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Task Analysis of the UH-60 Mission and Decision Rules for Developing a UH-60 Workload Prediction Model

Volume I: Summary Report

February 1989

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A composite scenario was used to conduct a comprehensive task analysis of the UH-60 mission. The analysis used a top-down approach to identify the mission's phases, functions, and tasks. Nine phases, 34 segments, 48 functions, and 138 tasks were identified. The crewmember performing each task was identified, and estimates of the sensory, cognitive, and psychomotor workload associated with the tasks were derived. Estimates of the task times were also derived.

The mission/task analysis data were used to develop a computer model of workload for UH-60 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 each crewmember in the performance of both sequential and concurrent tasks.

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Research Product 89-08

Task Analysis of the UH-60 Mission and Decision Rules for Developing a UH-60 Workload Prediction Model

Volume I: Summary Report

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Human Factors in Training and
Operational Effectiveness

FOREWORD

The potential impact that advanced technology will have on manpower and personnel requirements must be considered during the early stages of planning for system modifications. One critical consideration is the impact that advanced technology will have on the workload of the system operator(s). Since operator overload can result in a dramatic decrease in system effectiveness, operator workload must be considered throughout the system modification process.

This report describes how the modified Light Helicopter Family (LHX) methodology was used to conduct a comprehensive task analysis of the UH-60 mission. Information provided by the UH-60 mission/task analysis was used to establish a data base for developing a computer model that predicts workload for UH-60 crewmembers. Assessments of workload produced by the model provide a baseline for evaluating the workload impact of any high-technology modifications or product improvements.

The report consists of four volumes. Volume I describes the methodology for conducting the research; Volumes II-IV contain appendixes presenting the results of the research.

Appendixes A-E, presented in Volume II, summarize the results of the UH-60 baseline mission/task/workload analysis. The following specific information is presented in each of these appendixes:

- Appendix A summarizes the segments within each mission phase;
- Appendix B presents an alphabetical list of the unique mission functions;
- Appendix C summarizes the functions within each mission segment;
- Appendix D presents an alphabetical list of the unique tasks; and
- Appendix E presents Function Analysis Worksheets that summarize the workload data derived for each unique function.

The information presented in Volume II comprises a comprehensive task data base for developing the UH-60 workload prediction model.

Volume III of the report contains Appendixes F (the Function Summary Worksheets) and G (the Function Decision Rules Worksheets), which provide preliminary directions for building functions from the tasks identified in the analysis. Similarly, the Segment Summary Worksheets (Appendix H) and the Segment Decision Rules Worksheets (Appendix I), presented in Volume IV, provide preliminary directions for building mission segments from the functions.

The System Research Laboratory was responsible for this research, which was executed by the Aviation Research and Development Activity at Fort Rucker, Alabama. The work was sponsored by the UH-60 Program Manager at Aviation Systems Command (AVSCOM), St. Louis, Missouri, under a memorandum of agreement entitled "Establishment of Technical Coordination between ARI and AVSCOM."

The results were provided to the UH-60 Program Office to use as a baseline for the development of an electronics surveillance version of the UH-60K, which was used during the Source Selection Evaluation Board (SSEB) held at the Electronic Avionic Research and Development Command at Fort Monmouth, New Jersey. The UH-60 Program Office has continued to use this analysis as a baseline for all proposed model changes or other proposed multistage improvement program (MSIP). A computer model of this analysis was used to formulate the basis of the Special Operation Forces version of this aircraft. The authors provided specific briefings to the design team, which included the manufacturer (Sikorsky) and the UH-60 Program Office personnel.

EDGAR M. JOHNSON
Technical Director

ACKNOWLEDGMENTS

The mission/task analysis required to develop the UH-60 workload prediction model represents a complex and labor-intensive effort. The authors wish to acknowledge several individuals who made significant contributions to the analysis.

The baseline task analysis required in-depth knowledge of the cockpit configurations for both crewmembers of the UH-60 aircraft. Knowledge of the specific tasks performed by the crewmembers in the conduct of their mission was also essential. The authors were assisted by a number of instructor pilots from F Company, 9th Battalion, Aviation Training Brigade, at Fort Rucker, Alabama. CW3 Jim Hudson carefully reviewed the analysis of the mission into phases, segments, functions, and tasks. CPT Christopher Philbrick provided outstanding support in the coordination of activities with F Company.

The authors wish to thank Ms. Cassandra Hocutt, Anacapa Sciences, Inc., for her assistance in the development of the many workload prediction model decision rules. Her technical advice on computer logic and programming helped the authors develop smooth-flowing function and segment decision rules. Her assistance is greatly appreciated.

The authors also wish to thank Ms. Nadine McCollim, Anacapa Sciences, Inc., for the speed and accuracy with which she entered the task analysis data into a computer data base. Her work significantly enhanced the quality of the final product.

TASK ANALYSIS OF THE UH-60 MISSION AND DECISION RULES FOR DEVELOPING A UH-60 WORKLOAD PREDICTION MODEL. VOLUME I: SUMMARY REPORT

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INTRODUCTION

Combat helicopter operators will encounter heavy workload in the high-threat environment of the Air/Land Battle 2000 scenario. Advanced technology currently being proposed for the next generation of Army helicopters is designed to reduce the heavy crew workload. However, in some instances, technological improvements in aircraft capability may result in greater aircrew monitoring and decision-making responsibilities. Excessive demands on the mental resources of the crewmembers may jeopardize the quality of task performance. Since the performance of the system operators is critical to mission effectiveness, it is essential that management of operator workload be considered throughout the system design process (Shingledecker & Crabtree, 1982).

One reason that system designers have failed to consider operator workload in proposing advanced technology for new Army aircraft is that there has been no methodology for assessing operator workload prior to and during the system development process. Recently, however, Anacapa Sciences, Inc. personnel, under contract to the U.S. Army Research Institute Aviation Research and Development Activity (ARIARDA), developed a methodology for predicting operator workload during the conceptual phase of the system development process for the Army's Light Helicopter Family (LHX) aircraft (Aldrich, Craddock, & McCracken, 1984; Aldrich, Szabo, & Craddock, 1986; McCracken & Aldrich, 1984). The methodology was used to generate workload predictions for one- and two-crewmember configurations of the LHX during LHX system trade-off studies and analyses.

The LHX methodology employs a generic workload prediction model that can be tailored for use in making critical design decisions about any emerging weapon system. For example, the LHX methodology has been refined and used to develop a baseline model for predicting workload encountered by the operators of the AH-64A aircraft (Szabo & Bierbaum, 1986). The AH-64 workload prediction research was conducted in response to a request by the Aviation Systems Command (AVSCOM) for assistance in predicting the impact that proposed modifications of the emerging AH-64B helicopter may have on operator workload. In contrast to the LHX model, which is based on an analysis of a proposed system, the AH-64 baseline model is based on an existing aircraft. Consequently, the AH-64 workload analysis was conducted at a high level of task specificity.

Recently the Special Operation Forces (SOF) Program Management Office at AVSCOM was tasked to modify the UH-60 and CH-47 aircraft with new technology for SOF missions The modified aircraft have been designated the MH-60K and the MH-47E, respectively. The SOF Program Office requested that the Army Research Institute's (ARI) AVSCOM Element support the development of the MH-60K and MH-47E aircraft. Accordingly, the most recent applications of the workload methodology have been in support of the SOF modification.

This report presents the results of a comprehensive task analysis of the UH-60 mission and the recent development of a model for assessing the impact that proposed modifications for the SOF version of the UH-60 aircraft are likely to have on crew workload. The report also describes the latest refinements in the workload prediction methodology. The latest refinements are:

- addition of a visual-aided (Night Vision Goggles [NVG]) workload component, and
- the development of interval workload component rating scales to replace the ordinal workload component rating scales used in the LHX and AH-64 analyses.

The baseline workload prediction model will be exercised to produce estimates of total workload experienced by operators of the existing UH-60 aircraft in the performance of their current mission. The predictions of workload yielded by the baseline model will subsequently be compared with the results from exercising the model to generate predictions of MH-60K crew workload during performance of the SOF mission. The model will be exercised for various advanced technology configurations proposed for the MH-60K aircraft.

Objectives

The research described in this report has three general objectives:

- conduct a detailed analysis of the tasks that must be performed to accomplish the UH-60 combat mission;
- estimate the workload associated with the performance of the UH-60 mission tasks; and
- develop a computer model to predict UH-60 operator workload.

To accomplish the general objectives, the following specific objectives were established:

- identify the phases, segments, functions, and tasks required to perform the UH-60 combat mission;
- identify the crewmember(s) performing each task;

- estimate the workload associated with the sensory, cognitive, and psychomotor components of each task;
- define the temporal sequence of the tasks and estimate the duration of each task;
- identify the subsystem(s) representing the man-machine interface for each task;
- develop decision rules for combining the tasks to form each mission function; and
- develop decision rules for combining the functions to form each mission segment.

The research tasks that were performed to meet these objectives are described in the sections that follow.

METHODOLOGY

Conduct of the Mission/Task/Workload Analysis

This section describes the research tasks that were performed to conduct the mission/task/workload analysis for the existing UH-60 aircraft. The tasks are listed below in the order in which they were performed:

- develop a composite mission scenario (see Figure 1);
- divide the composite mission scenario into mission phases (see Appendix A);
- divide the mission phases into mission segments (see Appendix A);
- identify the functions in the mission segments (see Appendix C);
- identify the tasks in each unique mission function (see Appendix F);
- identify the crewmember(s) performing each task (see Appendix F);
- identify the subsystem(s) representing the man-machine interface for each task (see Appendix E);
- estimate the workload associated with the sensory, cognitive, and psychomotor components of each task (see Appendix E); and
- define the temporal sequence and estimate the duration of each task (see Appendix G).

A task-flow diagram depicting these tasks is presented in Figure 2. Each of the tasks is described in detail in succeeding paragraphs of this report; products resulting from the performance of the tasks are presented in the appendixes to the report.

Develop a Composite Mission Scenario

The first step in conducting the UH-60 mission/task/workload analysis was to develop a composite scenario of the UH-60 mission. The composite scenario was developed from information derived from three primary sources: (a) reviews of the UH-60 Operator's Manual, (b) reviews of the Army Training and Evaluation Program (ARTEP) Manual for Combat Aviation Battalions, and (c) interviews of UH-60 subject matter experts (SMEs). The scenario that was developed from these sources is graphically depicted in Figure 1. A fundamental assumption underlying this scenario is that the basic mission for the UH-60 aircraft is to provide air transportation of personnel and cargo in support of combat operations.

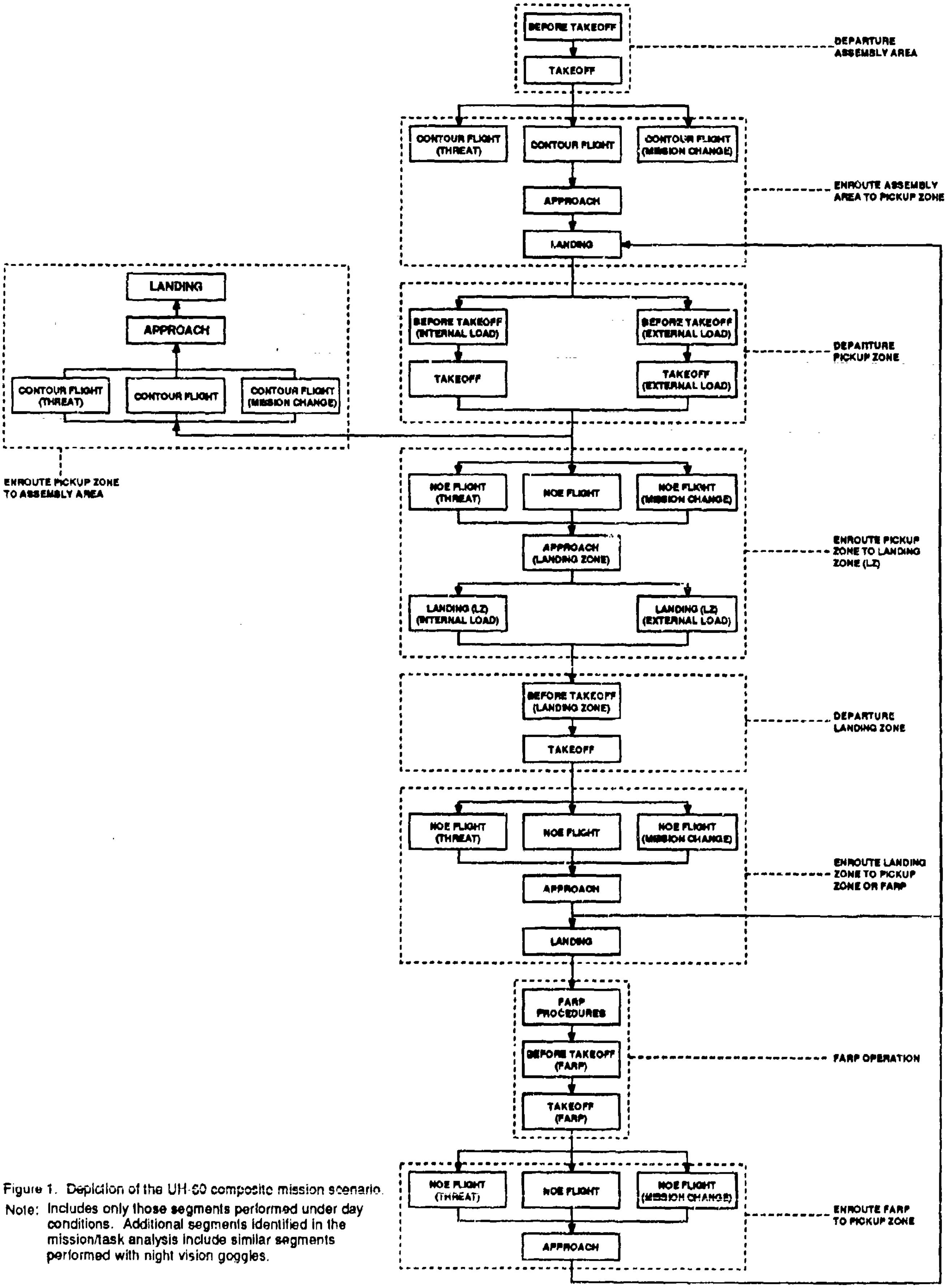

Figure 1. Depiction of the UH-60 composite mission scenario.

Note: Includes only those segments performed under day conditions. Additional segments identified in the mission/task analysis include similar segments performed with night vision goggles.

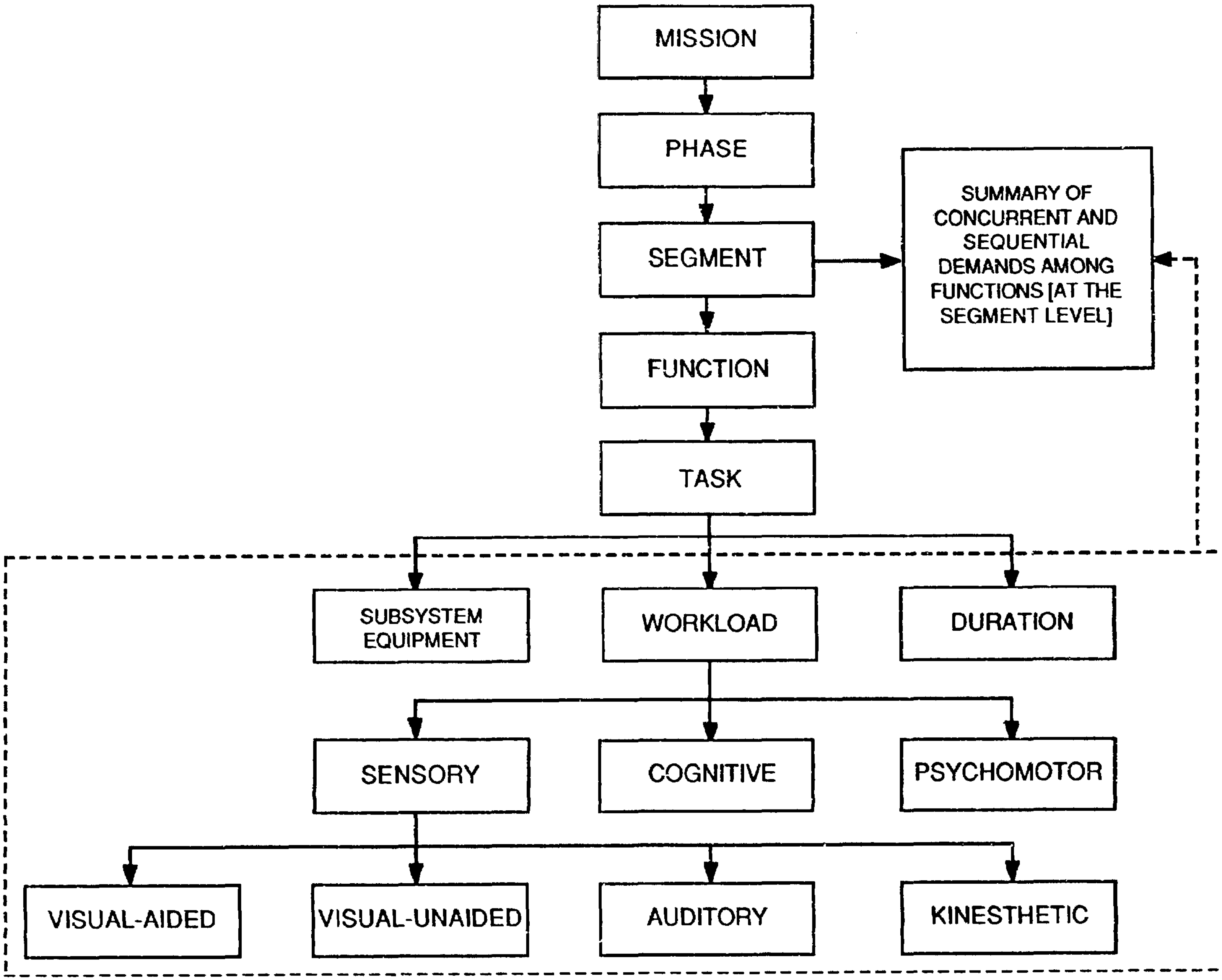

Figure 2. Task-flow diagram of the"top-down" procedure used tc conduct the UH-60 mission/task/workload analysis.

The scenario further assumes that the UH-60 combat support operations can be conducted under either day or night conditions and may include the transportation of both internal loads and external sling loads.

As shown in Figure 1, the UH-60 composite mission begins in an assembly area (AA) where preflight and departure operations are performed. The pilot then flies contour flight from the AA to a pick-up zone (PZ), where cargo and/or troops are assembled for pick-up. After completing the loading operations, the pilot flies nap-of-the-earth (NOE) to the landing zone (LZ) to insert the combat troops or deliver the cargo. After completing the troop and/or cargo delivery, the pilot flies NOE back to the PZ for another load. This pattern of activity is continued until refueling of the aircraft becomes necessary. The pilot then flies NOE from the LZ to the forward area arming and refueling point (FARP), where refueling operations are conducted. Upon completion of the FARP operations, the crew returns to the PZ for continuation of the mission. When the mission is complete, the pilot flies contour back to the AA where postflight activities are conducted. It is assumed that, during the conduct of these mission operations, the pilot's primary role is to fly the aircraft, while the copilot's primary role is to assist the pilot and perform navigation functions; furthermore, it is assumed that the mission is flown under optimal performance conditions (i.e., full moon at night, and no degradation due to weather or emergencies).

While the authors are aware that the activities and conditions encountered on any given mission may differ from those described above, the adoption of a composite scenario encompassing a standard set of assumptions was judged to be an essential step in conducting the mission analysis. First of all, such a scenario provides a basis for conducting a comprehensive analysis of all possible mission segments. Second, the scenario provides a standard against which the effect of proposed changes in the mission and/or the aircraft configuration can be assessed. Finally, the assumption of optimal conditions for performance of the mission permits the most conservative estimates of workload. Conservative estimates, based on "best case" conditions, provide a basis for determining the minimal level of automation that is necessary to avoid excessive workload during mission performance.

Divide the Composite Scenario Into Mission Phases

The composite scenario described above was subsequently divided into nine mission phases. At the request of AVSCOM, preflight and postflight operations were excluded from the analysis; consequently, the research begins with departure from the assembly area and ends with return to the assembly area. The nine phases included in the analysis are listed below in the order of their occurrence within the mission; the phases are also shown in Figure 1.

- Phase 1: Departure (AA),
- Phase 2: Enroute (AA-PZ),
- Phase 3: Departure (PZ),
- Phase 4: Enroute (PZ-LZ),
- Phase 5: Departure (LZ),
- Phase 6: Enroute (LZ-PZ) or (LZ-FARP),
- Phase 7: FARP Operations,
- Phase 8: Enroute (FARP-PZ), and
- Phase 9: Enroute (PZ-AA)

Divide the Mission Phases Into Segments

The nine mission phases selected for analysis were subsequently divided into mission segments. A mission segment is defined as a major sequence of events that has a definite start and end point during a mission phase. An example of a segment performed during the Departure phase of the UH-60 mission is Before Takeoff (External Load).

A total of 70 segments were identified for the nine mission phases selected for analysis. Thirty-four segments are unique (i.e., segments that are distinctly different from any other segment); the remaining 36 segments are duplicates of the 34 unique segments. The total number of segments identified in each of the nine mission phases is presented below[1].

- Phase 1: Departure (AA) - 3 segments,
- Phase 2: Enroute (AA-PZ) - 10 segments,
- Phase 3: Departure (PZ) - 7 segments,
- Phase 4: Enroute (PZ-LZ) - 12 segments,
- Phase 5: Departure (LZ) - 3 segments,
- Phase 6: Enroute (LZ-PZ) or (LZ-FARP) - 10 segments,
- Phase 7: FARP Operations - 5 segments,
- Phase 8: Enroute (FARP-PZ) - 10 segments, and
- Phase 9: Enroute (PZ-AA) - 10 segments.

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[1] The reported total for each mission phase includes all the segments that are performed during both day and night conditions for that phase--not just the number of unique segments in that phase.

The specific mission segments that must be performed to accomplish each of the nine mission phases under day and night conditions are listed in Appendix A[2]. The two-digit number assigned to each segment in Appendix A is based on the ordinal position of the segment within the composite scenario described above. Segments occurring more than once during the mission are identified by the ordinal position of their initial occurrence, and thus, retain the same numerical identifier throughout the scenario.

Identify the Functions in the Mission Segments

Each of the 34 unique mission segments was further divided into functions. A function is defined as a set of activities that must be performed either by an operator or by equipment in order to complete a portion of the mission segment. An example of a mission function performed during the previously presented segment, Before Takeoff (External Load), is Load Cargo (External).

A total of 48 unique functions were identified for the 34 mission segments. The unique functions were subsequently ordered in an alphabetical list, and a number (1-48) corresponding to the ordinal position of each function within the list was assigned. The number assigned in this manner to the function serves as an identifier for the function within the computer model data base.

The alphabetical list of functions and the numerical identifiers for the functions are presented in Appendix B. A list of the functions that must be performed to accomplish each of the 70 mission segments is presented in Appendix C.

Identify the Tasks for Each Unique Function

Each of the 48 unique functions was further divided into tasks. Each task defines a specific crew activity that is essential to the successful performance of the selected function. The task description consists of a verb and an object; the verb describes the action by the crewmember, and the object describes the recipient of the action. Examples

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[2] As previously noted, the segments listed for each phase in Figure 1 include only those segments performed under day conditions. The remaining segments identified in Appendix A for each mission phase are those segments that are performed with night vision goggles.

of tasks performed during the function, Load Cargo (External), include Set Cargo Release Switch, Control Altitude, and Evaluate Hand Signals. In the current analysis, the activities defined as tasks are the basic units of analysis.

A total of 138 unique tasks were identified for the 48 unique functions in the mission/task analysis. The unique tasks were alphabetized by object and verb and were then assigned a numerical identifier ranging from 1 through 138. Appendix D presents the alphabetical list of the tasks, as well as the task numbers.

The tasks identified for each of the 48 unique functions are summarized on Function Analysis Worksheets presented in Appendix E. The verb and object defining the tasks for a particular function are presented in columns one and two, respectively, of the worksheets; the numerical identifiers for the tasks are presented in column three. For the reader's benefit, an example of a Function Analysis Worksheet is presented in Figure 3. Specifically, Figure 3 summarizes the tasks for the function, Load Cargo (External). This function will be used as an example throughout the remainder of this report; therefore, the reader should refer to Figure 3 during succeeding presentations of (a) the types of information derived during the conduct of the mission/task/workload analysis and (b) the procedure used to develop the workload prediction model.

Identify the Appropriate Crewmember(s) for the Tasks

Once the tasks had been identified for each function, it was necessary to identify the crewmember(s) performing each task. Specifically, it was necessary to determine whether the pilot, copilot, or both crewmembers performed the task within a given function. Information derived from reviews of the operator's and ARTEP manuals, as well as information derived from interviews of UH-60 SMEs, provided the basis for assigning the tasks to a given crewmember. In general, all run-up and flight control tasks were assigned to the pilot, and all navigation and support tasks were assigned to the copilot.

On the Function Analysis Worksheets, tasks performed by the pilot are indicated by the letter "P" preceding the numerical identifier in the third column; similarly, tasks performed by the copilot are indicated by the letter "C." For example, the data presented in Figure 3 indicate that the task, Set Cargo Release Switch, is performed by the copilot, FUNCTION 14 Load Cargo (External) | UH-60 FUNCTION ANALYSIS | TOTAL TIME (Approximate) 243.5 Seconds

TASKS			WORKLOAD COMPONENTS					DURATION (SECONDS) DISCRETE/ CONTINUOUS	
VERB	OBJECT	TASK #	SUBSYSTEM(S)	SENSORY	COGNITIVE	PSYCHOMOTOR	SWITCH DESCRIPTION		
Set	Cargo Release Switch	C024	Cargo (UCA)	Visually Check Switch Position and Placement of Switch V-4	Decide Correct Position (ARM) C-1.2	Move Switch P-2.2	Toggle - 2 Positions (T-2)	1	
Set	EMER REL Switch	C052	Cargo (UCA)	Visually Check Switch Position and Placement of Switch V-4	Decide Correct Position (NORM) C-1.2	Move Switch P-2.2	Toggle - 3 Positions (T-3)	1	
Check	% TRQ Indicator (Inflight)	P138	Engine Instruments/ Flight Control (EIN/FC)	Feel Control Movements/ Visually Check Instrument Indications K-7/V-4	Interpret Readout and Verify Correct Status (Readout Within Limits C-3.7	Control Pressure P-2.6		1	
Adjust	Power	P108	Flight Control/ External Visual Field (FC/VEX)	Feel Control Movements/ Visually Detect Aircraft Movement K-7/V-1	Make Conditioned Association (Adjustment Needed) C-1	Control Pressure P-2.6		1	
Check	% TRQ Indicator (Inflight)	P138	Engine Instruments/ Flight Control (EIN/FC)	Feel Control Movements/ Visually Check Instrument Indications K-7/V-4	Interpret Readout and Verify Correct Status (Readout Within Limits C-3.7	Control Pressure P-2.6		1	
Control	Altitude	P014	Flight Control/ External Visual Field (FC/VEX)	Feel Control Movements/ Visually Detect Aircraft Movement K-7/V-1	Make Conditioned Association (Adjustment Needed) C-1	Control Pressure P-2.6		.5	
Control	Attitude	P020	Flight Control/ External Visual Field (FC/VEX)	Feel Control Movements/ Visually Detect Aircraft Movement K-7/V-1	Make Conditioned Association (Adjustment Needed) C-1	Control Pressure P-2.6		.5	
Control	Heading	P067	Flight Control/ External Visual Field (FC/VEX)	Feel Control Movements/ Visually Detect Aircraft Movement K-7/V-1	Make Conditioned Association (Adjustment Needed) C-1	Control Pressure P-2.6		.5	
Control	Drift	P050	Flight Control/ External Visual Field (FC/VEX)	Feel Control Movements/ Visually Detect Aircraft Movement K-7/V-1	Make Conditioned Association (Adjustment Needed) C-1	Control Pressure P-2.6		.5	
Evaluate	Hand Signals	P062	External Visual Field (VEX)	Visually Discriminate Hand Motion V-3.7	Evaluate Sensory Feedback C-3.7				(c)
Verify	Load Hookup	P073	External Visual Field (VEX)	Visually Discriminate Hand Motion/Visually Register Light V-3.7	Evaluate Sensory Feedback and Verify Correct Status (Hock Light Extinguished) C-3.7			1	

Figure 3. Example of a Function Analysis Worksheet.

while the tasks, Control Altitude and Evaluate Hand Signals, are performed by the pilot.

Identify the Subsystem(s) Associated With Each Task

The next step in the analysis was to identify the subsystem(s) representing the man-machine interface for each task. As shown in Figure 3, the subsystems identified for the UH-60 tasks are listed in the fourth column of the Function Analysis Worksheets. The tasks presented as examples above demonstrate a variety of subsystems. Specifically, the task, Set Cargo Release Switch, is associated with the Cargo subsystem, while the task, Control Altitude, is associated with the Flight Control and External Visual Field subsystems. Finally, the task, Evaluate Hand Signals, is associated with the External Visual Field subsystem only.

A total of 17 subsystems from five major categories were identified for the unique UH-60 mission tasks. Table 1 presents a summary of these subsystems and their identification codes.

Estimate the Workload Associated With Each Task

Workload, as the term is used in this research, is defined as the total attentional demand (i.e., mental workload) placed on the operator(s) as they perform the mission tasks. Consistent with Wicken's theory that workload is a multidimensional construct, the research methodology addresses three different components of workload: sensory, cognitive, and psychomotor (Wickens, 1984). The sensory component refers to the complexity of the visual (V), auditory (A), and/or kinesthetic (K) stimuli to which an operator must attend; the cognitive (C) component refers to the level of information processing required from the operator; the psychomotor (P) component refers to the complexity of the operator's behavioral responses. During the present research, the existing methodology for the LHX and AH-64 analyses was refined so that the attentional demand associated with the visual component of the mission tasks could be estimated under both naked eye (visual-unaided) and night vision goggle (visual-aided) conditions; these sensory components are designated by the letters "V" and "G," respectively. The steps performed to determine the workload associated with each of these components for the mission tasks are listed below:

• develop workload component scales,
• write verbal descriptors of workload, and
• assign numerical estimates of workload.

Each of these steps is described in detail in the paragraphs that follow.

Table 1

Summary of UH-60 Subsystems

Code	Subsystem
E	Engine Subsystem
EF	Fuel
EIN	Engine Instruments
EI	Ignition
F	Flight Control Subsystem
FB	Brakes
FC	Flight Controls
FI	Flight Instruments
FG	Gear
N	Navigation Subsystem
NM	Maps
NC	Navigation Controls
ND	Navigation Displays
U	Utility Subsystem
UAD	Advisory
UC	Communications
UL	Lighting
US	Survivability
UCA	Cargo
V	Visual Subsystem
VEX	External Visual Field
VG	Night Vision Goggles

Develop Workload Component Scales

In the present analysis, subjective judgments were used to derive estimates of workload associated with performance of the mission tasks. Separate estimates were derived for each of the six major workload components: visual-unaided (V), visual-aided (G), auditory (A), kinesthetic (K), cognitive (C), and psychomotor (P). The scales that were used in the present analysis of workload are shown in Table 2.

The workload component scales shown in Table 2 constitute a refinement of the 7-point rating scales previously used in the LHX and AH-64 workload analyses (Aldrich, Szabo, & Craddock, 1986; Szabo & Bierbaum, 1986). Specifically, two major refinements of the previous scales were effected: (a) the addition of a second visual scale and (b) the conversion of the ordinal scale measures to interval scale measures.

Visual-aided workload scale. In the previous research, the analyses of workload were based on the assumption that all mission operations were conducted under day conditions. Consequently, the visual workload component was designed to measure workload encountered when the crewmember receives visual information with the naked eye. In the UH-60 analysis, a second visual scale was constructed to measure workload when the crewmember receives visual information with night vision goggles. Both of the visual scales retain the same verbal anchors used in the prediction of AH-64 crew workload; however, the numerical values assigned to the verbal anchors within the two scales differ from those in the AH-64 analysis, as well as from each other. The derivation of different values for the anchors within each workload component scale represents a second refinement of the previous research methodology.

Interval scale measures. The workload component scales originally developed for the LHX and AH-64 workload analyses represent ordinal scales of measurement. In the present research, equal-interval scales were developed to replace the ordinal scale measures. A pair comparison survey methodology (Engen, 1971) was employed to construct the scales.

The first step in constructing the interval scales was to randomly assign a letter designator of A - G to the verbal anchors for each of the six workload component scales. A pair comparison survey was then designed by matching each verbal anchor within a given workload component scale with each of the other verbal anchors in that same scale. In this manner, a total of 21 pair comparisons were produced for each of the workload component scales. The matched pairs were then arranged randomly for presentation to SMEs.

Table 2

Workload Component Scales

Scale Value	Descriptors
	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
	Visual-Unaided (Naked Eye)
1.0	Visually Register/Detect (Detect Occurrence of Image)
3.7	Visually Discriminate (Detect Visual Differences)
4.0	Visually Inspect/Check (Discrete Inspection/Static Condition)
5.0	Visually Locate/Align (Selective Orientation)
5.4	Visually Track/Follow (Maintain Orientation)
5.9	Visually Read (Symbol)
7.0	Visually Scan/Search/Monitor (Continuous/Serial Inspection, Multiple Conditions)
	Auditory
1.0	Detect/Register Sound (Detect Occurrence of Sound)
2.0	Orient to Sound (General Orientation/Attention)
4.2	Orient to Sound (Selective Orientation/Attention)
4.3	Verify 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.)

Continued on next page.

Table 2: Workload Component Scales (Continued)

Scale Value	Descriptors
	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
	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-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

The matched pairs of verbal anchors for the visual (both naked eye and night vision goggles), auditory, cognitive, and psychomotor workload component scales were presented to 20 UH-60 instructor pilots (IPs) for the UH-60 Aviator Qualification Course (AQC) at the U.S. Army Aviation Center (USAAVNC) in Fort Rucker, Alabama. In the pair comparison survey, the pilots were instructed to review each pair individually and to select the verbal anchor they judged to represent the greater level of workload. In an effort to reduce the bias attributable to comparisons of current responses with previous judgments, the researcher read each pair individually to the IPs, who recorded their responses on answer sheets. The frequency with which the IPs selected each verbal anchor was used to compute a rating value for each verbal anchor on an approximately equal-interval scale.

The matched pairs for the kinesthetic workload component scale were similarly arranged in a questionnaire and administered by mail to a group of human factors experts who have had extensive research experience in workload measurement. Response frequencies for the kinesthetic verbal anchors were tabulated from completed questionnaires returned by 22 SMEs. The pair comparison methodology described above was then applied to the data to develop interval scale values for the kinesthetic workload component rating scale.

Write Verbal Descriptors of Workload

Once the interval scales had been developed for each workload component, short verbal descriptors of workload were written for each task. First, the specific components (i.e., visual-unaided, visual-aided, auditory, kinesthetic, cognitive, and psychomotor) that applied to the task were identified. Then, a descriptor of the specific workload associated with each of the components was written. The verbal descriptors for each of the tasks performed during the function, Load Cargo (External), are presented in columns five, six, and seven of the Function Analysis Worksheet presented in Figure 3.

Assign numerical estimates of workload. The verbal descriptors of workload were subsequently compared with the verbal anchors on the corresponding workload component scale (see Table 2). The purpose of the comparison was to identify the anchor within the appropriate scale that represented the "best match" with each descriptor. The interval value associated with the verbal anchor identified as the "best match" was then assigned to represent the level of workload for that particular component of the task.

For each task, the two analysts reached consensus in selecting the verbal anchor that best matched the short verbal descriptor of workload. The consensual matches were subsequently reviewed by UH-60 SMEs. The numerical estimates of the sensory, cognitive, and psychomotor workload associated with the tasks shown in Figure 3 are presented immediately below the corresponding verbal descriptors of workload. For example, the numerical estimate of the visual workload associated with the task, Set Cargo Release Switch, is 4; the cognitive workload associated with the task is 1.2; and the psychomotor workload is 2.2.[3]

Estimate the Time Required to Perform Each Task

The final step in conducting the mission/task/workload analysis was to estimate the amount of time required to perform each task. To derive the time estimates, each task was first identified as a discrete fixed, discrete random, or continuous task. These three categories of tasks are defined as follows:

- discrete fixed - tasks that have a definite start and end point within the function (e.g., Set TAILWHEEL Switch),
- discrete random - discrete tasks that occur intermittently and/or randomly during a portion of the function (e.g., Check Fuel Quantity Indicator), and
- continuous - tasks that occur continuously throughout the function or a portion of the function (e.g., Monitor Audio).

Once the tasks were categorized as discrete fixed, discrete random, or continuous, the length of time required to perform each task was estimated to the nearest half-second. The estimates were derived from interviews with UH-60 SMEs. As shown in Figure 3, the estimated length of the discrete fixed tasks (e.g., Set Cargo Release Switch = 1 second) and discrete random tasks (e.g., Control Altitude = .5 second) are presented in the ninth column of the Function Analysis Worksheets; the estimated lengths of the continuous tasks are presented in the tentn column. The continuous tasks (e.g., Evaluate Hand Signals) whose lengths vary within different functions are designated with the letter "c."

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[3] In the present analysis, the type of switch that is associated with a specific task is a major correlate of workload. Consequently, for each task involving a switch, the type of switch is presented in the eighth column of the Function Analysis Worksheets.

The total time required to perform all the tasks in a given function is shown in the upper right corner of each Function Analysis Worksheet. For example, the total time required to perform the function, Load Cargo (External), is 243.5 seconds. In most instances, the functions identified in the analysis consist of discrete tasks only; the total time for these functions is derived by summing the time spent on each of the discrete tasks and adding a half-second transition time between consecutive tasks. However, certain functions, such as the referent function, Load Cargo (External), have random tasks that are performed repeatedly for a specified period of time; the total time for these functions is affected by both the length of the random tasks and the total number of times the random tasks occur. A footnote presented at the bottom of the Function Analysis Worksheets presented in Appendix E for each of these types of functions explains the derivation of the total time. In addition, some functions contain random or continuous tasks that occur continuously throughout the function or a portion of the function. The length of these functions generally depends upon the specific segment in which the functions occur. These functions are designated by the word "continuous" instead of a total time.

Development of the Baseline Workload Prediction Model

The mission/task/workload analysis, described in the preceding sections, used a top-down approach to identify the tasks that must be performed to meet the objectives of the UH-60 mission. That is, the analysis started with the composite mission and proceeded, top-down, through the phases, segments, and functions to the task level. The tasks represent the basic units of analysis for which estimates of workload and time were derived. These data, in turn, will be used to establish a data base for developing a model to predict the total workload experienced by UH-60 crewmembers in the performance of their mission.

In developing the UH-60 workload prediction model, a "bottom-up" approach will be used. The bottom-up approach starts with the most basic elements in the analysis (i.e., the tasks) and builds upward to the segment level. First, the model selects the tasks identified for a specific function and combines them in such a way as to rebuild the functions from which the tasks were originally derived. Then, the model selects the appropriate set of functions, built in the previous step by combining the tasks, and combines them to re-build the original segments. The technical tasks that must be performed to develop the model are listed below and are graphically depicted in Figure 4.

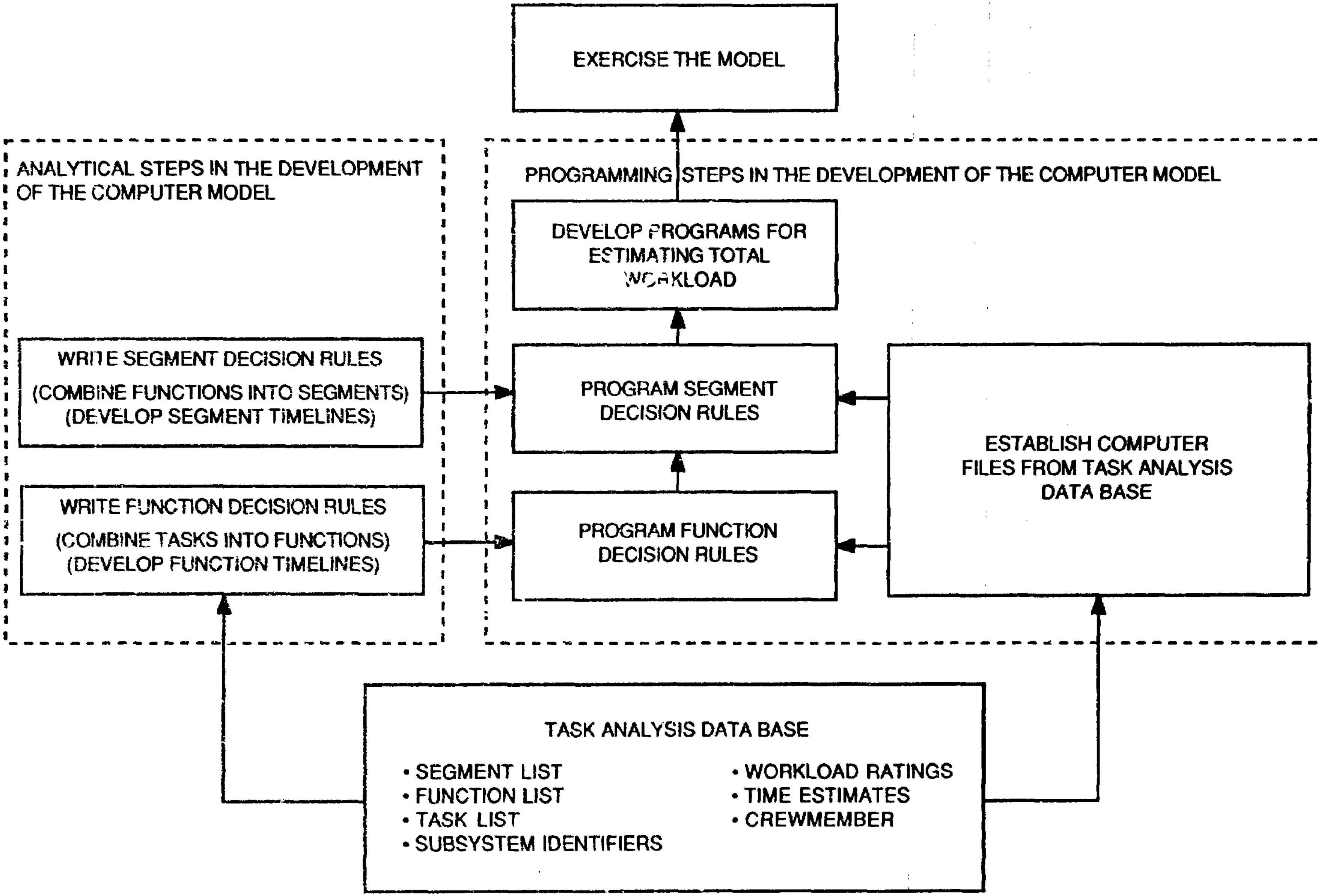

Figure 4. Bottom-up flow diagram outlining the technical tasks to be performed in developing the UH-60 workload prediction model.

- write preliminary decision rules;
- develop the computer model of workload; and
- exercise the model to produce estimates of total work.

As revealed in succeeding descriptions of these tasks, the preliminary decision rules have been written; however, the development and exercise of the computer model remain to be accomplished in a later phase of research.

Write Preliminary Decision Rules

The first step in developing the workload prediction model was to develop preliminary decision rules for building the mission segments from the task data base. 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 are designed to reconstruct the mission in such a way as to simulate the behavior of each crewmember at each point on the mission timeline. Once the mission timeline has been reconstructed through the implementation of the decision rules, estimates of total workload associated with concurrent tasks can be derived. Specifically, estimates of total workload for each crewmember will be produced for each workload component at half-second intervals within the mission. The procedures used to develop the decision rules and compute the workload totals are described in the following subsections.

Develop Function Decision Rules

Function decision rules were developed for each of the 48 unique functions identified in the mission/task analysis. The decision rules were developed in two stages. First, the tasks performed by each crewmember were identified and listed on worksheets referred to as Function Summary Worksheets. Then, the decision rules for combining the tasks listed on the summary sheets were developed and reported on Function Decision Rules Worksheets. The Function Summary Worksheets for each unique function are presented in Appendix F; the corresponding Function Decision Rules Worksheets are presented in Appendix G. The summary and decision rules sheets for the function, Load Cargo (External), used as a reference in preceding discussions of the mission/task/workload analysis, are presented in Figures 5 and 6, respectively.

As shown in Figure 5, the Function Summary Worksheets list, by name and code number, all the tasks performed during a given function. The left half of each summary sheet lists

UH-60 SEGMENT DECISION RULES

FUNCTION 14 Load Cargo (External)

PILOT			COPILOT		
DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS	DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS
			Set Cargo Release Switch (024)		
			Set EMER REL Switch (052)		
Check % TRQ Indicator (Inflight) (138)					
Adjust Power (108)					
Check % TRQ Indicator (Inflight) (138)					
		Evaluate Hand Signals (062)			
	Control Altitude (014)				
	Control Attitude (020)				
	Control Heading (067)				
	Control Drift (050)				
Verify Load Hook-up (073)					

Figure 5. Example of a Function Summary Worksheet.

UH-60 SEGMENT DECISION RULES

FUNCTION 14 Load Cargo (External)

PILOT			COPILOT		
DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS	DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS
3 seconds after Function 14 begins, program, in in sequence, the following tasks (include a .5-second delay between tasks): Task 138 for 1 second Task 108 for 1 second Task 138 for 1 second .5 second after Task 062 ends, program Task 073 for 1 second. Standby .5 second	4.5 seconds after Function 14 begins, randomly select (.25 probability) Tasks 014, 020, 050, and 067 at .5-second intervals. Continue for 237 seconds.	4.5 seconds after Function 14 begins, program Task 062 for 237 seconds.	Program, in sequence, the following tasks (include a .5-second delay between tasks): Task 024 for 1 second Task 052 for 1 second		

Figure 6. Example of a Function Decision Rules Worksheet.

the tasks performed by the pilot, while the right half lists the tasks performed by the copilot. For each crewmember, separate columns are used to identify discrete fixed, discrete random, and continuous tasks performed during the function. The spatial arrangement of the tasks on the worksheets corresponds roughly to the temporal sequence of the tasks. For example, the information presented in column 4 of Figure 5 indicates that the tasks, Set Cargo Release Switch and Set EMER REL Switch, are discrete fixed tasks performed in sequence by the copilot at the beginning of the function. When these two tasks are completed, the pilot begins performing a series of tasks that include discrete fixed (column 1), discrete random (column 2), and continuous tasks (column 3).

Once the summary worksheets had been completed for each function, decision rules were written to describe the exact manner in which the tasks must be combined to form the function. Decision rules for discrete fixed tasks (e.g., Set Cargo Release Switch) and continuous tasks (e.g., Evaluate Hand Signals) simply state the start point and the duration of the tasks on the function timeline (see columns 1 and 3, respectively, of Figure 6). In addition to duration, the decision rules for discrete random tasks (e.g., Control Altitude) state the probability and/or frequency of the random tasks' occurrence within the function (see column 2 of Figure 6).

Develop Segment Decision Rules

The next step in the development of the model was to write the segment decision rules. As previously stated, the segment decision rules use the bottom-up approach to build the mission segments from the functions that were built by implementing the function decision rules in the previous step. As before, the segments were developed in two stages: first by developing Segment Summary Worksheets and then by developing Segment Decision Rules Worksheets. The summary sheets for the 34 unique segments are presented in Appendix H, while the decision rules sheets are presented in Appendix I. Figures 7 and 8 present the summary sheet and the decision rules sheet, respectively, for the segment, Before Takeoff (External Load), in which the function, Load Cargo (External), used as the example throughout this report, occurs.

As shown in Figure 7, the Segment Summary Worksheets list all of the functions performed by each crewmember during a mission segment. The summary worksheets also identify the

UH-60 SEGMENT DECISION RULES

PHASE 3 Departure (PZ) SEGMENT 15 Before Takeoff (External Load)

PILOT			COPILOT		
DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS	DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS
		Monitor Audio (17)	Update Doppler (PZ) (46)		Monitor Audio (17)
			Load Aircraft (Internal) (13)		
	Perform Cockpit Communication (Pilot) (26)			Perform Cockpit Communication (Copilot) (25)	
	Perform Cockpit Communication (Copilot) (25)			Perform Cockpit Communication (Pilot) (26)	
Load Cargo (External) (14)			Load Cargo (External) (14)		
			Perform External Communication (27)		
			Perform Before Takeoff Check (Fly Through) (23)		

Figure 7. Example of a Segment Summary Worksheet.

UH-60 SEGMENT DECISION RULES

PHASE 3 DEPARTURE (PZ)

SEGMENT 15 Before Takeoff (External Load)

PILOT			COPILOT		
DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS	DISCRETE (FIXED)	DISCRETE (RANDOM)	CONTINUOUS
	Insert Function 25 each time the Copilot performs Function 25 and Function 26 each time the Copilot performs Function 26.	Start Segment 15 with Function 17. Function 17 lasts 369.5 seconds.	Start Segment 15 with Function 46. Function 46 lasts 8.5 seconds.		Start Function 17 concurrently with Function 46. Function 17 lasts 369.5 seconds.
			Start Function 13 when Function 46 ends. Function 13 lasts 96.5 seconds.	3 seconds after Segment 15 starts, 3 times randomly select (.50) Function 25 or Function 26. Functions 25 and 26 last 7 seconds each and cannot occur concurrently with Function 14 or Function 27. When selected, program Functions 25 and 26 to interrupt Functions 13 and 23.	
Start Function 14 when Function 13 ends. Function 14 lasts 243.5 seconds.			Start Function 14 when Function 13 ends. Function 14 lasts 243 seconds.		
			Start Function 27 when Copilot Function 14 ends. Function 27 lasts 12 seconds.		
			Start Function 23 when Function 27 ends. Function 23 lasts 17.5 seconds.		

Figure 8. Example of a Segment Decision Rules Worksheet.

type of function (i.e., discrete fixed, discrete random, or continuous) performed by the crewmembers and the approximate temporal arrangement of the functions within the segments. The Segment Decision Rules Worksheets contain the decision rules defining the sequence of the functions performed by each crewmember and the points on the mission segment timeline at which the functions begin and end. For example, the decision rule presented in column 1 of Figure 8 indicates that, in Segment 15, Before Takeoff (External Load), the pilot begins Function 14, Load Cargo (External), as soon as the copilot completes Function 13, Load Cargo (Internal). Thus, Function 14 begins at the 105-second point within Segment 15 (i.e., after the 8.5 seconds for copilot Function 46 plus the 96.5 seconds for copilot Function 13). Since Function 14 lasts 243 seconds, it ends 348 seconds after the segment begins (i.e., 105 seconds + 243 seconds).

Develop the Computer Model of Workload

The mission/task/workload analysis data presented on the Function Analysis Worksheets in Appendix E and the function and segment decision rules presented in Appendixes G and I will be used to develop a computer model to predict workload for the crewmembers of the UH-60 aircraft. The analysis of workload for UH-60 crewmembers will serve two primary functions:

- identify UH-60 tasks and subsystems that are candidates for automation, and
- provide a baseline for comparing workload associated with proposed configurations of the MH-60K aircraft.

The steps that must be implemented to develop the computer model consist of the following:

- build task data files,
- write computer programs to implement the decision rules, and
- generate predicted workload for the baseline UH-60 configuration.

These steps are depicted in the task-flow chart previously presented in Figure 4 and are described in detail below.

Build Task Data Files

The first step in developing the computer model is to build a series of data files from the information derived through the mission/task/workload analysis. The following specific files will be established:

- a list of mission segments,
- a list of unique functions,
- a list of unique tasks,
- a list of subsystem identifiers,
- estimates of the sensory, cognitive, and psychomotor workload for each task, and
- estimates of the duration of each task.

Information contained in the files will serve as the data base for developing and exercising the UH-60 workload prediction model.

Write Computer Programs to Implement the Decision Rules

The workload model will be developed by writing computer programs designed to combine the elements of the task analysis data base in accordance with the decision rules. By implementing the conditions specified in the decision rules, the model will simulate the behavior of both crewmembers at each half-second point on the mission timeline. By identifying all the tasks performed by each crewmember at any given point within the mission, the model provides a means for identifying instances in which two or more tasks must be performed concurrently. Estimates of total workload experienced in the performance of these concurrent tasks, as well as individual tasks, can then be derived.

Generate Predicted Workload for the Baseline UH-60 Configuration

The ultimate objective of the workload prediction model is to identify instances in which the requirement to perform two or more concurrent tasks results in operator overload. In meeting this objective, the model will produce estimates of total workload experienced by each crewmember at each half-second point on the mission timeline. The total workload for concurrent tasks will be computed by summing the ratings assigned, during the task analysis, to each workload component (i.e., visual-unaided, visual-aided, auditory, kinesthetic, cognitive, and psychomotor) of each concurrent task.

As an example, the tasks performed at the 130.5-second point on the mission timeline for the segment, Before Takeoff (External Load), is shown in Table 3. At this point during the mission, the pilot is performing four concurrent tasks. Specifically, the pilot is simultaneously monitoring audio, evaluating hand signals, controlling altitude, and transmitting communication. The total workload experienced by the pilot is determined by summing the values assigned to each of the workload components for each of these four tasks. Thus, the total cognitive (C) workload is 11.0 (1.0 + 3.7 + 1.0 + 5.3). The estimates of total workload will be used to identify points on the timeline at which the performance of concurrent tasks results in excessive workload, referred to hereafter as an "overload." Four specific indices of overload, as defined by Aldrich, Craddock, and McCracken (1984) and Szabo and Bierbaum (1986), will be used; these indices are described in the following paragraphs.

Table 3

Pilot Estimated Workload at the 130.5-Second Point of the Segment, Before Takeoff (External Load)

	FUNCTION/TASK	WORKLOAD COMPONENT ESTIMATES A	K	V	G	C	P
130.5	Function 17: Monitor Audio						
	Task 22: Monitor Audio	1.0	0.0	0.0	0.0	1.0	0.0
130.5	Function 14: Load Cargo (External)						
	Task 62: Evaluate Hand Signals	0.0	0.0	3.7	0.0	3.7	0.0
	Task 14: Control Altitude	0.0	4.0	1.0	0.0	1.0	2.6
130.5	Function 26: Perform Cockpit Communication (Pilot)						
	Task 30: Transmit Communication (Pilot)	4.3	0.0	0.0	0.0	5.3	2.2
	TOTAL WORKLOAD	5.3	4.0	4.7	0.0	11.0	4.6

Component overloads. A total value of 8 for any given component of concurrent tasks will designate a component overload. Thus, as many as six component overloads (i.e., visual-unaided, visual-aided, auditory, kinesthetic, cognitive, and psychomotor) may occur for two or more concurrent tasks. The value 8 was chosen as the criterion for a component overload because it exceeds the maximum value on any of the workload component rating scales. As an example, the data presented in Table 3 indicate that, at the 130.5-second point of the segment, Before Takeoff (External), the pilot experiences a cognitive component overload.

Overload conditions. An overload condition will exist whenever at least one component overload occurs for two or more concurrent tasks. Thus, the cognitive overload shown in Table 3 also represents an overload condition. In theory, as many as six component overloads may occur within a single overload condition. The concept of an overload condition is designed to identify the number of unique conditions within a mission segment that are associated with a component overload.

Overload density. Overload density refers to the percentage of time during a mission segment that a component overload is present. It is calculated by dividing the total number of half-second timelines with component overloads by the total number of half-second timelines in the segment. The number of timelines with component overloads is determined by counting the total number of half-second intervals with a value of 8 for at least one of the six workload components. Thus, if component overloads occur at 8 half-second intervals in a segment that lasts a total of 10 seconds, the overload density is 40% (i.e., 8 ÷ 20).

Subsystem overloads. The term "subsystem overload" is used to describe the relationship between a component overload and a subsystem. To identify subsystem overloads, a tally of the component overloads associated with each subsystem will be conducted for each of the mission segments. The component overload shown in Table 3 would be tallied with each of the subsystems associated with the four concurrent tasks producing the component overload. Information derived from the tallies of subsystem overloads will be used to identify those subsystems that are associated with high workload.

Generation of Predicted Workload for MH-60K Crewmembers

The methodology used in developing the UH-60 baseline workload prediction model will be used to predict workload associated with proposed configurations for the MH-60K aircraft. For example, when advanced technology subsystems and automation options are proposed for the modified aircraft, new workload descriptions will be written for the affected mission tasks. Workload estimates for the new MH-60K tasks will then be generated by comparing the new descriptors of workload to the verbal anchors on the workload component scales previously described. Computer files containing the new estimates will be established and the model will be exercised to predict the impact that the proposed automation options are likely to have on pilot and/or copilot workload.

The impact of the automation options will be determined by using the four indices of workload described above. The estimates of workload generated by the model for the MH-60K configuration will then be compared with those produced by the UH-60 baseline model to identify instances in which proposed system modifications for the MH-60K aircraft are likely to increase or decrease operator workload. This information, in turn, will assist MH-60K system engineers in making decisions early in the system development process.

CONCLUSION

The workload prediction methodology developed by ARIARDA provides a systematic means for estimating the impact of the emerging MH-60K aircraft on crew workload in advance of system development. Consequently, the methodology will provide information to assist MH-60K engineers in making critical design decisions early in the system modification program. The model thus provides a valuable tool for making decisions so that costly changes later in the system development process [illegible] avoided.

In addition, the methodology provides information for identifying emerging manpower, personnel, and training requirements associated with the system modifications. By assisting in the identification of these requirements, the methodology provides a means for factoring total system costs into the system modification program during the early stages of development.

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