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Research Report 1584

Task Analysis and Workload Prediction for the MH-47E Mission and a Comparison with CH-47D Workload Predictions

Volume I: Summary Report

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

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U.S. ARMY RESEARCH INSTITUTE FOR THE BEHAVIORAL AND SOCIAL SCIENCES

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For this research, a mission scenario was used to conduct a comprehensive task analysis for MH-47E operations. The analysis used a top-down approach to identify the phases, functions, and tasks for the mission. Researchers identified 5 phases, 15 segments, 73 functions, and 239 tasks. They also identified the crewmember performing each task and derived estimates of the sensory, cognitive, and psychomotor workload associated with the tasks. Estimates of the task durations also were derived.

The mission/task/workload analysis data were used to develop a computer model of workload for MH-47E crewmembers. The model used a bottom-up approach to build mission functions from tasks and mission segments from functions. Decision rules were written to specify the procedure for combining the tasks into functions and the functions into segments. The model permitted an analysis of total workload experienced by the pilot and copilot in the performance of both sequential and concurrent tasks. The predicted workload for the MH-47E pilot and copilot was compared to the CH-47D baseline workload prediction to determine the

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impact of the advanced technology on the MH-47E. The comparison indicated little difference in the predicted workload for the pilot and indicated a lower predicted workload for the copilot in the MH-47E.

Volume I of the report describes the methodology and summarizes the results of the research. Volume II contains the appendixes, which present the workload predictions of the CH-47D model; the MH-47E mission/task/workload analysis, decision rules, and workload predictions; and a comparison of the predictions from both models.

Research Report 1584

Task Analysis and Workload Prediction for the MH-47E Mission and a Comparison with CH-47D Workload Predictions

Volume I: Summary Report

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FOREWORD

The impact that advanced technology will have on manpower and personnel requirements must be considered during the planning of system modifications. A critical consideration is the impact that advanced technology will have on the workload of the system operator(s). Because high operator workload can result in a dramatic decrease in system effectiveness, it is imperative that operator workload be considered throughout the system development and modification process.

This two-volume report describes the methods used to conduct a comprehensive task analysis of the MH-47E mission and the results of the analysis. Information provided by the MH-47E mission/task/workload analysis was used to establish a database to develop a computer model that predicts workload for the MH-47E pilot and copilot. Predictions of workload produced by the MH-47E model were compared with the CH-47D baseline model (Bierbaum & Aldrich, 1989) to assess the workload impact of the high tech-nology modifications made in the MH-47E aircraft.

Volume I of the report describes the methodology and summarizes the results of the research; Volume II contains Appendixes presenting the results of the research. The following specific information is presented in each of the appendixes:

- Appendixes A and B present the results of exercising the CH-47D baseline model;
- Appendix C presents a summary of the MH-47E mission phases and segments;
- Appendix D lists mission functions;
- Appendix E summarizes the functions within each mission segment;
- Appendix F presents a list of tasks;
- Appendix G presents Function Analysis Worksheets that summarize the workload data for each function;
- Appendixes H through K present the decision rules for construction of the MH-47E workload prediction model;
- Appendixes L and M present the workload predictions for the pilot and copilot for the MH-47E mission segments; and

- Appendix N presents a comparison list of MH-47E and CH-47D segments and functions.

The U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) Systems Research Laboratory was responsible for this research, which was executed by the Aviation Research and Development Activity (ARIARDA) at Fort Rucker, Alabama. The work was sponsored by the Special Operations Aviation (SOA) program manager at the Aviation Systems Command (AVSCOM), St. Louis, Missouri. The work was performed under a Memorandum of Agreement entitled "Establishment of Technical Coordination between ARI and AVSCOM," dated 10 April 1985.

The results were provided to the SOA program office and the CH-47 program office to use as a baseline for other proposed multistage improvement programs (MSIP). The authors provided briefings to the SOA Crew Station Working Group, which included personnel from the manufacturers (Boeing, IBM, Singer-Link), AVSCOM, and the 160th SOAG.

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The authors wish to express their appreciation to the following individuals for their contribution to this research effort.

Chief Warrant Officer (CWO) John M. LeDuc, 160th Special Operations Aviation Group (SOAG), Fort Campbell, Kentucky, served as subject matter expert for the review of the MH-47E task analysis. The task analysis required in-depth knowledge of the MH-47E cockpit configuration and the tasks performed at the pilot and copilot stations. CWO LeDuc's knowledge of the specific tasks performed by the pilot and copilot in the conduct of their mission contributed greatly to the success of the task analysis.

Ms. Laura Fulford and Ms. Cassandra Hocutt, Anacapa Sciences, Inc., developed the Task Analysis/Workload (TAWL) Operator Simulation System (TOSS) to provide for the management of the MH-47E and CH-47D mission/task/workload database and the workload prediction models.

The authors especially thank Ms. Nadine McCollim, Anacapa Sciences, Inc., for the speedy and accurate typing of the numerous revisions of the task analysis. Her work significantly enhanced the quality of the final product.

TASK ANALYSIS AND WORKLOAD PREDICTION FOR THE MH-47E MISSION AND A COMPARISON WITH CH-47D WORKLOAD PREDICTIONS

Volume I: Summary Report

EXECUTIVE SUMMARY

Research Requirement:

The research reported in this two-volume document was conducted by the U.S. Army Research Institute Aviation Research and Development Activity (ARIARDA) to evaluate the impact that proposed modifications for the MH-47E aircraft will have on crew workload when compared to the crew workload of the CH-47D.

The concern in conducting the analyses was that high technology modifications being proposed for the existing aircraft systems may increase workload by placing additional demands on the mental resources of the crewmembers. The primary requirements of the research are to (a) conduct a detailed analysis of the operator tasks that must be performed during the MH-47E combat mission, (b) develop a computer model that predicts MH-47E operator workload, and (c) compare the MH-47E operator workload predictions with the CH-47D baseline operator workload predictions.

Procedure:

Anacapa Sciences personnel, under contract to ARIARDA, developed a methodology for predicting operator workload during the conceptual phase of system development for the Army's Light Helicopter Family (LHX) aircraft. The LHX workload prediction methodology has been refined and used to develop baseline models to predict workload encountered by operators of the AH-64A, UH-60A, and CH-47D aircraft. Whereas the LHX model was based on a generic analysis of an aircraft in the conceptual design phase of development, the other baseline models are based on analyses of existing systems. Consequently, the workload analyses of the AH-64A, UH-60A, and CH-47D were conducted at a much more detailed level than the LHX workload analysis. The refined workload prediction methodology has been named the Task Analysis/Workload (TAWL) methodology.

During the present workload analysis of the MH-47E, the TAWL methodology was used to accomplish the following technical objectives:

- produce estimates of operator workload during the CH-47D mission;
- identify the phases, segments, functions, and tasks in the MH-47E mission;
- identify the crewmember(s) performing each task;
- estimate the workload associated with the sensory, cognitive, and psychomotor components of each task;
- estimate the temporal sequence and duration of each task;
- identify the subsystem(s) representing the man-machine interface for each task;
- develop decision rules for combining the tasks into functions and for combining the functions into segments;
- utilize the TAWL Operator Simulation System (TOSS) software to produce predictions of MH-47E operator workload; and
- compare the MH-47E predicted operator workload with the CH-47D predicted operator workload.

Findings:

The MH-47E mission/task/workload analysis identified 5 phases, 15 unique segments, 73 unique functions, and 239 unique tasks. Under the conditions that the model was developed (e.g., proficient operators, optimal weather conditions), neither the CH-47D nor the MH-47E appear to place excessive workload demands on the operators. A comparison of the pilot workload for the MH-47E and the CH-47D resulted in the following observations:

- **The predicted visual-unaided workload was slightly lower for the MH-47E because much of the aircraft system monitoring is automatically performed by the MH-47E integrated avionics subsystems.**

- The reduction of visual-unaided workload is advantageous in that it allows the MH-47E pilot to shift attention to external visual tasks. Thus, in some segments, the predicted night vision goggle (NVG) workload was higher for the MH-47E than for the CH-47D. The increase in external visual attention indicates that the MH-47E pilot may have an increased awareness of the status and spatial location of the aircraft, of other air traffic, and of threats to the aircraft.

- The predicted kinesthetic and psychomotor workload was lower for the MH-47E during Segment 04 when the flight controls are coupled.

- The predicted overall workload (OW) was similar for both aircraft except that OW is lower for the MH-47E when the flight controls are coupled.

A comparison of the predicted workload for the copilot in the MH-47E and the CH-47D resulted in the following observations:

- The predicted visual-unaided workload was lower for the MH-47E than for the CH-47D due to the reduced requirements for map interpretation; present position is always available on the MH-47E multifunction display (MFD).
- The reduction of visual-unaided workload is advantageous in that it allows the MH-47E copilot to shift attention to external visual tasks. Thus, the predicted NVG workload was higher for the MH-47E than for the CH-47D. The increase in external visual attention indicates that the MH-47E copilot may have an increased awareness of the status and spatial location of the aircraft, of other air traffic, and of threats to the aircraft.
- The predicted cognitive workload was lower for the MH-47E because functions such as monitoring fuel consumption, checking system status, and determining present position are performed continuously by the mission processor.
- The predicted OW was generally lower for the MH-47E than for the CH-47D.

Utilization of Findings:

The predicted effect of the MH-47E modifications on operator workload can be used in making human engineering design decisions (i.e., is more automation needed). In addition, the task analysis data should prove useful in identifying training requirements for the MH-47E aircraft. An analysis of the tasks to be performed and the associated components within each task will allow the trainers to determine the methods of instruction needed and the equipment necessary for conducting the training.

TASK ANALYSIS AND WORKLOAD PREDICTION FOR THE MH-47E MISSION AND A COMPARISON WITH CH-47D WORKLOAD PREDICTIONS

Volume I: Summary Report

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GLOSSARY OF ACRONYMS AND ABBREVIATIONS

ANVIS	Aviator's Night Vision Imaging System
ARI	Army Research Institute for the Behavioral and Social Sciences
ARIARDA	Army Research Institute Aviation Research and Development Activity
ASE	Aircraft Survivability Equipment
AUD	Auditory
AVSCOM	Army Aviation Systems Command
COG	Cognitive Workload
CWO	Chief Warrant Officer
FARP	Forward Area Refueling Point
FLIR	Forward-Looking Infrared
GPS	Global Position System
IAS	Integrated Avionics Subsystem
KIN	Kinesthetic
LHX	Light Helicopter Family
LZ	Landing Zone
MFD	Multifunction Display
NOE	Nap-of-the-Earth
NVG	Night Vision Goggles, Visual-Aided
OC	Overload Conditions
OW	Overall Workload
PSY	Psychomotor Workload
SME	Subject Matter Expert
SOAG	Special Operations Aviation Group
SOF	Special Operations Forces
TAWL	Task Analysis/Workload
TOSS	TAWL Operator Simulation System
VIS	Visual-Unaided

TASK ANALYSIS AND WORKLOAD PREDICTION FOR THE MH-47E MISSION AND A COMPARISON WITH CH-47D WORKLOAD PREDICTIONS

INTRODUCTION

The Special Operations Forces (SOF) Aviation Project Office at the Army Aviation Systems Command (AVSCOM) has been tasked to modify existing CH-47D aircraft for SOF missions. The aircraft, designated the MH-47E, will be modified by replacing present instrumentation with a fully integrated cockpit featuring four multifunction displays (MFDs). The modifications include:

- terrain avoidance/terrain following radar,
- forward-looking infrared (FLIR) capability,
- flight symbology on the Aviator's Night Vision Imaging System (ANVIS),
- improved navigation capability, including global position system (GPS) and continuous present position display,
- improved flight control with all axes coupled to the mission computer,
- map display on the MFDs, and
- air-to-air refueling capability with automatic fuel consumption display.

The modifications for the MH-47E aircraft are designed to increase operational effectiveness and to reduce operator workload during SOF missions. The increased capabilities of the MH-47E aircraft have dramatically increased the amount of display information available to the operators and may increase operator workload by placing additional demand on the cognitive resources of the crewmembers. Although many tasks performed by the operators in the CH-47D have been automated in the MH-47E aircraft, technology that reduces an operator's need to maintain physical control of system functions often increases the operator's role as a monitor. Thus, in some instances, automation may simply change the nature of the task without decreasing operator workload.

A mission/task/workload analysis was needed to assess the impact of the MH-47E aircraft modifications and the SOF mission on crew workload. The SOF Aviation Project Office requested that the Army Research Institute Aviation Research and Development Activity (ARIARDA) use the task analysis/workload (TAWL) prediction methodology to (a) conduct a mission/task analysis for the CH-47D and MH-47E aircraft, (b) produce workload predictions for the CH-47D and MH-47E aircraft, and (c) compare the workload in the MH-47E with workload in the CH-47D.

The TAWL Methodology

Under contract to ARIARDA, Anacapa Sciences, Inc., personnel developed a TAWL methodology for predicting operator workload. Initially, the methodology was used to address design issues for the Army's light helicopter family (LHX) aircraft (Aldrich, Craddock, & McCracken, 1984; McCracken & Aldrich, 1984). The methodology was later refined and used to develop a model of operator workload for the AH-64A aircraft (Szabo & Bierbaum, 1986). Bierbaum, Fulford, and Hamilton (1990) provided a complete description of the TAWL prediction methodology and its computer support. The remainder of this subsection presents an overview of 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 identified in the theory. It recognizes six independent workload components: auditory, kinesthetic, visual-unaided, visual-aided, 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 between 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 could 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. The research analysts and MH-47 subject matter experts (SMEs) generated workload estimates by using equal-interval, verbally anchored rating scales; the scale values range from 1.0 to 7.0. This approach avoids the expense in time, money, and manpower required to derive empirical measures of workload for each task.

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 TAWL Operator Simulation System (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 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.

A criterion that represents an estimate of the overload threshold is used during execution of the model to produce estimates of 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 crewmember,
- the time intervals (half-second minimum interval) during which crewmembers experience high workload, and
- the components for which crewmembers experience high workload.

The information yielded by the TAWL methodology may enable system designers to reduce workload or to 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 time lines and task listings (at half-second intervals) that can be used to develop the system's manning and training requirements.

Research Objectives

The research described in this report was designed to address the issues of workload in the MH-47E aircraft. To place the MH-47E workload predictions in perspective relative to other similar aircraft, a baseline workload prediction model was prepared for the CH-47D aircraft. The task/workload analysis and model construction phases of the CH-47D baseline model were described in a report by Bierbaum and Aldrich (1989a). Thus, the present research has the following objectives:

- exercise the CH-47D model to produce estimates of operator workload during the CH-47D mission,
- produce an analysis of the tasks that must be performed to accomplish the MH-47E mission,
- develop a computer model to predict MH-47E operator workload,
- exercise the MH-47E model to produce estimates of operator workload during the MH-47E mission, and
- compare the MH-47E operator workload predictions with the CH-47D baseline operator workload predictions.

The report has two volumes. Volume I describes the research methods and research findings. Volume II comprises Appendixes A-N, which present the workload predictions of the CH-47D baseline model and contain the data produced during the task/workload analysis of the MH-47E aircraft. Volume II also contains the data produced during the construction of the MH-47E model, the workload predictions of the MH-47E model, and a comparison list of the segment and function names in the CH-47D and the MH-47E models.

ANALYSIS I - THE CH-47D WORKLOAD PREDICTION MODEL

Bierbaum and Aldrich (1989a) conducted a mission/task analysis of the CH-47D aircraft identifying 9 mission phases, 38 segments, 74 functions, and 164 tasks. The results of the mission/task analysis were used to develop a workload prediction model. The results from exercising the microcomputer-based CH-47D workload prediction model developed by Bierbaum and Aldrich are reported below. The results of the CH-47D analysis provide a baseline against which to compare the workload predictions for the MH-47E aircraft.

Method

The analysts used TOSS to automate the data entry and execute the CH-47D workload model; the steps required to implement the model are fully described by Bierbaum, Fulford, and Hamilton (1990) and are briefly summarized here. The task names, subsystems, and workload estimates from the task/workload analysis stage and the function and segment decision rules from the model construction stage of the CH-47D analysis (Bierbaum & Aldrich, 1989a) were entered into TOSS using the data entry routines of the system. Then, each of the 38 unique segments of the model was simulated. As mentioned above, 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 (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 of overload 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 six component overloads (i.e., cognitive, psychomotor, visual-aided, visual-unaided, auditory, and kinesthetic) could occur for each half-second interval on the mission time line. 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 exists when at least one component overload occurs. 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, Linton, Bittner, and Byers (1989) conducted research to determine the validity of the UH-60A workload prediction model. 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 TAWL's independent predictions for each of the six workload components into a single overall estimate of workload. Iavecchia et al. assumed additivity and summed the TAWL 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 = .81 to .95).

During the workload analysis of the CH-47D, 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:

$$OW = \left[\frac{AUD + KIN + VIS + NVG + COG + PSY}{6.0} \times 14.5 \right] + 7.2$$

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

This equation is useful to this research for two reasons. First, the equation 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 scientifically justified 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, complete with its slope (14.5) and intercept (7.2), 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 the analyses of the CH-47D and the MH-47E aircraft and in their comparison.

Results

Workload prediction graphs for the pilot and copilot were produced for each of the 38 CH-47D 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. An example of a segment workload prediction graph is presented in Figure 1. Figure 1 shows estimated workload for the pilot on each component during the Approach [NVG] segment of the mission. A brief description of the graph for each component in Figure 1 follows.

Workload associated with random cockpit communication can be seen in the Auditory graph as a pair of closely spaced peaks of workload. 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 is constant throughout the approach. The interruptions in the NVG workload are the result of the pilot checking the instruments and the threat alert system. These checks are also indicated by the increase in visual workload on the Visual graph at the time the NVG is interrupted. Cognitive workload associated with cockpit communication can be seen as

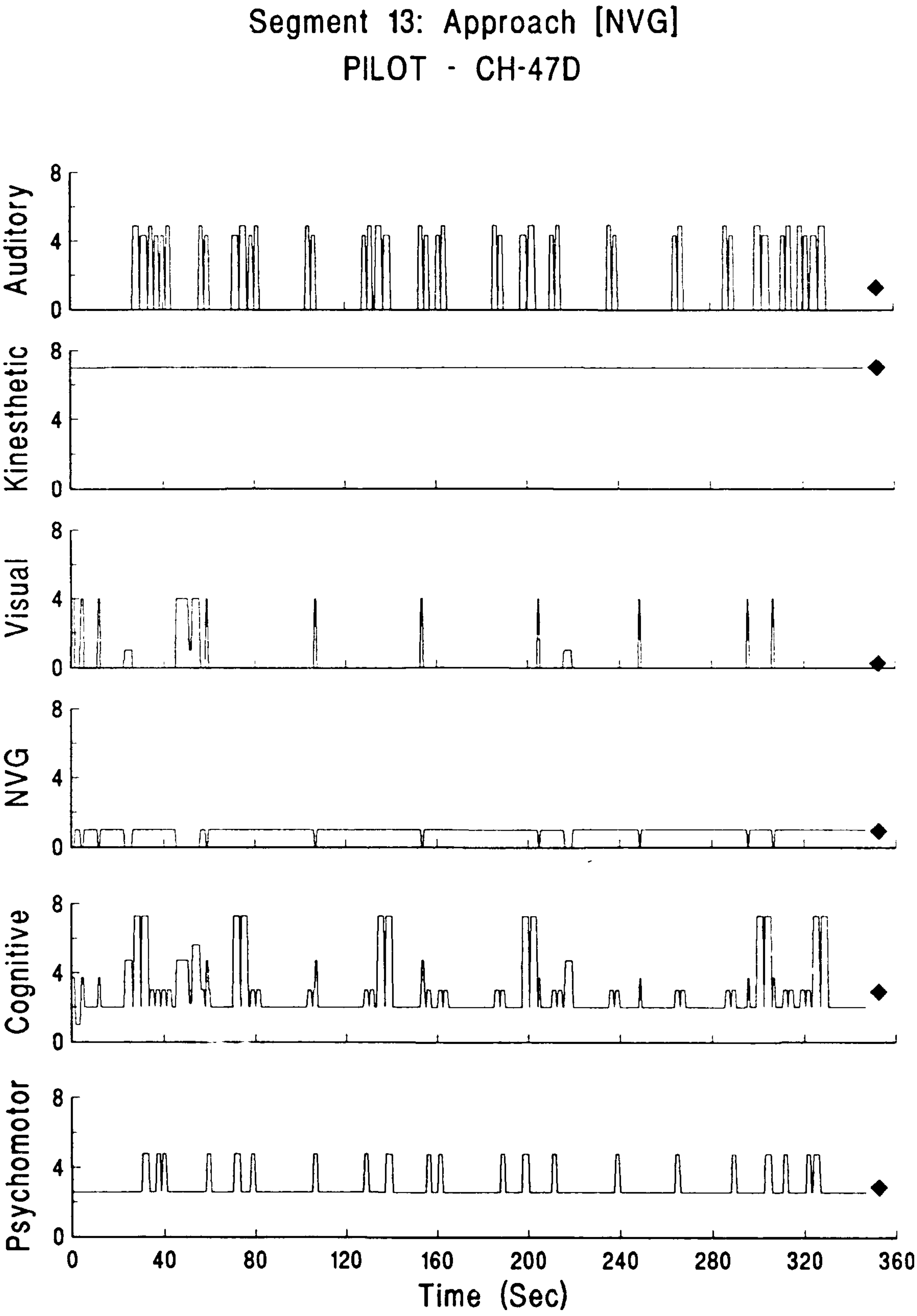


Figure 1. Example of a pilot segment workload prediction graph.

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 at the end of each graph indicates the mean component workload for the entire segment. Appendix A presents graphs of pilot workload for each of the 38 mission segments. Each page displays the pilot workload for one segment using six graphs, one for each workload component. Graphs of copilot workload for each of the mission segments are presented in Appendix B.

The CH-47D workload model predictions for the pilot and copilot are summarized in Tables 1 and 2, respectively. The tables show, for each of the 38 segments, the number of overload conditions (OC), the mean workload for each of the six components, and the predicted OW.

The workload predictions contained in the tables indicate the following:

- The only overload condition observed during the mission occurred during the nap-of-the-earth (NOE) and contour flight segments when a threat was present (overload conditions occurred for both the pilot and copilot during these segments).
- The pilot's average kinesthetic and psychomotor workload is higher during flight segments.
- The pilot's OW is highest in the Takeoff (External Load) segment.
- The copilot's average cognitive workload is highest when performing navigation during en route flight segments.
- The copilot's OW is highest in the NOE Flight (Mission Change) segment.
- Both crewmembers' OW is highest during flight segments.
- Proficient crewmembers can perform the CH-47D missions without encountering an overload condition, except when being engaged by a threat.

Table 1

Pilot Workload for the CH-47D Model by Segment

Segment	OC	AUD	KIN	VIS	NVG	COG	PSY	OW
01: Before Takeoff (Assembly Area)	0	0.6	3.4	1.5	0.0	2.6	1.2	29.8
02: Takeoff (Assembly Area)	0	2.9	7.0	1.3	0.0	3.8	3.3	51.4
03: Before Takeoff (Assembly Area) [NVG]	0	0.6	3.5	0.2	1.2	2.4	1.2	29.1
04: Takeoff (Assembly Area) [NVG]	0	2.5	7.0	0.4	1.8	3.5	3.2	52.0
05: Contour Flight	0	1.3	7.0	1.8	0.0	3.3	2.9	46.5
06: Contour Flight [NVG]	0	1.3	7.0	0.4	0.9	3.3	2.9	45.3
07: Contour Flight (Threat)	5	1.3	7.0	1.9	0.0	3.3	2.9	46.9
08: Contour Flight (Threat) [NVG]	0	1.3	7.0	0.4	1.1	3.3	2.9	46.0
09: Contour Flight (Mission Change)	0	1.3	7.0	1.8	0.0	3.2	2.9	46.4
10: Contour Flight (Mission Change) [NVG]	0	1.3	7.0	0.4	0.9	3.2	2.9	45.2
11: Approach	0	1.3	7.0	1.7	0.0	2.9	2.9	45.3
12: Landing	0	2.1	6.8	2.3	0.0	3.0	3.1	49.1
13: Approach [NVG]	0	1.3	7.0	0.3	0.9	2.9	2.9	44.1
14: Landing [NVG]	0	1.2	6.9	0.0	2.5	2.6	2.9	46.2
15: Before Takeoff (Internal Load)	0	1.9	1.0	1.0	0.0	3.0	0.4	24.9
16: Takeoff	0	2.7	7.0	2.3	0.0	4.4	3.2	54.5
17: Takeoff [NVG]	0	2.6	7.0	0.9	1.8	3.6	3.2	52.1
18: Before Takeoff (External Load)	0	1.3	4.8	1.2	0.0	3.0	1.8	36.2
19: Takeoff (External)	0	1.5	7.0	1.7	0.0	3.5	3.0	47.4
20: Before Takeoff (External Load) [NVG]	0	1.0	5.1	0.0	1.0	2.8	1.9	35.5
21: Takeoff (External) [NVG]	0	0.9	7.0	0.6	0.8	2.9	2.8	43.4
22: NOE Flight	0	1.3	7.0	1.8	0.0	3.2	2.9	46.3
23: NOE Flight [NVG]	0	1.3	7.0	0.4	0.9	3.3	2.9	45.4
24: NOE Flight (Threat)	2	1.3	7.0	1.9	0.0	3.3	2.9	46.8
25: NOE Flight (Threat) [NVG]	1	1.3	7.0	0.4	1.2	3.3	2.9	46.2
26: NOE Flight (Mission Change)	0	0.8	7.0	1.8	0.0	2.7	2.8	43.9
27: NOE Flight (Mission Change) [NVG]	0	0.8	7.0	0.4	0.9	2.7	2.8	42.7
28: Approach (LZ)	0	1.3	7.0	1.7	0.0	2.9	2.9	45.2
29: Landing (LZ, Internal Load)	0	1.1	6.5	2.4	0.0	2.6	2.7	44.0
30: Landing (LZ, External Load)	0	1.3	6.5	2.3	0.0	2.8	2.7	45.1
31: Approach (LZ) [NVG]	0	1.3	7.0	0.3	0.9	2.9	2.9	44.3
32: Landing (LZ, Internal Load) [NVG]	0	1.0	6.6	0.0	2.5	2.5	2.7	43.9
33: Landing (LZ, External Load) [NVG]	0	1.1	6.6	0.0	2.6	2.6	2.7	44.9
34: Before Takeoff (LZ)	0	2.6	1.0	1.0	0.0	3.6	0.6	28.4
35: FARP Procedures	0	0.9	3.4	2.4	0.0	3.0	1.3	34.0
36: FARP Procedures [NVG]	0	0.8	4.0	0.4	2.2	2.7	1.5	35.2
37: Before Takeoff (FARP)	0	2.6	1.0	1.0	0.0	2.8	0.6	26.6
38: Before Takeoff (LZ) [NVG]	0	2.5	1.0	0.0	1.0	3.9	0.5	28.7

Note. The following abbreviations are used as column headings in Table 1: OC = Overload Condition, AUD = Auditory, KIN = Kinesthetic, VIS = Visual-unaided, NVG = Visual-aided, COG = Cognitive, PSY = Psychomotor, OW = Overall Workload.

Table 2

Copilot Workload for the CH-47D Model by Segment

Segment	OC	AUD	KIN	VIS	NVG	COG	PSY	OW
01: Before Takeoff (Assembly Area)	0	0.8	0.1	2.5	0.0	2.0	2.3	25.4
02: Takeoff (Assembly Area)	0	2.9	0.2	1.4	0.0	2.9	0.5	26.2
03: Before Takeoff (Assembly Area) [NVG]	0	0.7	0.1	2.4	0.3	2.0	2.2	25.7
04: Takeoff (Assembly Area) [NVG]	0	2.5	0.2	0.7	1.2	3.2	0.4	27.2
05: Contour Flight	0	1.3	0.1	4.8	0.0	6.0	2.6	42.9
06: Contour Flight [NVG]	0	1.5	0.1	3.9	0.9	6.1	2.3	43.0
07: Contour Flight (Threat)	5	1.4	0.1	4.6	0.0	5.9	2.6	42.3
08: Contour Flight (Threat) [NVG]	0	1.5	0.1	3.5	0.8	5.5	2.4	40.3
09: Contour Flight (Mission Change)	0	1.5	0.1	4.4	0.0	5.6	3.2	42.7
10: Contour Flight (Mission Change) [NVG]	0	1.5	0.1	3.7	0.7	5.6	3.3	43.0
11: Approach	0	1.5	0.1	1.2	0.0	2.0	0.2	19.4
12: Landing	0	2.5	0.2	0.3	0.0	1.3	0.4	18.5
13: Approach [NVG]	0	1.6	0.1	0.7	0.8	2.4	0.4	21.5
14: Landing [NVG]	0	1.4	0.1	0.1	1.2	2.1	0.2	19.3
15: Before Takeoff (Internal Load)	0	2.6	0.1	3.6	0.0	2.4	1.7	32.6
16: Takeoff	0	2.7	0.2	2.1	0.0	3.7	0.7	29.7
17: Takeoff [NVG]	0	2.6	0.2	0.8	1.1	3.2	0.4	27.0
18: Before Takeoff (External Load)	0	1.5	0.1	2.0	0.0	1.8	0.7	22.0
19: Takeoff (External)	0	1.5	0.1	1.5	0.0	2.5	0.4	21.7
20: Before Takeoff (External Load) [NVG]	0	1.2	0.0	1.1	0.7	1.6	0.6	19.5
21: Takeoff (External) [NVG]	0	0.9	0.1	0.5	0.8	1.9	0.2	17.7
22: NOE Flight	0	1.3	0.1	4.8	0.0	6.4	3.2	45.2
23: NOE Flight [NVG]	0	1.3	0.1	4.0	0.7	6.3	2.6	43.5
24: NOE Flight (Threat)	2	1.5	0.1	4.5	0.0	6.1	3.0	43.7
25: NOE Flight (Threat) [NVG]	1	1.5	0.1	4.0	0.5	6.1	3.0	43.8
26: NOE Flight (Mission Change)	0	1.0	0.1	5.1	0.0	6.0	3.6	45.3
27: NOE Flight (Mission Change) [NVG]	0	1.0	0.1	4.6	0.5	6.0	3.5	45.0
28: Approach (LZ)	0	1.3	0.1	1.3	0.0	2.0	0.2	19.0
29: Landing (LZ, Internal Load)	0	1.3	0.1	1.3	0.0	1.8	0.2	18.3
30: Landing (LZ, External Load)	0	1.4	0.1	1.3	0.0	1.9	0.2	18.9
31: Approach (LZ) [NVG]	0	1.5	0.1	0.4	0.9	2.1	0.2	19.8
32: Landing (LZ, Internal Load) [NVG]	0	1.1	0.1	0.2	1.3	2.0	0.2	19.0
33: Landing (LZ, External Load) [NVG]	0	1.1	0.1	0.2	1.0	1.7	0.2	17.6
34: Before Takeoff (LZ)	0	2.6	0.2	1.9	0.0	2.6	1.2	27.7
35: FARP Procedures	0	1.0	0.1	1.5	0.0	2.2	0.1	19.0
36: FARP Procedures [NVG]	0	0.9	0.1	0.5	0.6	1.7	0.1	16.6
37: Before Takeoff (FARP)	0	3.6	0.3	2.2	0.0	2.2	1.4	30.6
38: Before Takeoff (LZ) [NVG]	0	2.5	0.1	2.4	0.0	3.2	1.5	30.7

Note. The following abbreviations are used as column headings in Table 2: OC = Overload Condition, AUD = Auditory, KIN = Kinesthetic, VIS = Visual-unaided, NVG = Visual-aided, COG = Cognitive, PSY = Psychomotor, OW = Overall Workload.

ANALYSIS II - THE MH-47E WORKLOAD PREDICTION MODEL

The MH-47E workload prediction model was developed with the same procedures as the CH-47D model (Bierbaum & Aldrich, 1989a). The following section includes a full description of the TAWL methodology used for the MH-47E for the benefit of the reader not in possession of the previous report. The section also includes the results of exercising the TOSS software in the analysis of workload for the MH-47E aircraft.

Method

Mission/Task/Workload Analysis

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

- develop a composite mission scenario,
- divide 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 MH-47E mission is shown in Figure 2. Each of the analytic steps is described in the following subsections.

Develop a Composite Mission Scenario

The first step in conducting the MH-47E mission/task/workload analysis was to develop a composite mission scenario. A composite mission is a combination of the unique operations present in several typical MH-47E missions. A composite mission scenario was developed for the MH-47E from unique mission profiles that differed in the:

- mode of flight (en route, contour, NOE),
- presence of a threat during flight, and
- receipt of mission changes during flight.

Information from three sources was used to develop the scenario: (a) the International Business Machines Integrated Avionics Subsystem (IAS) technical proposal, (b) the IAS control layer formats, and (c) interviews with 160th SOAG MH-47E SMEs.

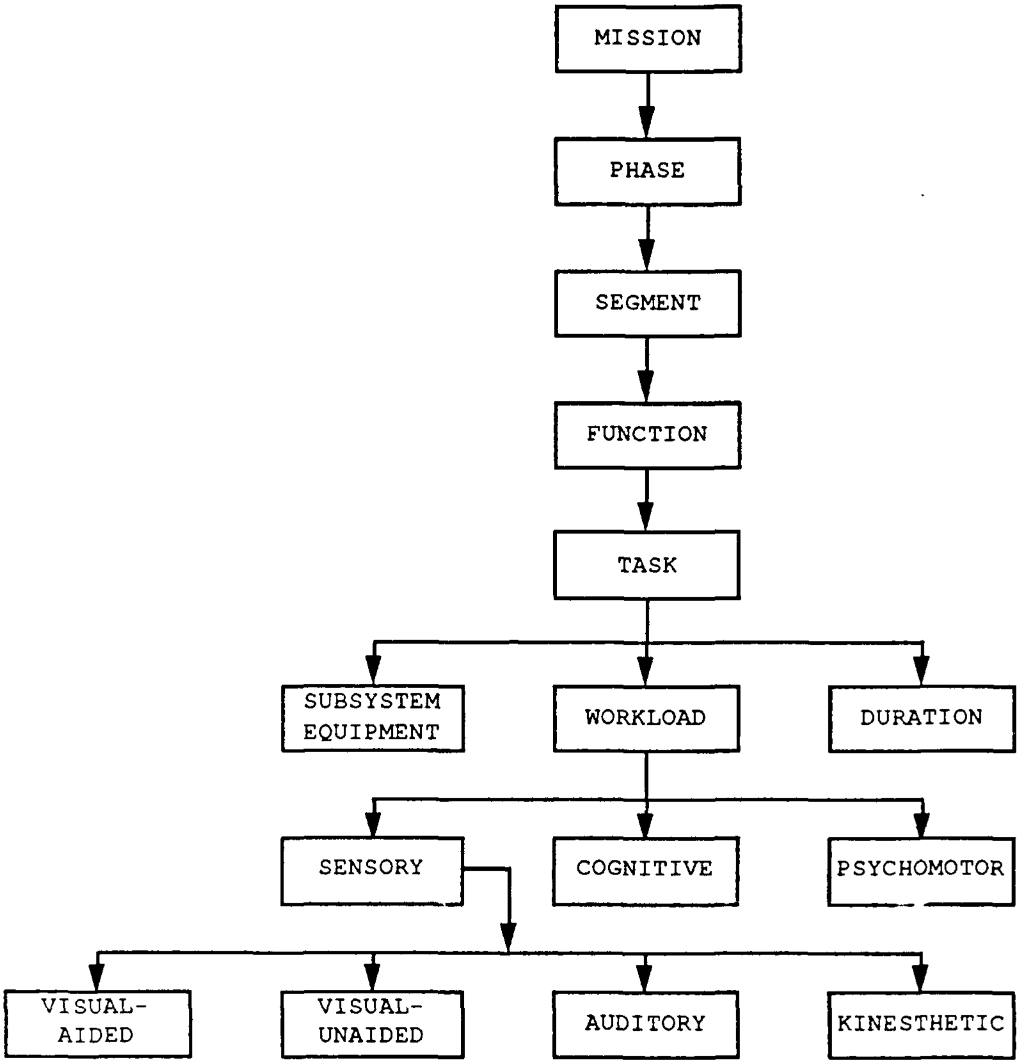


Figure 2. Diagram of the taxonomy used in the top-down analysis of the MH-47E mission.

The researchers made three assumptions in developing the mission scenario. First, the prototypical mission for the MH-47E aircraft is to support special operations by transporting personnel and internal cargo at night. Second, the pilot's primary role is to fly the aircraft and the copilot's primary role is to assist the pilot and to perform navigation functions. Third, the mission is flown under optimal conditions (i.e., full moon with no degradations due to weather or equipment). By assuming optimal conditions for the mission, the most conservative estimates of workload are produced.

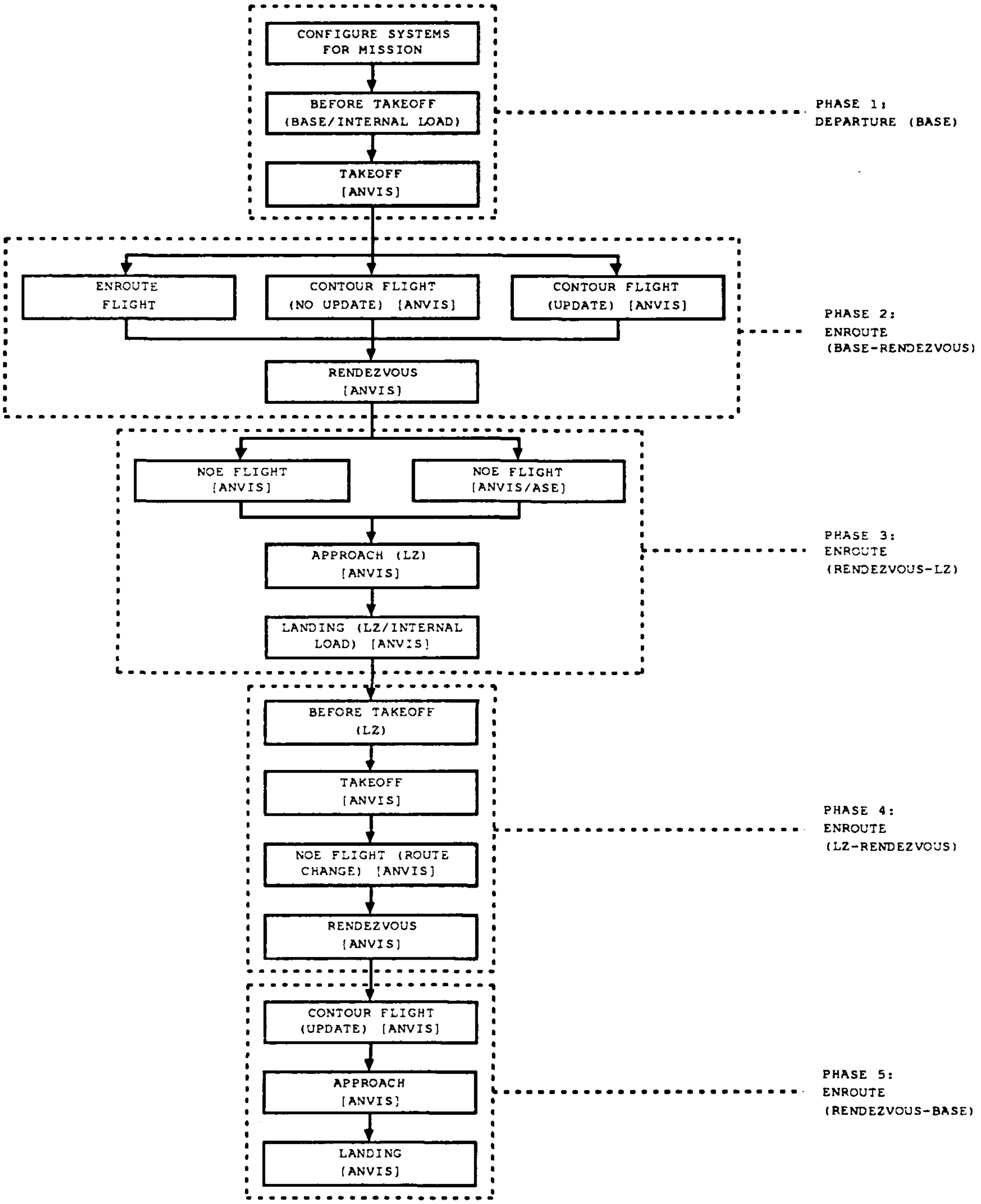
That is, if excessive workload occurs during optimal conditions, excessive workload also would be expected during degraded conditions.

The resultant MH-47E mission is depicted schematically in Figure 3. Dashed rectangles represent mission phases; solid rectangles represent mission segments. The MH-47E mission begins at a base where the crew performs preflight and departure operations. The pilot then flies contour flight from the base to a rendezvous point where air-to-air refueling operations are performed. After completing the refueling operations, the pilot flies NOE to the landing zone (LZ) where combat troops are inserted or cargo is delivered. After completing the troop and/or cargo delivery, the pilot flies NOE back to a rendezvous point for air-to-air refueling. Upon completion of the second refueling operation, the pilot flies contour back to the base where postflight activities are conducted.

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 MH-47E aircraft. Furthermore, the scenario developed for the MH-47E analysis is similar to the scenario and conditions used to develop the CH-47D workload prediction model (Bierbaum & Aldrich, 1989a). The close correspondence between the CH-47D mission and the MH-47E mission facilitated the comparison of workload predictions for the CH-47D and MH-47E aircraft.

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 Figure 3).



Note. The following abbreviations are used in Figure 3: ANVIS = Aviator's Night Vision Imaging System; ASE = Aircraft Survivability Equipment; LZ = Landing Zone.

Figure 3. Schematic diagram of the MH-47E composite mission scenario.

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 [ANVIS] is an example of a segment that appears in more than one mission phase.

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. For each function identified during mission decomposition, a Function Analysis Worksheet was developed to organize the information gained from the analysis. Figure 4 presents an example of a Function Analysis Worksheet.

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. Each task identified for a particular function was listed on the Function Analysis Worksheet for that function. Tasks were described by verbs and objects, which were listed in the first two columns of the worksheet. The verb described the crewmember's action; the object described the recipient of the action. Examples of verbs include check, set, position, monitor, and release; examples of objects include switches, knobs, helmets, and maps.

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 task data were entered on a Function Analysis Worksheet prepared for each function. Figure 4 presents the data for each of the tasks identified in the mission function entitled "Establish Approach [NVG]." Figure 4 is referred to in the following paragraphs, which describe how the task data were derived, and in the subsequent subsection, which describes the procedures used to develop the workload prediction model.

The verbs and objects defining the tasks are presented in Columns 1 and 2, respectively, of the Function Analysis Worksheet. The remaining columns present data on each of the following:

- crewmember(s) performing the task,
- numeric task identifier,
- the subsystem(s) on which the task is performed,
- the estimated workload imposed by the task,
- switch description (when appropriate,[1] and
- the task duration.

The procedures used to derive these data are described below.

Identify 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, or both. In general, all flight control tasks were assigned to the pilot; all navigation and support tasks were assigned to the copilot.

On the Function Analysis Worksheets, tasks performed by the pilot were indicated by the letter "P" preceding the numerical identifier in the third column; similarly, tasks performed by the copilot were indicated by the letter "C." For example, Column 3 in Figure 4 indicates that the pilot performs task number 234 entitled "Check % TRQ Indication (Inflight)."

Task identifier. Numerical identifiers for each task are presented in Column 3 following the crewmember's identification code.

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[1] The type of switch that is associated with a specific task is a correlate of workload. Consequently, for each task involving a switch, the type of switch is named in the eighth column of the Function Analysis Worksheet.

MH-47E FUNCTION ANALYSIS WORKSHEET

FUNCTION 21 Establish Approach [NVG] **TOTAL TIME (Approximate) 11 Seconds**

TASKS		TASK #	SUBSYSTEM(S)	WORKLOAD COMPONENTS			SWITCH DESCRIPTION	DURATION (SECONDS) DISCRETE/ CONTINUOUS
VERB	OBJECT			SENSORY	COGNITIVE	PSYCHOMOTOR		
Check	% TRQ Indication (Inflight)	P234	Engine/ANVIS Symbology/Flight Control (EN/ANV/FC)	Feel Control Movements/ Visually Check Symbolic Indications K-7/V-4	Interpret Readout and Verify Correct Status (Readout Within Limits) C-3.7	Control Pressure P-2.6		.5
Adjust	Power [NVG]	P171	Flight Control/Night Vision Goggles (FC/VG)	Feel Control Movements/ Visually Detect Aircraft Movement K-7/G-1	Make Conditioned Association (Adjustment Needed) C-1	Control Pressure P-2.6		2
Check	% TRQ Indication (Inflight)	P234	Engine/ANVIS Symbology/Flight Control (EN/ANV/FC)	Feel Control Movements/ Visually Check Symbolic Indications K-7/V-4	Interpret Readout and Verify Correct Status (Readout Within Limits) C-3.7	Control Pressure P-2.6		.5
Press	F/D Key (4)	P072	Multifunction Display (MFD)	Visually Locate Key V-3.7	Verify Correct Status C-1.2	Press Softkey P-2.2	Softkey	.5
Control	Attitude [NVG]	P025	Flight Control (FC)	Feel Control Movement K-7	Make Conditioned Association (Adjustment Needed) C-1	Control Pressure P-2.6		3
Press	HVR SYM Key (4)	P113	Multifunction Display (MFD)	Visually Locate Key V-3.7	Verify Correct Status C-1.2	Press Softkey P-2.2	Softkey	.5
Press	RTN Key (4)	P189	Multifunction Display (MFD)	Visually Locate Key V-3.7	Verify Correct Status C-1.2	Press Softkey P-2.2	Softkey	.5

Figure 4. Example of an MH-47E Function Analysis Worksheet.

Identify subsystem(s). The next step in the analysis was for SMEs to identify the subsystem(s) associated with each task. The subsystems identified for the tasks are listed in the fourth column of the Function Analysis Worksheets. For example, task number 072, entitled "Press F/D Key (4)" in Figure 4 is associated with the Multifunction Display.

Estimate 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 three different components of attention: cognitive, psychomotor, and sensory. 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; sensory workload refers to the complexity of the visual-unaided (VIS), visual-aided (NVG), auditory (AUD), and/or kinesthetic (KIN) stimuli to which an operator must attend.

To derive a workload estimate for each task, analysts first identified the specific workload components (i.e., cognitive, psychomotor, auditory, visual-unaided, visual-aided, 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 may be required to ensure that the switch is placed in the correct position. The verbal descriptions of the attentional demands imposed by a task are presented in Columns 5, 6, and 7 of the Function Analysis Worksheets.

Analysts derived estimates of component workload by comparing the verbal descriptions of component attentional demand with verbal anchors on corresponding component workload rating scales. Table 3 presents the workload scales for each component. Bierbaum and Aldrich (1989b) developed these 7-point, equal-interval rating scales for use in the UH-60A workload analysis. Although all the component workload scales employ the same numerical values, each scale is

Table 3

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, Vertical 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)
	Visual-Aided (Night Vision Goggles [NVG])
1.0	Visually Register/Detect (Detect Occurrence of Image) With NVG
4.8	Visually Inspect/Check (Discrete Inspection/Static Condition) With NVG
5.0	Visually Discriminate (Detect Visual Differences) With NVG
5.6	Visually Locate/Align (Selective Orientation) With NVG
6.4	Visually Track/Follow (Maintain Orientation) With NVG
7.0	Visually Scan/Search/Monitor (Continuous/Serial Inspection, Multiple Conditions) With NVG

Continued on the next page

Table 3

Workload Component Scales (Continued)

Scale Value	Verbal Anchors
	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 Auditory Feedback (Detect Occurrence of Anticipated Sound)
4.9	Interpret Semantic Content (Speech)
6.6	Discriminate Sound Characteristics (Detect Auditory Differences)
7.0	Interpret Sound Patterns (Pulse Rates, Etc.)
	Kinesthetic
1.0	Detect Discrete Activation of Switch (Toggle, Trigger, Button)
4.0	Detect Preset Position or Status of Object
4.8	Detect Discrete Adjustment of Switch (Discrete Rotary or Discrete Lever Position)
5.5	Detect Serial Movements (Keyboard Entries)
6.1	Detect Kinesthetic Cues Conflicting With Visual Cues
6.7	Detect Continuous Adjustment of Switches (Rotary Rheostat, Thumbwheel)
7.0	Detect Continuous Adjustment of Controls

unique. For example, although both the NVG and the visual-unaided tasks require the use of eyes, it is well known that NVG tasks require more attention than the same tasks performed unaided during daylight. The effects of system modifications are compared by component. The intent is not to compare ratings of the NVG tasks with ratings of the visual-unaided tasks or to compare auditory tasks with psychomotor tasks.

The analysts' task was to select the verbal anchor that most closely matched the written component attentional demand description. 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 numerical ratings of the cognitive, psychomotor, and sensory workload associated with the tasks were recorded on the Function Analysis Worksheet immediately below the corresponding verbal descriptions of component attentional demand. For example, the numerical rating of the visual-unaided workload associated with the task "Press F/D Key (4)" in Figure 4 is 3.7; the cognitive workload associated with the task is 1.2; and the psychomotor workload associated with the task is 2.2.

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 in Column 9 of the Function Analysis Worksheet; a letter "c" was placed in Column 10 when the task was judged to be a continuous task. (Mission requirements determine the duration of continuous tasks.) The total time required to perform all the tasks in a function was tabulated and entered in the upper right corner of the Function Analysis Worksheet. The duration of functions containing continuous tasks generally depend upon the segments in which the functions occur. For these functions, the word "continuous" was entered in the upper right corner of the Function Analysis Worksheet.

Development of the MH-47E 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 MH-47E mission. That is, the mission was progressively decomposed into phases, segments, functions, and tasks. Tasks represented the basic units of analysis for which estimates of workload and time were derived. These data, in turn, make up the data base used to develop the MH-47E workload prediction model.

A bottom-up approach was used to develop the MH-47E 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 are 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 5.

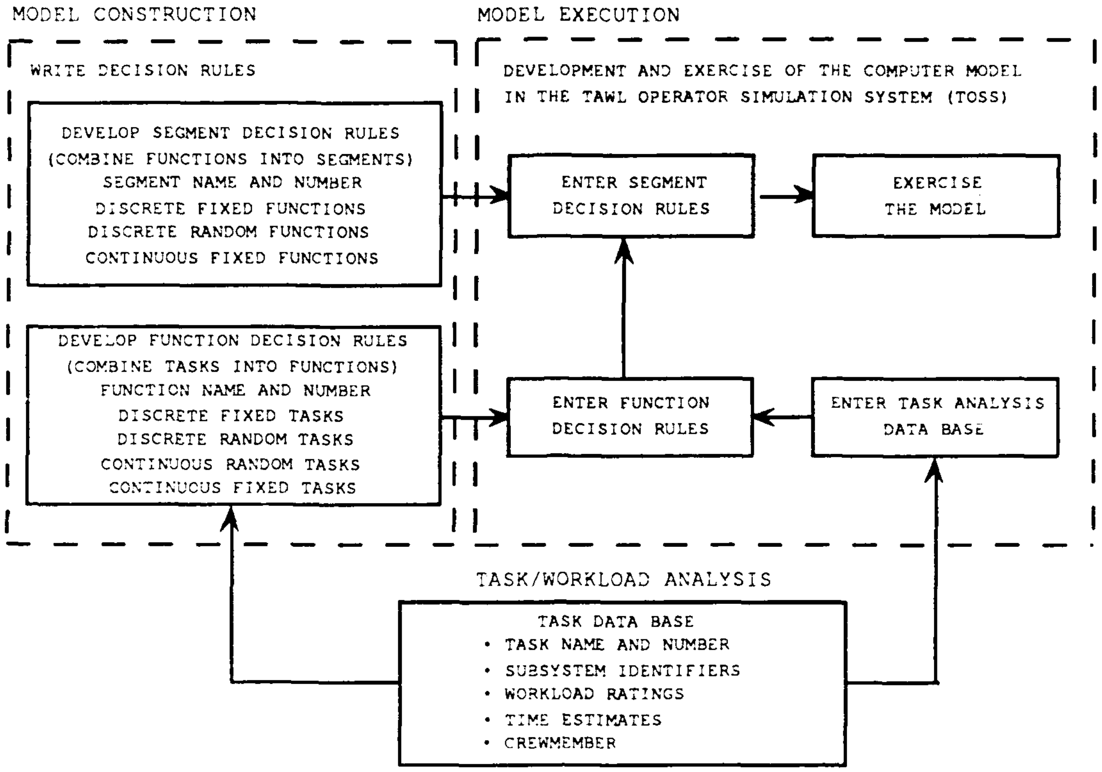

Figure 5. Bottom-up flow diagram outlining the technical steps performed in developing the MH-47E workload prediction model.

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. Figure 6 presents an example of a Function Summary Worksheet. Function Summary Worksheets 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 Bierbaum, Fulford, and Hamilton, (1990).

During the second stage, Function Decision Rules Worksheets were developed from the Function Summary Worksheets. An example of a Function Decision Rules Worksheet is presented in Figure 7. 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. Figures 8 and 9 present the Segment Summary Worksheet and the Segment Decision Rules Worksheet for Segment 14, Approach [ANVIS]. The function, Establish Approach [NVG], used as an example earlier in this report, occurs in this segment.

As illustrated in Figure 8, the Segment Summary Worksheets list all of the functions performed by the pilot and the copilot 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

MH-47E FUNCTION SUMMARY WORKSHEET

FUNCTION 21 Establish Approach [NVG]

PILOT				COPILOT			
DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS (FIXED)	CONTINUOUS (RANDOM)	DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS (FIXED)	CONTINUOUS (RANDOM)
Check % TRQ Indication (Inflight) (234)							
Adjust Power [NVG] (171)							
Check % TRQ Indication (Inflight) (234)							
Press F/D Key (4) (072)							
Press HVR SYM Key (4) (113)							
Press RTN Key (4) (189)							
Control Attitude [NVG] (025)							

Figure 6. Example of an MH-47E Function Summary Worksheet.

MH-47E FUNCTION DECISION RULES WORKSHEET

FUNCTION 21 Establish Approach [NVG]

PILOT				COPILOT			
DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS (FIXED)	CONTINUOUS (RANDOM)	DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS (FIXED)	CONTINUOUS (RANDOM)
Program in sequence, the following tasks: Task 234 for 1 second Task 171 for 2.5 seconds Task 234 for 1 second Task 072 for 1 second Task 113 for 1 second Task 189 for 1 second Task 025 for 3 seconds							

Figure 7. Example of an MH-47E Function Decision Rules Worksheet.

MH-47E SEGMENT SUMMARY WORKSHEET

PHASE 5 Enroute (Rendezvous - Base) **SEGMENT 14 Approach [ANVIS]**

PILOT			COPILOT		
DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS (FIXED)	DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS (FIXED)
Establish Approach [NVG] (21)	Monitor Threat (Pilot) (38) Perform Cockpit Communication (Pilot) (Coordination) (49) Perform Cockpit Communication (Copilot) (Coordination) (47) Check Approach Parameters (09) Perform Cockpit Communication (Pilot) (Normal) (50) Perform Cockpit Communication (Copilot) (Normal) (48)	Adjust Approach Parameters [NVG] (01) Monitor External Visual Field [NVG] (Pilot) (31)	Perform External Communication (Frequency Change) (52) Perform Before Landing Check (42) Perform External Communication (Transmit Code) (54)	Monitor Threat (Copilot) (37) Perform Cockpit Communication (Pilot) (Coordination) (49) Perform Cockpit Communication (Copilot) (Coordination) (47) Perform Cockpit Communication (Pilot) (Normal) (50) Perform Cockpit Communication (Copilot) (Normal) (48) Monitor FLIR Image (Copilot) (33)	Monitor External Visual Field [NVG] (Copilot) (30)

Figure 8. Example of an MH-47E Segment Summary Worksheet.

MH-47E SEGMENT DECISION RULES WORKSHEET

PHASE 5 Enroute (Rendezvous - Base) **SEGMENT 14 Approach [ANVIS]**

PILOT			COPILOT		
DISCRETE (FIXED)	**DISCRETE (RANDOM)**	**CONTINUOUS (FIXED)**	**DISCRETE (FIXED)**	**DISCRETE (RANDOM)**	**CONTINUOUS (FIXED)**
Start Segment 14 with Function 21. Function 21 lasts 7.5 seconds.	6 times during the segment, randomly select (.50) Function 47 or Function 49. Functions 47 and 49 last 7 seconds each and cannot occur concurrently with Function 09, 38, or 52. 2 times during the segment, randomly select Function 38. Function 38 lasts 3.5 seconds and cannot occur concurrently with Function 21, 47, or 49. 8 times during the segment, randomly select Function 09. Function 09 lasts 1 second and cannot occur concurrently with Function 21, 38, 47, or 49. Continued...	Start Function 01 when Function 21 ends. Function 01 lasts 340 seconds. Interrupt Function 01 when Function 09 occurs. Start Function 31 at the beginning of the segment. Function 31 lasts until the end of the segment. Interrupt Function 31 when Function 09, 21, or 38 occurs.	Start Segment 14 with Function 52. Function 52 lasts 21.5 seconds. Start Function 42 when Function 52 ends. Function 42 lasts 27.5 seconds. Interrupt Function 42 when Function 33, 37, 47, 48, 49, or 50 occurs. 200 seconds after the segment begins, start Function 54. Function 54 lasts 14 seconds.	Insert Function 47 each time the pilot performs Function 47 and Function 49 each time the pilot performs Function 49. 4 times during the segment, randomly select Function 37. Function 37 lasts 3.5 seconds and cannot occur concurrently with Function 47, 49, or 52. Insert Function 48 each time the pilot performs Function 48 and Function 50 each time the pilot performs Function 50. Continued...	Start Function 30 when Function 52 ends. Function 30 lasts until the end of the segment. Interrupt Function 30 when Function 33, 37, 42, or 54 occurs.

Figure 9. Example of an MH-47E Segment Decision Rules Worksheet.

segments. Again, see Bierbaum, Fulford, and Hamilton (1990) 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

As with the CH-47D, the TAWL Operator Simulation System (TOSS) was utilized to implement the MH-47E workload model. The mission/task/workload analysis data entered on the Function Analysis Worksheets and the function and segment decision rules constitute all the information necessary for TOSS to generate workload predictions for the MH-47E crewmembers. The development of the TOSS computer model required the entry of the task data and the entry of function and segment decision rules into TOSS. These data entry tasks are depicted in the task-flow diagram shown in Figure 5 and are described in detail below.

Enter task data. The first step in developing the computer model was to enter the data derived during the mission/task/workload analysis into TOSS. 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.

The above data items constitute the data base for the simulation of the pilot's and copilot's actions during the MH-47E 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 MH-47E crewmembers' workload.

Exercise the Model to Produce Estimates of Workload

The analysts used TOSS to execute each of the 15 unique mission segments in the MH-47E model to simulate operator task performance and to produce estimates of the total workload experienced by each crewmember during each half-second of the mission. TOSS computes the total workload for each component by summing the ratings assigned during the task analysis for each workload component (i.e., cognitive, psychomotor, visual-aided, visual-unaided, auditory, and kinesthetic) of each concurrent task.

Results

MH-47E Mission/Task/Workload Analysis

The mission scenario, described earlier, was divided into five mission phases. Preflight and postflight operations were excluded from the CH-47D baseline analysis. Consequently, the analysis for the MH-47E began with departure from the base and ended with return to the base. The five phases included in the analysis are listed below in the order of their occurrence within the mission.

- Phase 1: Departure (Base)
- Phase 2: Enroute (Base-Rendezvous)
- Phase 3: Enroute (Rendezvous-LZ)
- Phase 4: Enroute (LZ-Rendezvous)
- Phase 5: Enroute (Rendezvous-Base)

The five mission phases were subsequently divided into mission segments. Fifteen unique segments (i.e., segments that are distinctly different from any other segment) were identified and assigned unique two-digit identifiers. Three segments were found to occur more than once in the mission. The number of segments identified in each of the five mission phases are as follows.

- Phase 1: Departure (Base) - 3 segments
- Phase 2: Enroute (Base-Rendezvous) - 4 segments
- Phase 3: Enroute (Rendezvous-LZ) - 4 segments
- Phase 4: Enroute (LZ-Rendezvous) - 4 segments
- Phase 5: Enroute (Rendezvous-Base) - 3 segments

The specific mission segments that compose each of the five mission phases are listed in Appendix C.

The analysis of segments by SMEs resulted in the identification of a total of 73 unique functions. Each of the 73 functions was assigned a unique two-digit identifier. The number of functions required to compose each segment ranged from 9 to 18. Appendix D presents an alphabetical list of the 73 functions along with their identifiers. Appendix E presents the functions that compose each of the 15 mission segments.

The analysis of the 73 functions by SMEs resulted in the identification of 239 unique tasks. The number of tasks required to compose each function ranged from 1 to 38. The 239 unique tasks were assigned numerical identifiers from 001 to 239. Appendix F presents an alphabetical list of the tasks and their numerical identifiers. The data developed for all of the tasks in the 73 functions are shown on the Function Analysis Worksheets presented in Appendix G. The Function Summary Worksheets for all the functions in the model are presented in Appendix H. The Function Decision Rules Worksheets for all the functions in the model are presented in Appendix I. The Segment Summary Worksheets and the Segment Decision Rules Worksheets for the 15 mission segments are presented in Appendix J and Appendix K, respectively.

A total of 21 subsystems from 5 major categories were identified for the MH-47E mission tasks. Table 4 lists these subsystems along with their respective codes.

MH-47E Workload Predictions

The model was exercised for all 15 of the unique segments. Under the assumed conditions, and with the pilot and copilot sharing task requirements, only one overload condition was predicted for each crewmember. The overload condition occurred during the NOE Flight [ANVIS/ASE] segment when the APR-39 was activated. Similar to the CH-47D findings, the overload occurred as a result of the crew attempting to communicate as the APR-39 alert was sounding. Thus, the model indicates that proficient crewmembers can perform the MH-47E missions without encountering overload except when

Table 4

List of MH-47E Subsystems

CODE	SUBSYSTEM
E	ENGINE SUBSYSTEM
EF	Fuel
EN	Engine
F	FLIGHT CONTROL SUBSYSTEM
FB	Brakes
FC	Flight Control
FG	Gear
MFD	Multifunction Display
N	NAVIGATION SUBSYSTEM
NA	Navigation
NM	Maps
NRA	Radar
CDU	Control Display Unit
MC	Multimode Controller
TP	Transponder
U	UTILITY SUBSYSTEM
UAD	Advisory
UC	Communications
UL	Lighting
US	Survivability
DTU	Data Transfer Unit
UCA	Cargo
V	VISUAL SUBSYSTEM
VG	Night Vision Goggles
ANV	Aviator's Night Vision Imagery System
FLR	Forward-Looking Infrared (FLIR)

engaged by a threat. Graphs of pilot workload for all 15 unique segments are presented in Appendix L. Each page displays the pilot workload for one segment using 6 graphs; one for each component. The copilot data are presented in Appendix M.

The MH-47E workload model predictions for the pilot and copilot are summarized in Table 5 and 6, respectively. The tables present the number of OCs, the average workload for each of the six components, and the predicted OW for all 15 segments.

The data contained in Tables 5 and 6 indicate the following.

- The only overload condition observed during the mission occurred during the NOE Flight segment when a threat was present (overload conditions occurred for both the pilot and copilot during this segment).
- The pilot's average kinesthetic and psychomotor workload is higher during flight segments.
- The pilot's OW is highest in the Takeoff [ANVIS] segment.
- The copilot's average cognitive workload is highest when performing navigation during en route flight segments.
- The copilot's OW is highest in the NOE Flight (Route Change) segment.
- Both crewmembers' OW is highest during flight segments.
- Proficient crewmembers can perform the MH-47E mission without encountering an overload condition, except when being engaged by a threat.

Table 5

Pilot Workload for the MH-47E Model by Segment

Segment	OC	AUD	KIN	VIS	NVG	COG	PSY	OW
01: Configure Systems for Mission	0	2.5	1.0	0.1	1.0	3.4	0.6	27.9
02: Before Takeoff (Base/Internal Load)	0	1.0	4.3	1.7	1.1	3.3	1.7	38.8
03: Takeoff [ANVIS]	0	2.6	7.0	0.2	1.8	3.4	3.2	51.3
04: Enroute Flight [ANVIS]	0	1.7	1.0	0.6	0.9	3.4	0.3	25.2
05: Contour Flight (No Update) [ANVIS]	0	1.3	7.0	0.5	0.8	3.4	2.9	45.9
06: Contour Flight (Update) [ANVIS]	0	1.3	7.0	0.9	0.3	3.8	2.9	47.4
07: Rendezvous [ANVIS]	0	1.1	7.0	0.5	1.0	3.4	2.9	45.5
08: NOE Flight [ANVIS]	0	1.3	7.0	0.1	1.0	3.1	2.9	44.3
09: NOE Flight [ANVIS/ASE]	1	1.3	7.0	0.1	1.3	3.1	2.9	45.2
10: Approach (LZ) [ANVIS]	0	1.3	7.0	0.2	0.9	2.8	2.9	43.9
11: Landing (LZ/Internal Load) [ANVIS]	0	1.0	6.5	0.0	2.4	2.5	2.6	43.4
12: Before Takeoff (LZ) [ANVIS]	0	2.1	1.0	0.0	1.0	3.6	0.5	26.8
13: NOE Flight (Route Change) [ANVIS]	0	0.8	7.0	0.1	1.0	2.5	2.8	41.6
14: Approach [ANVIS]	0	1.3	7.0	0.2	0.9	2.8	2.9	43.8
15: Landing [ANVIS]	0	1.2	6.8	0.0	2.5	2.7	2.8	45.7

Note. The following abbreviations are used as column headings in Table 5: OC = Overload Condition, AUD = Auditory, KIN = Kinesthetic, VIS = Visual-unaided, NVG = Visual-aided, COG = Cognitive, PSY = Psychomotor, OW = Overall Workload.

Table 6

Copilot Workload for the MH-47E Model by Segment

Segment	OC	AUD	KIN	VIS	NVG	COG	PSY	OW
01: Configure Systems for Mission	0	2.5	0.3	1.2	0.0	2.1	0.7	23.6
02: Before Takeoff (Base/Internal Load)	0	1.1	0.1	1.1	0.8	1.8	0.6	20.7
03: Takeoff [ANVIS]	0	2.6	0.3	0.1	1.4	2.8	0.0	24.2
04: Enroute Flight	0	1.5	0.1	3.1	1.1	5.6	0.2	35.1
05: Contour Flight (No Update) [ANVIS]	0	1.5	0.1	3.2	0.9	5.5	0.1	34.6
06: Contour Flight (Update) [ANVIS]	0	1.5	0.2	3.2	0.8	5.4	0.1	34.2
07: Rendezvous [ANVIS]	0	1.4	0.1	1.9	0.1	2.8	0.3	23.1
08: NOE Flight [ANVIS]	0	1.3	0.1	3.9	0.8	6.0	0.0	36.7
09: NOE Flight [ANVIS/ASE]	1	1.3	0.2	2.6	1.4	5.5	0.5	35.0
10: Approach (LZ) [ANVIS]	0	1.5	0.1	0.2	0.9	1.9	0.1	18.7
11: Landing (LZ/Internal Load) [ANVIS]	0	1.1	0.1	0.2	1.3	2.0	0.1	18.9
12: Before Takeoff (LZ)	0	2.1	0.2	2.4	0.0	3.3	0.6	27.9
13: NOE Flight (Route Change) [ANVIS]	0	0.9	0.2	3.7	1.3	5.8	0.3	36.7
14: Approach [ANVIS]	0	1.7	0.1	0.8	0.6	2.5	0.2	21.4
15: Landing [ANVIS]	0	1.4	0.1	0.1	1.3	2.3	0.1	20.1

Note. The following abbreviations are used as column headings in Table 6: OC = Overload Condition, AUD = Auditory, KIN = Kinesthetic, VIS = Visual-unaided, NVG = Visual-aided, COG = Cognitive, PSY = Psychomotor, OW = Overall Workload.

ANALYSIS III - COMPARISON OF MH-47E AND CH-47D OPERATOR WORKLOAD PREDICTIONS

Method

To estimate the effect of the high technology modifications of the MH-47E on crewmember workload, 12 segments from the MH-47E mission were compared to 12 like segments from the CH-47D mission. Table 7 lists the compared segments by aircraft. A comparison of the functions in each segment for both aircraft is presented in Appendix N.

Results

The average component workloads for the 12 segments of the MH-47E and the CH-47D are presented in Figures 10 and 11. Figure 10 presents the average workload by component for the pilot in each of the segments; Figure 11 presents the copilot data.

Table 7

List of MH-47E and CH-47D Segments Compared

MH-47E Segment	CH-47D Segment
03: Takeoff [ANVIS]	04: Takeoff (Assembly Area) [NVG]
04: Enroute Flight [ANVIS]	06: Contour Flight [NVG]
05: Contour Flight (No Update) [ANVIS]	06: Contour Flight [NVG]
06: Contour Flight (Update) [ANVIS]	06: Contour Flight [NVG]
08: NOE Flight [ANVIS]	23: NOE Flight [NVG]
09: NOE Flight [ANVIS/ASE]	25: NOE Flight (Threat) [NVG]
10: Approach (LZ) [ANVIS]	31: Approach (LZ) [NVG]
11: Landing (LZ, Internal Load) [ANVIS]	32: Landing (LZ, Internal Load) [NVG]
12: Before Takeoff (LZ) [ANVIS]	38: Before Takeoff (LZ) [NVG]
13: NOE Flight (Route Change) [ANVIS]	27: NOE Flight (Mission Change) [NVG]
14: Approach [ANVIS]	13: Approach [NVG]
15: Landing [ANVIS]	14: Landing [NVG]

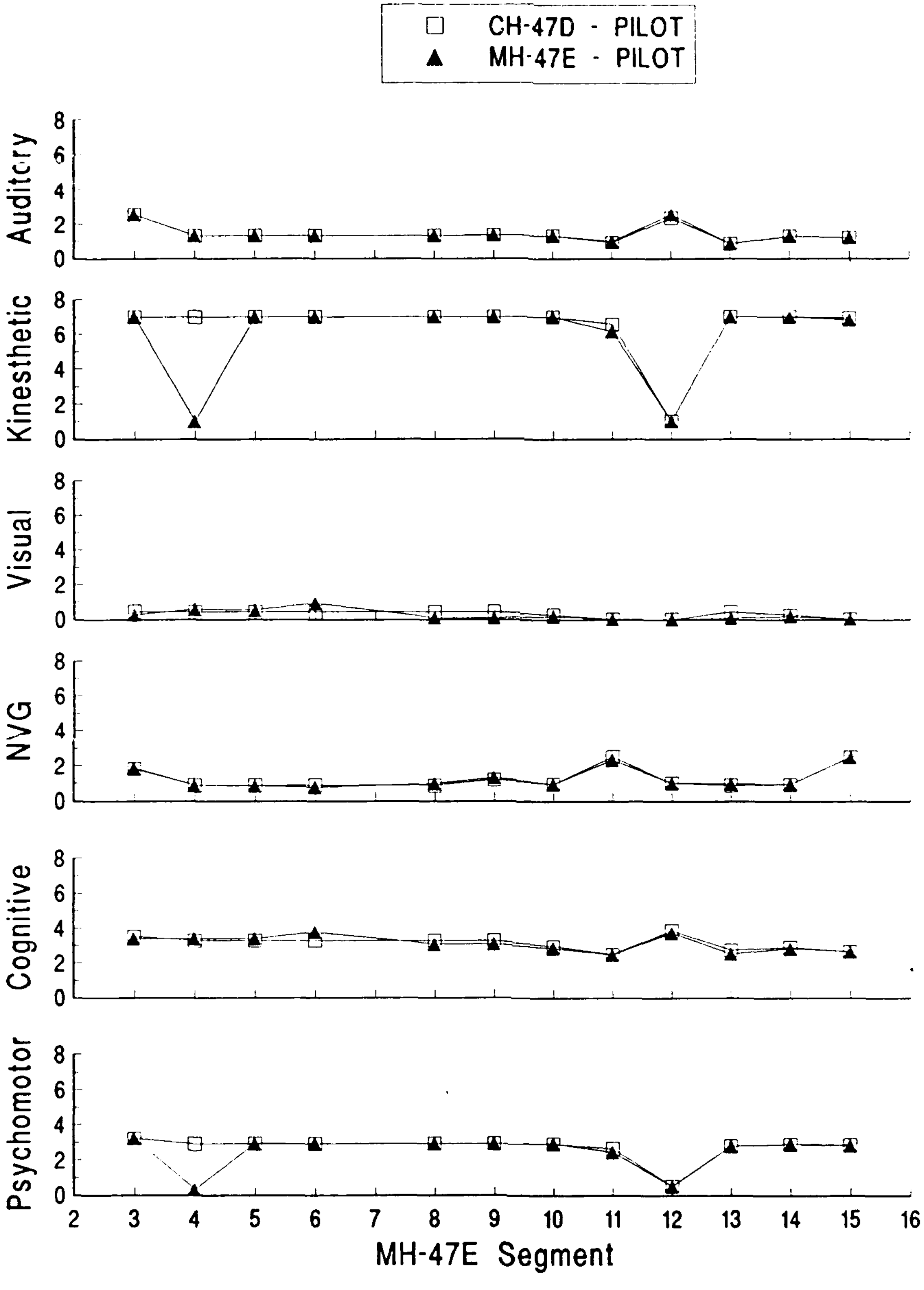

Figure 10. Pilot's average component workload by segment.

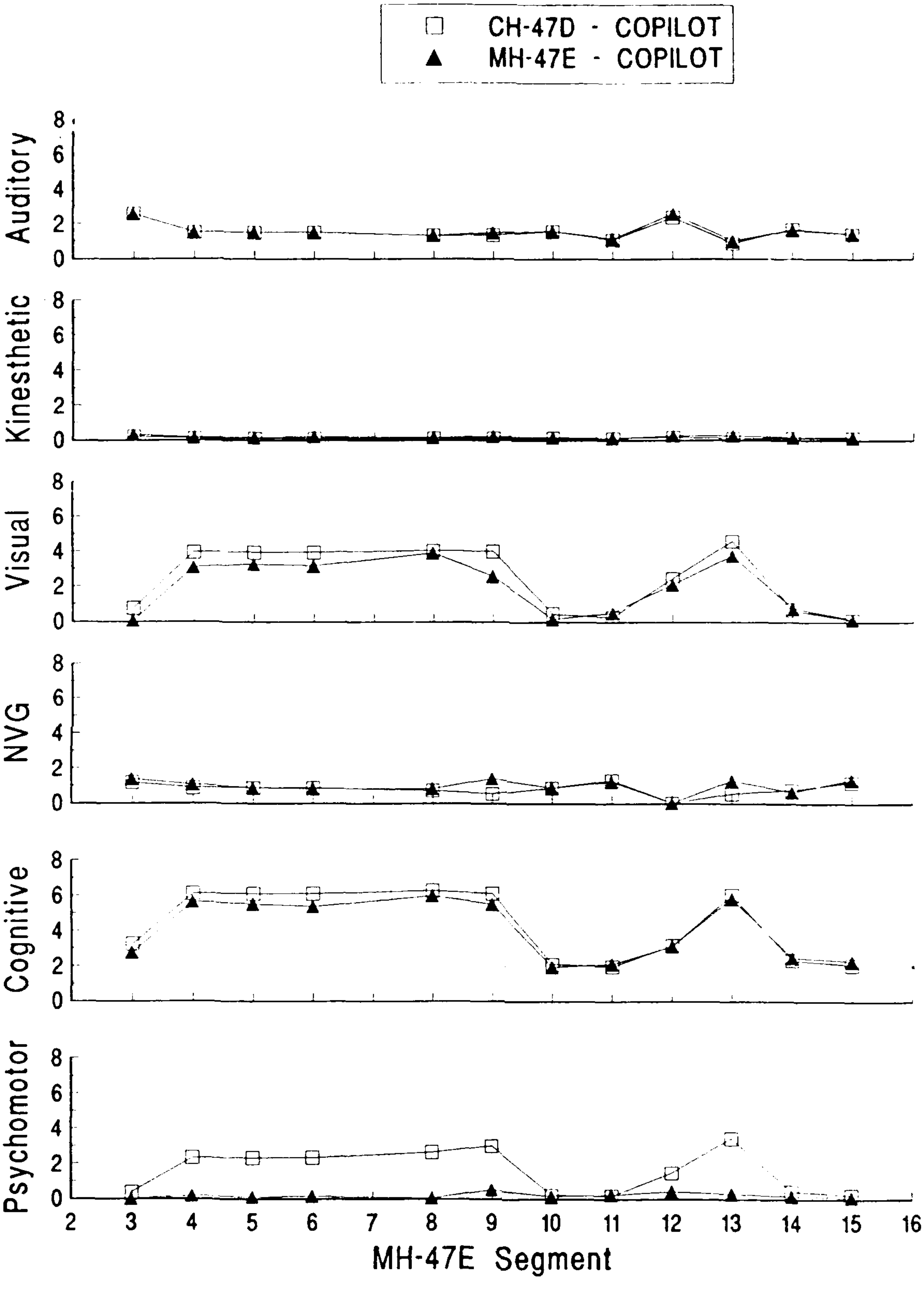

Figure 11. Copilot's average component workload by segment.

An analysis of the pilot workload by component graph (Figure 10) indicates little difference in the predicted pilot auditory, visual-unaided, or cognitive predicted workload for the two aircraft. However, the kinesthetic, NVG, and psychomotor workload differed in certain segments. For example, when all controls for the MH-47E are coupled during contour flight (Segment 4), the reduction in kinesthetic and psychomotor workload is significant. The small increase in NVG workload for the MH-47E is a result of the pilot spending more time looking outside the aircraft.

The copilot workload by component graph (Figure 11) indicates no difference in the copilot auditory or kinesthetic predicted workload for the two aircraft. However, the elimination of the copilot's requirement to handle maps, determine present position, and calculate fuel consumption reduced the visual-unaided, cognitive, and psychomotor workload during contour and NOE flight (Segments 05, 06, 08, 09). This change also enables the copilot to spend more time looking outside the aircraft, which increases NVG workload.

Predicted OW for the CH-47D and MH-47E is shown in Figure 12. The top figure compares the pilot's predicted OW for the two aircraft. The bottom figure compares the copilot's predicted OW for the two aircraft.

An examination of the pilot's predicted OW graph (Figure 12) reveals the effect of control coupling during contour flight (Segment 04) in the MH-47E. An examination of the copilot's predicted OW graph (Figure 12) indicates a lower OW for the MH-47E in nearly all segments. This finding reflects the copilot's reduced task requirements in the MH-47E, except for the approach and landing segments (Segments 10, 11, 14, 15).

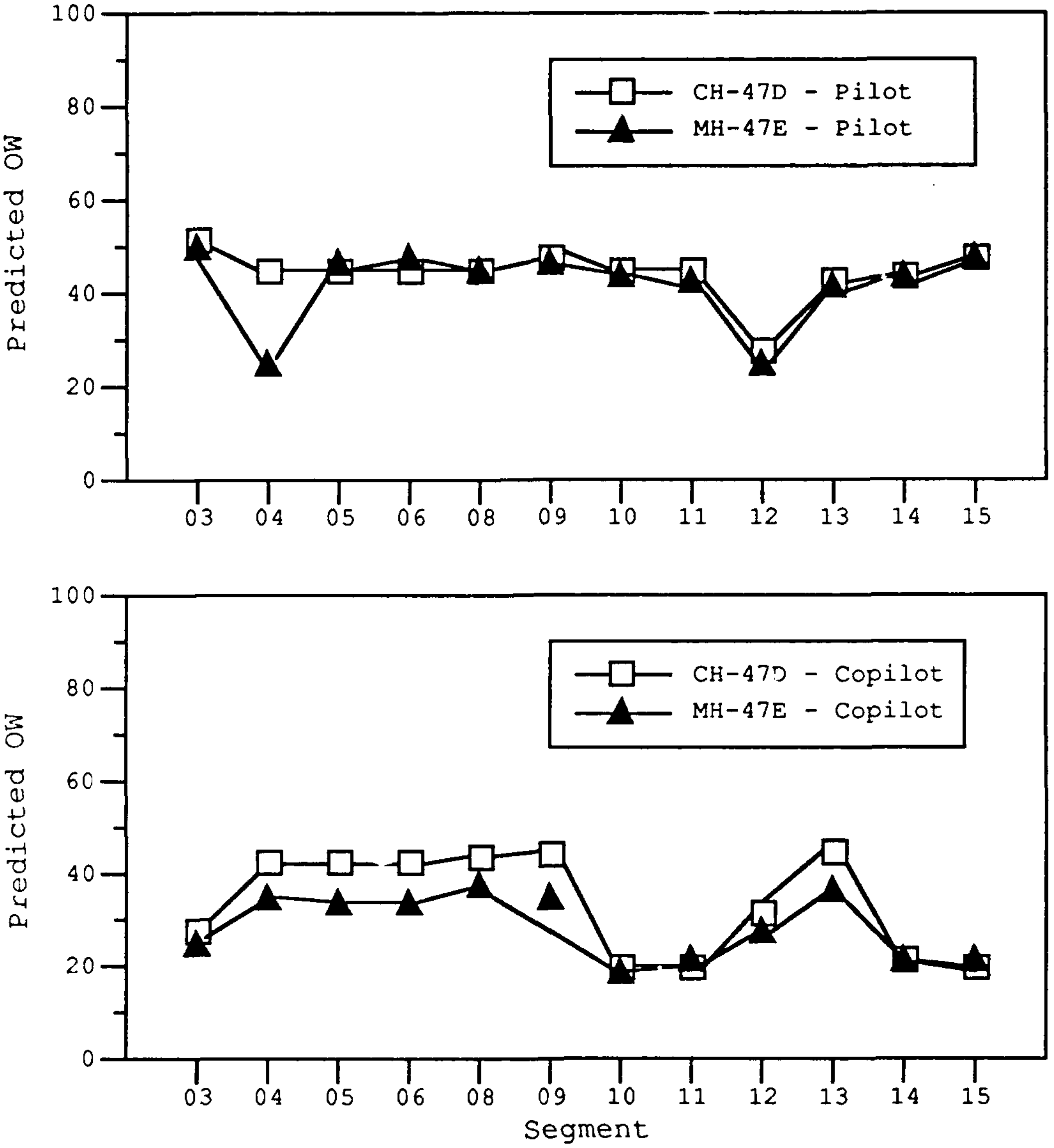

Figure 12. Comparison of MH-47E and CH-47D predicted OW by segment for the pilot (upper) and copilot (lower).

CONCLUSIONS

The workload prediction methodology developed by ARIARDA provides a systematic means for estimating the workload impact of the advanced technology being proposed for new aircraft and the impact of modifications of existing aircraft. Under the conditions assumed during model development (e.g., proficient operators, optimal weather conditions), neither the CH-47D nor the MH-47E appears to place excessive workload demands on its operators. A comparison of the predicted workload for the pilot of the MH-47E and the CH-47D resulted in the following observations.

- The predicted visual-unaided workload was slightly lower for the MH-47E due to the fact that much of the aircraft system monitoring is automatically performed by the MH-47E integrated avionics subsystems.
- The reduction of visual-unaided workload is advantageous in that it allows the MH-47E pilot to shift attention to external visual tasks. Thus, in some segments, the predicted NVG workload was higher for the MH-47E than for the CH-47D. The increase in external visual attention indicates that the MH-47E pilot may have an increased awareness of the status and spatial location of the aircraft, of other air traffic, and of threats to the aircraft.
- The predicted kinesthetic and psychomotor workload was lower for the MH-47E when flight controls are coupled during Segment 04.
- The predicted OW was similar for both aircraft except that OW is lower for the MH-47E when the controls are coupled.

A comparison of the predicted workload for the copilot in the MH-47E and the CH-47D resulted in the following observations.

- The predicted visual-unaided workload was lower for the MH-47E than for the CH-47D due to the reduced requirements for map interpretation; present position is always available on the MH-47E multifunction display.
- The reduction of visual-unaided workload is advantageous in that it allows the MH-47E copilot to shift attention to external visual tasks. Thus, the predicted NVG workload was higher for the MH-47E than for the CH-47D. The increase in external visual

attention indicates that the MH-47E copilot may have an increased awareness of the status and spatial location of the aircraft, of other air traffic, and of threats to the aircraft.

- The predicted cognitive workload was lower for the MH-47E because functions such as monitoring fuel consumption, checking system status, and determining present position are performed continuously by the mission processor.
- The predicted OW was generally lower for the MH-47E than for the CH-47D.

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