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Operator Workload Predictions for the Revised AH-64A Workload Prediction Model

Volume I: Summary Report

David B. Hamilton and Carl R. Bierbaum
Anacapa Sciences, Inc.

Field Unit at Fort Rucker, Alabama
Charles A. Gainer, Chief

Training Systems Research Division
Jack H. Hiller, Director

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EDGAR M. JOHNSON **Technical Director**	**MICHAEL D. SHALER** **COL, AR** **Commanding**

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Hamilton, David B.; and Bierbaum, Carl R.

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P.O. Box 489
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13. ABSTRACT (*Maximum 200 words*)
Under a previous contract, researchers used a composite scenario to conduct a comprehensive task analysis of the AH-64A attack mission. The analysis produced workload estimates and decision rules for developing an AH-64A workload prediction model. For this research, the task analysis/workload (TAWL) methodology was used to construct a workload prediction model. The TAWL Operator Simulation System (TOSS) was used to implement the model on an IBM-compatible microcomputer, and the original function and task analysis was refined to produce a more accurate simulation of crew task activity. In addition, the ordinal workload rating scales used in the original analysis were replaced with equal-interval scales. The predictions generated by the model constructed for this research indicate that under optimum conditions (a) neither the pilot nor the copilot/gunner experiences excessive workload, (b) the pilot has higher overall workload than the copilot/gunner in most mission segments, and (c) AH-64A workload is high relative to other Army aircraft that have been analyzed for workload. This model can be used as a baseline for analyzing future modifications to the aircraft. This report (Volume I) (Continued)

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describes the methodology, summarizes the results of the research, and contains a 5.25-inch floppy diskette with model data files. Volume II (ARI Research Note 92-62) contains the appendixes, which present the AH-64A mission/task/workload analysis, decision rules, and workload predictions.

OPERATOR WORKLOAD PREDICTIONS FOR THE REVISED AH-64A WORKLOAD PREDICTION MODEL

Volume I: Summary Report

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ARI	U.S. Army Research Institute for the Behavioral and Social Sciences
ARIARDA	Army Research Institute Aviation Research and Development Activity
AUD	Auditory
COG	Cognitive Workload
DCD	Directorate of Combat Developments
FARP	Forward Arming and Refueling Point
KIN	Kinesthetic
LHX	Light Helicopter Family
LOAL	Lock on After Launch
LOBL	Lock on Before Launch
LZ	Landing Zone
NOE	Nap-of-the-Earth
OW	Overall Workload
PSY	Psychomotor Workload
SME	Subject Matter Expert
SOF	Special Operations Forces
TAWL	Task Analysis/Workload
TOSS	TAWL Operator Simulation System
VIS	Visual
USAAVNC	U.S. Army Aviation Center

OPERATOR WORKLOAD PREDICTIONS FOR THE REVISED AH-64A WORKLOAD PREDICTION MODEL

Volume I: Summary Report

Introduction

The sophistication and complexity of the new technology employed in modern military systems has increased over time and will continue to increase in the future. Although the capabilities of the systems are increasing, the capabilities of the human operator are fixed and of limited capacity. If the system requirements of modern aviation/weapons systems exceed the capabilities of their operators, the results can be catastrophic, both in terms of life and equipment. Thus, the operator workload associated with utilizing new technology is of concern to both the administrators of existing systems and the developers of new systems.

The Air/Land Battle 2000 scenario represents a high-threat environment that will place heavy workload demands on combat helicopter operators. Advanced technology in Army helicopters is designed to reduce workload; however, technological improvement in aircraft capability often results in increases in the monitoring and decision-making responsibilities of the aircrew. These activities, in turn, can jeopardize the quality of task performance by placing excessive demands on the mental resources of the crewmembers. Because the mission effectiveness of an aircraft is a function of the performance of the system operators, as well as its equipment, operator workload must be monitored throughout the system design process.

The AH-64A (Apache) attack helicopter is equipped with advanced technology aviation and weapons systems. Operating the aircraft is generally thought to place high demands on its pilot and copilot/gunner. One reason that technology has failed to reduce operator workload in the AH-64A aircraft is because of the lack of a methodology for assessing operator workload during the development of the system.

Anacapa Sciences, Inc., under contract to the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI), has developed a methodology for predicting operator workload using the information produced from a task analysis of the system. The methodology originally was developed during the concept exploration and definition phase of the system development process for the Army's Light Helicopter Family (LHX) aircraft (McCracken & Aldrich, 1984; Aldrich, Craddock, & McCracken, 1984; Aldrich, Szabo, & Craddock, 1986; Aldrich & Szabo, 1986). Analyses were conducted to compare the operator workload of one- and two-crewmember configurations of the LHX.

Original AH-64A Mission/Task/Workload Analysis

Under a previous contract to ARI, Anacapa Sciences researchers conducted a comprehensive task/workload analysis of all phases of the AH-64A attack mission. A composite mission scenario was developed from five mission profiles that assumed optimal flight conditions. In the scenario, the pilot's primary function was to fly the aircraft and the gunner's primary function was to acquire and engage targets. No reconnaissance or team leader functions were performed by the crew. During the analysis, 7 mission phases were identified and divided into 52 unique mission segments. The segments were further divided into 159 unique functions with 688 individual tasks necessary to perform the mission. The subsystem, crewmember, and time for each task was recorded. The results of the AH-64A analysis are described in a technical report by Szabo and Bierbaum (1986).

A function summary sheet was developed for each of the 159 unique functions to identify the specific tasks performed by each crewmember. Function decision rules were written to identify the sequence and time for the performance of these tasks. Following the development of the function summary sheets and decision rules, segment summary sheets and decision rules were written. The segment decision rules specify the procedure (sequence and time) for combining the functions created by the function decision rules to form each mission segment.

Subsequently, the methodology used to perform the AH-64A analysis was refined for use in predicting the effect on operator workload of modifications to Army special operations helicopters. The methodology has been used to predict the crewmember workload for existing and modified versions of the UH-60A aircraft (Bierbaum, Szabo, & Aldrich, 1989; Bierbaum & Hamilton, 1990), and CH-47D aircraft (Bierbaum & Aldrich, 1989; Bierbaum & Hamilton, 1991). The refined version of the methodology is called the Task Analysis/Workload (TAWL) methodology. In addition, computer support for the methodology has been developed and named the TAWL Operator Simulation System (TOSS). Hamilton, Bierbaum, and Fulford (1991) provide a complete description of the TAWL methodology and the TOSS software. Initial validation of the UH-60A model and the TAWL methodology is described in a report by Iavecchia, Linton, Bittner, and Byers (1989).

The TAWL Methodology

A TAWL workload prediction model is developed in three stages. In the first stage, the analyst performs a task/workload analysis on the system. A prototype mission for the system is developed and is progressively decomposed into phases, segments, functions, and tasks. The analysis yields estimates of the duration of tasks, a description of the sequence of tasks, and a description of the crewmember and subsystem associated with each task. The workload analysis is based on a multiple resources theory of human attention and yields independent estimates of the cognitive, psychomotor, and sensory components of workload (hereafter referred to as workload components) for each task. The theory differs from other multiple resource theories of attention in the nature and number of components that are identified. It recognizes five independent workload components: auditory, kinesthetic, visual, cognitive, and psychomotor. Typically, other theories do not recognize multiple sensory components. See Wickens (1984) for a review of other multiple resource theories of attention and their relation to workload.

The TAWL methodology treats each of the workload components independently for two reasons. First, although interactions among the components probably occur, an adequate definition of the nature of the interactions does not exist. Second, the additional information that results from treating workload components individually is useful for determining appropriate ways to reduce workload or to redistribute workload among the crewmembers, subsystems, or components. For example, a designer can decide whether additional information should be presented visually or aurally by determining which component has the least amount of workload.

The workload analysis is based upon subjective estimates of operator workload rather than estimates derived through experimentation. Research analysts and subject matter experts (SMEs) generate workload estimates by using equal-interval, verbally anchored rating scales; the scale values range from 1.0 to 7.0.

In the second stage of the TAWL methodology, the analyst develops a model of each crewmember's actions by recombining tasks to simulate the behavior of the crewmembers during each segment of the mission. Function decision rules are developed that describe the sequencing of tasks within each function; segment decision rules are developed that describe the start time, stop time, and interaction of the functions within each segment. It is assumed that the segments can be combined to model the crewmember's behavior for individual mission phases and for the entire mission.

In the third stage of the TAWL methodology, the analyst executes the model to simulate the crewmembers' actions during the operation of the system. The TOSS computer software performs the simulation and produces estimates of each crewmember's cognitive, psychomotor, and sensory workload for each half-second of the mission. The estimates of workload for each component are generated by summing the workload for that component across all tasks that the crewmember performs during each half-second of the mission. For example, during a specific half-second interval, the pilot performs the following tasks: Control Attitude, Check External Scene, and Transmit Communication. The cognitive workload for the three tasks during that interval is 1.0, 1.0, and 5.3, respectively. Thus, the estimate of cognitive workload for the pilot during that interval is 7.3. An estimate of the overload threshold is used during execution of the model to measure the amount of time during the mission that each crewmember experiences an overload condition.

Using the TAWL prediction methodology, an analyst can develop a model of a system and use the model's output to determine:

- the absolute and relative workload of the crewmembers,
- the time intervals during which crewmembers experience high workload, and
- the components for which crewmembers experience high workload.

The TAWL methodology yields sufficient information to enable system designers to reduce or redistribute workload over time, crewmembers, or components. Designers also may use the information to identify design alternatives that result in lower workload. In addition to the uses described above, the methodology yields mission timelines and task listings that can be used to develop the system's manning and training requirements.

Research Objectives

The research described in this report was conducted to produce two objectives. Because the original AH-64A mission analysis was the first in a series of analyses for Army aircraft, the modeling techniques and workload scales that were developed with experience were not incorporated in the early model. Thus, the first objective was to restructure the initial AH-64A mission analysis to produce more accurate simulations of the crewmembers' task activities and to use equal-interval workload rating scales. The second objective was to execute the revised model using the TOSS software and to report on the predictions generated by the model. This document is intended to accompany the submission of the computer executable form of the revised AH-64A workload prediction model and should provide sufficient information to utilize the model for future research.

The methods used to revise the AH-64A mission/task/workload analysis and to develop the AH-64A workload prediction model have been described in detail elsewhere (Szabo & Bierbaum, 1986; Hamilton, Bierbaum, & Fulford, 1991; Bierbaum & Hamilton, 1990; 1991). The following section includes some general information about the nature of the revisions made to the previous analyses and a description of the TAWL methodology for the reader who may not have access to the literature cited previously.

Method

Mission/Task/Workload Analysis

The mission tasks and workload for both the pilot and copilot/gunner were analyzed. The analytic tasks are listed below in the order in which they were performed:

- develop a composite mission scenario,
- divide the mission scenario into phases,
- divide mission phases into segments,
- identify functions in the mission segments,
- identify tasks for each function, and
- analyze individual tasks.

A diagram of the taxonomy used in the top-down analysis of the AH-64A mission is shown in Figure 1. Each of the analytic steps is described in the following subsections.

Develop a Composite Mission Scenario

The first step in conducting the AH-64A mission/task/workload analysis was to develop a composite mission scenario of the AH-64A attack mission. To accomplish this task, 10

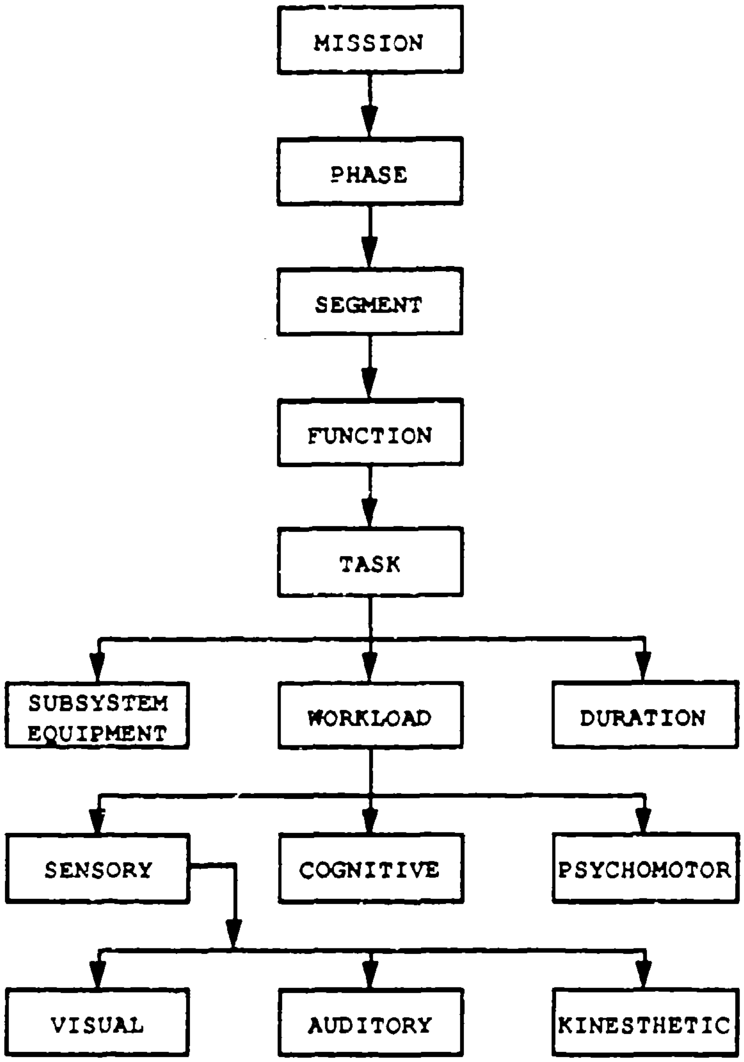

Figure 1. Diagram of the taxonomy used in the top-down analysis of the AH-64A mission.

AH-64A mission profiles, prepared by the Directorate of Combat Developments (DCD) at the U.S. Army Aviation Center (USAAVNC), were examined. The 10 missions were actually two sets of 5 basic missions. One set consisted of 5 missions in a European setting; the other set consisted of the same 5 missions in a Mideast scenario. The 5 missions included in each set were (a) antiarmor, (b) antipersonnel and materiel, (c) antiair defense, (d) deep attack, and (e) rear battle.

The resultant AH-64A mission is depicted schematically in Figures 2 and 3. Dashed rectangles represent mission phases; solid rectangles represent mission segments. In the composite scenario, the AH-64A mission begins in an assembly area where preflight and departure operations are performed. The pilot flies contour flight from the assembly area to a holding area where inbound battle coordination is conducted. From the holding area, the pilot flies nap-of-the-earth (NOE) to the battle area. In the battle area, the copilot/gunner and the pilot acquire and engage targets until all munitions are expended. The pilot then flies NOE to the forward arming and refueling point (FARP), where rearming and refueling operations are conducted. Upon completion of the FARP operations, the crew returns to the battle area for a second series of engagements. When the second load of munitions is expended, the pilot flies NOE to the holding area where outbound battle coordination is conducted. The pilot then flies contour back to the assembly area where terminal and postflight operations are conducted.

In addition to the characteristics described above, the composite scenario assumes that the pilot's primary role in the mission is to fly the aircraft and the gunner's primary role is to acquire and engage targets. Additionally, the mission is flown under optimal performance conditions (i.e., no degradation due to weather, casualties, or emergencies). Although the activities and conditions encountered on any given mission may differ from those described above, the phases of the mission adopted for this research are representative of tactical missions for the AH-64A aircraft.

The only revision made to the scenario in the present analysis was that the hover hold capabilities of the aircraft are now used by the crew. In the original mission scenario, this feature was not used.

Divide Mission Scenario Into Phases

Once the mission was identified, it was divided into temporally discrete, uninterruptible, and nonrepeating divisions called phases. A phase is defined as a required, logical part of a mission that may be accomplished in several ways. Phases must be performed sequentially (i.e., phases cannot be performed concurrently) and must be contiguous. All portions of the mission are encompassed under one of the mission phases, and every phase must be performed to accomplish the mission. Thus, the mission consists of a sequence of phases placed end to end (see Figures 2 and 3).

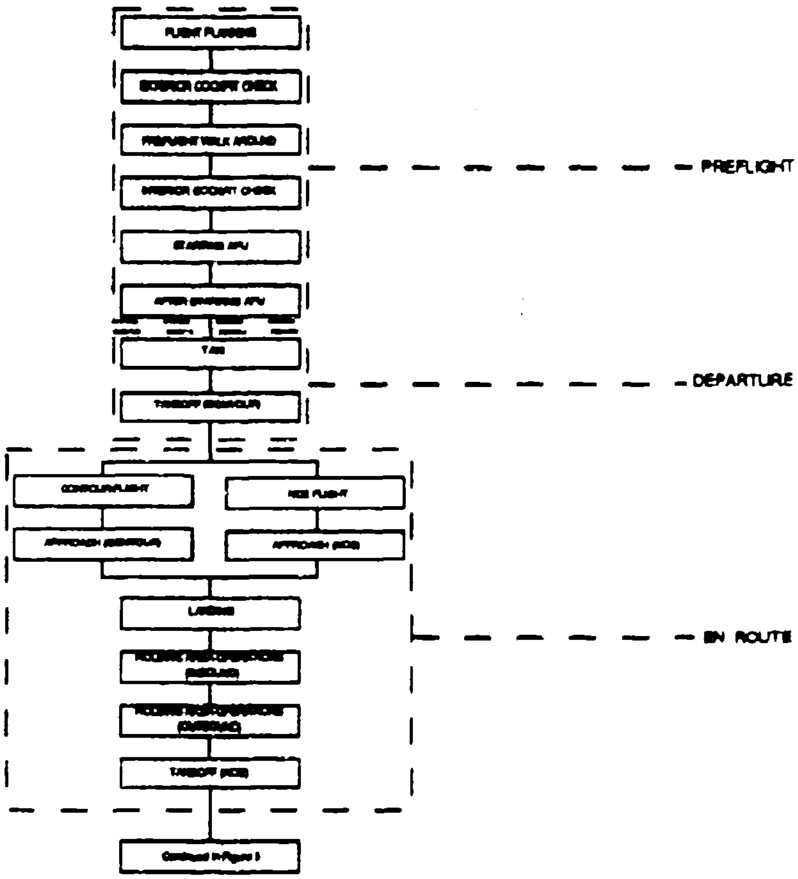

Figure 2. Schematic diagram of the first three phases of the AH-64A composite mission scenario.

The revisions to the original phase analyses did not identify any necessary changes to the mission phases.

Divide Mission Phases Into Segments

The mission phases were divided into temporally discrete, uninterruptible parts called segments. A segment represents a particular method of accomplishing a part of a phase. Segments must be sequential to other segments and must be contiguous. Different segments may represent different methods for accomplishing the same portion of a phase; thus, every segment identified for a phase may not be needed to complete that phase. A segment defined for one phase may appear in other phases. Takeoff (NOE) is an example of a segment that appears in more than one mission

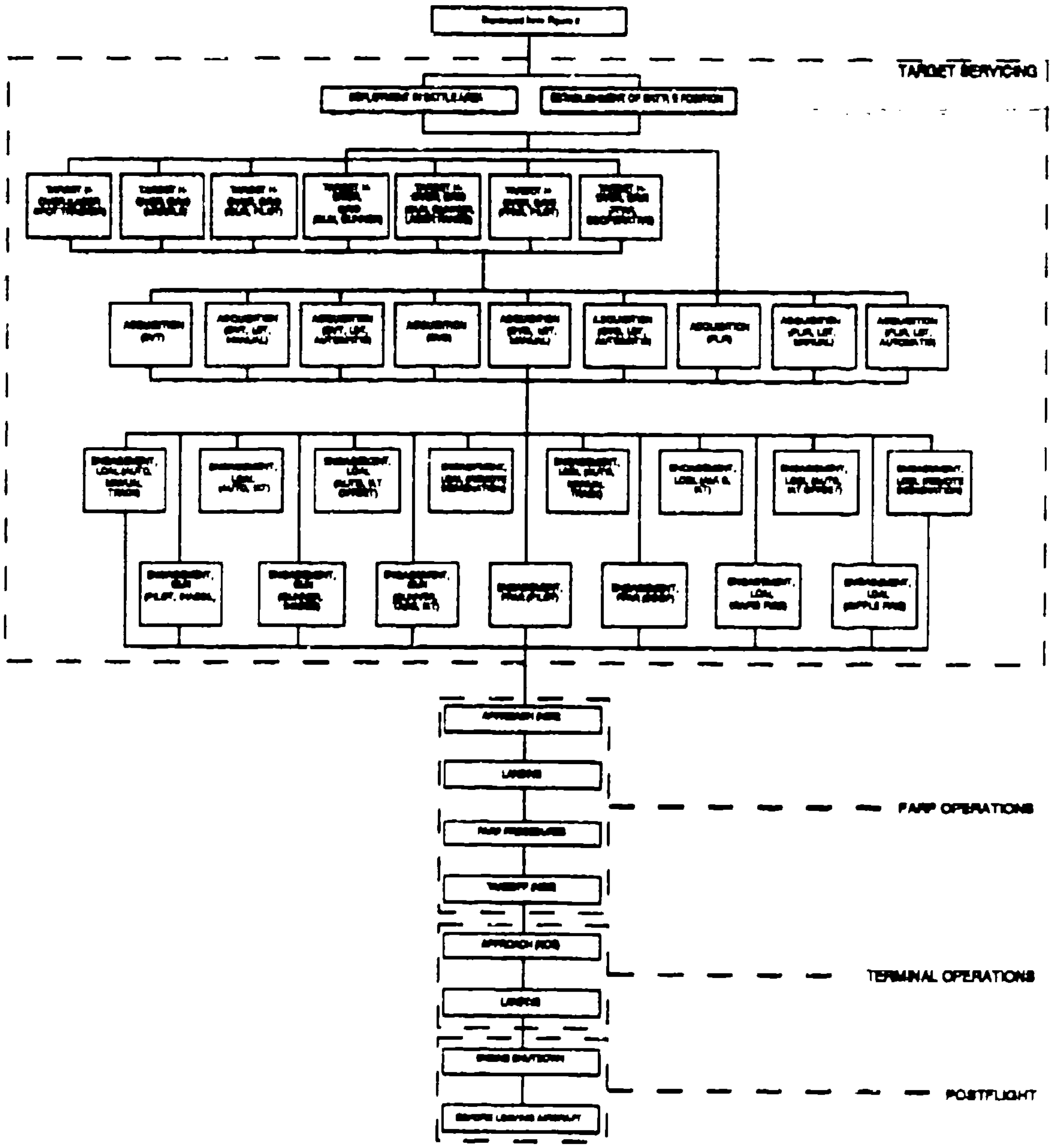

Figure 3. Schematic diagram of the second four phases of the AH-64A composite mission scenario.

phase. The revisions to the original segment analyses did not identify any necessary changes to the mission segments.

Identify Functions in the Mission Segments

The next step was to identify all interruptible parts of segments, which are called functions. A function is defined as a collection of a crewmember's actions that are necessary to carry out a single logical activity. The same function may be performed in different segments. Functions can be performed concurrently or sequentially. Examples of functions are Establish Hover, Monitor Threat, Perform Navigation, and Check Flight Parameters.

The function analysis of the original model was modified to provide better modeling of the crewmembers actions. The changes are too numerous to be described here; however, the following three examples provide an understanding of the nature of the model revisions.

First, a number of functions were added to the model. For example, experience with other models has shown that at least two types of crewmember communications are necessary for accurate modeling. In one type of communication, the crewmembers exchange detailed and critical mission information (e.g., target grid coordinates or location). This type of communication occurs infrequently, demands crewmember attention, and produces high workload. In another type of communication, the crewmembers exchange simple information. Although the information conveyed in this type of communication is critical, it is not typically difficult to decipher or understand. This type of communication occurs almost continuously, demands little crewmember attention, and produces low workload. Thus, the function analysis was revised to contain two sets of cockpit communications functions: one with high workload and one with low workload.

Second, the organization of many functions was revised. For example, the functions in the original model that accomplished flying included external visual monitoring tasks. These functions were interrupted when random cockpit checks were scheduled. This organization made it necessary to add flying tasks to the functions for cockpit checks so that the crewmember continued to fly the aircraft while performing the internal checks. In the revision, flying functions contain only flying tasks and functions that control visual attention are represented independently. This reorganization simplifies the structure of the model and allows the analyst to manipulate the pilot's visual attention independently from his psychomotor attention.

Finally, some complicated functions, whose tasks could be constructed from existing simpler functions, were deleted or replaced with only the set of tasks that made them unique. For example, the original function 70, Fire Weapon, Missile, Ripple Fire, Lock on After Launch (LOAL), contained 18 tasks. During the revision, function 70 was shortened to the three unique tasks that it contained and was renamed Prepare for Ripple Fire (LOAL). The segment decision rule that contained function 70 was modified to use five existing functions and the revised function 70 to simulate all the crew activities that were in the original function.

Identify Tasks for Each Function

The lowest level of mission decomposition is the task. Tasks are defined as the uninterruptible crew activities that are required for the successful completion of a function. Tasks can be performed concurrently or sequentially. Tasks are described by verbs and objects. The verb describes the crewmember's action; the object describes the recipient of the action. Examples of verbs include check, set, position, monitor, and release; examples of objects include switches, knobs, helmets, and maps.

Revisions were made to the original task analyses to add crewmember actions to the model that previously did not exist (e.g., engage hover hold switch). In addition, some tasks in the original analysis were redundant and were deleted from the analysis.

Analyze Individual Tasks

Each task was analyzed separately to produce the information required to develop the workload prediction model. For each task, the analysts identified the crewmember who performed the task, the subsystem used to perform the task, the workload imposed by the task, and the duration of the task. The following paragraphs describe how the task data were derived.

Crewmember(s). Once the tasks for each function were identified, SMEs identified the crewmember(s) responsible for performing the task. Specifically, each task within a given function was assigned to the pilot, copilot/gunner, or both. In general, all flight control tasks were assigned to the pilot; all navigation and support tasks were assigned to the copilot/gunner.

Task identifier. Numerical task identifiers were assigned to each task. During the original analysis, all the tasks were alphabetized and assigned a task number. During the revision, new and revised tasks were assigned unused identifiers arbitrarily.

Subsystem(s). SMEs identified the subsystem(s) associated with the mission tasks. For example, task number 643, entitled Pull Weapons Trigger, is associated with the armament subsystem. Up to three subsystems were identified for each task.

Workload. Workload, as the term is used in this research, is defined as the total attentional demand placed on the operators as they perform the mission tasks. This research methodology recognizes five different components of attention: cognitive, psychomotor, visual, kinesthetic, and auditory. Thus, workload is the demand on each of these components imposed by all the tasks an operator is performing currently. The methodology further assumes that each of the components is a limited resource that, when expended, will result in degraded task performance or task shedding. Cognitive workload (COG) refers to the level of information processing required of the operator; psychomotor workload (PSY) refers to the complexity of the operator's behavioral responses; visual (VIS), auditory (AUD), and kinesthetic (KIN) refer to the complexity of the stimuli to which an operator must attend.

To derive a workload estimate for each task, the analysts first identified the specific workload components (i.e., cognitive, psychomotor, auditory, visual, and kinesthetic) that applied to each task. Then, they wrote a short verbal description of the attentional demands imposed on each component. Often the performance of a task imposed demands on several components. For example, consider the task of setting a switch in the cockpit. First, cognitive attention is required to decide that a new switch position is necessary. Next, psychomotor attention is expended to move the switch. Finally, visual attention is required to ensure that the switch is placed in the correct position.

The three analysts derived estimates of component workload by comparing the verbal descriptions of component attentional demand with verbal anchors on corresponding component workload rating scales. The scales used in the original workload analysis were ordinal workload rating scales. The verbal anchors on each scale were judged to represent increasing levels of workload corresponding to the numerical values of 1 to 7. During the present revision to the workload analysis, the ordinal rating scales were replaced with 7-point, equal-interval rating scales that were developed for use in a UH-60A workload analysis (Bierbaum, Szabo, & Aldrich, 1989). Table 1 presents the workload scales for each component.

The analysts selected the verbal anchor for each component that most closely matched the written description of the attentional demand. The rating scale value associated with the verbal anchor selected was assigned to represent the level of workload for that component of the task. The matches between tasks and the verbal anchors made in the original workload analysis remained, for the most part, unchanged. However, most of the numerical values for the verbal anchors changed when the equal-interval ratings scales were incorporated in the analysis.

Estimate task duration. As the final step in the mission/task/workload analysis, the analysts estimated the amount of time required to perform each task. The duration of each discrete task was recorded. The total time required to perform all the tasks in a function was tabulated. The duration of functions containing continuous tasks was labeled continuous.

Development of the AH-64A Workload Prediction Model

The mission/task/workload analysis described above used a top-down approach to identify the tasks that must be performed to accomplish the objectives of the AH-64A mission. That is, the mission was progressively decomposed into phases, segments, functions, and tasks. The task was the basic unit of analysis for which estimates of workload and time were derived. These data, in turn, were used to develop the AH-64A workload prediction model.

A bottom-up approach was used to develop the AH-64A workload prediction model. The approach started with the basic elements produced by the analysis (i.e., the tasks) and successively composed the mission functions and segments. The development steps are listed below in the order in which they were performed:

- write decision rules,
- develop the computer model, and
- exercise the model to produce estimates of workload.

The steps performed in developing the model and producing estimates of workload are depicted schematically in Figure 4.

Table 1

Workload Component Scales

Scale Value	Verbal Anchors
	Cognitive
1.0	Automatic (Simple Association)
1.2	Alternative Selection
3.7	Sign/Signal Recognition
4.6	Evaluation/Judgment (Consider Single Aspect)
5.3	Encoding/Decoding, Recall
6.8	Evaluation/Judgment (Consider Several Aspects)
7.0	Estimation, Calculation, Conversion
	Psychomotor
1.0	Speech
2.2	Discrete Actuation (Button, Toggle, Trigger)
2.6	Continuous Adjustive (Flight Control, Sensor Control)
4.6	Manipulative
5.8	Discrete Adjustive (Rotary, Thumbwheel, Lever Position)
6.5	Symbolic Production (Writing)
7.0	Serial Discrete Manipulation (Keyboard Entries)
	Visual-Unaided (Naked Eye)
1.0	Visually Register/Detect (Detect Occurrence of Image)
3.7	Visually Discriminate (Detect Visual Differences)
4.0	Visually Inspect/Check (Discrete Inspection/Static Condition)
5.0	Visually Locate/Align (Selective Orientation)
5.4	Visually Track/Follow (Maintain Orientation)
5.9	Visually Read (Symbol)
7.0	Visually Scan/Search/Monitor (Continuous/Serial Inspection, Multiple Conditions)
	Auditory
1.0	Detect/Register Sound (Detect Occurrence of Sound)
2.0	Orient to Sound (General Orientation/Attention)
4.2	Orient to Sound (Selective Orientation/Attention)
4.3	Verify Feedback (Detect Occurrence of Anticipated Sound)
4.9	Interpret Semantic Content (Speech)
6.6	Discriminate Sound (Detect Auditory differences)
7.0	Interpret Sound Patterns (Pulse Rates, Etc.)
	Kinesthetic
1.0	Detect Discrete Activation (Toggle, Trigger, Button)
4.0	Detect Preset Position or Status of Object
4.8	Detect Discrete Adjustment (Discrete Rotary or Lever)
5.5	Detect Serial Movements (Keyboard Entries)
6.1	Detect Kinesthetic Cues Conflicting With Visual Cues
6.7	Detect Continuous Adjustment (Rotary Rheostat, Thumbwheel)
7.0	Detect Continuous Adjustment of Controls

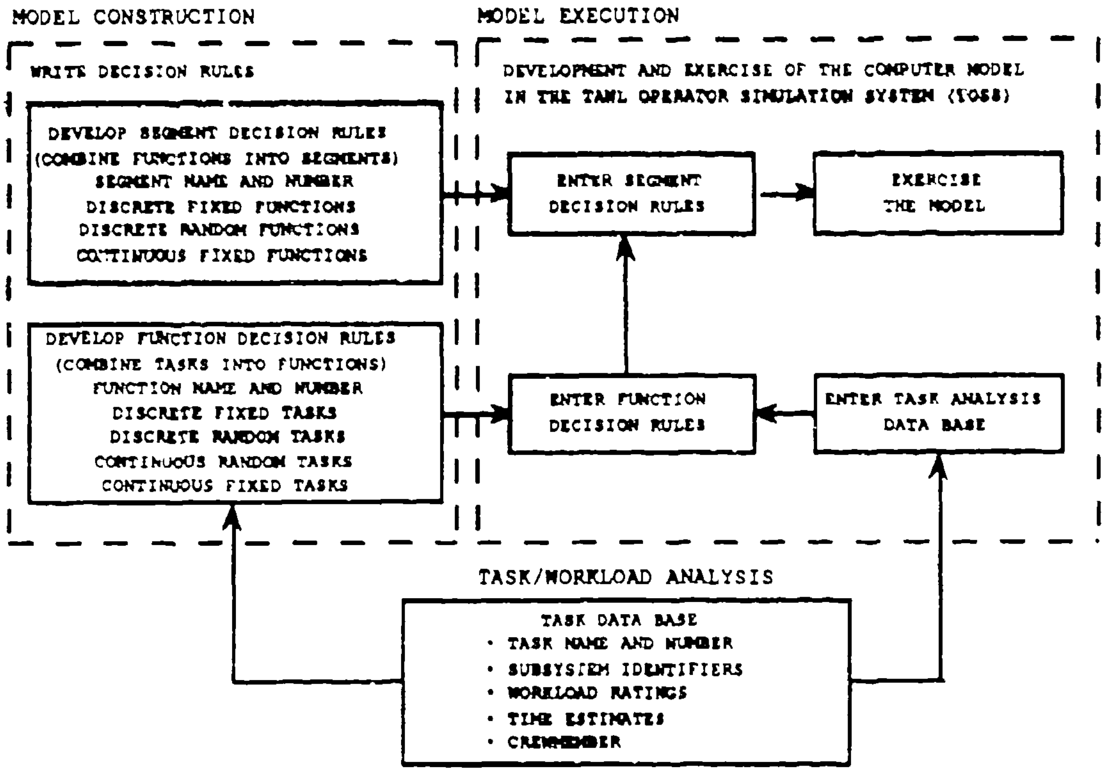

Figure 4. Bottom-up task flow diagram outlining the technical steps performed in developing the AH-64A workload prediction model.

Write Decision Rules

The first step in developing the workload prediction model was to develop decision rules for composing the mission segments from the task data base. A decision rule comprises the information necessary to schedule a task or function in the mission (e.g., start time and duration). First, function decision rules were developed for combining the tasks into functions. Then, segment decision rules were developed to combine the functions into segments. The function and segment decision rules provided the information necessary to reconstruct the mission to simulate the behavior of each crewmember at each point on the mission timeline. The procedures used to develop the decision rules are described in the following subsections.

Develop function decision rules. Function decision rules were developed for each of the functions identified in the mission/task/workload analysis. The decision rules were developed in two stages. During the first stage, Function Summary Worksheets were developed to describe three types of information. First, the crewmember performing each task was indicated by placing the task name and number in a column under the appropriate crewmember's title. Second, the approximate temporal relationships among the tasks were portrayed by the position of the tasks on the worksheet: tasks placed higher on the page occurred prior to tasks placed lower on the page. Concurrent tasks were placed side by side. Third, the task category (discrete fixed, discrete random, continuous fixed, and continuous random) was indicated by placing the task name in one of the four columns below each crewmember's title. For complete definitions of the task categories, see Hamilton, Bierbaum, and Fulford (1991).

During the second stage, Function Decision Rules Worksheets were developed from the Function Summary Worksheets. Function decision rules were developed that specify the information necessary to schedule the tasks in the function. Decision rules for discrete fixed tasks and continuous tasks state the start time and the duration of the tasks on the function timeline. In addition to duration, the decision rules for discrete random tasks state the probability and/or frequency of the random tasks' occurrence within the function.

Develop segment decision rules. The next step in the development of the model was to write the segment decision rules. The segment decision rules comprise the information necessary to build the mission segments from the functions. The segments were developed in two stages: first, by developing Segment Summary Worksheets and then, by developing Segment Decision Rules Worksheets.

The Segment Summary Worksheets list all the functions performed by the pilot and the copilot/gunner during a mission segment. The Segment Summary Worksheets also identify the function category (discrete fixed, discrete random, or continuous fixed) and the approximate temporal arrangement of the functions within the segments. Again, see Hamilton, Bierbaum, and Fulford (1991) for complete definitions of the function categories. The Segment Decision Rules Worksheets contain the decision rules that define the onset times for functions and their duration. In addition, the functions that cannot occur concurrently (referred to in TOSS as clash pairs) and functions that interrupt other functions are defined in the segment decision rules.

Develop the Computer Model

TOSS was utilized to implement the AH-64A workload model. The mission/task/ workload analysis data and the function and segment decision rules constitute all the information necessary for TOSS to generate workload predictions for the AH-64A crewmembers. The development of the TOSS computer model required the entry of the task data and the entry of function and segment decision rules. The data entry tasks are depicted in the task flow diagram shown in Figure 4 and are described in detail below.

Enter task data. The first step in developing the computer model was to enter into TOSS the data derived during the mission/task/workload analysis. Specifically, the following data were entered:

- unique task name and number,
- subsystem names and identifiers, and
- the component (sensory, cognitive, and psychomotor) workload ratings for each task.

These data items constitute the data base for the simulation of the pilot's and copilot/gunner's actions during the AH-64A mission.

Enter decision rules. The second step in developing the computer model was to enter into TOSS the function decision rules and segment decision rules using the data entry routines of the system. Specifically, the following data were entered from the function decision rules worksheets:

- function name and number,
- task start time,
- task duration,
- task crewmember, and
- task frequency for random tasks.

Additionally, the following data were entered from the segment decision rules worksheets:

- unique segment name and number,
- function start time,
- function duration,
- function interrupts,
- function clash pairs, and
- function frequency for random functions.

These data provided TOSS with sufficient information to predict AH-64A crewmembers' workload.

Exercise the Model to Produce Estimates of Workload

The analysts used TOSS to simulate operator performance and to produce estimates of the total workload experienced by each crewmember. The steps required to implement the model are fully described in Hamilton, Bierbaum, and Fulford (1991) and are briefly summarized here. The task names, subsystems, and workload estimates and the function and segment decision rules of the AH-64A analysis were entered into TOSS using the data entry routines of the system. Then, each of the 52 unique segments of the model was simulated. As was mentioned earlier, TOSS computes the total workload for each component for each crewmember; workload is computed at half-second intervals throughout the mission segment.

At the end of the simulation of each segment, TOSS computed several descriptive statistics (i.e., peak, mean, and standard deviation) for the half-second workload predictions. In addition, TOSS identified the intervals in the mission segment during which the performance of concurrent tasks resulted in excessive workload (referred to hereafter as overload). Four specific indexes of overload, as defined by Aldrich, Craddock, and McCracken (1984) and Szabo and Bierbaum (1986), were computed by TOSS. Additionally, a metric that combined the workload component predictions into a single overall workload index was computed. These indexes are described in the following paragraphs.

Component Overload

A component overload occurs when the total workload for a single component reaches or exceeds a value of 8 during a half-second interval of the mission simulation. Thus, as many as five component overloads (i.e., cognitive, psychomotor, visual, auditory, and kinesthetic) could occur for each half-second interval on the mission timeline. The value 8 was chosen as the overload threshold because it exceeds the maximum value on the 7-point workload component rating scales.

Overload Condition

An overload condition is a variable-length period that contains at least one component overload. A new overload condition is counted when the tasks contributing to a component overload change. Overload conditions identify the unique task conditions within a mission segment that generate one or more component overloads.

Overload Density

Overload density is the percentage of time during a mission segment that a component overload is present. Overload density is computed by dividing (a) the number of half-second intervals in a mission segment that contain component overloads by (b) the total number of half-second intervals in the segment.

Subsystem Overload

Subsystem overloads are the number of half-second intervals during which a subsystem is associated with a component overload. All subsystems associated with the tasks being performed during a component overload are assigned an overload. The tallies of subsystem overloads identify the subsystems that are associated with high workload.

Overall Workload

Iavecchia et al. (1989) conducted research to determine the validity of a UH-60A workload prediction model (Bierbaum, Szabo, & Aldrich, 1989). The researchers obtained subjective ratings of overall workload (OW) from pilots performing a typical UH-60A mission in the UH-60A flight simulator. During mission segments, pilots estimated their overall workload using a continuous bipolar scale that ranged from 0 to 100. The extreme values were verbally anchored to "Very Low Workload" and "Very High Workload."

To compare their observed measures of OW with TAWL's predictions of workload, Iavecchia et al. (1989) transformed TOSS' independent predictions for each of the workload components into a single overall estimate of workload. Iavecchia et al. assumed additivity and summed the predictions across both time and components to produce a single estimate of workload for each crewmember during each segment. The correlations between the subjective OW observed by Iavecchia et al. and the transformed TAWL predictions were high (r = .82 to .95).

During the workload analysis of the AH-64A, a regression equation was derived from the data reported by Iavecchia et al. (1989). The equation first averages across workload components, then scales the mean into the 0 - 100 range used for OW. For each mission segment described in this report, TOSS computed the predicted OW using the following equation:

$$OW = \left[\frac{AUD + KIN + VIS + COG + PSY}{5.0} \times 14.5 \right] + 7.2$$

where AUD, KIN, VIS, COG, and PSY represent the mean auditory, kinesthetic, visual, cognitive, and psychomotor workload for the segment.

This equation is useful to this research for two reasons. First, it represents the only empirical link between the subjective measures of workload reported in the literature and the predictions generated by the TAWL methodology. Second, it is currently the only method to combine TAWL workload component predictions into a single metric of operator workload.

In spite of its utility, several caveats should be made about the use of this equation. First, scaling the workload component mean is unnecessary to demonstrate high correlations between OW and TAWL workload predictions. The equation is useful only in scaling TAWL workload predictions to predict aviator OW.

Second, the relationship between the 7-point scales used to generate TAWL workload predictions and the 0 - 100 OW scale is unclear. The 7-point scales were developed to estimate the workload of a single component for a single task over a half-second time period, whereas the OW scale was developed as an estimate of the workload for all components over a much greater period of time. Furthermore, the 7-point scales have a nominal overload threshold (the point at which task performance is expected to degrade) of 8, whereas it is unclear what value on the 100-point scale represents the overload threshold. If the 0 - 100 scale is to represent the extent of operator workload and that workload includes situations of task degradation due to high workload, then the overload threshold must lie somewhere on the high end of the OW. That point, however, has not been determined.

Third, this regression equation, generated from empirical results, differs from any simple scaling equation generated analytically. For example, the slope of the equation that converts a 7-point scale to a 100-point scale would be 14.3, similar to the slope of 14.5 in the OW regression equation. However, the intercept of the equation would be 0.0, whereas the intercept of the OW regression equation is 7.5. Thus, if all TAWL component workload predictions were 0.0, the equation would predict OW to be 7.5.

Regardless of the possible inaccuracies of the empirically derived OW regression equation, it is currently the only link between the workload predictions generated by a TAWL prediction model and a subjective measure of workload reported in the literature. Therefore, it has been used to compute an overall estimate of aviator workload in this analysis.

Results

AH-64A Mission/Task/Workload Analysis

The mission scenario, mission phases, and mission segments were not changed from the original mission/task/workload analysis reported by Szabo and Bierbaum (1986); however, a brief overview of the phase and segment analysis are repeated here. The mission scenario, described earlier, was divided into seven mission phases. The seven mission phases were subsequently divided into mission segments. Fifty two unique segments (i.e., segments that are distinctly different from any other segment) were identified and assigned unique numerical identifiers. Five segments were found to occur more than once in the mission. The seven mission phases and the number of segments identified in each are as follows:

- Phase 1: Preflight - 6 segments
- Phase 2: Departure - 2 segments
- Phase 3: En Route - 8 segments
- Phase 4: Target Servicing - 34 segments
- Phase 5: FARP Operations - 4 segments
- Phase 6: Terminal Operations - 2 segments
- Phase 7: Postflight - 2 segments

The specific mission segments that compose each of the seven mission phases are listed in Appendix A.

The analysis of the mission segments resulted in the identification of 184 unique functions. Each of the 184 functions was assigned a unique numerical identifier from 1 to 191 (7 of the function identifiers were not used in the revised model). The number of functions required to compose each segment ranged from 3 to 25. Appendix B presents a list of the 184 mission functions along with their identifiers. Appendix C presents the functions that compose each of the 52 mission segments.

The analysis of the 184 functions resulted in the identification of 698 unique tasks. The number of tasks required to compose each function ranged from 1 to 39. The

698 unique tasks were assigned numerical identifiers from 1 to 708 (10 of the task identifiers were not used in the revised model). Appendix D presents a list of the tasks, their numerical identifiers, associated subsystems, and component workload ratings. The Function Decision Rules for all the functions in the model are presented in Appendix E. The Segment Decision Rules for the 52 mission segments are presented in Appendix F.

A total of 36 subsystems from 7 major categories were identified for the AH-64A mission tasks. Table 2 lists these subsystems along with their respective codes.

AH-64A Workload Prediction Model Computer Files

A 5.25 inch double-sided, double-density IBM-compatible computer floppy diskette is included with this report. The diskette contains all the information used to construct the AH-64A workload prediction model in two formats: TOSS and dBase III. The next two paragraphs describe the contents of the diskette and explains how the files are used.

The 10 data files that end in the three-letter extension .dat (e.g., model.dat) are the TOSS files that contain the information for the model. Using these files requires that the TOSS software be installed according to the instructions in the TAWL User's Guide - Version 4.0 (Hamilton et al., 1991). To install the AH-64A workload prediction model, create a subdirectory on the computer's hard drive on which TOSS is installed and copy the data files on the diskette to that subdirectory. Executing the TOSS software lists the AH-64A workload prediction model in its list of available models.

The 9 data files that end in the three-letter extension .dbf (e.g., model.dbf) are in dBase III format. The data in these files are labeled and can be accessed using the dBase III program. Use of these files does not require the installation of TOSS.

AH-64A Workload Predictions

The model was exercised for all 52 of the unique segments. Under the assumed conditions and with the pilot and copilot/gunner sharing task requirements, no overload conditions were predicted for either crewmember. Thus, the model indicates that proficient crewmembers can perform the AH-64A missions without encountering overload.

Table 2

List of AH-64A Subsystems

CODE	SUBSYSTEM
A	Armament Subsystem
AFC	Fire Control Computer
AGC	Gun Control
AL	Laser
AMC	Missile Control
ARC	Rocket Control
ASG	Symbol Generator
AW	Weapons
E	Engine Subsystem
EF	Fuel
EE	Engine
EIN	Engine Instruments
EO	Engine Oil
EI	Ignition
F	Flight Control Subsystem
FA	Air Frame
FB	Brakes
FC	Flight Control
FI	Flight Instruments
FG	Gear
FH	Hydraulics
FR	Rotor
FT	Transmission
N	Navigation Subsystem
NM	Maps
NC	Navigation Control
ND	Navigation Display
S	Safety Subsystem
SG	Ground Security
S	Safety
U	Utility Subsystem
UAD	Advisory
UAI	Anti-Ice
UAP	APU
UC	Communications
UEL	Electrical
UEN	Environmental
UF	Flight Forms
UL	Lighting
US	Survivability
UV	Video
V	Visual Subsystem
VEX	External Visual Field
VSC	Sensor Control
VSD	Sensor Display
VVD	Visual Display

Workload prediction graphs for the pilot and copilot/gunner were produced for each of the 52 AH-64A mission segments. The graphs present the total workload of each component for all tasks the crewmember performs during each half-second of the mission segment. As an example of a segment workload prediction graph, Figure 5 shows the estimated workload for the pilot on each component during the Approach (NOE) segment of the mission. The causes of the workload depicted in the graph for each component are discussed in the following paragraph.

The workload associated with random cockpit communication is shown in the Auditory graph as a pair of peaks between 10 and 20 s. The higher peak occurs when the pilot receives the communication and the lower peak occurs when the pilot transmits. The Kinesthetic graph indicates the pilot is continuously on the controls and the kinesthetic workload varies little throughout the approach. The variability in the Visual workload is the result of the pilot checking the instruments and the threat alert system. Cognitive workload associated with cockpit communication can be seen as a pair of peaks each time that communication occurs. Finally, the Psychomotor graph indicates the workload associated with moving the flight controls while flying and the switch activation required to communicate. The diamond symbol at the end of each graph indicates the mean component workload for the entire segment. Graphs of pilot workload for all 52 unique segments are presented in Appendix G. Each page displays the pilot workload for one segment using five graphs: one for each component. The copilot/gunner data are presented in Appendix H in the same format.

The AH-64A workload model predictions for the pilot and copilot/gunner are summarized in Tables 3 and 4, respectively. The tables present the duration, the average workload for each of the five components, and the predicted OW for all 52 segments. Across all segments, the mean OW for the pilot and copilot/gunner was 53.3 (*SD* = 10.7) and 39.6 (*SD* = 11.4), respectively. Pilot workload was significantly greater than copilot/gunner workload, $t(51) = 6.75$, $p \leq .0005$. Additionally, the correlation between pilot and copilot/gunner workload was not significantly different from zero, $r = .128$, $p > .10$.

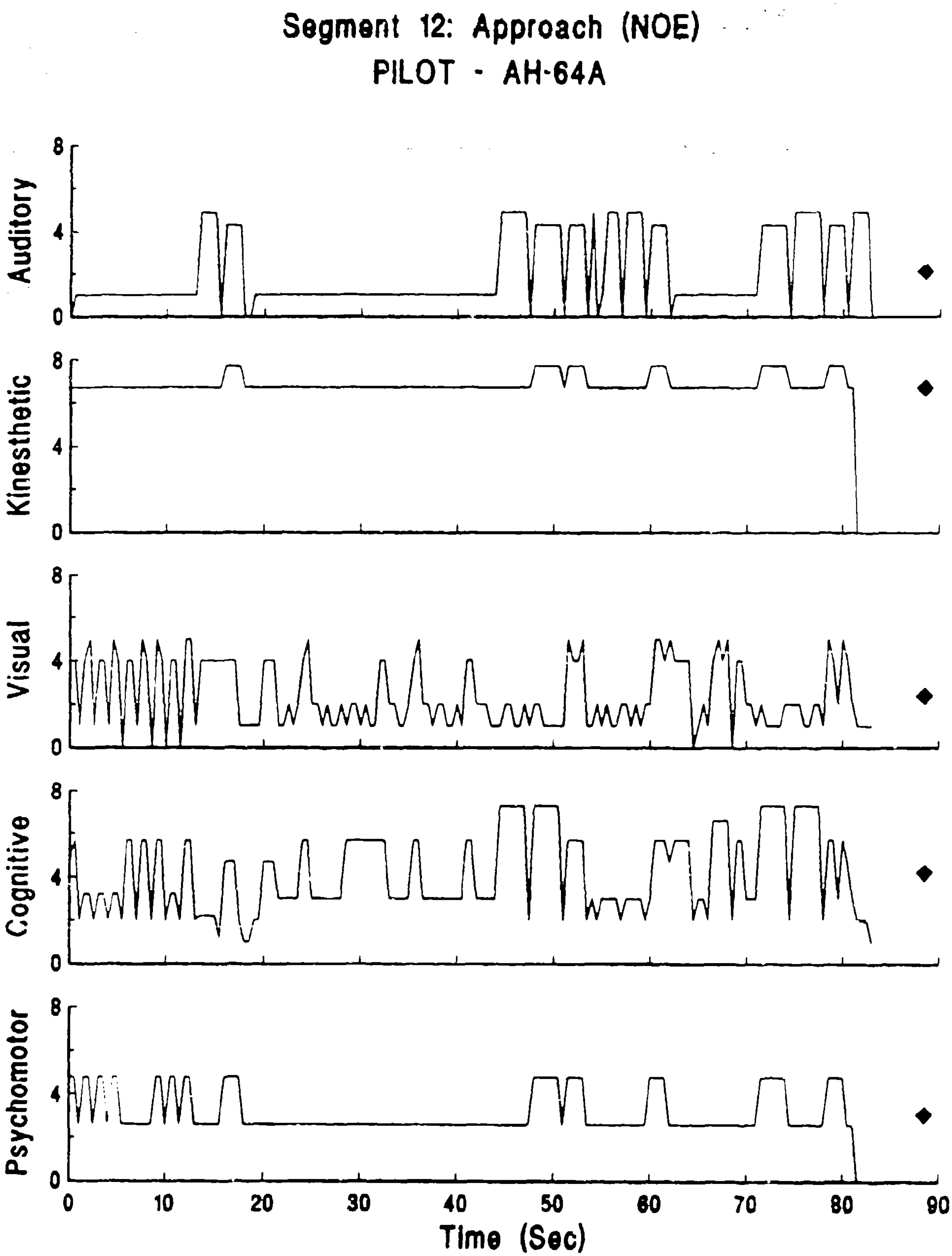

Figure 5. Example of the pilot workload prediction graphs for a segment.

Table 3

Pilot Workload for the AH-64A Model by Segment

Segment	Duration	AUD	KIN	VIS	COG	PSY	OW
1: Flight Planning	2319	2.1	0.0	3.0	5.3	4.4	50.2
2: Exterior Cockpit Check	666	0.0	0.0	4.8	3.6	4.1	43.6
3: Preflight Walk Around	1317	0.0	0.0	3.9	3.5	0.8	31.0
4: Interior Cockpit Check	404	0.0	1.1	2.4	2.8	3.1	34.1
5: Starting APU	186	1.5	0.0	3.2	3.6	1.4	35.7
6: After Starting APU	1351	1.4	0.4	1.8	2.3	1.1	27.4
7: Taxi	447	1.4	4.9	3.5	3.4	2.3	52.1
8: Takeoff (Contour)	471	1.6	6.8	3.4	4.6	3.0	63.4
9: Contour Flight	450	1.8	6.8	2.4	4.4	2.8	59.9
10: NOE Flight	450	2.0	6.9	2.7	4.7	2.9	62.9
11: Approach (Contour)	142	2.6	6.9	2.6	4.6	3.2	65.1
12: Approach (NOE)	84	2.1	6.7	2.4	4.2	3.1	61.0
13: Landing	195	1.8	5.3	1.9	3.6	2.9	52.0
14: Holding Area Operations (Inbound)	134	3.0	1.0	3.2	5.7	1.1	47.9
15: Holding Area Operations (Outbound)	134	2.2	1.0	3.2	5.0	1.1	43.5
16: Takeoff (NOE)	471	1.7	6.8	3.4	4.7	3.0	63.7
17: Establishment of Battle Position	331	1.9	6.8	5.7	6.0	2.9	74.9
18: Deployment in Battle Area	422	1.7	6.8	4.8	5.5	2.8	69.8
19: Target Handover (LST)	56	1.4	4.2	1.3	3.9	2.0	44.2
20: Target Handover, Grid (Missile)	84	1.3	3.1	1.2	3.7	1.7	38.9
21: Target Handover, Grid (Gun, Pilot)	78	1.3	3.3	1.7	4.1	2.0	42.7
22: Target Handover, Grid (Gun, CPG)	88	1.2	3.0	1.2	3.7	1.7	38.4
23: Target Handover, Grid (Gun, CPG, LRF)	75	1.3	3.4	1.2	3.8	1.8	40.3
24: Target Handover, Grid (FFAR, Pilot)	91	0.3	3.0	2.3	3.2	2.6	40.0
25: Target Handover, Grid (FFAR, CO-OP)	85	1.2	3.1	2.1	4.0	2.5	44.6
26: Acquisition (DTV)	58	2.2	6.9	1.9	3.9	3.0	59.0
27: Acquisition (DTV, LST, Manual)	41	2.3	6.9	2.2	4.3	3.0	61.6
28: Acquisition (DTV, LST, Automatic)	52	2.3	6.9	2.0	3.9	3.0	59.8
29: Acquisition (DVO)	54	2.3	6.9	1.9	3.9	3.0	59.4
30: Acquisition (DVO, LST, Manual)	41	2.3	6.9	2.1	4.2	3.0	61.2
31: Acquisition (DVO, LST, Automatic)	52	2.3	6.9	2.0	3.9	3.0	59.8
32: Acquisition (FLIR)	62	2.1	6.9	1.8	3.8	3.0	58.0
33: Acquisition (FLIR, LST, Manual)	41	2.3	6.9	2.1	4.2	3.0	61.2
34: Acquisition (FLIR, LST, Automatic)	52	2.3	6.9	2.0	3.9	3.0	59.8
35: Engagement, LOAL (Auto, Manual Track)	36	1.7	6.8	1.9	3.9	2.8	56.8
36: Engagement, LOAL (Auto, IAT)	37	1.7	6.8	1.8	3.8	2.8	56.6
37: Engagement, LOAL (Auto, IAT Offset)	39	1.7	6.8	1.8	3.8	2.8	56.2
38: Engagement, LOAL (Remote Designation)	30	1.4	6.8	2.1	4.1	2.8	56.7
39: Engagement, LOBL (Auto, Manual Track)	35	1.8	6.8	1.9	3.9	2.9	57.1
40: Engagement, LOBL (Auto, IAT)	36	1.7	6.8	1.9	3.9	2.8	56.8
41: Engagement, LOBL (Auto, IAT Offset)	39	1.7	6.8	1.8	3.8	2.8	56.3
42: Engagement, LOBL (Remote Designation)	77	1.3	6.7	1.4	3.7	2.7	53.1
43: Engagement, Gun (Pilot, IHADSS)	28	2.0	7.0	4.3	4.5	4.8	72.5
44: Engagement, Gun (CPG, IHADSS)	31	1.9	6.8	2.0	4.0	2.9	58.2
45: Engagement, Gun (CPG, TADS, IAT)	34	1.8	6.8	1.9	3.9	2.9	57.3
46: Engagement, FFAR (Pilot)	56	1.5	6.8	3.7	3.5	4.2	64.6
47: Engagement, FFAR (CO-OP)	66	1.7	6.9	3.0	3.9	3.9	63.6
48: Engagement, LOAL (Rapid Fire)	45	1.6	6.8	1.7	3.7	2.8	55.3
49: Engagement, LOAL (Ripple Fire)	65	1.4	6.8	1.5	3.5	2.8	53.3
50: FARP Procedures	534	1.4	1.8	1.8	3.6	1.5	36.6
51: Engine Shutdown	150	1.7	1.4	3.3	4.1	3.2	46.4
52: Before Leaving Aircraft	525	1.2	0.0	4.4	5.0	3.9	49.3

Note. Duration is given in seconds. The following abbreviations are used as column headings in Table 3: AUD = Auditory, KIN = Kinesthetic, VIS = Visual, COG = Cognitive, PSY = Psychomotor, OW = Overall Workload.

Table 4

Copilot/Gunner Workload for the AH-64A Model by Segment

Segment	Duration	AUD	KIN	VIS	COG	PSY	OW
1: Flight Planning	2319	1.7	0.0	3.1	5.0	4.3	47.7
2: Exterior Cockpit Check	666	0.0	0.0	0.6	0.5	0.0	10.2
3: Preflight Walk Around	1317	0.0	0.0	0.0	0.0	0.0	7.2
4: Interior Cockpit Check	404	0.0	1.0	1.6	2.3	2.7	29.2
5: Starting APU	186	1.5	0.0	2.6	3.2	1.2	31.8
6: After Starting APU	1351	1.3	0.2	4.6	5.1	4.7	53.0
7: Taxi	447	1.6	0.1	1.4	2.4	0.4	24.5
8: Takeoff (Contour)	471	1.9	0.1	1.4	2.5	0.5	25.8
9: Contour Flight	450	1.7	0.1	4.3	5.9	3.2	51.1
10: NOE Flight	450	1.8	0.2	4.0	5.5	3.1	49.3
11: Approach (Contour)	142	3.2	0.3	1.6	3.7	0.8	35.1
12: Approach (NOE)	84	3.3	0.4	2.1	4.4	1.1	39.6
13: Landing	195	1.3	0.1	1.2	2.1	0.2	21.3
14: Holding Area Operations (Inbound)	134	3.2	2.9	1.4	6.0	4.2	58.8
15: Holding Area Operations (Outbound)	134	3.1	3.2	1.4	6.3	3.0	56.4
16: Takeoff (NOE)	471	1.9	0.1	1.2	2.5	0.5	25.4
17: Establishment of Battle Position	331	1.9	0.1	5.0	6.2	2.2	51.6
18: Deployment in Battle Area	422	1.9	0.1	4.3	5.5	2.0	47.1
19: Target Handover (LST)	56	3.0	0.2	3.1	3.6	3.0	44.4
20: Target Handover, Grid (Missile)	84	2.3	0.2	3.8	3.8	3.5	46.2
21: Target Handover, Grid (Gun, Pilot)	78	2.4	0.2	3.6	3.8	3.4	45.9
22: Target Handover, Grid (Gun, CPG)	88	2.2	0.1	4.1	4.1	4.0	49.6
23: Target Handover, Grid (Gun, CPG, LRF)	75	2.5	0.2	3.9	3.9	3.9	48.4
24: Target Handover, Grid (FFAR, Pilot)	91	2.8	0.1	3.2	4.2	3.0	45.6
25: Target Handover, Grid (FFAR, CO-OP)	85	2.3	0.2	3.3	3.5	3.3	43.8
26: Acquisition (DTV)	58	2.2	3.4	4.5	4.0	1.9	53.6
27: Acquisition (DTV, LST, Manual)	41	2.3	2.1	3.9	3.8	1.6	47.0
28: Acquisition (DTV, LST, Automatic)	52	2.3	0.4	4.0	4.0	0.9	40.7
29: Acquisition (DVO)	54	2.3	3.4	4.6	4.1	2.0	54.5
30: Acquisition (DVO, LST, Manual)	41	2.3	2.1	3.9	3.8	1.7	47.1
31: Acquisition (DVO, LST, Automatic)	52	2.3	0.4	4.0	4.0	0.9	40.8
32: Acquisition (FLIR)	62	2.1	3.4	4.3	4.0	2.0	53.0
33: Acquisition (FLIR, LST, Manual)	41	2.3	2.1	3.9	3.8	1.7	47.1
34: Acquisition (FLIR, LST, Automatic)	52	2.3	0.4	4.0	4.0	0.9	40.8
35: Engagement, LOAL (Auto, Manual Track)	36	1.7	0.9	3.9	4.1	2.1	44.2
36: Engagement, LOAL (Auto, IAT)	37	1.7	0.6	2.5	3.2	1.1	33.9
37: Engagement, LOAL (Auto, IAT Offset)	39	1.7	0.8	2.5	3.4	1.2	35.1
38: Engagement, LOAL (Remote Designation)	30	3.2	0.7	1.6	4.7	0.9	39.1
39: Engagement, LOBL (Auto, Manual Track)	35	1.8	1.3	3.8	4.5	3.0	49.0
40: Engagement, LOBL (Auto, IAT)	36	1.7	1.0	2.3	3.6	1.9	37.9
41: Engagement, LOBL (Auto, IAT Offset)	39	1.7	1.2	2.5	3.8	2.0	39.3
42: Engagement, LOBL (Remote Designation)	77	2.8	0.4	1.3	4.1	0.6	33.4
43: Engagement, Gun (Pilot, IHADSS)	28	2.0	0.1	2.7	3.8	0.3	33.0
44: Engagement, Gun (CPG, IHADSS)	31	1.9	0.3	5.1	3.2	2.2	43.7
45: Engagement, Gun (CPG, TADS, IAT)	34	1.8	0.5	2.8	3.3	0.8	34.0
46: Engagement, FFAR (Pilot)	56	1.5	0.1	1.7	2.7	0.2	24.8
47: Engagement, FFAR (CO-OP)	66	1.7	0.2	2.0	3.0	0.4	28.3
48: Engagement, LOAL (Rapid Fire)	45	1.6	1.1	3.9	4.5	2.6	46.9
49: Engagement, LOAL (Ripple Fire)	65	2.5	0.8	2.7	4.6	1.5	42.3
50: FARP Procedures	534	1.4	0.1	1.5	2.5	0.2	23.7
51: Engine Shutdown	150	1.6	0.2	1.9	2.7	1.1	28.9
52: Before Leaving Aircraft	525	1.2	0.0	2.3	3.1	1.4	30.6

Note. Duration is given in seconds. The following abbreviations are used as column headings in Table 4: AUD = Auditory, KIN = Kinesthetic, VIS = Visual, COG = Cognitive, PSY = Psychomotor, OW = Overall Workload.

The data contained in Tables 3 and 4 indicate the following:

- Proficient crewmembers can perform the AH-64A mission without encountering overload conditions.
- The pilot's average cognitive workload is highest while establishing the battle position.
- The pilot's OW is highest in the Engagement, Gun (Pilot, IHADSS) segment.
- The copilot/gunner's average cognitive workload is highest when performing navigation during en route flight segments and when exchanging battle information.
- The copilot/gunner's OW is highest in the Holding Area Operations (Inbound) segment.
- Both crewmembers' OW is highest while deploying in the battle area and establishing the battle position.

Comparison With Other Aircraft

As mentioned earlier, TAWL analyses have been conducted for the UH-60A (Bierbaum, Szabo, & Aldrich, 1989), MH-60K (Bierbaum & Hamilton, 1990), CH-47D (Bierbaum & Aldrich, 1989), and MH-47E (Bierbaum & Hamilton, 1991) aircraft. Each of these analyses calculated the OW metric. Thus, the metric can be used to compare aircrew workload across these different systems.

The across-segment pilot OW for the UH-60A, MH-60K, CH-47A, and MH-47E was 42.4 (n = 34, SD = 8.1), 40.7 (n = 15, SD = 8.1), 42.3 (n = 38, SD = 7.7), and 41.1 (n = 15, SD = 8.0), respectively. The 10.9 point difference in mean OW between the AH-64A pilot and the highest pilot workload found for these other Army aircraft (i.e., UH-60A) was significant, $t(84) = 5.1$, $p = \leq .0005$.

The across-segment copilot OW for the UH-60A, MH-60K, CH-47A, and MH-47E was 29.7 (n = 34, SD = 11.1), 26.5 (n = 15, SD = 7.7), 29.2 (n = 38, SD = 10.6), and 27.4 (n = 15, SD = 7.1), respectively. The 9.9 point difference in mean OW between the AH-64A copilot and the UH-60A copilot was significant, $t(84) = 4.0$, $p = \leq .0005$.

Conclusions

The workload prediction methodology developed by ARIARDA provides a systematic means for estimating the workload imposed by the advanced technology in Army aircraft. Under the conditions assumed during model development (e.g., proficient operators, optimal weather conditions), the AH-64A does not place excessive workload demands on its operators. The analysis of the predicted workload for the AH-64A aircraft resulted in the following conclusions.

- Proficient crewmembers can perform the AH-64A mission without encountering overload conditions.
- Pilot workload is significantly greater than copilot/gunner workload.
- Pilot and copilot workload was not co-related; that is, high workload for one crewmember was not accompanied by high workload for the other.
- AH-64A pilot and copilot workload is significantly greater than the workload found in other Army aircraft that have been analyzed for workload (i.e., UH-60A, MH-60K, CH-47D, MH-47E).

The significant difference and lack of correlation between pilot and copilot/gunner workload in the aircraft indicate that the task load could be reallocated from the pilot to the copilot/gunner to balance the workload across the crewmembers and segments. Furthermore, good crew coordination techniques may allow burdened crewmembers to share workload, thereby increasing the correlation between the pilot and copilot/gunner workload. However, the AH-64A workload prediction model may not capture the task-sharing procedures that experienced aircrews develop because it only uses Army regulation flight procedures. Nonetheless, segment-specific task allocation may be a feasible method for distributing the crew workload to balance the workload across mission segments and increase the relationship between pilot and copilot workload.

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