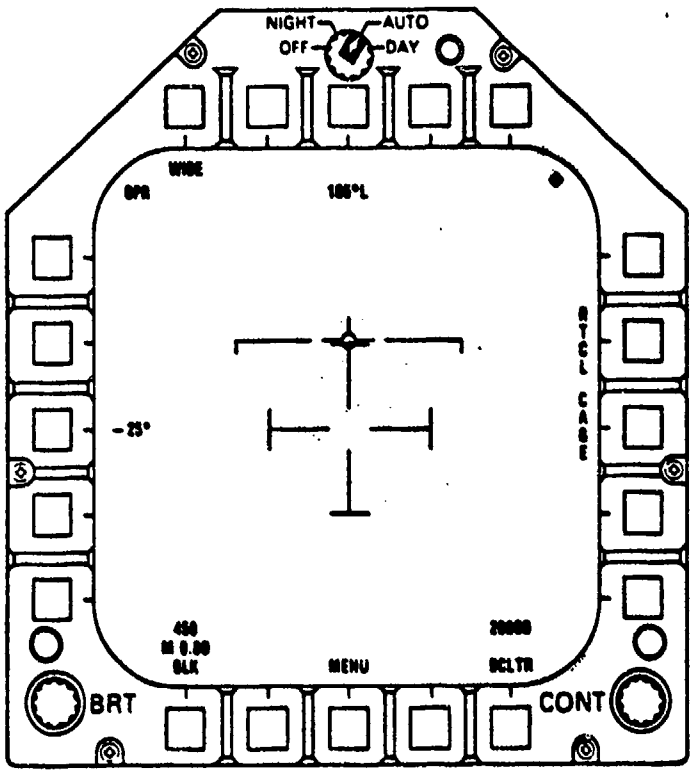


Figure 34 RAM/ACE FLIR Display

center of the display respectively. The remaining FLIR options are discussed below:

WIDE/NAR - This is an alternate action button that changes the FLIR field-of-view (FOV). The FLIR FOV switches on the stick in the front seat and hand controllers in the rear seat duplicate this function. The FLIR's FOVs are 12° (wide) and 3° (narrow).

NOTE: The wide FOV reticle with the short perpendicular tic marks indicates the area of narrow FOV if selected.

A/G WPN - Selects the Maverick display if available.

PRI STEP - Steps priority targets for the Boresight

correlator enhancement only.

NOTE: The FOV reticle automatically returns upon designation to aid the designation refinement process.

CAGE - Cages the FLIR head to 0° azimuth and -7° in elevation.

DCLTR - Removes the velocity vector and horizon line as well as airspeed, Mach and altitude.

To move the FLIR head, TDC functions must be assigned to the FLIR display by using the TDC assignment switch in either the front or rear cockpits. A diamond will appear in the upper right corner of the display indicating TDC control. To slew the FLIR head, apply forces to the TDC without depressing it. To designate a target, depress the TDC to the action position and then release it. The FLIR should now be ground stabilized on whatever is located under the center of the FOV reticle. Slewing can also be accomplished while the TDC is held in the action position for designation refinement and/or updating.

Radar Display

The available radar modes in the ABL are Real Beam Ground Map (RBGM) and 10 ft. resolution SAR (EXP-1). The RBGM air-to-ground radar format used in RAM/ACE is shown in Figure 35. It is a $\pm 70^{\circ}$ Plan Position Indicator (PPI) format with four equal range arcs. On the left side of the display is the radar elevation caret (<) and optimum

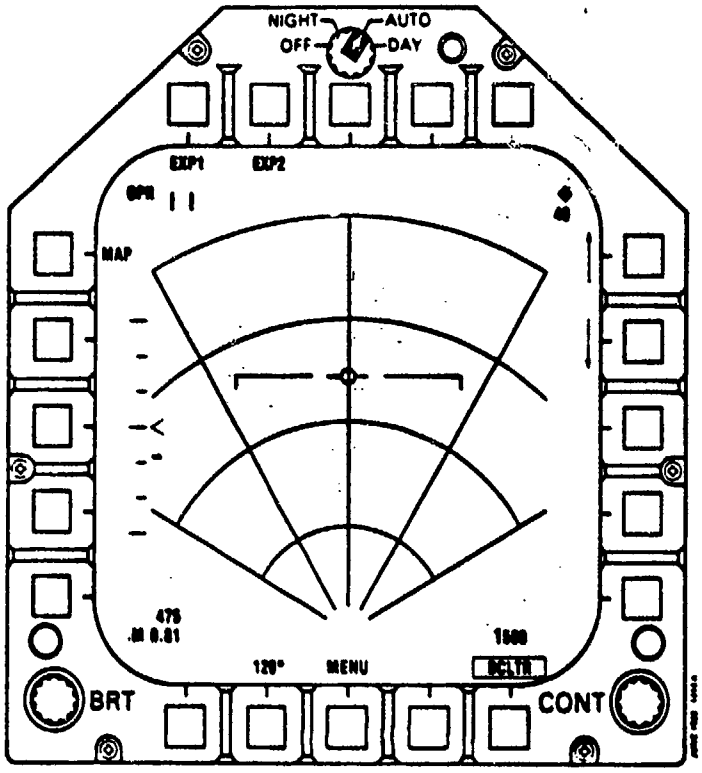


Figure 35 RAM/ACE Radar Real Beam Ground Map Display

elevation mark (-). The scale represents $\pm 30^{\circ}$ in elevation. All of the functions around the periphery of the radar format can be selected via the buttons and using the Hands on Throttle and Stick (HOTAS) cursor. To select an option using the HOTAS cursor, place the cursor over the option, then depress and release the TDC.

The display options on the radar format are outlined below:

OPR - Indicates that the radar is on and operating.

MAP - Indicates that the current operating mode is RBGM.

120° - Current azimuth scan. The azimuth scan can be changed in one of two ways. First, the button below the current azimuth scan can be pressed, each time scrolling to a new number. Or, the HOTAS cursor can be placed down on the lower left of the format and all of the azimuth scan options automatically appear for selection by the HOTAS cursor.

DCLTR - Removes the velocity vector and horizon line.

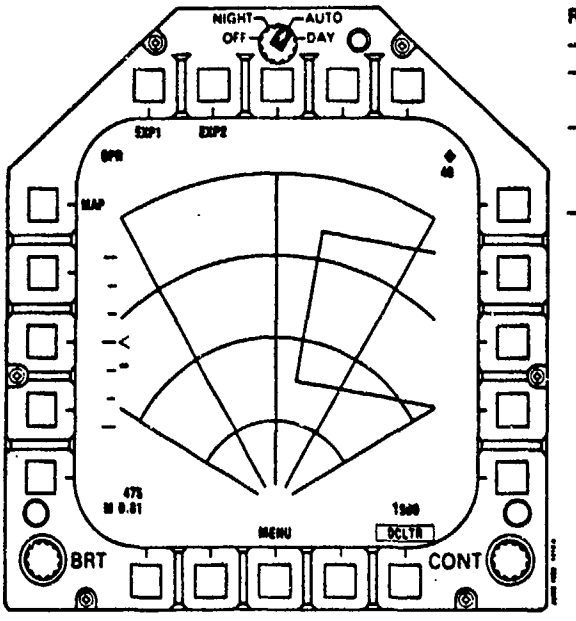
80 - The up arrow increments the range scale and the down arrow decrements the range scale. The available range scales are 10, 20, 40, 80, and 160 nautical miles.

EXP 1 - When designated, selects the 10 ft. resolution SAR mode centered around the designated point.

- When undesignated, selects the invideo EXP1 outline that defines the 10 ft. resolution SAR patch. This outline is slewable within the radar video and once the TDC is depressed to the action position and released, the 10 ft. SAR mode (EXP-1) is entered about the center of the EXP-1 cursor. The process is illustrated in Figure 36.

EXP 2 - Select Very High Resolution (VHR) SAR imagery only during the SAR enhancements.

To designate a target on the radar display, the following procedure must be used. Use the TDC to position the HOTAS cursor within the radar video presentation. Depress and hold the TDC. A radar cursor (in video) replaces the HOTAS cursor. While holding in the TDC, move

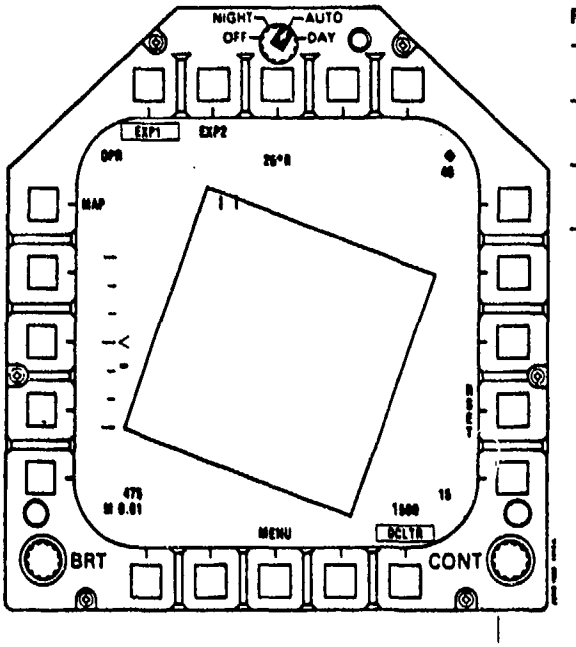


Radar Real Beam Ground Map Mode Display

- Expand 1 Option Selected
- Undesignated

- The Expand 1 Outline is Displayed and it Can Be Slewed Using the TDC When EXP1 is Selected While Undesignated.

- When EXP1 is Selected While Designated, the Radar Immediately Changes From the Map Mode to the Expand 1 Mode.



Radar Expand 1 Mode Display

- Undesignated

- The EXP1 Radar Map (10 ft Resolution SAR) Appears.

- "20R" Indicates That the Radar Azimuth Angle is 20° Right of Boresight.

- The 10 ft SAR Map Covers a Range of 10 to 40 NM.

Figure 36 RAM/ACE RBGM to EXPI Progression

the radar cursor over the desired target and release the TDC. The radar cursor is replaced by a stabilized invideo cue showing the location of the designated target. The HOTAS cursor returns to the display. If any other source (FLIR, navigation system, etc) is used to designate a target, a stabilized cue will also appear in the radar video. This procedure is used in both MAP and EXP1 radar modes, and is shown in Figure 37. If, as you get closer to the target, a refinement of the previous designation is desired, the same procedure as the original designation should be followed.

Electronic Horizontal Situation Indicator (EHSI)

The EHSI is a symbolic representation of the classical electro-mechanical Horizontal Situation Indicator (HSI) with greater inherent flexibility. An illustration of the EHSI display and a brief description of the symbology is shown in Figure 38.

Around the periphery of the EHSI format are several button selectable options. These include:

WYPT - Selection of this option puts great circle steering to the selected waypoint (3 in the example) on the HUD heading scale.

4 - The up arrow increments the waypoint number and the down arrow decrements the waypoint number. The selected waypoint number is displayed between the two

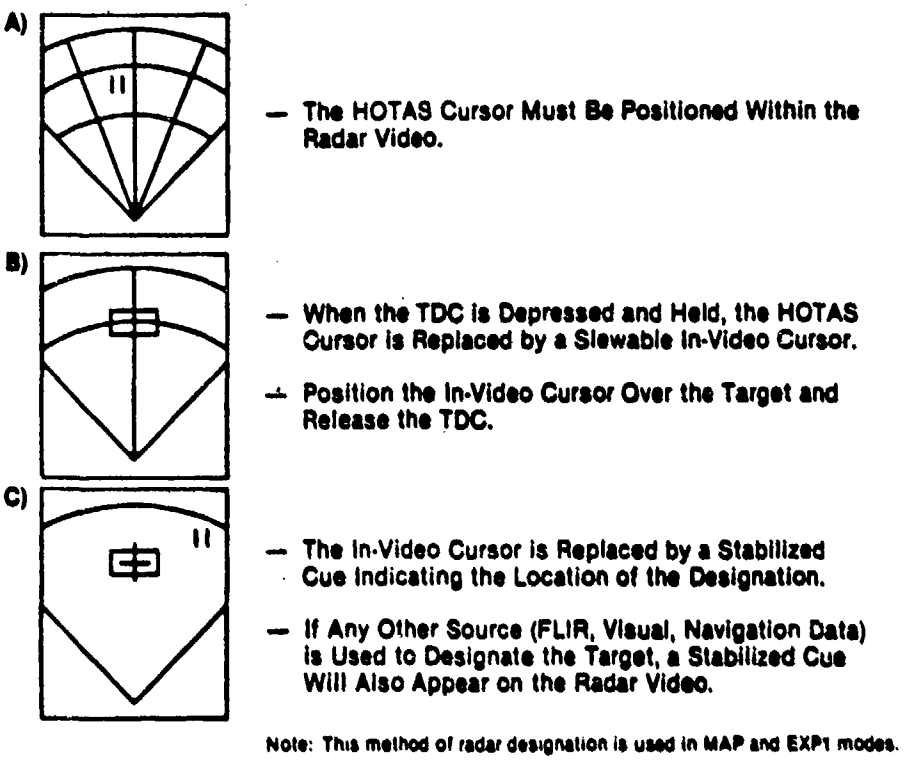
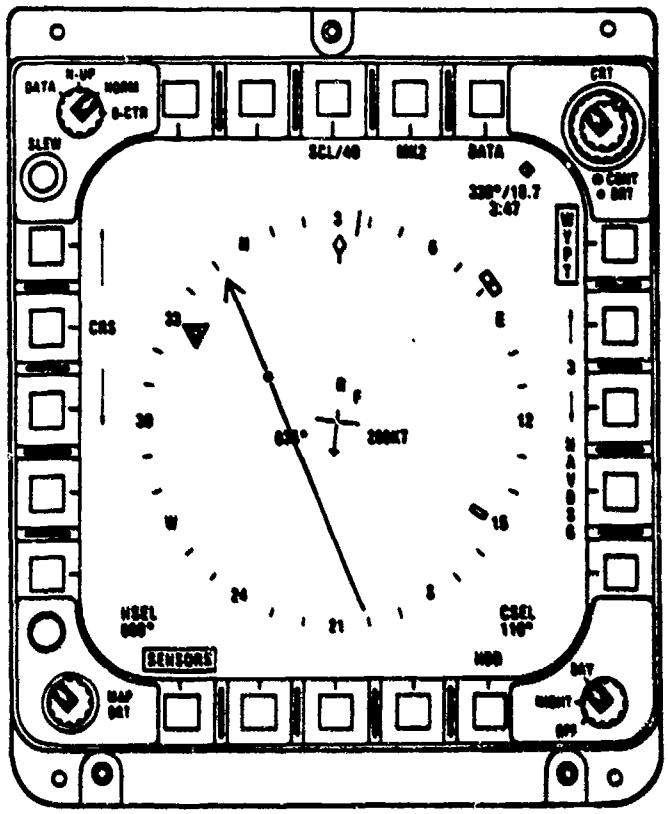


Figure 37 RAM/ACE Radar Designation Procedure

arrows. There are ten (0-9) waypoint numbers available and three mark locations (M1, M2, M3) that can also be used as waypoints. The waypoints can also be incremented via the waypoint step button on the front seat throttle or aft seat hand controllers.

NAVDSG - When "NAVDSG" is depressed, a designation is performed on the selected waypoint number and all available sensors are slaved to the designation line-of-sight.

HDD - Selects the Head Down Display used for Terrain Following flight.



- TDC assignment indication
- Waypoint situation symbol
- Designated point situation symbol which replaces the waypoint situation symbol
- Waypoint bearing pointer
- Designated point bearing pointer
- Bearing pointer tails
- 330°/18.7 3:47 — Bearing/range/time-to-go to selected waypoint
- Lubber line for magnetic heading
- Ground track pointer
- Heading select bug
- HSEL 060° — Heading select bug setting
- Course line reference
- CSEL 110° — Course line setting
- 030° 200KT — Aircraft magnetic heading and groundspeed
- R = Center of radar footprint
- F = Center of FLIR footprint

Figure 38 RAM/ACE EHSI Display

SENSORS - When this option is selected, the centers of the Radar (R) and FLIR (F) footprints are displayed on the EHSI.

CRS HDG - If waypoint steering (WYPT) is selected and the up and down arrow associated with the "CRS" option is also selected, the course line appears and a digital readout of waypoint course is displayed on the lower right of the EHSI. The course line rotates about the waypoint symbol on the EHSI as the course changes. If the button associated with the "CRS" option is depressed, "CRS" changes to "HDG". Now the up and down arrows rotate the heading select bug around the periphery of the compass rose and also change the Heading Select (HSEL) digital readout on the lower left of the EHSI.

SCL/XXX - Depressing the button above the range scale option decreases the EHSI range scale one increment. The range scales available are 160, 80, 40, 20, and 10 nautical miles. The range scales are from the center of the aircraft symbol to the inner diameter of the compass rose. When the range scale is at 10 NM, one more depression of the scale button scrolls the range scale back to 160 NM.

MKX - There are three mark locations available in the navigation computer, MK1, MK2, and MK3. Depression of the button above MK1 will store the coordinates of the designated point, if designated, or perform and overfly mark if undesignated. Also, the mark location number will

automatically increment to MK2. If all three mark locations are full and the mark button is depressed, the new location overwrites the previously stored location.

DATA - When "DATA" is selected, the EHSI data sublevel is selected which is illustrated in Figure 39.

Depression of the data option calls up the data display as shown. "A/C" is automatically the selected data option when the data button is depressed. Whenever the data sublevel is selected, the compass rose, pointers, waypoint and TACAN symbols and non-data-associated options are removed from the display. Upon depression of HSI, the display returns to normal HSI display. To review stored waypoint data, the "WYPT" option on the EHSI sublevel display should be selected. An illustration of the waypoint sublevel display is shown in Figure 40.

The waypoint number is incremented or decremented using the buttons next to the up and down arrows. Data for waypoints 0 through 9 plus Mark 1, Mark 2, and Mark 3 can be displayed. Changing the waypoint number on the data sublevel display does not change the waypoint number selected for steering. To enter data for a waypoint, the UFC option button is depressed and the latitude, longitude, and elevation data are entered via the up-front control. The HSI button is used to return to the top level EHSI display.

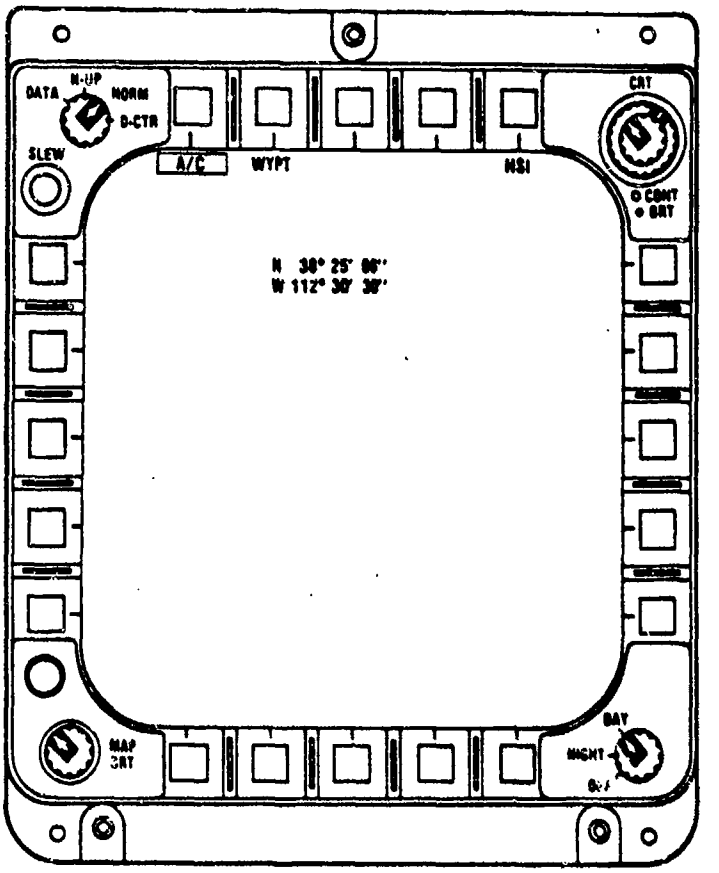


Figure 39 RAM/ACE EHSI Data Sublevel, Aircraft Option Selected

SAR POP-UP MECHANIZATION

For the radar to generate a SAR map the radar needs line-of-sight (LOS) to the target area. If the ingressing aircraft is terrain following to avoid threats a pop-up maneuver is required to get radar LOS. To help the pilot perform the pop-up maneuver and make sure that target LOS is achieved, when the pilot commands pop-up using the front seat throttle switch, the TF cue on the HUD reverts to a

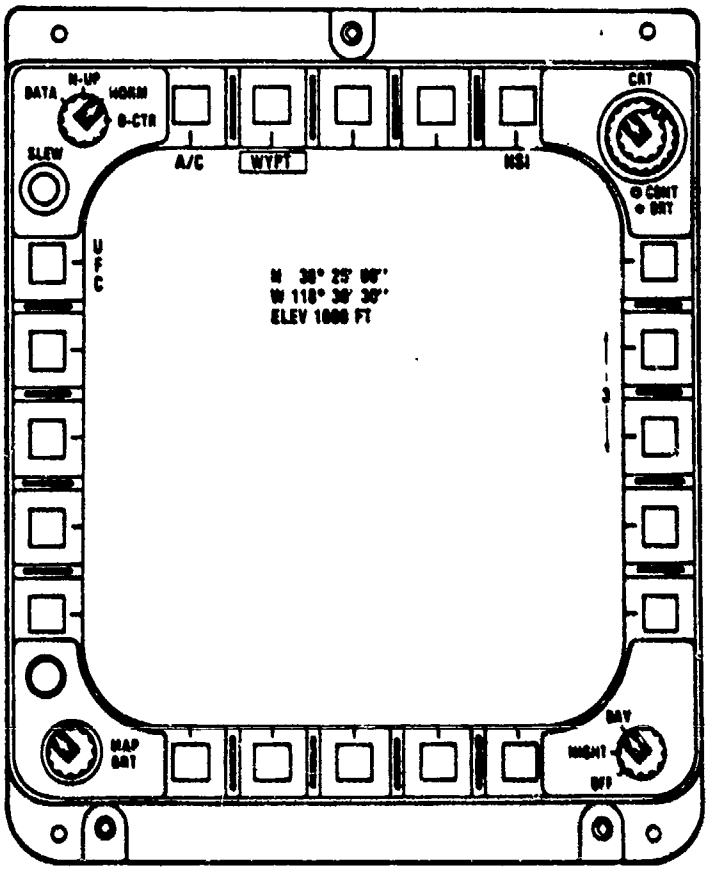


Figure 40 RAM/ACE EHSI Data Sublevel, Waypoint Option Selected

command pop-up symbol, which displays longitudinal commands only, as shown in Figure 41. Upon selection of the pop-up mode, all TF modes are turned off. The pilot's task is to manually fly the velocity vector to the pop-cue. If the steering cue is followed, the aircraft will climb until a 3° depression angle to the target is achieved. The commanded altitude will stay constant until a SAR map is formed. At that time, the pilot will have to cancel the

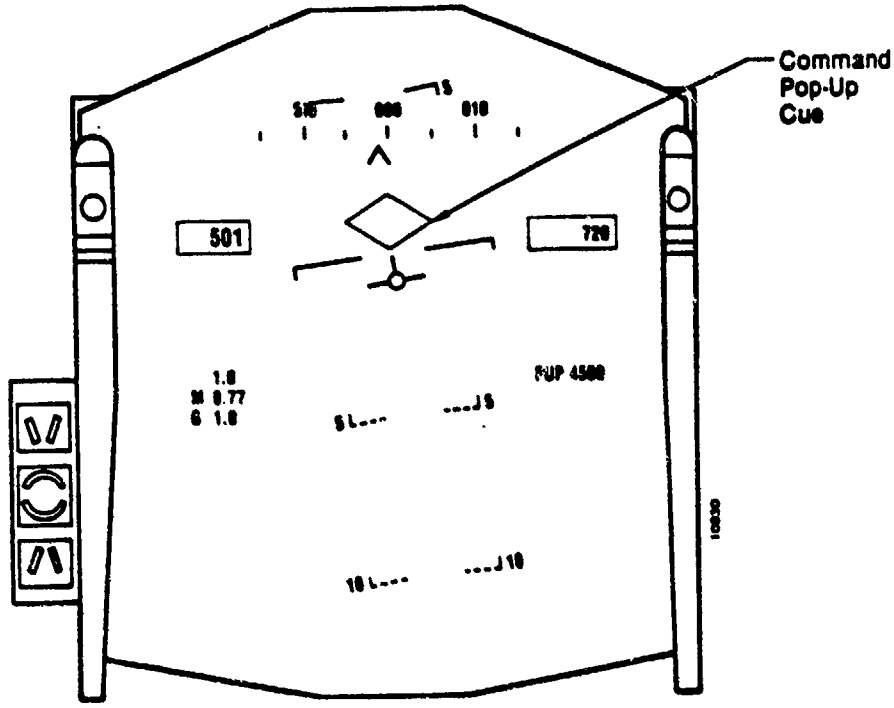


Figure 41 RAM/ACE Pop-Up Command Symbology on the HUD

pop-up mode and use the UFC to re-engage a TF mode.

The aircrew has to determine when to command the pop-up cue as there is no automated coupling to target range or offset angle. Also, the aircraft does not have to be level when the SAR map is taken. The limiting factors are:

a) Less than or equal to 4G's longitudinal

b) No asymmetrical G limit

c) Between 8° and 60° heading offset.

SENSOR IMAGERY INTERPRETATION

The two imaging sensors aboard the ABL are the SAR radar and the FLIR. Both sensors provide imagery to the operator in a television-like video format. The SAR imagery is substantially different than normal monochromatic video imagery from cameras. The FLIR imagery looks much like television video but is generated by a substantially different mechanism. The following sections provide a brief description of the sensor imagery.

SAR Imagery

The displayed imagery from the SAR differs from normal video pictures in that it presents a bird's eye view of the area being mapped by the radar regardless of the line of sight depression angle from aircraft to target. In normal video, the shades of gray are a measure of the amount of light reflected from an object to the camera. In the SAR imagery, the brighter areas are those of higher radar return, while dark areas are those of little or no return. When something blocks the radar beam or return, a dark area, or "shadow" appears. Figure 42 presents a sample of high resolution SAR imagery. Shown in this figure are areas of varying return, radar "shadows", and bright spots showing hard targets (large returns). Since SAR imagery is very different from what most aircrews are used to seeing, sample imagery of test targets will be discussed during the sensor training session. Figure 43 presents a comparison

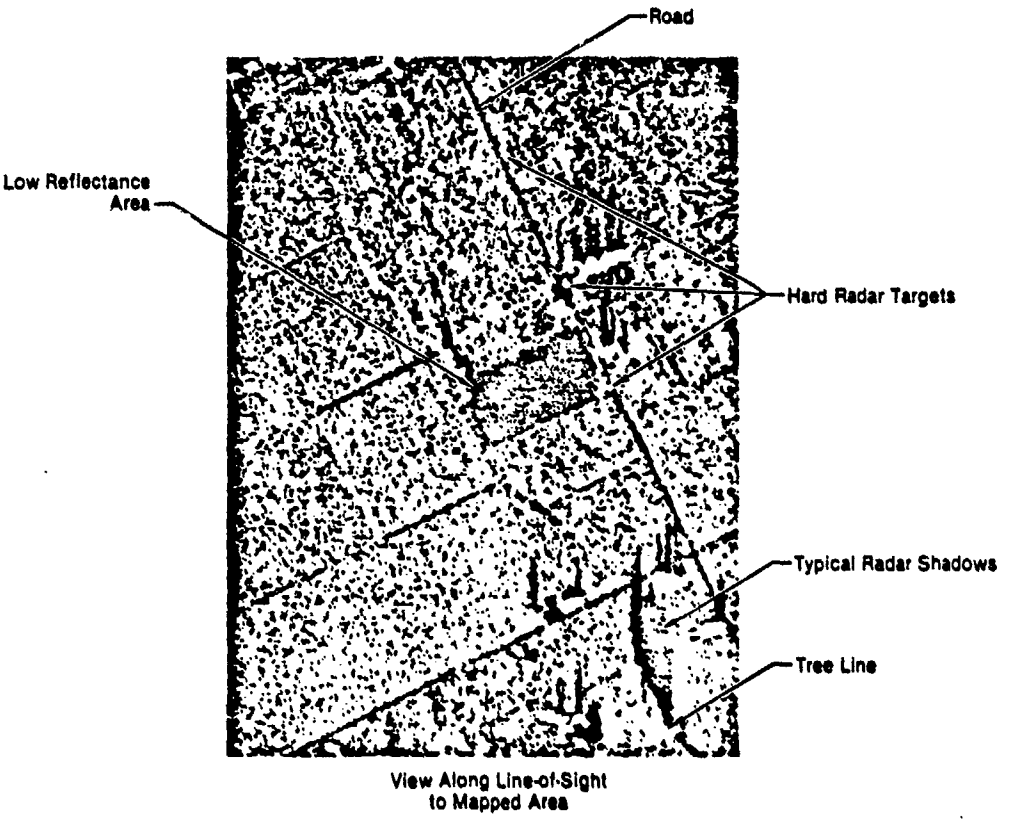


Figure 42 Representative SAR Imagery

of a paper map, a SAR map, and an aerial photograph of the same ground area.

FLIR Imagery

FLIR imagery differs from normal video in that the gray shade are a measure of the apparent temperature of an

Figure 43 Imagery Comparison

object or area in the scene. The FLIR sensor converts the infrared energy emitted by the scene to the visible spectrum. Most FLIR systems have the option to set the video to show the hottest areas as bright spots and the coolest areas as dark (white hot), or just the reverse (black hot). For either method, the differing levels of brightness on the imagery indicate the relative temperature of that area of the scene. The white hot presentation usually provides a picture which looks very similar to normal television video. The black hot presentation, which is used in this simulation, provides a reverse image effect. Figure 44 presents some FLIR imagery representative of that produced by second generation FLIR sensors.

Since FLIR imagery looks so much like television imagery and no special interpretation techniques will be used in the RAM/ACF study, the FLIR interpretation training will be limited to viewing imagery during the practice mission runs.

IIR MAVERICK

The IIR Maverick, as shown in Figure 45, is an infrared guided, rocket powered, air-to-surface missile. It is operated in a launch and leave attack mode. The primary use of the missile is to provide high probability of kill against small hard targets. The missile is 98

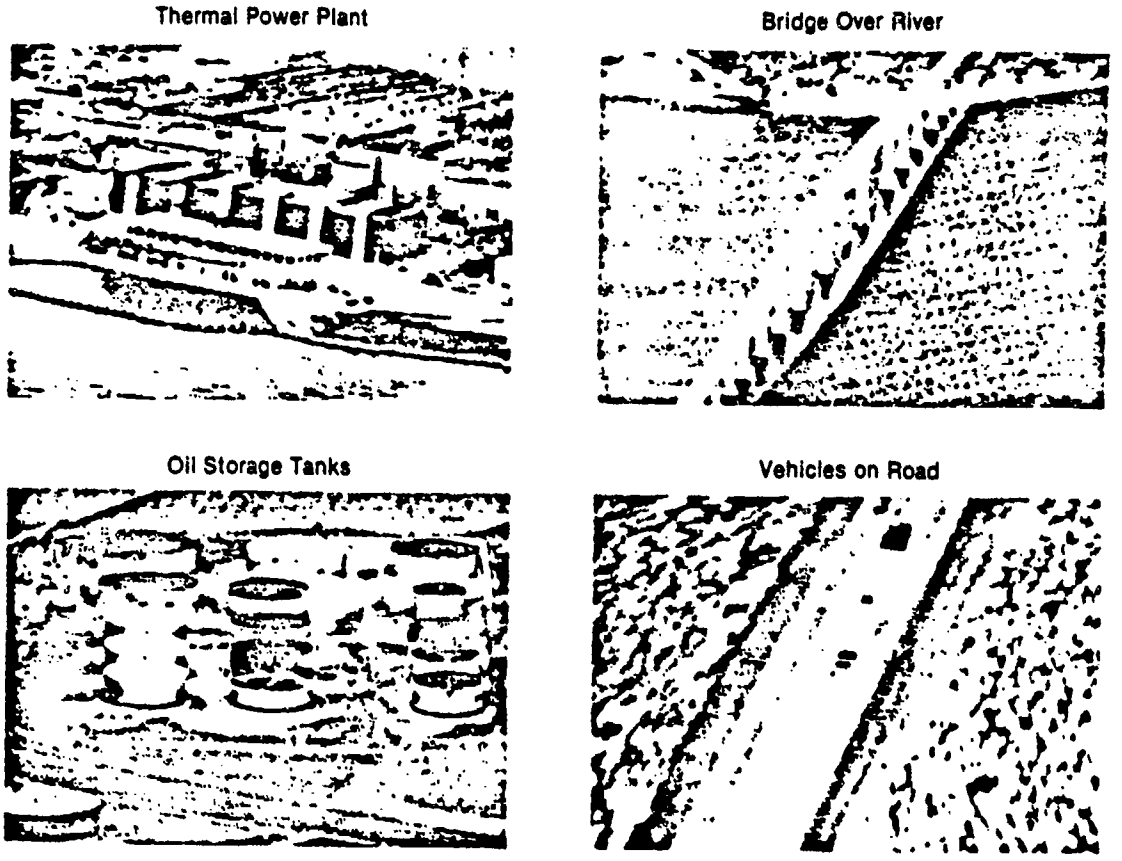


Figure 44 Typical FLIR Imagery

inches long, 12 inches in diameter and has cruciform wings with a 28.5 inch wing span. The missile weighs 450 pounds, including the 125 pound warhead.

The Imaging Infrared (IIR) Maverick generates its own display video that can be presented on a cockpit MPD. An example of the IIR maverick display is illustrated in Figure 46. If Mavericks are available on the ABL and they have been properly selected on the armament control display, (weapon "not ready" cue is no longer present),

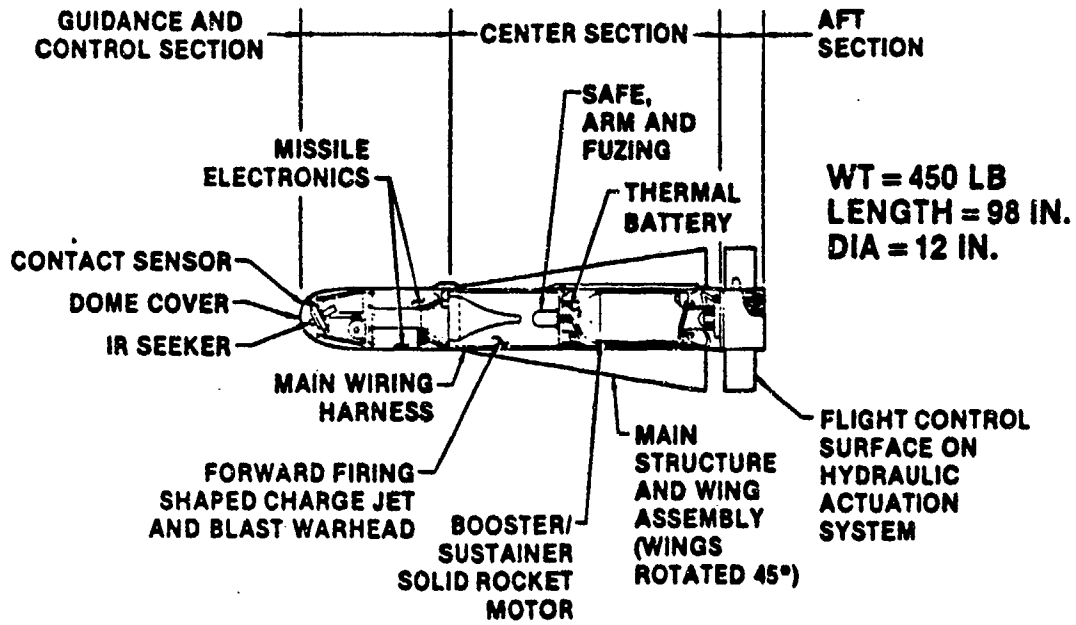


Figure 45 Imaging Infrared Maverick

"A/G WPN" option on either the MENU or FLIR formats can be used to select the IIR Maverick display.

The long horizontal and vertical lines on the IIR Maverick display represent the missile boresight lines. The opening is called the track gate. The three horizontal lines centered in azimuth, below the display center represent -10°, -20°, and -30° in elevation. The RAM/ACE IIR Maverick model allows the missile's head to be slewed $\pm 30^{\circ}$ in elevation and $\pm 40^{\circ}$ in azimuth. The TDC, in the no action position, is used to slew the Maverick head. Each Maverick must be uncaged prior to slewing or lock-on. The cross at the center of the display in Figure 46 is the Maverick head indicator which moves around the display

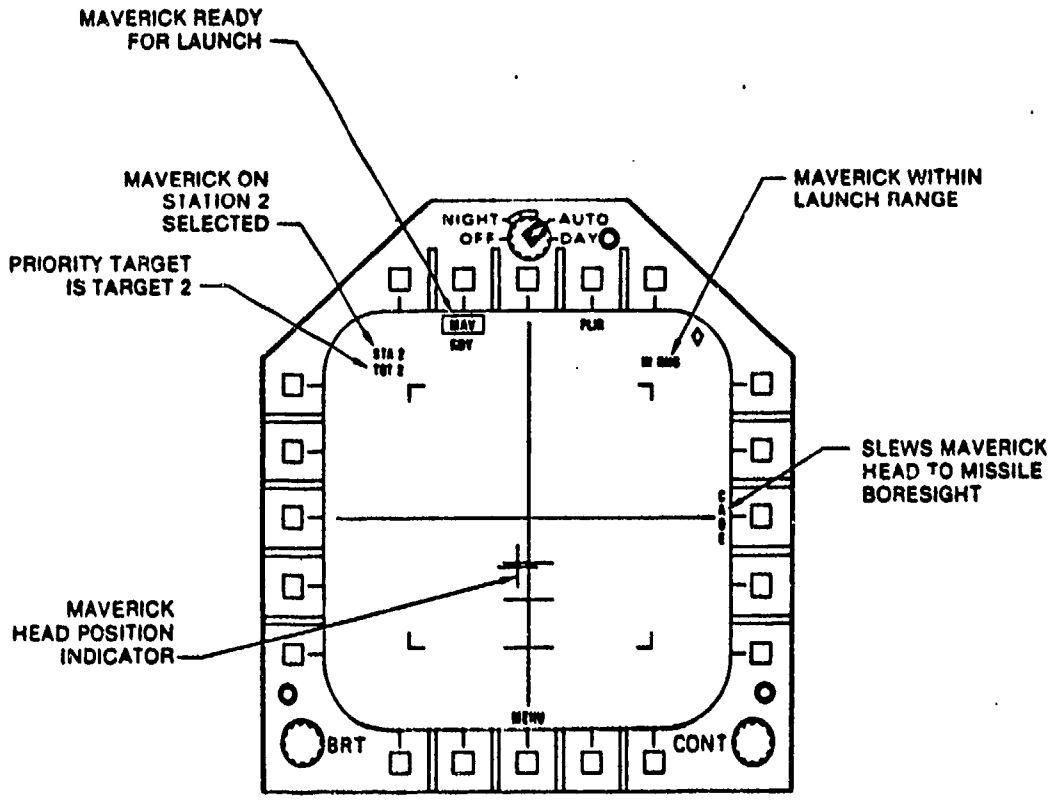


Figure 46 IIR Maverick Display

indicating head location with respect to missile boresight. When the TDC switch is depressed to the action position, Maverick contrast track is commanded. When contrast track is accomplished the size of the opening in the track gate decreases. The pilot must then maneuver the aircraft so that the target is within $\pm 10^{\circ}$ in azimuth and within range constraints prior to receiving an "IN RNG" cue on the HUD and Maverick display for firing. Upon Maverick launch the video display goes blank.

The MENU or FLIR display can be selected directly from the Maverick format using the button options. Also, the FLIR/Maverick display alternate switch can be used to rapidly alternate between the FLIR and Maverick formats.

ABL Ratings

Now that you have completed reading the description of the ABL, please give your best estimate of pilot workload for this configuration. You may refer back to any part of this document as needed. Ratings should be made by placing either a 1 (low), 2 (medium), or 3 (high) in each of the blank spaces below. Refer to page 5 of this document for a refresher on the definition of each of these ratings.

ABL

Segment	Time Load	Mental Effort Load	Psychological Stress Load
Penetration	_____	_____	_____
Target Acquisition	_____	_____	_____
Weapon Delivery	_____	_____	_____

Pilot Name: _____

Unit: _____

Your thoughts and comments on this part of the exercise are welcome. You may use the back of this page for any comments you may have. After completion of this page, remove it from this book and mail it, with the other two rating sheets, in the envelope provided. Now continue to the next section.

TF/TA Instructions

The next section contains a description of an automatic Terrain Following/Terrain Avoidance (TF/TA) subsystem. Consider it to be added to the ABL configuration. The TF/TA has two operating modes: manual TF/TA and automatic TF/TA. The manual TF/TA mode provides pitch and steering commands, but requires the pilot to manually fly the aircraft. Automatic TF/TA is coupled to the flight control system and requires the pilot to simply monitor the system via the HUD or HDD. For the purpose of this exercise, consider the TF/TA system to be in the automatic mode.

Once again, keep in mind the BI mission previously described. Estimates will be required for each segment (Penetration, Target Acquisition, and Weapon Delivery) in each dimension (Timeload, Mental Effort Load, and Psychological Stress Load).

AUTOMATIC TF/TA

The automatic TF/TA enhancement has a flight trajectory generator that is expanded to three dimensions from the vertical plane limitations of TF flight only. The system generates flight commands which can be flown manually by the pilot or coupled directly to the flight control system so that the aircraft automatically follows the generated trajectory. Data for the TF/TA algorithms are supplied from a combination of sensed data (e.g., radar altimeters, forward looking radars and laser scanners) and stored data (e.g., Digital Land Mass Data). In general, both pitch and roll maneuvers are used to maximize the masking benefits afforded by the topography. The flight path is constrained by the mission route between waypoints and maximum desired lateral deviations.

The UFC is used to enable the TF/TA mode as discussed previously. Both automatic and manual TF/TA modes are available. In automatic TF/TA modes the pilot simply monitors the system via the HUD and HDD as necessary. In manual TF/TA mode the same commands are displayed on the HUD and HDD as in automatic TF/TA mode. The HUD symbology for TF/TA is shown in Figure 47.

The format shows the pilot a programmed tactical corridor which represents the commanded TF/TA flightpath. The corridor is shown as three connected boxes. The boxes are connected on the bottom center with a dashed line. The

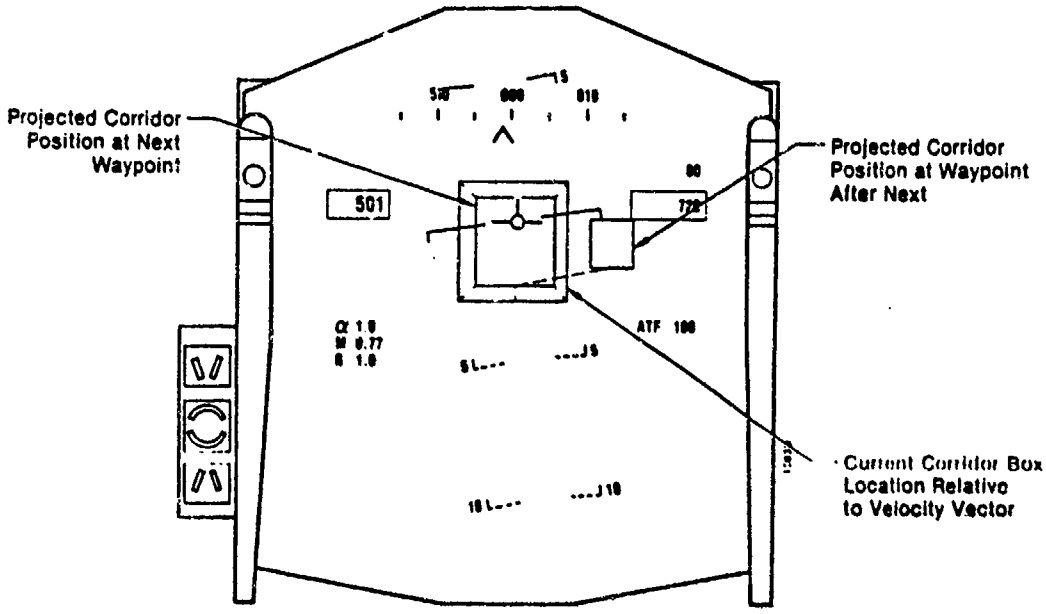


Figure 47 TF/TA HUD Format, Programmed Tactical Corridor

corridor is roll stabilized and always provides the pilot with flight path commands down the corridor or back to the corridor if he strays away. On the right side of the HUD the automatic terrain following (ATF) commanded altitude is shown to allow the pilot to correlate commanded altitude versus actual altitude. The foreground box shows commanded course, which is assumed to be in the center of the box. The second and third boxes are earth-position stabilized over the next two significant terrain features and/or pre-programmed turn points. As the aircraft approaches it, the second box increases in size until it corresponds to the current (i.e., foreground) box. At the instant these two

boxes coincide, the aircraft is passing the next action point. The third box now becomes the second and a new third box appears in the distance.

Switching from automatic to manual TF/TA can be accomplished rapidly via the paddle switch located on the front of the stick. At anytime the pilot can override the automatic TF/TA commands by applying manual stick forces of greater than 2 pounds. Once the stick is released (less than 2 pounds), the system automatically reverts back to automatic TF/TA.

TF/TA Ratings

Please give your best estimate of pilot workload for this configuration. You may refer back to any part of this document as needed. Ratings should be made by placing either a 1 (low), 2 (medium), or 3 (high) in each of the blank spaces below. Refer to page 5 of this document for a refresher on the definition of each of these ratings.

TF/TA

Segment	Time Load	Mental Effort Load	Psychological Stress Load
Penetration	_____	_____	_____
Target Acquisition	_____	_____	_____
Weapon Delivery	_____	_____	_____

Pilot Name: _____

Unit: _____

Your thoughts and comments on this part of the exercise are welcome. You may use the back of this page for any comments you may have. After completion of this page, remove it from this book and mail it, with the other two rating sheets, in the envelope provided. Now continue to the next section.

TTA Instructions

This is the last section of this exercise and it contains a description of an automatic Terrain/Threat Avoidance (TTA) subsystem. Consider it to be added to the ABL configuration separately and independently of the TF/TA subsystem. The TTA system also has two operating modes: manual and automatic. Once again, for the purpose of this exercise, consider the TTA system to be in the automatic mode.

Keep in mind the mission scenario described on page 3. Estimates will be required for each segment (Penetration, Target Acquisition, and Weapon Delivery) in each dimension (Time Load, Mental Effort Load, and Psychological Stress Load).

AUTOMATIC TERRAIN/THREAT AVOIDANCE

The classical method of preparing to face surface-to-air threats is to receive a premission intelligence briefing which educates the aircrews to the types and last known positions of the threats. This data is usually hours if not days old and is highly vulnerable to error due to the mobility of modern threat systems. During premission planning, the pilot plans his route to avoid prebriefed threats and still meet his Time Over Target (TOT) and fuel requirements. Once airborne, the pilot is required to monitor his threat display and adjust his route to avoid detected threats real-time while flying low and fast. After returning to his recovery base, the pilot debriefs with intelligence personnel on his mission. This consists of a Bomb Damage Assessment (BDA) and the aircrew's best guess on when and where threat detection/sightings were made.

The automatic terrain/threat avoidance enhancement assumes a Data Transfer Module (DTM) has been used. The DTM contains the route of flight and latest intelligence summaries for the area of concern. The pilot transferred the data stored on the DTM into his aircraft computers for display on cockpit displays. Airborne, data received from the aircraft's threat sensors is automatically fed to the onboard computers and a real-time threat data base update is accomplished. Once loaded, the computers analyze the

threats and automatically optimize the route of flight to skirt both the newly detected threats and still perform terrain avoidance as required. The new route will be shown on a cockpit display along with the great circle route for comparison. The pilot will have the choice of accepting this new route or flying his own.

The UFC is used to enable the TTA mode. Once enabled, two different displays need to be monitored, the HDD and threat displays. The HDD will show the terrain avoidance portion of the enhancement and the threat display will show the threat avoidance portion of the enhancement. Both formats will illustrate the pre-computed great circle path (solid line) and the newly computed threat induced portion (dashed line). An example of the threat display during TTA flight is illustrated in Figure 48.

The pilot has the option of reverting to manual flight simply by hitting the paddle switch on the front of the stick which will keep the aircraft in TTA modes but will require hand flying. Reselection of automatic TTA mode has to be accomplished via the UFC. Complete deselection of TTA mode also has to be accomplished via the UFC. The HUD display for TTA is the same as for TF/TA except "ATA" for automatic TTA and "MTA" for manual TTA is displayed on the HUD.

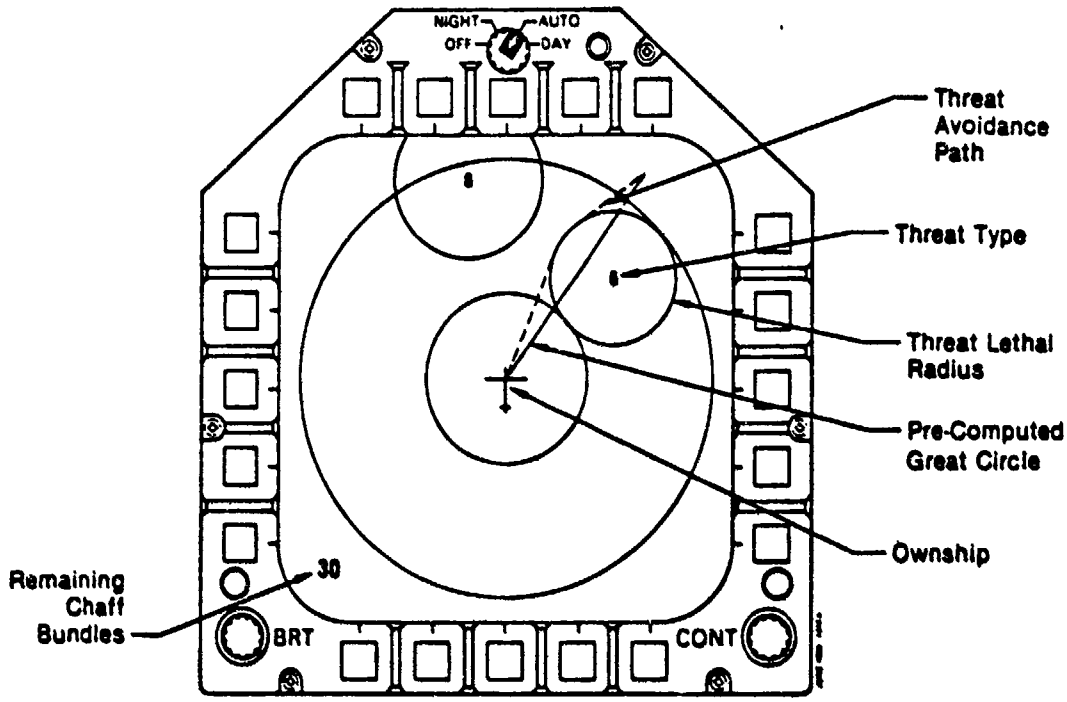


Figure 48 TTA Threat Display

TTA Ratings

Please give your best estimate of pilot workload for this configuration. You may refer back to any part of this document as needed. Ratings should be made by placing either a 1 (low), 2 (medium), or 3 (high) in each of the blank spaces below. Refer to page 5 of this document for a refresher on the definition of each of these ratings.

TTA

Segment	Time Load	Mental Effort Load	Psychological Stress Load
Penetration	_____	_____	_____
Target Acquisition	_____	_____	_____
Weapon Delivery	_____	_____	_____

Pilot Name: _____

Unit: _____

Your thoughts and comments on this part of the exercise are welcome. You may use the back of this page for any comments you may have. After completion of this page, remove it from this book and mail it, with the other two rating sheets, in the envelope provided. Please retain this book until you are directed to return it. At that time you should return it in the large envelope provided. Thank you for fine efforts.

APPENDIX D

SWAT WORKLOAD RATINGS SUMMARY

Table 26 SWAT Workload Ratings (1986), ABL Configuration

Segment	Subject	Group	Ratings			Workload Score
			TL	MEL	PSL	
PEN	1	Effort	3	3	2	95.1
	2	Time	2	2	2	59.9
	3	Effort	2	2	3	45.7
	4	Stress	2	2	2	52.2
	5	Time	2	2	2	59.9
	6	Stress	1	2	2	41.8
	7	Stress	2	1	3	59.0
	8	Stress	1	1	1	0.0
TF/TA	1	Effort	2	2	2	40.8
	2	Time	1	1	1	0.0
	3	Effort	3	2	2	70.0
	4	Stress	1	2	2	41.8
	5	Time	2	3	3	76.3
	6	Stress	2	2	3	72.0
	7	Stress	3	3	3	100.0
	8	Stress	2	2	2	52.2
TTA	1	Effort	2	1	2	16.0
	2	Time	3	3	3	100.0
	3	Effort	2	3	2	65.9
	4	Stress	1	2	2	41.8
	5	Time	2	2	2	59.9
	6	Stress	2	2	2	52.2
	7	Stress	2	2	2	52.2
	8	Stress	1	2	1	13.0

Table 27 SWAT Workload Ratings (1986), TF/TA Configuration

Segment	Subject	Group	Ratings			Workload Score
			TL	MEL	PSL	
PEN	1	Effort	2	2	1	26.2
	2	Time	2	3	2	70.4
	3	Effort	2	3	2	65.9
	4	Stress	1	2	2	41.8
	5	Time	2	3	3	76.3
	6	Stress	1	1	2	28.8
	7	Stress	2	2	3	72.0
	8	Stress	2	2	2	52.2
TF/TA	1	Effort	2	2	2	40.8
	2	Time	1	1	1	0.0
	3	Effort	3	1	2	45.2
	4	Stress	1	1	2	28.8
	5	Time	2	3	3	76.3
	6	Stress	2	2	2	52.2
	7	Stress	2	3	2	63.1
	8	Stress	1	1	1	0.0
TTA	1	Effort	2	1	2	16.0
	2	Time	2	2	1	45.7
	3	Effort	2	3	2	65.9
	4	Stress	1	2	2	41.8
	5	Time	2	2	2	59.9
	6	Stress	2	2	2	52.2
	7	Stress	1	1	1	0.0
	8	Stress	1	1	1	0.0

Table 28 SWAT Workload Ratings (1986), TTA Configuration

Segment	Subject	Group	Ratings			Workload Score
			TL	MEL	PSL	
PEN	1	Effort	2	1	2	16.0
	2	Time	2	2	2	59.9
	3	Effort	2	2	2	40.8
	4	Stress	1	2	1	13.0
	5	Time	2	2	2	59.9
	6	Stress	1	1	2	28.8
	7	Stress	1	1	3	48.5
	8	Stress	2	2	2	52.2
TF/TA	1	Effort	2	2	2	40.8
	2	Time	1	1	1	0.0
	3	Effort	3	1	2	45.2
	4	Stress	1	1	2	28.8
	5	Time	2	2	2	59.9
	6	Stress	2	2	2	52.2
	7	Stress	2	3	2	63.1
	8	Stress	2	2	2	52.2
TTA	1	Effort	2	1	1	1.4
	2	Time	2	3	3	76.3
	3	Effort	2	2	2	40.8
	4	Stress	1	2	2	41.8
	5	Time	2	2	2	59.9
	6	Stress	2	2	2	52.2
	7	Stress	1	1	1	0.0
	8	Stress	1	2	2	41.8

APPENDIX E

SIMULATION MODEL

INTER-ARRIVAL TIME AND SERVICE TIME DISTRIBUTIONS

This Appendix provides detailed information about the twelve different task categories used in the discrete event simulation models. This information is presented in four tables. The first of these, Table 29, presents all pertinent information by task category. It begins with the category title and an indication of whether the task is repetitive (R) or non-repetitive (N). TYPE is a number assigned to each category for identification purposes.

PRIORITY refers to the priority initially assigned to that task category, as described in Chapter IV. The task inter-arrival time and service time distributions are also listed, with appropriate parameter values. The mean values of each of these distributions presented in Table 29 apply to the Penetration Segment of the Advanced Baseline (ABL) configuration. The standard deviations apply to all segments and all configurations. The Multiple Resource Model requirements are also listed along with numerical codes (1 or 2) to designate which dimension of each resource is required. Finally, a brief verbal description of each task is presented.

Table 30 lists the mean values of the inter-arrival time and service time distributions for each flight segment and all cockpit configurations. Chapter IV describes in detail how these values were developed from those found in Table 29.

Table 29 Pilot Task Summary

	TASKS		
	FLY AIRCRAFT	NAVIGATE	ASSESS ENVIRONMENT
TASK TYPE	1	2	3
TASK PRIORITY	3	2	2
INTER-ARRIVAL TIME	NORM(9.5,1)	NORM(90,5)	NORM(55,1.5)
SERVICE TIME	EXP(1.509)	NORM(3,0.5)	NORM(3,0.7)
MULTIPLE RESOURCE MODEL			
MODALITY	VISUAL (1)	VISUAL (1)	VISUAL (1)
CODE	SPATIAL (2)	VERBAL (1)	SPATIAL (2)
STAGE	RESPOND (2)	ENCODE (1)	ENCODE (1)
REPETITIVE/ NONREPETITIVE	R	R	R

Table 29 Pilot Task Summary (Continued)

	TASKS		
	ASSESS MISSION PLAN	MONITOR/ASSESS AIRCRAFT SYSTEMS	CONFIGURE AIRCRAFT SYSTEMS
TASK TYPE	4	5	6
TASK PRIORITY	1	2	3
INTER-ARRIVAL TIME	NORM(250,20)	NORM(10,1)	NORM(35,3)
SERVICE TIME	NORM(5,1.2)	NORM(1,0.2)	NORM(1.9,.45)
MULTIPLE RESOURCE MODEL			
MODALITY	VISUAL (1)	VISUAL (1)	VISUAL (1)
CODE	VERBAL (1)	VERBAL (1)	SPATIAL (2)
STAGE	ENCODE (1)	ENCODE (1)	RESPOND (2)
REPETITIVE/ NONREPETITIVE	R	R	R

Table 29 Pilot Task Summary (Continued)

	TASKS		
	WAYPOINT ARRIVAL	MANEUVER AIRCRAFT	DEFENSIVE MANEUVER
TASK TYPE	7	8	9
TASK PRIORITY	3	3	3
INTER-ARRIVAL TIME	ONCE ONLY	ONCE ONLY	EXP(550)
SERVICE TIME	NORM(5,1)	NORM(9,2)	NORM(10,2)
MULTIPLE RESOURCE MODEL			
MODALITY	VISUAL (1)	VISUAL (1)	VISUAL (1)
CODE	SPATIAL (2)	SPATIAL (2)	SPATIAL (2)
STAGE	ENCODE (1)	RESPOND (2)	RESPOND (2)
REPETITIVE/ NONREPETITIVE	N	N	R

Table 29 Pilot Task Summary (Continued)

	TASKS		
	ACQUIRE TARGET	ACTIVATE OFFENSIVE SYSTEMS	COMMUNICATIONS
TASK TYPE	10	11	12
TASK PRIORITY	3	3	2
INTER-ARRIVAL TIME	NORM(16.95,4)	ONCE ONLY	ONCE ONLY
SERVICE TIME	NORM(4,0.9)	NORM(5,1)	NORM(10,2)
MULTIPLE RESOURCE MODEL			
MODALITY	VISUAL (1)	VISUAL (1)	AUDITORY (2)
CODE	SPATIAL (2)	SPATIAL (2)	VERBAL (1)
STAGE	ENCODE (1)	RESPOND (2)	ENCODE (2)
REPETITIVE/ NONREPETITIVE	R	N	N

Table 30 Task/Segment Summary, All Configurations, Mean Inter-arrival and Service Times

SEGMENT	PENETRATION		TARGET ACQUISITION		WEAPON DELIVERY	
TASK	$1/\lambda$	$1/\mu$	$1/\lambda$	$1/\mu$	$1/\lambda$	$1/\mu$
FLY AIRCRAFT	9.5	1.509	11.4	1.509	4.56	1.509
NAVIGATE	90.0	3.0	67.5	3.0	67.5	3.0
ASSESS ENVIRONMENT	55.0	3.0	18.0	3.0	18.0	3.0
ASSESS MISSION PLAN	250.0	5.0	150.0	5.0	150.0	5.0
MONITOR/ ASSESS AIRCRAFT SYSTEMS	10.0	1.0	6.0	1.0	6.0	1.0
CONFIGURE AIRCRAFT SYSTEMS	35.0	3.0	24.5	3.0	24.5	3.0
WAYPOINT ARRIVAL	300.0	5.0	----	---	----	---
MANEUVER AIRCRAFT	300.0	9.0	----	---	----	---
DEFENSIVE MANEUVER	550.0	10.0	357.5	10.0	357.5	10.0
ACQUIRE TARGET	----	---	16.95	4.0	----	---
ACTUATE OFFENSIVE SYSTEM	----	---	----	---	33.9	5.0
COMMUNI-CATIONS	600.0	10.0	----	---	----	---

$1/\lambda$ - Mean inter-arrival time
$1/\mu$ - Mean service time

APPENDIX F

SIMULATION PROGRAMS

The first part of this appendix lists the serial processing simulation program while the second part lists the parallel processing simulation program.

SERIAL PROCESSING MODEL:

```
PREAMBLE LAST COLUMN IS 72 ''
''PROGRAM SSABL - ENTIRE MISSION, 25 REPLICATIONS
EVENT NOTICES INCLUDE END.SIM, DATA.RESET,
     A.ARRIVAL, B.ARRIVAL, C.ARRIVAL,
     D.ARRIVAL, E.ARRIVAL, F.ARRIVAL,
     G.ARRIVAL, H.ARRIVAL, I.ARRIVAL,
     J.ARRIVAL, K.ARRIVAL, L.ARRIVAL,
     PEN.ACQ, ACQ.WPN
     EVERY E.O.S HAS A JOB
THE SYSTEM OWNS A QUEUE, AND A WORK
PERMANENT ENTITIES
     EVERY PILOT HAS A BUSY
TEMPORARY ENTITIES
     EVERY TASK HAS AN A.TIME, A TYPE, A PRIOR,
          A SERV.TIME AND MAY BELONG TO THE QUEUE, AND
          THE WORK
DEFINE SECONDS TO MEAN UNITS
DEFINE SIM.TIME, A.TIME, INT.4, INT.5, INT.6, INT.7,
     INT.8, INT.9, P.IDLE, A.IDLE, W.IDLE, INT.1, INT.2,
     INT.3, SERV.TIME AS REAL VARIABLES
DEFINE BUSY, TYPE, PRIOR, N, INTER, NUM.ARRIVE, JOB,
     NCOUNT, POSSIBLE.INT AS INTEGER VARIABLES
DEFINE P1.ARR, P2.ARR, P1.SERV, P2.SERV AS 1-DIM VARIABLES
DEFINE QUEUE AS A SET RANKED BY PRIOR
DEFINE PREEMPT AS A ROUTINE GIVEN 1 ARGUMENT
TALLY INT.TOT AS THE SUM OF INTER
TALLY ARR.TOT AS THE SUM OF NUM.ARRIVE
TALLY POS.TOT AS THE SUM OF POSSIBLE.INT
ACCUMULATE AV.BUSY AS THE MEAN OF BUSY
'' THE FOLLOWING STATEMENTS ARE USED TO COLLECT FINAL
'' STATISTICS
TALLY PEN.MEAN AS THE MEAN, PEN.VAR AS THE VARIANCE OF
   P.IDLE
TALLY ACQ.MEAN AS THE MEAN, ACQ.VAR AS THE VARIANCE OF
   A.IDLE
TALLY WPN.MEAN AS THE MEAN, WPN.VAR AS THE VARIANCE OF
   W.IDLE
```

```
TALLY PEN1.INT AS THE MEAN, PEN2.INT AS THE VARIANCE OF
   INT.1
TALLY ACQ1.INT AS THE MEAN, ACQ2.INT AS THE VARIANCE OF
   INT.2
TALLY WPN1.INT AS THE MEAN, WPN2.INT AS THE VARIANCE OF
   INT.3
TALLY PEN3.INT AS THE MEAN, PEN4.INT AS THE VARIANCE OF
   INT.4
TALLY ACQ3.INT AS THE MEAN, ACQ4.INT AS THE VARIANCE OF
   INT.5
TALLY WPN3.INT AS THE MEAN, WPN4.INT AS THE VARIANCE OF
   INT.6
TALLY PEN5.INT AS THE MEAN, PEN6.INT AS THE VARIANCE OF
   INT.7
TALLY ACQ5.INT AS THE MEAN, ACQ6.INT AS THE VARIANCE OF
   INT.8
TALLY WPN5.INT AS THE MEAN, WPN6.INT AS THE VARIANCE OF
   INT.9
END
MAIN
DEFINE II, J, REPS AS INTEGER VARIABLES
READ SIM.TIME, RESET.TIME
START NEW CARD
READ N, REPS
PRINT 3 LINES WITH N, REPS THUS
THIS EXPERIMENT MODELS A PILOT IN AN AIR-TO-GROUND MISSION
  *** DIFFERENT TASKS ARE USED TO LOAD THE PILOT.
  *** REPLICATIONS OF EACH MISSION ARE ACCOMPLISHED.
SKIP 2 LINES
RESERVE P1.ARR(*) AS N, P2.ARR(*) AS N,
        P1.SERV(*) AS N, P2.SERV(*) AS N
PRINT 2 LINES THUS
  TASK NUMBER    ARRIVAL RATE          SERVICE RATE
             PARAM 1     PARAM 2    PARAM 1     PARAM 2
FOR II = 1 TO N, DO
     START NEW CARD
     READ P1.ARR(II), P2.ARR(II), P1.SERV(II), P2.SERV(II)
     PRINT 1 LINE WITH II, P1.ARR(II), P2.ARR(II),
                           P1.SERV(II), P2.SERV(II) THUS
****      *.*****     *.*****    *.*****    *.*****
LOOP
SKIP 2 LINES
PRINT 2 LINES WITH SIM.TIME, RESET.TIME THUS
     TOTAL SIMULATION TIME =  ******   SECONDS
     DATA RESET TIME       =  ****.*   SECONDS
SKIP 2 LINES
LET N.PILOT = 1
CREATE EVERY PILOT
LET PILOT = 1
```

```
FOR J = 1 TO REPS
DO
   SCHEDULE AN A.ARRIVAL NOW
   SCHEDULE A B.ARRIVAL NOW
   SCHEDULE A C.ARRIVAL NOW
   SCHEDULE A D.ARRIVAL NOW
   SCHEDULE AN E.ARRIVAL NOW
   SCHEDULE A F.ARRIVAL NOW
   SCHEDULE A G.ARRIVAL IN 300. SECONDS
   SCHEDULE AN I.ARRIVAL NOW
   SCHEDULE A PEN.ACQ IN 500 SECONDS
   SCHEDULE A ACQ.WPN IN 545 SECONDS
   SCHEDULE A L.ARRIVAL IN 250. SECONDS
   SCHEDULE A DATA.RESET IN RESET.TIME SECONDS
   SCHEDULE AN END.SIM IN SIM.TIME SECONDS
   START SIMULATION
LOOP
PRINT 2 LINES THUS
              IDLE TIME RATIO SUMMARY
PHASE                    MEAN        STANDARD DEVIATION
PRINT 3 LINES WITH PEN.MEAN, SQRT.F(PEN.VAR/REPS),
                   ACQ.MEAN, SQRT.F(ACQ.VAR/REPS),
                   WPN.MEAN, SQRT.F(WPN.VAR/REPS) THUS
PENETRATION           *.****       **.*****
TARGET ACQUISITION    *.****       **.*****
WEAPON DELIVERY       *.****       **.*****
SKIP 2 LINES
PRINT 2 LINES THUS
          TASK INTERRUPTION RATIO SUMMARY
PHASE                    MEAN      STANDARD DEVIATION
PRINT 9 LINES WITH PEN1.INT, SQRT.F(PEN2.INT/REPS),
                   ACQ1.INT, SQRT.F(ACQ2.INT/REPS),
                   WPN1.INT, SQRT.F(WPN2.INT/REPS),
                   PEN3.INT, SQRT.F(PEN4.INT/REPS),
                   ACQ3.INT, SQRT.F(ACQ4.INT/REPS),
                   WPN3.INT, SQRT.F(WPN4.INT/REPS),
                   PEN5.INT, SQRT.F(PEN6.INT/REPS),
                   ACQ5.INT, SQRT.F(ACQ6.INT/REPS),
                   WPN5.INT, SQRT.F(WPN6.INT/REPS) THUS
PENETRATION           *.****       **.*****
TARGET ACQUISITION    *.****       **.*****
WEAPON DELIVERY       *.****       **.*****
PEN (NEW)             *.****       **.*****
ACQ (NEW)             *.****       **.*****
WPN (NEW)             *.****       **.*****
PEN (POSSIBLE)        *.****       **.*****
ACQ (POSSIBLE)        *.****       **.*****
WPN (POSSIBLE)        *.****       **.*****
CALL SNAP.R
STOP
END
```

```
EVENT A.ARRIVAL SAVING THE EVENT NOTICE
''FLY AIRCRAFT TASK
DEFINE NEW1 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW1
LET NUM.ARRIVE = 1
LET A.TIME(NEW1) = TIME.V
LET TYPE(NEW1) = 1
LET SERV.TIME(NEW1) = EXPONENTIAL.F(P1.SERV(1), 1)
LET PRIOR(NEW1) = 3
CALL PREEMPT GIVEN NEW1
RESCHEDULE THIS A.ARRIVAL IN
   NORMAL.F(P1.ARR(1), P2.ARR(1),1) SECONDS
RETURN
END
EVENT B.ARRIVAL SAVING THE EVENT NOTICE
''NAVIGATE TASK
DEFINE NEW2 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW2
LET NUM.ARRIVE = 1
LET A.TIME(NEW2) = TIME.V
LET TYPE(NEW2) = 2
LET SERV.TIME(NEW2) =
    NORMAL.F(P1.SERV(2), P2.SERV(2), 2)
LET PRIOR(NEW2) = 2
CALL PREEMPT GIVEN NEW2
RESCHEDULE THIS B.ARRIVAL IN
    NORMAL.F(P1.ARR(2), P2.ARR(2), 2) SECONDS
RETURN
END
EVENT C.ARRIVAL SAVING THE EVENT NOTICE
''ASSESS ENVIRONMENT TASK
DEFINE NEW3 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW3
LET NUM.ARRIVE = 1
LET A.TIME(NEW3) = TIME.V
LET TYPE(NEW3) = 3
LET SERV.TIME(NEW3) =
    NORMAL.F(P1.SERV(3), P2.SERV(3), 3)
LET PRIOR(NEW3) = 2
CALL PREEMPT GIVEN NEW3
RESCHEDULE THIS C.ARRIVAL IN
    NORMAL.F(P1.ARR(3), P2.ARR(3), 3) SECONDS
RETURN
END
EVENT D.ARRIVAL SAVING THE EVENT NOTICE
''ASSESS MISSION PLAN TASK
DEFINE NEW4 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW4
LET NUM.ARRIVE = 1
LET A.TIME(NEW4) = TIME.V
LET TYPE(NEW4) = 4
LET SERV.TIME(NEW4) = NORMAL.F(P1.SERV(4), P2.SERV(4), 4)
```

```
LET PRIOR(NEW4) = 1
CALL PREEMPT GIVEN NEW4
RESCHEDULE THIS D.ARRIVAL IN
    NORMAL.F(P1.ARR(4), P2.ARR(4), 4) SECONDS
RETURN
END
EVENT E.ARRIVAL SAVING THE EVENT NOTICE
''MONITOR/ASSESS AIRCRAFT SYSTEMS TASK
DEFINE NEW5 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW5
LET NUM.ARRIVE = 1
LET A.TIME(NEW5) = TIME.V
LET TYPE(NEW5) = 5
LET SERV.TIME(NEW5) = NORMAL.F(P1.SERV(5), P2.SERV(5), 5)
LET PRIOR(NEW5) = 2
CALL PREEMPT GIVEN NEW5
RESCHEDULE THIS E.ARRIVAL IN
    NORMAL.F(P1.ARR(5), P2.ARR(5), 5) SECONDS
RETURN
END
EVENT F.ARRIVAL SAVING THE EVENT NOTICE
''CONFIGURE AIRCRAFT SYSTEMS TASK
DEFINE NEW6 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW6
LET NUM.ARRIVE = 1
LET A.TIME(NEW6) = TIME.V
LET TYPE(NEW6) = 6
LET SERV.TIME(NEW6) = NORMAL.F(P1.SERV(6), P2.SERV(6), 6)
LET PRIOR(NEW6) = 3
CALL PREEMPT GIVEN NEW6
RESCHEDULE THIS F.ARRIVAL IN
    NORMAL.F<xI P2.ARR(6), 6) SECONDS
RETURN
END
EVENT G.ARRIVAL SAVING THE EVENT NOTICE
''WAYPOINT ARRIVAL TASK
DEFINE NEW7 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW7
LET NUM.ARRIVE = 1
LET A.TIME(NEW7) = TIME.V
LET TYPE(NEW7) = 7
LET SERV.TIME(NEW7) = NORMAL.F(P1.SERV(7), P2.SERV(7), 9)
LET PRIOR(NEW7) = 3
CALL PREEMPT GIVEN NEW7
RETURN
END
EVENT H.ARRIVAL SAVING THE EVENT NOTICE
''MANEUVER AIRCRAFT TASK
DEFINE NEW8 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW8
LET NUM.ARRIVE = 1
LET A.TIME(NEW8) = TIME.V
```

```
LET TYPE(NEW8) = 8
LET SERV.TIME(NEW8) = NORMAL.F(P1.SERV(8), P2.SERV(8), 9)
LET PRIOR(NEW8) = 3
CALL PREEMPT GIVEN NEW8
RETURN
END
EVENT I.ARRIVAL SAVING THE EVENT NOTICE
''DEFENSIVE MANEUVER TASK
DEFINE NEW9 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW9
LET NUM.ARRIVE = 1
LET A.TIME(NEW9) = TIME.V
LET TYPE(NEW9) = 9
LET SERV.TIME(NEW9) = NORMAL.F(P1.SERV(9), P2.SERV(9), 7)
LET PRIOR(NEW9) = 3
CALL PREEMPT GIVEN NEW9
RESCHEDULE THIS I.ARRIVAL IN EXPONENTIAL.F(P1.ARR(9), 7)
    SECONDS
RETURN
END
EVENT J.ARRIVAL SAVING THE EVENT NOTICE
''ACQUIRE TARGET TASK
DEFINE NEW10 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW10
LET NUM.ARRIVE = 1
LET A.TIME(NEW10) = TIME.V
LET TYPE(NEW10) = 10
LET SERV.TIME(NEW10) =
    NORMAL.F(P1.SERV(10), P2.SERV(10), 8)
LET PRIOR(NEW10) = 3
CALL PREEMPT GIVEN NEW10
RESCHEDULE THIS J.ARRIVAL IN
    NORMAL.F(P1.ARR(10),P2.ARR(10),8) SECONDS
RETURN
END
EVENT K.ARRIVAL SAVING THE EVENT NOTICE
''ACTIVATE OFFENSIVE SYSTEM TAS"
DEFINE NEW11 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW11
LET NUM.ARRIVE = 1
LET A.TIME(NEW11) = TIME.V
LET TYPE(NEW11) = 11
LET SERV.TIME(NEW11) =
    NORMAL.F(P1.SERV(11), P2.SERV(11), 9)
LET PRIOR(NEW11) = 3
CALL PREEMPT GIVEN NEW11
RETURN
END
EVENT L.ARRIVAL SAVING THE EVENT NOTICE
''COMMUNICATIONS TASK
DEFyNE NEW12 AS AN INTEGER VARIABLE
CREATE A TASK CALLED NEW12
```

```
LET NUM.ARRIVE = 1
LET A.TIME(NEW12) = TIME.V
LET TYPE(NEW12) = 12
LET SERV.TIME(NEW12) =
    NORMAL.F(P1.SERV(12), P2.SERV(12), 9)
LET PRIOR(NEW12) = 2
CALL PREEMPT GIVEN NEW12
RETURN
END
EVENT PEN.ACQ
'' THIS EVENT CAUSES A TRANSITION FROM THE PENETRATION
'' PHASE TO THE TARGET ACQUISITION PHASE
LET P.IDLE = 1 - AV.BUSY
LET INT.1 = INT.TOT/ARR.TOT
LET INT.4 = INT.TOT/(ARR.TOT-NCOUNT)
LET INT.7 = POS.TOT/(ARR.TOT-NCOUNT)
LET NCOUNT = 0
SCHEDULE A J.ARRIVAL NOW
RESET THE TOTALS OF BUSY, INTER, NUM.ARRIVE, POSSIBLE.INT
LET P1.ARR(1) = 1.2*P1.ARR(1)
LET P1.ARR(2) = 0.75*P1.ARR(2)
LET P1.ARR(3) = 0.6*P1.ARR(3)
LET P1.ARR(4) = 0.6*P1.ARR(4)
LET P1.ARR(5) = 0.6*P1.ARR(5)
LET P1.ARR(6) = 0.7*P1.ARR(6)
LET P1.ARR(9) = 0.65*P1.ARR(9)
RETURN
END
EVENT ACQ.WPN
'' THIS EVENT CAUSES A TRANSITION FROM THE TARGET
'' ACQUISTION PHASE TO THE WEAPON DELIVERY PHASE
LET A.IDLE = 1 - AV.BUSY
LET INT.2 = INT.TOT/ARR.TOT
LET INT.5 = INT.TOT/(ARR.TOT - NCOUNT)
LET INT.8 = POS.TOT/(ARR.TOT - NCOUNT)
LET NCOUNT = 0
SCHEDULE A K.ARRIVAL IN 10.0 SECONDS
RESET THE TOTALS OF BUSY, INTER, NUM.ARRIVE, POSSIBLE.INT
LET P1.ARR(1) = 0.4*P1.ARR(1)
RETURN
END
ROUTINE PREEMPT GIVEN NEW
DEFINE NEW AS AN INTEGER VARIABLE
IF BUSY(PILOT) = 1
   LET POSSIBLE.INT = 1
   FOR EACH TASK IN WORK
   DO
      IF PRIOR(NEW) GT PRIOR(TASK)
         REMOVE THE FIRST TASK FROM WORK
         REMOVE THIS E.O.S FROM EV.S(I.E.O.S)
         LET SERV.TIME(TASK) =
            NORMAL.F(P1.SERV(TYPE(TASK)),
```

```
            P2.SERV(TYPE(TASK)), 10)
         FILE THIS TASK IN QUEUE
         FILE THIS NEW IN WORK
         LET INTER = 1
         LET NUM.ARRIVE = 1
         LET NCOUNT = NCOUNT +1
         SCHEDULE AN E.O.S(NEW) IN SERV.TIME(NEW) SECONDS
      ELSE
         FILE THIS NEW IN QUEUE
      ALWAYS
   LOOP
ELSE
   FILE THIS NEW IN WORK
   LET BUSY(PILOT) = 1
   SCHEDULE AN E.O.S(NEW) IN SERV.TIME(NEW) SECONDS
ALWAYS
RETURN
END
EVENT E.O.S(TASK)
DEFINE TASK AS AN INTEGER VARIABLE
IF TYPE(TASK) = 7
   SCHEDULE AN H.ARRIVAL NOW
ALWAYS
REMOVE THIS TASK FROM WORK
DESTROY THIS TASK CALLED TASK
IF QUEUE IS EMPTY
     LET BUSY(PILOT) = 0
ELSE
     FOR EACH TASK IN QUEUE
     DO
        IF TYPE(TASK) = 12
           IF TIME.V - A.TIME(TASK) GT 50.0
              ADD 1 TO PRIOR(TASK)
           ALWAYS
        ELSE
           IF TIME.V - A.TIME(TASK) GT 10.0
              ADD 1 TO PRIOR(TASK)
           ALWAYS
        ALWAYS
     LOOP
     REMOVE FIRST TASK FROM QUEUE
     FILE THIS TASK IN WORK
     SCHEDULE AN E.O.S(TASK) IN SERV.TIME(TASK)
          SECONDS
ALWAYS
RETURN
END
EVENT END.SIM
'' THIS EVENT ENDS THE SIMULATION AND COMPUTES FINAL
'' STATISTICS
LET W.IDLE = 1 - AV.BUSY
LET INT.3 = INT.TOT/ARR.TOT
```

```
LET INT.6 = INT.TOT/(ARR.TOT - NCOUNT)
LET INT.9 = POS.TOT/(ARR.TOT - NCOUNT)
LET NCOUNT = 0
LET P1.ARR(1) = 2.083*P1.ARR(1)
LET P1.ARR(2) = 1.333*P1.ARR(2)
LET P1.ARR(3) = 1.667*P1.ARR(3)
LET P1.ARR(4) = 1.667*P1.ARR(4)
LET P1.ARR(5) = 1.667*P1.ARR(5)
LET P1.ARR(6) = 1.429*P1.ARR(6)
LET P1.ARR(9) = 1.538*P1.ARR(9)
LET TIME.V = 0
LET BUSY(PILOT) = 0
RESET THE TOTALS OF INTER, NUM.ARRIVE, BUSY, POSSIBLE.INT
FOR EVERY A.ARRIVAL IN EV.S(I.A.ARRIVAL), DO
   REMOVE THIS A.ARRIVAL FROM EV.S(I.A.ARRIVAL)
   DESTROY THIS A.ARRIVAL
LOOP
FOR EVERY B.ARRIVAL IN EV.S(I.B.ARRIVAL), DO
   REMOVE THIS B.ARRIVAL FROM EV.S(I.B.ARRIVAL)
   DESTROY THIS B.ARRIVAL
LOOP
FOR EVERY C.ARRIVAL IN EV.S(I.C.ARRIVAL), DO
   REMOVE THIS C.ARRIVAL FROM EV.S(I.C.ARRIVAL)
   DESTROY THIS C.ARRIVAL
LOOP
FOR EVERY D.ARRIVAL IN EV.S(I.D.ARRIVAL), DO
   REMOVE THIS D.ARRIVAL FROM EV.S(I.D.ARRIVAL)
   DESTROY THIS D.ARRIVAL
LOOP
FOR EVERY E.ARRIVAL IN EV.S(I.E.ARRIVAL), DO
   REMOVE THIS E.ARRIVAL FROM EV.S(I.E.ARRIVAL)
   DESTROY THIS E.ARRIVAL
LOOP
FOR EVERY F.ARRIVAL IN EV.S(I.F.ARRIVAL), DO
   REMOVE THIS F.ARRIVAL FROM EV.S(I.F.ARRIVAL)
   DESTROY THIS F.ARRIVAL
LOOP
FOR EVERY G.ARRIVAL IN EV.S(I.G.ARRIVAL), DO
   REMOVE THIS G.ARRIVAL FROM EV.S(I.G.ARRIVAL)
   DESTROY THIS G.ARRIVAL
LOOP
FOR EVERY H.ARRIVAL IN EV.S(I.H.ARRIVAL), DO
   REMOVE THIS H.ARRIVAL FROM EV.S(I.H.ARRIVAL)
   DESTROY THIS H.ARRIVAL
LOOP
FOR EVERY I.ARRIVAL IN EV.S(I.I.ARRIVAL), DO
   REMOVE THIS I.ARRIVAL FROM EV.S(I.I.ARRIVAL)
   DESTROY THIS I.ARRIVAL
LOOP
FOR EVERY J.ARRIVAL IN EV.S(I.J.ARRIVAL), DO
   REMOVE THIS J.ARRIVAL FROM EV.S(I.J.ARRIVAL)
   DESTROY THIS J.ARRIVAL
```

```
LOOP
FOR EVERY K.ARRIVAL IN EV.S(I.K.ARRIVAL), DO
   REMOVE THIS K.ARRIVAL FROM EV.S(I.K.ARRIVAL)
   DESTROY THIS K.ARRIVAL
LOOP
FOR EVERY L.ARRIVAL IN EV.S(I.L.ARRIVAL), DO
   REMOVE THIS L.ARRIVAL FROM EV.S(I.L.ARRIVAL)
   DESTROY THIS L.ARRIVAL
LOOP
FOR EVERY E.O.S IN EV.S(I.E.O.S), DO
   REMOVE THIS E.O.S FROM EV.S(I.E.O.S)
   DESTROY THIS E.O.S
LOOP
FOR EVERY TASK IN WORK, DO
   REMOVE THIS TASK FROM WORK
   DESTROY THIS TASK
LOOP
FOR EVERY TASK IN QUEUE, DO
   REMOVE THIS TASK FROM QUEUE
   DESTROY THIS TASK
LOOP
RETURN
END
EVENT DATA.RESET
RESET THE TOTALS OF BUSY, INTER, NUM.ARRIVE, POSSIBLE.INT
LET NCOUNT = 0
RETURN
END
ROUTINE SNAP.R
FOR EACH TASK IN QUEUE, LIST ATTRIBUTES OF TASK
FOR EACH TASK IN WORK, LIST ATTRIBUTES OF TASK
LIST ATTRIBUTES OF EACH A.ARRIVAL IN EV.S(I.A.ARRIVAL)
LIST ATTRIBUTES OF EACH B.ARRIVAL IN EV.S(I.B.ARRIVAL)
LIST ATTRIBUTES OF EACH C.ARRIVAL IN EV.S(I.C.ARRIVAL)
LIST ATTRIBUTES OF EACH D.ARRIVAL IN EV.S(I.D.ARRIVAL)
LIST ATTRIBUTES OF EACH E.ARRIVAL IN EV.S(I.E.ARRIVAL)
LIST ATTRIBUTES OF EACH F.ARRIVAL IN EV.S(I.F.ARRIVAL)
LIST ATTRIBUTES OF EACH G.ARRIVAL IN EV.S(I.G.ARRIVAL)
LIST ATTRIBUTES OF EACH H.ARRIVAL IN EV.S(I.H.ARRIVAL)
LIST ATTRIBUTES OF EACH I.ARRIVAL IN EV.S(I.I.ARRIVAL)
LIST ATTRIBUTES OF EACH J.ARRIVAL IN EV.S(I.J.ARRIVAL)
LIST ATTRIBUTES OF EACH K.ARRIVAL IN EV.S(I.K.ARRIVAL)
LIST ATTRIBUTES OF EACH L.ARRIVAL IN EV.S(I.L.ARRIVAL)
LIST ATTRIBUTES OF EACH E.O.S IN EV.S(I.E.O.S)
LIST TIME.V, N.WORK, N.QUEUE, BUSY(PILOT)
SKIP 2 LINES
RETURN
END
```

PARALLEL PROCESSING MODEL:

```
PREAMBLE LAST COLUMN IS 72 ''
''PROGRAM MRMABL - COMPLETE MISSION, 25 REPS
EVENT NOTICES INCLUDE END.SIM, DATA.RESET,
     A.ARRIVAL, B.ARRIVAL, C.ARRIVAL, D.ARRIVAL,
     E.ARRIVAL, F.ARRIVAL, G.ARRIVAL, H.ARRIVAL,
     I.ARRIVAL, J.ARRIVAL, K.ARRIVAL, L.ARRIVAL,
     PEN.ACQ, ACQ.WPN
     EVERY E.O.S HAS A JOB
THE SYSTEM OWNS A QUEUE, A WORK, A TEMP1, A TEMP2, AND
     A TEMP3
PERMANENT ENTITIES INCLUDE PILOT
TEMPORARY ENTITIES
     EVERY TASK HAS AN A.TIME, A TYPE, A PRIOR,
     A SERV.TIME, A COMP.TIME, A REM.TIME, A MODAL,
     A CODE, A STAGE, AN EVPOINTER AND MAY BELONG TO THE
     QUEUE, THE WORK, THE TEMP1, THE TEMP2, AND THE TEMP3
DEFINE SECONDS TO MEAN UNITS
DEFINE SIM.TIME, A.TIME,
     P.IDLE, A.IDLE, W.IDLE, SIM.1, SIM.2, SIM.3,
     UP.TOTAL, DEG.TOTAL, SERV.TIME
     AS REAL VARIABLES
DEFINE BUSY, TYPE, PRIOR, N, NUM.ARRIVE, JOB, MODAL,
     CODE, STAGE, SIMUL, EVPOINTER
     AS INTEGER VARIABLES
DEFINE P1.ARR, P2.ARR, P1.SERV, P2.SERV AS 1-DIM VARIABLES
DEFINE MRM, TEST AS INTEGER, 2-DIM VARIABLES
DEFINE QUEUE AS A SET RANKED BY PRIOR
DEFINE WORK AS A SET RANKED BY LOW COMP.TIME
DEFINE TEMP1 AS A SET RANKED BY REM.TIME
DEFINE TEMP2 AS A SET RANKED BY REM.TIME
DEFINE PREEMPT AS A ROUTINE GIVEN 2 ARGUMENTS
DEFINE DEGRADE AS A ROUTINE GIVEN 1 ARGUMENT
DEFINE UPGRADE AS A ROUTINE GIVEN 1 ARGUMENT
DEFINE CHANGE AS A ROUTINE GIVEN 1 ARGUMENTS
DEFINE ADJUST AS A ROUTINE GIVEN 2 ARGUMENTS
DEFINE RECOVER AS A ROUTINE
DEFINE CORRECT AS A ROUTINE
TALLY SIM.TOT AS THE SUM OF SIMUL
TALLY ARR.TOT AS THE SUM OF NUM.ARRIVE
ACCUMULATE AV.BUSY AS THE MEAN OF BUSY
'' THE FOLLOWING STATEMENTS ARE USED TO COLLECT FINAL
'' STATISTICS
TALLY PEN.MEAN AS THE MEAN, PEN.VAR AS THE VARIANCE OF
    P.IDLE
TALLY ACQ.MEAN AS THE MEAN, ACQ.VAR AS THE VARIANCE OF
    A.IDLE
TALLY WPN.MEAN AS THE MEAN, WPN.VAR AS THE VARIANCE OF
    W.IDLE
TALLY PEN1.SIM AS THE MEAN, PEN2.SIM AS THE VARIANCE OF
```

```
    SIM.1
TALLY ACQ1.SIM AS THE MEAN, ACQ2.SIM AS THE VARIANCE OF
    SIM.2
TALLY WPN1.SIM AS THE MEAN, WPN2.SIM AS THE VARIANCE OF
    SIM.3
END
MAIN
DEFINE II, J, REPS AS INTEGER VARIABLES
READ SIM.TIME, RESET.TIME
START NEW CARD
READ N, REPS
PRINT 4 LINES WITH N, REPS THUS
THIS EXPERIMENT USES A MULTIPLE RESOURCE MODEL
TO DESCRIBE A PILOT IN AN AIR-TO-GROUND MISSION.
** DIFFERENT TASKS ARE USED TO LOAD THE PILOT.
*** REPLICATIONS OF EACH MISSION ARE ACCOMPLISHED.
SKIP 2 LINES
RESERVE P1.ARR(*) AS N, P1.SERV(*) AS N,
        P2.ARR(*) AS N, P2.SERV(*) AS N
RESERVE MRM(*,*), TEST(*,*) AS 2 BY 3
PRINT 2 LINES THUS
   TASK NUMBER    ARRIVAL RATE     SERVICE RATE
              PARAM 1   PARAM 2  PARAM 1     PARAM 2
FOR II = 1 TO N, DO
     START NEW CARD
     READ P1.ARR(II), P2.ARR(II), P1.SERV(II), P2.SERV(II)
     PRINT 1 LINE WITH II, P1.ARR(II), P2.ARR(II),
       P1.SERV(II), P2.SERV(II) THUS
   ***       *.***     *.***      *.***       *.***
LOOP
SKIP 2 LINES
PRINT 2 LINES WITH SIM.TIME, RESET.TIME THUS
     TOTAL SIMULATION TIME =  ******   SECONDS
     DATA RESET TIME       =  ****.*   SECONDS
SKIP 2 LINES
LET N.PILOT = 1
CREATE EVERY PILOT
LET PILOT = 1
FOR J = 1 TO REPS, DO
   SCHEDULE AN A.ARRIVAL NOW
   SCHEDULE A B.ARRIVAL NOW
   SCHEDULE A C.ARRIVAL NOW
   SCHEDULE A D.ARRIVAL NOW
   SCHEDULE AN E.ARRIVAL NOW
   SCHEDULE AN F.ARRIVAL NOW
   SCHEDULE A G.ARRIVAL IN 300.0 SECONDS
   SCHEDULE AN I.ARRIVAL IN EXPONENTIAL.F(P1.ARR(9),10)
      SECONDS
   SCHEDULE A PEN.ACQ IN 500 SECONDS
   SCHEDULE A ACQ.WPN IN 545 SECONDS
   SCHEDULE AN L.ARRIVAL IN 250.0 SECONDS
   SCHEDULE A DATA.RESET IN RESET.TIME SECONDS
```

```
   SCHEDULE AN END.SIM IN SIM.TIME SECONDS
   START SIMULATION
LOOP
PRINT 2 LINES THUS
                IDLE TIME RATIO SUMMARY
PHASE                 MEAN            STANDARD DEVIATION
PRINT 3 LINES WITH PEN.MEAN, SQRT.F(PEN.VAR/REPS),
                   ACQ.MEAN, SQRT.F(ACQ.VAR/REPS),
                   WPN.MEAN, SQRT.F(WPN.VAR/REPS) THUS
PENETRATION          *.*****                 *.*****
TARGET ACQUISITION   *.*****                 *.*****
WEAPON DELIVERY      *.*****                 *.*****
SKIP 2 LINES
PRINT 2 LINES THUS
           SIMULTANEOUS TASK RATE SUMMARY
PHASE                MEAN           STANDARD DEVIATION
PRINT 3 LINES WITH PEN1.SIM, SQRT.F(PEN2.SIM/REPS),
                   ACQ1.SIM, SQRT.F(ACQ2.SIM/REPS),
                   WPN1.SIM, SQRT.F(WPN2.SIM/REPS) THUS
PENETRATION          *.*****                 *.*****
TARGET ACQUISITION   *.*****                 *.*****
WEAPON DELIVERY      *.*****                 *.*****
CALL SNAP.R
STOP
END
EVENT A.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW1, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW1
LET NUM.ARRIVE = 1
LET A.TIME(NEW1) = TIME.V
LET TYPE(NEW1) = 1
LET SERV.TIME(NEW1) = EXPONENTIAL.F(P1.SERV(1), 1)
LET PRIOR(NEW1) = 3
LET MODAL(NEW1) = 1
LET CODE(NEW1) = 2
LET STAGE(NEW1) = 2
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0
   CALL ADJUST GIVEN NEW1, KEY
ELSE
   CALL DEGRADE GIVEN NEW1
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW1, KEY
   ELSE
      IF PRIOR(NEW1) GT 1
         CALL PREEMPT GIVEN NEW1, KEY
      ELSE
         FILE NEW1 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
```

```
CALL STATUS
RESCHEDULE THIS A.ARRIVAL IN
    NORMAL.F(P1.ARR(1), P2.ARR(1), 1) SECONDS
RETURN
END
EVENT B.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW2, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW2
LET NUM.ARRIVE = 1
LET A.TIME(NEW2) = TIME.V
LET TYPE(NEW2) = 2
LET SERV.TIME(NEW2) = NORMAL.F(P1.SERV(2), P2.SERV(2),2)
LET PRIOR(NEW2) = 2
LET MODAL(NEW2) = 1
LET CODE(NEW2) = 1
LET STAGE(NEW2) = 1
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0.
   CALL ADJUST GIVEN NEW2, KEY
ELSE
   CALL DEGRADE GIVEN NEW2
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW2, KEY
   ELSE
      IF PRIOR(NEW2) GT 1
         CALL PREEMPT GIVEN NEW2, KEY
      ELSE
         FILE NEW2 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RESCHEDULE THIS B.ARRIVAL IN
    NORMAL.F(P1.ARR(2), P2.ARR(2), 2) SECONDS
RETURN
END
EVENT C.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW3, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW3
LET NUM.ARRIVE = 1
LET A.TIME(NEW3) = TIME.V
LET TYPE(NEW3) = 3
LET SERV.TIME(NEW3) = NORMAL.F(P1.SERV(3), P2.SERV(3),3)
LET PRIOR(NEW3) = 1
LET MODAL(NEW3) = 1
LET CODE(NEW3) = 2
LET STAGE(NEW3) = 1
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0.
   CALL ADJUST GIVEN NEW3, KEY
```

```
ELSE
   CALL DEGRADE GIVEN NEW3
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW3, KEY
   ELSE
      IF PRIOR(NEW3) GT 1
         CALL PREEMPT GIVEN NEW3, KEY
      ELSE
         FILE NEW3 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RESCHEDULE THIS C.ARRIVAL IN
    NORMAL.F(P1.ARR(3), P2.ARR(3), 3) SECONDS
RETURN
END
EVENT D.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW4, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW4
LET NUM.ARRIVE = 1
LET A.TIME(NEW4) = TIME.V
LET TYPE(NEW4) = 4
LET SERV.TIME(NEW4) = NORMAL.F(P1.SERV(4), P2.SERV(4), 4)
LET PRIOR(NEW4) = 1
LET MODAL(NEW4) = 1
LET CODE(NEW4) = 1
LET STAGE(NEW4) = 1
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0
   CALL ADJUST GIVEN NEW4, KEY
ELSE
   CALL DEGRADE GIVEN NEW4
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW4, KEY
   ELSE
      IF PRIOR(NEW4) GT 1
         CALL PREEMPT GIVEN NEW4, KEY
      ELSE
         FILE NEW4 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RESCHEDULE THIS D.ARRIVAL IN
    NORMAL.F(P1.ARR(4), P2.ARR(4), 4) SECONDS
RETURN
END
EVENT E.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW5, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW5
```

```
LET NUM.ARRIVE = 1
LET A.TIME(NEW5) = TIME.V
LET TYPE(NEW5) = 5
LET SERV.TIME(NEW5) = NORMAL.F(P1.SERV(5), P2.SERV(5),5)
LET PRIOR(NEW5) = 2
LET MODAL(NEW5) = 1
LET CODE(NEW5) = 1
LET STAGE(NEW5) = 1
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0.
   CALL ADJUST GIVEN NEWS, KEY
ELSE
   CALL DEGRADE GIVEN NEW5
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW5, KEY
   ELSE
      IF PRIOR(NEW5) GT 1
         CALL PREEMPT GIVEN NEW5, KEY
      ELSE
         FILE NEW5 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RESCHEDULE THIS E.ARRIVAL IN
    NORMAL.F(P1.ARR(5), P2.ARR(5), 5) SECONDS
RETURN
END
EVENT F.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW6, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW6
LET NUM.ARRIVE = 1
LET A.TIME(NEW6) = TIME.V
LET TYPE(NEW6) = 6
LET SERV.TIME(NEW6) = NORMAL.F(P1.SERV(6), P2.SERV(6),6)
LET PRIOR(NEW6) = 3
LET MODAL(NEW6) = 1
LET CODE(NEW6) = 2
LET STAGE(NEW6) = 2
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0.
   CALL ADJUST GIVEN NEW6, KEY
ELSE
   CALL DEGRADE GIVEN NEW6
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW6, KEY
   ELSE
      IF PRIOR(NEW6) GT 1
         CALL PREEMPT GIVEN NEW6, KEY
      ELSE
```

```
            FILE NEW6 IN QUEUE
         ALWAYS
      ALWAYS
ALWAYS
CALL STATUS
RESCHEDULE THIS F.ARRIVAL IN NORMAL.F(P1.ARR %I SECONDS
RETURN
END
EVENT G.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW7, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW7
LET NUM.ARRIVE = 1
LET A.TIME(NEW7) = TIME.V
LET TYPE(NEW7) = 7
LET SERV.TIME(NEW7) = NORMAL.F(P1.SERV(7), P2.SERV(7) ,9)
LET PRIOR(NEW7) = 3
LET MODAL(NEW7) = 1
LET CODE(NEW7) = 2
LET STAGE(NEW7) = 1
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0
   CALL ADJUST GIVEN NEW7, KEY
ELSE
   CALL DEGRADE GIVEN NEW7
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW7, KEY
   ELSE
      IF PRIOR(NEW7) GT 1
         CALL PREEMPT GIVEN NEW7, KEY
      ELSE
         FILE NEW7 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RETURN
END
EVENT H.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW8, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW8
LET NUM.ARRIVE = 1
LET A.TIME(NEW8) = TIME.V
LET TYPE(NEW8) = 8
LET SERV.TIME(NEW8) = NORMAL.F(P1.SERV(8), P2.SERV(8),9)
LET PRIOR(NEW8) = 3
LET MODAL(NEW8) = 1
LET CODE(NEW8) = 2
LET STAGE(NEW8) = 2
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0.
```

```
   CALL ADJUST GIVEN NEW8, KEY
ELSE
   CALL DEGRADE GIVEN NEW8
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW8, KEY
   ELSE
      IF PRIOR(NEW8) GT 1
         CALL PREEMPT GIVEN NEW8, KEY
      ELSE
         FILE NEW8 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RETURN
END
EVENT I.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW9, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW9
LET NUM.ARRIVE = 1
LET A.TIME(NEW9) = TIME.V
LET TYPE(NEW9) = 9
LET SERV.TIME(NEW9) = NORMAL.F(P1.SERV(9), P2.SERV(9),7)
LET PRIOR(NEW9) = 3
LET MODAL(NEW9) = 1
LET CODE(NEW9) = 2
LET STAGE(NEW9) = 2
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0.
   CALL ADJUST GIVEN NEW9, KEY
ELSE
   CALL DEGRADE GIVEN NEW9
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW9, KEY
   ELSE
      IF PRIOR(NEW9) GT 1
         CALL PREEMPT GIVEN NEW9, KEY
      ELSE
         FILE NEW9 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RESCHEDULE THIS I.ARRIVAL IN
    EXPONENTIAL.F(P1.ARR(9), 7) SECONDS
RETURN
END
EVENT J.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW10, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW10
LET NUM.ARRIVE = 1
```

```
LET A.TIME(NEW10) = TIME.V
LET TYPE(NEW10) = 10
LET SERV.TIME(NEW10) =
    NORMAL.F(P1.SERV(10), P2.SERV(10), 8)
LET PRIOR(NEW10) = 3
LET MODAL(NEW10) = 1
LET CODE(NEW10) = 2
LET STAGE(NEW10) = 1
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0
   CALL ADJUST GIVEN NEW10, KEY
ELSE
   CALL DEGRADE GIVEN NEW10
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW10, KEY
   ELSE
      IF PRIOR(NEW10) GT 1
         CALL PREEMPT GIVEN NEW10, KEY
      ELSE
         FILE NEW10 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RESCHEDULE THIS J.ARRIVAL IN
    NORMAL.F(P1.ARR(10), P2.ARR(10), 8) SECONDS
RETURN
END
EVENT K.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW11, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW11
LET NUM.ARRIVE = 1
LET A.TIME(NEW11) = TIME.V
LET TYPE(NEW11) = 11
LET SERV.TIME(NEW11) =
    NORMAL.F(P1.SERV(11), P2.SERV(11),9)
LET PRIOR(NEW11) = 3
LET MODAL(NEW11) = 1
LET CODE(NEW11) = 2
LET STAGE(NEW11) = 2
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0.
   CALL ADJUST GIVEN NEW11, KEY
ELSE
   CALL DEGRADE GIVEN NEW11
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW11, KEY
   ELSE
      IF PRIOR(NEW11) GT 1
         CALL PREEMPT GIVEN NEW11, KEY
```

```
      ELSE
         FILE NEW11 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RETURN
END
EVENT L.ARRIVAL SAVING THE EVENT NOTICE
DEFINE NEW12, KEY AS INTEGER VARIABLES
CREATE A TASK CALLED NEW12
LET NUM.ARRIVE = 1
LET A.TIME(NEW12) = TIME.V
LET TYPE(NEW12) = 12
LET SERV.TIME(NEW12) =
    NORMAL.F(P1.SERV(12), P2.SERV(12),9)
LET PRIOR(NEW12) = 2
LET MODAL(NEW12) = 2
LET CODE(NEW12) = 1
LET STAGE(NEW12) = 1
LET KEY = 0
IF N.WORK = 0
   LET DEG.TOTAL = 0.
   CALL ADJUST GIVEN NEW12, KEY
ELSE
   CALL DEGRADE GIVEN NEW12
   IF DEG.TOTAL LT 1.0
      CALL ADJUST GIVEN NEW12, KEY
   ELSE
      IF PRIOR(NEW12) GT 1
         CALL PREEMPT GIVEN NEW12, KEY
      ELSE
         FILE NEW12 IN QUEUE
      ALWAYS
   ALWAYS
ALWAYS
CALL STATUS
RETURN
END
EVENT PEN.ACQ
'' THIS EVENT CAUSES A TRANSITION FROM THE PENETRATION
'' PHASE TO THE TARGET ACQUISITION PHASE
LET P.IDLE = 1 - AV.BUSY
LET SIM.1 = SIM.TOT/ARR.TOT
SCHEDULE A J.ARRIVAL NOW
RESET THE TOTALS OF BUSY, NUM.ARRIVE, SIMUL
LET P1.ARR(1) = 1.2*P1.ARR(1)
LET P1.ARR(2) = 0.75*P1.ARR(2)
LET P1.ARR(3) = 0.6*P1.ARR(3)
LET P1.ARR(4) = 0.6*P1.ARR(4)
LET P1.ARR(5) = 0.6*P1.ARR(5)
LET P1.ARR(6) = 0.7*P1.ARR(6)
```

```
LET P1.ARR(9) = 0.65*P1.ARR(9)
RETURN
END
EVENT ACQ.WPN
'' THIS EVENT CAUSES A TRANSITION FROM THE TARGET
'' ACQUISITION PHASE TO THE WEAPON DELIVERY PHASE
LET A.IDLE = 1 - AV.BUSY
LET SIM.2 = SIM.TOT/ARR.TOT
SCHEDULE A K.ARRIVAL IN 10.0 SECONDS
RESET THE TOTALS OF BUSY, NUM.ARRIVE, SIMUL
LET P1.ARR(1) = 0.4*P1.ARR(1)
RETURN
END
ROUTINE STATUS
IF N.WORK GE 1
   LET BUSY = 1
ELSE
   LET BUSY = 0
ALWAYS
RETURN
END
ROUTINE PREEMPT GIVEN NEW, KEY
'' THIS ROUTINE DETERMINES IF A TASK IN WORK SHOULD BE
'' PREEMPTED AND, IF SO, INITIATES THAT ACTION
DEFINE NEW, KEY AS INTEGER VARIABLES
FOR EACH TASK IN WORK
DO
   LET REM.TIME(TASK) = COMP.TIME(TASK) - TIME.V
   IF PRIOR(TASK) = 1
      REMOVE THIS TASK FROM WORK
      FILE THIS TASK IN TEMP1
   ELSE
      IF PRIOR(TASK) = 2
         REMOVE THIS TASK FROM WORK
         FILE THIS TASK IN TEMP2
      ALWAYS
   ALWAYS
LOOP
IF N.TEMP1 GT 0
   FOR EACH TASK IN TEMP1,
   UNTIL DEG.TOTAL LT 1.0
   DO
      REMOVE THE FIRST TASK FROM TEMP1
      CALL UPGRADE GIVEN TASK
      CALL CHANGE GIVEN TASK
      CALL CORRECT
      LET NUM.ARRIVE = 1
      FILE THIS TASK IN TEMP3
      CALL DEGRADE GIVEN NEW
   LOOP
   IF DEG.TOTAL LT 1.0
      CALL RECOVER
```

```
      CALL ADJUST GIVEN NEW, KEY
   ALWAYS
ALWAYS
IF M.WORK(NEW) = 0
   IF PRIOR(NEW) LT 3
      IF KEY = 0
         FILE NEW IN QUEUE
         CALL RECOVER
      ALWAYS
   ELSE
      FOR EACH TASK IN TEMP2,
      UNTIL DEG.TOTAL LT 1.0
      DO
         REMOVE FIRST TASK FROM TEMP2
         CALL UPGRADE GIVEN TASK
         CALL CHANGE GIVEN TASK
         CALL CORRECT
         FILE THIS TASK IN TEMP3
         LET NUM.ARRIVE = 1
         CALL DEGRADE GIVEN NEW
      LOOP
      IF DEG.TOTAL LT 1.0
         CALL RECOVER
         CALL ADJUST GIVEN NEW, KEY
      ELSE
         IF KEY = 0
            FILE NEW IN QUEUE
            CALL RECOVER
         ALWAYS
      ALWAYS
   ALWAYS
ELSE
   CALL RECOVER
ALWAYS
CALL RECOVER
RETURN
END
ROUTINE ADJUST GIVEN NEW, KEY
'' THIS ROUTINE RESCHEDULES TASK COMPLETION TIMES IN WORK
'' AND UPDATES STATUS OF RESOURCES BEING USED
'' WHEN AN ADDITIONAL TASK IS ASSIGNED TO WORK
DEFINE NEW, KEY AS INTEGER VARIABLES
FOR EACH TASK IN WORK
DO
   LET REM.TIME(TASK) = COMP.TIME(TASK) - TIME.V
   LET SERV.TIME(TASK) = REM.TIME(TASK) + DEG.TOTAL *
REM.TIME(TASK)
   REMOVE THIS EVPOINTER(TASK) FROM EV.S(I.E.O.S)
   SCHEDULE AN E.O.S(TASK) IN SERV.TIME(TASK) SECONDS
   LET EVPOINTER(TASK) = E.O.S
   LET COMP.TIME(TASK) = TIME.V + SERV.TIME(TASK)
LOOP
```

```
LET SERV.TIME(NEW) = SERV.TIME(NEW) +
    DEG.TOTAL * SERV.TIME(NEW)
LET COMP.TIME(NEW) = TIME.V + SERV.TIME(NEW)
IF KEY = 1
   REMOVE THIS NEW FROM QUEUE
ALWAYS
FILE NEW IN WORK
SCHEDULE AN E.O.S(NEW) IN SERV.TIME(NEW) SECONDS
LET EVPOINTER(NEW) = E.O.S
IF MODAL(NEW) = 1
   ADD 1 TO MRM(2,1)
ELSE
   ADD 1 TO MRM(1,1)
ALWAYS
IF CODE(NEW) = 1
   ADD 1 TO MRM(2,2)
ELSE
   ADD 1 TO MRM(1,2)
ALWAYS
IF STAGE(NEW) = 1
   ADD 1 TO MRM(2,3)
ELSE
   ADD 1 TO MRM(1,3)
ALWAYS
IF N.WORK GT 1
   LET SIMUL = 1
ALWAYS
RETURN
END
ROUTINE RECOVER
'' THIS ROUTINE REASSIGNS TASKS TO WORK OR QUEUE AFTER
'' DETERMINATION OF PREEMPTION HAS BEEN MADE
FOR EACH TASK IN TEMP1
DO
   REMOVE THE FIRST TASK FROM TEMP1
   FILE THIS TASK IN WORK
LOOP
FOR EACH TASK IN TEMP2
DO
   REMOVE THE FIRST TASK FROM TEMP2
   FILE THIS TASK IN WORK
LOOP
FOR EACH TASK IN TEMP3
DO
   REMOVE THE FIRST TASK FROM TEMP3
   LET SERV.TIME(TASK) = NORMAL.F(P1.SERV(TYPE(TASK)),
      P2.SERV(TYPE(TASK)),10)
   FILE THIS TASK IN QUEUE
   REMOVE THIS EVPOINTER(TASK) FROM EV.S(I.E.O.S)
LOOP
RETURN
END
```

```
ROUTINE CHANGE GIVEN DEL.TASK
'' THIS ROUTINE REDUCES RESOURCES BEING USED WHEN A
'' PREEMPTED TASK IS REMOVED FROM WORK
DEFINE DEL.TASK AS AN INTEGER VARIABLE
IF TYPE(DEL.TASK) = 1
   LET SERV.TIME(DEL.TASK) = EXPONENTIAL.F(P1.SERV(1),10)
ELSE
   LET SERV.TIME(DEL.TASK) =
      NORMAL.F(P1.SERV(TYPE(DEL.TASK)),
      P2.SERV(TYPE(DEL.TASK)),10)
ALWAYS
IF SERV.TIME(DEL.TASK) LE 0.
   LET SERV.TIME(DEL.TASK) = 0.1 * REM.TIME(DEL.TASK)
ALWAYS
LET COMP.TIME(DEL.TASK) = TIME.V + SERV.TIME(DEL.TASK)
IF MODAL(DEL.TASK) = 1
   SUBTRACT 1 FROM MRM(2,1)
ELSE
   SUBTRACT 1 FROM MRM(1,1)
ALWAYS
IF CODE(DEL.TASK) = 1
   SUBTRACT 1 FROM MRM(2,2)
ELSE
   SUBTRACT 1 FROM MRM(1,2)
ALWAYS
IF STAGE(DEL.TASK) = 1
   SUBTRACT 1 FROM MRM(2.3)
ELSE
   SUBTRACT 1 FROM MRM(1,3)
ALWAYS
RETURN
END
ROUTINE CORRECT
'' THIS ROUTINE DECREASES THE SERVICE TIME OF TASKS BEING
'' WORKED WHEN ANOTHER TASK IS REMOVED FROM WORK
DEFINE NTASK AS AN INTEGER VARIABLE
FOR EACH NTASK IN WORK
DO
   LET REM.TIME(NTASK) = COMP.TIME(NTASK) - TIME.V
   LET SERV.TIME(NTASK) = REM.TIME(NTASK) * UP.TOTAL
   IF SERV.TIME(NTASK) LE 0.
      LET SERV.TIME(NTASK) = 0.01 * REM.TIME(NTASK)
   ALWAYS
   REMOVE THIS EVPOINTER(NTASK) FROM EV.S(I.E.O.S)
   SCHEDULE AN E.O.S(NTASK) IN SERV.TIME(NTASK) SECONDS
   LET EVPOINTER(NTASK) = E.O.S
   LET COMP.TIME(NTASK) = TIME.V + SERV.TIME(NTASK)
LOOP
FOR EACH NTASK IN TEMP1
DO
   LET REM.TIME(NTASK) = COMP.TIME(NTASK) - TIME.V
   LET SERV.TIME(NTASK) = REM.TIME(NTASK) * UP.TOTAL
```

```
   IF SERV.TIME(NTASK) LE 0.
      LET SERV.TIME(NTASK) = 0.01 * REM.TIME(NTASK)
   ALWAYS
   REMOVE THIS EVPOINTER(NTASK) FROM EV.S(I.E.O.S)
   SCHEDULE AN E.O.S(NTASK) IN SERV.TIME(NTASK) SECONDS
   LET EVPOINTER(NTASK) = E.O.S
   LET COMP.TIME(NTASK) = TIME.V + SERV.TIME(NTASK)
LOOP
FOR EACH NTASK IN TEMP2
DO
   LET REM.TIME(NTASK) = COMP.TIME(NTASK) - TIME.V
   LET SERV.TIME(NTASK) = REM.TIME(NTASK) * UP.TOTAL
   IF SERV.TIME(NTASK) LE 0.
      LET SERV.TIME(NTASK) = 0.01 * REM.TIME(NTASK)
   ALWAYS
   REMOVE THIS EVPOINTER(NTASK) FROM EV.S(I.E.O.S)
   SCHEDULE AN E.O.S(NTASK) IN SERV.TIME(NTASK) SECONDS
   LET EVPOINTER(NTASK) = E.O.S
   LET COMP.TIME(NTASK) = TIME.V + SERV.TIME(NTASK)
LOOP
RETURN
END
ROUTINE DEGRADE GIVEN NEW
'' THIS ROUTINE DETERMINES THE DEGRADATION WHICH WILL
'' RESULT IF A NEW TASK IS ADDED TO WORK
DEFINE NEW, OVERLAP, I, J, TOT.RESOURCES AS INTEGER
   VARIABLES
LET OVERLAP = 0
LET DEG.TOTAL = 0.
LET TOT.RESOURCES = 0
FOR I = 1 TO 2, DO
   FOR J = 1 TO 3, DO
      LET TEST(I,J) = MRM(I,J)
   LOOP
LOOP
IF MODAL(NEW) = 1
   ADD 1 TO TEST(2,1)
ELSE
   ADD 1 TO TEST(1,1)
ALWAYS
IF CODE(NEW) = 1
   ADD 1 TO TEST(2,2)
ELSE
   ADD 1 TO TEST(1,2)
ALWAYS
IF STAGE(NEW) = 1
   ADD 1 TO TEST(2,3)
ELSE
   ADD 1 TO TEST(1,3)
ALWAYS
FOR I = 1 TO 2, DO
   FOR J = 1 TO 3, DO
```

```
      LET TOT.RESOURCES = TOT.RESOURCES + TEST(I,J)
      IF TEST(I,J) GT 0
         LET OVERLAP = OVERLAP + TEST(I,J) - 1
      ALWAYS
   LOOP
LOOP
IF OVERLAP GT 3
   LET DEG.TOTAL = 1.1
ELSE
   IF OVERLAP GT 2
      LET DEG.TOTAL = UNIFORM.F(.9, 1.1, 10)
   ELSE
      IF OVERLAP GT 1
         LET DEG.TOTAL = UNIFORM.F(.6, .9, 10)
      ELSE
         IF OVERLAP GT 0
            LET DEG.TOTAL = UNIFORM.F(.3, .6, 10)
         ELSE
            IF TOT.RESOURCES GT 3
               LET DEG.TOTAL = UNIFORM.F(.1, .3, 10)
            ALWAYS
         ALWAYS
      ALWAYS
   ALWAYS
ALWAYS
RETURN
END
ROUTINE UPGRADE GIVEN OLD
'' THIS ROUTINE DETERMINES THE IMPROVEMENT FACTOR FOR
'' SERVICE TIME WHEN A TASK IS REMOVED FROM WORK
DEFINE OLD, OVERLAP, COUNT, I, J, TOT.RESOURCES,
   OLD.RESOURCES AS INTEGER VARIABLES
LET OVERLAP = 0
LET UP.TOTAL = 0.
LET TOT.RESOURCES = 0
LET COUNT = 0
LET F1 = 0.
LET F2 = 0.
LET OLD.RESOURCES = 0
FOR I = 1 TO 2, DO
   FOR J = 1 TO 3, DO
      LET OLD.RESOURCES = OLD.RESOURCES + MRM(I,J)
      IF MRM(I,J) GT 0
         LET COUNT = COUNT + MRM(I,J) - 1
      ALWAYS
   LOOP
LOOP
IF COUNT GT 3
   LET F1 = 1.1
ELSE
   IF COUNT GT 2
      LET F1 = UNIFORM.F(.9, 1.1, 10)
```

```
   ELSE
      IF COUNT GT 1
         LET F1 = UNIFORM.F(.6, .9, 10)
      ELSE
         IF COUNT GT 0
            LET F1 = UNIFORM.F(.3, .6, 10)
         ELSE
            IF OLD.RESOURCES GT 3
               LET F1 = UNIFORM.F(.1, .3, 10)
            ALWAYS
         ALWAYS
      ALWAYS
   ALWAYS
ALWAYS
FOR I = 1 TO 2, DO
   FOR J = 1 TO 3, DO
      LET TEST(I,J) = MRM(I,J)
   LOOP
LOOP
IF MODAL(OLD) = 1
   SUBTRACT 1 FROM TEST(2,1)
ELSE
   SUBTRACT 1 FROM TEST(1,1)
ALWAYS
IF CODE(OLD) = 1
   SUBTRACT 1 FROM TEST(2,2)
ELSE
   SUBTRACT 1 FROM TEST(1,2)
ALWAYS
IF STAGE(OLD) = 1
   SUBTRACT 1 FROM TEST(2,3)
ELSE
   SUBTRACT 1 FROM TEST(1,3)
ALWAYS
FOR I = 1 TO 2, DO
   FOR J = 1 TO 3, DO
      LET TOT.RESOURCES = TOT.RESOURCES + TEST(I,J)
      IF TEST(I,J) GT 0
         LET OVERLAP = OVERLAP + TEST(I,J) - 1
      ALWAYS
   LOOP
LOOP
IF OVERLAP GT 3
   LET F2 = 1.1
ELSE
   IF OVERLAP GT 2
      LET F2 = UNIFORM.F(.9, 1.1, 10)
   ELSE
      IF OVERLAP GT 1
         LET F2 = UNIFORM.F(.6, .9, 10)
      ELSE
         IF OVERLAP GT 0
```

```
            LET F2 = UNIFORM.F(.3, .6, 10)
         ELSE
            IF TOT.RESOURCES GT 3
               LET F2 = UNIFORM.F(.1, .3, 10)
            ALWAYS
         ALWAYS
      ALWAYS
   ALWAYS
ALWAYS
LET UP.TOTAL = F1/(1 + F1)
RETURN
END
EVENT E.O.S(TASK)
'' THIS EVENT DESTROYS A TASK WHICH HAS COMPLETED SERVICE
DEFINE TASK, KEY AS INTEGER VARIABLES
CALL UPGRADE GIVEN TASK
CALL CHANGE GIVEN TASK
IF TYPE(TASK) = 7
   SCHEDULE AN H.ARRIVAL NOW
ALWAYS
REMOVE THE FIRST TASK FROM WORK
DESTROY THIS TASK CALLED TASK
CALL CORRECT
IF QUEUE IS NOT EMPTY
   FOR EACH TASK IN QUEUE
   DO
      IF TYPE(TASK) = 12
         IF TIME.V - A.TIME(TASK) GT 50.0
            ADD 1 TO PRIOR(TASK)
         ALWAYS
      ELSE
         IF TIME.V - A.TIME(TASK) GT 10.0
            ADD 1 TO PRIOR(TASK)
         ALWAYS
      ALWAYS
      CALL DEGRADE GIVEN TASK
      IF DEG.TOTAL LT 1.0
         LET COMP.TIME(TASK) = TIME.V + SERV.TIME(TASK)
         REMOVE THE FIRST TASK FROM QUEUE
         LET KEY = 0
         CALL ADJUST GIVEN TASK, KEY
      ELSE
         IF PRIOR(TASK) GT 1
            LET KEY = 1
            CALL PREEMPT GIVEN TASK, KEY
         ALWAYS
      ALWAYS
   LOOP
ALWAYS
CALL STATUS
RETURN
END
```

```
EVENT END.SIM
'' THIS EVENT PROVIDES TERMINAL STATISTICS AND ENDS
'' SIMULATION
DEFINE I, J, THING AS INTEGER VARIABLES
LET W.IDLE = 1 - AV.BUSY
LET SIM.3 = SIM.TOT/ARR.TOT
LET P1.ARR(1) = 2.083*P1.ARR(1)
LET P1.ARR(2) = 1.333*P1.ARR(2)
LET P1.ARR(3) = 1.667*P1.ARR(3)
LET P1.ARR(4) = 1.667*P1.ARR(4)
LET P1.ARR(5) = 1.667*P1.ARR(5)
LET P1.ARR(6) = 1.429*P1.ARR(6)
LET P1.ARR(9) = 1.538*P1.ARR(9)
LET TIME.V = 0.
LET BUSY = 0
RESET THE TOTALS OF NUM.ARRIVE, BUSY, SIMUL
UNTIL EV.S(I.A.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.A.ARRIVAL)
   DESTROY A.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.B.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.B.ARRIVAL)
   DESTROY B.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.C.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.C.ARRIVAL)
   DESTROY C.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.D.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.D.ARRIVAL)
   DESTROY D.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.E.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.E.ARRIVAL)
   DESTROY E.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.F.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.F.ARRIVAL)
   DESTROY F.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.G.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.G.ARRIVAL)
   DESTROY G.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.H.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.H.ARRIVAL)
   DESTROY H.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.I.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.I.ARRIVAL)
   DESTROY I.ARRIVAL CALLED THING
LOOP
```

```
UNTIL EV.S(I.J.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.J.ARRIVAL)
   DESTROY J.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.K.ARRIVAL) IS EMPTY, DO
00 0
   REMOVE FIRST THING FROM EV.S(I.K.ARRIVAL)
   DESTROY K.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.L.ARRIVAL) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.L.ARRIVAL)
   DESTROY L.ARRIVAL CALLED THING
LOOP
UNTIL EV.S(I.E.O.S) IS EMPTY, DO
   REMOVE FIRST THING FROM EV.S(I.E.O.S)
   DESTROY E.O.S CALLED THING
LOOP
UNTIL WORK IS EMPTY, DO
   REMOVE FIRST TASK FROM WORK
   DESTROY THIS TASK CALLED TASK
LOOP
UNTIL QUEUE IS EMPTY, DO
   REMOVE FIRST TASK FROM QUEUE
   DESTROY THIS TASK CALLED TASK
LOOP
UNTIL TEMP1 IS EMPTY, DO
   REMOVE FIRST TASK FROM TEMP1
   DESTROY THIS TASK CALLED TASK
LOOP
UNTIL TEMP2 IS EMPTY, DO
   REMOVE FIRST TASK FROM TEMP2
   DESTROY THIS TASK CALLED TASK
LOOP
UNTIL TEMP3 IS EMPTY, DO
   REMOVE FIRST TASK FROM TEMP3
   DESTROY THIS TASK CALLED TASK
LOOP
FOR I = 1 TO 2, DO
   FOR J = 1 TO 3, DO
      LET NRM(I, J) = 0
      LET TEST(I,J) = 0
   LOOP
LOOP
RETURN
END
EVENT DATA.RESET
'' THIS EVENT RESETS DATA COUNTERS AT A SPECIFIC TIME
RESET THE TOTALS OF NUM.ARRIVE, SIMUL, BUSY
RETURN
END
ROUTINE SNAP.R
DEFINE I, J AS INTEGER VARIABLES
```

```
FOR EACH TASK IN QUEUE, LIST ATTRIBUTES OF TASK
FOR EACH TASK IN WORK, LIST ATTRIBUTES OF TASK
FOR EACH TASK IN TEMP1, LIST ATTRIBUTES OF TASK
FOR EACH TASK IN TEMP2, LIST ATTRIBUTES OF TASK
FOR EACH TASK IN TEMP3, LIST ATTRIBUTES OF TASK
LIST ATTRIBUTES OF EACH A.ARRIVAL IN EV.S(I.A.ARRIVAL)
LIST ATTRIBUTES OF EACH B.ARRIVAL IN EV.S(I.B.ARRIVAL)
LIST ATTRIBUTES OF EACH C.ARRIVAL IN EV.S(I.C.ARRIVAL)
LIST ATTRIBUTES OF EACH D.ARRIVAL IN EV.S(I.D.ARRIVAL)
LIST ATTRIBUTES OF EACH E.ARRIVAL IN EV.S(I.E.ARRIVAL)
LIST ATTRIBUTES OF EACH F.ARRIVAL IN EV.S(I.F.ARRIVAL)
LIST ATTRIBUTES OF EACH G.ARRIVAL IN EV.S(I.G.ARRIVAL)
LIST ATTRIBUTES OF EACH H.ARRIVAL IN EV.S(I.H.ARRIVAL)
LIST ATTRIBUTES OF EACH I.ARRIVAL IN EV.S(I.I.ARRIVAL)
LIST ATTRIBUTES OF EACH J.ARRIVAL IN EV.S(I.J.ARRIVAL)
LIST ATTRIBUTES OF EACH K.ARRIVAL IN EV.S(I.K.ARRIVAL)
LIST ATTRIBUTES OF EACH L.ARRIVAL IN EV.S(I.L.ARRIVAL)
LIST ATTRIBUTES OF EACH E.O.S IN EV.S(I.E.O.S)
LIST TIME.V, N.WORK, N.QUEUE, BUSY, N.TEMP1, N.TEMP2,
     N.TEMP3, DEG.TOTAL, UP.TOTAL
FOR I = 1 TO 2, DO
   FOR J = 1 TO 3, DO
      LIST MRM(I,J)
   LOOP
LOOP
SKIP 2 LINES
RETURN
END
```

APPENDIX G

WORKLOAD TRANSFORMATION

SURVEY AND RESULTS

WORKLOAD SURVEY

Many jobs can be described as multi-task situations. These jobs are characterized by a variety of repetitive tasks which demand an individual's attention. Common examples of these multi-task situations include driving a car in heavy traffic, operating a nuclear power plant, flying an aircraft, or being a command post controller or an air traffic controller.

In a multi-task environment, tasks may arrive at random times so that an operator's workload varies. The time required to complete each task may also be random. These tasks may arrive so one task is completed before another arrives, or they may overlap so that more than one task is present at a time. In some cases more than one task may be accomplished at a time, while in other cases a single task may require an operator's complete attention. Some tasks may have a higher priority than others and may interrupt lower priority tasks. If a task cannot interrupt another, and cannot be accomplished simultaneously, it must wait until an operator is free to work on that task.

Assume that you are the operator in a multi-task environment as just described. Your WORKLOAD could be described as LOW, MEDIUM, or HIGH and characterized as

follows:

LOW WORKLOAD:

- No, or very few, interruptions in the planning, execution, or monitoring of tasks. Spare time exists between many tasks.

MEDIUM WORKLOAD:

- Task planning, execution and monitoring are often interrupted. Little spare time. Tasks occasionally occur simultaneously.

HIGH WORKLOAD:

- Task planning, execution and monitoring are interrupted most of the time. Very little spare time. Tasks frequently occur simultaneously. Considerable difficulty in accomplishing all tasks.

I would like you to translate these categorical ratings to numerical ratings. Assume that three measures of merit have been developed as surrogates for workload. That is, assume workload cannot be measured directly so three other measures have been identified as possible surrogates, or replacements. These measures are Spare Time, Task Interruption Rate, and Simultaneous Task Rate.

First, consider Spare Time which is the percentage of time when you are not working on any tasks. For each of

the three categories described, what range of Spare Time would you associate with it?

HIGH WORKLOAD: 0 %≤ [SPARE TIME] ≤ ____ %

MEDIUM WORKLOAD: ____ %≤ [SPARE TIME] ≤ ____ %

LOW WORKLOAD: ____ %≤ [SPARE TIME] ≤ 100 %

Next, consider the Task Interruption Rate. This is the percentage of tasks interrupted at least once before completion. It is fair to assume that the more often tasks are interrupted, the higher your workload will be.

HIGH WORKLOAD: ____ %≤ [TASK INTERRUPT RATE] ≤ 100 %

MEDIUM WORKLOAD: ____ %≤ [TASK INTERRUPT RATE] ≤ ____ %

LOW WORKLOAD: 0 %≤ [TASK INTERRUPT RATE] ≤ ____ %

Finally, consider the Simultaneous Task Rate. This is the percentage of tasks that will be accomplished simultaneously with another task. It is fair to assume that a high Simultaneous Task Rate corresponds to high workload.

HIGH WORKLOAD: __ %≤ [SIMULTANEOUS TASK RATE] ≤ 100 %

MEDIUM WORKLOAD: __ %≤ [SIMULTANEOUS TASK RATE] ≤ ____ %

LOW WORKLOAD: 0 %≤ [SIMULTANEOUS TASK RATE] ≤ ____ %

What is your age? _____

Circle one: MALE FEMALE

Are you a pilot? YES NO

Are you familiar with any of the multi-task situations described
in the first paragraph? If so, which ones?

Thank you for your time and cooperation.

Table 31 Simulation Output, SWAT Score Transformations (All Responses)

SIMULATION OUTPUT PARAMETER	PARAMETER RANGES	SWAT CONVERSION
PILOT IDLE RATE (PIR)	0% ≤ PIR ≤ 12.3%	HIGH (3)
	12.3% ≤ PIR ≤ 44.1%	MEDIUM (2)
	44.1% ≤ PIR ≤ 100%	LOW (1)
TASK INTERRUPT RATE (TIR)	69.3% ≤ TIR ≤ 100%	HIGH (3)
	28.9% ≤ TIR ≤ 69.3%	MEDIUM (2)
	0% ≤ TIR ≤ 28.9%	LOW (1)
SIMULTANEOUS TASK RATE (STR)	65.5% ≤ STR ≤ 100%	HIGH (3)
	26.2% ≤ STR ≤ 65.5%	MEDIUM (2)
	0% ≤ STR ≤ 26.2%	LOW (1)

Table 32 Simulation Output, SWAT Score Transformations (Pilots Only)

SIMULATION OUTPUT PARAMETER	PARAMETER RANGES	SWAT CONVERSION
PILOT IDLE RATE (PIR)	0% ≤ PIR ≤ 11.1%	HIGH (3)
	11.1% ≤ PIR ≤ 42.1%	MEDIUM (2)
	42.1% ≤ PIR ≤ 100%	LOW (1)
TASK INTERRUPT RATE (TIR)	68.6% ≤ TIR ≤ 100%	HIGH (3)
	27.9% ≤ TIR ≤ 68.6%	MEDIUM (2)
	0% ≤ TIR ≤ 27.9%	LOW (1)
SIMULTANEOUS TASK RATE (STR)	65.3% ≤ STR ≤ 100%	HIGH (3)
	25.1% ≤ STR ≤ 65.3%	MEDIUM (2)
	0% ≤ STR ≤ 25.1%	LOW (1)

Table 33 Simulation Output, SWAT Score Transformations (Experts Only)

SIMULATION OUTPUT PARAMETER	PARAMETER RANGES	SWAT CONVERSION
PILOT IDLE RATE (PIR)	0% ≤ PIR ≤ 17.5%	HIGH (3)
	17.5% ≤ PIR ≤ 65.5%	MEDIUM (2)
	65.5% ≤ PIR ≤ 100%	LOW (1)
TASK INTERRUPT RATE (TIR)	73.8% ≤ TIR ≤ 100%	HIGH (3)
	37.5% ≤ TIR ≤ 73.8%	MEDIUM (2)
	0% ≤ TIR ≤ 37.5%	LOW (1)
SIMULTANEOUS TASK RATE (STR)	67.5% ≤ STR ≤ 100%	HIGH (3)
	31.3% ≤ STR ≤ 67.5%	MEDIUM (2)
	0% ≤ STR ≤ 31.3%	LOW (1)

APPENDIX H

WORKLOAD RATINGS AND PREDICTIONS

This appendix contains a complete listing of all workload ratings and predictions. These numerical values are the SWAT ratings, scaled between 0 and 100, for the three flight segments: penetration (PEN), target acquisition (ACQ), and weapon delivery (WPN). Each set of workload ratings are categorized by predictor type (PRED), cockpit configuration (CONFIG), and the original method used to develop the predictors (METHOD). Definitions of terms used in this Appendix are as follows:

PREDICTORS:

o SWAT - Data derived from workload measurements or estimates and not modified by simulation output.

o SSI - Workload estimates developed by using pilot idle time as the surrogate Time Load predictor, as determined from the serial processing model.

o SSTA - Workload estimates developed by using task interrupt rate, serial processing model, where task preempts are counted as interrupts and subsequent arrivals of preempted tasks are counted as new arrivals.

o SSTB - Workload estimates developed by using task interrupt rate, serial processing model, where task preempts are counted as interrupts and subsequent arrivals of preempted tasks are not counted as new arrivals.

o SSTC - Workload estimates developed by using task interrupt rate, serial processing model, where the arrival

of a new task while at least one other task is being worked is counted as a task interruption. Subsequent arrivals of preempted tasks are counted as new arrivals.

o SSTD - Workload estimates developed by using task interrupt rate, serial processing model, where the arrival of a new task while at least one other task is being worked is counted as a task interruption. Subsequent arrivals of preempted tasks are not counted as new arrivals.

o MRMI - Workload estimates developed by using pilot idle time as the surrogate Time Load predictor, as determined from the parallel processing model.

o MRMS - Workload estimates developed by using task interrupt rate as the surrogate Time Load predictor, as determined by the parallel processing model.

CONFIGURATIONS:

o ABL - Advanced Baseline

o TFTA - Terrain Following/Terrain Avoidance

o TTA - Terrain/Threat Avoidance

METHODS:

o SWAT - RAM/ACE SWAT workload measurements (1982)

o PRO - RAM/ACE SWAT workload estimates (1982)

o SCH - PRO-SWAT workload estimates (1986)

Table 34 Workload Measurements and Estimates

PRED	PEN	ACQ	WPN	CONFIG	METHOD
SSI	65.9	40.8	45.2	ABL	SCH
SSI	59.9	30.0	100.0	ABL	SCH
SSI	45.7	40.8	95.1	ABL	SCH
SSI	52.2	52.2	69.4	ABL	SCH
SSI	59.9	76.3	83.6	ABL	SCH
SSI	52.2	72.0	69.4	ABL	SCH
SSI	59.0	82.8	69.4	ABL	SCH
SSI	10.4	52.2	40.6	ABL	SCH
SSI	26.2	40.8	16.0	TFTA	SCH
SSI	70.4	30.0	45.7	TFTA	SCH
SSI	65.9	16.0	65.9	TFTA	SCH
SSI	52.2	39.3	52.2	TFTA	SCH
SSI	76.3	76.3	59.9	TFTA	SCH
SSI	39.2	52.2	52.2	TFTA	SCH
SSI	72.0	63.1	10.4	TFTA	SCH
SSI	52.2	10.4	10.4	TFTA	SCH
SSI	16.0	40.8	1.4	TTA	SCH
SSI	59.9	30.0	76.3	TTA	SCH
SSI	40.8	16.0	40.8	TTA	SCH
SSI	23.5	39.2	52.2	TTA	SCH
SSI	59.9	59.9	59.9	TTA	SCH
SSI	39.2	52.2	52.2	TTA	SCH
SSI	59.0	63.1	10.4	TTA	SCH
SSI	52.2	52.2	52.2	TTA	SCH
SSTD	8.0	8.0	86.2	ABL	PRO
SSTD	71.2	71.2	100.0	ABL	PRO
SSTD	21.2	45.6	86.2	ABL	PRO
SSTD	71.2	84.9	100.0	ABL	PRO
SSTD	71.2	45.6	86.2	ABL	PRO
SSTD	0.0	8.0	24.3	TFTA	PRO
SSTD	35.6	21.2	60.0	TFTA	PRO
SSTD	0.0	45.6	60.0	TFTA	PRO
SSTD	61.9	45.6	60.0	TFTA	PRO
SSTD	13.7	58.0	86.2	TFTA	PRO
SSTD	21.2	45.6	46.8	TTA	PRO
SSTD	21.2	45.6	100.0	TTA	PRO
SSTD	45.6	21.2	37.5	TTA	PRO
SSTD	21.2	21.2	100.0	TTA	PRO
SSTD	8.0	31.8	86.2	TTA	PRO
SSTB	0.0	0.0	61.9	ABL	PRO
SSTB	61.9	61.9	74.3	ABL	PRO
SSTB	13.7	35.6	61.9	ABL	PRO
SSTB	61.9	74.3	74.3	ABL	PRO
SSTB	61.9	35.6	61.9	ABL	PRO
SSTB	0.0	0.0	0.0	TFTA	PRO
SSTB	35.6	13.7	35.6	TFTA	PRO

Table 34 Workload Measurements and Estimates (Continued)

PRED	PEN	ACQ	WPN	CONFIG	METHOD
SSTB	0.0	35.6	35.6	TFTA	PRO
SSTB	61.9	35.6	35.6	TFTA	PRO
SSTB	13.7	48.8	61.9	TFTA	PRO
SSTB	13.7	35.6	21.7	TTA	PRO
SSTB	13.7	35.6	74.3	TTA	PRO
SSTB	35.6	13.7	13.7	TTA	PRO
SSTB	13.7	13.7	74.3	TTA	PRO
SSTB	0.0	21.7	61.9	TTA	PRO
SSTB	64.5	39.3	14.6	ABL	SCH
SSTB	29.9	0.0	46.3	ABL	SCH
SSTB	44.2	39.3	64.5	ABL	SCH
SSTB	41.8	41.8	41.8	ABL	SCH
SSTB	29.9	46.3	29.9	ABL	SCH
SSTB	41.8	61.5	41.8	ABL	SCH
SSTB	48.5	72.4	41.8	ABL	SCH
SSTB	0.0	41.8	13.0	ABL	SCH
SSTB	24.7	39.3	14.6	TFTA	SCH
SSTB	40.4	0.0	15.7	TFTA	SCH
SSTB	64.5	14.6	64.5	TFTA	SCH
SSTB	41.8	28.8	41.8	TFTA	SCH
SSTB	46.3	46.3	29.9	TFTA	SCH
SSTB	28.8	41.8	41.8	TFTA	SCH
SSTB	61.5	52.6	0.0	TFTA	SCH
SSTB	41.8	0.0	0.0	TFTA	SCH
SSTB	14.6	39.3	0.0	TTA	SCH
SSTB	29.9	0.0	46.3	TTA	SCH
SSTB	39.3	14.6	39.3	TTA	SCH
SSTB	13.0	28.8	41.8	TTA	SCH
SSTB	29.9	29.9	29.9	TTA	SCH
SSTB	28.8	41.8	41.8	TTA	SCH
SSTB	48.5	52.6	0.0	TTA	SCH
SSTB	41.8	41.8	41.8	TTA	SCH
SSTC	8.0	24.3	86.2	ABL	PRO
SSTC	71.2	86.2	100.0	ABL	PRO
SSTC	21.2	60.0	86.2	ABL	PRO
SSTC	71.2	100.0	100.0	ABL	PRO
SSTC	71.2	60.0	86.2	ABL	PRO
SSTC	8.0	8.0	24.3	TFTA	PRO
SSTC	45.6	21.2	60.0	TFTA	PRO
SSTC	8.0	45.6	60.0	TFTA	PRO
SSTC	71.2	45.6	60.0	TFTA	PRO
SSTC	21.2	58.0	86.2	TFTA	PRO
SSTC	21.2	45.6	46.8	TTA	PRO
SSTC	21.2	45.6	100.0	TTA	PRO
SSTC	45.6	21.2	37.5	TTA	PRO
SSTC	21.2	21.2	100.0	TTA	PRO

Table 34 Workload Measurements and Estimates (Continued)

PRED	PEN	ACQ	WPN	CONFIG	METHOD
SSTC	8.0	31.8	86.2	TTA	PRO
MRMI	64.5	40.8	45.2	ABL	SCH
MRMI	29.9	30.0	100.0	ABL	SCH
MRMI	44.2	40.8	65.9	ABL	SCH
MRMI	41.8	52.2	69.4	ABL	SCH
MRMI	29.9	76.3	83.6	ABL	SCH
MRMI	41.8	72.0	69.4	ABL	SCH
MRMI	48.5	32.2	69.4	ABL	SCH
MRMI	0.0	52.2	40.6	ABL	SCH
MRMI	24.7	40.8	16.0	TFTA	SCH
MRMI	40.4	30.0	45.7	TFTA	SCH
MRMI	64.5	16.0	65.9	TFTA	SCH
MRMI	41.8	39.2	52.2	TFTA	SCH
MRMI	46.3	76.3	59.9	TFTA	SCH
MRMI	28.8	52.2	52.2	TFTA	SCH
MRMI	61.5	63.1	10.4	TFTA	SCH
MRMI	41.8	10.4	10.4	TFTA	SCH
MRMI	14.6	40.8	1.4	TTA	SCH
MRMI	29.9	30.0	76.3	TTA	SCH
MRMI	39.3	16.0	40.8	TTA	SCH
MRMI	13.0	39.2	52.2	TTA	SCH
MRMI	29.9	59.9	59.9	TTA	SCH
MRMI	28.8	52.2	52.2	TTA	SCH
MRMI	48.5	63.1	10.4	TTA	SCH
MRMI	41.8	52.2	52.2	TTA	SCH
MRMS	65.9	70.0	45.2	ABL	SCH
MRMS	59.9	53.7	100.0	ABL	SCH
MRMS	45.7	70.0	65.9	ABL	SCH
MRMS	52.2	69.4	69.4	ABL	SCH
MRMS	59.9	100.0	83.6	ABL	SCH
MRMS	52.2	89.2	69.4	ABL	SCH
MRMS	59.0	100.0	69.4	ABL	SCH
MRMS	10.4	69.4	40.6	ABL	SCH
MRMS	26.2	40.8	45.2	TFTA	SCH
MRMS	70.4	30.0	69.4	TFTA	SCH
MRMS	65.9	16.0	95.1	TFTA	SCH
MRMS	52.2	39.2	69.4	TFTA	SCH
MRMS	76.3	76.3	83.6	TFTA	SCH
MRMS	39.2	52.2	69.4	TFTA	SCH
MRMS	72.0	63.1	27.6	TFTA	SCH
MRMS	52.2	10.4	27.6	TFTA	SCH
MRMS	16.0	40.8	30.6	TTA	SCH
MRMS	59.9	30.0	100.0	TTA	SCH
MRMS	40.8	16.0	70.0	TTA	SCH
MRMS	23.5	39.2	69.4	TTA	SCH
MRMS	29.9	59.9	83.6	TTA	SCH

Table 34 Workload Measurements and Estimates (Continued)

PRED	PEN	ACQ	WPN	CONFIG	METHOD
MRMS	39.2	52.2	69.4	TTA	SCH
MRMS	59.0	63.1	27.6	TTA	SCH
MRMS	52.2	52.2	69.4	TTA	SCH
SSTD	65.9	40.8	45.2	ABL	SCH
SSTD	59.9	30.0	100.0	ABL	SCH
SSTD	45.7	40.8	95.1	ABL	SCH
SSTD	52.2	52.2	69.4	ABL	SCH
SSTD	59.9	76.3	83.6	ABL	SCH
SSTD	52.2	72.0	69.4	ABL	SCH
SSTD	59.0	82.8	69.4	ABL	SCH
SSTD	10.4	52.2	40.6	ABL	SCH
SSTD	24.7	40.8	45.2	TFTA	SCH
SSTD	40.4	30.0	69.4	TFTA	SCH
SSTD	64.5	16.0	95.1	TFTA	SCH
SSTD	41.8	39.3	69.4	TFTA	SCH
SSTD	46.3	76.3	83.6	TFTA	SCH
SSTD	28.8	52.2	69.4	TFTA	SCH
SSTD	61.5	63.1	27.6	TFTA	SCH
SSTD	41.8	10.4	27.6	TFTA	SCH
SSTD	16.0	40.8	30.6	TTA	SCH
SSTD	59.9	30.0	100.0	TTA	SCH
SSTD	40.8	16.0	70.0	TTA	SCH
SSTD	23.5	39.2	69.4	TTA	SCH
SSTD	59.9	59.9	83.6	TTA	SCH
SSTD	39.2	52.2	69.4	TTA	SCH
SSTD	59.0	63.1	27.6	TTA	SCH
SSTD	52.2	52.2	69.4	TTA	SCH
SSTC	65.9	70.0	45.2	ABL	SCH
SSTC	59.9	53.7	100.0	ABL	SCH
SSTC	45.7	70.0	95.1	ABL	SCH
SSTC	52.2	69.4	69.4	ABL	SCH
SSTC	59.9	100.0	83.6	ABL	SCH
SSTC	52.2	89.2	69.4	ABL	SCH
SSTC	59.0	100.0	69.4	ABL	SCH
SSTC	10.4	69.4	40.6	ABL	SCH
SSTC	26.2	40.8	45.2	TFTA	SCH
SSTC	70.4	30.0	69.4	TFTA	SCH
SSTC	65.9	16.0	95.1	TFTA	SCH
SSTC	52.2	39.3	69.4	TFTA	SCH
SSTC	76.3	76.3	83.6	TFTA	SCH
SSTC	39.2	52.2	69.4	TFTA	SCH
SSTC	72.0	63.1	27.6	TFTA	SCH
SSTC	52.2	10.4	27.6	TFTA	SCH
SSTC	16.0	40.8	30.6	TTA	SCH
SSTC	59.9	30.0	100.0	TTA	SCH
SSTC	40.8	16.0	70.0	TTA	SCH

Table 34 Workload Measurements and Estimates (Continued)

PRED	PEN	ACQ	WPN	CONFIG	METHOD
SSTC	23.5	39.2	69.4	TTA	SCH
SSTC	59.9	59.9	83.6	TTA	SCH
SSTC	39.2	52.2	69.4	TTA	SCH
SSTC	59.0	63.1	27.6	TTA	SCH
SSTC	52.2	52.2	69.4	TTA	SCH
SWAT	7.99	0.0	87.57	ABL	PRO
SWAT	71.2	87.57	100.0	ABL	PRO
SWAT	21.23	45.55	61.92	ABL	PRO
SWAT	71.2	83.63	100.0	ABL	PRO
SWAT	61.92	45.55	61.92	ABL	PRO
SWAT	0.0	7.99	7.99	TFTA	PRO
SWAT	45.55	37.56	45.55	TFTA	PRO
SWAT	0.0	45.55	45.55	TFTA	PRO
SWAT	61.92	45.55	45.55	TFTA	PRO
SWAT	37.56	57.98	61.92	TFTA	PRO
SWAT	13.74	45.55	31.81	TTA	PRO
SWAT	13.74	45.55	74.35	TTA	PRO
SWAT	45.55	13.74	37.56	TTA	PRO
SWAT	37.56	37.56	83.63	TTA	PRO
SWAT	0.0	21.73	61.92	TTA	PRO
SSI	8.0	8.0	87.6	ABL	PRO
SSI	71.2	71.2	100.0	ABL	PRO
SSI	21.2	45.6	87.6	ABL	PRO
SSI	71.2	84.9	100.0	ABL	PRO
SSI	71.2	45.6	87.6	ABL	PRO
SSI	8.0	8.0	8.0	TFTA	PRO
SSI	45.6	21.2	45.6	TFTA	PRO
SSI	8.0	45.6	45.6	TFTA	PRO
SSI	71.2	45.6	45.6	TFTA	PRO
SSI	21.2	58.0	71.2	TFTA	PRO
SSI	21.2	45.6	31.8	TTA	PRO
SSI	21.2	45.6	84.9	TTA	PRO
SSI	45.6	21.2	21.2	TTA	PRO
SSI	21.2	21.2	84.9	TTA	PRO
SSI	8.0	31.8	71.2	TTA	PRO
SSTA	0.0	0.0	61.9	ABL	PRO
SSTA	61.9	61.9	74.4	ABL	PRO
SSTA	13.7	35.6	61.9	ABL	PRO
SSTA	61.9	74.4	74.4	ABL	PRO
SSTA	61.9	61.9	61.9	ABL	PRO
SSTA	0.0	0.0	0.0	TFTA	PRO
SSTA	35.6	13.7	35.6	TFTA	PRO
SSTA	0.0	35.6	35.6	TFTA	PRO
SSTA	61.9	35.6	35.6	TFTA	PRO
SSTA	13.7	48.8	61.9	TFTA	PRO
SSTA	13.7	35.6	21.7	TTA	PRO

Table 34 Workload Measurements and Estimates (Continued)

PRED	PEN	ACQ	WPN	CONFIG	METHOD
SSTA	13.7	35.6	74.4	TTA	PRO
SSTA	35.6	13.7	13.7	TTA	PRO
SSTA	13.7	13.7	74.4	TTA	PRO
SSTA	0.0	21.7	61.9	TTA	PRO
MRMI	0.0	8.0	87.6	ABL	PRO
MRMI	61.9	71.2	100.0	ABL	PRO
MRMI	13.7	45.6	87.6	ABL	PRO
MRMI	61.9	84.9	100.0	ABL	PRO
MRMI	61.9	45.6	87.6	ABL	PRO
MRMI	0.0	8.0	8.0	TFTA	PRO
MRMI	35.6	21.2	45.6	TFTA	PRO
MRMI	0.0	45.6	45.6	TFTA	PRO
MRMI	61.9	45.6	45.6	TFTA	PRO
MRMI	13.7	58.0	71.2	TFTA	PRO
MRMI	13.7	45.6	31.8	TTA	PRO
MRMI	13.7	45.6	84.9	TTA	PRO
MRMI	35.6	21.2	21.2	TTA	PRO
MRMI	13.7	21.2	84.9	TTA	PRO
MRMI	0.0	31.8	71.2	TTA	PRO
MRMS	8.0	24.3	87.6	ABL	PRO
MRMS	71.2	87.6	100.0	ABL	PRO
MRMS	21.2	59.9	87.6	ABL	PRO
MRMS	71.2	100.0	100.0	ABL	PRO
MRMS	71.2	59.9	87.6	ABL	PRO
MRMS	8.0	8.0	24.3	TFTA	PRO
MRMS	45.6	21.2	60.0	TFTA	PRO
MRMS	8.0	45.6	60.0	TFTA	PRO
MRMS	71.2	45.6	60.0	TFTA	PRO
MRMS	21.2	58.0	87.6	TFTA	PRO
MRMS	21.2	45.6	46.8	TTA	PRO
MRMS	21.2	45.6	100.0	TTA	PRO
MRMS	45.6	21.2	37.6	TTA	PRO
MRMS	21.2	21.2	100.0	TTA	PRO
MRMS	8.0	31.8	87.6	TTA	PRO
SWAT	95.1	40.8	16.0	ABL	SCH
SWAT	59.9	0.0	100.0	ABL	SCH
SWAT	45.7	70.0	65.9	ABL	SCH
SWAT	52.2	41.8	41.8	ABL	SCH
SWAT	59.9	76.3	59.9	ABL	SCH
SWAT	41.8	72.0	52.2	ABL	SCH
SWAT	59.0	100.0	52.2	ABL	SCH
SWAT	0.0	53.2	13.0	ABL	SCH
SWAT	26.2	40.8	16.0	TFTA	SCH
SWAT	70.4	0.0	45.7	TFTA	SCH
SWAT	65.9	45.2	65.9	TFTA	SCH
SWAT	41.8	28.8	41.8	TFTA	SCH

Table 34 Workload Measurements and Estimates (Continued)

PRED	PEN	ACQ	WPN	CONFIG	METHOD
SWAT	76.3	76.3	59.9	TFTA	SCH
SWAT	28.8	52.2	52.2	TFTA	SCH
SWAT	72.0	63.1	0.0	TFTA	SCH
SWAT	52.2	0.0	0.0	TFTA	SCH
SWAT	16.0	40.8	1.4	TTA	SCH
SWAT	59.9	0.0	76.3	TTA	SCH
SWAT	40.8	45.2	40.8	TTA	SCH
SWAT	13.0	28.8	41.8	TTA	SCH
SWAT	59.9	59.9	59.9	TTA	SCH
SWAT	28.8	52.2	52.2	TTA	SCH
SWAT	48.5	63.1	0.0	TTA	SCH
SWAT	52.2	52.2	41.8	TTA	SCH
SSTA	64.5	39.3	14.6	ABL	SCH
SSTA	29.9	0.0	46.3	ABL	SCH
SSTA	44.2	39.3	64.5	ABL	SCH
SSTA	41.8	41.8	41.8	ABL	SCH
SSTA	29.9	46.3	29.9	ABL	SCH
SSTA	41.8	61.5	41.8	ABL	SCH
SSTA	48.5	72.4	41.8	ABL	SCH
SSTA	0.0	41.8	13.0	ABL	SCH
SSTA	24.7	39.3	14.6	TFTA	SCH
SSTA	40.4	0.0	15.7	TFTA	SCH
SSTA	64.5	14.6	64.5	TFTA	SCH
SSTA	41.8	28.8	41.8	TFTA	SCH
SSTA	46.3	46.3	29.9	TFTA	SCH
SSTA	28.8	41.8	41.8	TFTA	SCH
SSTA	61.5	52.6	0.0	TFTA	SCH
SSTA	41.8	0.0	0.0	TFTA	SCH
SSTA	14.6	39.3	0.0	TTA	SCH
SSTA	29.9	0.0	46.3	TTA	SCH
SSTA	39.3	14.6	39.3	TTA	SCH
SSTA	13.0	28.8	41.8	TTA	SCH
SSTA	29.9	29.9	29.9	TTA	SCH
SSTA	28.8	41.8	41.8	TTA	SCH
SSTA	48.5	52.6	0.0	TTA	SCH
SSTA	41.8	52.2	41.8	TTA	SCH
SWAT	0.0	7.99	61.92	ABL	SWAT
SWAT	45.55	100.0	87.57	ABL	SWAT
SWAT	0.0	74.35	100.0	ABL	SWAT
SWAT	37.56	87.57	45.55	ABL	SWAT
SWAT	74.35	45.55	45.55	ABL	SWAT
SWAT	7.99	45.55	87.57	TFTA	SWAT
SWAT	0.0	45.55	45.55	TFTA	SWAT
SWAT	0.0	13.74	61.92	TFTA	SWAT
SWAT	57.98	37.56	31.81	TFTA	SWAT
SWAT	75.64	57.98	100.0	TFTA	SWAT

Table 34 Workload Measurements and Estimates (Continued)

PRED	PEN	ACQ	WPN	CONFIG	METHOD
SWAT	37.56	45.55	23.82	TTA	SWAT
SWAT	0.0	45.55	61.92	TTA	SWAT
SWAT	31.81	13.74	37.56	TTA	SWAT
SWAT	37.56	37.56	63.21	TTA	SWAT
SWAT	0.0	38.1	100.0	TTA	SWAT

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