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U.S. Army Research Institute
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Research Report 1576

Task Analysis and Workload Prediction Model of the MH-60K Mission and a Comparison with UH-60A Workload Predictions

Volume I: Summary Report

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

91-11472



October 1990

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91 9 25 -- 037

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified			1b. RESTRICTIVE MARKINGS --		
2a. SECURITY CLASSIFICATION AUTHORITY --			3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for public release; distribution is unlimited.		
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE --					
4. PERFORMING ORGANIZATION REPORT NUMBER(S) ASI690-328-90-I			5. MONITORING ORGANIZATION REPORT NUMBER(S) ARI Research Report 1576		
6a. NAME OF PERFORMING ORGANIZATION Anacapa Sciences, Inc.		6b. OFFICE SYMBOL (If applicable) --		7a. NAME OF MONITORING ORGANIZATION U.S. Army Research Institute Aviation Activity	
6c. ADDRESS (City, State, and ZIP Code) P.O. Box 489 Fort Rucker, AL 36362-5000			7b. ADDRESS (City, State, and ZIP Code) ATTN: PERI-IR Fort Rucker, AL 36362-5354		
8a. NAME OF FUNDING/SPONSORING ORGANIZATION U.S. Army Research Institute for the Behavioral and Social Sciences		8b. OFFICE SYMBOL (If applicable) PERI-I		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER MDA903-87-C-0523	
8c. ADDRESS (City, State, and ZIP Code) 5001 Eisenhower Avenue Alexandria, VA 22333-5600			10. SOURCE OF FUNDING NUMBERS		
		PROGRAM ELEMENT NO. 63007A		PROJECT NO. 793	WORK UNIT ACCESSION NO. 05
11. TITLE (Include Security Classification) Task Analysis and Workload Prediction Model of the MH-60K Mission and a Comparison with UH-60A Workload Predictions. Volume I: Summary Report					
12. PERSONAL AUTHOR(S) Bierbaum, Carl R.; and Hamilton, David B.					
13a. TYPE OF REPORT Interim		13b. TIME COVERED FROM 88/12 TO 90/04		14. DATE OF REPORT (Year, Month, Day) 1990, October	
15. PAGE COUNT					
16. SUPPLEMENTARY NOTATION The report is organized into three volumes. Volume II (ARI Research Note 91-01) contains Appendixes A through G; Volume III (ARI Research Note 91-02) contains Appendixes H through N.					
17. COSATI CODES			18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)		
FIELD	GROUP	SUB-GROUP	Mission analysis Modeling		
05	08		Task analysis		
			Aviation workload		
19. ABSTRACT (Continue on reverse if necessary and identify by block number)					
A mission scenario was used to conduct a comprehensive task analysis for MH-60K operations. The analysis used a top-down approach to identify the phases, functions, and tasks for the mission. Five phases, 15 segments, 71 functions, and 230 tasks were identified. Researchers identified the crewmember performing each task and derived estimates of the sensory, cognitive, and psychomotor workload associated with each task. 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-60K 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-60K pilot and copilot was compared to the UH-60A baseline workload prediction to determine the impact (Continued)					
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☐ UNCLASSIFIED/UNLIMITED ☒ SAME AS RPT. ☐ DTIC USERS			21. ABSTRACT SECURITY CLASSIFICATION Unclassified		
22a. NAME OF RESPONSIBLE INDIVIDUAL Charles A. Gainer			22b. TELEPHONE (Include Area Code) (205) 255-4404		22c. OFFICE SYMBOL PERI-IR

ARI Research Report 1576

19. ABSTRACT (Continued)

of the MH-60K advanced technology. The comparison indicated very little difference in the predicted workload for the pilot and indicated a lower predicted workload for the copilot in the MH-60K.

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**Task Analysis and Workload Prediction
Model of the MH-60K Mission and a Comparison
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Volume I: Summary Report

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Office, Deputy Chief of Staff for Personnel
Department of the Army

October 1990

Army Project Number
2Q263007A793

Human Factors in Training
Operational Effectiveness

Approved for public release; distribution is unlimited.

FOREWORD

The Army Research Institute Aviation Research and Development Activity (ARIARDA) at Fort Rucker, Alabama, is an operational unit of the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI). This work was performed within the Systems Research Laboratory portion of ARIARDA's research mission. Research is conducted in-house and is augmented by on-site contract support as required. This report documents work that supports the U.S. Army Aviation Systems Command (AVSCOM) at St. Louis, Missouri. The work was performed under the Memorandum of Understanding between AVSCOM and ARI, "Establishment of Technical Coordination Between ARI and AVSCOM," 10 April 1985.

The potential impact of advanced technology on manpower and personnel requirements must be considered when planning system modifications. Since high operator workload can result in a dramatic decrease in system effectiveness, the impact of advanced technology on workload for the system operator(s) is a critical consideration.

This three-volume report describes the methodology used to conduct a comprehensive task analysis of the MH-60K mission and gives the results of the analysis. Information provided by the MH-60K mission/task/workload analysis was used to establish a data base and to develop a computer model that predicts workload for the MH-60K pilot and copilot. Assessments of workload produced by the models are compared with the UH-60A baseline model to assess the impact on workload of the high technology modifications made in the MH-60K aircraft.

Volume I describes the methodology and summarizes the results of the research. Volume II of the reports contains Appendixes A through G and presents the results of exercising the UH-60A baseline model and the MH-60K mission/task/workload analysis. Volume III contains Appendixes H through N. The information presented in Appendixes H through K is sufficient to simulate the crewmembers' actions during the MH-60K mission.

During the avionics design for the "K" model, a series of aircrew station reviews was held among the Program Manager's Office, AVSCOM; Special Operation Forces, Fort Campbell, Kentucky; and the Sikorsky Aircraft Division to review design specifications and assess their impact on the crew station. Specific briefings on this methodology were provided to the CH-47 and UH-60 Program Offices at AVSCOM and to individuals in the following organizations: Sikorsky Aircraft, Stratford, Connecticut; IBM, Poughkeepsie, New York; and Boeing Helicopter Company

of Pennsylvania. In addition, individual briefings were given to representatives of AVSCOM, ARI, and Sikorsky Aircraft. The computer-supported methodology has been used to assess operator workload in a number of Army modeling systems.



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ACKNOWLEDGMENTS

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

Chief Warrant Officer (CWO) Ernest G. Cooper, 160th Special Operations Aviation Group (SOAG), Fort Campbell, Kentucky, served as subject matter expert for the review of the MH-60K task analysis. The task analysis required in-depth knowledge of the cockpit configuration for the pilot and copilot of the MH-60K aircraft. CWO Cooper's knowledge of the specific tasks performed by the pilot and copilot when conducting missions contributed greatly to the success of the task analysis.

Ms. Laura Fulford and Ms. Cassandra Hocutt, Anacapa Sciences, Inc., spent many hours developing the Task Analysis/Workload (TAWL) Operator Simulation System (TOSS) that is used to manage the MH-60K and UH-60A mission/task/workload data base 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 MODEL OF THE MH-60K MISSION AND A COMPARISON WITH UH-60A WORKLOAD PREDICTIONS

Volume I: Summary Report

EXECUTIVE SUMMARY

Requirement:

The research reported in this three-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-60K aircraft will have on crew workload when compared to the crew workload of the UH-60A.

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 were to conduct a detailed analysis of the operator tasks that must be performed during the MH-60K combat mission, to develop a computer model that predicts MH-60K operator workload, and to compare the MH-60K operator workload predictions with the UH-60A 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 and UH-60A aircraft. Whereas the LHX model was based on a generic analysis of an aircraft in the conceptual design phase of development, the AH-64A and UH-60A models are based on analyses of existing systems. Consequently, the workload analyses of the AH-64A and UH-60A 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. The TAWL methodology was used to meet the following technical objectives:

- produce estimates of operator workload during the UH-60A combat mission;

- identify the phases, segments, functions, and tasks in the MH-60K combat 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-60K operator workload; and
- compare the MH-60K predicted operator workload with the UH-60A predicted operator workload.

Findings:

A total of 5 phases, 15 unique segments, 71 unique functions, and 230 unique tasks were identified in the MH-60K mission/task/workload analysis. Under the conditions that the model was developed (e.g., proficient operators, optimal weather conditions), neither the UH-60A nor the MH-60K appear to place excessive workload demands on the operators. A comparison of the pilot workload for the MH-60K and the UH-60A resulted in the following observations:

- The MH-60K aircraft had higher night-vision goggle (NVC) workload than the UH-60A. The increase in external visual attention may provide the MH-60K pilot with increased awareness of the status and spatial location of the aircraft, of other air traffic, and of threats to the aircraft.
- The MH-60K aircraft had lower visual workload because of the reduction of aircraft system monitoring, which is automatically performed by the integrated avionics subsystems.
- The MH-60K aircraft had reduced kinesthetic and psychomotor workload when flight controls are coupled.

- The overall workload in the MH-60K was similar to the UH-60A in all segments except when the controls are coupled in the MH-60K.

A comparison of the copilot workload for the MH-60K and the UH-60A resulted in the following observations:

- The MH-60K aircraft had reduced visual workload because of the reduced requirements for map interpretation. The position is always readily available on the multifunction displays (MFDs).
- The MH-60K aircraft had higher NVG workload than the UH-60A. The increase in external visual attention may provide the MH-60K copilot with increased awareness of the status and spatial location of the aircraft, other air traffic, and threats to the aircraft.
- The MH-60K had lower cognitive workload because functions such as fuel consumption, checking system status, and determining present position are performed continuously by the mission processor.
- The overall workload in the MH-60K was generally lower than the overall workload in UH-60A.

Utilization of Findings:

The predicted effect of the MH-60K 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-60K aircraft. An analysis of the tasks to be performed and the associated components within each task will allow the trainer to determine the methods of instruction needed and the equipment necessary for conducting the training.

TASK ANALYSIS AND WORKLOAD PREDICTION MODEL OF THE MH-60K MISSION
AND A COMPARISON WITH UH-60A WORKLOAD PREDICTIONS

Volume I: Summary Report

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Task Analysis and Workload Prediction Model of the MH-60K Mission and a Comparison with UH-60A Workload Predictions

INTRODUCTION

The Special Operations Forces (SOF) Aviation Project Office at the Army Aviation Systems Command (AVSCOM) has been tasked to modify existing UH-60A aircraft for SOF missions. The aircraft, designated the MH-60K, 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 being prepared for the MH-60K aircraft are designed to increase operational effectiveness and to reduce operator workload during SOF missions. The increased mission capabilities of the MH-60K aircraft have dramatically increased the amount of display information available to the operators and may increase operator workload by placing additional demands on the cognitive resources of the crewmembers. Although many tasks performed by the operators in the UH-60A have been automated in the MH-60K 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-60K 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 UH-60A and MH-60K aircraft, (b) produce workload predictions for the UH-60A and MH-60K aircraft, and (c) compare the workload in the MH-60K with workload in the UH-60A.

The TAWL Methodology

Under contract to ARIARDA, Anacapa Sciences personnel developed TAWL 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 (1989) provided a complete description of the TAWL prediction methodology and its computer support. The remainder of this subsection presents an overview of the latest version 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. For a review of other multiple resources theories of attention and their relation to workload, see Wickens (1984).

The TAWL methodology treats each of the workload components independently for two reasons. First, although interactions between the components probably occur, adequate definitions of the nature of the interactions do 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 had 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-60 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.

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 in functions; segment decision rules are developed that describe the sequencing of functions in segments. It is assumed that the segments can be combined to model the crewmember's behavior for individual 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 concurrently 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 (in half-second minimum intervals) 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.

Overview

The research described in this report is designed to address the issues of workload in the MH-60K aircraft. To place the MH-60K workload predictions in perspective relative to other similar aircraft, a baseline workload prediction model was prepared for the UH-60A aircraft. The task/workload analysis and model construction phases of the UH-60A baseline model were described in a report by Bierbaum, Szabo, and Aldrich (1989). Thus, the present research has the following objectives:

- exercise the UH-60A model to produce estimates of operator workload during the UH-60A combat mission,
- produce an analysis of the tasks that must be performed to accomplish the MH-60K combat mission,
- develop a computer model to predict MH-60K operator workload,
- exercise the MH-60K model to produce estimates of operator workload during the MH-60K mission, and
- compare the MH-60K operator workload predictions with the UH-60A baseline operator workload predictions.

The research is reported in three volumes. Volume I summarizes the methods and results of the research. Volume II comprises Appendixes A through G, which present the workload predictions of the UH-60A baseline model and contain the data produced during the task/workload analysis of the MH-60K aircraft. Volume III comprises Appendixes H through N, which contain the data produced during the construction of the MH-60K model, the workload predictions of the MH-60K model, and a comparison list of the segment and function names in the UH-60A and the MH-60K models.

ANALYSIS I - THE UH-60A WORKLOAD PREDICTION MODEL

Bierbaum, Szabo and Aldrich (1989) conducted a mission/task analysis of the UH-60A aircraft identifying 9 mission phases, 34 segments, 48 functions, and 138 tasks. The results of the mission/task analysis were used to develop a workload prediction model. The results from exercising the microcomputer-based UH-60A workload prediction model developed by Bierbaum, Szabo, and Aldrich are reported below, and the results of the analysis provide a baseline against which to compare the workload predictions for the MH-60K aircraft.

Method

The analysts used the TOSS software to automate the data entry and execute the UH-60A workload model; the steps required to implement the model are fully described by Bierbaum, Fulford, and Hamilton (1989) 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 UH-60A analysis (Bierbaum, Szabo, & Aldrich, 1989), were entered into TOSS using the data entry routines of the system. Then, each of the 34 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 was used to compute several descriptive statistics (peak, mean, and standard deviation) for the half-second workload predictions. In addition, TOSS was used to identify 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; 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) may 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 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 whenever the tasks contributing to a component overload change. Overload conditions identify the unique conditions within a mission segment associated with a component overload.

Overload Density

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

Subsystem Overload

Subsystem overload is the number of half-second intervals that 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) for pilots performing a typical UH-60A mission in the UH-60A flight simulator. During mission segments, pilots provided ratings of their workload using a continuous scale that ranged from 0 to 100, with the extreme values verbally anchored to "Very Low Workload" and "Very High Workload." To establish the validity of the UH-60A workload prediction model, the observed OW measures were compared to the workload predictions produced by the model.

However, the UH-60A workload prediction model produces predictions of workload independently for six workload components and does not produce a single overall estimate of workload. To compare crew OW with TAWL predictions required that they combine the predictions across components and time to produce a single workload index comparable to OW. The researchers assumed simple additivity and summed the UH-60A predictions across time and components to generate an estimate of OW for each crewmember during each segment. The correlations between the subjective OW observed by Iavecchia et al. and the OW predicted by the UH-60A model were high ($r = .82$ to $.95$).

During the present workload analysis of the UH-60A, TOSS was used to implement a regression equation derived from the data reported by Iavecchia et al. (1989), to scale the OW predicted by TAWL into the 0-100 range used for OW. For all mission segments 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.

Several points should be made about this regression equation. First, if the measure of model validity is in the degree of correlation between OW and UH-60A component averages, then scaling is unnecessary. The equation is only useful in generating predictions of aviator's OW from TAWL workload predictions. Second, the relationship between the 7-point scales used to generate the UH-60A predictions and the 0 to 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 where this point is on the OW scale. If the 0 to 100 scale is taken to represent the extent of workload experience and if that experience includes situations of task degradation due to high workload, then the overload point on the OW scale has not been logically or empirically determined.

Third, this regression equation, generated from empirical results, differs from any simple scaling equation generated logically. For example, the slope of the equation that scaled a 7-point scale to a 100-point scale would be 14.3, similar to the slope of 14.5 in the equation. However, the intercept of the 7-point to a 100-point 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 pilot 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 an overall subjective measure of workload. Therefore, it has been used to compute an overall estimate of aviator workload in the analyses of the UH-60A, the MH-60K, and their comparison.

Results

Workload prediction graphs for the pilot and copilot were produced for each of the 34 UH-60A 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 pilot segment workload prediction graph is presented in Figure 1. Figure 1 shows estimated workload for the pilot on each component during the Before Takeoff (External Load) [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 initially indicates low workload while the aircraft is on the ground and increased workload at the time (110 seconds elapsed time) the pilot initiates a hover to pick up the external load. The NVG (visual-aided) graph shows that the pilot experiences relatively low NVG workload until he begins to hover the aircraft. At that time (110 sec.), the NVG workload increases as the pilot shifts attention to the ground guide for directions over the sling load. The interruption in the NVG workload shortly after 100 seconds is the result of the pilot checking the instruments before picking the aircraft up to a hover. This instrument check is also indicated by the increase in unaided visual workload at the same elapsed time on the visual graph. The completion of external load hook-up can be seen when the NVG workload decreases between 400 and

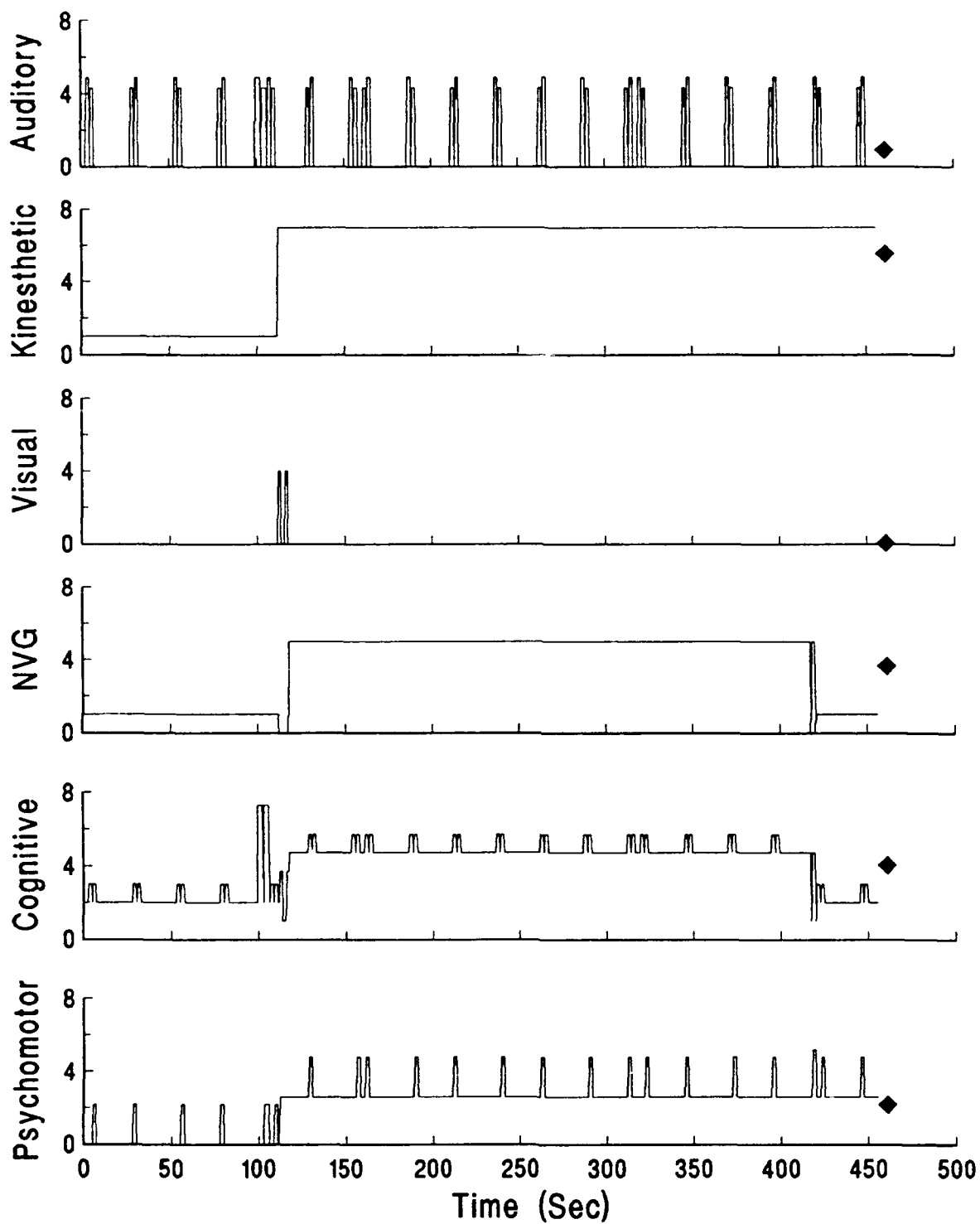


Figure 1. Example of a pilot segment workload prediction graph.

450 seconds of elapsed time. At this time, the pilot ceases observing the ground guide and returns to monitoring outside the aircraft. The cognitive workload is low when the pilot is simply monitoring outside the aircraft but increases when the pilot begins to hover the aircraft. In addition, cognitive workload associated with cockpit communication can be seen as a pair of peaks each time communication occurs. Finally, the psychomotor graph indicates the workload associated with moving the flight controls while hovering 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 34 mission segments. Each page displays the pilot workload for one segment using 6 graphs, one for each workload component. Appendix B presents graphs of copilot workload for each of the mission segments.

The UH-60A workload model predictions for the pilot and copilot are summarized in Tables 1 and 2, respectively. The tables show, for each of the 34 segments, the number of overload conditions (OC), the average workload for each of the 6 components, and the predicted OW.

The data contained in the tables indicate the following:

- The only overload condition observed during the mission occurred during the NOE and the 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 average OW is highest in the Takeoff (External Load) segment.
- The copilot's average cognitive workload is higher when performing navigation during en route flight segments.
- The average copilot's OW is highest in the NOE Flight (Mission Change) segment.
- Both crewmembers' average OW is higher during flight segments.
- Proficient crewmembers can perform the UH-60A missions without encountering an overload condition, except when being engaged by a threat.

Table 1

Pilot Workload for the UH-60A Model by Segment

Segment	OC	AUD	KIN	VIS	NVG	COG	PSY	OW
01: Before Takeoff (Assembly Area)	0	1.0	1.4	1.3	0.0	2.8	0.4	23.6
02: Takeoff	0	2.7	7.0	2.0	0.0	3.6	3.2	52.1
03: Takeoff [NVG]	0	1.5	7.0	0.3	1.1	2.8	3.0	45.1
04: Contour Flight	0	1.3	7.0	1.9	0.0	3.2	2.9	46.8
05: Contour Flight [NVG]	0	1.3	7.0	0.4	0.9	3.2	2.9	45.1
06: Contour Flight (Threat)	6	1.3	7.0	2.0	0.0	3.3	2.9	47.2
07: Contour Flight (Threat) [NVG]	3	1.3	7.0	0.4	1.0	3.2	2.9	45.4
08: Contour Flight (Mission Change)	0	1.3	7.0	1.9	0.0	3.2	2.9	46.8
09: Contour Flight (Mission Change) [NVG]	0	1.3	7.0	0.4	0.9	3.2	2.9	45.2
10: Approach	0	1.3	7.0	1.2	0.0	2.9	2.9	44.1
11: Approach [NVG]	0	1.3	7.0	0.2	0.9	2.9	2.9	43.9
12: Landing	0	2.1	6.6	2.0	0.0	3.0	2.9	47.1
13: Landing [NVG]	0	1.2	6.8	0.0	1.4	2.6	2.8	42.9
14: Before Takeoff (Internal Load)	0	1.7	1.0	1.0	0.0	2.9	0.4	23.9
15: Before Takeoff (External Load)	0	1.1	5.1	2.8	0.0	4.1	2.1	44.0
16: Before Takeoff (External Load) [NVG]	0	0.9	5.5	0.1	3.6	4.0	2.2	46.6
17: Takeoff (External)	0	3.5	7.0	2.2	0.0	4.9	3.4	57.9
18: Takeoff (External) [NVG]	0	2.7	7.0	0.9	0.7	3.5	3.2	50.7
19: NOE Flight	0	1.3	7.0	1.9	0.0	3.2	2.9	46.7
20: NOE Flight [NVG]	0	1.3	7.0	0.4	0.9	3.2	2.9	45.2
21: NOE Flight (Threat)	6	1.3	7.0	2.1	0.0	3.3	2.9	47.3
22: NOE Flight (Threat) [NVG]	2	1.3	7.0	0.4	1.0	3.3	2.9	45.7
23: NOE Flight (Mission Change)	0	0.8	7.0	2.0	0.0	2.7	2.8	44.2
24: NOE Flight (Mission Change) [NVG]	0	0.8	7.0	0.4	0.9	2.7	2.8	42.5
25: Approach (LZ)	0	1.3	7.0	1.2	0.0	2.9	2.9	44.0
26: Approach (LZ) [NVG]	0	1.3	7.0	0.2	0.9	2.9	2.9	44.0
27: Landing (LZ, Internal Load)	0	1.2	6.5	2.1	0.0	2.6	2.7	43.6
28: Landing (LZ, Internal Load) [NVG]	0	1.1	6.6	0.1	1.4	2.5	2.7	41.4
29: Landing (LZ, External Load)	0	1.3	6.5	2.2	0.0	2.8	2.8	44.6
30: Landing (LZ, External Load) [NVG]	0	1.2	6.6	0.1	1.4	2.7	2.8	42.5
31: Before Takeoff (LZ)	0	2.0	1.0	0.0	1.0	3.2	0.4	25.6
32: FARP Procedures	0	0.8	3.1	1.4	0.0	2.2	1.1	28.2
33: FARP Procedures [NVG]	0	0.7	3.8	0.2	0.9	2.2	1.4	29.1
34: Before Takeoff (FARP)	0	2.8	1.0	1.0	0.0	3.1	0.7	28.1

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 UH-60A Model by Segment

Segment	OC	AUD	KIN	VIS	NVG	COG	PSY	OW
01: Before Takeoff (Assembly Area)	0	1.1	0.1	4.0	0.0	2.8	3.5	34.9
02: Takeoff	0	2.7	0.2	1.6	0.0	3.1	0.4	26.6
03: Takeoff (NVG)	0	1.5	0.1	0.5	1.2	2.3	0.2	21.3
04: Contour Flight	0	1.3	0.1	4.8	0.0	6.1	2.6	42.9
05: Contour Flight (NVG)	0	1.5	0.1	3.7	0.8	6.1	2.4	42.1
06: Contour Flight (Threat)	6	1.3	0.1	4.7	0.0	5.9	2.4	42.1
07: Contour Flight (Threat) (NVG)	3	1.3	0.1	3.5	1.1	6.0	2.1	41.4
08: Contour Flight (Mission Change)	0	1.5	0.1	4.4	0.0	5.5	3.0	42.1
09: Contour Flight (Mission Change) (NVG)	0	1.5	0.1	3.8	0.4	5.5	3.0	41.9
10: Approach	0	1.5	0.1	1.2	0.0	1.9	0.2	18.7
11: Approach (NVG)	0	1.6	0.1	0.3	0.8	1.2	0.2	19.5
12: Landing	0	2.4	0.2	0.6	0.0	1.5	0.2	19.1
13: Landing (NVG)	0	1.4	0.1	0.2	1.4	2.2	0.2	20.1
14: Before Takeoff (Internal Load)	0	2.0	0.1	4.3	0.0	2.0	2.0	32.1
15: Before Takeoff (External Load)	0	1.2	0.1	2.6	0.0	1.4	0.9	22.2
16: Before Takeoff (External Load) (NVG)	0	1.0	0.1	1.5	0.7	1.4	0.7	20.1
17: Takeoff (External)	0	3.5	0.3	2.2	0.0	4.0	1.0	33.6
18: Takeoff (External) (NVG)	0	2.7	0.3	1.5	0.5	3.1	0.7	28.2
19: NOE Flight	0	1.3	0.1	4.8	0.0	6.4	2.9	44.4
20: NOE Flight (NVG)	0	1.3	0.1	4.4	0.4	6.4	2.5	43.5
21: NOE Flight (Threat)	6	1.5	0.1	4.6	0.0	6.1	2.2	42.0
22: NOE Flight (Threat) (NVG)	2	1.5	0.1	4.2	0.4	6.2	2.3	42.5
23: NOE Flight (Mission Change)	0	1.0	0.1	5.0	0.0	6.0	3.3	44.5
24: NOE Flight (Mission Change) (NVG)	0	1.0	0.1	4.7	0.3	6.0	3.6	45.2
25: Approach (LZ)	0	1.3	0.1	1.3	0.0	1.9	0.2	18.7
26: Approach (LZ) (NVG)	0	1.3	0.1	0.4	0.9	1.9	0.2	18.6
27: Landing (LZ, Internal Load)	0	1.2	0.1	1.5	0.0	1.7	0.3	18.5
28: Landing (LZ, Internal Load) (NVG)	0	1.1	0.1	0.4	1.4	1.9	0.3	19.4
29: Landing (LZ, External Load)	0	1.3	0.1	1.5	0.0	1.8	0.3	19.2
30: Landing (LZ, External Load) (NVG)	0	1.2	0.1	0.4	1.4	2.0	0.3	20.0
31: Before Takeoff (LZ)	0	2.0	0.1	2.9	0.0	2.7	0.8	27.3
32: FARP Procedures	0	0.8	0.1	0.5	0.0	1.0	0.1	13.2
33: FARP Procedures (NVG)	0	0.7	0.1	0.1	0.7	1.1	0.1	13.6
34: Before Takeoff (FARP)	0	3.7	0.2	2.6	0.0	2.4	1.2	31.8

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.

ANALYSIS II - THE MH-60K WORKLOAD PREDICTION MODEL

The MH-60K workload prediction model was developed with the same procedures as the UH-60A model (Bierbaum, Szabo, & Aldrich, 1989). The following section includes a full description of the TAWL methodology used for the MH-60K 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-60K aircraft and a comparison of MH-60K and UH-60A operator workload predictions.

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 into phases,
- divide mission phases into segments,
- identify functions in the mission segment,
- identify tasks for each function, and
- analyze individual tasks.

A diagram of the taxonomy used in the top-down analysis of the MH-60K 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-60K 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-60K missions. A composite mission scenario was developed for the MH-60K from unique mission profiles that differed in the following ways:

- the mode of flight (en route, contour, NOE),
- the presence of a threat during flight, and
- the 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 UH-60A SMEs. The researchers made three assumptions in developing the mission scenario. First, the prototypical

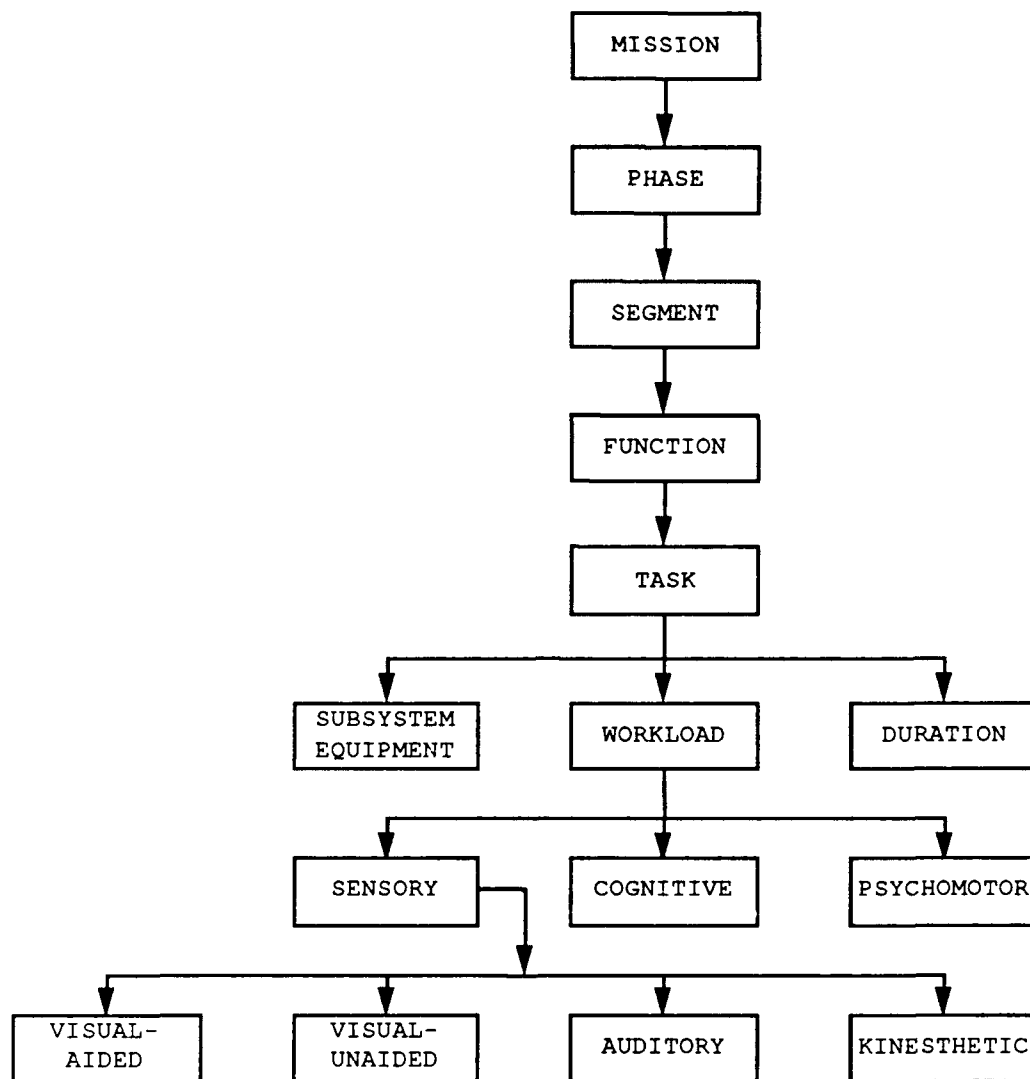


Figure 2. Diagram of the taxonomy used in the top-down analysis of the MH-60K mission.

mission for the MH-60K 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-60K mission is depicted schematically in Figure 3. Dashed rectangles represent mission phases; solid rectangles represent mission segments. The MH-60K 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.

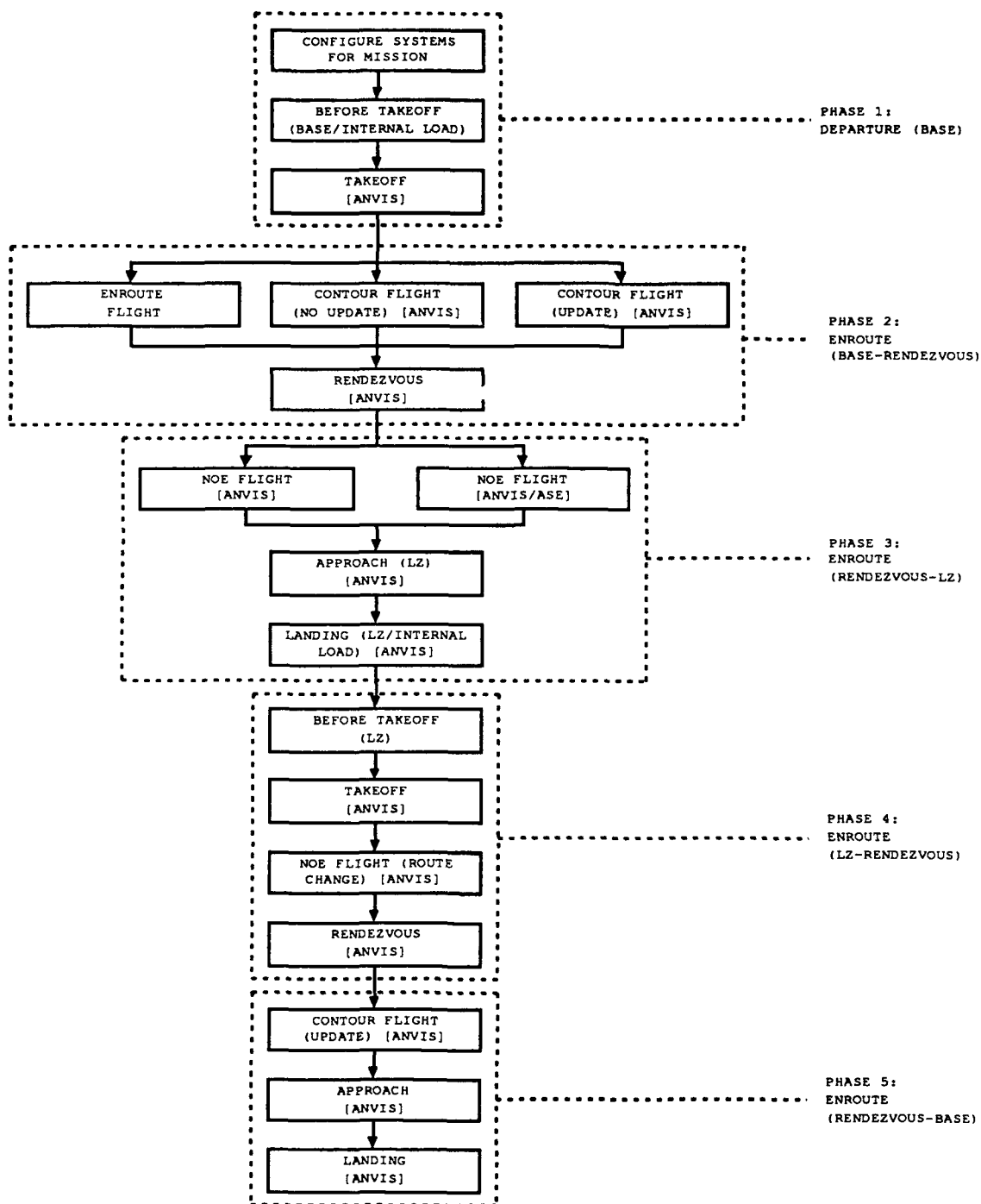
Although the activities and conditions encountered on any given mission may differ from those described above, the phases of the mission adopted for this research are representative of tactical missions for the MH-60K aircraft. Furthermore, the scenario developed for the MH-60K analysis is highly similar to the scenario and conditions used to develop the UH-60A workload prediction model (Bierbaum, Szabo, & Aldrich, 1989). The close correspondence between the UH-60A mission and the MH-60K mission facilitated the comparison of workload predictions for the UH-60A and MH-60K aircraft.

Divide Mission 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).

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



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-60K composite mission scenario.

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 one or more 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

MH-60K FUNCTION ANALYSIS WORKSHEET

FUNCTION 57 Perform IFF Procedures

TOTAL TIME (Approximate) 10.5 Seconds

TASKS		TASK #	WORKLOAD COMPONENTS				SWITCH DESCRIPTION	DURATION (SECONDS) DISCRETE/ CONTINUOUS
VERB	OBJECT		SUBSYSTEM(S)	SENSORY	COGNITIVE	PSYCHOMOTOR		
Press	IFF Key (1)	C110	Multifunction Display/Transponder (MFD/TP)	Visually Locate Key V-3.7	Verify Correct Status C-1.2	Press Softkey P-2.2	Softkey	.5
Press	IFF MODE Key (1)	C111	Multifunction Display/Transponder (MFD/TP)	Visually Locate Key V-3.7	Verify Correct Status C-1.2	Press Softkey P-2.2	Softkey	.5
Check	IFF Code	C109	Control Display Unit/ Transponder (CDU/TP)	Visually Inspect Readout V-4.0	Interpret Sensory and Symbolic Readout and Verify Correct Status (Correct Code) C-3.7			5
Press	IFF NORM/STBY Key (1)	C112	Multifunction Display/Transponder (MFD/TP)	Visually Locate Key V-3.7	Verify Correct Status (NORM) C-1.2	Press Softkey P-2.2	Softkey	.5
Press	BCN OPER Key (1)	C027	Multifunction Display/Transponder (MFD/TP)	Visually Locate Key V-3.7	Verify Correct Status C-1.2	Press Softkey P-2.2	Softkey	.5
Press	RTN Key (1)	C183	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-60K Function Analysis Worksheet.

data for each of the tasks identified in the mission function entitled "Perform IFF Procedures." 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,
- task identifiers,
- the subsystem(s) on which the task is performed,
- the estimated workload imposed by the task, 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, the analyses identified the crewmembers performing the task. Specifically, each task within a given function was assigned to the pilot, copilot, or both crewmembers. SMEs made the assignments. 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" 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 copilot performs the task "Check IFF Code."

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

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 were listed in the fourth column of the Function Analysis Worksheets. For example, the task Check IFF Code in Figure 4 is associated with the Control Display Unit and the Transponder.

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. Consistent with Wickens' theory of human information processing, human attention is viewed as a multidimensional

construct of limited availability (Wickens, 1984). 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 these 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, the 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 was 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.

The 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, Szabo, and Aldrich (1989) 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 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

Table 3

Workload Component Scales

Scale Value	Verbal Anchors
<u>Cognitive</u>	
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
<u>Psychomotor</u>	
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)
<u>Visual-Unaided (Naked Eye)</u>	
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)
<u>Visual-Aided (Night Vision Goggles [NVG])</u>	
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
<u>Auditory</u>	
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.)
<u>Kinesthetic</u>	
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

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 IFF Key" 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 2.2.¹

¹The 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.

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; the 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-60K Workload Prediction Model

The mission/task/workload analysis described above used a top-down approach to identify the tasks that must be performed to meet the objectives of the MH-60K 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-60K workload prediction model.

A bottom-up approach was used to develop the MH-60K 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 computer model, and
- exercise model to produce estimates of workload.

The steps performed in developing the model and producing estimates of workload are depicted schematically in Figure 5.

Write Decision Rules

The first step in developing the workload prediction model was to write 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

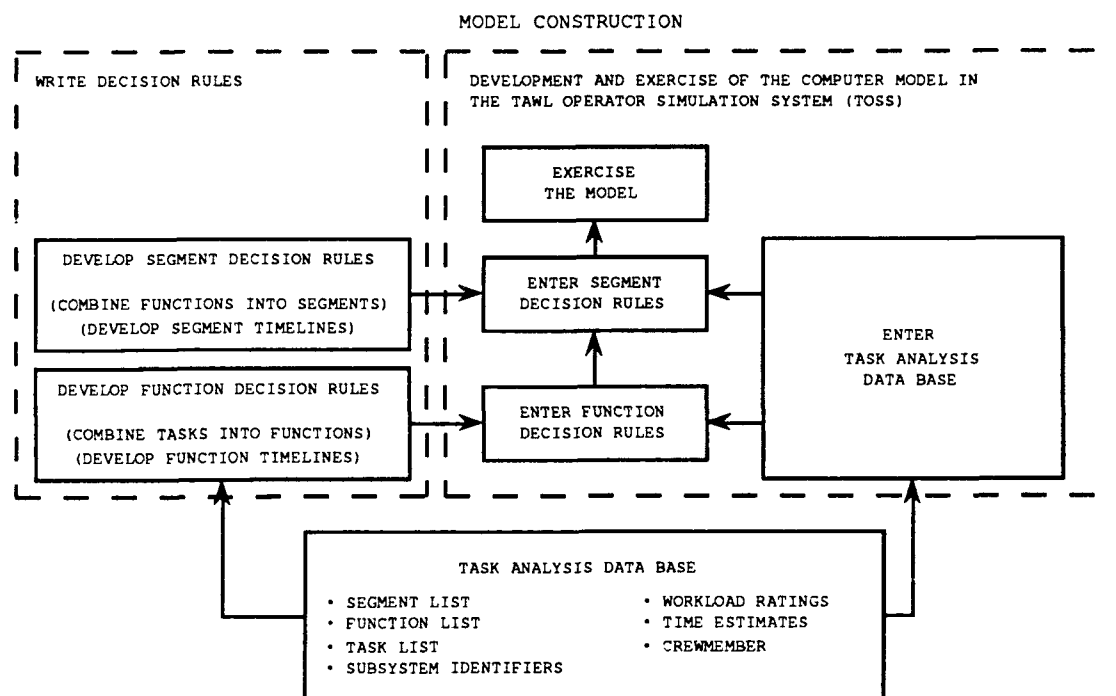


Figure 5. Bottom-up flow diagram outlining the technical steps performed in developing the MH-60K workload prediction model.

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

MH-60K FUNCTION SUMMARY WORKSHEET

FUNCTION 57 Perform IFF Procedures

PILOT				COPILOT			
DISCRETE FIXED	DISCRETE RANDOM	CONTINUOUS FIXED	CONTINUOUS RANDOM	DISCRETE FIXED	DISCRETE RANDOM	CONTINUOUS FIXED	CONTINUOUS RANDOM
				Press IFF Key (1) (110) Press IFF MODE Key (1) (111) Check IFF Code (109) Press IFF NORM/STBY Key (1) (112) Press BCN OPER Key (1) (027) Press RTN Key (1) (183)			

Figure 6. Example of an MH-60K Function Summary Worksheet.

(discrete fixed, discrete random, continuous fixed, and continuous random) was indicated by placing the task category name in one of the four columns below each crewmember's title. For complete definitions of the task categories, see Bierbaum, Fulford, and Hamilton, (1989).

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 the segment, Rendezvous [ANVIS]. The function, Perform IFF Procedures, 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 random) and the approximate temporal arrangement of the functions within segments. Again, see Bierbaum, Fulford, and Hamilton (1989) for the 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.

Develop Computer Model

As with the UH-60A, the TAWL Operator Simulation System (TOSS) was utilized to implement the MH-60K 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 crewmembers of the

MH-60K FUNCTION DECISION RULES WORKSHEET

FUNCTION 57 Perform IFF Procedures

PILOT				COPILOT			
DISCRETE FIXED	DISCRETE RANDOM	CONTINUOUS FIXED	CONTINUOUS RANDOM	DISCRETE FIXED	DISCRETE RANDOM	CONTINUOUS FIXED	CONTINUOUS RANDOM
				Program, in sequence, the following tasks (include a .5-second delay between tasks): Task 110 for .5 second Task 111 for .5 second Task 109 for 5 seconds Task 112 for .5 second Task 027 for .5 second Task 183 for .5 second Standby .5 second			

Figure 7. Example of an MH-60K Function Decision Rules Worksheet.

MH-60K SEGMENT SUMMARY WORKSHEET

PHASE 2 Enroute (Base - Rendezvous)

*SEGMENT 07 Rendezvous [ANVIS]

PILOT			COPILOT		
DISCRETE FIXED	DISCRETE RANDOM	CONTINUOUS FIXED	DISCRETE FIXED	DISCRETE RANDOM	CONTINUOUS FIXED
Perform Rendezvous [NVG] (61) Perform Aerial Refueling [NVG] (39)	Monitor Threat (Pilot) (38)	Adjust Level of Flight Parameters [NVG] (04)	Perform External Communication (Frequency Change) (52)	Monitor Threat (Copilot) (37)	
	Perform Cockpit Communication (Pilot) (Coordination) (49)	Monitor External Visual Field [NVG] (Pilot) (31)	Perform Rendezvous Check (60)	Perform Cockpit Communication (Pilot) (Coordination) (49)	
	Perform Cockpit Communication (Copilot) (Coordination) (47)		Perform IFF Procedures (57)	Perform Cockpit Communication (Copilot) (Coordination) (47)	
	Check Flight Parameters (13)		Perform Rendezvous [NVG] (61)	Perform Cockpit Communication (Pilot) (Normal) (50)	
	Perform Cockpit Communication (Pilot) (Normal) (50)		Perform Aerial Refueling [NVG] (39)	Perform Cockpit Communication (Copilot) (Normal) (48)	
	Perform Cockpit Communication (Copilot) (Normal) (48)		Depart Rendezvous [NVG] (19)	Monitor FLIR Image (Copilot) (33)	
	Monitor FLIR Image (Pilot) (34)				

*Denotes segment that occurs in more than one mission phase.

Figure 8. Example of an MH-60K Segment Summary Worksheet.

SEGMENT DECISION RULES WORKSHEET

PHASE 2 Enroute (Base - Rendezvous)

*SEGMENT 07 Rendezvous [ANVIS]

PILOT			COPILOT	
DISCRETE FIXED	DISCRETE RANDOM	CONTINUOUS FIXED	DISCRETE FIXED	DISCRETE RANDOM
7 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 13, 38, 52, or 60.	Start Segment 07 with Function 04. Function 04 lasts until the end of the segment. Interrupt Function 04 when Function 13 occurs.	Start Segment 07 with Function 04. Function 04 lasts until the end of the segment. Interrupt Function 04 when Function 13 occurs.	Start Segment 07 with Function 52. Function 52 lasts 22.5 seconds.	Insert Function 47 each time the pilot performs Function 47 and Function 49 each time the pilot performs Function 49.
2 times during the segment, randomly select Function 38. Function 38 lasts 3.5 seconds and cannot occur concurrently with Function 13, 47, or 49.	Start Function 31 at the beginning of the segment. Function 31 lasts until the end of the segment. Interrupt Function 31 when Function 13, 34, or 38 occurs.	Start Function 31 at the beginning of the segment. Function 31 lasts until the end of the segment. Interrupt Function 31 when Function 13, 34, or 38 occurs.	Start Function 57 when Function 60 ends. Function 57 lasts 10.5 seconds. Interrupt Function 57 when Function 33, 37, 47, or 49 occurs.	2 times during the segment, randomly select Function 37. Function 37 lasts 3.5 seconds and cannot occur concurrently with Function 47, 49, 52, or 60.
Start Function 61 when Function 57 ends. Function 61 lasts 62.5 seconds. Interrupt Function 61 when Function 38, 47, or 49 occurs.	Start Function 61 when Function 57 ends. Function 61 lasts 62.5 seconds. Interrupt Function 61 when Function 33, 34, 37, 38, 47, or 49 occurs.	Start Function 61 when Function 57 ends. Function 61 lasts 62.5 seconds. Interrupt Function 61 when Function 33, 34, 37, 38, 47, or 49 occurs.	Continued...	Continued...

*Denotes a segment that occurs in more than one mission phase.

Figure 9. Example of an MH-60K Segment Decision Rules Worksheet.

MH-60K aircraft. The development of the TOSS computer model requires 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 mission segment names,
- unique function names,
- unique task names,
- 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 MH-60K 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:

- 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:

- function start time,
- function duration,
- function interrupts,
- function clash pairs, and
- function frequency for random functions.

These data provided the TOSS software with sufficient information to simulate the MH-60K mission and predict crewmembers' workload.

Exercise Model to Produce Estimates of Workload

The analysts used TOSS to execute each of the 15 unique mission segments in the MH-60K 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-60K Mission/Task Analysis

The mission scenario, described earlier, was divided into five mission phases. Preflight and postflight operations were excluded from the UH-60A baseline analysis. Consequently, the analysis for the MH-60K 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 decomposition of segments by SMEs resulted in the identification of a total of 71 unique functions. Each of the 71 functions was assigned a unique two-digit identifier. The number of functions required to compose each segment ranged from 8 to 17. Appendix D presents an alphabetical list of the 71 functions along with their identifiers. Appendix E presents the functions that compose each of the 15 mission segments.

The decomposition of the 71 functions by SMEs resulted in the identification of 230 unique tasks. The number of

tasks required to compose each function ranged from 1 to 37. The 230 unique tasks were assigned numerical identifiers from 001 to 230. Appendix F presents an alphabetical list of the tasks and their numerical identifiers. The data developed for all of the tasks in the 71 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-60K mission tasks. Table 4 lists these subsystems along with their respective codes.

MH-60K 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 UH-60A 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-60K missions without encountering overload except when 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-60K workload model predictions for the pilot and copilot are summarized in Tables 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 average OW is highest in the Contour Flight (Update) segment.
- The copilot's average cognitive workload is higher when performing navigation during en route flight segments.
- The copilot's average OW is highest in the NOE Flight (Route Change) segment.

Table 4

List of MH-60K 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)

Table 5

Pilot Workload for the MH-60K Model by Segment

Segment	OC	AUD	KIN	VIS	NVG	COG	PSY	OW
01: Configure Systems for Mission	0	2.6	1.0	0.1	1.0	3.4	0.7	28.3
02: Before Takeoff (Base/Internal Load)	0	1.2	4.7	0.9	1.8	3.1	1.9	40.2
03: Takeoff [ANVIS]	0	1.5	7.0	0.1	2.0	2.7	3.0	46.5
04: Enroute Flight	0	1.1	1.0	0.5	0.9	3.1	0.3	23.5
05: Contour Flight (No Update) [ANVIS]	0	1.3	7.0	0.5	0.8	3.4	2.9	45.7
06: Contour Flight (Update) [ANVIS]	0	1.3	7.0	0.9	0.8	3.8	2.9	47.4
07: Rendezvous [ANVIS]	0	1.1	7.0	0.5	1.0	3.4	2.9	45.6
08: NOE Flight [ANVIS]	0	1.3	7.0	0.1	1.0	3.1	2.9	44.2
09: NOE Flight [ANVIS/ASE]	1	1.3	7.0	0.1	1.5	3.1	2.9	45.5
10: Approach (LZ) [ANVIS]	0	1.3	7.0	0.2	0.9	2.9	2.9	43.9
11: Landing (LZ/Internal Load) [ANVIS]	0	1.0	6.6	0.1	2.5	2.5	2.7	44.1
12: Before Takeoff (LZ)	0	1.8	1.0	0.0	1.0	3.1	0.4	24.9
13: NOE Flight (Route Change) [ANVIS]	0	0.8	7.0	0.1	1.0	2.5	2.8	41.5
14: Approach [ANVIS]	0	1.1	7.0	0.2	0.9	2.8	2.9	42.9
15: Landing [ANVIS]	0	1.2	6.8	0.1	2.7	2.7	2.8	46.2

Table 6

Copilot Workload for the MH-60K Model by Segment

Segment	OC	AUD	KIN	VIS	NVG	COG	PSY	OW
01: Configure Systems for Mission	0	2.6	0.2	0.7	0.0	1.7	0.7	21.5
02: Before Takeoff (Base/Internal Load)	0	1.3	0.1	1.2	0.2	1.3	0.7	18.6
03: Takeoff [ANVIS]	0	1.5	0.1	0.1	1.2	1.9	0.1	18.7
04: Enroute Flight	0	1.3	0.1	3.5	1.2	5.6	0.3	35.8
05: Contour Flight (No Update) [ANVIS]	0	1.5	0.1	3.2	0.7	5.5	0.3	34.1
06: Contour Flight (Update) [ANVIS]	0	1.5	0.1	2.5	1.5	5.5	0.3	35.0
07: Rendezvous [ANVIS]	0	1.4	0.1	2.4	0.2	3.3	0.4	25.8
08: NOE Flight [ANVIS]	0	1.3	0.1	3.3	1.2	5.9	0.2	36.0
09: NOE Flight [ANVIS/ASE]	1	1.3	0.1	2.0	1.8	5.5	0.7	34.7
10: Approach (LZ) [ANVIS]	0	1.4	0.1	0.1	0.9	1.9	0.2	18.1
11: Landing (LZ/Internal Load) [ANVIS]	0	1.2	0.1	0.3	1.3	1.9	0.2	18.9
12: Before Takeoff (LZ)	0	1.8	0.1	1.9	0.0	2.6	0.6	23.9
13: NOE Flight (Route Change) [ANVIS]	0	0.9	0.2	3.5	1.3	5.8	0.3	36.2
14: Approach [ANVIS]	0	1.5	0.1	0.9	0.6	2.4	0.3	21.1
15: Landing [ANVIS]	0	1.4	0.1	0.1	1.3	2.2	0.2	19.7

Note. The following abbreviations are used as column headings in Tables 5 and 6: OC = Overload Condition, AUD = Auditory, KIN = Kinesthetic, VIS = Visual-unaided, NVG = Visual-aided, COG = Cognitive, PSY = Psychomotor, OW = Overall Workload.

- Both crewmembers' average OW is higher during flight segments.
- Proficient crewmembers can perform the MH-60K mission without encountering an overload condition, except when being engaged by a threat.

Comparison of MH-60K and UH-60A Operator Workload Predictions

To estimate the effect of the high technology modifications of the MH-60K on crewmember workload, 12 segments from the MH-60K mission were compared to 12 like segments from the UH-60A mission. Table 7 lists the compared segments by aircraft. A list of functions in each segment being compared is presented in Appendix N.

The average component workloads for the 12 segments of the MH-60K and UH-60A are presented in Figures 10 and 11. Figure 10 presents the average workload by component for the pilot in each of the segments being compared. Figure 11 presents the average workload by component for the copilot in each of the segments.

Table 7

List of MH-60K and UH-60A Segments Compared

MH-60K Segment	UH-60A Segment
03: Takeoff [ANVIS]	03: Takeoff [NVG]
04: Enroute Flight	05: Contour Flight [NVG]
05: Contour Flight (No Update) [ANVIS]	05: Contour Flight [NVG]
06: Contour Flight (Update) [ANVIS]	05: Contour Flight [NVG]
08: NOE Flight [ANVIS]	20: NOE Flight [NVG]
09: NOE Flight [ANVIS/ASE]	22: NOE Flight (Threat) [NVG]
10: Approach (LZ) [ANVIS]	26: Approach (LZ) [NVG]
11: Landing (LZ, Internal Load) [ANVIS] [NVG]	28: Landing (LZ, Internal Load)
12: Before Takeoff (LZ)	31: Before Takeoff (LZ)
13: NOE Flight (Route Change) [ANVIS] [NVG]	24: NOE Flight (Mission Change)
14: Approach [ANVIS]	11: Approach [NVG]
15: Landing [ANVIS]	13: Landing [NVG]

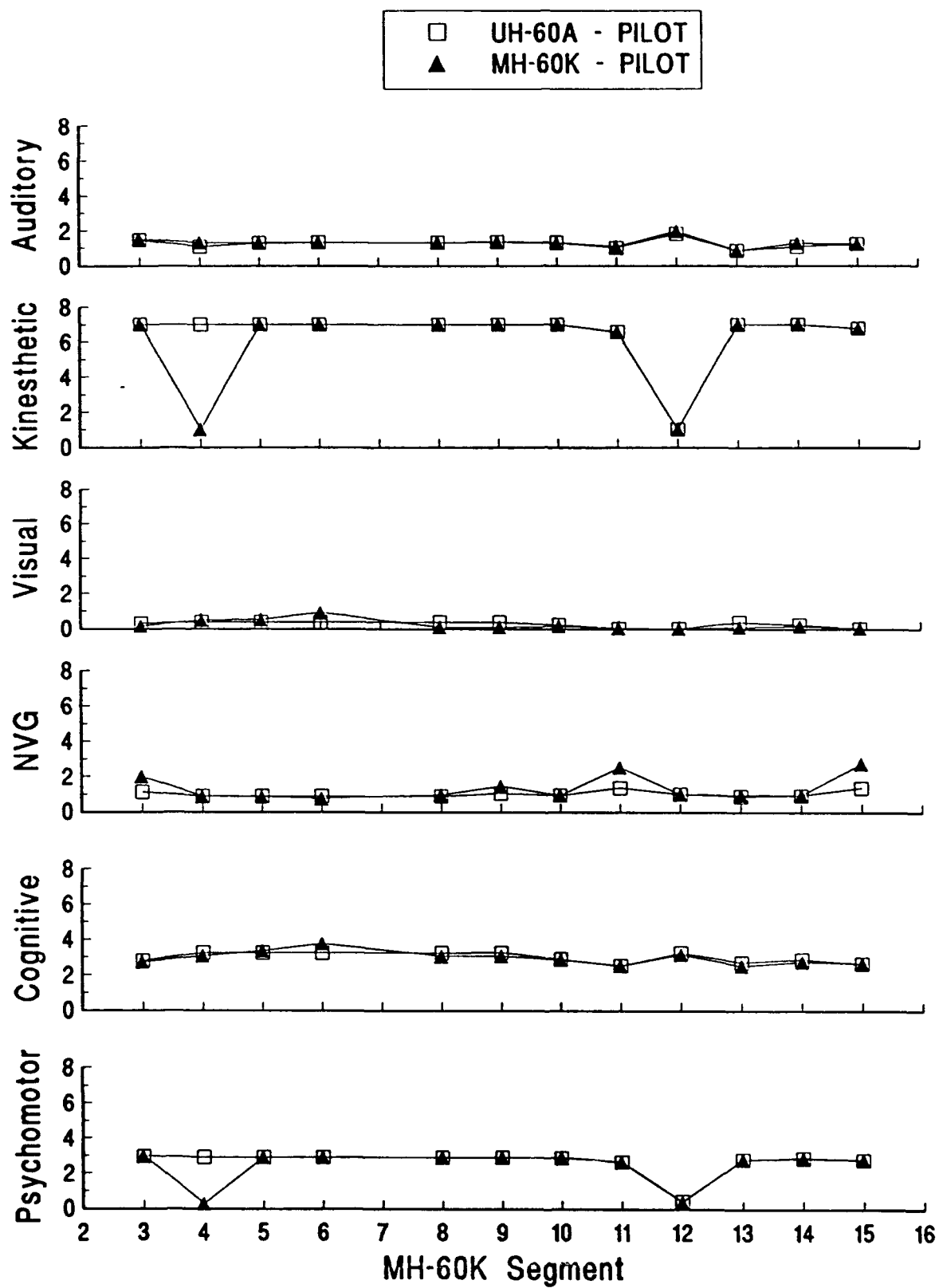


Figure 10. Pilot's average component workload by segment.

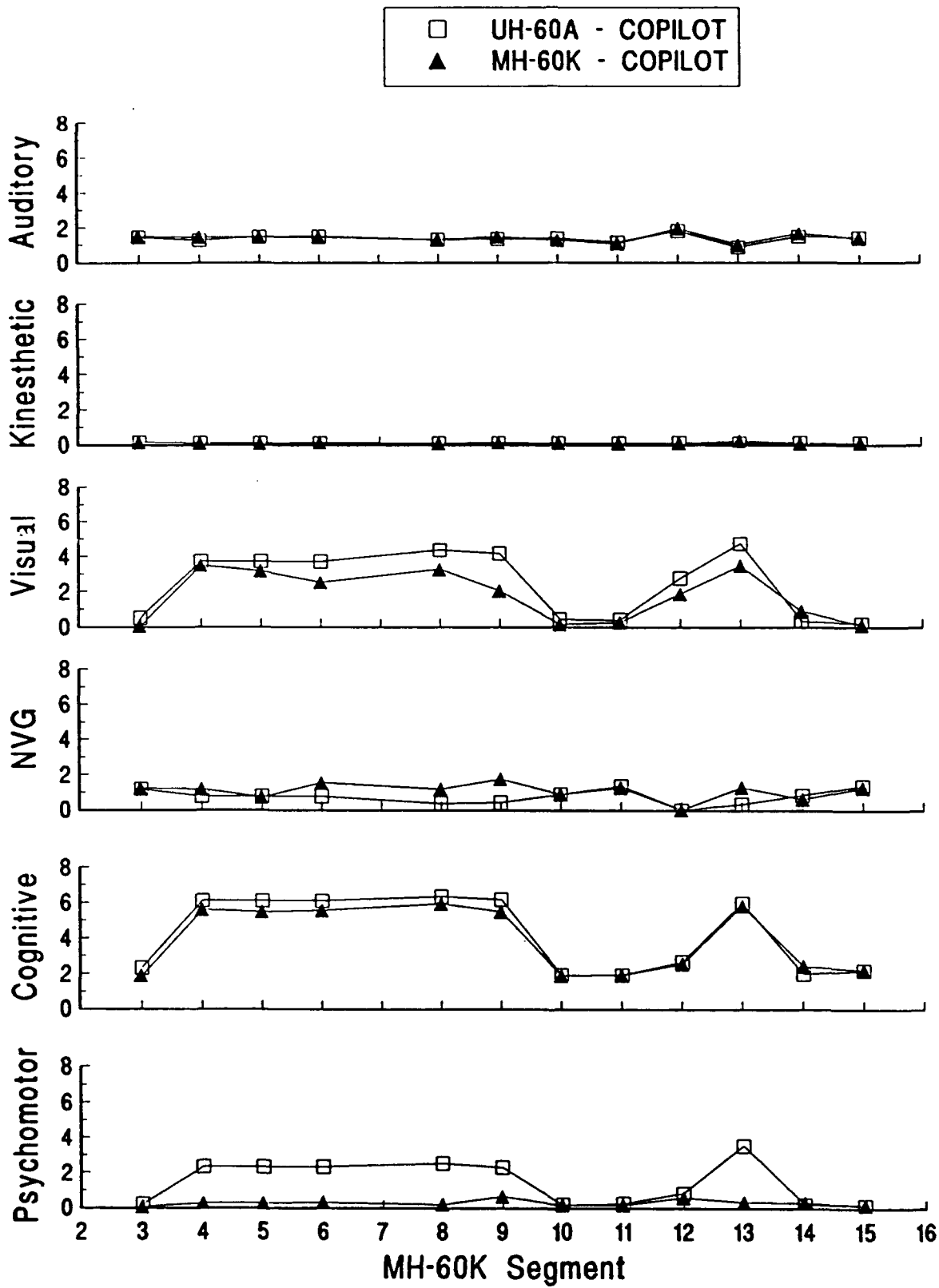


Figure 11. Copilot's average component workload by segment.

An analysis of the pilot workload by component graph (Figure 10) indicates little difference in the 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-60K are coupled during contour flight (Segment 04), the reduction in kinesthetic and psychomotor workload is significant. The small increase in NVG workload for the MH-60K is a result of a requirement for the pilot to spend more time looking outside the aircraft.

The copilot workload by component graph (Figure 11) indicates there is no difference in the copilot auditory or kinesthetic predicted workload for the two aircraft. However, eliminating the requirement in the MH-60K for the copilot to handle maps, determine present position, and calculate fuel requirements reduces 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 produces the increase in NVG workload.

Predicted OW for the UH-60A and MH-60K 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) shows the effect of control coupling during contour flight (Segment 04) in the MH-60K. An examination of the copilot's predicted OW graph (Figure 12) indicates a lower OW for the MH-60K in nearly all segments. This finding reflects the copilot's reduced task requirements in the MH-60K, except for the approach and landing segments (Segments 10, 11, 14, 15).

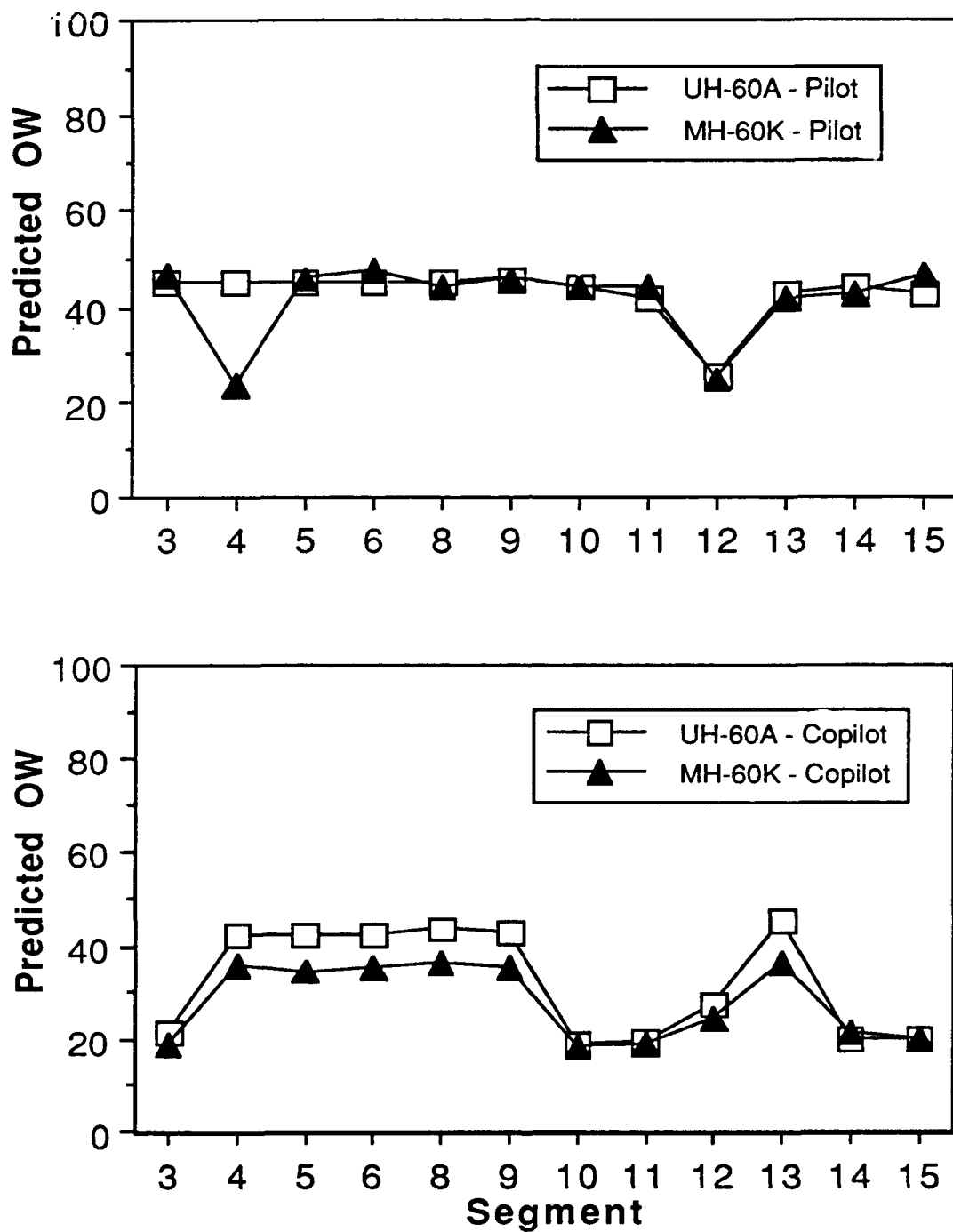


Figure 12. Comparison of MH-60K and UH-60A predicted OW by segment for the pilot (upper) and copilot (lower).

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 UH-60A nor the MH-60K appears to place excessive workload demands on their operators. A comparison of the workload for the pilot of the MH-60K and the UH-60A resulted in the following observations:

- In some segments, the MH-60K aircraft was found to have higher NVG workload than the UH-60A. The increase in external visual attention may provide the MH-60K pilot with increased awareness of the status and spatial location of the aircraft, of other air traffic, and of threats to the aircraft.
- The MH-60K aircraft was found to have slightly lower visual-unaided workload due to the reduction of aircraft system monitoring which is automatically performed by the integrated avionics subsystems.
- The MH-60K aircraft was found to have reduced kinesthetic and psychomotor workload when flight controls are coupled during Segment 04.
- The overall workload in the MH-60K was found to be similar to the UH-60A in all segments except when the controls are coupled in the MH-60K.

A comparison of the copilot workload for the MH-60K and the UH-60A resulted in the following observations:

- The MH-60K aircraft was found to have reduced visual-unaided workload due to the reduced requirements for map interpretation because present position is always readily available on the MFD.
- The MH-60K aircraft was found to have higher NVG workload than the UH-60A. The increase in external visual attention may provide the MH-60K copilot with increased awareness of the status and spatial location of the aircraft, of other air traffic, and of threats to the aircraft.

- The MH-60K was found to have lower cognitive workload because functions such as fuel consumption, checking system status, and determining present position are performed continuously by the mission processor.
- The overall workload in the MH-60K was found to be generally lower than the overall workload in UH-60A.

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