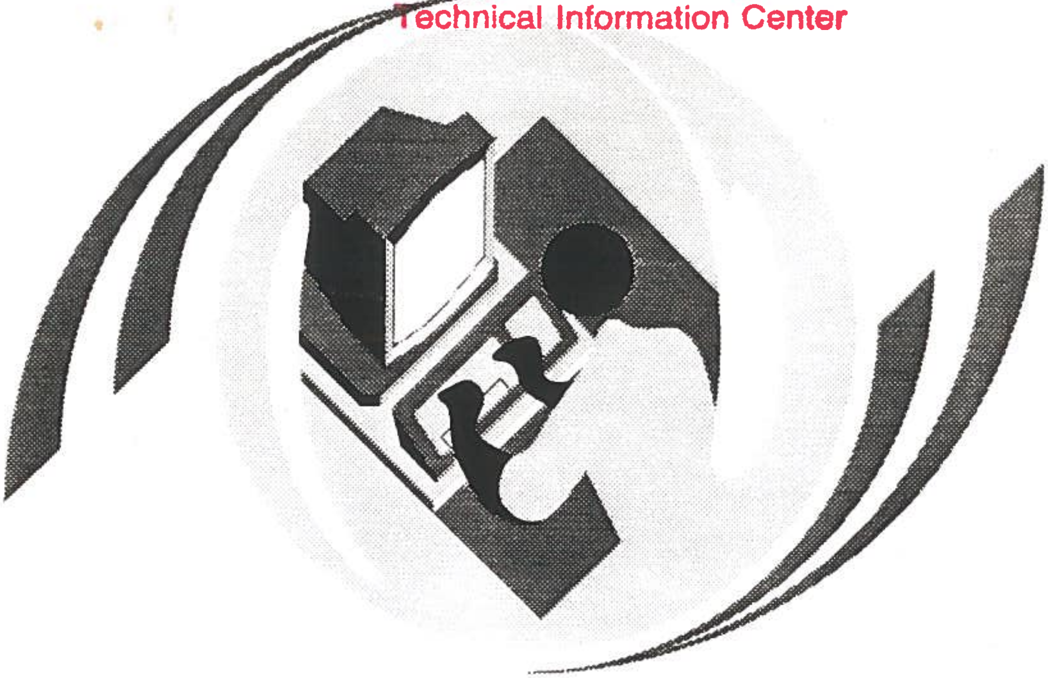

METHODOLOGY FOR CORRELATION OF ATC CONTROLLER WORKLOAD AND ERRORS

Phase II
Final Report

Contract DTRS-57-87-C-00107

Prepared for:

DOT SBIR Program Office, DTS-23
U.S. Department of Transportation
Transportation Systems Center
Kendall Square
Cambridge, Massachusetts 02142

November 3, 1989

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FINAL PROJECT SUMMARY REPORT

PROJECT IDENTIFICATION INFORMATION

1. BUSINESS FIRM AND ADDRESS:

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2. DOT PROGRAM:
SBIR - 1987 Phase II

3. DOT CONTRACT NUMBER:
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4. PERIOD OF PERFORMANCE
From: October 1, 1987 To: November 3, 1989

5. PROJECT TITLE:
Methodology for Correlation of Controller Workload and Errors

SUMMARY OF COMPLETED PROJECT

The purpose of the research and development conducted in Phase II was to provide the Federal Aviation Administration (FAA) with a valid method of evaluating design changes early in the system development life cycle. This method is embodied in PATCAM, the Predictive Air Traffic Control Analysis Model, the primary product of Phase II. PATCAM is an engineering tool for use in predicting the workload and performance of air traffic controllers in future transition states of the National Airspace System.

Phase II research and development activities focused on designing and implementing a powerful demonstration of PATCAM's capabilities. Research activities included model enhancement and validation, development of controller task networks, and construction of databases representing validated operational activities for two future NAS transition states: the Advanced Automation System (AAS) and an AAS enhancement, the Advanced En Route Air Traffic Control (AERA 2) environment. The Phase II research led to the introduction of a new construct, the mental interface, to represent important cognitive structures that have not been previously considered in analyses of controller workload and performance.

PATCAM permits the comparison of predicted demands on the controller and consequent controller performance, as a function of available skills and cognitive resources. Comparisons can be made on the basis of simulated "critical incidents," which appear in the comparable AAS and AERA 2 scenarios. Because the AAS and AERA 2 operations concepts have evolved beyond the baselines used for PATCAM development, results of the AAS and AERA 2 comparisons are presented for proof-of-concept purposes only. For example, results indicate that the simulated AERA 2 controller can deal with significantly more ATC situations than can the simulated AAS controller in the same amount of time, with no appreciable increase in task-induced demand.

Phase II has demonstrated the feasibility of developing a validated, predictive tool for evaluating the workload and performance effects of planned system capabilities. Further research is recommended to expand the tool's scope and usefulness in identifying potential trouble spots for correction prior to design and fabrication of increasingly automated air traffic control systems.

APPROVAL SIGNATURES

1. PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR *(typed)*
Elizabeth D. Murphy

2. PRINCIPAL INVESTIGATOR/ PROJECT DIRECTOR *(Signature)*
Elizabeth D. Murphy

3. DATE
11/2/89

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We are especially grateful to members of the air traffic controller teams who provided information needed to develop the PATCAM databases and to validate PATCAM output. Contributing teams included the Sector Suite Requirements Validation Team (SSRVT), the Systems Requirements Team (SRT), the Air Traffic AAS Test Team (ATATT), and the Air Traffic AERA Concepts Team (ATACT). Special thanks to former controllers, Gomer Jones and Wayne Tobey, for patiently and generously sharing their broad knowledge of air traffic control: past, present, and future.

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LIST OF ACRONYMS

A/O	And/or
AAS	Advanced Automation System
ABS	Absolute value
AERA 2	Advanced En Route Air Traffic Control
APR	Automated Problem Resolution
APREQ	Approval Request
ATACT	Air Traffic AERA Concepts Team
ATATT	Air Traffic ASS Test Team
ATC	Air Traffic Control
ATSME	ATACT Member Serving as SME
C	Calculated from lower-level values by application of computational procedures
CD	Condition Dependent; value linked to levels of situational variables
CMTP	Current Mental Traffic Picture
COTS	Commercial-off-the-shelf
CPM	Controller Performance Model
CWM	Controller Workload Model
DD	Data display
DMC	Decision Making Criteria
DOT	Department of Transportation
FAA	Federal Aviation Administration
FDE	Flight Data Entry
FSD	Future Situation Display
IM	Input Message
IS	Interface Specific; rated by SMEs
ISSS	Initial Sector Suite System

LIST OF ACRONYMS (Concluded)

MAPPS	Maintenance Personnel Performance Simulation
MAX	Maximize
MIN	Minimize
MM	Mental Model
NAS	National Airspace System
PATCAM	Predictive Air Traffic Control Analysis Model
PC	Personal Computer
PIREP	Pilot Report
PMTP	Projected Mental Traffic Picture
SBIR	Small Business Innovation Research
SDP	Software Development Plan
SME	Subject Matter Expert
SPSS	Statistical Package for the Social Sciences
SSRVT	Sector Suite Requirements Validation Team
SRT	Systems Requirements Team
SV	Simulation variable; value selected from an allowable range by the PATCAM user
SWP/C	Sector Workload Picture
TS	Task Specific; rated by SMEs
USI	User-System Interface
VORTAC	VHF Omni-directional Range Tactical Air Navigation System
VSCS	Voice Switching and Control System
W/L	Workload

SECTION 1 - INTRODUCTION

This final report documents the Phase II research activities, which produced PATCAM, the Predictive Air Traffic Control Analysis Model. In its current implementation, PATCAM is a proof-of-concept engineering tool designed to demonstrate a method for generating early estimates of the effects of system changes on controller workload and performance. The Phase II version of PATCAM includes task databases for two specific transition states of the future National Airspace System (NAS): the Advanced Automation System (AAS) and the Advanced En Route Air Traffic Control (AERA 2) system. These demonstration databases allow the PATCAM user to generate predictions of simulated AAS and AERA 2 controller workload and performance, for purposes of identifying areas of potential overloading or underloading of the controller's cognitive resources. The PATCAM tool is designed so that any defined system state can be analyzed in terms of controller workload and performance. As illustrated in Figure 1-1, research activities have included model development, AAS and AERA 2 task database enhancement, software development, and model validation.

1.1 RESEARCH AND DEVELOPMENT OBJECTIVES

The Phase II research and development focused on the following technical objectives:

- Development of an efficient capability to test the impact of design alternatives on controller workload and performance
- Generation and validation of realistic scenarios to represent controller activities in future ATC transition states

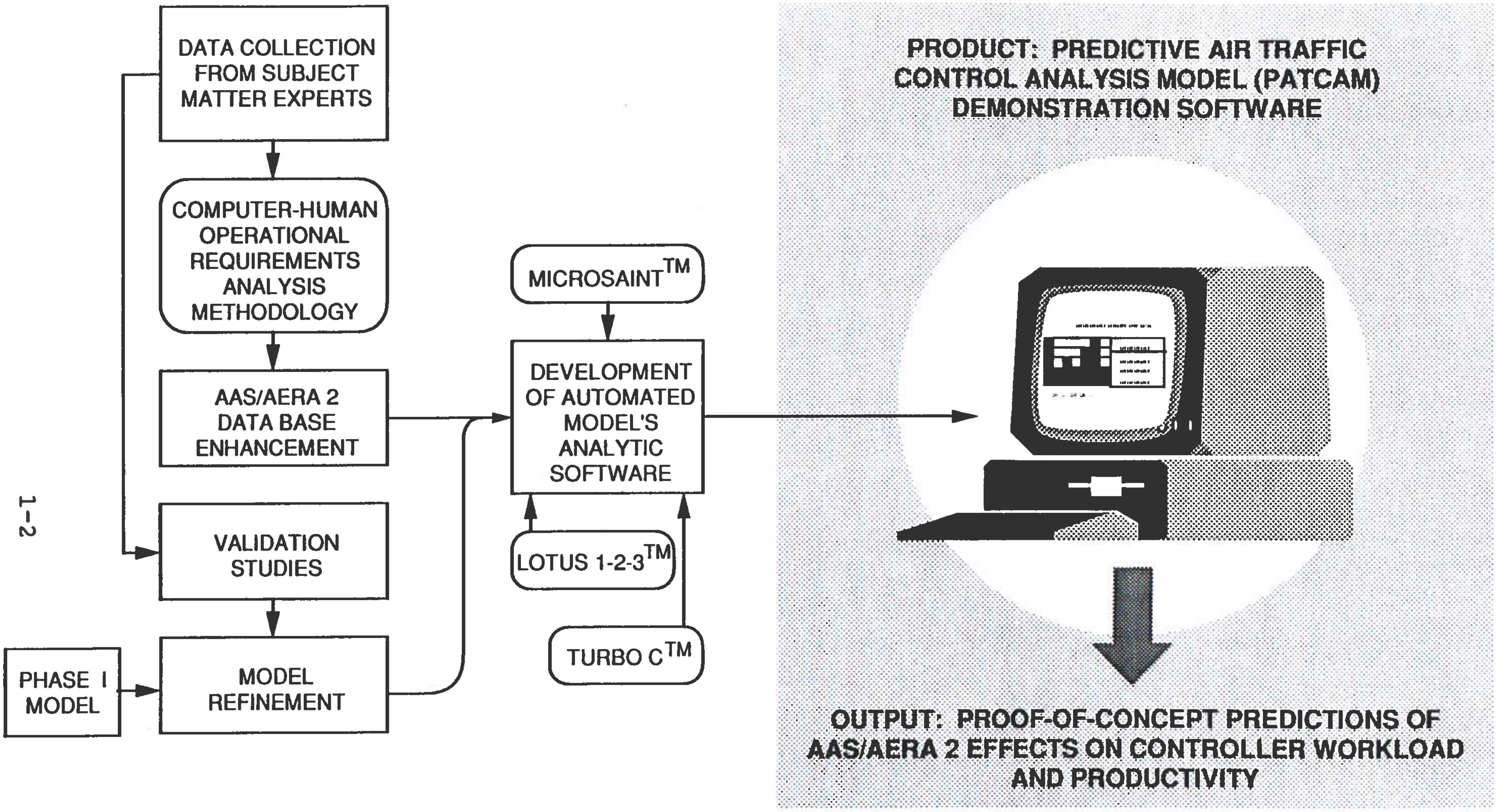

Figure 1-1. Overview of Phase II Research and Development

- Validation of the models of controller workload and performance

- Comparison of predicted controller workload and performance in selected transition states

Methods of achieving these objectives are detailed in the body of this report.

1.2 PROJECT SCOPE AND ASSUMPTIONS

The PATCAM concept encompasses a broad range of topics: controller workload and performance, predictive modeling, automation of predictive models, database development, and generation of valid, usable output. The Phase II research and development was designed to build a proof-of-concept version of PATCAM and to demonstrate its capabilities. For demonstration purposes, database development focused on the representation of sufficient AAS and AERA 2 task data to permit the comparison of controller workload and performance in critical air traffic control situations.

A general modeling premise was that actual or proposed system capabilities may affect controller workload and performance in ways that can be modeled adequately by representation of the relationships between selected variables. The following specific modeling assumptions permitted technical objectives to be met within available resources:

- ATC system capabilities are functioning normally.

- ATC staffing levels are adequate.

- Predictions are based on routine operations.

- The work environment meets human factors engineering requirements as specified by the FAA (1985).

- Personal factors not directly traceable to elements of system design are outside the scope of the analysis.

The Phase II proof-of-concept development has implemented the PATCAM concept within the boundaries established by these assumptions.

1.3 OVERVIEW OF DOCUMENT

The remainder of this report describes in detail the research and development carried out and the results obtained during Phase II. Section 2 focuses on development of the controller workload and performance models. Section 3 describes the process and results of work performed to enhance the AAS and the AERA 2 task databases. Section 4 summarizes the methods used and the products of software-development activities. Section 5 includes the results of the model-validation studies. Section 6 presents predictions of controller workload and performance in the model-based AAS and the AERA 2 environments. After discussing the relationship between workload and performance, Section 7 offers recommendations for further research and development of the PATCAM concept. Section 8 provides estimates of the feasibility of developing a full implementation of PATCAM. Finally, Section 9 lists the references cited in the text. Ten appendices of technical material provide further detail on the project's methods and products.

SECTION 2 - MODEL DEVELOPMENT

The starting point for Phase II research was the Controller Performance Model developed in Phase I (CTA, 1987). This model is represented in Figure 2-1. It was further elaborated in Phase II to permit the calculation of separate values for Controller Workload and Controller Performance. As a result, two sub-models evolved in Phase II: The Controller Workload Model (CWM) and the Controller Performance Model (CPM). The CWM hierarchy is shown in Figure 2-2, and the CPM hierarchy appears in Figure 2-3. Both sub-models retain the basic structural properties of the original model (i.e., a hierarchy of functional or operational levels characterized at each level by a set of attributes). This structure provides the basis for the bottom-up calculation of values for higher-level workload or performance attributes, depending on the active sub-model. Terms used in the CWM and the CPM are defined in the Glossary (Appendix A).

2.1 MODEL ENHANCEMENTS

The central enhancement to the modeling of controller workload and performance was the derivation of separate models, one for workload and another for performance. The Phase II CPM (Figure 2-3) begins with the CWM, introducing skill attributes at the CWM's task level. Above the task level, CPM attributes become performance attributes rather than demand attributes. Performance is understood as a function of the match between operational requirements (i. e., demands) and available skills, as that match is moderated by motivational aspects of the controller's job and by job-supported vigilance levels.

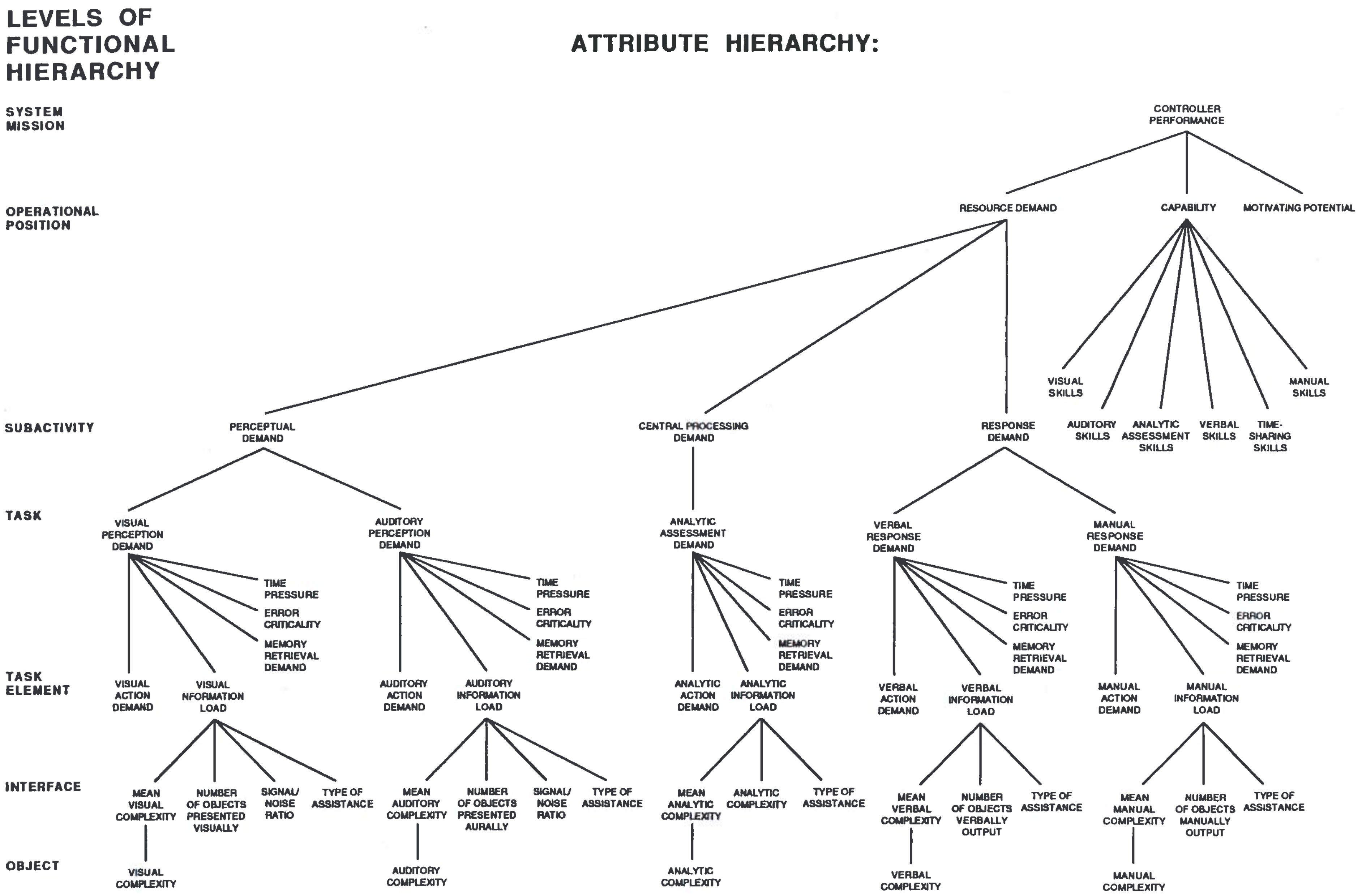

Figure 2-1. Phase I Controller Performance Model

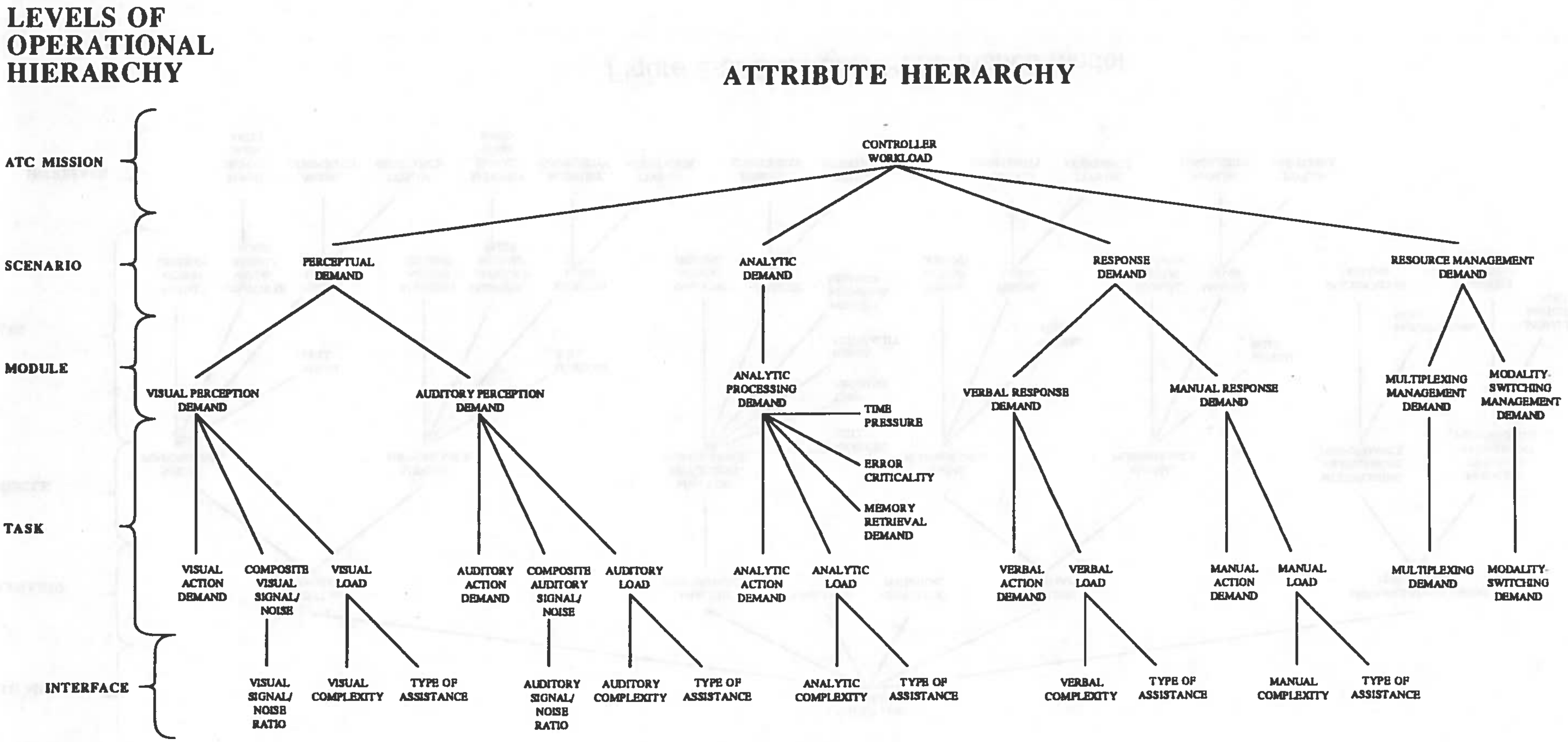

Figure 2-2. Controller Workload Model

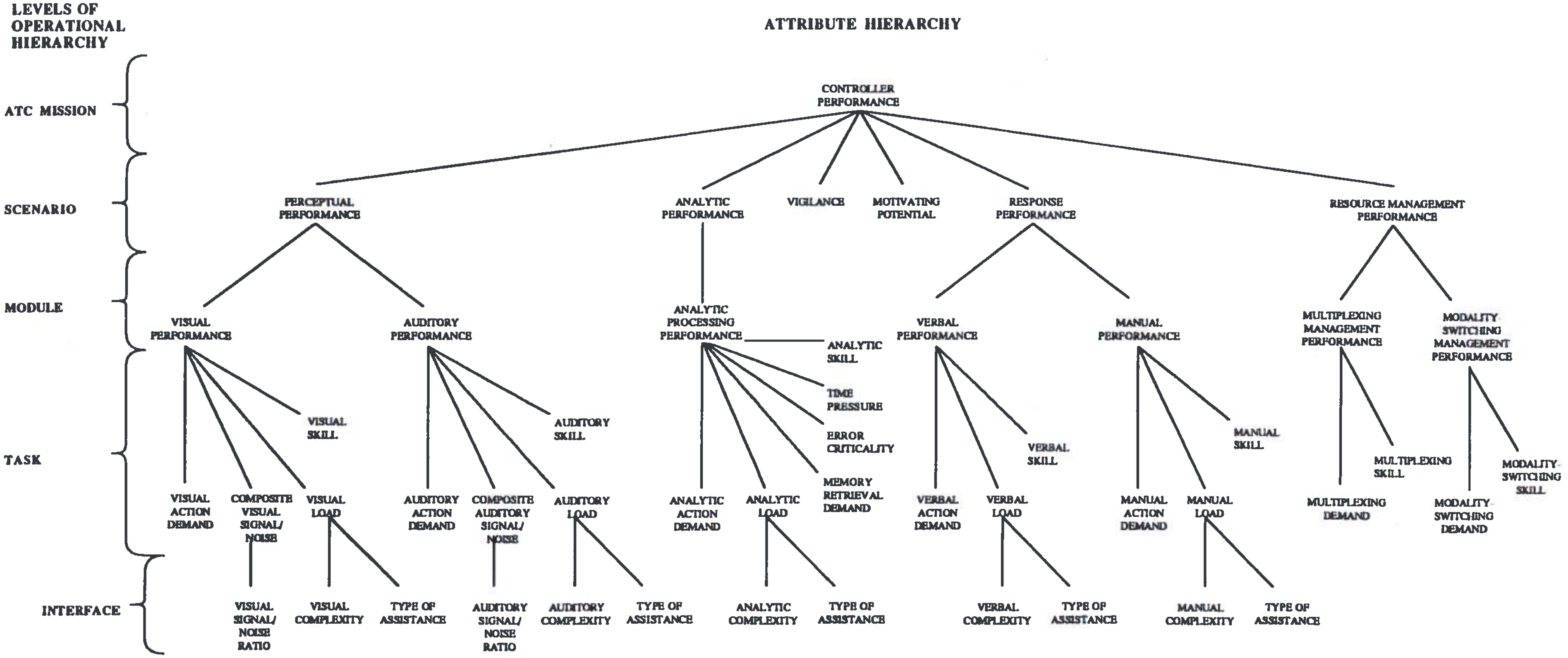

Figure 2-3. Controller Performance Model

2.1.1 Phase II Terminology

Some changes in terminology occurred in Phase II. For example, two levels of the functional/operational hierarchy were renamed to permit direct comparisons of predicted workload and performance for the AAS and AERA 2. The Operational Position level was renamed the Scenario level, and the Subactivity level was renamed the Module level. Scenarios are operationally realistic task sequences designed to illustrate the controller's routine in response to various air traffic control (ATC) events. Modules are sub-units of scenarios. For example, "Aircraft Enters Sector" and "Managing Personal Workload" are modules in both the AAS and the AERA 2 scenarios (Appendix B).

Use of Module and Scenario levels allows direct comparison of the AAS and AERA 2 not otherwise possible because of the variation in subactivity and activity naming and content between the AAS operations concept (FAA, 1988) and the AERA 2 operations concept (CTA, 1986). This variation is traceable to the different perspectives of the controller teams that developed the operations concepts. The direct comparability allowed by the module-and-scenario approach supports greater confidence in the comparisons than would be possible for comparisons between subactivities and activities.

2.1.2 Phase II Interface Level

In another enhancement to the modeling structure, the task element level and the object level have been integrated within the Interface level, where the focus is on each interface accessed by the controller. Each interface associated with a task represents a task element and contains the informational objects required for task performance. This enhancement serves to reduce PATCAM's personal-computer (PC) storage requirements, which were nearing saturation in attempting to implement the Phase I functional levels.

2.1.3 Mental Interfaces

The Phase II research extended the concept of "interface" to include not only the visual, auditory, and manual interfaces, but also the "mental interfaces" or cognitive models accessed by the controller. Each visual, auditory, and manual interface is made up of the related data objects grouped to logical displays or input message categories in the operations concepts (CTA, 1986; FAA, 1988). By analogy, mental interfaces are made up of cognitive structures, which are populated by data extracted from the ATC environment. For example, the controller's "picture" of the current traffic situation is a schematic knowledge structure representing the sector. It is populated by the data the controller requires for situational awareness (e.g., number of controlled aircraft; aircraft position, speed, altitude; weather conditions; existing conflict situations). This cognitive structure provides a situation-based context for decision making. Distortions in cognitive structures can be responsible for errors of perception, analysis, and decision making.

This research has hypothesized four mental interfaces, as defined in the Glossary (Appendix A):

- Current Mental Traffic Picture (CMTP)
- Projected Mental Traffic Picture (PMTP)
- Sector Workload Picture (SWP)
- Decision-making Criteria (DMC)

Inclusion of the mental interfaces allows the CWM and the CPM to model a greater proportion of the controller's mental activity than is possible from modeling only the cognitive activity associated with visual, auditory, analytic, verbal, and manual aspects of external interfaces. Since differences in performance can be traced to differences in cognitive models (Hahn, 1988; Woods, 1989), it is essential for models of controller workload and performance to include a means of representing mental workload and performance. A study to investigate the mental interfaces is documented in Section 5.

2.1.4 Phase II Attributes

Each interface is characterized by a set of attributes directly traceable to the object and interface attributes in the Phase I model. The set of Phase I attributes that represented numerical counts of objects presented or processed has been deleted to avoid redundancy with a software-based counting function that tracks the number of task occurrences. This frequency information is used in calculating the relative contribution of each task to its module, and so forth.

The action demand attributes now appear at the task level to capture the overall action demands of each task. Thus, action demands are rated on the basis of individual task verbs, rather than task element verbs. The effects of Time Pressure, Error Criticality, and Memory Retrieval Demand are now captured for each task in calculating Analytic Processing Demand. Since each task in the Phase II AAS and the AERA 2 databases is modeled as having a cognitive component, all tasks are affected by Time Pressure, Error Criticality, and Memory Retrieval Demand. Each of these attributes represents a source of error in performance. The effects of their interactions are modeled in the algorithms that permit estimation of Analytic Processing Demand for each task (Appendices C and D).

The following subsections present overviews of the Phase II models.

2.2 THE CONTROLLER WORKLOAD MODEL

As illustrated in Figure 2-2, the CWM represents demands imposed on the controller's cognitive resources, from the interface level to the mission level. The algorithms used to perform CWM calculations are provided in Appendix C.

2.2.1 Climbing the Demand Tree

Visual, auditory, analytic, verbal, and manual demands are gradually aggregated into demands on three resource pools at the scenario level: perceptual, analytic, and response pools. (See the Phase I final report, CTA, 1987b, for further information on the concept of resource pools and Multiple Resource Theory as developed by Wickens, 1984).

Task-level demands for timesharing (Multiplexing) and switching attention across resource pools (Modality-Switching) are gradually aggregated into Resource Management Demand at the scenario level. The algorithms provide for scenario-level demands to be combined, yielding a value for Controller Workload. The Phase II CWM can be exercised independently of the CPM to generate predictions of overall workload (i. e., operational demand) experienced by the simulated controller in the AAS and AERA 2 scenarios.

2.2.2 CWM Algorithms

The algorithms employed by the CWM permit the estimation of resource loadings on the basis of interface complexity ratings, situation-dependent demands, and the level of automated assistance provided to the controller. The relationships represented in the algorithms are based, to the extent possible, on research in workload assessment (e.g., Aldrich & Szabo, 1986; North, 1986; Stein, 1985), workload and performance modeling (e.g., CTA, 1987a; Lane, Streib, Glenn, & Wherry, 1981; Siegel, Bartter, Wolf, Knee, & Haas, 1984; Siegel & Wolf, 1969), and engineering psychology (e.g., Wickens, 1984). Other sources of expertise for development of the algorithms included research-team knowledge of the current and future air traffic control environment as well as experience in documenting operations concepts for the AAS and AERA 2. The relationships among the CWM algorithms are summarized in Figure C-2 (Appendix C).

The tree-climbing heuristic of taking the maximum value is based on similar modeling research in a satellite ground-control environment (CTA, 1987a). In that research, validation results indicated that a "highest-value" approach improved the match between model-based predictions and operators' direct ratings. An example of the "highest value" approach in the present research is represented in CWM algorithm S1 (Appendix C). In this case, inputs to the algorithm are the scenario-level values for Perceptual Demand, Analytic Demand, Response Demand, and Resource Management Demand. Suppose that those values were as follows on a five-point scale where 1 = Low and 5 = High:

- Perceptual Demand--Moderate-to-High (4)
- Analytic Demand--Moderate (3)
- Response Demand--Low-to-Moderate (2)
- Resource Management Demand--Moderate (3)

One approach to finding one value to represent controller demand at the scenario level would be to take the mean of those values (i.e., (4 + 3 + 2 + 3)/4 = 12/4 = 3). This procedure would yield a value of Moderate (3) for controller demand. Our working heuristic, however, says that overall demand should never be lower than the highest demand experienced for any one resource. If we accepted a value of 3 for controller demand, we would be accpting a value lower than the highest resource demand (i.e., 4 for Perceptual Demand). Our heuristic is based on the assumption that demand does not "average out" across resources.

Another approach considered in the earlier research was to make demand additive (i.e., to increase the highest demand on the basis of other demands). In the example, since High (5) is the limit of the scale, we would increase the highest demand of the contributing attributes (4 for Perceptual Demand) to a 5 for controller demand. However, previous work on validating a similar model found that this approach caused the model to overestimate workload in comparison to operators' direct ratings of workload. The approach settled on was to take the highest value of the contributing attribute values as representative of that set of values (CTA, 1987a). Thus, in our example, the PATCAM procedure is to take the highest value (4) as the value for Controller Workload at the scenario level.

Generation of predictions for controller performance is the function of Phase II's Controller Performance Model.

2.3 THE CONTROLLER PERFORMANCE MODEL

As illustrated in Figure 2-3, the CPM essentially represents the interplay between imposed demands and the skills available to meet those demands. Because performance involves more than a simple match of demand and skill, the

CPM includes other variables to represent the effects of alertness and motivational factors. These variables are named Motivating Potential (Hackman & Oldham, 1980) and Vigilance. The algorithms used to perform CPM calculations are provided in Appendix D.

2.3.1 Climbing the Performance Tree

The CPM begins by modeling interface-level demands in exactly the same way as they are modeled by the CWM. At the task level, CWM attributes are joined by the skill attributes for each performance category: visual, auditory, analytic, verbal, manual, multiplexing management, and modality switching. This matching of available skill with predicted operational demand produces values for the seven performance categories at the module level.

Visual and auditory performance are combined to yield a value for predicted Perceptual Peformance at the scenario level. In the same way, verbal and manual performance are combined to yield a value for predicted Response Performance at the scenario level. Similarly, Multiplexing-Management Performance and Modality-Switching Management Performance are combined to generate predicted Resource Management Performance at the scenario level. Analytic Performance is predicted directly, as a function of Analytic Processing Performance, for all the modules in a scenario. Results for these four resource-related categories of performance are moderated by the effects of the job's ability to support internal work motivation and by the effects of the controller's level of alertness, both of which are pre-set by the PATCAM user.

Finally, a value for predicted Controller Performance can be calculated for each scenario defined as contributing to a mission. The Phase II performance algorithms can be exercised independently of the workload algorithms to generate predictions of Controller Performance in the simulated AAS and AERA 2 environments. Predictions of Controller Performance are useful in assessing the human performance requirements of future NAS transition states.

2.3.2 CPM Algorithms

The algorithms employed by the CPM permit the estimation of performance levels on the basis of demand-skill matching and the moderating effects of job-related attentional and motivational factors. The relationships represented in the CPM algorithms are based on the literature in the area of performance shaping factors (e.g., Meister, 1985; Swain & Guttmann 1983), on Wickens' (1984) discussion of vigilance in process control, and on Hackman and Oldham's (1980) findings on the motivational effects of job characteristics, such as skill variety, task significance, and feedback from supervisors. The relationships among the CPM algorithms are summarized in Figure D-2 (Appendix D).

A working heuristic in the CPM is that performance is most conservatively represented by the lowest value when several attributes contribute to a higher-level attribute. For example, in CPM algorithm S1 (Appendix D), the lowest value of the four scenario-level attributes is taken as initially representing controller performance. Suppose that we have the following values for those attributes:

- Perceptual Performance--Moderate (3)
- Analytic Performance--Moderate-to-High (4)
- Response Performance--Low-to-Moderate (2)

- Resource Management Performance--Moderate (3)

Reasoning that the lowest performance cannot be "brought up" by higher performance on other resource-related attributes, we take the lowest value (2) as the initial value for controller performance.

We know, however, that performance can be affected by various other performance shaping factors, which may be internal or external to the individual (Meister, 1985). To represent the effects of these individual and environmental variables, we include IF...THEN...ELSE statements for controller alertness (Vigilance) and for external job characteristics (Motivating Potential). If vigilance is greater than or equal to Moderate-to-High (4), the initial value for controller performance is increased one level (from 2 to 3 in our example). If vigilance is less-than or equal to Low-to-Moderate (2), the initial value for controller performance is decreased one level (from 2 to 1 in our example). In a similar way, the effects of motivational factors are incorporated after vigilance effects have been factored in. Thus, if motivating potential is greater-than or equal to Moderate-to-High (4), the value for controller performance is increased one level (from 3 to 4, in our example, assuming that vigilance is 4). If motivating potential is less-than or equal to Low-to-Moderate (2), the value for controller performance is decreased by one (from 3 to 2, in our example, assuming that vigilance is 4). The algorithms are constructed to keep all results on the five-point scale: 1 = Low, 2 = Low-to-Moderate, 3 = Moderate, 4 = Moderate-to-High, and 5 = High.

Before it was possible to perform correlational studies to validate the relationships represented in the CWM and the

CPM, it was necessary to develop PATCAM databases for the AAS and AERA 2 and to develop an automated approach to performing the PATCAM calculations.

SECTION 3 - TASK DATABASE ENHANCEMENT

This research developed two proof-of-concept databases for investigation of potential workload and performance effects. These databases represent the AAS and AERA 2 environments for application of PATCAM's algorithms. The contents of each database are linked directly to the operations concepts for these future NAS transition states. Some data required by PATCAM were developed by this research, extending the operations concepts where necessary. The resulting databases provide the PATCAM user with the ability to take a "critical incident" approach to comparing projected AAS and AERA 2 workload and performance.

3.1 OPERATIONS CONCEPT DEVELOPMENT

Previous work performed by CTA for the FAA has produced extensive documentation of operations concepts for the AAS and AERA 2. In this context, an operations concept is a description of the operational interaction between the air traffic controller and the automated AAS/AERA 2 capabilities. An operations concept represents the air traffic controllor's role in the overall human-computer ATC system.

Development of the AAS and AERA 2 operations concepts occurred with the cooperation of two controller teams: the Sector Suite Requirements Validation Team (SSRVT) for the AAS, and the Air Traffic AERA Concepts Team (ATACT) for AERA 2. The operations concept development methodology is described in detail by Lenorovitz and Phillips (1987). The process involves iterative review and discussion until the controller team is satisfied that the controller's role in a future system phase has been understood and represented to the extent possible working from current knowledge of that phase.

The full AAS operations concept includes 428 tasks and from two to nine task elements (subtasks) per task (FAA, 1988). The AERA 2 operations concept defined 66 new tasks for the controller (CTA, 1986). In both documents, tasks are further characterized in terms of information requirements, including the logical displays the controller is expected to access in performing each task. These operations concepts have been validated as operationally accurate by their respective controller teams.

3.2 PATCAM's AAS TASK DATABASE

The database representing the AAS controller's tasks is based on the July, 1988 version of the AAS operations concept (FAA, 1988). PATCAM's AAS task database contains 84 unique tasks, their associated interfaces as derived from the task element statements, and nodes for interface and task attribute values. Simulation parameters can be adjusted by the PATCAM user for purposes of asking "what if" questions. (For further detail, see the description of simulation parameters in the User's Guide, Appendix E).

The tasks that reside in PATCAM's AAS task database are those used in the AAS monitoring macro and scenarios (Appendix B). Estimation of most attribute and weighting factor values for these tasks relied on ratings documented in the AAS operations concept and on further data collection.

3.2.1 AAS Scenario Development

The AAS monitoring macro and scenarios are based on operational scenarios developed and validated by the SSRVT

(FAA, 1987). These scenarios were tailored to facilitate a comparison between controller workload and performance in the AAS and AERA 2 environments. The scenarios focus on critical ATC situations, such as aircraft-to-aircraft conflicts and aircraft-to-airspace conflicts. A premise of the modeling methodology is that these situations will be handled differently by the AAS and AERA 2 controllers as a function of the available system capabilities.

The tailored scenarios were presented to the SSRVT at a team meeting. Changes suggested by the team were incorporated into the final set of scenarios (Appendix B). Estimates of AAS task durations were also provided by the SSRVT. These estimates of duration are documented in the left-most column of each scenario page. They were used as input to PATCAM's task-network simulation and as a basis for time-derived weighting factors.

3.2.2 Estimation of Attribute and Weighting Factor Values

Lower-level attribute ratings provide input to PATCAM's computational procedures. Lower-level ratings are traced to the following sources:

- Documented values in the AAS operations concept
- Values collected from AAS subject-matter experts (SMEs)
- Situation-dependent values
- Simulation parameters set by the PATCAM user

All ratings and values occur along the five-point scale.

3.2.2.1 <u>Values from the AAS Operations Concept</u>

The AAS operations concept provided ratings for task criticality and frequency (FAA, 1988). Task criticality ratings were mapped to the five-point scale to determine values for Error Criticality. The inverse of a task's frequency provided a value for its Memory Retrieval Demand, on the five-point scale. The heuristic employed holds that tasks performed more frequently than others will exert a lower retrieval demand because the knowledge to be retrieved will be more readily accessible as a function of frequent use (Bainbridge, 1987; Card, Moran, & Newell, 1986). Tasks performed less frequently will impose a greater retrieval demand because the knowledge to be retrieved will be subject to greater interference between cognitive units in long-term memory (Martindale, 1981).

A correlational study of the relationship between Error Criticality and Memory Retrieval Demand found a significant negative correlation ($r = -.41$, two-tailed $p \leq .001$). The means and standard deviations were as follows ($N = 71$):

	Mean	Standard Deviation
Memory Retrieval Demand	3.2535	1.9692
Error Criticality	3.1831	1.3764

The correlational findings indicate that Error Criticality decreases as Memory Retrieval Demand increases, and vice versa. This is an encouraging finding in that high Memory Retrieval Demand is associated with low Error Criticality. Thus, tasks with high demands for retrieval of information from long-term memory are typically lower in criticality than are tasks with low retrieval demands.

Tasks with high demands for retrieval of information from long-term memory are candidates for automated memory aiding in the form of on-line checklists for procedures and other complex sets of information. Tasks in PATCAM's databases that are associated with high Memory Retrieval Demand are starred (**) in Appendix B; tasks high in Error Criticality are marked with a plus sign (+) in Appendix B. Other AAS tasks that are high in Memory Retrieval Demand can be identified as those with low frequency in Appendix E, Task Element Report, of the AAS operations concept (FAA, 1988), Volume II.

Both Error Criticality and Memory Retrieval Demand can be considered stressors representing sources of error in human performance (Finkelman & Kirschner, 1980; Eason, 1987; Kinney, 1977; Meister, 1985; Office of Aviation Medicine, 1986; Woodson, 1981). Methods for reducing and ameliorating errors and their consequences in highly complex systems are discussed by numerous researchers (e.g., Reason, 1986; Swain, 1973; Weiner, 1989; Woods, 1985). Reduction of task demands may be necessary for tasks that are moderately high or high in imposed demand. Although a consistently moderate level of demand is necessary to maintain controller alertness, demand levels that remain consistently above moderate for more than a few minutes are likely to lead to degradation of performance (Bikson, 1987; Hancock & Chignell, 1988). Conversely, tasks that are below moderate in imposed demand are likely to underload the controller's highly trained resources, leading to "capture" of the controller's attention by irrelevant stimuli in the operational environment (Empson, 1987; Reason, 1979).

3.2.2.2 Subject-matter-expert Ratings

Ratings of the interface complexity attributes and of the task action demand attributes were collected from five AAS subject-matter experts. A sample of the data collection package is provided in Appendix F. A correlational analysis of interrater agreement on Visual Complexity yielded the results presented in Table 3-1 (a). Four SMEs showed good agreement with at least one other SME on the visual complexity of AAS interfaces (for raters one and two, $r = .49$, $p \leq .01$; for raters one and three, $r = .69$, $p \leq .001$; for raters two and three, $r = .49$, $p \leq .01$; for raters one and five, $r = .39$, $p \leq .05$). As indicated in Table 3-1 (b), all raters showed good-to-strong agreement with at least one other rater on the analytic complexity of AAS interfaces.

It was not possible to calculate interrater correlations for Auditory Interface Complexity or for Verbal Interface Complexity because of the small number of interfaces in those categories and because some raters did not rate all the auditory or verbal interfaces. Table 3-2 provides the data collected from raters for the auditory and verbal interfaces. Inspection of this data indicates agreement between raters one through three for the low auditory complexity of the Alert and Resolution Display and agreement between raters two and three on the high auditory complexity of the Voice Switching and Control System (VSCS) interface. Similarly, raters one through three agreed on the high verbal complexity of the VSCS interface, with rater four giving only a slightly lower rating. There was no significant agreement between raters on Manual Interface Complexity, which may be highly design dependent.

Inspection of raters' standard deviations on visual and analytic interface complexities indicates that raters one, two, three, and five used a larger scale range than did rater four (Table 3-3, a and b). In rating manual complexity, however, all raters used a similar range of the five-point scale (Table 3-3, c). Close similarities in

Table 3-1. Interrater Agreement on Selected Complexity Dimensions of AAS Interfaces: a) Visual Complexity; and b) Analytic Complexity

a) Interrater Correlations for the Visual Complexity of AAS Interfaces (N=37)

	SME$_1$	SME$_2$	SME$_3$	SME$_4$	SME$_5$
SME$_1$	1.0000				
SME$_2$	.4906**	1.0000			
SME$_3$	.6907***	.4924**	1.0000		
SME$_4$	.0887	.1109	.1879	1.0000	
SME$_5$	.3856*	.3048	.3534*	.1270	1.0000

b) Interrater Correlations for the Analytic Complexity of AAS Interfaces (N=39)

	SME$_1$	SME$_2$	SME$_3$	SME$_4$	SME$_5$
SME$_1$	1.0000				
SME$_2$	.5964***	1.0000			
SME$_3$	.7253***	.6259***	1.0000		
SME$_4$	.1428	.1651	.2981	1.0000	
SME$_5$	.5199***	.3717*	.5917***	.5825***	1.0000

2-Tailed Significance:

*	$p \leq .05$
**	$p \leq .01$
***	$p \leq .001$

Table 3-2. Ratings by AAS SMEs for the Complexities of Auditory and Verbal Interfaces

	Auditory Complexity					Verbal Complexity				
Interface	SME$_1$	SME$_2$	SME$_3$	SME$_4$	SME$_5$	SME$_1$	SME$_2$	SME$_3$	SME$_4$	SME$_5$
(1)	L	L	—	M-H	M-H					
(8)	L	L	L	M-H	L-M					
(9)	—	L	—	M-H	L-M					
(42)	L	H	H	M-H	—	H	H	H	M-H	—

(1)	AERA Alert Display
(8)	Alert & Resolution Display
(9)	Alert & Resolution Display Manipulation
(42)	Voice Switching and Control System (VSCS) Display

L	Low
L-M	Low-to-Moderate
M	Moderate
M-H	Moderate-to-High
H	High

Table 3-3. Means and Standard Deviations of AAS Interface Ratings for a) Visual Complexity; b) Analytical Complexity; and c) Manual Complexity

	(a) Visual Complexity (N=37)		(b) Analytic Complexity (N=39)		(c) Manual Complexity (N=23)	
Raters	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
SME$_1$	2.7027	1.1514	3.3333	1.1082	2.4783	.6653
SME$_2$	1.9459	1.0527	2.3590	1.2873	1.3478	.8847
SME$_3$	2.2973	1.3716	2.8974	1.3533	1.9130	.7928
SME$_4$	3.2973	.6176	3.5128	.7208	3.3043	.6350
SME$_5$	2.0270	.9570	2.3333	.8983	2.1304	.5481

standard deviations indicate the extent of homogeneity between raters.

Task action verbs are the verbs that begin each of the AAS and AERA 2 task statements (e.g., Receive, Enter, Evaluate, Formulate). Task verb meanings are defined in Appendix C, Task Verbs, of FAA (1988), Volume 1. Task action demands refer to the workload imposed by the verb's physical or mental action, apart from the object acted upon (e.g., the effort involved in receiving, entering, evaluating, or formulating). Subject-matter experts used the five-point scale to rate five kinds of action demand: visual, auditory, analytic, verbal, and manual.

Interrater agreement on the task action demands was good for some pairs of raters on visual action demand, analytic action demand, verbal action demand, and manual action demand (Table 3-4). All raters tended to use the same range of the scale, as indicated by results for standard deviations (Table 3-5). There was no significant agreement between raters on Auditory Action Demand.

3.2.2.3 Situation-dependent Values

Values for Time Pressure depend directly on the levels of situational variables in the simulated ATC environment. As indicated in the CWM and CPM specifications for Time Pressure (Appendices C and D), the salient situational variables are number of aircraft, number of conflicts, and number of special use airspace/weather elements. Thus, values for Time Pressure increase or decrease as a function of increases or decreases in the levels of these variables in the PATCAM simulation of ATC operations.

Table 3-4. Interrater Agreement on Four Categories of Task Action Demand: a) Visual Action Demand; b) Analytic Action Demand; c) Verbal Action Demand; and d) Manual Action Demand

a) Interrater correlations for the Visual Action Demand of "visual" verbs used to define AAS tasks (N=9)

	SME$_1$	SME$_2$	SME$_3$	SME$_4$	SME$_5$
SME$_1$	1.0000				
SME$_2$	.4505	1.0000			
SME$_3$	.1251	.4966	1.0000		
SME$_4$	-.1125	.4183	.9363***	1.0000	
SME$_5$	.6201	.7319*	.7167*	.6124	1.0000

b) Interrater Correlations for the Analytic Action Demand of "analytic" verbs used to define AAS tasks (N=11)

	SME$_1$	SME$_2$	SME$_3$	SME$_4$	SME$_5$
SME$_1$	1.0000				
SME$_2$	.6818*	1.0000			
SME$_3$	.3721	.7181*	1.0000		
SME$_4$	.2751	.7111*	.7328*	1.0000	
SME$_5$	.0793	.2732	.5271	.4308	1.0000

2-Tailed Significance:

*	$p \leq .05$
**	$p \leq .01$
***	$p \leq .001$

Table 3-4. Interrater Agreement on Four Categories of
Task Action Demand: a) Visual Action Demand; b) Analytic Action Demand;
c) Verbal Action Demand; and d) Manual Action Demand (Concluded)

c) Interrater correlations for the Verbal Action Demand of "verbal" verbs used to define AAS tasks (N=25)

	SME$_1$	SME$_2$	SME$_3$	SME$_4$	SME$_5$
SME$_1$	1.0000				
SME$_2$	.4488*	1.0000			
SME$_3$	.4537*	.7534***	1.0000		
SME$_4$	.3454	.1889	.2526	1.0000	
SME$_5$	.4601*	.7667***	.7241***	.1823	1.0000

d) Interrater correlations for the Manual Action Demand of "manual" verbs used to define AAS tasks (N=42)

	SME$_1$	SME$_2$	SME$_3$	SME$_4$	SME$_5$
SME$_1$	1.0000				
SME$_2$	-.1673	1.0000			
SME$_3$	-.0114	.0324	1.0000		
SME$_4$	-.1346	.6485***	.0439	1.0000	
SME$_5$	-.0456	-.0708	.3627*	.0237	1.0000

2-Tailed Significance:

*	$p \leq .05$
**	$p \leq .01$
***	$p \leq .001$

Table 3-5. Means and Standard Deviations of AAS Task Action Verb Ratings for a) Visual Action Demand; b) Analytic Action Demand; c) Verbal Action Demand; and d) Manual Action Demand.

	(a) Visual Action Demand (N=9)		(b) Analytic Action Demand (N=11)		(c) Verbal Action Demand (N=25)		(d) Manual Action Demand (N=42)	
Raters	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
SME_1	2.7778	1.4814	3.2727	1.1037	3.3200	1.3454	2.7857	1.3350
SME_2	3.2222	1.3944	3.8182	1.4013	2.6000	1.1180	2.3810	.9358
SME_3	3.5556	1.4240	3.1818	1.3280	3.0400	1.2069	2.5000	.8040
SME_4	3.0000	1.5000	2.8182	1.1677	2.3600	.9074	2.2619	1.0373
SME_5	3.0000	1.2247	4.0909	.8312	2.9600	1.0985	3.4048	.5437

Multiplexing Demand and Modality-Switching Demand are task-level attributes whose values are linked to those of other task-level values. The value for Multiplexing Demand depends on the number of interfaces the controller must access while performing a task (Appendices C and D). Since timesharing or multiplexing is conceptualized as occurring within a task, the number of interfaces per task indicates the extent to which the controller's attention must be timeshared or multiplexed for that task. Because the occurrence of a task is situation-dependent, the level of Multiplexing Demand is also situation-dependent.

Modality-switching is included in the CWM and the CPM to capture the sequential switching of resource allocation as a function of demand. Modality-switching is tied to the number of individual resource pools and the number of major resource pools involved in task performance (Appendices C and D). Individual resource pools are tapped according to the types of interfaces the controller must access per task: visual, auditory, analytic (mental), verbal, and/or manual. Major resource pools are perceptual (visual + auditory), analytic, and response-related (verbal + manual). Again, since task occurrence is situation-dependent, the level of Modality-Switching Demand is situation-dependent.

3.2.2.4 Simulation Parameters

Parameter values are set by the PATCAM user for one workload and performance attribute, Type of Assistance. This attribute represents the level of automated aiding available to the controller. The following scale guides the user's selection of a setting for this attribute:

- Low (1) - Low-resolution display of ATC situation; simple projective aids; short-term conflict alerting; no requirement for automation of flight data information or estimation of sector workload factors.

- Low-to-Moderate (2) - Higher-resolution display technology; color used selectively for highlighting; automation of flight data information and flight data entry notations is required.
- Moderate (3) - Requirements include advanced projective capabilities; extended conflict alerting; tools to assist the controller in constructing trial flight plans; messages to remind the controller of actions to be taken; estimation of selected current and future sector workload factors.
- Moderate-to-High (4) - Requirements include automated conflict resolution; automated coordination; advanced graphical projection of expected traffic and potential conflicts; extension of previously automated capabilities (e.g., automated reassessment of controller-entered trial plans for their current feasibility; predicted nonconformance).
- High (5) - Requirements include fully automated, high-altitude, en route ATC; automated ground-to-air communication.

Simulation parameters set by the PATCAM user for generation of performance predictions include the skill attributes, Vigilance, and Motivating Potential. The user selects values along the five-point scale for each of these attributes. Definitions of scale values for these attributes appear in Appendix G.

3.3 PATCAM'S AERA 2 TASK DATABASE

The AERA 2 capabilities will provide automated aiding for some aspects of problem solving and decision making that will be performed by the AAS controller without machine aiding. For purposes of comparing estimated AAS and AERA 2 workload and performance, it was necessary to represent the following system changes, which are associated with AERA 2:

- Computer-generated resolutions to predicted problems between flight plans, flight plans and flow restrictions, and flight plans and airspace restrictions
- Automated Coordination between sector controllers and between sector controllers and the Traffic Management Coordinator
- Automated notification to the controller that a previously requested pilot-preferred route is now available
- Graphical display of predicted traffic patterns and of predicted sector workload factors

PATCAM's AERA 2 task database is designed, accordingly, to permit assessment of the potential workload and performance effects of these system changes.

The 27 unique tasks that reside in PATCAM's AERA 2 task database are those used in the AERA 2 monitoring macro and scenarios (Appendix B). Estimates of attribute and weighting factor values for these tasks were provided by ATACT team members and by other AERA 2 subject-matter experts.

3.3.1 AERA 2 Scenario Development

The AERA 2 monitoring macro and scenarios represent transformations of the AAS monitoring macro and scenarios. The same situations or modules occur in the same order in both sets of scenarios. In the AERA 2 scenarios, however, the simulated controller makes use of the AERA 2 capabilities and performs tasks defined in the AERA 2 Operations Concept (CTA, 1986). The transformed macro and scenarios have been developed and reviewed by in-house AERA 2 subject-matter experts.

Both the AAS operations concept amd the AERA 2 operations concept have undergone further development during the course of this project. Thus, the current PATCAM scenarios represent "slices in time" or "freeze frames." Both sets of scenarios would need to be updated on the basis of further developments in the concepts of the AAS and the AERA 2 controller's role before any firm conclusions could be drawn about relative workload and performance. Therefore, the current PATCAM scenarios shall be used for demonstration purposes only.

3.3.2 Extension of the AERA 2 Functional Hierarchy

Although the ATACT-validated operations concept for AERA 2 stops at the task level, interfaces associated with each task are identified in the Dialogue Description summary (Table 4-1, CTA, 1986). From this information, consulted in conjunction with the ATACT-validated system-level specification for AERA 2 (MITRE, 1986), it was possible to develop "strawman" task elements for the AERA 2 tasks in PATCAM's task database. This set of task elements is presented in Appendix H.

The structure of the task elements for an AERA 2 task was modeled on the structure of task elements for comparable AAS tasks, as documented in FAA (1988), Volume II, Task Element Report. For example, a "REQUEST" task in AAS is decomposed into task elements according to a certain set of task element verbs: INITIATE, EXECUTE, DETECT. Decomposition of AERA 2 tasks into task elements was guided by this previously-validated task-to-task-element structure. The "strawman" task elements were developed and reviewed by in-house AERA 2 subject-matter experts.

The process of developing AERA 2 task elements contributed to this project's identification of AERA 2 task interfaces. The task-to-interface links represent the task elements for purposes of a PATCAM analysis of predicted workload and performance.

3.3.3 Estimation of Attribute and Weighting Factor Values

Lower-level attribute ratings for input to PATCAM's algorithms are traceable to several sources:

- Values collected from ATACT team members and other AERA 2 subject-matter experts
- Situation-dependent values
- Simulation parameters set by the PATCAM user

These values provide the basis for PATCAM's predictions of workload and performance in the simulated AERA 2 environment.

3.3.3.1 Values Collected from AERA 2 SMEs

During the process of developing the AERA 2 operations concept, ATACT team members were asked to rate the AERA 2 tasks for duration, frequency, and criticality. Although the mean frequencies are essentially identical for four of the five raters (Table 3-6), significant interrater correlations were found only for raters two and four ($r = .47$, $p \leq .05$) and for raters three and five ($r = .48$, $p \leq .05$). The present research mapped mean frequency ratings to the five-point scale for purposes of determining values for Memory Retrieval Demand. Mean duration ratings were used to determine values for AERA 2 task durations. Since ATACT team members agreed that all AERA 2 tasks should be considered highly critical, all AERA 2 tasks in the database were rated "High" on Error Criticality.

Ratings of AERA 2 interface complexities were provided by three, in-house AERA 2 subject-matter experts. A

Table 3-6. Estimated Frequency of Performing AERA 2 Tasks. (N=25)

Raters	Mean	Std. Dev.
$ATSME_1$	4.5600	.5831
$ATSME_2$	4.8800	.6000
$ATSME_3$	4.6000	.5000
$ATSME_4$	4.8400	.3742
$ATSME_5$	3.2800	1.3699

Note: ATSME = ATACT Member Serving as SME.

Table 3-7. Interrater Agreement on Selected Complexity Dimensions of AERA 2 Interfaces: a) Visual Complexity; b) Analytic Complexity; c) Auditory Complexity; and d) Manual Complexity

a) Interrater Correlations for the Visual Complexity of AERA 2 Interfaces (N=23)

	SME_{A1}	SME_{A2}	SME_{A3}
SME_{A1}	1.0000		
SME_{A2}	.3029	1.0000	
SME_{A3}	.2247	.5026**	1.0000

b) Interrater Correlations for the Analytic Complexity of AERA 2 Interfaces (N=27)

	SME_{A1}	SME_{A2}	SME_{A3}
SME_{A1}	1.0000		
SME_{A2}	.3445*	1.0000	
SME_{A3}	.6031***	.5992***	1.0000

c) Interrater Correlations for the Auditory Complexity of AERA 2 Interfaces (N=3)

	SME_{A1}	SME_{A2}	SME_{A3}
SME_{A1}	1.0000		
SME_{A2}	.7559	1.0000	
SME_{A3}	1.0000**	.7559	1.0000

d) Interrater Correlations for the Manual Complexity of AERA 2 Interfaces (N=11)

	SME_{A1}	SME_{A2}	SME_{A3}
SME_{A1}	1.0000		
SME_{A2}	.1416	1.0000	
SME_{A3}	.7518**	-.0667	1.0000

2-Tailed significance:

*	$p \leq .05$
**	$p \leq .01$
***	$p \leq .001$

Table 3-8. Means and Standard Deviations of AERA 2 Interface Ratings for a) Visual Complexity; b) Analytic Complexity; c) Auditory Complexity; and d) Manual Complexity

	(a) Visual Complexity (N=23)		(b) Analytic Complexity (N=27)		(c) Auditory Complexity (N=3)		(d) Manual Complexity (N=11)	
Raters	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
SME_{A1}	3.0870	1.4433	3.4815	1.4243	2.0000	1.7321	3.0909	1.5136
SME_{A2}	2.3043	1.1846	3.1111	1.2195	2.6667	1.5275	2.2727	1.2721
SME_{A3}	2.6957	.9261	2.6667	1.0000	2.3333	2.3094	2.3636	1.2863

correlational analysis of their ratings found significant agreement on several complexity dimensions, as illustrated in Table 3-7. Inspection of standard deviations (Table 3-8) indicates that the AERA 2 raters generally used a similar range of the five-point scale.

3.3.3.2 Situation-dependent Values

Situation-dependent attributes are the same as those for the AAS task database: Time Pressure, Multiplexing Demand, and Modality-Switching Demand. Situational variables are the same: number of aircraft, number of conflicts, and number of special use airspace/weather elements. The same initial settings for these situational variables were used as a basis for comparing AAS and AERA 2 predictions. In this way, the situation remained constant, while the capabilities available to the controller changed.

3.3.3.3 Simulation Parameters

Simulation parameters set by the PATCAM user are the same for the AERA 2 simulations as for the AAS simulations: Type of Assistance, the skill attributes, Vigilance, and Motivating Potential.

3.4 CRITICAL-INCIDENT COMPARISONS

Both the AAS and AERA 2 scenarios focus on critical incidents, i.e., situations that are crucial to accomplishment of the controller's mission, the safe and expeditious flow of air traffic through the sector. Critical incidents, which can occur during routine operations, include aircraft-to-aircraft conflicts, aircraft-to-airspace conflicts, and nonconformance situations. The question of interest is to what extent the AERA 2 capabilities will reduce controller workload and improve controller performance in handling such critical incidents.

The enhanced task databases developed during Phase II permit the comparison of workload and performance in the simulated AAS and AERA 2 environments in terms of critical incidents. Because the calculations involved are extremely time consuming to perform by hand, it was necessary to design and implement an integrated software tool to automate the workload and performance models prior to making the comparisons.

SECTION 4 - SOFTWARE-TOOL DEVELOPMENT

Software development activities focused on automating the controller workload and performance models. The goal of these activities was to demonstrate the feasibility of providing the FAA with an efficient and flexible tool for use in estimating the human workload and performance effects of system changes. Development activities were allocated to five phases: planning, requirements analysis, design, coding, and integration/test.

4.1 SOFTWARE PLANNING

This phase of software development produced a software development plan (SDP), which defined and guided the engineering and management of the implementation activities. The SDP followed a format based on standard formats for software development plans (e.g., Department of Defense, 1985). The following topics were addressed by the SDP:

- SCOPE
- APPLICABLE DOCUMENTS
- RESOURCES AND ORGANIZATION
- DEVELOPMENT SCHEDULE AND MILESTONES
- SOFTWARE DEVELOPMENT PROCEDURES

The SDP included a chart showing the allocation of PATCAM functionality to software builds (Table 4-1). This chart guided development activities leading up to each of the demonstrations of increasingly complex software capabilities.

The SDP was updated periodically to reflect current status and remaining work.

Table 4-1. Allocation of PATCAM Functionality to Software Builds

CAPABILITY	BUILD		
A. USER-SYSTEM INTERFACE	1	2	3
1. Introductory Display	●		
2. Home Menu	●		
3. Select/Load Task Networks			
Monitoring Macro	●		
2 AAS Scenarios		1	●
AERA 2 Scenarios			●
Loading Message		●	
4. Select/Load Situational Parameters			
Load/Edit/Create	●		
High/Medium/Low Defaults	●		
Specify Sector/Assistance Parameters			●
Specify Controller/Job Attributes			●
Name Controller Attributes File			●
5. Select Report Parameters			
Default Parameters	●		
Predefined (User) Parameter Sets			●
Simulation Parameters			●
Simulation Processing Message	●		
Name Output File	●		
Report Level	C	●	
Statistical Information	C	●	
6. Reporting of Results			
Select/Load Results File	●		
Summary of Parameters Used	●		
Workload Tables		●	
Workload Graphics		●	
Performance Tables			●
Performance Graphics			●
Attribute Statistics	●		
Simulation Log	●		
Simulation Log Statistics		●	
B. FUNCTIONALITY			
1. CPM/CWM Algorithms			
Proof of Concept for Lateral & Vertical	●		
CWM to Task Level	●		
Complete CWM per Revisions		●	
CPM			●
2. Analysis			
Report Results of Tree	●		
Attribute Statistics Report	●		
Simulation Log	●		
3. User-System Interface (USI)			
Re-baseline USI (Port to C)		●	
File Conversion and Parsing		●	
Tabular Hardcopy Capabilities			●

c = canned

4.2 SOFTWARE REQUIREMENTS ANALYSIS

The goal of this development phase was to identify specific functionalities and data inputs/outputs of the software tool. PATCAM functions were classified into four top-level categories, as illustrated in Figure 4-1:

- USI
- Simulation
- CWM/CPM Calculations
- Analysis

Data inputs and outputs associated with each of these functions are labeled on Figure 4-1.

4.2.1 User-System Interface Requirements

The USI is an important consideration in any software analysis tool. It was especially important for PATCAM to have a simple and effective USI because commercial-off-the-shelf (COTS) software packages were used to implement other PATCAM functions. A common USI was needed to "glue" these packages together in a manner transparent to the user. Thus, the purpose of the USI function is to provide a consistent, easy to use capability for the PATCAM user to employ in specifying parameters of each test case and in analyzing the results of a PATCAM simulation.

USI requirements were developed and refined by application of a complete USI design life-cycle methodology (Figure 4-2). This methodology was applied in stages:

- Stage 1 - Definition of design objectives and system requirements
- Stage 2 - Task-analytic modeling of user-system processes and the user-system dialogue

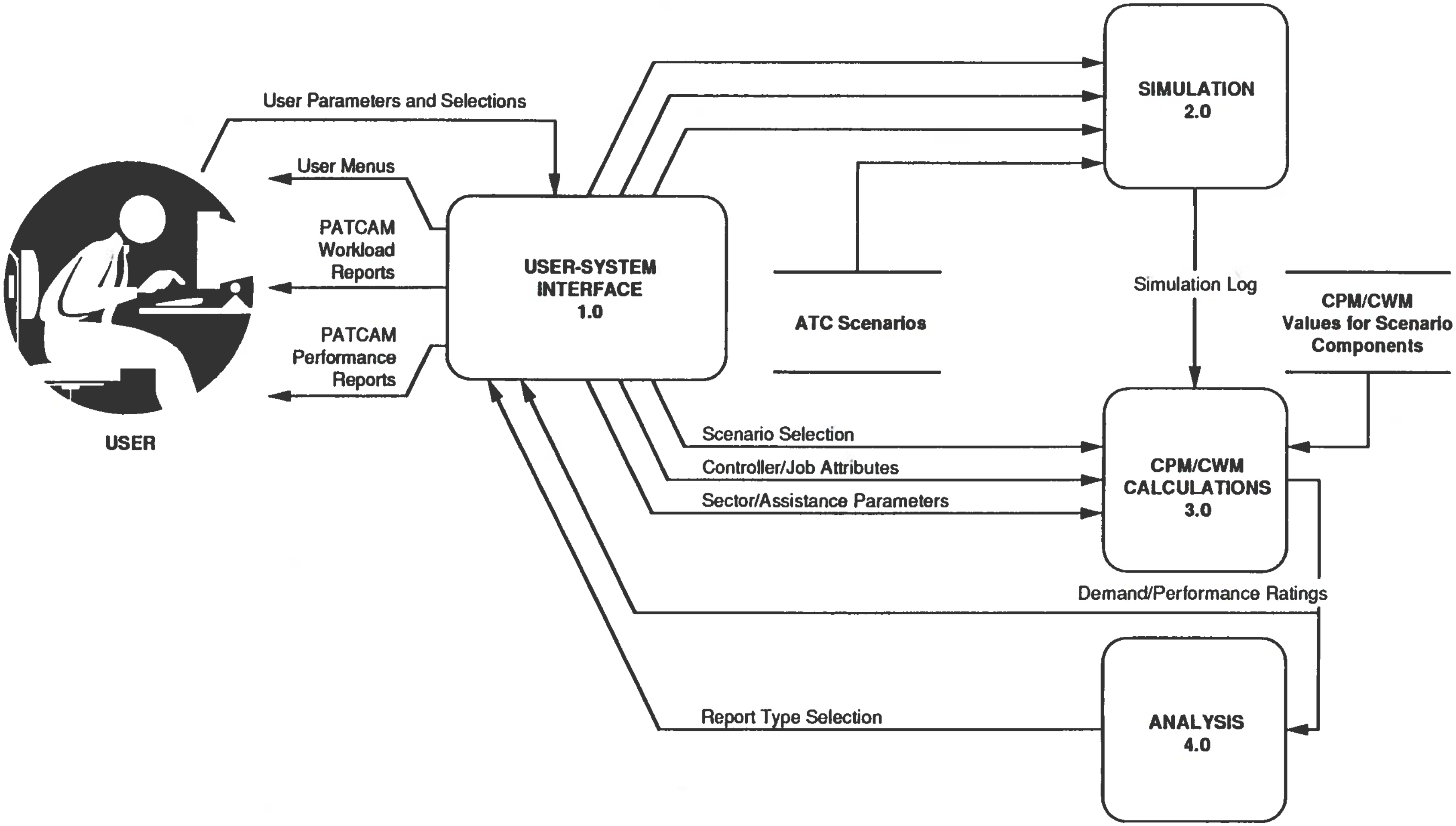

Figure 4-1. Allocation of PATCAM Functions

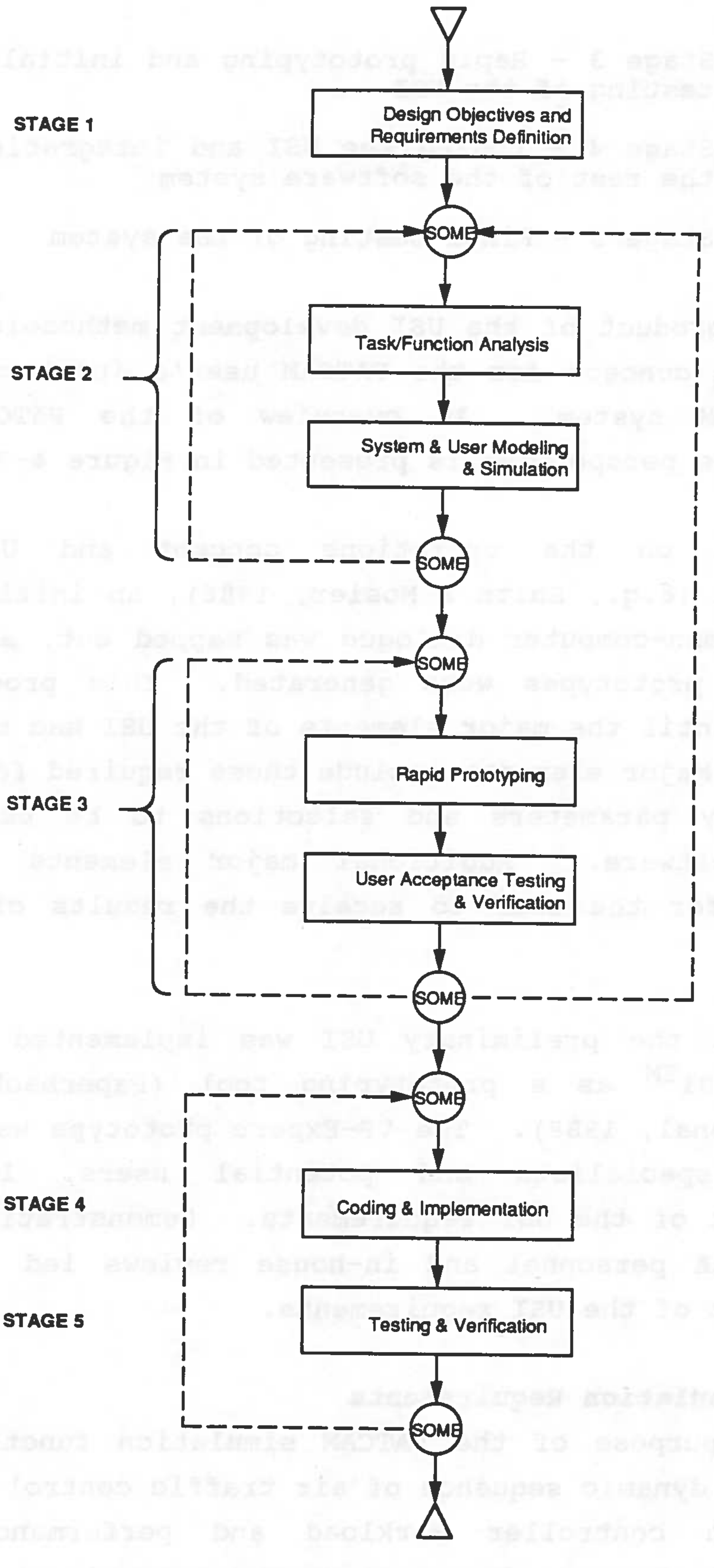

Figure 4-2. Stages of User Interface Development

- Stage 3 - Rapid prototyping and initial usability testing of the USI
- Stage 4 - Coding the USI and integrating it with the rest of the software system
- Stage 5 - Final testing of the system

An early product of the USI development methodology was an operations concept for the PATCAM user's interactions with the PATCAM system. An overview of the PATCAM user's interactive perspective is presented in Figure 4-3.

Based on the operations concept and USI design guidelines (e.g., Smith & Mosier, 1986), an initial version of the human-computer dialogue was mapped out, and pencil-and-paper prototypes were generated. This procedure was iterated until the major elements of the USI had been firmly defined. Major elements include those required for the user to specify parameters and selections to be used by the PATCAM software. Additional major elements are those required for the user to receive the results of a PATCAM analysis.

Next, the preliminary USI was implemented using VP-Expert 2.01^{TM} as a prototyping tool (Paperback Software International, 1988). The VP-Expert prototype was reviewed by USI specialists and potential users, leading to refinement of the USI requirements. Demonstrations of the USI to FAA personnel and in-house reviews led to further refinement of the USI requirements.

4.2.2 Simulation Requirements

The purpose of the PATCAM simulation functions is to provide a dynamic sequence of air traffic control situations for which controller workload and performance can be

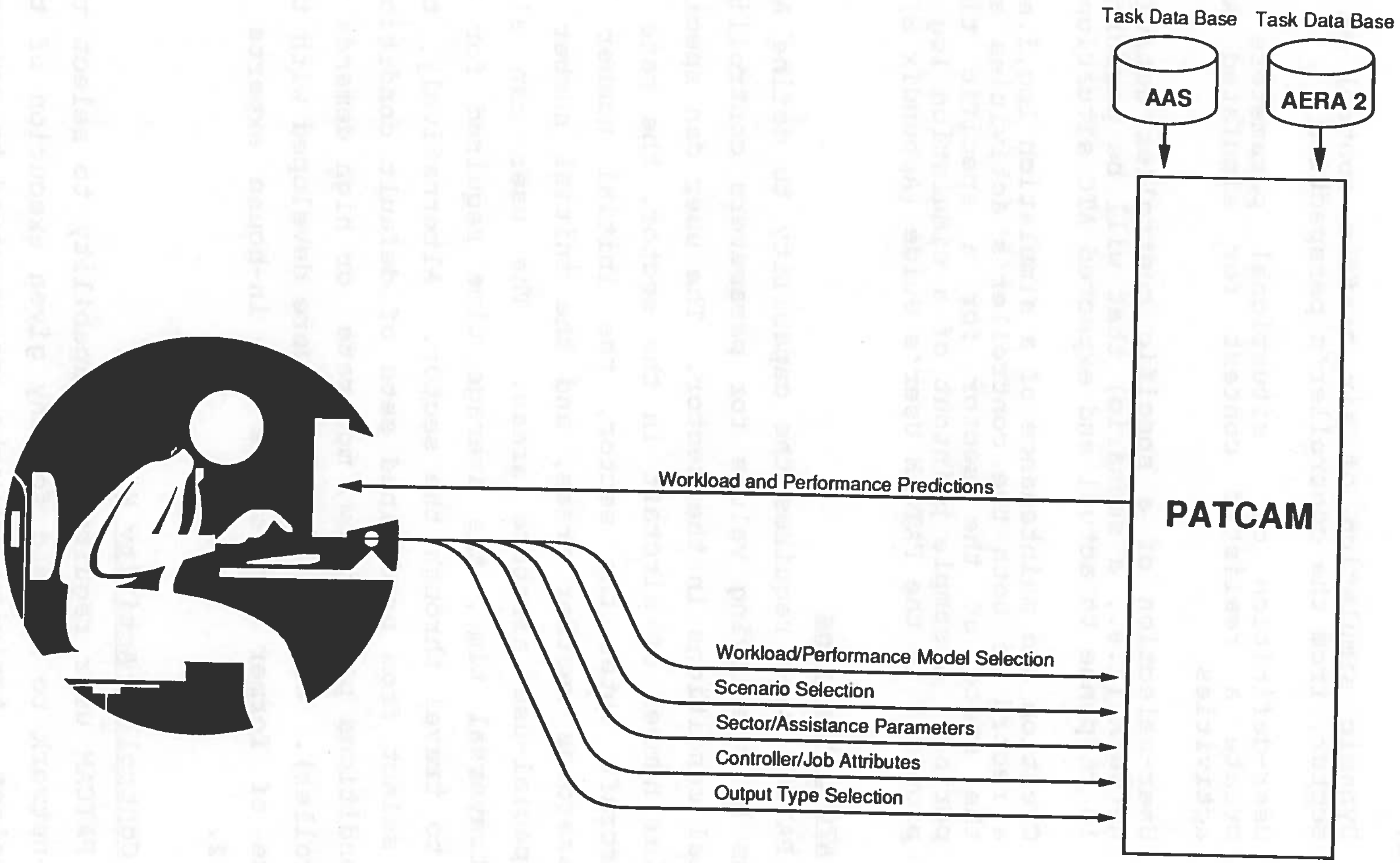

Figure 4-3. PATCAM User's Interactive Perspective

predicted. The following simulation requirements were identified:

- Dynamic simulation of air traffic control at a sector, from the controller's perspective
- User-definition of situational parameters to create a realistic context for simulated ATC activities
- User-selection of a specific controller activity network (i.e., a scenario) that will be performed in response to actual and expected ATC situations
- Creation and maintenance of a simulation log,i.e., a record of both the controller's activities and the state of the sector for a specific time period. A sample printout of a simulation log is provided in the PATCAM User's Guide (Appendix E).

4.2.2.1 ATC Situations

The PATCAM user requires the capability to define ATC situations by specifying values for parameters controlling the initial conditions in the sector. The user can specify the initial number of aircraft in the sector, the rate at which aircraft enter the sector, the initial number of active hazardous weather areas, and the initial number of active special-use airspace areas. The user can also specify traversal time, the average time required for an aircraft to travel through the sector. Alternatively, the user can select from predefined sets of default conditions (i.e., conditions placing low, moderate, or high demands on the controller). Default conditions were developed with the assistance of former controllers and in-house experts on AAS/AERA 2.

4.2.2.2 Controller Activity Networks

The PATCAM user requires the capability to select the activity network to be used for any given execution of the PATCAM toolset. Activity networks are required to maintain information about the hierarchical and sequential relationships of ATC tasks, modules, and scenarios. These activity networks are also required to maintain task identification information that is traceable to the AAS operations concept (FAA, 1988) or to the AERA 2 operations concept (CTA, 1986). Activity networks maintain information about the relationships between tasks and ATC situations.

4.2.2.3 Simulation Functions

To implement requirements for high-fidelity simulations, the following development functions were provided through the MicroSaint™ component of PATCAM:

- Time-sequenced scripting of ATC situations and tasks
- Random sequencing of the monitoring macro
- Establishment and maintenance of queues
- Construction of continuous situational patterns
- User-defined variables and expressions
- Capabilities for developing a library of simulation functions

A specific simulation run is evaluated for controller workload and performance by application of PATCAM's computational procedures.

4.2.3 CWM/CPM Computational Requirements

The CWM and CPM calculations are required to embody the PATCAM methodology. The purpose of these functions is to implement the CWM and CPM hierarchical prediction algorithms (Appendices C and D). The implemented algorithms produce raw demand and performance ratings for the air traffic control simulation being evaluated. These raw ratings are then compiled and analyzed to produce predictive reports.

The PATCAM user requires the capability to specify values for selected nodes of the CPM. These nodes accept values for controller attributes such as Visual Skill, Auditory Skill, Analytic Skill, Verbal Skill, Manual Skill, Multiplexing Skill, Modality-Switching Skill, and Vigilance. User-specified values can also be entered for selected nodes of both the CWM and the CPM. These nodes accept values for demand- and performance-shaping factors defined as Type of Assistance and Motivating Potential (Appendix A).

4.2.4 Analysis Requirements

The purpose of the analysis function is to transform raw CWM and CPM data into predictive measures of controller workload and performance. This function is required to provide standard statistical measures such as means, standard deviations, and ranges. The PATCAM user can specify the level of analysis desired (i.e., task, module, scenario) and the presentation media (i.e., textual or graphical display and/or hardcopy of textual reports).

4.2.5 Database Requirements

PATCAM needs to access two primary databases for each set of tasks to be analyzed:

- CWM database (including task attributes)
- CPM database (including task attributes)

These databases are required to represent the structure and the tree-climbing properties of the CWM (Figure 2-2) and the CPM (Figure 2-3).

4.2.5.1 CWM Database

This database is used to establish and maintain the algorithms that implement the Controller Workload Model (Appendix C). Additionally, the CWM database is used to maintain task-specific constant values for attributes associated with the model. Values that remain constant are those for the interface complexities and the task action demands.

4.2.5.2 CPM Database

This database is used to establish and maintain the algorithms that implement the Controller Performance Model. Additionally, the CPM database is used to maintain task-specific constant values for attributes associated with the model. Values for the interface complexities and the task action demands remain constant in the CPM calculations just as they do in the CWM calculations.

4.3 SOFTWARE DESIGN

The major objective of this development phase was to derive a software design to implement the requirements identified in the previous phase. Figure 4-4 illustrates the top-level design of the PATCAM system and the relationships between its central components: the USI, the simulation engine, and the analysis engine.

4.3.1 USI Design

A major element of the USI is the USI scenario editor. Using this capability, the PATCAM user selects a scenario (i.e., a controller activities network) and a sector model. Using the sector model, the PATCAM user defines the initial conditions in the sector, as a situational context for running a scenario simulation. Input from the scenario editor is used by the simulation engine to simulate a

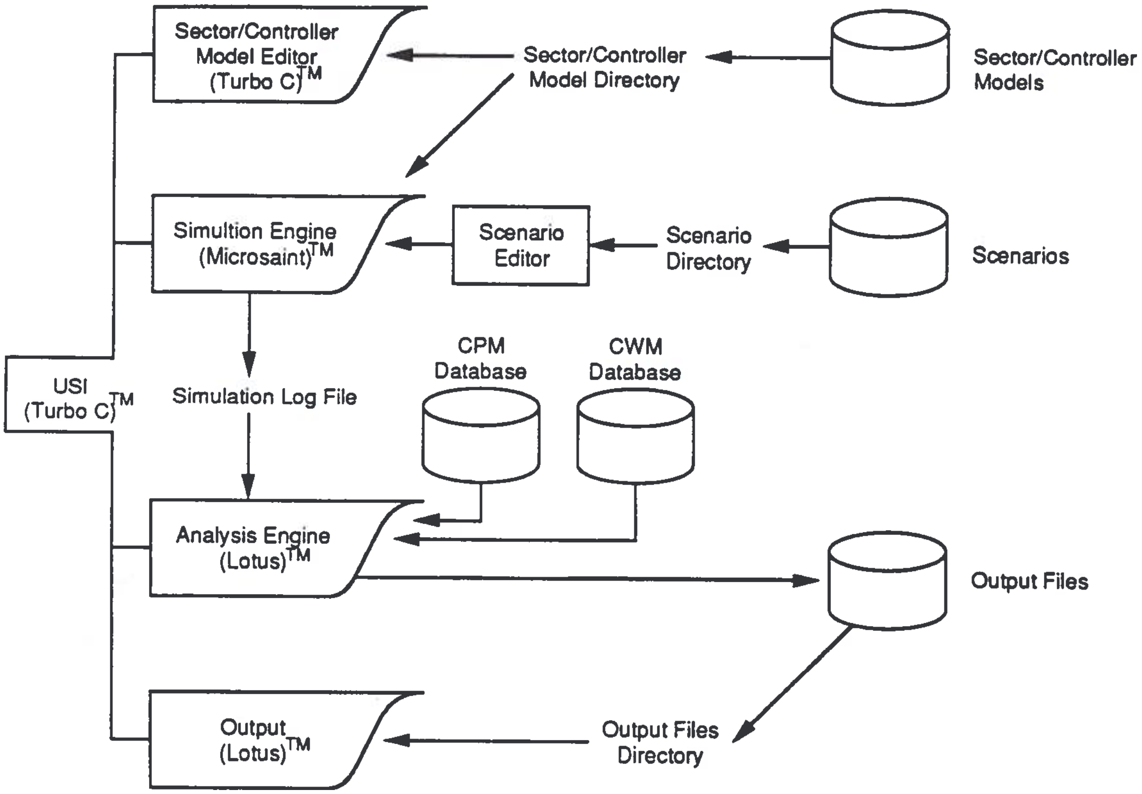

Figure 4-4. Top-Level Design of PATCAM System

controller working a specific sector using the capabilities of a particular NAS transition state.

4.3.1.1 USI Scenario Editor

Through the scenario editor, the PATCAM user selects a specific pre-defined controller activities network (e.g., AAS Scenario 1, AERA 2 Scenario 2) for input to the simulation engine. To provide a realistic and practical basis for simulating the controller's on-shift operations, the PATCAM databases for the AAS and AERA 2 specify paths through and across the validated subactivities, grouping tasks into modules that represent either tactical or strategic modes of operation. Modules are groups of tasks performed by the controller to meet a specific goal (e.g., to resolve an aircraft-to-aircraft conflict; to plan for anticipated sector workload).

For example, the module "Processing Aircraft...to Aircraft...Conflict" depicts the AAS controller operating in a tactical mode, responding to a potential conflict situation, which the controller has detected in an earlier module (Appendix B, AAS Scenarios). The modules "Monitoring for Conflicts" and "Managing Personal Workload," which occur in both the AAS and AERA2 scenarios, depict the controller operating in a strategic, anticipatory mode (Appendix B).

Both tactical and strategic modules are grouped into scenarios. Each unique task is represented in the task attributes database. Tasks are linked to their parent modules and to the lower-level nodes representing interfaces.

Once the PATCAM user initiates a simulation, the modules in a scenario are triggered by simulated events in the sector model. A set of modules together make up a scenario, which defines the baseline activities of a simulation run. Multiple scenarios make up a mission, which represents the range of controller operations using the capabilities of a specific NAS stage (e.g., AAS or AERA 2).

4.3.1.2 Sector Model

A sector model is a simulation model describing the initial ATC situation in the sector that the controller is working. The PATCAM user creates a sector model by specifying such variables as the number of aircraft in the sector at the start of the simulation, the frequency of aircraft entering the sector, the number of active special-use airspaces, and the number of weather elements. The user enters these data through the medium of the user-system interface. Once entered, sector models are stored as data files. Directories of these files, as well as Controller Activities Networks and analysis outputs, are kept in directory files.

Although the PATCAM user defines the initial parameters of the sector model, it is dynamic and controlled by the simulation engine. During simulation, a simulation log is kept of the sector conditions for each task that is executed. The simulation software keeps track of start time for task execution and records the status of the situational parameters at that moment (e.g., the number of aircraft in the sector at time 00:10:15). The analysis engine uses this simulation log to calculate the effects of dynamic, simulation-dependent attributes (e.g., the Visual Signal-to-Noise Ratio of a particular display).

Thus, the sector model allows the realistic modeling and simulation of a complex dynamic environment.

4.3.2 PATCAM Simulation Engine

PATCAM uses MicroSAINT™ as its simulation engine. MicroSAINT™ dynamically models ATC situations and the controller's responses to or anticipations of situations. Situations may be actual or potential conflicts. The simulation engine creates two parallel networks, a sector events network, which is built from the sector model, and a controller task network, which is built from the controller activities network. MicroSAINT™ uses these networks to run a dynamic simulation and to create a simulation log of the executed tasks and corresponding sector conditions. This simulation log is used by the analysis engine for the purpose of deriving situation-specific, calculated attribute values for each executed task.

4.3.3 PATCAM Analysis Engine

The heart of the PATCAM analysis engine is a COTS software package, Lotus 123™. The simulation log output is loaded into this package, which houses the task attributes data and the algorithms that make up the workload and performance models. Workload or performance estimates are calculated for each level of a model's hierarchy, and the results are displayed interactively to the analyst as tables or bar graphs.

4.3.3.1 Task Attributes Database

Each unique task in the AAS and AERA 2 scenarios is represented by a record in the task attributes database. A task is the lowest-level, time-bounded, goal-directed unit of activity in the PATCAM workload and performance models. For purposes of predicting workload and performance, a task is defined by the demands associated with the task action verb, the informational loadings imposed by the accessed interface(s), and task-specific modifying attributes (i.e., Time Pressure, Error Criticality, and Memory Retrieval Demand). Tasks are further defined by the situation-dependent values they receive for multiplexing demand and modality-switching demand.

4.3.3.2 Workload and Performance Models: Attribute Values and Computational Procedures

As illustrated in Figures 2-2 and 2-3, each level of the workload and performance models is characterized by one or more attributes. Some attributes are largely interface- or task-specific (e.g., Visual Complexity, Visual Action Demand, Error Criticality). Others depend heavily on sector conditions at a given time (e.g., number of aircraft and number of weather elements in the sector influences the Visual Signal-to-Noise Ratio of the Situation Display, a logical interface). Still others are simulation variables, which are pre-set by the PATCAM user (e.g., Type of Assistance, Motivating Potential). The nature of a particular attribute is indicated by the following coding scheme, employed in the Glossary (Appendix A):

- C - Calculated from lower-level values by application of computational procedures
- CD - Condition Dependent; value linked to levels of situational variables
- IS - Interface Specific; rated by SMEs
- SV - Simulation variable; value selected from an allowable range by the PATCAM user
- TS - Task Specific; rated by SMEs

The computational procedures consist of tree-climbing algorithms and combining algorithms. Tree-climbing algorithms are rules used to calculate an intermediate value based on attributes of different classes (e.g., to derive a value for the Visual Load of an interface from its rating for Visual Complexity and the user-selected value for Type of Assistance). Combining algorithms are used to combine several intermediate values of the same class into a single higher-level attribute value (e.g., the Visual Load for all the interfaces in a task). The contribution of each component is determined by time-based weighting factors (e.g., individual task durations contribute to overall module duration). Estimates of average task duration were provided by the AAS and AERA 2 controller teams.

Computational procedures for the Controller Workload Model are presented in Appendix C. Those for the Controller Performance Model are presented in Appendix D. All values and computed results occur along the five-point scale (Low to High).

4.4 SOFTWARE CODING

Implementation of the software design proceeded in a series of three builds (Table 4-1). The use of COTS software packages reduced the amount of coding required to a reasonable and practical level. Following the initial USI prototyping, coding efforts focused on the implementation of the user-system interface. After the USI was completely analyzed and designed, PATCAM's interface was coded in Turbo-C 2.0^{TM} (Borland International, 1988).

Implementation of the functional levels and algorithms was supported by Lotus 123^{TM}. The AAS and AERA 2 controller activity networks (scenarios) were built in MicroSAINT^{TM}. A software notebook was developed and maintained throughout the project to document implementation issues and decisions.

4.5 SOFTWARE INTEGRATION AND TESTING

Software testing occurred in parallel with software coding, throughout the development of the software builds (Table 4-1). Small test cases were used to validate the computational procedures as coded. SBIR analysts performed the required test calculations by hand and results were compared to the automatically generated values produced by PATCAM software. This procedure led SBIR researchers to re-think and re-work several design concepts. For example, the scale for Time Pressure (Appendix C, Appendix D) was revised to capture the effects of task time constraints more precisely.

Simulation functions were tested by running simulations with four different sets of simulation parameters (Table 4-2). Even with extreme values the simulation behaved as expected.

Each software build was reviewed by project staff and other in-house specialists. The USI was stringently reviewed for robustness, usability, and adherence to standard human factors USI design guidelines (e.g., Smith & Mosier, 1986). The first two software builds were demonstrated to FAA Headquarters staff (e.g., AAM-500, AAP-120) for comment and review. The third build is scheduled for post-delivery demonstration to AAM-500.

Software integration was accomplished through the vehicle of the USI. Interactions between Lotus 123^{TM} and MicroSAINT^{TM} were made completely transparent to the user, and the MicroSAINT^{TM} interface was integrated within the PATCAM USI to the extent necessary. The PATCAM user's interactions with the PATCAM software are detailed in the user's guide (Appendix E).

Table 4-2. Simulation Test Parameters

Parameter	Test 1	Test 2	Test 3	Test 4
Initial number of aircraft	25	1	50	0
Number of special use airspace	1	1	5	0
Number of hazardous weather cells	1	1	3	0
Rate at which aircraft enter the sector (x aircraft/ every y minutes)	1/3	1/3	1/1	1/.5
Average time in sector	20	20	10	2

With the completion of task-database enhancement and software development, it became possible to perform the CWM/CPM validation studies and to generate proof-of-concept predictions for workload and performance attributes in the simulated AAS and AERA 2 environments.

SECTION 5 - VALIDATION STUDIES

Model validation efforts focused on validating PATCAM's predictive output. In the absence of operational or simulated systems for the AAS and AERA 2, it was necessary to gauge validity on the basis of the best available projections about these future systems. The best available projections are contained in the operations concepts for the AAS and AERA 2 (FAA, 1988; CTA, 1986). These operations concepts have been validated by extensive and iterative controller team review, as have the system level specifications for both the AAS and AERA 2 (FAA, 1986; MITRE, 1986). These representations of the AAS and AERA 2 environments are the best available bases for approximate modeling (Karat, 1988) of AAS/AERA 2 controller workload and performance. As described in Section 4, the PATCAM databases hold subsets of both the AAS and the AERA 2 operations concepts. This section describes research activities designed to address the issue of the validity of PATCAM's higher-level predictions.

5.1 VALIDATION OF WORKLOAD AND PERFORMANCE PREDICTIONS

The issue of predictive validity was addressed for both the Controller Workload Model and the Controller Performance Model. Subject-matter experts' direct ratings of higher-level model attributes were compared to automated CWM and CPM output derived from a combination of lower-level SME ratings, situation-dependent values, and pre-set simulation parameters. Results of these comparisons indicate the extent to which the model can be accepted as an ATC expert. Current results indicate that the CWM can be considered an expert predictor, particularly in the areas of visual demand, analytic demand, and controller workload. Results for the CPM indicate that the model closely approximates SME prediction of visual, auditory, and analytic performance at the module level. In the absence of operational environments in which to collect workload and performance data, this automated approximation of a human expert can provide the kind of early feedback needed by system designers in regard to potential workload and performance effects of proposed system capabilities.

5.1.1 Method

The approach to CWM/CPM validation focused on comparing model-based predictions of higher-level attribute values with subject-matter-experts' direct ratings for the same attributes. This approach was previously employed in validating a model of human performance in a NASA-ground-control environment (CTA, 1987). A similar method has been used by researchers at Hay Systems in validating their model of cognitive requirements (Rossmeissl & Charles, 1988).

5.1.1.1 Subjects

The original validation group of six SMEs for the AAS included two highly experienced former controllers, who have extensive experience in the development of the operations concept for the AAS (FAA, 1988). A third SME was an experimental psychologist, who has also worked closely for several years with the controller team charged with the development of operational requirements for the AAS. Three other AAS operations concept developers were included in the original SME validation group, but their ratings were later omitted from the analysis because of their self-reported misgivings about the reliability of their responses.

5.1.1.2 Materials

The validation package for the CWM included a map of a generic ATC sector (Appendix B), the set of AAS scenarios

(Appendix B), rating forms on which SMEs recorded their estimates of demands on controller resources, and instructions for completing the rating forms. A sample of the instructions and CWM rating forms appears in Appendix I. Initial situational conditions for the generic sector were defined as follows:

- Number of aircraft under the sector's control = 20
- Average time to traverse the sector = 20 minutes
- Average rate at which aircraft enter/exit the sector = one per minute

The following assumptions were made about the ATC situation:

- All aircraft are equipped with transponders (Mode C)
- Handoffs are normally initiated automatically and always accepted
- Data blocks are automatically suppressed when aircraft leave the sector

The CPM validation package included three selected AAS scenario modules, rating forms on which subjects recorded their estimates of controller performance, and instructions for completing the forms. A sample of this package appears in Appendix I.

5.1.1.3 Procedure

The CWM validation package was mailed to the full sample of six SMEs for the AAS. The SMEs were instructed on how to complete the rating forms and were encouraged to call the Principal Investigator with any questions. The rating forms directed raters' attention to specific scenario segment or modules, which they were to rate for the various module-level attributes (e.g., Visual Perception Demand, Analytic Processing Demand, and Manual Response Demand).

SMEs also rated the overall demands of the complete scenarios. All ratings were made using the five-point scale (1=Low; 3=Moderate; 5=High). When the rating forms were returned, raters' responses were inspected for face validity and interrater agreement.

Three of the AAS requirements developers voiced concern about the reliability of their responses. These concerns centered on their relative unfamiliarity with the current ATC operational environment. These raters and one of the former controllers also appeared to have had some difficulties in completing the rating task. For example, they supplied ratings for demands that did not trace to the module being rated (e.g., Auditory Perception Demand was rated for a module with no overtly auditory tasks). Thus, four sets of responses were discarded, and responses from two SMEs were analyzed to estimate CWM validity.

Three SMEs with good agreement on the lower-level complexity ratings participated in an exercise to validate the CPM algorithms. The CPM validation package was mailed to them. They were instructed on completing the forms and encouraged to call with questions. The completed CWM and CPM ratings are referred to as SMEs' "direct ratings," for purposes of comparison with model-based predictions.

Model-based predictions were made separately on the basis of lower-level complexity ratings and task action demand ratings supplied by the same SMEs whose validation responses were accepted for analysis. For example, SME1's interface-level complexity ratings and task action demand ratings, which had been collected months before the validation ratings, were input for use by the CWM/CPM algorithms. Predictions of higher-level attribute values were then generated, on the basis of this SME's and only this SME's, lower-level values. Situational variables were selected to match the initial sector conditions defined in the validation package. Simulation parameters (i.e., Type of Assistance, Vigilance, and Motivating Potential) were set at Moderate (3).

In this way, individual sets of predicted values were generated by PATCAM for AAS workload and performance. These sets of values were then compared to the same experts' direct ratings of higher-level workload and performance attribute values.

5.1.1.4 Data Analysis

Completed rating forms were inspected for indications of deviation from instructions. For example, if a subject rated a particular module for Auditory Perception Demand when there were no auditory tasks in that module, his ratings were not accepted for analysis.

Using the Statistical Package for the Social Sciences (Norusis, 1986), correlational analyses were performed to determine the consistency between model-based predictions and subjects' direct ratings, for sets of ratings that satisfied inspection criteria.

5.1.2 Results of CWM Validation

Comparison of SMEs' direct ratings of task-level Visual Load with model-based predictions for nineteen AAS tasks yielded the correlational results presented in Table 5-1a. The correlations of particular interest to the validation study are those indicating the agreement between a human expert's direct ratings (e.g., SME1) and automated, model-based predictions generated from that same expert's

Table 5-1. CWM Validation: Comparison of SMEs' Direct Ratings and Model-Based Predictions for Two Task-Level Attributes, a) Visual Load, and b) Analytic Load

a) Direct Ratings of Visual Load Compared to Model-Based Predictions (N=19)

	SME_1	MOD_1	SME_2	MOD_2
SME_1	1.0000			
MOD_1	.0496	1.0000		
SME_2	$.6531^{**}$	.1840	1.0000	
MOD_2	-.0941	$.7716^{***}$	.2453	1.0000

b) Direct Ratings of Analytic Load Compared to Model-Based Predictions (N=20)

	SME_1	MOD_1	SME_2	MOD_2
SME_1	1.0000			
MOD_1	$.5406^{*}$	1.0000		
SME_2	$.6502^{**}$	.2292	1.0000	
MOD_2	$.4981^{+}$	$.9859^{***}$	.2070	1.0000

$+$ $p \leq .05$
$*$ $p \leq .02$
$**$ $p \leq .01$
$***$ $p \leq .001$

lower-level attribute ratings (e.g., MOD1). Ratings provided by the two SMEs are consistent with each other, and predictions made by the model are consistent with each other. There is, however, no significant consistency between direct ratings and model-based predictions.

A similar comparison of direct ratings and model-based predictions of task-level Analytic Load yielded the correlational results presented in Table 5-1b. Once again, ratings provided by the SMEs are consistent with each other, and predictions made by the model's algorithms are highly consistent ($r = .9859$, $p \leq .001$). In this case, there is also a finding of strong consistency between one SME and the model-based predictions generated from his lower-level values ($r = .5406$, $p \leq .02$). Interestingly, this expert's direct-ratings were also consistent with model-based predictions generated by the other expert's lower-level values ($r = .4981$, $p \leq .05$).

Comparison of SMEs' direct ratings of module-based demands for visual perception with model-based predictions of those demands produced the correlational results presented in Table 5-2a. Again we find good agreement between experts ($r = .4889$, $p \leq .05$) and between model-based predictions ($r = .4867$, $p \leq .05$). There is, however, no significant consistency between direct ratings and model-based predictions of module-level demands for visual perception.

A similar comparison of direct ratings and model-based predictions of analytic demands at the module level yielded the results presented in Table 5-2b. For the correlations of particular interest, we find some agreement between SME1 and MOD1 ($r = .3981$, $p \leq .1$) and good agreement between SME2

Table 5-2. CWM Validation: Comparison of SMEs' Direct Ratings and Model-Based Predictions for Two Module-Level Attributes, a) Visual Perception Demand and b) Analytic Processing Demand

a) Direct Ratings of Visual Perception Demand Compared to Model-Based Predictions (N=22)

	SME$_1$	MOD$_1$	SME$_2$	MOD$_2$
SME$_1$	1.0000			
MOD$_1$	.3364	1.0000		
SME$_2$	.4889^{+}	.2558	1.0000	
MOD$_2$	.0482	.4867^{+}	-.2358	1.0000

b) Direct Ratings of Analytic Processing Demand Compared to Model-Based Predictions (N=22)

	SME$_1$	MOD$_1$	SME$_2$	MOD$_2$
SME$_1$	1.0000			
MOD$_1$	.3981^{o}	1.0000		
SME$_2$	.7952***	.5056*	1.0000	
MOD$_2$	.3244	.9465***	.4817^{+}	1.0000

o $p \leq .1$
\+ $p \leq .05$
* $p \leq .02$
** $p \leq .01$
*** $p \leq .001$

and MOD2 ($r = .4817$, $p \leq .05$). As before, the two SMEs are strongly consistent with each other ($r = .7952$, $p \leq .001$), and the model-based predictions are especially consistent ($r = .9465$, $p \leq .001$).

5.1.3 Results of CPM Validation

Comparison of SMEs' direct ratings of performance with model-based predictions for three AAS modules yielded the results presented in Tables 5-3, 5-4, and 5-5. Results for Module 11, Processing Aircraft-to-Aircraft Conflicts (Table 5-3) indicate strong agreement between SME1's direct ratings of Visual Performance, Auditory Performance, and Analytic Performance and MOD1's model-based predictions of those same attributes ($r = .7559$, 2-tailed $p \leq .05$). Especially strong agreement was found between SME3's direct ratings and the MOD3 model-based predictions ($r = .8660$, $p \leq .02$).

There were several instances of significant agreement between direct ratings and model-based predictions for the other modules included in the study: Processing Aircraft User-Preferred Route (Table 5-4) and Processing Flow Restriction Noncompliance (Table 5-5). For both of these modules, SME1's direct ratings exhibited strong agreement with model-based predictions ($r = .8660$, $p \leq .02$). Direct ratings supplied by SME1 also showed strong agreement with the model-based predictions generated from SME2's lower-level values (Table 5-4, $r = .8660$, $p \leq .02$). SME1's direct ratings agreed well with MOD2 ($r = .9820$, $p \leq .02$), with SME3's direct ratings ($r = .8660$, $p \leq .02$), and with MOD3 ($r = .8660$, $p \leq .02$) in predicting the AAS controller's visual, auditory, and analytic performance in processing flow restriction noncompliance (Table 5-5). SME3's direct ratings showed good agreement with MOD2 for the same module (Table 5-5, $r = .7559$, $p \leq .05$).

Table 5-3. CPM Validation: Correlations between SMEs' Direct Ratings and Model -Based Predictions of Module-Level Performance Attributes (N=3) for Module 11, Processing Aircraft-to-Aircraft Conflicts†

	SME_1	MOD_1	SME_2	MOD_2	SME_3	MOD_3
SME_1	1.000					
MOD_1	.7559*	1.0000				
SME_2	-.9449**	-.5000	1.0000			
MOD_2	.7559*	1.0000***	-.5000	1.0000		
SME_3	.3273	.8660**	0.0	.8660**	1.0000	
MOD_3	.7559*	1.0000***	-.5000	1.0000***	.8660**	1.0000

Two-Tailed Significance:

*	$p \leq .05$
**	$p \leq .02$
***	$p \leq .001$

† <u>Given Controller Profile</u>:

Visual Skill = Superior (5)
Auditory Skill = Satisfactory (3)
Analytic Skill = Above Average (4)
Multiplexing Skill = Minimally Acceptable (1)
Modality-Switching Skill = Above Average (4)

<u>Type of Assistance:</u>

Moderate (3) level of automated decision aiding.

Table 5-4. CPM Validation: Correlations Between SMEs' Direct Ratings and Model-Based Predictions of Module-Level Performance Attributes (N=3) for Module 16, Processing Aircraft User-Preferred Route†

	SME$_1$	MOD$_1$	SME$_2$	MOD$_2$	SME$_3$	MOD$_3$
SME$_1$	1.000					
MOD$_1$	$.8660^{**}$	1.0000				
SME$_2$	$-.8660^{**}$	-.5000	1.0000			
MOD$_2$	$.8660^{**}$	1.0000^{***}	-.5000	1.0000		
SME$_3$	0.0	-.5000	-.5000	-.5000	1.0000	
MOD$_3$	.5000	$.8660^{**}$	0.0	$.8660^{**}$	$-.8660^{**}$	1.0000

Two-Tailed Significance:

*	$p \leq .05$
**	$p \leq .02$
***	$p \leq .001$

† Given Controller Profile:

Visual Skill = Superior (5)
Auditory Skill = Satisfactory (3)
Analytic Skill = Above Average (4)
Multiplexing Skill = Minimally Acceptable (1)
Modality-Switching Skill = Above Average (4)

Type of Assistance:

Moderate (3) level of automated decision aiding.

Table 5-5. CPM Validation: Correlations Between SMEs' Direct Ratings and Model-Based Predictions of Module-Level Performance Attributes (N=3) for Module 17, Processing Flow Restriction Noncompliance[†]

	SME_1	MOD_1	SME_2	MOD_2	SME_3	MOD_3
SME_1	1.000					
MOD_1	.8660**	1.0000				
SME_2	0.0	.5000	1.0000			
MOD_2	.9820**	.9449**	.1890	1.0000		
SME_3	.8660**	.5000	-.5000	.7559*	1.0000	
MOD_3	.8660**	1.000***	.5000	.9449**	.5000	1.0000

Two-Tailed Significance:

* p≤ .05
** p≤ .02
*** p≤ .001

[†] <u>Given Controller Profile</u>:

Visual Skill = Superior (5)
Auditory Skill = Satisfactory (3)
Analytic Skill = Above Average (4)
Multiplexing Skill = Minimally Acceptable (1)
Modality-Switching Skill = Above Average (4)

<u>Type of Assistance:</u>

Moderate (3) level of automated decision aiding.

There were three instances of significant negative relationships (Tables 5-3 and 5-4). SME1's direct ratings varied negatively with SME2's direct ratings of performance attributes in processing aircraft-to-aircraft conflict ($r = -.9449$, $p \leq .02$). For processing a user-preferred route, SME1's direct ratings were negatively correlated with SME2's direct ratings ($r = -.8660$, $p \leq .02$); and SME3's direct ratings were negatively correlated with MOD3's predicted ratings ($r = -.8660$, $p \leq .02$). There were no findings of significant negative correlations between a rater's direct ratings and model-based predictions generated by that rater's lower-level values.

As indicated on Tables 5-3, 5-4 and 5-5, model-based predictions agreed well with each other, sometimes reaching perfect agreement ($r = 1.0000$, $p \leq .001$).

5.1.4 Discussion of CWM/CPM Validation

The strong positive correlations between raters' direct ratings of analytic demands, at the task and module levels, and the CWM's predictions support the validity of the CWM algorithms in predicting the analytic demands of planned system capabilities. The results for visual demands suggest that rating and predicting visual demands prior to design is less well-understood than rating and predicting analytic demands. Since the strongest concern about increased automation focuses on its potential cognitive effects, finding a valid predictor of those effects in the CWM algorithms can be considered a step forward.

The strong positive correlations between raters' direct ratings and the CPM's predictions indicate a high level of support for the validity of the CPM algorithms in predicting visual, auditory, and analytic performance. Results also indicate good agreement between two of the raters on one of the modules (Table 5-5). The significant negative correlations presented in Tables 5-3 and 5-4, however, raise some questions about SME2's and SME3's direct ratings of performance attributes.

A conclusion based on CWM and CPM validation results is that the most valid predictions can be made by the CPM using SME1's set of lower-level attribute values (i.e., ratings for the complexity attributes and the task-action-demand attributes). Predictions of AAS controller workload and performance based on this set of values have been pre-run and are available in PATCAM's predefined reports.

5.2 INVESTIGATION OF MENTAL INTERFACES

A study was performed to investigate the role of the controller's cognitive structures in workload and performance. A mental interface is a cognitive structure that the controller accesses when performing a task. Mental interfaces may be thought of as 'sketch pads' in working memory (Bower, 1975), which provide the context for the manipulation and transformation of information that the controller has extracted from external information displays. This research has proposed four such mental 'sketch pads': the CMTP, the PMTP, the SWP, and the DMC. These cognitive structures are conceptualized as being linked to knowledge stored in long-term memory (e.g., knowlege of sector geometry, knowledge of carrier schedules and routes). The linkage to long-term memory suggests that cognitive models may vary across individual controllers as a function of training and experience.

This research further proposes that the quality of the controller's mental interfaces plays a significant role in his or her perception of workload and in the efficiency and effectiveness of performance. A study of pilots' cognitive models (Hahn, 1988) has shown differences in performance associated with the cognitive models of novice and expert pilots. To our knowledge, the link between cognitive structures and error is one that has not been examined in the ATC environment.

Each of the four proposed mental interfaces is a unique grouping of task information or "mental objects" from the AAS operations concept (FAA, 1988). Mental objects are "conceptual 'images' which exist in the mind of the controller" (CTA, 1984). Although the contents of the four mental interfaces follow logically from this operations concept, the original process for determining the grouping of mental objects was subjective. Thus, given the importance of the concept of mental interface to understanding the relationship between controller workload and performance, it was necessary to investigate these groupings empirically.

5.2.1 Method

Mental interfaces imply a certain degree of organization or relatedness of mental objects. For example, the mental objects "time, location, route, and altitude information" and "aircraft proximity" are related as features of the CMTP. The purpose of this study was to examine the grouping of such mental objects, which were proposed as the contents of the four mental interfaces.

Previous research has drawn upon multidimensional scaling techniques to determine the grouping or proximity of mental constructs (Roske-Hofstrand & Papp, 1985; Schvaneveldt, Durso, Goldsmith, Breen, & Cooke, 1985). The procedure is for individuals to rate the degree of similarity of terms that are features or aspects of a particular mental construct. These similarity ratings provide an indication of the 'distance' between terms. Presumably, terms that are closely related form "clusters" in multidimensional space, while those that are unrelated are 'further' apart. In the present study, we expect that mental objects within a particular mental interface will form distinct clusters in multidimensional space.

Eighteen active controllers participated as raters in this study. Five raters were from the Systems Requirements Team (SRT) for VSCS. Thirteen raters were members of the Air Traffic AAS Test Team (ATATT). The rating task took place in a single one-hour session, with participants responding to the prepared rating materials (Appendix J).

5.2.2 Correlational Results

Analysis of the rating data for five of the 18 subjects indicates a high level of consistency between subjects. As shown in Table 5-6, inter-subject correlations are strong. This high degree of inter-subject consistency suggests an underlying structure to the data. The expectation is that this structure will correspond to the four mental interfaces proposed by this research. Further data analysis is required to test this expectation.

5.2.3 Discussion

Identification and inclusion of the mental interfaces is one of PATCAM's innovative features. All SMEs who responded to the data collection package (Appendix F) agreed that the four proposed mental interfaces represent and contribute to significant aspects of the controller's cognitive workload and performance. The consistent levels of agreement on analytic complexity (Tables 3-1 and 3-7) as well as the results for predictive validity on analytic attributes (Tables 5-1 and 5-2) can be partially attributed to inclusion of the mental interfaces. Although this is a new area of investigation in air traffic control applications, it has been widely studied by researchers in other domains (e.g., Rasmussen, 1981; Woods & Roth, 1986). Further investigation of the role of mental models in air traffic control is recommended, with further discussion supplied in Section 7.

The work described thus far provided the basis for demonstrating PATCAM's Phase II capabilities.

Table 5-6. Inter-subject correlations on ratings of air traffic control terms (N=135)

	S_1	S_2	S_3	S_4	S_5
S_1	1.0000				
S_2	.0287	1.0000			
S_3	.3676**	.0833	1.0000		
S_4	.2019*	.2885**	.2078	1.0000	
S_5	.2769**	.2647**	.2244*	.4313**	1.0000

One-Tailed Significance:

*	$p \leq .01$
**	$p \leq .001$

SECTION 6 - PROOF-OF-CONCEPT PREDICTIONS OF CONTROLLER WORKLOAD AND PERFORMANCE

Completion of AAS/AERA 2 task database enhancement, model validation studies, and software-tool development made possible a phased demonstration of PATCAM's predictive capabilities. In the first phase, the CWM and CPM were exercised to predict AAS controller workload and performance. In the second phase, a similar procedure was followed to generate predictions of AERA 2 controller workload and performance. Finally, the predicted workload and performance levels were compared across the simulated AAS and AERA 2 environments. Results of these model-based comparisons are presented for proof-of-concept purposes.

6.1 MODEL-BASED AAS WORKLOAD AND PERFORMANCE

The validated AAS scenarios and the AAS database provided the basis for PATCAM's predictions of the simulated AAS controller's workload and performance. The choice was made to use individual SME ratings rather than some measure of central tendency across SMEs. The concern was that collapsing ratings into means or medians would tend to produce predictions that could not be traced to any one data source. Using individual sets of ratings maintained a traceability between an individual SME's ratings and the model's predictions based on those ratings.

Model-based predictions of scenario-level demands on the controller and scenario-level controller performance in the simulated AAS environment produced the values presented in Table 6-1.

Correlational studies of these sets of values produced the results presented in Table 6-2. These results indicate

Table 6-1. PATCAM Predictions of AAS Workload and Performance*

	DEMAND			PERFORMANCE		
	CWM/SME$_1$	CWM/SME$_2$	CWM/SME$_3$	CPM/SME$_1$	CPM/SME$_2$	CPM/SME$_3$
Scenario 1:						
Perceptual	4	3	3	4	4	4
Analytic	4	4	4	4	4	3
Response	2	2	2	3	3	4
Resource Management	2	2	2	3	3	3
Scenario 2:						
Perceptual	4	3	3	4	3	4
Analytic	4	4	3	3	4	3
Response	2	2	2	3	2	4
Resource Management	2	2	2	3	2	3

*given pre-defined parameter settings:

Visual Skill = 5
Auditory Skill = 3
Analytic Skill = 4
Manual Skill = 5
Verbal Skill = 3
Modality-Switching Skill = 4

Multiplexing Skill = 1
Vigilance = 3
Motivating Potential = 3
AAS Type of Assistance = 3

Scale:
1 = Low
2 = Low to Moderate
3 = Moderate
4 = Moderate to High
5 = High

Table 6-2. Correlational Results for PATCAM's Predictions of AAS Workload (N=4)

	AAS Scenario 1			AAS Scenario 2		
	$CWMSME_1$	$CWMSME_2$	$CWMSME_3$	$CWMSME_1$	$CWMSME_2$	$CWMSME_3$
$CWMSME_1$	1.0000			1.0000		
$CWMSME_2$	.9045^{+}	1.0000		.9045^{+}	1.0000	
$CWMSME_3$	.9045^{+}	1.0000**	1.0000	1.0000**	.9045^{+}	1.0000

+ $p \leq .10$
** $p \leq .001$

high levels of consistency among model-based predictions of workload attributes generated from SMEs lower-level ratings. As indicated by Table 6-3, consistency levels are lower for predictions of performance, although there is one instance of perfect agreement for performance on AAS Scenario 1 ($r = 1.0000$, $p \leq .001$).

Looking back to the data (Table 6-1), we see that predicted demand ranges from a relatively low level (2) to a relatively high level (4), for the pre-defined controller and job profiles. Predicted performance varies within this same range (2-4). Means and standard deviations are as follows (N=4):

	AAS Scenario 1		AAS Scenario 2	
	Mean	Std. Dev.	Mean	Std. Dev.
CWMSME1	3.0000	1.1547	3.0000	1.1547
CWMSME2	2.7500	.9574	2.7500	.9574
CWMSME3	2.7500	.9574	2.5000	.5774
CPMSME1	3.5000	.5774	3.2500	.5000
CPMSME2	3.5000	.5774	2.7500	.9574
CPMSME3	3.5000	.5774	3.5000	.5774

Thus, the Controller Workload Model predicts generally moderate demand for both AAS scenarios, and the Controller Performance Model predicts generally moderate or slightly above-average performance in the simulated AAS environment, given the pre-defined controller profile.

6.2 MODEL-BASED AERA 2 WORKLOAD AND PERFORMANCE

The AERA 2 scenarios and the AERA 2 databases provided the basis for PATCAM's predictions of the simulated AERA 2 controller's workload and performance. The controller

Table 6-3. Correlational Results for PATCAM's Predictions of AAS Controller Performance (N=4)

	AAS Scenario 1			AAS Scenario 2		
	CPMSME_1	CPMSME_2	CPMSME_3	CPMSME_1	CPMSME_2	CPMSME_3
CPMSME_1	1.0000			1.0000		
CPMSME_2	1.0000**	1.0000		.1741	1.0000	
CPMSME_3	0.0	0.0	1.0000	.5774	-.3015	1.0000

** $p \leq .001$

profile remained the same as it was in generating the AAS predictions, in order to maintain comparability of results. Type of Assistance was set at Moderate-to-High (4) for AERA 2, as a reflection of the increased automated aiding provided by the AERA 2 capabilities. Again, results were generated from individual lower-level ratings supplied by the AERA 2 SMEs (SMEA1, SMEA2, and SMEA3).

Model-based predictions of scenario-level demands on the controller and controller performance in the simulated AERA 2 environment produced the values presented in Table 6-4.

Correlational studies of these sets of values produced the results presented in tables 6-5 and 6-6. Again we see a pattern of consistency in predictions of scenario-level demands, especially for AERA 2 Scenario 1. Consistency in predictions of AERA 2 controller performance is lower, but reaches perfect agreement in two instances, one for each scenario.

Inspection of the data (Table 6-4) indicates that predicted demand for the AERA 2 scenarios ranges from Low-to-Moderate (2) to Moderate-to-High (4). Predicted performance on the AERA 2 scenarios ranges from Moderate (3) to Moderate-to-High (4). Means and standard deviations are as follows (N=4):

	AERA 2 Scenario 1		AERA 2 Scenario 2	
	Mean	Std. Dev.	Mean	Std. Dev.
CWMSMEA1	3.2500	.9574	3.0000	.8165
CWMSMEA2	3.0000	1.1547	3.2500	.5000
CWMSMEA3	3.0000	1.1547	2.7500	.9574
CPMSMEA1	3.5000	.5774	3.5000	.5774
CPMSMEA2	3.2500	.5000	3.5000	.5774
CPMSMEA3	3.2500	.5000	3.2500	.5000

Table 6-4. PATCAM Predictions of AERA2 Workload and Performance*

	DEMAND			PERFORMANCE		
	CWM/SME_{A1}	CWM/SME_{A2}	CWM/SME_{A3}	CPM/SME_{A1}	CPM/SME_{A2}	CPM/SME_{A3}
Scenario 1:						
Perceptual	3	2	2	4	3	3
Analytic	4	4	4	4	4	4
Response	2	2	2	3	3	3
Resource Management	4	4	4	3	3	3
Scenario 2:						
Perceptual	3	4	2	4	4	3
Analytic	3	3	3	4	4	4
Response	2	3	2	3	3	3
Resource Management	4	3	4	3	3	3

*given pre-defined parameter settings:

Visual Skill = 5
Auditory Skill = 3
Analytic Skill = 4
Manual Skill = 5
Verbal Skill = 3
Modality-Switching Skill = 4
Multiplexing Skill = 1
Vigilance = 3
Motivating Potential = 3
AERA 2 Type of Assistance = 4

Scale: 1 = Low
2 = Low to Moderate
3 = Moderate
4 = Moderate to High
5 = High

Table 6-5. Correlational Results for PATCAM's Predictions of AERA2 Workload (N=4)

	AERA2 Scenario 1			AERA2 Scenario 2		
	CWMSME$_{A1}$	CWMSME$_{A2}$	CWMSME$_{A3}$	CWMSME$_{A1}$	CWMSME$_{A2}$	CWMSME$_{A3}$
CWMSME$_{A1}$	1.0000			1.0000		
CWMSME$_{A2}$	$.9045^{+}$	1.0000		0.0	1.0000	
CWMSME$_{A3}$	$.9045^{+}$	1.0000^{**}	1.0000	.8528	-.5222	1.0000

$+$ $p \leq .1$
$**$ $p \leq .001$

Table 6-6. Correlational Results for PATCAM's Predictions of AERA2 Controller Performance (N=4)

	AERA2 Scenario 1			AERA2 Scenario 2		
	CPMSME$_{A1}$	CPMSME$_{A2}$	CPMSME$_{A3}$	CPMSME$_{A1}$	CPMSME$_{A2}$	CPMSME$_{A3}$
CPMSME$_{A1}$	1.0000			1.0000		
CPMSME$_{A2}$	.5774	1.0000		1.0000**	1.0000	
CPMSME$_{A3}$	.5774	1.0000**	1.0000	.5774	.5774	1.0000

** $p \leq .001$

Thus, the Controller Workload Model predicts generally moderate demand levels for both AERA 2 scenarios, and the Controller Performance Model predicts slightly above-average performance in the simulated AERA 2 environment, given the pre-defined controller profile.

6.3 COMPARISONS OF PREDICTED AAS AND AERA 2 WORKLOAD AND PERFORMANCE

Table 6-7 presents the values obtained when PATCAM's predictions of Analytic Demand are generated for AAS Scenario 1 and AERA 2 Scenario 1. Correlational analysis of these data produces a pattern of high consistency between predictions of cognitive demand in both the simulated AAS and AERA 2 environments (Table 6-8).

Table 6-9 presents the values obtained when PATCAM's predictions of Analytic Performance are generated for AAS Scenario 1 and AERA 2 Scenario 1. Correlational analysis of these data produces a pattern of relatively strong consistency between predictions of cognitive performance in both the simulated AAS and AERA 2 environments (Table 6-10).

When predicted values for scenario-level attributes are combined to obtain a value for overall, scenario-level workload and when these results are weighted for the contribution of each scenario to the mission, the results obtained show a near-perfect agreement for predicted AAS and AERA 2 workload (Table 6-11). Model-based results for predicted AAS and AERA 2 performance are identical at the scenario and mission levels (Table 6-12).

Table 6-7. PATCAM Predictions of Analytic Demand*

AAS Scenario 1 vs. AERA2 Scenario 1

Module	CWM/SME$_1$	CWM/SME2	CWM/SME$_3$	CWM/SME$_{A1}$	CWM/SME$_{A2}$	CWM/SME$_{A3}$
1	3	3	2	3	3	3
2	3	3	2	4	4	4
3	2	3	2	3	2	3
4	99**	99**	99**	5	5	5
5	5	5	4	5	4	5
6	4	4	4	4	4	4
7	5	5	5	4	4	4
8	5	5	4	5	5	5
9	5	5	5	5	5	5
10	5	5	5	5	5	5
11	5	5	5	5	5	5
12	5	5	5	5	5	5
13	4	4	4	4	4	4
14	4	4	4	4	3	3
15	4	4	4	4	4	4
16	3	3	3	4	4	4

*given pre-defined parameter settings:
AAS Type of Assistance = 3
AERA2 Type of Assistance = 4
**99 = missing data

Scale: 1 = Low
2 = Low to Moderate
3 = Moderate
4 = Moderate to High
5 = High

Table 6-8. Comparison of the Simulated AAS and AERA 2 Environments for the Predicted Analytic Demand of Scenario 1 Modules (N=15)

	CWMSME$_1$	CWMSME$_2$	CWMSME$_3$	CWMSME$_{A1}$	CWMSME$_{A2}$	CWMSME$_{A3}$
CWMSME$_1$	1.0000					
CWMSME$_2$	$.9706^{**}$	1.0000				
CWMSME$_3$	$.9142^{***}$	$.9131^{***}$	1.0000			
CWMSME$_{A1}$	$.8677^{***}$	$.8479^{***}$	$.7696^{***}$	1.0000		
CWMSME$_{A2}$	$.8052^{***}$	$.7315^{***}$	$.7277^{**}$	$.8882^{***}$	1.0000	
CWMSME$_{A3}$	$.8007^{***}$	$.7917^{***}$	$.6882^{**}$	$.9435^{***}$	$.9183^{***}$	1.0000

Model-based results for AAS:	Model-based results for AERA 2:
CWMSME$_1$	CWMSME$_{A1}$
CWMSME$_2$	CWMSME$_{A2}$
CWMSME$_3$	CWMSME$_{A3}$

** $p \leq .01$
*** $P \leq .001$

Table 6-9. PATCAM Predictions of Analytic Performance*

AAS Scenario 1 vs. AERA2 Scenario 1

Module	CPM/SME$_1$	CPM/SME2	CPM/SME$_3$	CPM/SME$_{A1}$	CPM/SME$_{A2}$	CPM/SME$_{A3}$
1	3	4	3	3	3	3
2	4	4	3	4	4	4
3	3	3	3	4	3	3
4	99**	99**	99**	4	4	4
5	4	4	4	4	4	4
6	4	4	4	4	4	4
7	3	4	4	4	4	4
8	4	4	4	4	4	4
9	4	4	4	4	4	4
10	4	4	4	4	4	4
11	4	4	4	4	4	4
12	4	4	4	4	4	4
13	4	4	3	4	4	4
14	4	4	4	4	4	4
15	4	4	4	4	4	4
16	4	4	3	4	4	4

*given pre-defined parameter settings:

Visual Skill = 5
Auditory Skill = 3
Analytic Skill = 4
Manual Skill = 5
Verbal Skill = 3
Modality-Switching Skill = 4

Multiplexing Skill = 1
Vigilance = 3
Motivating Potential = 3
AAS Type of Assistance = 3
AERA 2 Type of Assistance = 4

**99 = missing data

Scale: 1 = Low
2 = Low to Moderate
3 = Moderate
4 = Moderate to High
5 = High

Table 6-10. Comparison of the Simulated AAS and AERA 2 Environments for the Controller's Predicted Analytic Performance on Scenario 1 (N=15)

	CPMSME_1	CPMSME_2	CPMSME_3	CPMSME_{A1}	CPMSME_{A2}	CPMSME_{A3}
CPMSME_1	1.0000					
CPMSME_2	$.5345^{*}$	1.0000				
CPMSME_3	.3536	.3780	1.0000			
CPMSME_{A1}	$.5345^{*}$	-.0714	.3780	1.0000		
CPMSME_{A2}	$.5833^{*}$	$.5345^{*}$	.3536	$.5345^{*}$	1.0000	
CPMSME_{A3}	$.7845^{***}$	$.6814^{**}$	$.5547^{*}$	$.6814^{**}$	$.7845^{***}$	1.0000

Model-based results for AAS:	Model-based results for AERA 2:
CPMSME_1	CPMSME_{A1}
CPMSME_2	CPMSME_{A2}
CPMSME_3	CPMSME_{A3}

* $p \leq .05$
** $p \leq .01$
*** $P \leq .001$

Table 6-11. Model-Based Predictions of Simulated AAS and AERA2 Controller Workload*

	Predicted AAS Controller Workload			vs.	Predicted AERA 2 Controller Workload		
	CWM/SME$_1$	CWM/SME$_2$	CWM/SME$_3$		CWM/SME$_{A1}$	CWM/SME$_{A2}$	CWM/SME$_{A3}$
Scenario 1	4	4	4		4	4	4
Scenario 2	4	4	3		4	4	4
Mission	4	4	3		4	4	4

* Given Controller Profile:

Visual Skill = Superior (5)
Auditory Skill = Satisfactory (3)
Analytic Skill = Above Average (4)
Multiplexing Skill = Minimally Acceptable (1)
Modality-Switching Skill = Above Average (4)

Type of Assistance:
    AAS = 3
    AERA2 = 4
Vigilance = 3
Motivating Potential = 3

Scale: 1 = Low
2 = Low to Moderate
3 = Moderate
4 = Moderate to High
5 = High

Table 6-12. Model-Based Predictions of Simulated AAS and AERA 2 Controller Performance.*

	Predicted AAS Controller Performance			vs.	Predicted AERA2 Controller Performance		
	CPM/SME$_1$	CPM/SME$_2$	CPM/SME$_3$		CPM/SME$_{A1}$	CPM/SME$_{A2}$	CPM/SME$_{A3}$
Scenario 1	3	3	3		3	3	3
Scenario 2	3	3	3		3	3	3
Mission	3	3	3		3	3	3

* Given Controller Profile:

Visual Skill = Superior (5)
Auditory Skill = Satisfactory (3)
Analytic SKill = Above Average (4)
Multiplexing Skill = Minimally Acceptable (1)
Modality-Switching Skill = Above Average (4)

Type of Assistance:
AAS = 3
AERA2 = 4
Vigilance = 3
Motivating Potential = 3

Scale: 1 = Low
2 = Low to Moderate
3 = Moderate
4 = Moderate to High
5 = High

Inspection of the simulation logs for the AAS and AERA 2 simulation runs indicates a considerable increase in the number of tasks and modules completed by the AERA 2 controller (Table 6-13). These increases range from 15.9% for tasks completed in Scenario 2 to 48.1% for modules completed in Scenario 1.

6.4 DISCUSSION OF AAS AND AERA 2 COMPARISONS

What appears to be happening in the AERA 2 simulations is related to Geer's (1981) definition of workload as the ratio of time required to time available for task completion. It appears that the AERA 2 capabilities, as reflected in the AERA 2 scenarios, allow the simulated AERA 2 controller to complete more tasks and modules than the simulated AAS controller is able to complete in the same amount of simulation time. Because the overall time required is reduced in the AERA 2 scenarios, the AERA 2 controller has time available to do more, to deal with additional ATC situations.

The results for predicted AERA 2 workload and performance, as compared to predicted AAS workload and performance, indicate no change, for the controller profile on which the results are based. One interpretation is that the simulated AERA 2 controller is enabled to do more, with no increase in predicted workload, yet no improvement in predicted performance. On the one hand, the simulated AERA 2 controller can complete more tasks and deal with more ATC situations (modules), without increasing workload over AAS levels. If this result is borne out by performance data, it will lend support to the value of the AERA 2 capabilities in improving controller productivity. On the other hand, since there is no predicted change in performance between the

Table 6-13. Percentage Increases in Number of Tasks and Modules Completed by the Simulated AERA 2 Controller As Compared to the Simulated AAS Controller

	Scenario 1			Scenario 2		
	AAS	AERA 2	% Increase	AAS	AERA 2	% Increase
Tasks Completed	174	240	37.9%	207	240	15.9%
Modules Completed	27	40	48.1%	31	40	29.0%

simulated AAS and AERA 2 controllers, error rates can be expected to remain constant. Thus, the model predicts an absolute increase in number of errors with AERA 2 simply because there is more opportunity for error. This prediction needs to be tested empirically.

The comparative results for the AAS and AERA 2 were based, in part, on the assumptions that AERA 2 will increase automated aiding to the controller and that all AERA 2 tasks should be rated "High" for Error Criticality. It may be that the high error criticalities for the AERA 2 tasks partially offset the benefits of increased decision aiding. The point here is that the simulation results depend heavily on the simulation parameter settings and the lower-level attribute values. The PATCAM user might want to ask "what if" questions by varying the settings for the controller profiles and sector conditions.

A further note of caution about interpretation of the results is that the simulated controllers complete task sequences. One task is completed before another is initiated. Parallel processing or timesharing occurs within tasks in the sense that task elements are performed concurrently (i.e., interfaces are accessed in parallel per task). Extension of the model to include across-task resource conflicts (North, 1985) can be expected to increase simulation fidelilty and the sensitivity of model-based predictions. Enhancement of simulation fidelity is discussed in more detail in Section 7.

The comparisons that have been made in Section 6 are offered purely as indicators of PATCAM capabilities. They are the kinds of comparisons that can be made using the current PATCAM databases and functions. Because the AAS and

AERA 2 operations concepts have evolved since the PATCAM baselines were established, the PATCAM databases would need to be updated before any firm conclusions could be drawn about the full AAS and AERA 2 systems in terms of relative controller workload and performance.

SECTION 7 - DISCUSSION AND RECOMMENDATIONS FOR FURTHER RESEARCH AND DEVELOPMENT

Previous research indicates that the relationship between workload and performance is non-linear. The present research represents performance as a function of a demand-skill tradeoff, moderated by job-related and attentional factors. Results of the validation studies indicate that PATCAM can be considered as an expert predictor of analytic demand and performance. Additional research and development are recommended to enhance similar fidelity and to implement the full PATCAM concept.

7.1 DISCUSSION

Previous efforts to assess the effects of automation have taken place after increasingly automated systems have become operational (e.g., Bainbridge, 1987; Melton et al., 1976). In a study designed to assess the effects of the computer-based Automated Radar Terminal Systems-III (ARTS-III), researchers reported that total stress increased with the introduction of increased automation (Melton et al., 1976). According to the authors, the increased stress was not attributable to increased workload because measures of workload showed either an insignificant change or a net decrease in workload as a result of ARTS-III. Decreases in workload were attributed to reduction of coordination between controllers, flight-strip management, and radar and radio equipment adjustments. While these aspects of workload were decreasing, the number of controlled aircraft increased by 3-4% and the number of contacts per aircraft increased by 1-4% at the two facilities participating in the study (Melton et al., 1976). Perhaps the increased stress resulted from the absolute increase in air traffic and ground-to-air/air-to-ground communication.

The predictions generated by the present research suggest that increased automation can be expected to allow the controller to complete goal-oriented sets of tasks more quickly. The controller is then freed to respond to additional ATC situations (i.e., to do more in the same amount of time).

If handling increased numbers of aircraft, in absolute terms, is stressful to controllers, it may be associated with increased error rates. A study performed by Langan-Fox and Empson (1985) found that handling of aircraft under forced-pace conditions increased error rates by three to six orders of magnitude.

Figure 7-1 illustrates the expected relationships between workload, available resources, and performance. When demand is too low, no matter how high resource availability, performance is prone to error. Conversely, when demand is too high and resources are low-to-moderate, performance is poor. The best performance is obtained, for all resource availabilities, when demand increases in proportion with resources, with demand staying in a below-moderate to moderate range. Increases in demand are associated with increased anxiety levels (Smith & Melton, 1974), which can contribute to inefficient problem-solving performance. As described by these authors, "ATC work even at its least demanding is still somewhat anxiety-arousing" (p. 600). The PATCAM algorithms incorporate the effects of these relationships between workload, resource availability, anxiety, and performance.

The research and development conducted in Phase II demonstrate that it is possible to make systematic

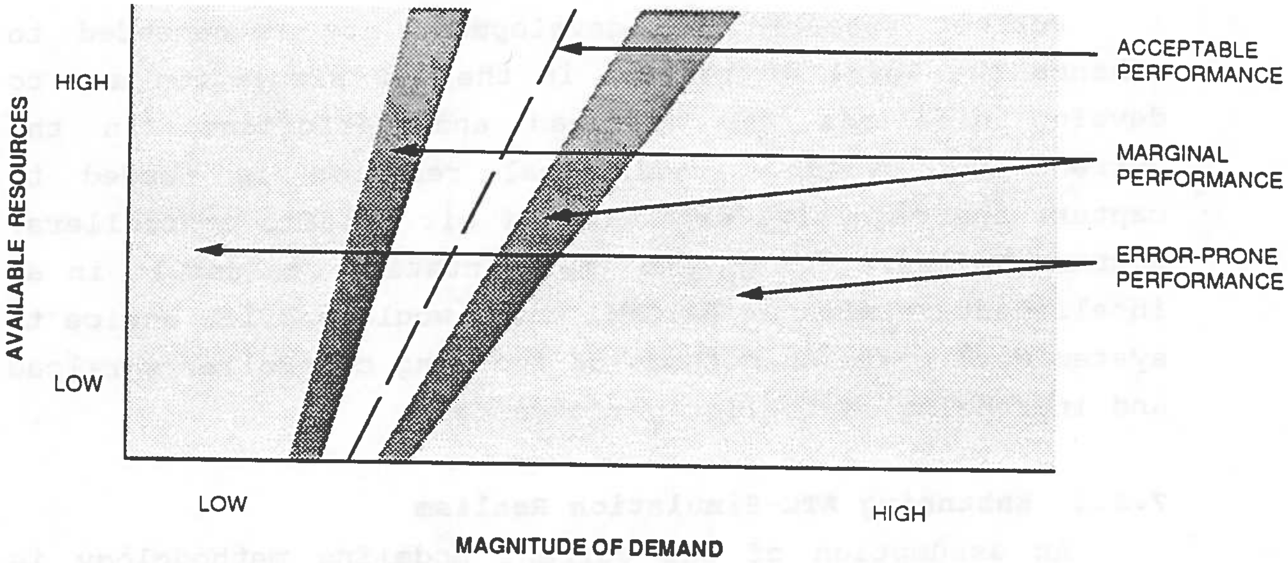

Figure 7-1. Framework for conceptualizing the relationship between workload, available resources, and performance. *(Adapted from Bikson, 1987)*

projections of the workload and performance effects of planned system capabilities prior to design. The validity of these projections appears to be strongest for analytic demand and performance. In these areas, PATCAM can be used as an expert predictor.

7.2 RECOMMENDATIONS FOR FURTHER RESEARCH

Further research and development are recommended to enhance the level of realism in the ATC simulation and to develop baselines for workload and performance in the current ATC system. Additional research is needed to capture the cognitive expertise of air traffic controllers. Further software design and implementation can result in an intelligent version of PATCAM, which would provide advice to system developers on methods of reducing controller workload and increasing controller performance.

7.2.1 Enhancing ATC-Simulation Realism

An assumption of the current modeling methodology is that a task is accomplished by concurrent or time-shared performance of its task elements. Further refinement would allow the methodology to represent overlapping or concurrent tasks. Overlapping tasks might occur not only within scenario modules but also across scenario modules, just as they occur in the real-world ATC environment.

Other concepts for increasing realism include the following:

- allocate tasks between R and D controllers, in order to obtain separate workload and performance estimates for crew members
- include a weighting factor for task difficulty to allow finer discrimination between tasks in their contributions to module-level attributes

- consider other situational variables (e.g., equipment failure, aircraft emergencies)
- investigate the role of informal communication between crew members and sectors
- include additional attributes of air traffic controller performance (e.g., social-psychological characteristics, such as organizational climate)

7.2.2 Baselining the Current System

Currently, PATCAM permits comparison between two task databases: the AAS database and the AERA 2 database. Thus, a set of predictions based on AAS expert ratings is used as a baseline for evaluation of the AERA 2 predictions. Development of a baseline for the current system would permit incremental comparison of the NAS transition states. For example, the Initial Sector Suite System (ISSS) capabilities could be compared with those of the current system in terms of controller workload and performance. Later transition states could then be compared with added confidence in the results.

Since the future transition states are, by definition, not yet operational, it is not possible to collect performance data to validate PATCAM's algorithms. If the criterion for validation of a performance model is "performance itself," there is a need to establish a performance baseline for the current system (Wickens, Harwood, Segal, Tkalcevic, & Sherman, 1988, p. 171). PATCAM's algorithms should be applied to a representation of the current system and tested against performance data collected on the current system to increase confidence in the validity of predictive output.

7.2.3 Capturing Cognitive Expertise

A major area for further investigation is the role of cognitive structures in the outcome of critical ATC incidents. The investigation of "mental interfaces" by the current research suggests that a rich repository of expertise is waiting to be documented. Elicitation and representation of the expert controller's cognitive models can add significantly to an understanding of the effects of new automated capabilities. As concluded by Hahn (1988), "cognitive models...are correlated with performance, and...there are performance differences among models" (p. 878). Once they are identified, cognitive models that support superior performance can be used in training developmental controllers.

Other important areas for further investigation are the role of planning for sector management and the controller's development and use of knowledge-based strategies when necessary to go beyond predefined procedures. Experienced controllers report their reliance on a plan for managing the sector as opposed to operating in a reactive mode in response to ATC events as they occur. In addition to supporting refinement of the modeling methodology, documentation of sector-management plans could support training of developmental controllers on specific sectors. Similarly, documentation of knowlege-based strategies could enhance predictive modeling, interface design, and developmental training.

7.2.4 Making PATCAM an Intelligent Tool

In its current implementation, PATCAM permits the user to generate workload and performance predictions based on task analytic data. These predictions can be used to identify potential trouble spots in a proposed system. Once trouble spots are identified, their resolution is the responsibility of the PATCAM user (e.g., a system designer). A next step would be to develop an expert advisor to the PATCAM user.

Using various techniques from artificial intelligence, knowledge-base development would allow PATCAM to emulate not only the ATC subject-matter-expert, but also the expert analyst and system designer.

The potential benefits of developing PATCAM's full capabilities have been demonstrated by the Phase II research. The feasibility of further development is addressed in Section 8.

SECTION 8 - ESTIMATES OF FEASIBILITY

The Phase II research and development has shown the feasibility of developing the PATCAM concept. The practical issues must be addressed, however, before full implementation can be considered feasible.

8.1 FEASIBILITY OF FULL IMPLEMENTATION WITH CURRENT HARDWARE CONFIGURATION

The Phase II demonstration is PC-based. Because of computer memory and processing limitations, full implementation of PATCAM is not feasible with the current configuration. Significantly expanded computer power and storage will be needed to handle the expanded data bases, which are required for full representation of the current system, AAS, and AERA 2, and other NAS transition states.

8.2 FEASIBILITY OF FULL IMPLEMENTATION WITH UPGRADED CONFIGURATION

If upgraded hardware and processing capabilities were available, it would be entirely feasible to develop a complete database for the current system as a baseline for comparison with later transition states. It would also be feasible to develop the enhanced PATCAM capabilities described in Section 7.

8.3 CONCLUSION

The Phase II research and development has demonstrated PATCAM's capabilities and potential benefits. By modeling the contributors to controller workload and performance, PATCAM can answer questions about the effects on the controller of planned changes in levels of ATC automation. PATCAM has been shown to be an especially proficient, expert predictor of analytic demand (i.e., mental workload). Use of a fully developed PATCAM engineering tool, prior to system design and implementation, can help to calibrate analytic demand in such a way that the controller’s analytic resources are neither overloaded nor underloaded. By assessing analytic demand and identifying potential instances of overload or underload, PATCAM can contribute to a reduction in the rate of operational errors associated with fluctuating levels of mental workload.

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APPENDIX A

GLOSSARY

Algorithm	a mathematical expression used to combine or aggregate values for several cases of a single component of the CWM/CPM hierarchy (e.g., to calculate a value for Analytic Processing Demand across all the tasks in a module); a combining algorithm may incorporate weighting factors and/or intermediate values derived by a tree-climbing algorithm.
Analytic Action Demand (TS)	a scale value derived by expert rating of analytic task verbs; an index of the demand imposed by the nature of the mental activity required apart from the interface(s) included in the task statement.
Analytic Complexity (IS)	a scale value derived by expert rating of interfaces for the load they impose on the controller's analytic processing resources.
Analytic Demand (C)	the combined demand, across all the modules in a scenario, for analytic processing (e.g., mental projection or transformation of data, problem solving, decision making).
Analytic Load (C)	a value for the analytic processing demand imposed by the information associated with a task apart from the action required; determined by Analytic Complexity with Type of Assistance acting to reduce the loading if assistance is appropriate.
Analytic Performance (C)	a SCENARIO-level attribute of the CPM; an estimate of the efficiency and effectiveness of mental actions (e.g., memory scanning, mental projection) across all the modules in a scenario.

C = calculated value
CD = condition-dependent value
IS = interface-specific rating
SV = simulation variable
TS = task-specific rating/value

Analytic Processing Demand (C)	problem-solving and decision-making load at the module level, as determined according to computational procedures applied across all the tasks in a module.
Analytic Processing Performance (C)	degree of success in problem solving and decision making, across all the tasks in a module.
Analytic Processing Skill (SV)	an estimate of available problem-solving and decision-making skills in the controller population as a function of education, training, and on-the-job experience; a simulation variable.
ATC Mission (C)	highest level of the CWM/CPM hierarchy; level at which controller workload and performance are predicted across all controller scenarios.
Attribute	a quality or characteristic of a component of the CWM/CPM hierarchy (e.g., some attributes at the module level are Visual Perception Demand, Auditory Perception Demand, Analytic Processing Demand, Verbal Response Demand, and Multiplexing Management Demand).
Auditory Action Demand (TS)	a scale value derived by expert ranking of auditory task verbs; an indicator of the demand imposed by the nature of the listening activity apart from the interface included in the task element statement.
Auditory Complexity (IS)	a scale value derived by expert rating of interfaces for the load they impose on the controller's auditory resources.
Auditory Load (C)	a value for the level of auditory perception required by the information associated with a task apart from the action required; determined by Auditory Complexity with Type of Assistance acting to

	reduce the loading if assistance is appropriate.
Auditory Perception Demand (C)	listening load at the module level, as determined according to computational procedures applied across all the tasks in a module.
Auditory Performance (C)	degree of accuracy in hearing and listening, across all the tasks in a module segment.
Auditory Signal/ Noise Ratio (CD)	the ratio between relevant and irrelevant messages received at an auditory interface; an indication of auditory "clutter"; a function of situational variables.
Auditory Skill (SV)	an estimate of available auditory perception (listening) skills in the controller population as a function of education, training, and on-the-job experience; a simulation variable.
Cognitive Model	a generic knowledge structure that guides the cognitive processes of attention, expectation, inference and interpretation (Graesser & Nakamura, 1982); a memory structure that holds a set of information and maintains the relationships among elements of information for use in reasoning (Allen, 1982); an organizational unit of memory (Norman, 1979).
Combining Algorithm	(See Algorithm)
Component	a segment of the CWM/CPM hierarchy that represents levels of abstraction of the controller's role; in descending order of abstraction, the model's components are ATC MISSION, SCENARIO, MODULE, TASK and INTERFACE.
Composite Auditory Signal/Noise (C)	average auditory signal-to-noise ratio for all the auditory interfaces in a task.

Composite Visual Signal/Noise (C)	average visual signal-to-noise ratio for all the visual interfaces in a task.
Controller Activities Network	PATCAM's internal network simulation model that represents the tasks that an air traffic controller performs. This model resides within PATCAM and is necessary for the simulation. It includes information about the controller task networks, the demands associated with each controller task, and information about what triggers each task.
Controller Performance (C)	output across scenarios in terms of the controller's efficiency and effectiveness; level of controller performance is largely determined by the balance of demands and skills, as moderated by Motivating Potential and Vigilance.
Controller Performance Model (CPM)	the conceptual, theoretical model that is used to compare demands on the controller's resources to the available skills; the CPM also considers the effects of performance-moderating factors, Motivating Potential and Vigilance. This model is represented as a hierarchy of components, attributes, and mathematical expressions.
Controller Workload (C)	extent of resource demands placed on the controller by perceptual, analytic, verbal, and manual procedures and operations, as well as by requirements to parallel process or switch between attentional resources allocated to those procedures and operations.
Controller Workload Model (CWM)	the conceptual, theoretical model that is used to predict demands on the controller's attentional and resource management capacities; this model is represented as a hierarchy of components, attributes, and mathematical expressions.

Effectiveness	accuracy, appropriateness of human performance
Efficiency	timeliness in meeting human performance requirements
Error	slips or mistakes traceable to demands imposed by system capabilities and procedural requirements; a mistake is an inappropriate intention; a slip is an action that was not intended (Lewis & Norman, 1986); sources of error represented in the CWM/CPM are demands for time-sharing and/or parallel processing across resource pools, as well as demands for accurate performance under time pressure; all CWM/CPM attributes are either direct or indirect sources of error.
Error Criticality (TS)	a priority rating based on the consequences that will occur if a task is performed incorrectly; criticality in itself increases the demand for accuracy and timeliness, thus increasing the demand for attentional resources.
Event	an occurrence (in a simulation) that either directly or indirectly alters the state of the system being simulated (e.g., an aircraft entering the sector).
Interface	level of the CWM/CPM at which information is exchanged between the controller and an information source or destination (e.g., logical display, input message category, mental model).
Intermediate Value	a numerical result, determined by a tree-climbing algorithm, for the scale value of an attribute to which multiple attributes contribute; see Algorithm.
Manual Action Demand (TS)	a scale value derived by expert ranking of manual task verbs; an

	indication of the demand imposed by the nature of the manual activity required apart from the interface included in the task statement.
Manual Complexity (IS)	a scale value derived by expert rating of interfaces for the load they impose on the controller's manual resources.
Manual Load (C)	a value for the manual demand associated with information presented by a task apart from the action required; determined by Manual Complexity, with Type of Assistance acting to reduce the loading if assistance is appropriate.
Manual Performance (C)	degree of efficiency and effectiveness in executing physical actions, across all the tasks in a module.
Manual Response Demand (C)	physical load at the module level, as determined according to computational procedures applied across all tasks in a module.
Manual Skill (SV)	physical-manipulation skills in the controller population as a function of education, training, and on-the-job experience; a simulation variable.
Memory Retrieval Demand (TS)	the extent to which a task imposes a demand for retrieval of information from long-term memory as a function of the relative frequency of performance; the assumption is that less frequently performed tasks impose greater demands for long-term memory retrieval.
Modality-switching Demand (CD)	requirement for shifting attention sequentially from one perceptual, processing, or responding resource to another (e.g., from visual to analytic to verbal) in performing a task.

Modality-switching Management Demand (C)	requirement for providing sufficient attentional resources when attention must be shifted sequentially from one perceptual, processing, or responding resource to another (e.g., from visual to analytic to verbal) in performing the tasks grouped within a module.
Modality-switching Management Performance (C)	degree of efficiency and effectiveness in switching attention between perceiving, processing, and responding, across all the tasks in a module.
Modality-switching Skill (SV)	the extent to which the controller is able to switch attention rapidly between perceiving, processing and responding; a simulation variable.
Model	in common usage the term "model" is defined as a generalized or hypothetical representation of some aspect of reality. Two types of models are components of PATCAM: 1) Controller Workload Model/ Controller Performance Model. These are the conceptual, theoretical models that are used to calculate demands on the controller's resources and to predict controller performance. These models can be represented as hierarchies of components, attributes, and mathematical expressions. 2) Controller Activities Network. This is the network simulation model that represents the tasks that an air traffic controller performs. This model resides within PATCAM and is necessary for the simulation. It includes information about the controller tasks, the demands associated with each controller task, and information about what triggers each task.

Module	the level of the CWM/CPM hierarchy at which tasks are grouped into task networks to accomplish an objective; see Appendix B for examples.
Motivating Potential (SV)	the degree to which the controller's job promotes internal work motivation; contributors to Motivating Potential are Skill Variety, Task Identity, Task Significance, Autonomy, and Job Feedback (Hackman & Oldham, 1980).
Multiplexing Demand (CD)	requirement for per task timesharing of attentional resources (e.g., performing visual detection and analytic evaluation at the same time).
Multiplexing Management Demand (C)	requirement for providing sufficient attentional resources when time-sharing of resources is necessary at the module level.
Multiplexing Management Performance (C)	degree of efficiency and effectiveness in time-sharing or parallel processing portions of more than one task, across all the tasks in a module.
Multiplexing Skill (SV)	the extent to which the controller is able to perform parallel processing, i.e., to perform more than one task simultaneously, as in scanning a display for aircraft-to-aircraft conflicts while issuing instructions to a pilot; a simulation variable.
Network	the representation of a simulation data structure that contains both parent-child (hierarchical) and sibling relationships, and may include relationships where a "child" has more than one "parent."
Network Simulation	the simulation of a system that is represented by a network model.
Operations Concept	a description of the operational interaction between the air traffic controller and automated ATC

	capabilities; a structured representation of the controller's role in the overall human-computer ATC system.
Perceptual Demand (C)	the combined demand, across all the modules in a scenario, for visual and auditory perception.
Perceptual Performance (C)	a SCENARIO-level attribute of the CPM; an estimate of the efficiency and effectiveness of visual and auditory perception across all the modules in a scenario.
Performance	levels of efficiency and effectiveness (speed and accuracy) achieved in executing operational duties and responsibilities
Resource Management Demand (C)	the combined demand, across all the modules in a scenario, for efficient and effective allocation of resources when multiplexing and/or modality-switching are required.
Resource Management Performance (C)	a SCENARIO-level attribute of the CPM; an estimate of the efficiency and effectiveness of multiplexing-management and modality-switching management across all the modules in a scenario.
Response Demand (C)	the combined level of Verbal Response Demand and Manual Response Demand for all the modules in a scenario.
Response Performance (C)	a SCENARIO-level attribute of the CPM; an estimate of the efficiency and effectiveness of verbal and manual responses across all the modules in a scenario.
Scenario	a predefined ATC task sequence that has been validated as operationally realistic; a component of the Controller Workload Model (CWM) and the Controller Performance Model (CPM) hierarchies; at this level,

	achievement of the ATC mission is represented by groupings of modules performed by the controller; see Appendix B for examples.
Sector Model	a simulation model describing sector conditions in terms of situational variables (e.g., number of aircraft in the sector, number of weather elements).
Simulation	the process of designing a model of an existing or future system and conducting experiments with this model for the purpose either of understanding the behavior of the system or of evaluating various strategies for the operation of the system; simulation modeling is an experimental and applied methodology that seeks to describe the behavior of systems, construct theories or hypotheses that account for the observed behavior, and use the theories to predict future behavior, that is, the effects that will be produced by changes in the system or in its method of operation (Shannon, 1975).
Simulation Variable	a CWM/CPM attribute to which a range of values (L-M-H) can be assigned by the PATCAM user as input to the CWM/CPM algorithms; examples are Type of Assistance and Vigilance.
Skill	level of ability, proficiency, and expertness in using appropriate knowledge effectively; skill level correlates with speed of performance, error rate, attentional loading, and adaptability (i.e., speed and adaptability increase with skill; error rate and attentional loading decrease with skill).
Snapshot	status of the simulation variables at a specified point in time.

Task	a level of the CWM/CPM hierarchy at which human perceptual, analytic, and responding behaviors are defined according to a task verb taxonomy and a set of data objects (CTA, 1988); a task is a goal-directed, ordered, time-bounded sequence of psychomotor and/or cognitive actions.
Task Network	(see Module)
Time Pressure (CD)	the ratio of time required to time available to perform a task element; often used as a definition of workload (Geer, 1981; Meister, 1985); in the PATCAM simulation, a function of number of aircraft, number of conflicts, and number of special use airspace and weather elements in a sector.
Tree-climbing Algorithm	in the PATCAM context, a tree-climbing algorithm is a method for converting the ratings of multiple attributes into a single, intermediate value; for example, values for Visual Complexity and Type of Assistance are combined by a tree-climbing algorithm, which is applied to each interface in a task, yielding a separate, intermediate value for each interface; then, these intermediate values are combined algorithmically by a tree-climbing algorithm to produce a value for the task's visual load.
Trigger	the condition that causes or activates a simulation event (or execution of a task)
Type of Assistance (SV)	support provided by interface-level capabilities such as data presentation/data management techniques; a simulation variable.
Verbal Action Demand (TS)	a scale value derived by expert ranking of verbal task verbs; an indicator of the demand imposed by the nature of the verbal activity apart from the object included in the

	task statement.
Verbal Complexity (IS)	a scale value derived by expert rating of interfaces for the load they impose on the controller's verbal resources.
Verbal Load (C)	a value for the psycholinguistic demand imposed by verbal tasks apart from the action required; determined by Verbal Complexity, with Type of Assistance acting to reduce the loading if assistance is appropriate.
Verbal Performance (C)	degree of speed and accuracy in communicating orally with others (e.g., pilots, other controllers), across all the tasks in a module.
Verbal Response Demand (C)	outgoing communication load at the module level, as determined according to computational procedures applied across all the tasks in a module.
Verbal Skill (SV)	an estimate of available communication skills in the controller population as a function of education, training, and on-the-job experience; a simulation variable.
Vigilance (SV)	the extent to which the controller is able to remain attentive and alert; a simulation variable.
Visual Action Demand (TS)	a scale value derived by expert ranking of visual task verbs; an indicator of the demand imposed by the nature of the visual activity apart from the object acted upon.
Visual Complexity (IS)	a scale value derived by expert rating of interfaces for the load they impose on the controller's visual resources.
Visual Load (C)	a value for the visual demand imposed by data presented on the controller's visual displays apart from the action required; determined by Visual Complexity, with Type of Assistance

	acting to reduce demand if assistance is appropriate.
Visual Perception Demand (C)	loading on visual resources at the module level, as determined according to computational procedures applied across all the tasks in a module.
Visual Performance (C)	degree of speed and accuracy in recognizing data objects that are displayed visually, across all the tasks in a module.
Visual Signal/Noise Ratio (CD)	the ratio between relevant and irrelevant data presented at a visual interface; an indication of visual "clutter"; a function of situational variables.
Visual Skill (SV)	an estimate of available visual perception skills in the controller population, as a function of education, training, and on-the-job experience; a simulation variable.
Weighting Factors	variables used to load the contribution of each instance of a lower-level component to its higher-level parent component (e.g., to compute the contribution of each task to its parent module as a function of performance time); loadings are based on task durations.
Workload	demands on the air traffic controller that originate in characteristics of presented information and characteristics of required mental and psychomotor responses.

APPENDIX B

BASELINE SCENARIOS

AAS SCENARIOS

ADVANCED AUTOMATION SYSTEM (AAS):

BASELINE OPERATIONAL SCENARIOS

Two baseline operational scenarios and a monitoring macro for an en route, high altitude sector are provided. The scenarios were built from the expanded operational scenarios in the July 1987 edition of the *FAA Air Traffic Control Operations Concept* (DOT/FAA/AP-87-01, Vol. II, Appendix H). These scenarios focus on ATC tasks that may be considered for support by increased automation. They have been used as baselines for estimating demand on controller resources in the AAS environment.

The scenarios should be viewed independently; activity, weather, etc., in one scenario have no bearing on another baseline scenario. The routine, on-going monitoring tasks that a controller performs are presented together separately, before either of the scenarios. Monitoring is incorporated with each scenario, as time permits.

The scenarios concern sector 80, an en route, high altitude sector at a fictitious Denver Center. This sector exchanges traffic with four adjacent high-altitude sectors (Sectors 90, 91, 92, and 93) and three low-altitude sectors (Sectors 71, 72, and 77). Included in the sector are two navigational aids, VHF Omnidirectional Range Tactical Air Navigation (VORTACs) ESB and HLA. Figure B-1 shows the fictitious airspace structure assumed for these scenarios.

The AAS scenarios and the AAS monitoring macro have been reviewed and validated by the SSRVT. The task durations, given in seconds, are estimates provided by the SSRVT. Each scenario is made up of a set of task groupings or modules. In each module, the controller responds in a tactical mode to an ATC event or performs strategic operations such as monitoring or sector workload assessment.

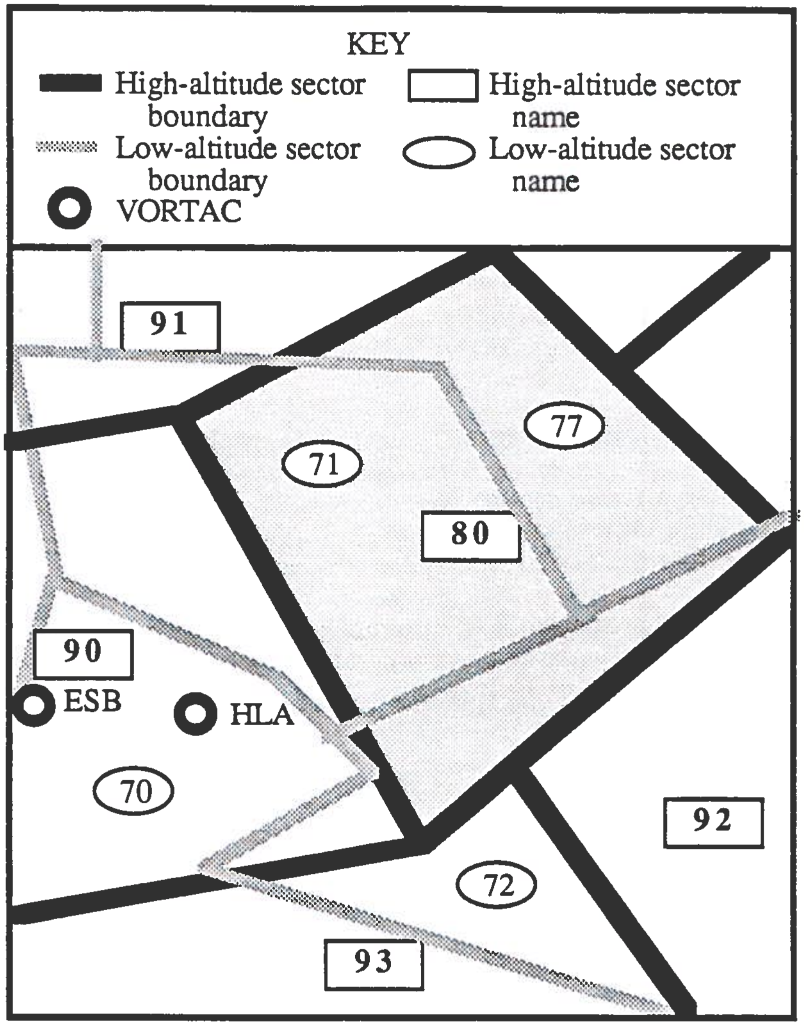

Figure B-1. Operational scenario sector airspace diagram adapted from FAA (1987), Vol. I, pg. B-1.

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: MONITORING MACRO

DUR*	SITUATION OR TASK		Module
	Aircraft Enters Sector		(1)
2 **	4.6.1	Receive handoff request	
2	4.6.6	Determine response to handoff request	
2	4.6.4	Accept automatic handoff	
5	4.13.6	Receive initial radio contact from pilot	
10	1.6.11	Enter FDE notations	
5	3.5.1	Validate Mode C altitude	
	Monitoring for Conflicts		(2)
5 +	1.1.1	Review Flight Data Display for present and/or future aircraft separation	
5 +	1.1.2	Review Situation Display for potential violation of aircraft separation standards	
10	1.6.11	Enter FDE notations	
5	1.1.4	Project mentally an aircraft's future position/ altitude/path	
5 +	1.1.12	Review Situation Display for potential violation of airspace separation standards	
5 +	1.1.13	Review display for potential violation of flow restriction	
5	1.1.14	Review display for potential violation of conformance criteria	
5 +	1.1.7	Determine whether aircraft may be separated by less than prescribed minima	
5	1.1.16	Determine whether conformance criteria may be violated	
5 +	1.1.15	Determine whether airspace separation standards may be violated	
5	1.1.17	Determine whether flow restrictions may be violated	
	Aircraft Leaves Sector		(3)
2	4.7.2	Observe automatic initiation of handoff	
5	4.7.4	Receive handoff acceptance	
2 **	4.13.4	Determine frequency in use by receiving sector	

*Duration in Seconds
**High Memory Retrieval Demand
+ High Error Criticality

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: MONITORING MACRO

DUR*	SITUATION OR TASK		Module
10	4.13.5	Issue change of frequency to pilot	
10	1.6.11	Enter FDE notations	
10	4.7.8	Verify aircraft leaving sector	
	Housekeeping		(4)
4**	1.6.1	Offset a data block	

*Duration in Seconds
**High Memory Retrieval Demand
+ High Error Criticality

AAS SCENARIO 1

The following scenario is for an AAS controller in an en route, high altitude sector. The tasks are listed in order of occurrence. At the beginning of the scenario there is a restricted airspace.

Flight UA522 conflicts with a restricted airspace, requiring the controller to resolve the conflict. After resolving the airspace conflict, the controller evaluates his workload. The controller detects a potential aircraft conflict between EA124 and CA024, but before the conflict can be resolved, another flight, UA105, encounters severe air turbulence and requests a change in altitude. The controller issues a clearance to UA105. The controller amends the aircraft's flight plan and passes on the weather information. Returning to the aircraft-to-aircraft conflict, the controller reviews the situation for resolution. The controller detects and resolves Flight AA321 lateral nonconformance using trial planning. The aircraft conflict between EA124 and CA024 is also processed using trial planning. The controller clears a change in altitude with controller(s) of nearby sector(s), along the immediate flight path of CA024 before issuing a clearance. A special use airspace in the sector becomes unrestricted, allowing the controller to provide Flight UA005 with a previously denied user-preferred route.

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
	Scenario Begins		
		(Monitoring 1-3 minutes)	
	Flight UA522 Conflicts with Airspace		(5)
15 **	4.11.12	Receive alert of predicted problem with specified plan	
5 **+	2.3.6	Determine validity of airspace conflict notice or indication	
10 **	2.1.7	Review potential conflict situation for resolution	
5 **	4.11.7	Request Quick Trial Planning	
15 **	4.11.17	Request Airspace Conflict Display	
15 **	2.3.8	Determine appropriate action to resolve airspace conflict situation	
15	4.10.4	Formulate clearance with appropriate instructions	
15	4.10.5	Issue clearance and instructions to pilot	
15	4.5.3	Enter Flight Plan Amendment	
15	1.6.11	Enter FDE Notations	
15	4.10.7	Verify aircraft compliance with clearance	
		(Monitoring 1-2 minutes)	
	Managing Personal Workload		(6)
15 **	6.8.2	Evaluate workload factors not included in automated information	
15 **	6.8.5	Request sector workload predictions	
10 **	6.8.6	Evaluate sector workload predictions	
15 **	6.8.1	Determine impending controller overload	
		(Monitoring 1-1.5 minutes)	
	Controller detects potential Aircraft (EA124) to Aircraft (CA024) Conflict		(7)
10 **+	2.1.9	Perceive potential aircraft conflict situation	
10 **	2.1.7	Review potential conflict situation for resolution	

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
	(Monitoring 0-.5 minutes)		
	Aircraft (UA105) Encounters Severe Turbulence and Requests Altitude Change		(8)
10 **	5.1.8	Receive PIREP on weather	
10	4.1.2	Receive clearance request from pilot	
40	1.1.4	Project mentally an aircraft's future position/altitude/path	
60	4.1.17	Evaluate mental flight plan projection for appropriateness	
15	4.1.5	Request clearance/approval from another controller *(controller for sector 92)*	
15	4.10.4	Formulate a clearance with appropriate instructions	
10	4.10.5	Issue clearance and instructions to pilot	
15	1.6.11	Enter FDE Notations	
15	4.10.7	Verify aircraft compliance with clearance	
10 **	5.1.4	Enter PIREP into system	
	(Monitoring 1-2 minutes)		
	Looking for Aircraft (EA124) to Aircraft (CA024) Conflict Resolution		(9)
10 **	2.1.7	Review potential conflict situation for resolution	
	(Monitoring 0-.5 minutes)		
	Processing (Lateral) Non-Conformance of Flight AA321		(10)
5 **	3.2.6	Detect lateral/altitude non-conformance indication	
10 **	3.2.11	Evaluate lateral non-conformance indication for action needed	
15 **	4.10.8	Query pilot regarding conformance with clearance	
5 **	3.2.7	Request Reconformance Aid	
15 **	3.2.8	Evaluate trial plan generated by reconformance aid for appropriate atitude/route	
10 **	3.2.3	Determine maneuver to establish/restore flight plan conformance	

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
25	4.10.4	Formulate clearance with appropriate instructions	
20	4.10.5	Issue clearance and instructions to pilot	
10	4.5.3	Enter Flight Plan Amendment	
15	4.10.7	Verify aircraft compliance with clearance	
		(Monitoring 0-.5 minutes)	
		Processing Aircraft (EA124) to Aircraft (CA024) Conflict	(11)
15 **	2.1.7	Review potential conflict situation for resolution	
20 **+	2.1.8	Determine appropriate action to resolve conflict situation	
10 **	4.11.1	Determine need for Trial Planning	
30 **	4.11.2	Request specified plan(s) for aircraft (CA024)	
10 **	4.11.3	Review retrieved plan(s) for correctness/appropriateness to traffic situation	
5 **	4.11.6	Enter Trial Plan Amendment	
15 **	4.11.13	Receive trial plan notice of no conflict/restriction violation	
10 **	4.11.9	Evaluate trial planning results for correctness/ appropriateness to traffic situation	
10 **	4.11.15	Enter Trial Plan save	
		Processing Pointout and APREQ for EA124 and CA024 (who will be in Sector 92)	(12)
15 **	4.8.1	Initiate Pointout	
10	4.8.4	Receive acceptance of pointout	
10 **	4.12.1	Inhibit automatic handoff for designated tracks (EA124 and CA024)	
25	4.10.4	Formulate a clearance with appropriate instructions (for CA024)	
5 **	4.10.1	Select Trial Plan for implementation	

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
15	4.1.5	Request clearance/approval from another controller (controller for sector 92)	
15	4.1.6	Receive clearance approval/clearance restriction from another controller *(controller for sector 92)*	
	Issuing Clearance to CA024 to resolve conflict		(13)
15	4.10.5	Issue clearance and instructions to pilot (CA024)	
15	1.6.11	Enter FDE Notations	
15	4.10.7	Verify aircraft compliance with clearance	
	Manual Handoff of EA124 and CA024 to Sector 92		(14)
5 **	4.7.9	Detect manual handoff mode indication	
10 **	4.7.1	Initiate handoff function (EA124)	
10	4.7.4	Receive handoff acceptance	
10 **	4.7.1	Initiate handoff function (CA024)	
10	4.7.4	Receive handoff acceptance	
	(Monitoring .5-1 minute)		
	Restriction on Special Use Airspace is Lifted		(15)
5 **	3.3.5	Observe display of Airspace Restriction Status change	
	Processing Aircraft (UA005) User-Preferred Route		(16)
5 **	4.11.1	Determine need for trial plan	
5 **	4.11.2	Request specified plan(s) for aircraft	
15 **	4.11.4	Review retrieved plan(s) for correctness/appropriateness to traffic situation	
15	1.1.4	Project mentally an aircraft's future position/altitude/path	
15	4.1.17	Evaluate mental flight plan projection for appropriateness	

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
15	4.1.11	Determine appropriate mental or automated plan for aircraft clearance	
30	4.10.4	Formulate clearance with appropriate instructions	
5 **	4.10.1	Select trial plan for implementation	
15	4.10.5	Issue clearance and instructions to pilot	
10	1.6.11	Enter FDE Notations	
10	4.10.7	Verify aircraft compliance with clearance	
	(Monitoring 0-3 minutes)		
	Scenario Ends		

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AAS SCENARIO 2

The following scenario is for an AAS controller in an en route, high altitude sector. The tasks are listed in order of occurrence.

Throughout the scenario, the controller performs normal monitoring, as time permits.

Flight UA111 has a predicted noncompliance with a flow restriction. The controller uses trial planning to resolve the flow restriction noncompliance. Testing of the trial plan indicates an aircraft conflict, requiring the trial plan to be amended using quick trial planning. The controller evaluates sector workload and responds to a computer-generated reminder to issue a clearance to UA111. The controller detects and resolves non-conformance for Flight NE120. The controller also processes a user-preferred route for aircraft NJ225. Approval is sought from the controller of sector 90 before clearance is granted. The controller is alerted to an imminent aircraft conflict between flights AA221 and NJ532. The conflict is resolved by issuing a clearance to change altitude of NJ532.

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK		Module
	Scenario Begins		
		(Monitoring 1-3 minutes)	
	Processing Flow Restriction Noncompliance for UA111		(17)
15 **	4.11.12	Receive alert of predicted problem with specified plan	
15 **	3.1.15	Determine validity of flow restriction violation indication	
5 **	3.1.4	Review options to bring aircraft into conformance with traffic management restrictions	
5 **	4.11.1	Determine need for trial plan	
5	4.1.17	Evaluate mental flight plan projection for appropriateness	
10 **	4.11.2	Request specified plan(s) for aircraft	
5 **	4.11.6	Enter trial plan amendment	
5 **	4.11.12	Receive alert of predicted problem with specified plan	
5 **	4.11.11	Evaluate alert of predicted problem with specified plan against flight plan/traffic/weather	
5 **	4.11.17	Request Airspace Conflict Display	
5 **	4.11.7	Request Quick Trial Planning	
5 **	4.11.9	Evaluate trial planning results for correctness/ appropriateness to traffic situation	
20 **	4.11.15	Enter trial plan save	
25	4.1.11	Determine appropriate mental or automated plan for aircraft clearance	
5	4.10.4	Formulate clearance with appropriate instructions	
10 **	4.10.1	Select trial plan for implementation	
15	4.10.5	Issue clearance and instructions to pilot	
15	4.5.3	Enter Flight Plan Amendment	
10	4.10.7	Verify aircraft compliance with clearance	

*Duration in Seconds
**High Memory Retrieval Demand

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK		Module
		(Monitoring 1-2.5 minutes)	
	Managing Personal Workload		(18)
15 **	6.8.2	Evaluate workload factors not included in automated information	
5 **	6.8.5	Request sector workload predictions	
15 **	6.8.6	Evaluate sector workload predictions	
15 **	6.8.1	Determine impending controller overload	
		(Monitoring .5 minute)	
	Computer-Generated Reminder of Needed Actions for UA111		(19)
5	4.1.9	Receive computer-generated reminder notice on clearance	
15	4.10.4	Formulate clearance with appropriate instructions	
15	4.10.5	Issue clearance and instructions to pilot	
25	1.6.11	Enter FDE notations	
10	4.10.7	Verify aircraft compliance with clearance	
		(Monitoring 2-3.5 minutes)	
	Processing Nonconformance of Flight NE120		(20)
5 **	3.2.6	Detect lateral/altitude nonconformance indication	
15 **	3.2.11	Evaluate lateral nonconformance indication for action needed	
5 **	3.2.9	Request Display of FDE for flight plan	
15	3.2.10	Evaluate flight data to determine future course of action	
15 **	4.10.8	Query pilot regarding conformance with clearance	
5 **	3.2.7	Request Reconformance Aid	
15 **	3.2.8	Evaluate trial plan generated by reconformance aid for appropriate altitude/route	
15 **	3.2.3	Determine maneuver to establish/retsore flight plan conformance	

*Duration in Seconds
**High Memory Retrieval Demand

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK		Module
10	4.10.4	Formulate clearance with appropriate instructions	
15 **	4.10.1	Select trial plan for implementation	
25	4.10.5	Issue clearance and instructions to pilot	
10	4.10.7	Verify aircraft compliance with clearance	
		(Monitoring 1-2 minutes)	
	Processing User-Preferred Route for Flight NJ225		(21)
5 **	4.5.11	Receive requested flight plan change	
5 **	4.11.1	Determine need for trial plan	
5 **	4.11.2	Request specified plan(s) for aircraft	
15 **	4.11.4	Review retrieved plan(s) for correctness/appropriateness to traffic situation	
15	1.1.4	Project mentally an aircraft's future position/altitude/path	
15	4.1.17	Evaluate mental flight plan projection for appropriateness	
5	4.1.16	Formulate controller plan of action for clearance generation	
15	4.1.5	Request clearance/approval from another controller	
15	4.1.6	Receive clearance/approval from another controller	
20	4.10.4	Formulate clearance with appropriate instructions	
15	4.10.5	Issue clearance and instructions to pilot	
15	1.6.11	Enter FDE Notations	
10	4.10.7	Verify aircraft compliance with clearance	
		(Monitoring 3-4 minutes)	
	Processing Aircraft (AA221) to Aircraft (NJ532) Conflict		(22)
5 **+	2.1.1	Detect aircraft conflict alert indication	
5 **	2.1.2	Determine validity of potential aircraft conflict notice or indication	
5 **+	2.1.8	Determine appropriate action to resolve conflict situation	
5	4.10.4	Formulate a clearance with appropriate instructions (NJ532)	

*Duration in Seconds
**High Memory Retrieval Demand
+High Error Criticality

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK	Module
10 25	4.10.5 4.5.3	Issue clearance and instructions to pilot (NJ532) Enter Flight Plan Amendment (NJ532)
15	4.10.7	Verify aircraft compliance with clearance
		(Monitoring 2-3 minutes)
	Scenario Ends	

*Duration in Seconds

AERA 2 SCENARIOS

Advanced En Route Air Traffic Control (AERA) 2:

Baseline Operational Scenarios

In the AERA 2 monitoring macro and scenarios, the simulated controller responds to the same ATC events as appear in the AAS scenarios. The AERA 2 scenarios are intended to show the controller performing the same functions as those performed in the AAS, with the additional aiding provided by new system capabilities (e.g., Automated Problem Resolution, Automated Coordination). Running comparable AAS and AERA 2 scenarios modules through PATCAM generates data that permits comparison of anticipated workload and performance between system phases and levels of automation.

Tasks describing the controller's use of the AERA 2 capabilities are defined in the <u>AERA 2 Operations Concept</u> (CTA, 1986). Some of the tasks defined in that document have been incorporated into the AAS operations concept as a result of correspondence meetings between the AAS controller team and the AERA 2 controller team. Numbering of the tasks in the scenarios reflects the updated AAS operations concept to the extent that some of the tasks will occur for AERA 1. The remaining tasks use the AERA 2 numbering scheme (CTA, 1986).

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: MONITORING MACRO

DUR*	SITUATION OR TASK		Module
	Aircraft Enters Sector		(1)
2 **	4.6.1	Receive handoff request	1-2
2	4.6.6	Determine response to handoff request	
3.5 +	4.1.50	Receive trial/pending plan	
2	4.6.4	Accept automatic handoff	
3	4.6.5	Determine that aircraft is entering sector	
4 **	4.6.7	Receive control of aircraft	
10	1.6.11	Enter FDE Notations	
5	3.5.1	Validate Mode-C altitude	
	Monitoring for Conflicts		(2)
5	3.4.5	Project mentally the range/bearing between aircraft	
9 +	1.1.2	Review Situation Display for potential violation of aircraft separation standards	
10 +	1.1.54	Evaluate displayed future situation	
9 +	1.1.13	Review displays for potential violation of flow restrictions	
3 +	1.1.56	Review data block for alert indications	
5 +	1.1.58	Review Flight Data Display for present/future A/C separation	
6 +	1.1.57	Review alert(s) of predicted problem(s)	
19 +	1.1.15	Determine whether airspace separation standards may be violated	
	Aircraft Leaves Sector		(3)
2	4.7.2	Observe automatic initiation of handoff	
6 +	4.7.50	Select trial/pending plan for transfer	
5	4.7.4	Receive handoff acceptance	
2 **	4.13.4	Determine frequency in use by receiving sector	
10	4.13.5	Issue change of frequency to pilot	

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: MONITORING MACRO

DUR*	SITUATION OR TASK		Module
3	4.7.8	Determine that aircraft is leaving sector	
7	4.7.12	Inform controller of relinquished control of aircraft	
	1.7	**Managing Display of Flight Data Blocks**	(4)
4 **	1.6.1	Offset a data block	

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AERA 2 SCENARIO 1

The following scenario is an adaptation of AAS scenario I for the AERA 2 environment. The module names correspond exactly to the module names in AAS Scenario 1, but the tasks within modules reflect operational requirements as defined in the AERA 2 Operations Concept (CTA, 1986). Tasks are listed in order of occurrence.

Throughout the scenario, as time permits, the controller performs normal monitoring

When Flight UA522 is within twenty minutes of conflicting with a restricted airspace, the controller receives an alert and resolutions to the predicted problem. After resolving the conflict, the controller evaluates sector workload. The controller detects a potential conflict between EA124 and CA024 and immediately receives an automated alert. Before the conflict can be resolved, another flight, UA105, encounters severe turbulence. The controller issues a clearance to UA105, amends the aircraft's flight plan, and forwards the weather information by entering it into the automated system.

The controller returns to the aircraft-to-aircraft conflict situation, receiving and evaluating automated resolutions and requesting additional resolutions. The controller receives a nonconformance alert and deals with that situation before returning to the aircraft-to-aircraft conflict, which is processed with the aid of trial planning. Before issuing a clearance, the controller issues a pointout and uses automated coordination to clear the selected resolution with controller(s) of nearby sector(s), along the immediate flight path of CA024.

After issuing a clearance to CA024 and handing off both EA124 and CA024, the controller receives notice that a previously restricted airspace is no longer restricted. The automated system informs the controller that UA005 can now be granted a previously denied user-preferred route.

Throughout the scenario, selection of a plan as current has the effect of automatically updating system information about the affected aircraft. This frees the controller from the task of entering flight-data-entry notations.

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
	Scenario Begins		
	(Monitoring 1-3 minutes)		
	Flight UA522 Conflicts With Airspace		(5)
2 +	2.7.50	Receive alert of predicted problem	
4 +	2.7.51	Evaluate alert of predicted problem	
2 +	2.7.53	Receive resolutions to predicted problem	
5 +	2.7.54	Evaluate resolutions to predicted problem	
15 **	4.11.17	Request Airspace Conflict Display	
15	4.10.4	Formulate a clearance with appropriate instructions	
15	4.10.5	Issue clearance and instructions to pilot	
3.5 +	4.10.50	Select plan (resolution) as current plan	
15	4.10.7	Verify aircraft compliance with clearance	
	(Monitoring 1-2 minutes)		
	Managing Personal Workload		(6)
15 **	6.8.2	Consider workload factors not included in automated informaton	
10 +	1.1.54	Evaluate displayed future situation	
6 +	6.8.50	Request display of sector workload factor	
6.5 +	6.8.51	Evaluate displayed sector workload factor	
15 **	6.8.1	Determine impending controller overload	
	(Monitoring 1-1.5 minutes)		
	Controller Detects Potential Aircraft (EA124) to Aircraft (CA024) Conflict		(7)
10 **	2.1.7	Review potential conflict situation for resolution	
2 +	2.7.50	Receive alert of predicted problem	
4 +	2.7.51	Evaluate alert of predicted problem	

*Duration in Seconds
**High Memory Retrieval Demand
+ High Error Criticality

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
	(Monitoring 0-.5 minutes)		
	Aircraft (UA105) Encounters Turbulence and Requests Altitude Change		(8)
10 **	5.1.8	Receive PIREP on weather	
10	4.1.2	Receive clearance request from pilot	
5 +	1.1.53	Request display of future situation	
14 **	4.11.5	Enter Trial Plan	
6 +	1.1.55	Select trial plan to use in display of future situation	
10 +	1.1.54	Evaluate displayed future situation	
6 +	4.11.60	Select plan for automated coordination	
8 +	4.1.56	Receive automated coordination response	
15	4.10.4	Formulate a clearance with appropriate instructions	
10	4.10.5	Issue clearance and instructions to pilot	
3.5 +	4.10.50	Select plan as current plan	
15 **	4.10.7	Verify aircraft compliance with clearance	
10 **	5.1.4	Enter PIREP into system	
	(Monitoring 1-2 minutes)		
	Looking for Aircraft (EA124) to Aircraft (CA024) Conflict Resolution		(9)
2 +	2.7.53	Receive resolution to predicted problem	
5 +	2.7.54	Evaluate resolutions to predicted problem	
3 +	2.7.62	Request resolutions to predicted problem	
	(Monitoring 0-.5 minute)		
	Processing (Lateral) Nonconconformance of Flight AA321		(10)
2 +	2.7.50	Receive alert of predicted problem	
4 +	2.7.51	Evaluate alert of predicted problem	
2 +	2.7.53	Receive resolutions to predicted problem	
5 +	2.7.54	Evaluate resolutions to predicted problem	
15 **	4.10.8	Query pilot regarding compliance with clearance	

*Duration in Seconds
**High Memory Retrieval Demand
+ High Error Criticality

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
20	4.10.5	Issue clearance and instructions to pilot	
3.5 +	4.10.50	Select plan as current plan	
15	4.10.7	Verify aircraft compliance with clearance	
		Processing Aircraft (EA124) to Aircraft (CA024) Conflict	(11)
15 **	2.1.7	Review potential conflict situation for resolution	
14	4.11.10	Formulate trial plan mentally	
6.5 +	4.11.62	Request specified plan(s) for aircraft	
6.5 +	4.11.64	Review stored plans for correctness to traffic situation	
10.5 +	4.11.63	Revise/enter retrieved plan	
15 **	4.11.13	Receive trial plan notice of no conflict/restriction violation	
10 **	4.11.15	Enter trial plan save	
		Processing Pointout and APREQ for EA124 and CA024 (who will be in Sector 92)	(12)
15 **	4.8.1	Initiate pointout	
10	4.8.4	Receive acceptance of pointout	
3 **	4.12.1	Inhibit automatic handoff for all tracks or for designated track (EA124 & CA024)	
6 +	4.11.60	Select plan for automated coordination	
8 +	4.1.56	Receive automated coordination response	
15	4.10.4	Formulate a clearance with appropriate instructions (CA024)	
3.5 +	4.10.50	Select plan as current plan	
		Issuing Clearance to CA024 to Resolve Conflict	(13)
15	4.10.5	Issue clearance and instructions to pilot (CA024)	
15	1.6.11	Enter FDE notations	
15	4.10.7	Verify aircraft compliance with clearance	
		Manual Handoff of EA124 and CA024 to Sector 92	(14)
5 **	4.7.9	Detect manual handoff mode indication	

*Duration in Seconds

**High Memory Retrieval Demand

+ High Error Criticality

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK		Module
10 **	4.7.1	Initiate handoff function (EA124)	
10	4.7.4	Receive handoff acceptance	
10 **	4.7.1	Initiate handoff function (CA024)	
10	4.7.4	Receive handoff acceptance	
		(Monitoring .5-1 minute)	
		Restriction on Special Use Airspace is Lifted	(15)
5 **	3.3.5	Observe display of airspace restriction status change	
		Processing Aircraft (UA005) User-Preferred Route	(16)
5.5 +	2.9.51	Receive notice of aircraft no longer affected by flow/airspace restriction	
10 **	3.3.1	Advise pilot of airspace restriction release	
16 **	4.4.8	Query pilot about flight plan	
15	4.10.4	Formulate a clearance with appropriate instructions	
15	4.10.5	Issue clearance and instructions to pilot	
3.5 +	4.10.50	Select plan as current plan	
10	4.10.7	Verify aircraft compliance with clearance	
		(Monitoring 0-3 minutes)	
		Scenario Ends	

*Duration in Seconds
**High Memory Retrieval Demand
+ High Error Criticality

AERA 2 SCENARIO 2

The following scenario is adapted from AAS Scenario 2 to represent the operational activities of an AERA 2 controller in an en route, high altitude sector. Module names are identical to those in AAS Scenario 2. Modules and tasks within modules are listed in order of occurrence.

Throughout the scenario, the controller performs normal monitoring, as time permits.

Following initial monitoring, the controller receives an alert of predicted noncompliance with a flow restriction. The controller receives and evaluates automated resolutions to the predicted problem, requests additional information, and issues a clearance to the pilot of UA111. The controller evaluates sector workload and responds to a computer-generated reminder to issue a clearance to UA111.

The controller receives an alert and resolutions to the predicted nonconformance of flight NE120. The controller also processes a user-preferred route for aircraft NJ225. The controller uses automated coordination to seek clearance approval from another controller. An aircraft-to-aircraft conflict alert triggers the generation of automated resolutions, which the controller evaluates. The controller opts to issue a change-of-altitude clearance to flight NE532.

Throughout the scenario, selection of a plan as current has the effect of automatically updating system information. This frees the controller from the task of entering flight-data-entry notations.

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK		Module
	Scenario Begins		
	(Monitoring 1-3 Minutes)		
	Processing Flow Restriction Noncompliance for UA111		(17)
2 +	2.7.50	Receive alert of predicted problem	
4 +	2.7.51	Evaluate alert of predicted problem	
2 +	2.7.53	Receive resolutions to predicted problem	
5 +	2.7.54	Evaluate resolutions to predicted problem	
32.5 +	2.7.55	Request Rationale for maneuver type/ranking	
46 +	2.7.56	Evaluate rationale for maneuver type/ranking	
5 **	4.11.17	Request Airspace Conflict Display	
3.5 +	4.11.55	Select plan as pending plan	
5	4.10.4	Formulate a clearance with appropriate instructions	
3.5 +	4.10.50	Select plan as current plan	
15	4.10.5	Issue clearance and instructions to pilot	
10	4.10.7	Verify aircraft compliance with clearance	
	(Monitoring 1-2.5 minutes)		
	Managing Personal Workload		(18)
15 **	6.8.2	Consider workload factors not included in automated information	
10 +	1.1.54	Evaluate displayed future situation	
6 +	6.8.50	Request display of sector workload factor	
6.5 +	6.8.51	Evaluate displayed sector workload factor	
15 **	6.8.1	Determine impending controller overload	
	(Monitoring .5 minute)		
	Computer-Generated Reminder of Needed Actions for UA111		(19)
5	4.1.9	Receive computer-generated reminder notice on clearance	
15	4.10.4	Formulate a clearance with appropriate instructions	

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK		Module
15	4.10.5	Issue clearance and instructions to pilot	
25	1.6.11	Enter FDE notations	
10	4.10.7	Verify aircraft compliance with clearance	
	(Monitoring 2-3.5 minutes)		
	Processing Nonconformance of Flight NE120		(20)
2 +	2.7.50	Receive alert of predicted problem	
4 +	2.7.51	Evaluate alert of predicted problem	
2 +	2.7.53	Receive resolutions to predicted problem	
5 +	2.7.54	Evaluate resolutions to predicted problem	
15 **	4.10.8	Query pilot regarding compliance with clearance	
4 +	3.2.52	Request display of conformance bounds	
4 +	3.2.53	Evaluate display of conformance bounds	
10	4.10.4	Formulate a clearance with appropriate instructions	
3.5 +	4.10.50	Select plan as current plan	
25	4.10.5	Issue clearance and instructions to pilot	
10	4.10.7	Verify aircraft compliance with clearance	
	(Monitoring 1-2 minutes)		
	Processing User-Preferred Route for Flight NJ225		(21)
16	4.1.2	Receive clearance request from pilot	
5 +	1.1.53	Request display of future situation	
4 **	4.11.5	Enter trial plan	
6 +	1.1.55	Select trial plan to use in display of future situation	
10 +	1.1.54	Evaluate displayed future situation	
6 +	4.11.60	Select plan for automated coordination	
8 +	4.1.56	Receive automated coordination response	
20	4.10.4	Formulate a clearance with appropriate instructions	
15	4.10.5	Issue clearance and instructions to pilot	
3.5 +	4.10.50	Select plan as current plan	
10	4.10.7	Verify aircraft compliance with clearance	
	(Monitoring 3-4 minutes)		

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

AERA 2-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK		Module
	Processing Aircraft (AA221) to Aircraft (NJ532) Conflict		(22)
2 +	2.7.50	Receive alert of predicted problem	
4 +	2.7.51	Evaluate alert of predicted problem	
2 +	2.7.53	Receive resolutions to predicted problem	
5 +	2.7.54	Evaluate resolutions to predicted problem	
5	4.10.4	Formulate a clearance with appropriate instructions	
10	4.10.5	Issue clearance and instructions to pilot	
3.5 +	4.10.50	Select plan (resolution) as current plan	
15	4.10.7	Verify aircraft compliance with clearance	
	Scenario Ends		

* Duration in Seconds
** High Memory Retrieval Demand
\+ High Error Criticality

APPENDIX C

CONTROLLER WORKLOAD MODEL

Mission Level (Workload):

a.) S —> MIS: controller_workload (mission) =

$$\sum_{a=1}^{n} \left[\text{controller\_demand(scenario}_a\text{) * weighting\_factor(scenario}_a\text{)} \right]$$

$$\text{weighting\_factor(scenario}_a\text{) = } \frac{\text{duration(scenario}_a\text{)}}{\text{duration(mission)}}$$

Scenario Level (Workload):

a.) S1: controller_demand(scenario$_a$) =

$$\text{MAX [perceptual\_demand(scenario}_a\text{), analytic\_demand(scenario}_a\text{),}$$
$$\text{response\_demand(scenario}_a\text{), resource\_management demand(scenario}_a\text{)]}$$

b.) M —> S1: perceptual_demand(scenario$_a$) =

$$\sum_{b=1}^{n} \left[\text{perceptual\_demand(module}_b\text{) * weighting\_factor(module}_b\text{)} \right]$$

$$\text{weighting\_factor(module}_b\text{) = } \frac{\text{duration(module}_b\text{)}}{\text{duration(scenario}_a\text{)}}$$

M —> S2: analytic_demand(scenario$_a$) =

$$\sum_{b=1}^{n} \left[\text{analytic\_demand(module}_b\text{) * weighting\_factor(module}_b\text{)} \right]$$

$$\text{weighting\_factor(module}_b\text{) = } \frac{\text{duration(module}_b\text{)}}{\text{duration(scenario}_a\text{)}}$$

M —> S3: $\text{response\_demand}(\text{scenario}_a)$ =

$$\sum_{b=1}^{n} \left[\text{response\_demand}(\text{module}_b) * \text{weighting\_factor}(\text{module}_b) \right]$$

$$\text{weighting\_factor}(\text{module}_b) = \frac{\text{duration}(\text{module}_b)}{\text{duration}(\text{scenario}_a)}$$

M —> S4: $\text{resource\_management\_demand}(\text{scenario}_a)$ =

$$\sum_{b=1}^{n} \left[\text{resource\_management\_demand}(\text{module}_b) * \text{weighting\_factor}(\text{module}_b) \right]$$

$$\text{weighting\_factor}(\text{module}_b) = \frac{\text{duration}(\text{module}_b)}{\text{duration}(\text{scenario}_a)}$$

Module Level (Workload)

a.) M1: $\text{perceptual\_demand}(\text{module}_b)$ =

$$\text{MAX} \left[\text{visual\_perception\_demand}(\text{module}_b), \text{auditory\_perception\_demand}(\text{module}_b) \right]$$

M2: $\text{response\_demand}(\text{module}_b)$ =

$$\text{MAX} \left[\text{verbal\_response\_demand}(\text{module}_b), \text{manual\_response\_demand}(\text{module}_b) \right]$$

M3: $\text{resource\_management\_demand}(\text{module}_b)$ =

$$\text{MAX} \left[\text{multiplexing\_management\_demand}(\text{module}_b), \text{modality\_switching\_management\_demand}(\text{module}_b) \right]$$

b.) T —> M1: visual_perception_demand(module$_b$) =

$$\sum_{c=1}^{n}\left[\text{visual\_demand}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c)\right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M2: auditory_perception_demand(module$_b$) =

$$\sum_{c=1}^{n}\left[\text{auditory\_demand}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c)\right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M3: analytic_demand(module$_b$) =

$$\sum_{c=1}^{n}\left[\text{analytic\_processing\_demand}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c)\right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M4: verbal_response_demand(module$_b$) =

$$\sum_{c=1}^{n}\left[\text{verbal\_demand}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c)\right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M5: $\text{manual\_response\_demand}(\text{module}_b)$ =

$$\sum_{c=1}^{n} \left[\text{manual\_demand}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c) \right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M6: $\text{multiplexing\_management\_demand}(\text{module}_b)$ =

$$\sum_{c=1}^{n} \left[\text{multiplexing\_demand}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c) \right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M7: $\text{modality\_switching\_management\_demand}(\text{module}_b)$ =

$$\sum_{c=1}^{n} \left[\text{modality\_switching\_demand}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c) \right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

Task Level (Workload):

a.) T1: $\text{visual\_demand}(\text{task}_c)$ =

$$\text{MAX [visual\_action\_demand}(\text{task}_c), \text{visual\_load}(\text{task}_c)];$$

```
IF composite_visual_signal_to_noise(task$_c$) = 1
    THEN MIN [visual_demand(task$_c$) + 2, 5]
    ELSE IF composite_visual_signal_to_noise(task$_c$) = 2
        THEN MIN [visual_demand(task$_c$) +1, 5]
```

```
T2:     auditory_demand($task_C$) =

            MAX [ auditory_action_demand($task_C$), auditory_load($task_C$)];

        IF composite_auditory_signal_to_noise($task_C$) = 1
            THEN MIN [auditory_demand($task_C$) + 2, 5]
            ELSE IF composite_auditory_signal_to_noise($task_C$) = 2
                THEN MIN [auditory_demand($task_C$) +1, 5]


T3:     analytic_processing_demand($task_C$) =

            MAX [ analytic_action_demand($task_C$), analytic_load($task_C$),
                memory_retrieval_demand($task_C$)];

        IF error_criticality($task_C$) >= 4
            THEN MIN [analytic_demand($task_C$) + 1, 5]
            ELSE IF error_criticality($task_C$) <= 2
                THEN MAX [analytic_demand($task_C$) — 1, 1];

        IF time_pressure($task_C$) >= 3
            THEN MIN [analytic_demand($task_C$) + 1, 5]
            ELSE IF time_pressure($task_C$) <= 2
                THEN MAX [analytic_demand($task_C$) — 1, 1]
```

Time_pressure($task_C$) = min [Σ events, 5] or max [Σ events, 1]

	SCORE			
EVENTS	**0**	**1**	**2**	**3**
number of aircraft	< 10	10-20	21-30	>30
number of conflicts	0	1	2	>2
number of special_use_airspace and weather elements	0	1-2	3-4	>4

T4: verbal_demand(task_c) =

MAX [verbal_action_demand(task_c), verbal_load(task_c)];

T5: manual_demand(task_c) =

MAX [manual_action_demand(task_c), manual_load(task_c)];

T6: multiplexing_demand(task_c) =

demand value	number of interfaces
1	1 or 2
2	3
3	4
4	5
5	>5

T7: modality_switching_demand(task_c) =

demand value	number of resource pools	number of major resource pools
1	1	1
2	2	1
3	2	2
4	3	2
5	>= 3	3
5	>= 4	2

b) I1—> T1: $\text{visual\_load}(\text{task}_c) =$

$$\frac{\sum_{d=1}^{n} \left[\text{ visual\_load}(\text{interface}_d)\right]}{\text{number\_visual\_interfaces}}$$

I2 —> T2: $\text{auditory\_load}(\text{task}_c) =$

$$\frac{\sum_{d=1}^{n} \left[\text{ auditory\_load}(\text{interface}_d)\right]}{\text{number\_auditory\_interfaces}}$$

I3 —> T3: $\text{analytic\_load}(\text{task}_c) =$

$$\frac{\sum_{d=1}^{n} \left[\text{ analytic\_load}(\text{interface}_d) \right.}{\text{number\_analytic\_interfaces}}$$

I4 —> T4: $\text{verbal\_load}(\text{task}_c) =$

$$\frac{\sum_{d=1}^{n} \left[\text{ verbal\_load}(\text{interface}_d)\right]}{\text{number\_verbal\_interfaces}}$$

I5 —> T5: manual_load(task_c) =

$$\frac{\sum_{d=1}^{n}\left[\text{manual\_load}(\text{interface}_d)\right]}{\text{number\_manual\_interfaces}}$$

S/N1 —> TS/N1: composite_visual_signal_to_noise(task_c) =

$$\frac{\sum_{d=1}^{n}\left[\text{visual\_signal\_to\_noise\_ratio}(\text{interface}_d)\right]}{\text{number\_visual\_interfaces}}$$

S/N2 —> TS/N2: composite_auditory_signal_to_noise(task_c) =

$$\frac{\sum_{d=1}^{n}\left[\text{auditory\_signal\_to\_noise\_ratio}(\text{interface}_d)\right]}{\text{number\_auditory\_interfaces}}$$

Interface Level (Workload):

I1: visual_load (interface_d) =

$\text{MAX}\ [\ \text{visual\_complexity}\ (\text{interface}_d) - (\text{type\_of\_assistance} - 1)/2,\ 1];$

I2: auditory_load (interface_d) =

$\text{MAX}\ [\ \text{auditory\_complexity}(\text{interface}_d) - (\text{type\_of\_assistance} - 1)/2,\ 1];$

I 3: analytic_load (interface_d) =

MAX [analytic_complexity(interface_d) — (type_of_assistance — 1)/2, 1];

I 4: verbal_load (interface_d) =

MAX [verbal_complexity(interface_d) — (type_of_assistance — 1)/2, 1];

I 5: manual_load (interface_d) =

MAX [manuall_complexity(interface_d) — (type_of_assistance — 1)/2, 1];

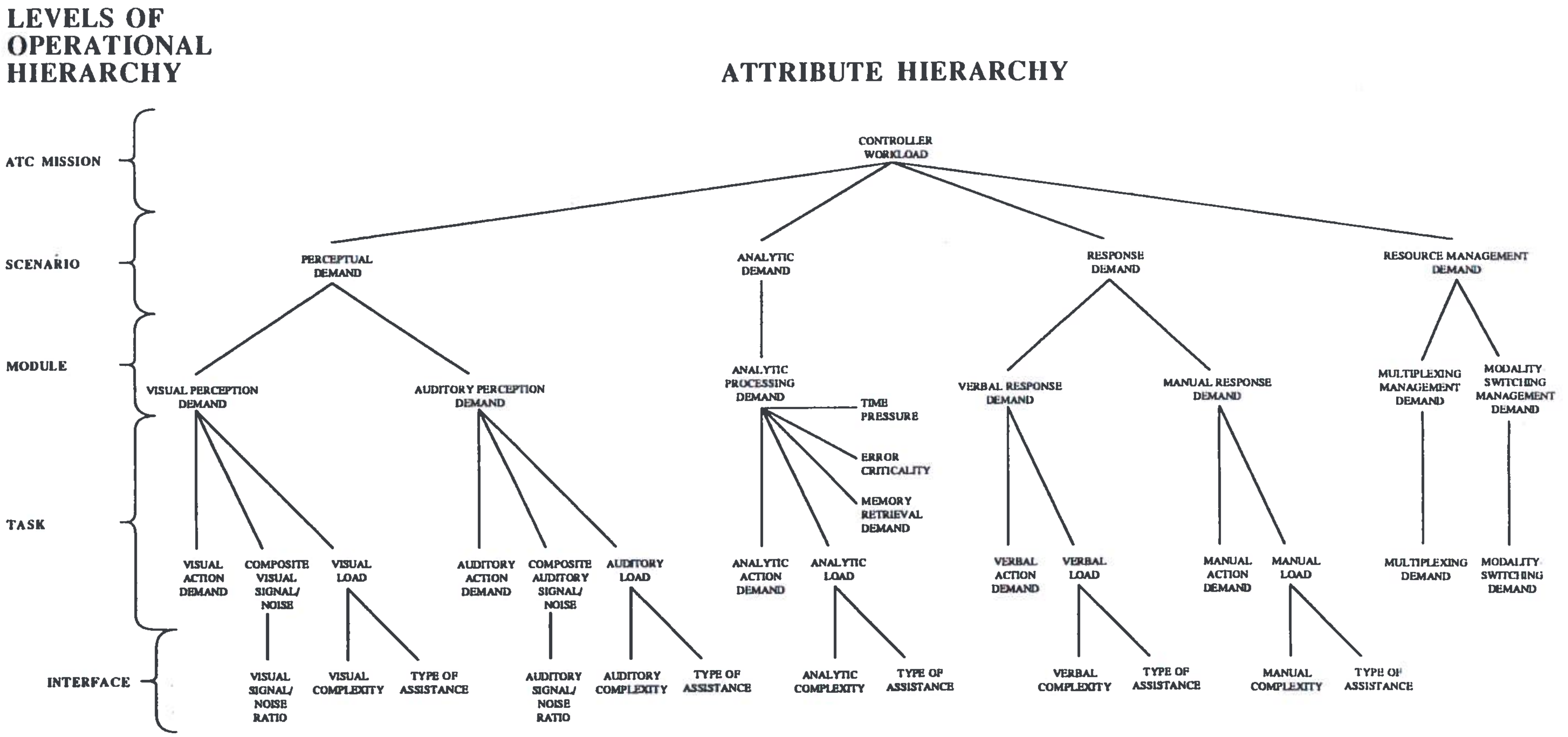

Figure C-1. Controller Workload Model

9/30/89

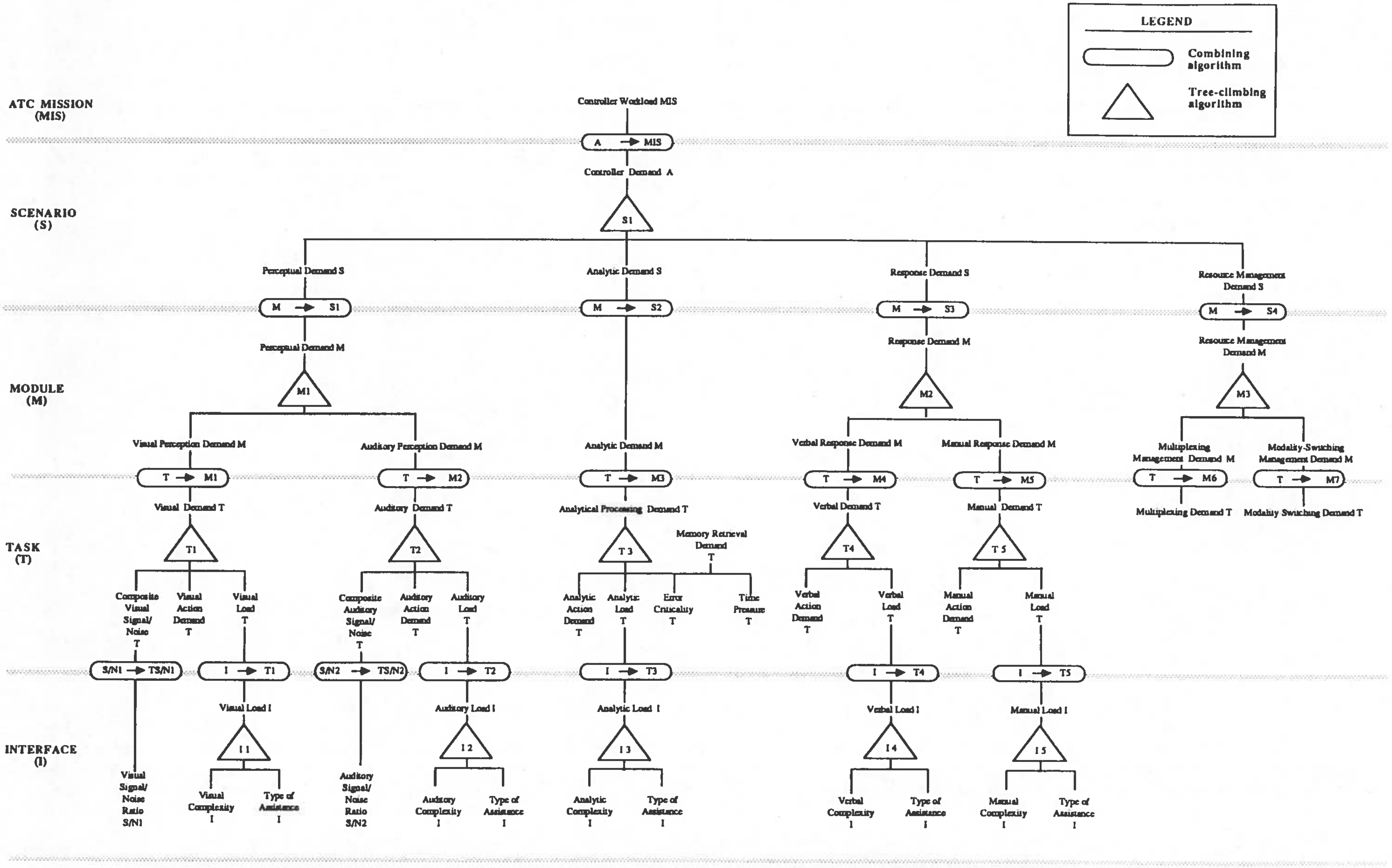

Figure C-2. CPM Overview: Attribute Tree, Combining Algorithms, and Tree-Climbing Rules

APPENDIX D

CONTROLLER PERFORMANCE MODEL

Mission Level (Performance):

a.) S —> MIS: controller_performance (mission) =

$$\sum_{a=1}^{n}\Big[\text{controller\_performance}(\text{scenario}_a) * \text{weighting\_factor}(\text{scenario}_a)\Big]$$

$$\text{weighting\_factor}(\text{scenario}_a) = \frac{\text{duration}(\text{scenario}_a)}{\text{duration}(\text{mission})}$$

Scenario Level (Performance):

a.) S1:

```
controller_performance(scenario$_a$) =

MIN [ perceptual_performance(scenario$_a$),
      analytic_performance(scenario$_a$),
      response_performance(scenario$_a$),
      resource_management performance(scenario$_a$)];

IF vigilance(scenario$_a$) >= 4
      THEN MIN [controller_performance(scenario$_a$) + 1, 5]
      ELSE IF vigilance(scenario$_a$) <= 2
            THEN MAX [controller_performance(scenario$_a$) — 1, 1];

IF motivating_potential(scenario$_a$) >= 4
      THEN MIN [controller performance(scenario$_a$) + 1, 5]
      ELSE IF motivating_potential(scenario$_a$) <= 2
            THEN MAX [controller_performance(scenario$_a$) — 1, 1]
```

b.) M —> S1: $\text{perceptual\_performance}(\text{scenario}_a) =$

$$\sum_{b=1}^{n}\left[\text{perceptual\_performance}(\text{module}_b) * \text{weighting\_factor}(\text{module}_b)\right]$$

$$\text{weighting\_factor}(\text{module}_b) = \frac{\text{duration}(\text{module}_b)}{\text{duration}(\text{scenario}_a)}$$

M —> S2: $\text{analytic\_performance}(\text{scenario}_a) =$

$$\sum_{b=1}^{n}\left[\text{analytic\_performance}(\text{module}_b) * \text{weighting\_factor}(\text{module}_b)\right]$$

$$\text{weighting\_factor}(\text{module}_b) = \frac{\text{duration}(\text{module}_b)}{\text{duration}(\text{scenario}_a)}$$

M —> S3: $\text{response\_performance}(\text{scenario}_a) =$

$$\sum_{b=1}^{n}\left[\text{response\_performance}(\text{module}_b) * \text{weighting\_factor}(\text{module}_b)\right]$$

$$\text{weighting\_factor}(\text{module}_b) = \frac{\text{duration}(\text{module}_b)}{\text{duration}(\text{scenario}_a)}$$

M —> S4: $\text{resource\_management\_performance}(\text{scenario}_a) =$

$$\sum_{b=1}^{n}\left[\text{resource\_management\_performance}(\text{module}_b) * \text{weighting\_factor}(\text{module}_b)\right]$$

$$\text{weighting\_factor}(\text{module}_b) = \frac{\text{duration}(\text{module}_b)}{\text{duration}(\text{scenario}_a)}$$

Module Level (Performance)

a.) M1: perceptual_performance(module$_b$) =

MIN [visual performance(module$_b$), auditory_performance(module$_b$)]

M3: response_performance(module$_b$) =

MIN [verbal performance(module$_b$), manual_performance(module$_b$)]

M3: resource_management_performance(module$_b$) =

MIN [multiplexing_management_performance(module$_b$),
modality_switching_management_performance(module$_b$)]

b.) T —> M1: visual_performance(module$_b$) =

$$\sum_{c=1}^{n} \left[\text{visual\_performance}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c) \right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M2: auditory_performance(module$_b$) =

$$\sum_{c=1}^{n} \left[\text{auditory\_performance}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c) \right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M3: $\text{analytic\_performance}(\text{module}_b) =$

$$\sum_{c=1}^{n}\left[\text{analytic\_processing\_performance}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c)\right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M4: $\text{verbal\_performance}(\text{module}_b) =$

$$\sum_{c=1}^{n}\left[\text{verbal\_performance}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c)\right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M5: $\text{manual\_performance}(\text{module}_b) =$

$$\sum_{c=1}^{n}\left[\text{manual\_performance}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c)\right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M6: $\text{multiplexing\_management\_performance}(\text{module}_b) =$

$$\sum_{c=1}^{n}\left[\text{multiplexing\_management\_performance}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c)\right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

T —> M7: modality_switching_management_performance(module$_b$) =

$$\sum_{c=1}^{n} \left[\text{modality\_switching\_management\_performance}(\text{task}_c) * \text{weighting\_factor}(\text{task}_c) \right]$$

$$\text{weighting\_factor}(\text{task}_c) = \frac{\text{duration}(\text{task}_c)}{\text{duration}(\text{module}_b)}$$

Task Level (Performance):

a.) T1: visual_performance (task$_c$) =

visual_skill — DIV [ABS(visual_skill — visual_demand(task$_c$)) / 2]

visual_demand(task$_c$) =

MAX [visual_action_demand(task$_c$), visual_load(task$_c$)];

```
IF composite_visual_signal_to_noise(task$_c$) = 1
    THEN MIN [visual_demand(task$_c$) + 2, 5]
    ELSE IF composite_visual_signal_to_noise(task$_c$) = 2
        THEN MIN [visual_demand(task$_c$) +1, 5]
```

T2: auditory_performance (task$_c$) =

auditory_skill — DIV [ABS(auditory_skill — auditory_demand(task$_c$)) / 2]

auditory_demand(task$_c$) =

MAX [auditory_action_demand(task$_c$), auditory_load(task$_c$)];

```
IF composite_auditory_signal_to_noise($task_C$) =  1
        THEN MIN [auditory_demand($task_C$) + 2, 5]
        ELSE IF composite_auditory_signal_to_noise($task_C$) =  2
                THEN MIN [auditory_demand($task_C$) +1, 5]


T3:     analytic_processing_performance ($task_C$)  =

        analytic_skill — DIV [ABS(analytic_skill — analytic_demand($task_C$)) / 2]

analytic_demand($task_C$)  =

        MAX [ analytic_action_demand($task_C$), analytic_load($task_C$),
                memory_retrieval_demand($task_C$)];

IF error_criticality($task_C$) >=  3
        THEN MIN [analytic_demand($task_C$) + 1, 5]
        ELSE IF error_criticality($task_C$) <= 2
                THEN MAX [analytic_demand($task_C$) — 1, 1];

IF time_pressure($task_C$) >=  4
        THEN MIN [analytic_demand($task_C$) + 1, 5]
        ELSE IF time_pressure($task_C$) <= 2
                THEN MAX [analytic_demand($task_C$) — 1]
```

Time_pressure($task_C$) = min [$\sum$ events, 5] or max [$\sum$ events, 1]

	SCORE			
EVENTS	**0**	**1**	**2**	**3**
number of aircraft	<10	10-20	21-30	>30
number of conflicts	0	1	2	>2
number of special_use_airspace and weather elements	0	1-2	3-4	>4

T4: verbal_performance (task$_C$) =

verbal_skill — DIV [ABS(verbal_skill — verbal_demand(task$_C$)) / 2]

verbal_demand(task$_C$) =

MAX [verbal_action_demand(task$_C$), verbal_load(task$_C$)];

T5: manual_performance (task$_C$) =

manual_skill — DIV [ABS(manual_skill — manual_demand(task$_C$)) / 2]

manual_demand(task$_C$) =

MAX [manual_action_demand(task$_C$), manual_load(task$_C$)];

T6: multiplexing_performance (task$_C$) =

multiplexing_skill — DIV [ABS(multiplexing_skill — multiplexing_demand(task$_C$)) / 2]

multiplexing_demand(task$_C$) =

demand value	number of interfaces
1	1 or 2
2	3
3	4
4	5
5	>5

T7: modality-switching_performance (task$_c$) =

$$\text{modality\_switching\_skill} - \text{DIV}\left[\text{ABS}(\text{modality\_switching\_skill} - \text{modality\_switching\_demand}(\text{task}_c)) / 2\right]$$

modality_switching_demand(task$_c$) =

demand value	number of resource pools	number of major resource pools
1	1	1
2	2	1
3	2	2
4	3	2
5	>= 3	3
5	>= 4	>=2

b) I1—> T1: visual_load(task$_c$) =

$$\frac{\sum_{d=1}^{n} \left[\text{visual\_load}(\text{interface}_d) \right]}{\text{number\_visual\_interfaces}}$$

I2 —> T2: auditory_load(task$_c$) =

$$\frac{\sum_{d=1}^{n} \left[\text{auditory\_load}(\text{interface}_d) \right]}{\text{number\_auditory\_interfaces}}$$

I3 —> T3: $\text{analytic\_load}(\text{task}_c) =$

$$\frac{\sum_{d=1}^{n} [\ \text{analytic\_load}(\text{interface}_d)}{\text{number\_analytic\_interfaces}}$$

I4 —> T4: $\text{verbal\_load}(\text{task}_c) =$

$$\frac{\sum_{d=1}^{n} [\ \text{verbal\_load}(\text{interface}_d)]}{\text{number\_verbal\_interfaces}}$$

I5 —> T5: $\text{manual\_load}(\text{task}_c) =$

$$\frac{\sum_{d=1}^{n} [\ \text{manual\_load}(\text{interface}_d)]}{\text{number\_manual\_interfaces}}$$

S/N1 —> TS/N1: $\text{composite\_visual\_signal\_to\_noise}(\text{task}_c) =$

$$\frac{\sum_{d=1}^{n} [\ \text{visual\_signal\_to\_noise\_ratio}(\text{interface}_d)]}{\text{number\_visual\_interfaces}}$$

S/N2 —> TS/N2: composite_auditory_signal_to_noise(task$_c$) =

$$\frac{\sum_{d=1}^{n}\left[\text{auditory\_signal\_to\_noise\_ratio}(\text{interface}_d)\right]}{\text{number\_auditory\_interfaces}}$$

Interface Level (Workload):

I1: visual_load (interface$_d$) =

MAX [visual_complexity (interface$_d$) — (type_of_assistance — 1)/2, 1];

I2: auditory_load (interface$_d$) =

MAX [auditory_complexity(interface$_d$) — (type_of_assistance — 1)/2, 1];

I 3: analytic_load (interface$_d$) =

MAX [analytic_complexity(interface$_d$) — (type_of_assistance — 1)/2, 1];

I 4: verbal_load (interface$_d$) =

MAX [verbal_complexity(interface$_d$) — (type_of_assistance — 1)/2, 1];

I 5: manual_load (interface$_d$) =

MAX [manuall_complexity(interface$_d$) — (type_of_assistance — 1)/2, 1];

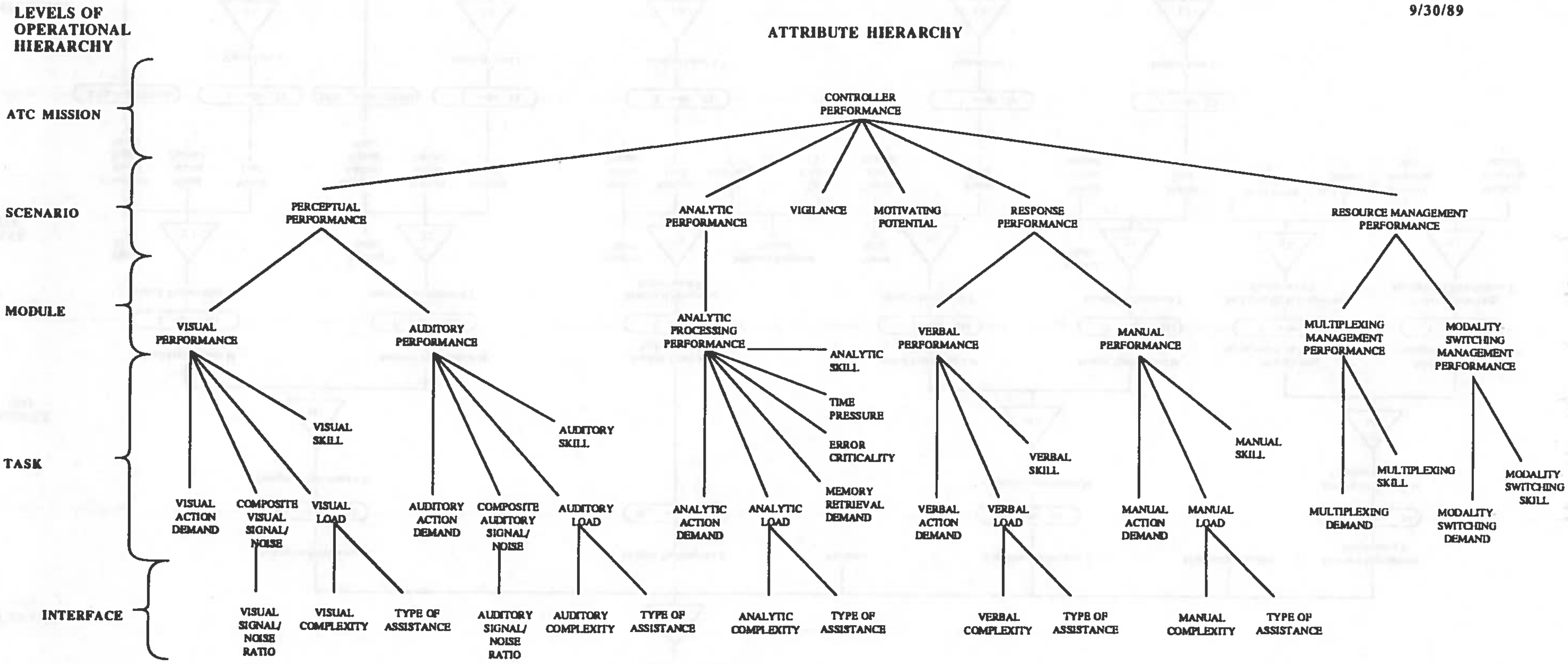

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Figure D-1. Controller Performance Model

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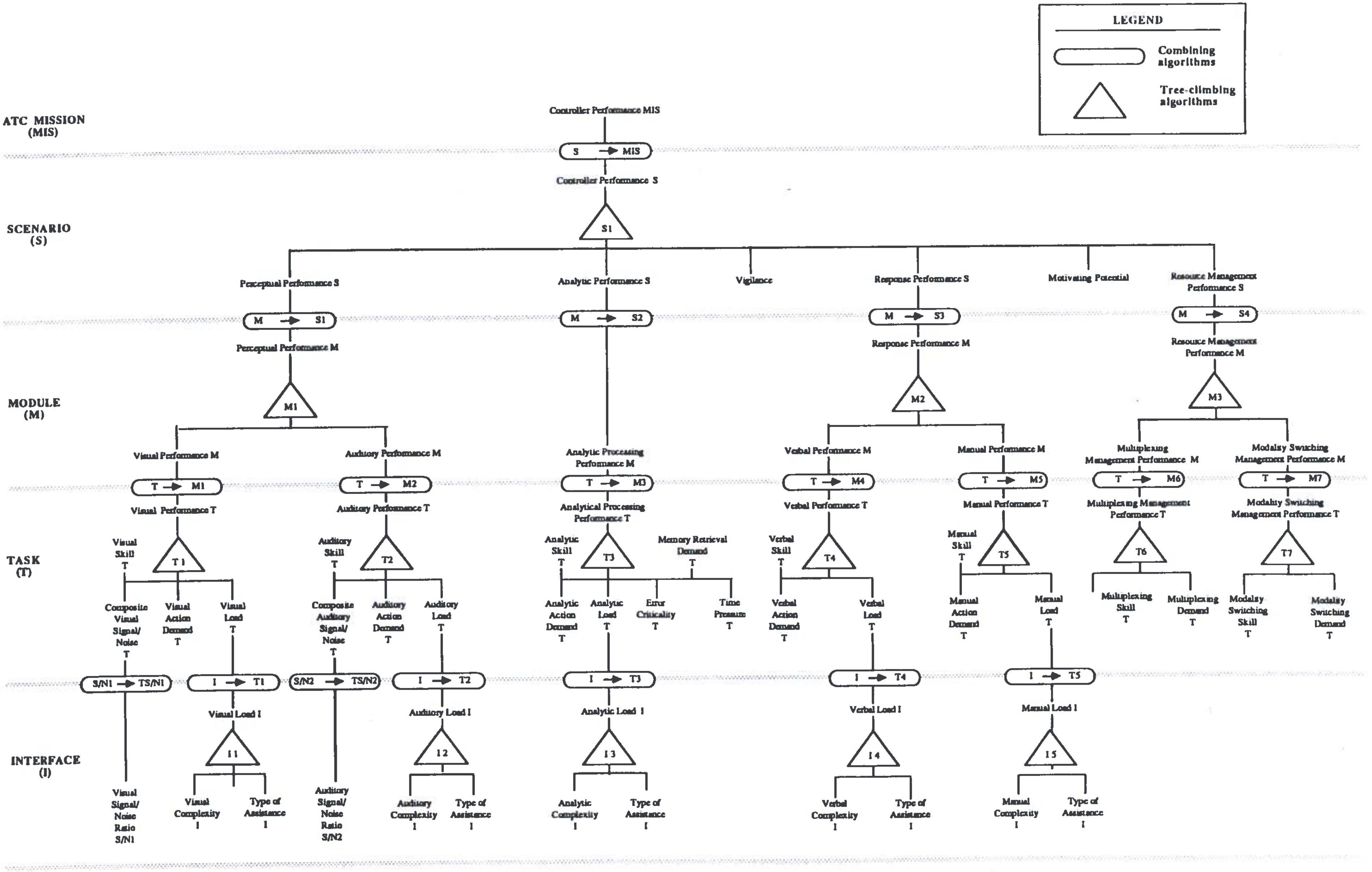

Figure D-2. CPM Overview: Attribute Tree, Combining Algorithms, and Tree-Climbing Rules

APPENDIX E

USER'S GUIDE TO PATCAM

TABLE OF CONTENTS

TABLE OF CONTENTS

1.0 Hardware/Software Requirements for Running PATCAM

1.1 Hardware Requirements

The following hardware is required to run PATCAM:

IBM PC AT or compatible with 640 kilobytes of memory, running PC-DOS™ or MS-DOS™ 3.2.

Minimum 20 Megabyte hard disk drive.

Clock/Calendar.

Dot Matrix Printer.

Color Graphics Adapter (CGA) and a compatible monitor.

1.2 Software Requirements

The following commercially available software is also required to run PATCAM:

PC-DOS™, version 3.2 by IBM Corp., or MS-DOS™, Version 3.2 by Microsoft Corporation.

Lotus 1-2-3™, version 2.01 by Lotus Development Corporation.

MicroSAINT™, version 3.1 by Micro Analysis and Design, Inc.

1.3 Installing PATCAM

1.3.1 PATCAM Software

The following steps must be followed to install version 1.0 of the PATCAM software on your system:

1. Create a directory named "PATCAM" on the software drive. Refer to the DOS manual that is supplied with the computer system for instructions on creating a directory.

2. Insert PATCAM software diskette number one into the disk drive.

3. Move to the disk drive, change to the PATCAM directory, and move back to the software drive. Then change to the PATCAM directory on the software drive. For purposes of this discussion, the disk drive will be referred to as "A:" and the software drive will be referred to as "C:". The DOS commands for this step are:

```
A:
CD\PATCAM
C:
CD\PATCAM
```

4. Copy all files from the PATCAM directory on software diskettes numbers 1 to 4 into the PATCAM directory on the software drive. For each diskette, the DOS command is:

```
COPY A: *.*
```

When these steps have been completed, entering the DOS command "DIR" on the software drive PATCAM directory should result in the following list of files:

```
          Directory of C:\PATCAM
          .                 <DIR>
          ..                <DIR>

  AAS1HI.TIP
  AAS1HI.TIW
  AAS1HI.MIP
  AAS1HI.MIW
  AAS1HI.SIP
  AAS1HI.SIW
  AAS1HI.LOG
  PAAS1HI.TIP
  PAAS1HI.TIW
  PAAS1HI.MIP
  PAAS1HI.MIW
  PAAS1HI.SIP
  PAAS1HI.SIW
  PAAS1HI.LOW
  PAAS1HI.LOP
  AAS1MD.TIP
  AAS1MD.TIW
  AAS1MD.MIP
  AAS1MD.MIW
  AAS1MD.SIP
  AAS1MD.SIW
  AAS1MD.LOG
  PAAS1MD.TIP
  PAAS1MD.TIW
  PAAS1MD.MIP
  PAAS1MD.MIW
  PAAS1MD.SIP
  PAAS1MD.SIW
  PAAS1MD.LOG
  AAS1LW.TIP
  AAS1LW.TIW
  AAS1LW.MIP
  AAS1LW.MIW
  AAS1LW.SIP
  AAS1LW.SIW
  AAS1LW.LOG
  PAAS1LW.TIP
  PAAS1LW.TIW
  PAAS1LW.MIP
  PAAS1LW.MIW
  PAAS1LW.SIP
```

PAAS1LW.SIW
PAAS1LW.LOW
PAAS1LW.LOP
AAS2HI.TIP
AAS2HI.TIW
AAS2HI.MIP
AAS2HI.MIW
AAS2HI.SIP
AAS2HI.SIW
AAS2HI.LOG
PAAS2HI.TIP
PAAS2HI.TIW
PAAS2HI.MIP
PAAS2HI.MIW
PAAS2HI.SIP
PAAS2HI.SIW
PAAS2HI.LOW
PAAS2HI.LOP
AAS2MD.TIP
AAS2MD.TIW
AAS2MD.MIP
AAS2MD.MIW
AAS2MD.SIP
AAS2MD.SIW
AAS2MD.LOG
PAAS2MD.TIP
PAAS2MD.TIW
PAAS2MD.MIP
PAAS2MD.MIW
PAAS2MD.SIP
PAAS2MD.SIW
PAAS2MD.LOG
AAS2LW.TIP
AAS2LW.TIW
AAS2LW.MIP
AAS2LW.MIW
AAS2LW.SIP
AAS2LW.SIW
AAS2LW.LOG
PAAS2LW.TIP
PAAS2LW.TIW
PAAS2LW.MIP
PAAS2LW.MIW
PAAS2LW.SIP
PAAS2LW.SIW
PAAS2LW.LOW
PAAS2LW.LOP
AERA1HI.TIP
AERA1HI.TIW
AERA1HI.MIP
AERA1HI.MIW
AERA1HI.SIP
AERA1HI.SIW
AERA1HI.LOG

PAERA1HI.TIP
PAERA1HI.TIW
PAERA1HI.MIP
PAERA1HI.MIW
PAERA1HI.SIP
PAERA1HI.SIW
PAERA1HI.LOW
PAERA1HI.LOP
AERA1MD.TIP
AERA1MD.TIW
AERA1MD.MIP
AERA1MD.MIW
AERA1MD.SIP
AERA1MD.SIW
AERA1MD.LOG
PAERA1MD.TIP
PAERA1MD.TIW
PAERA1MD.MIP
PAERA1MD.MIW
PAERA1MD.SIP
PAERA1MD.SIW
PAERA1MD.LOG
AERA1LW.TIP
AERA1LW.TIW
AERA1LW.MIP
AERA1LW.MIW
AERA1LW.SIP
AERA1LW.SIW
AERA1LW.LOG
PAERA1LW.TIP
PAERA1LW.TIW
PAERA1LW.MIP
PAERA1LW.MIW
PAERA1LW.SIP
PAERA1LW.SIW
PAERA1LW.LOW
PAERA1LW.LOP
AERA2HI.TIP
AERA2HI.TIW
AERA2HI.MIP
AERA2HI.MIW
AERA2HI.SIP
AERA2HI.SIW
AERA2HI.LOG
PAERA2HI.TIP
PAERA2HI.TIW
PAERA2HI.MIP
PAERA2HI.MIW
PAERA2HI.SIP
PAERA2HI.SIW
PAERA2HI.LOW
PAERA2HI.LOP
AERA2MD.TIP
AERA2MD.TIW

```
AERA2MD.MIP
AERA2MD.MIW
AERA2MD.SIP
AERA2MD.SIW
AERA2MD.LOG
PAERA2MD.TIP
PAERA2MD.TIW
PAERA2MD.MIP
PAERA2MD.MIW
PAERA2MD.SIP
PAERA2MD.SIW
PAERA2MD.LOG
AERA2LW.TIP
AERA2LW.TIW
AERA2LW.MIP
AERA2LW.MIW
AERA2LW.SIP
AERA2LW.SIW
AERA2LW.LOG
PAERA2LW.TIP
PAERA2LW.TIW
PAERA2LW.MIP
PAERA2LW.MIW
PAERA2LW.SIP
PAERA2LW.SIW
PAERA2LW.LOW
PAERA2LW.LOP
CWM.BAT
MSAINT.BAT
CPM.BAT
LOG.BAT
HI_WKLD.E
MED_WKLD.E
LOW_WKLD.E
HI_PERF.E
MED_PERF.E
LOW_PERF.E
OUTPUTS.F
SCRIPTS.F
MODELS.F
SCRIPT.WK1
AIRPORT.EXE
OUTPUT.EXE
SIMULATE.EXE
PATCAM.EXE
MODEL.EXE
SKILL.DAT
MODFILE.DAT
NAME.DAT
        200 File(s) NNNNNN bytes free.
```

This completes the installation of the files needed in the PATCAM directory.

1.3.2 LOTUS Files

In order to run PATCAM, the LOTUS executable files must be in a directory named "123" on the software drive. If the LOTUS executable files are located in a directory called "123" proceed to step 3. If the LOTUS executable files are located in another directory, the following steps must be followed to ensure that PATCAM works properly on your system:

1. Create a directory named "123" on the software drive.

2. Install or re-install LOTUS 1-2-3™ in the directory created in step 1 by following the LOTUS user's manual.

3. Insert PATCAM software diskette number 5 into the disk drive.

4. Move to the disk drive, change to the 123 directory, and move back to the software drive. Then change to the 123 directory on the software drive. The DOS commands for this step are as follows:

   ```
   A:
   CD\123
   C:
   CD\123
   ```

5. Copy all files from the 123 directory on software diskettes numbers 5 and 6 into the 123 directory on the software drive. For each diskette, the DOS command is as follows:

   ```
   COPY A: *.*
   ```

   When these steps have been completed, entering the DOS command "DIR *.WK1" on the software drive 123 directory should result in the following list of files:

   ```
   Directory of C:\123

   AASCWM1.WK1
   AASCWM2.WK1
   AERACWM1.WK1
   AERACWM2.WK1
   BEGIF.WK1
   BEGTI.WK1
   COMBINE.WK1
   CWM3.WK1
   MOD.WK1
   SIMLOG.WK1
           10 File(s) NNNNNN bytes free
   ```

   This completes the installation of the LOTUS files.

1.3.3 MicroSAINT™

Before running PATCAM, MicroSAINT™ must be installed on your system. The following steps must be followed to install MicroSAINT™ on your system:

1. Install MicroSAINT™ by following the instructions in section 2 of the MicroSaint User's Guide.

2. Insert PATCAM software diskette number 6 into the disk drive.

3. Move to the disk drive, change to the MSAINT\NETWORKS directory, and move back to the software drive. Then change to the MSAINT\NETWORKS directory on the software drive. The DOS commands for this step are as follows:

```
A:
CD\MSAINT\NETWORKS
C:
CD\MSAINT\NETWORKS
```

4. Copy all files from the MSAINT\NETWORKS directory on software diskette number 6 into the MSAINT\NETWORKS directory on the software drive. The DOS command is as follows:

```
COPY A: *.*
```

When these steps have been completed, entering the DOS command "DIR" on the software drive MSAINT\NETWORKS directory should result in the following list of files:

```
Directory of C:\MSAINT\NETWORKS

.              <DIR>
..             <DIR>

AAS_1.MOD
AAS_1.VAR
AAS_1.JBQ
AAS_1.SNA
AAS_1.QUE
AAS_1.FNC
XAAS_1.MOD
XAAS_1.VAR
XAAS_1.JBQ
XAAS_1.SNA
XAAS_1.QUE
XAAS_1.FNC
AAS_2.MOD
AAS_2.VAR
AAS_2.JBQ
AAS_2.SNA
AAS_2.QUE
AAS_2.FNC
XAAS_2.MOD
XAAS_2.VAR
```

```
XAAS_2.JBQ
XAAS_2.SNA
XAAS_2.QUE
XAAS_2.FNC
AERA_1.MOD
AERA_1.VAR
AERA_1.JBQ
AERA_1.SNA
AERA_1.QUE
AERA_1.FNC
XAERA_1.MOD
XAERA_1.VAR
XAERA_1.JBQ
XAERA_1.SNA
XAERA_1.QUE
XAERA_1.FNC
AERA_2.MOD
AERA_2.VAR
AERA_2.JBQ
AERA_2.SNA
AERA_2.QUE
AERA_2.FNC
XAERA_2.MOD
XAERA_2.VAR
XAERA_2.JBQ
XAERA_2.SNA
XAERA_2.QUE
XAERA_2.FNC
        50 FILE(S) NNNNNN bytes free.
```

This completes the installation of the MicroSAINT™ files.

1.3.4 Requirements for the AUTOEXEC.BAT File

The AUTOEXEC.BAT file is described in the DOS reference manual that is supplied with the computer system. The commands in this file are automatically executed whenever the system is powered on or reset.

The AUTOEXEC.BAT file should include the DOS directory in its path setting. This allows PATCAM to use and access all DOS commands.

1.4 PATCAM Data Limits

The limit to the amount of data that can be stored in the PATCAM file is determined primarily by the amount of available space on the drive on which PATCAM is installed. If PATCAM is run when too little memory is available, PATCAM will stop at an arbitrary point during its LOTUS calculations, and nothing further can be done until the system is rebooted. When this occurs, an error message will blink in the top right hand corner of the LOTUS screen. At this point, the system must be rebooted.

If a memory problem is suspected, use the CHKDSK command to see if enough memory is available. If enough memory is available, try running PATCAM again.

Otherwise examine the AUTOEXEC.BAT file in the root directory of the hard disk to determine what memory-resident software is loading that is using up the memory.

2.0 Entering PATCAM

The user runs PATCAM from the C:\PATCAM directory by typing "PATCAM" at the DOS command line. PATCAM will display an introductory screen and a prompt "Press END to quit PATCAM, any other key to continue." Pressing ESC will return the user to DOS. Pressing any other key will bring up a display with the HOME menu (Figure E-1).

The user can select one of three options in the HOME menu: Model, Simulator, and Output. Selecting Model will transfer the user to the sector/controller model editor. Selecting Simulator will allow the user to run a simulation model based on a scenario and a sector/controller model. Finally, selecting Output allows the user to view the simulation results in tables or in graphs.

The user can scroll through the list using the <UpArrow> and <DownArrow> keys and specify a selection by using <RETURN>. The user can access the HELP window by pressing <F1>. The user can also quit PATCAM and return to DOS by pressing the <END> key.

3.0 Predefined PATCAM Results

PATCAM contains twelve predefined model-based results. These results are provided because one simulation run takes approximately two hours and fifteen minutes. The results can be viewed on the screen or printed from within PATCAM. Section 6.0 of the User's Guide explains how this may be accomplished. Figures E-2 through E-7b show the various printouts available in PATCAM.

The output filenames and a brief description of the predefined results are as follows:

OUTPUT NAME	SCENARIO	INITIAL CONDITIONS
AAS1HI	AAS Scenario 1	High Workload and Performance
AAS1MD	AAS Scenario 1	Medium Workload and Performance
AAS1LW	AAS Scenario 1	Low Workload and Performance
AAS2HI	AAS Scenario 2	High Workload and Performance
AAS2MD	AAS Scenario 2	Medium Workload and Performance
AAS2LW	AAS Scenario 2	Low Workload and Performance
AERA1HI	AERA 2 Scenario 1	High Workload and Performance
AERA1MD	AERA 2 Scenario 1	Medium Workload and Performance
AERA1LW	AERA 2 Scenario 1	Low Workload and Performance
AERA2HI	AERA 2 Scenario 2	High Workload and Performance
AERA2MD	AERA 2 Scenario 2	Medium Workload and Performance
AERA2LW	AERA 2 Scenario 2	Low Workload and Performance

The initial conditions are specified in Figure E-8.

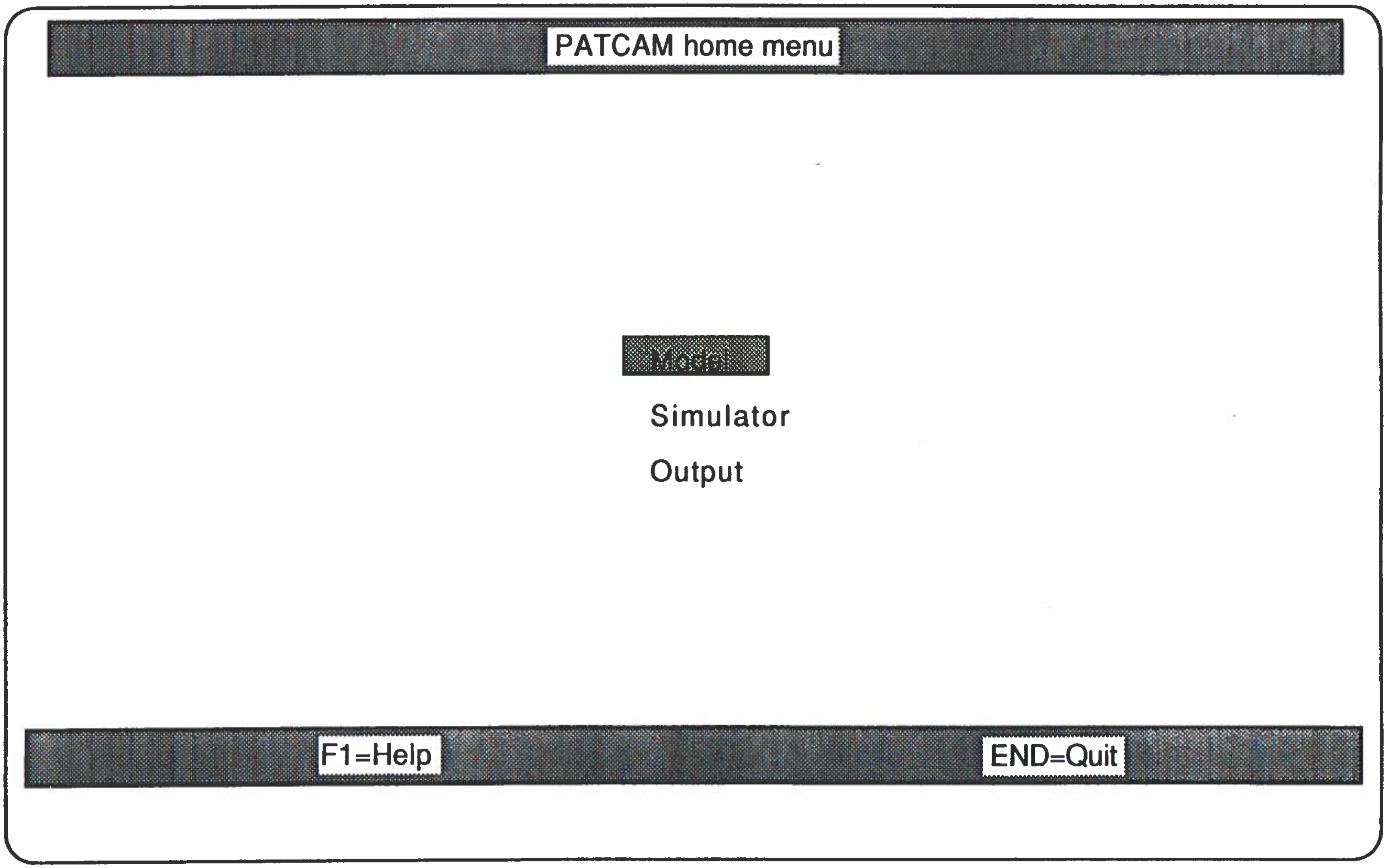

Figure E-1. PATCAM home menu

```
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SIMULATION PARAMETER INFORMATION                          PATCAM SECTOR/ASSISTANCE PARAMETERS SET
                    Scenario:   AAS_scenario_1                     Initial Aircraft in Sector:   20
             Output Filename:   TEST1                                   Initial Weather:         0
Actual Run Time (hrs:min:sec):  00:26:07                  Initial Special-Use-Airspace:         0
      Actual Number of Tasks:   174                      Avg Travel Time Through Sector:        20
                                                          Frequency Aircraft Enters Sector:       1
                                                                      Type of Assistance:        3
----------------------------------------------------------------------------------------------------
                                           SIMLUATION LOG
             # of    # Spec Use    # of       # of        # of        ----(hrs:min:sec)----
Instance   Aircraft   Airspace    Weather   Conflicts   Handoffs    Starttime   Duration   Task No.
----------------------------------------------------------------------------------------------------
    1        20          0          0          0           1        00:00:00    00:00:01     4.6.1
    2        20          0          0          0           1        00:00:01    00:00:02     4.6.6
    3        21          0          0          0           0        00:00:03    00:00:02     4.6.4
    4        21          0          0          0           0        00:00:06    00:00:05    4.13.6
    5        21          0          0          0           0        00:00:11    00:00:06    1.6.11
    6        21          0          0          0           0        00:00:17    00:00:05     3.5.1
    7        21          0          0          0           0        00:00:22    00:00:02     4.7.2
    8        21          0          0          0           0        00:00:25    00:00:04     4.7.4
    9        21          0          0          0           0        00:00:29    00:00:02    4.13.4
   10        21          0          0          0           0        00:00:30    00:00:15    4.13.5
   11        21          0          0          0           0        00:00:45    00:00:09    1.6.11
   12        19          0          0          0           0        00:00:55    00:00:12     4.7.8
   13        19          0          0          0           0        00:01:06    00:00:04     1.1.1
   14        19          0          0          0           0        00:01:10    00:00:06     1.1.2
   15        19          0          0          0           0        00:01:16    00:00:10    1.6.11
   16        19          0          0          0           0        00:01:26    00:00:04     1.1.4
   17        19          0          0          0           0        00:01:30    00:00:07    1.1.12
   18        19          0          0          0           0        00:01:37    00:00:05    1.1.13
   19        19          0          0          0           1        00:01:42    00:00:05    1.1.14
   20        19          0          0          0           1        00:01:47    00:00:06     1.1.7
   21        19          0          0          0           1        00:01:53    00:00:05    1.1.16
   22        19          0          0          0           1        00:01:58    00:00:05    1.1.15
```
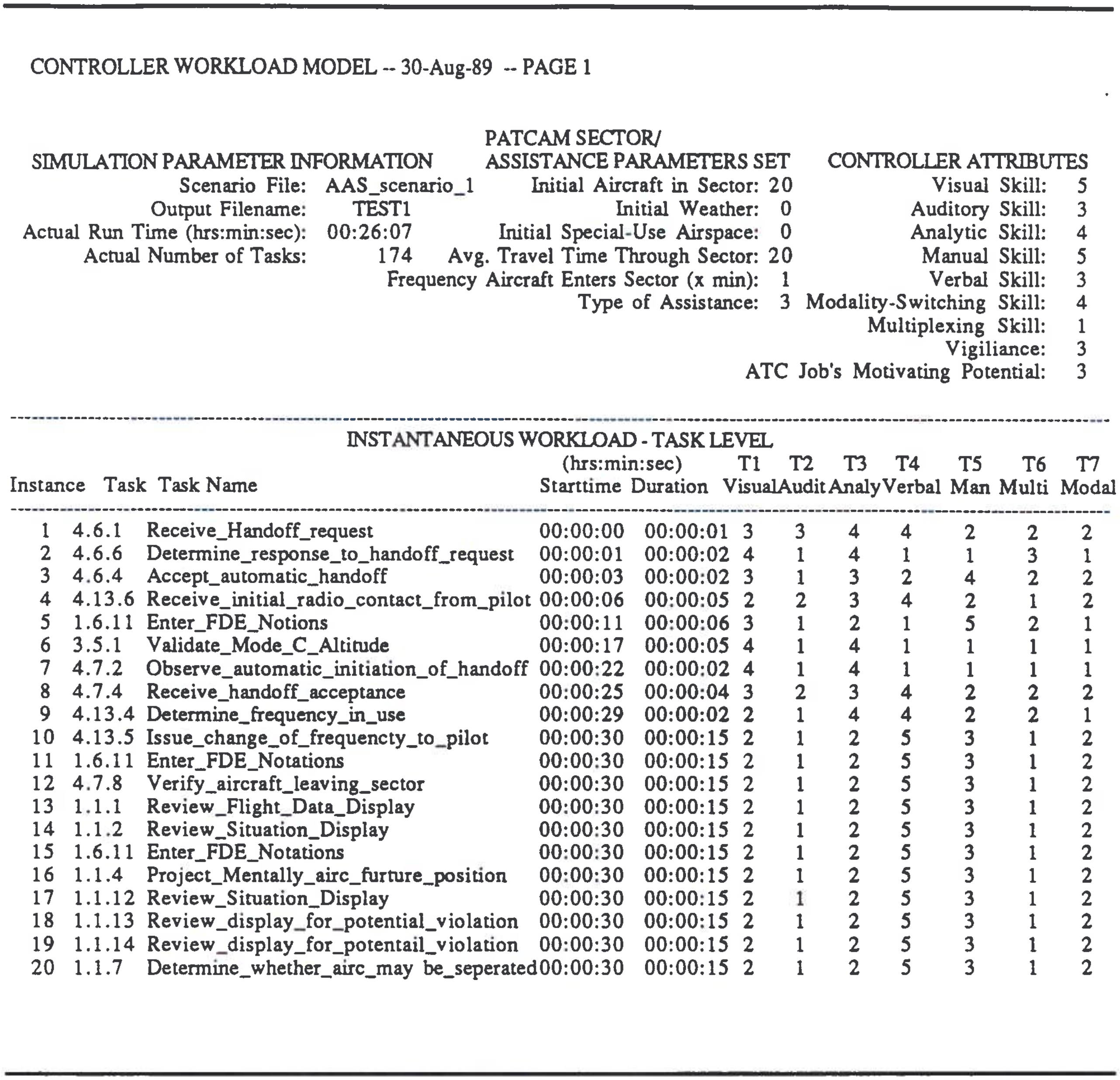

Figure E-2. SAMPLE SIMULATION LOG PRINTOUT



```
CONTROLLER WORKLOAD MODEL -- 30-Aug-89 -- PAGE 1

                                          PATCAM SECTOR/
SIMULATION PARAMETER INFORMATION          ASSISTANCE PARAMETERS SET        CONTROLLER ATTRIBUTES
             Scenario File:  AAS_scenario_1    Initial Aircraft in Sector: 20            Visual Skill:  5
           Output Filename:   TEST1                    Initial Weather:  0          Auditory Skill:  3
Actual Run Time (hrs:min:sec):  00:26:07     Initial Special-Use Airspace:  0          Analytic Skill:  4
      Actual Number of Tasks:       174   Avg. Travel Time Through Sector: 20            Manual Skill:  5
                              Frequency Aircraft Enters Sector (x min):  1            Verbal Skill:  3
                                                   Type of Assistance:  3 Modality-Switching Skill:  4
                                                                              Multiplexing Skill:  1
                                                                                      Vigiliance:  3
                                                                   ATC Job's Motivating Potential:  3

------------------------------------------------------------------------------------------------------
                            INSTANTANEOUS WORKLOAD - TASK LEVEL
                                                    (hrs:min:sec)       T1    T2   T3   T4    T5   T6   T7
Instance  Task  Task Name                           Starttime Duration VisualAuditAnalyVerbal Man Multi Modal
------------------------------------------------------------------------------------------------------
  1  4.6.1   Receive_Handoff_request                  00:00:00  00:00:01 3    3    4    4     2    2    2
  2  4.6.6   Determine_response_to_handoff_request    00:00:01  00:00:02 4    1    4    1     1    3    1
  3  4.6.4   Accept_automatic_handoff                 00:00:03  00:00:02 3    1    3    2     4    2    2
  4  4.13.6 Receive_initial_radio_contact_from_pilot 00:00:06  00:00:05 2    2    3    4     2    1    2
  5  1.6.11 Enter_FDE_Notions                        00:00:11  00:00:06 3    1    2    1     5    2    1
  6  3.5.1   Validate_Mode_C_Altitude                 00:00:17  00:00:05 4    1    4    1     1    1    1
  7  4.7.2   Observe_automatic_initiation_of_handoff  00:00:22  00:00:02 4    1    4    1     1    1    1
  8  4.7.4   Receive_handoff_acceptance               00:00:25  00:00:04 3    2    3    4     2    2    2
  9  4.13.4 Determine_frequency_in_use               00:00:29  00:00:02 2    1    4    4     2    2    1
 10  4.13.5 Issue_change_of_frequencty_to_pilot      00:00:30  00:00:15 2    1    2    5     3    1    2
 11  1.6.11 Enter_FDE_Notations                      00:00:30  00:00:15 2    1    2    5     3    1    2
 12  4.7.8   Verify_aircraft_leaving_sector           00:00:30  00:00:15 2    1    2    5     3    1    2
 13  1.1.1   Review_Flight_Data_Display               00:00:30  00:00:15 2    1    2    5     3    1    2
 14  1.1.2   Review_Situation_Display                 00:00:30  00:00:15 2    1    2    5     3    1    2
 15  1.6.11 Enter_FDE_Notations                      00:00:30  00:00:15 2    1    2    5     3    1    2
 16  1.1.4   Project_Mentally_airc_furture_position   00:00:30  00:00:15 2    1    2    5     3    1    2
 17  1.1.12 Review_Situation_Display                 00:00:30  00:00:15 2    1    2    5     3    1    2
 18  1.1.13 Review_display_for_potential_violation   00:00:30  00:00:15 2    1    2    5     3    1    2
 19  1.1.14 Review_display_for_potentail_violation   00:00:30  00:00:15 2    1    2    5     3    1    2
 20  1.1.7   Determine_whether_airc_may be_seperated00:00:30  00:00:15 2    1    2    5     3    1    2
```

Figure E-3. CONTROLLER WORKLOAD MODEL -- SAMPLE TASK-LEVEL PRINTOUT

```
CONTROLLER PERFORMANCE MODEL -- 30-Aug-89  -- PAGE 1

                                              PATCAM SECTOR/
SIMULATION PARAMETER INFORMATION              ASSISTANCE PARAMETERS SET    CONTROLLER ATTRIBUTES
           Scenario File:  AAS_scenario_1           Initial Aircraft in Sector: 20             Visual  Skill:   5
         Output Filename:     TEST1                    Initial  Weather:  0              Auditory  Skill:   3
Actual Run Time (hrs:min:sec):  00:26:07       Initial Special-Use Airspace:  0              Analytic  Skill:   4
      Actual Number of Tasks:        174      Avg. Travel Time Through Sector: 20              Manual  Skill:   5
                                       Frequency Aircraft Enters Sector (x min):  1               Verbal  Skill:   3
                                                         Type of Assistance:  3 Modality-Switching  Skill:   4
                                                                                   Multiplexing  Skill:   1
                                                                                         Vigiliance:   3
                                                                      ATC Job's Motivating  Potential:   3

-----------------------------------------------------------------------------------------------------------------
                                   INSTANTANEOUS PERFORMANCE - TASK LEVEL
                                                     (hrs:min:sec)        T1    T2    T3    T4    T5    T6    T7
Instance  Task  Task Name                          Starttime Duration VisualAudit AnalyVerbal  Man  Multi Modal
-----------------------------------------------------------------------------------------------------------------

   1   4.6.1   Receive_Handoff_request               00:00:00  00:00:01  3     3     4     4     2     2     2
   2   4.6.6   Determine_response_to_handoff_request 00:00:01  00:00:02  4     1     4     1     1     3     1
   3   4.6.4   Accept_automatic_handoff              00:00:03  00:00:02  3     1     3     2     4     2     2
   4   4.13.6  Receive_initial_radio_contact_from_pilot 00:00:06  00:00:05  2     2     3     4     2     1     2
   5   1.6.11  Enter_FDE_Notions                     00:00:11  00:00:06  3     1     2     1     5     2     1
   6   3.5.1   Validate_Mode_C_Altitude              00:00:17  00:00:05  4     1     4     1     1     1     1
   7   4.7.2   Observe_automatic_initiation_of_handoff 00:00:22  00:00:02  4     1     4     1     1     1     1
   8   4.7.4   Receive_handoff_acceptance            00:00:25  00:00:04  3     2     2     4     2     2     2
   9   4.13.4  Determine_frequency_in_use            00:00:29  00:00:02  1     1     3     4     2     2     1
  10   4.13.5  Issue_change_of_frequencty_to_pilot   00:00:30  00:00:15  2     1     2     4     3     1     2
  11   1.6.11  Enter_FDE_Notations                   00:00:30  00:00:15  2     1     2     4     3     1     2
  12   4.7.8   Verify_aircraft_leaving_sector        00:00:30  00:00:15  2     1     2     4     3     1     2
  13   1.1.1   Review_Flight_Data_Display            00:00:30  00:00:15  2     1     2     4     3     1     2
  14   1.1.2   Review_Situation_Display              00:00:30  00:00:15  2     1     2     4     3     1     2
  15   1.6.11  Enter_FDE_Notations                   00:00:30  00:00:15  2     1     2     4     3     1     2
  16   1.1.4   Project_Mentally_airc_furture_position 00:00:30  00:00:15  2     1     2     4     3     1     2
  17   1.1.12  Review_Situation_Display              00:00:30  00:00:15  1     1     2     4     3     1     2
  18   1.1.13  Review_display_for_potential_violation 00:00:30  00:00:15  2     1     2     3     3     1     1
  19   1.1.14  Review_display_for_potentail_violation 00:00:30  00:00:15  2     1     2     3     3     1     1
  20   1.1.7   Determine_whether_airc_may be_seperated00:00:30  00:00:15  2     1     2     3     3     1     2
```

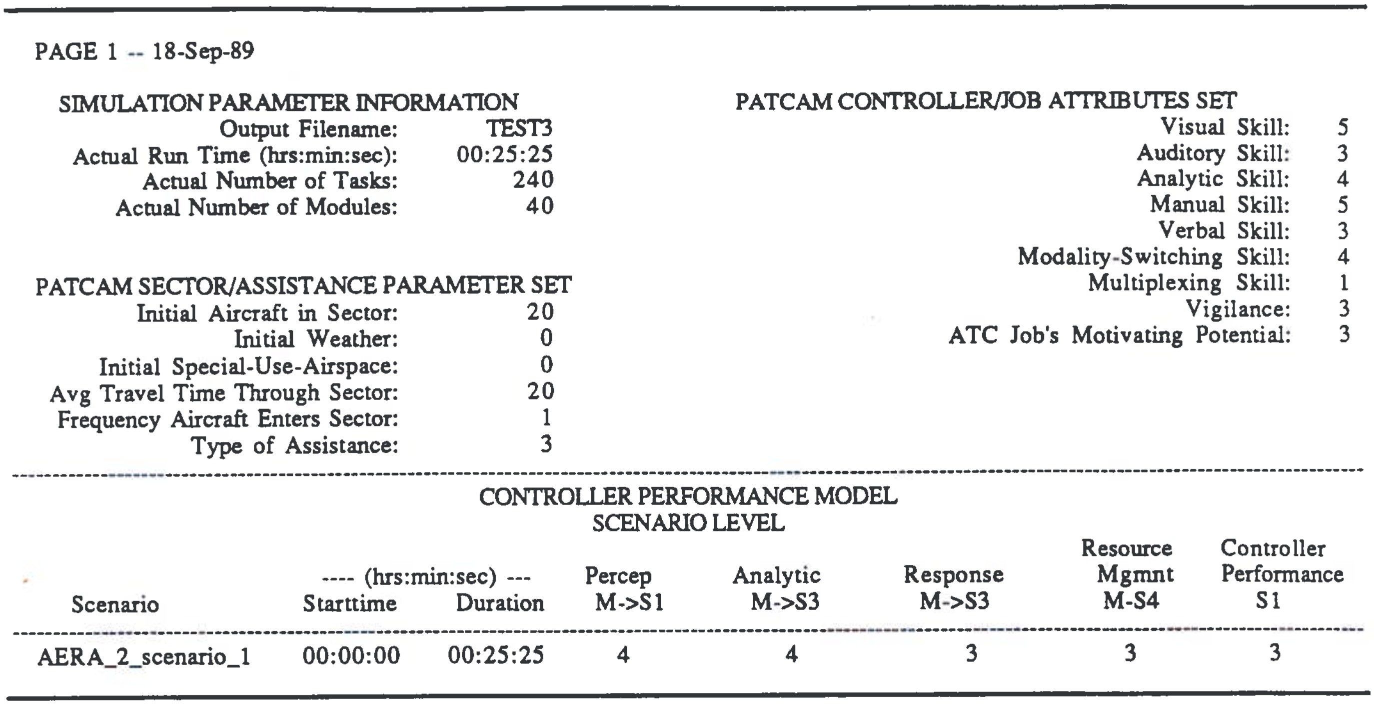
Figure E-4. CONTROLLER PERFORMANCE MODEL -- SAMPLE TASK-LEVEL PRINTOUT

```
CONTROLLER WORKLOAD MODEL -- 14-Sep-89 -- PAGE 1

      SIMULATION PARAMETER INFORMATION                    PATCAM CONTROLLER/JOB ATTRIBUTES SET
                            Scenario:  AAS_scenario_1                         Visual Skill:  5
                     Output Filename:       TEST1                           Auditory Skill:  3
        Actual Run Time (hrs:min:sec):    00:26:07                           Analytic Skill:  4
             Actual Number of Tasks:         174                               Manual Skill:  5
           Actual Number of Modules:          27                               Verbal Skill:  3
                                                                    Modality-Switching Skill:  4
   PATCAM SECTOR/ASSISTANCE PARAMETER SET                                Multiplexing Skill:  1
            Initial Aircraft in Sector:       20                                  Vigilance:  3
                      Initial Weather:         0            ATC Job's Motivating Potential:  3
         Initial Special-Use-Airspace:         0
          Avg Travel Time Through Sector:      2
         Frequency Aircraft Enters Sector:     1
                    Type of Assistance:        3

---------------------------------------------------------------------------------------------------------
                                          MODULES LEVEL
Module                                 ----(hrs:min:sec)---  visual  audit   analy  verbal  manual  multi  modal
  #        Module Name                 Starttime  Duration  T->M1   T->M2   T->M3   T->M4   T->M5  T->M6  T-M7
---------------------------------------------------------------------------------------------------------
  1   Aircraft_Enters_Sector           00:00:00  00:00:22     3       1       3       2       3      2      1
  3   Aircraft_Leaves_Sector           00:00:22  00:00:44     3       1       3       3       3      2      1
  2   Monitoring_for_Conflicts         00:01:06  00:01:01     3       1       3       1       2      2      2
  1   Aircraft_Enters_Sector           00:02:07  00:00:31     3       1       3       2       3      2      1
  3   Aircraft_Leaves_Sector           00:02:39  00:00:34     3       1       3       3       3      2      1
  5   Conflicts_W/_Airspace            00:03:12  00:02:14     3       1       5       2       3      2      2
  3   Aircraft_Leaves_Sector           00:05:26  00:00:36     3       1       3       3       3      2      1
  1   Aircraft_Enters_Sector           00:06:02  00:00:24     3       1       3       2       3      2      1
  2   Monitoring_for_Conflicts         00:06:26  00:00:57     3       1       3       1       2      2      2
  6   Managing_Personal_Workload       00:07:23  00:00:54     2       1       4       2       2      3      1
  3   Aircraft_Leaves_Sector           00:08:18  00:00:40     3       1       3       2       3      3      1
  1   Aircraft_Enters_Sector           00:08:58  00:00:23     3       1       3       2       3      2      1
  7   Aircraft_to_Aircraft_Conflict    00:09:21  00:00:19     4       1       5       1       1      2      3
  3   Aircraft_Leaves_Sector           00:09:41  00:00:39     3       1       4       2       3      2      1
  8   Encounter_Severe_Turbulence      00:10:20  00:03:30     3       1       5       2       2      2      1
```

Figure E-5. CONTROLLER WORKLOAD MODEL -- SAMPLE MODULE-LEVEL PRINTOUT

```
CONTROLLER PERFORMANCE MODEL -- 14-Sep-89  -- PAGE 1

        SIMULATION PARAMETER INFORMATION                PATCAM CONTROLLER/JOB ATTRIBUTES SET
                      Scenario:  AAS_scenario_1                              Visual  Skill:   5
               Output Filename:           TEST1                            Auditory  Skill:   3
 Actual Run Time (hrs:min:sec):        00:26:07                            Analytic  Skill:   4
        Actual Number of Tasks:             174                              Manual  Skill:   5
      Actual Number of Modules:              27                              Verbal  Skill:   3
                                                                  Modality-Switching  Skill:   4
   PATCAM SECTOR/ASSISTANCE PARAMETER SET                               Multiplexing  Skill:   1
          Initial  Aircraft  in  Sector:     20                                 Vigilance:   3
                   Initial  Weather:          0              ATC Job's Motivating Potential:   3
     Initial  Special-Use-Airspace:           0
      Avg Travel Time Through Sector:         2
     Frequency Aircraft Enters Sector:        1
                 Type  of  Assistance:        3
-----------------------------------------------------------------------------------------------------
                                              MODULES LEVEL
Module                                 ----(hrs:min:sec)---  visual  audit  analy  verbal manual  multi  modal
  #        Module Name                 Starttime  Duration  T->M1   T->M2  T->M3  T->M4  T->M5  T->M6  T-MA7
-----------------------------------------------------------------------------------------------------
  1   Aircraft_Enters_Sector           00:00:00  00:00:22     3       2      2      2      3      2      2
  3   Aircraft_Leaves_Sector           00:00:22  00:00:44     3       2      3      3      2      3      1
  2   Monitoring_for_Conflicts         00:01:06  00:01:01     3       2      3      1      2      2      2
  1   Aircraft_Enters_Sector           00:02:07  00:00:31     3       2      3      2      3      2      2
  3   Aircraft_Leaves_Sector           00:02:39  00:00:34     3       2      3      3      3      2      1
  5   Conflicts_W/_Airspace            00:03:12  00:02:14     3       1      4      2      2      3      2
  3   Aircraft_Leaves_Sector           00:05:26  00:00:36     3       1      3      3      3      2      1
  1   Aircraft_Enters_Sector           00:06:02  00:00:24     3       2      3      2      2      2      2
  2   Monitoring_for_Conflicts         00:06:26  00:00:57     3       2      3      2      2      2      2
  6   Managing_Personal_Workload       00:07:23  00:00:54     2       1      3      2      2      3      1
  3   Aircraft_Leaves_Sector           00:08:18  00:00:40     3       2      3      2      3      3      1
  1   Aircraft_Enters_Sector           00:08:58  00:00:23     3       2      2      2      3      2      1
  7   Aircraft_to_Aircraft_Conflict    00:09:21  00:00:19     4       1      4      1      1      2      3
  3   Aircraft_Leaves_Sector           00:09:41  00:00:39     3       1      3      2      3      2      2
  8   Encounter_Severe_Turbulence      00:10:20  00:03:30     3       1      4      2      2      2      1
```

Figure E-6. CONTROLLER PERFORMANCE MODEL -- SAMPLE MODULE-LEVEL PRINTOUT



```
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  SIMULATION PARAMETER INFORMATION                 PATCAM CONTROLLER/JOB ATTRIBUTES SET
                 Output Filename:      TEST3                               Visual  Skill:    5
   Actual Run Time (hrs:min:sec):   00:25:25                             Auditory  Skill:    3
         Actual Number of Tasks:         240                             Analytic  Skill:    4
       Actual Number of Modules:          40                               Manual  Skill:    5
                                                                           Verbal  Skill:    3
                                                               Modality-Switching  Skill:    4
PATCAM SECTOR/ASSISTANCE PARAMETER SET                               Multiplexing  Skill:    1
         Initial Aircraft in Sector:      20                                  Vigilance:    3
                    Initial Weather:       0                ATC Job's Motivating Potential:    3
       Initial Special-Use-Airspace:       0
       Avg Travel Time Through Sector:    20
       Frequency Aircraft Enters Sector:   1
                  Type of Assistance:      3
------------------------------------------------------------------------------------------------
                              CONTROLLER PERFORMANCE MODEL
                                     SCENARIO LEVEL
                                                                          Resource  Controller
                        ---- (hrs:min:sec) ---   Percep   Analytic   Response  Mgmnt   Performance
  Scenario               Starttime   Duration   M->S1    M->S3      M->S3     M-S4       S1
------------------------------------------------------------------------------------------------
AERA_2_scenario_1        00:00:00   00:25:25     4        4          3         3          3
```
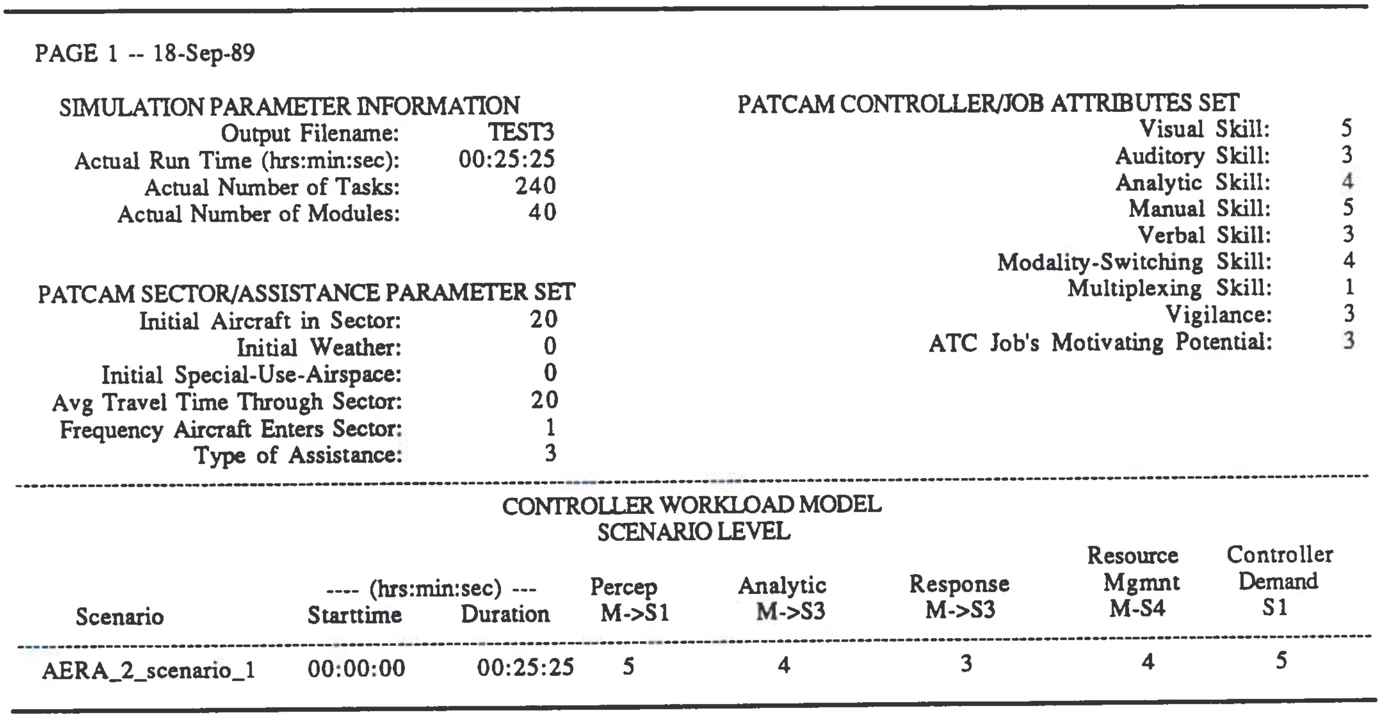

Figure E-7a. CONTROLLER PERFORMANCE MODEL -- SAMPLE SCENARIO-LEVEL PRINTOUT



```
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  SIMULATION PARAMETER INFORMATION                 PATCAM CONTROLLER/JOB ATTRIBUTES SET
                 Output Filename:      TEST3                               Visual  Skill:    5
   Actual Run Time (hrs:min:sec):   00:25:25                             Auditory  Skill:    3
         Actual Number of Tasks:         240                             Analytic  Skill:    4
       Actual Number of Modules:          40                               Manual  Skill:    5
                                                                           Verbal  Skill:    3
                                                               Modality-Switching  Skill:    4
PATCAM SECTOR/ASSISTANCE PARAMETER SET                               Multiplexing  Skill:    1
         Initial Aircraft in Sector:      20                                  Vigilance:    3
                    Initial Weather:       0                ATC Job's Motivating Potential:    3
       Initial Special-Use-Airspace:       0
       Avg Travel Time Through Sector:    20
       Frequency Aircraft Enters Sector:   1
                  Type of Assistance:      3
------------------------------------------------------------------------------------------------
                              CONTROLLER WORKLOAD MODEL
                                     SCENARIO LEVEL
                                                                          Resource  Controller
                        ---- (hrs:min:sec) ---   Percep   Analytic   Response  Mgmnt    Demand
  Scenario               Starttime   Duration   M->S1    M->S3      M->S3     M-S4       S1
------------------------------------------------------------------------------------------------
AERA_2_scenario_1        00:00:00   00:25:25     5        4          3         4          5
```

Figure E-7b. CONTROLLER WORKLOAD MODEL -- SAMPLE SCENARIO-LEVEL PRINTOUT

	CONDITIONS		
	HIGH	MEDIUM	LOW
WORKLOAD	AAS1HI AAS2HI AERA1HI AERA2HI	AAS1MD AAS2MD AERA1MD AERA2MD	AAS1LW AAS2LW AERA1LW AERA2LW
Initial # of Aircraft	35	22	10
Initial # of Weather	5	3	1
Initial # of Special-Use-Airspace	1	1	1
Average Time Through the Sector	20	10	7
Ratio/Aircraft Enter the Sector (x min)	1	3	5
Type of Assistance	1	3	5
Visual Skill	3	3	3
Auditory Skill	3	3	3
Analytic Skill	3	3	3
Manual Skill	3	3	3
Verbal Skill	3	3	3
Modality-Switching Skill	3	3	3
Multiplexing Skill	3	3	3
Vigilance	3	3	3
Motivating Potential	3	3	3

	CONDITIONS		
	HIGH	MEDIUM	LOW
PERFORMANCE	AAS1HI AAS2HI AERA1HI AERA2HI	AAS1MD AAS2MD AERA1MD AERA2MD	AAS1LW AAS2LW AERA1LW AERA2LW
Initial # of Aircraft	22	22	22
Initial # of Weather	3	3	3
Initial # of Special-Use-Airspace	1	1	1
Average Time Through the Sector	10	10	10
Ratio/Aircraft Enter the Sector (x-per min.)	3	3	3
Type of Assistance	3	3	3
Visual Skill	5	3	1
Auditory Skill	5	3	1
Analytic Skill	5	3	1
Manual Skill	5	3	1
Verbal Skill	5	3	1
Modality-Switching Skill	5	3	1
Multiplexing Skill	5	3	1
Vigilance	5	3	1
Motivating Potential	5	3	1

Figure E-8. Initial Conditions for Predefined PATCAM Results

4.0 Building a Sector/Controller Model

The PATCAM model file is displayed in two form-fill page formats. The first page (shown in Figure E-9) allows the user to specify the six values of the sector/assistance parameters set. The second page (shown in Figure E-10) allows the user to specify values for the seven controller skills and the two controller job attributes that make up the controller/job attributes set.

4.1 Manipulating PATCAM Sector/Controller Model Files

The user can execute one of five file manipulation commands, selected from the FILE pull-up menu, which the user accesses by pressing <F2>. Once a pull-up menu is brought up, the user scrolls to the appropriate command using the <UpArrow> and <DownArrow> keys and pressing <RETURN>. If the user wishes to abort the file manipulation command selection, pressing <ESC> will return the user to the last opened model, provided one is open. The five file manipulation commands are:

New_File : creates and displays a new Sector/Controller Model file with default values.

Open_File : Opens and displays a model file. This command brings up a subwindow listing the directory of the existing Sector/ Controller Model files. The user can scroll through the list using the <UpArrow> and <DownArrow> keys and specify a selection by pressing <RETURN>. If the user wishes to abort the file selection, pressing <ESC> will return the user to the last opened model, provided one is open. If the user has a file already open and changes have been made to that file, the user will be prompted to save the currently open file.

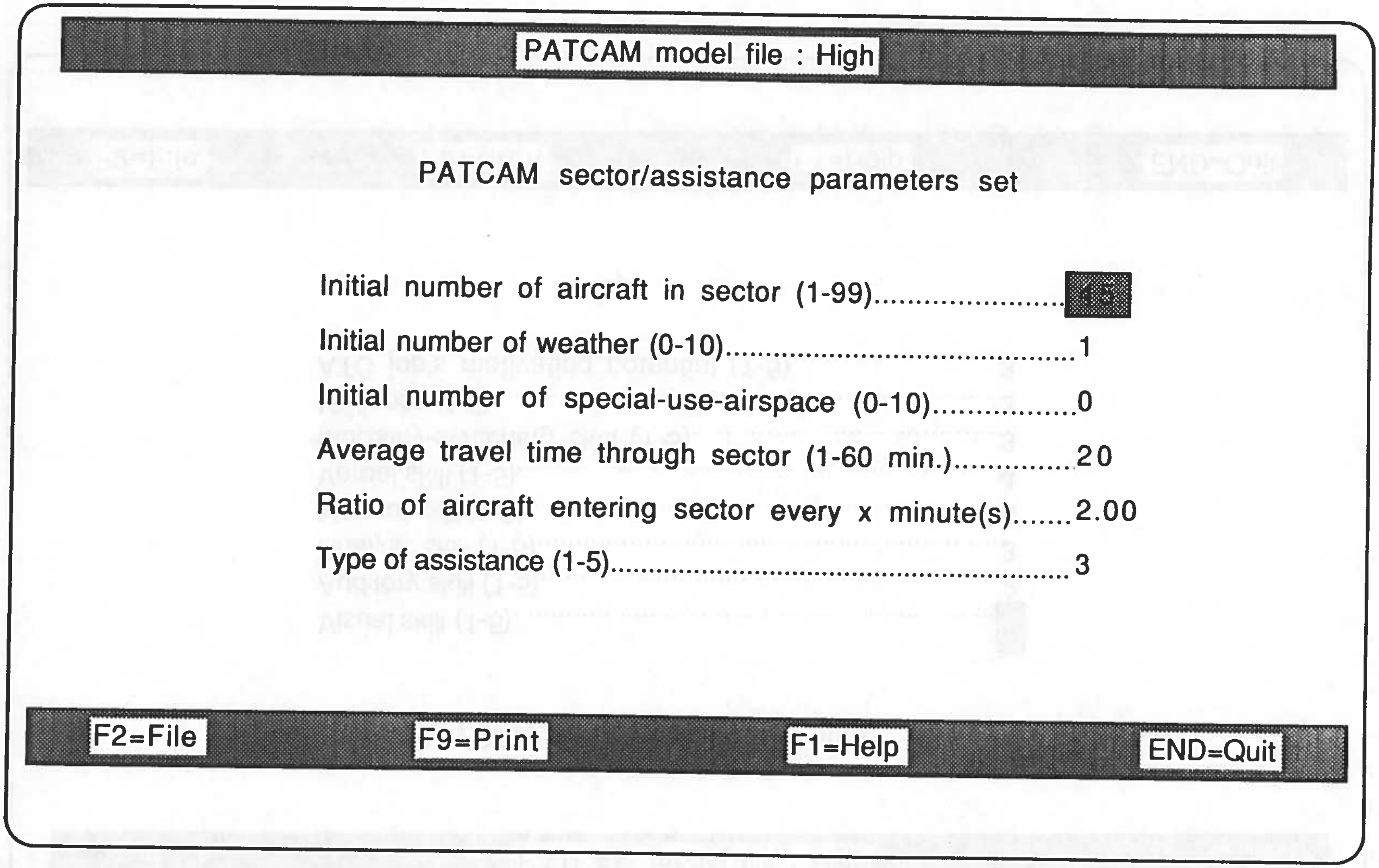
Save_File : Saves the changes made to the open file, and returns the user to the open file.

Write_To : Copies the open file to a new file. The user is prompted for a file name. A file name can be up to seven characters long. If the user enters a name that is reserved by PATCAM, PATCAM will prompt the user for a different name. Reserved file names are files used by the user-system interface (USI) software.

Delete_File : Deletes an existing model file. This command brings up a subwindow listing the directory of the existing Sector/ Controller Model. The user can scroll through the list using the <UpArrow> and <DownArrow> keys and specify a selection by pressing <RETURN>. If the user wishes to abort the file selection, pressing <ESC> will return the user to the last opened model, provided one is open. If the user tries to delete a reserved file, PATCAM will warn the user and return the user to the open output file.

4.2 Navigating the Sector/Controller Model Editor

The user scrolls to a specific attribute by using the <UpArrow> and <DownArrow>, or <RETURN> key. The user can also page using the <PgUp> or <PgDn> keys. The user can access the HELP window by pressing <F1>.



PATCAM model file : High

PATCAM sector/assistance parameters set

Initial number of aircraft in sector (1-99)........................15

Initial number of weather (0-10)...1

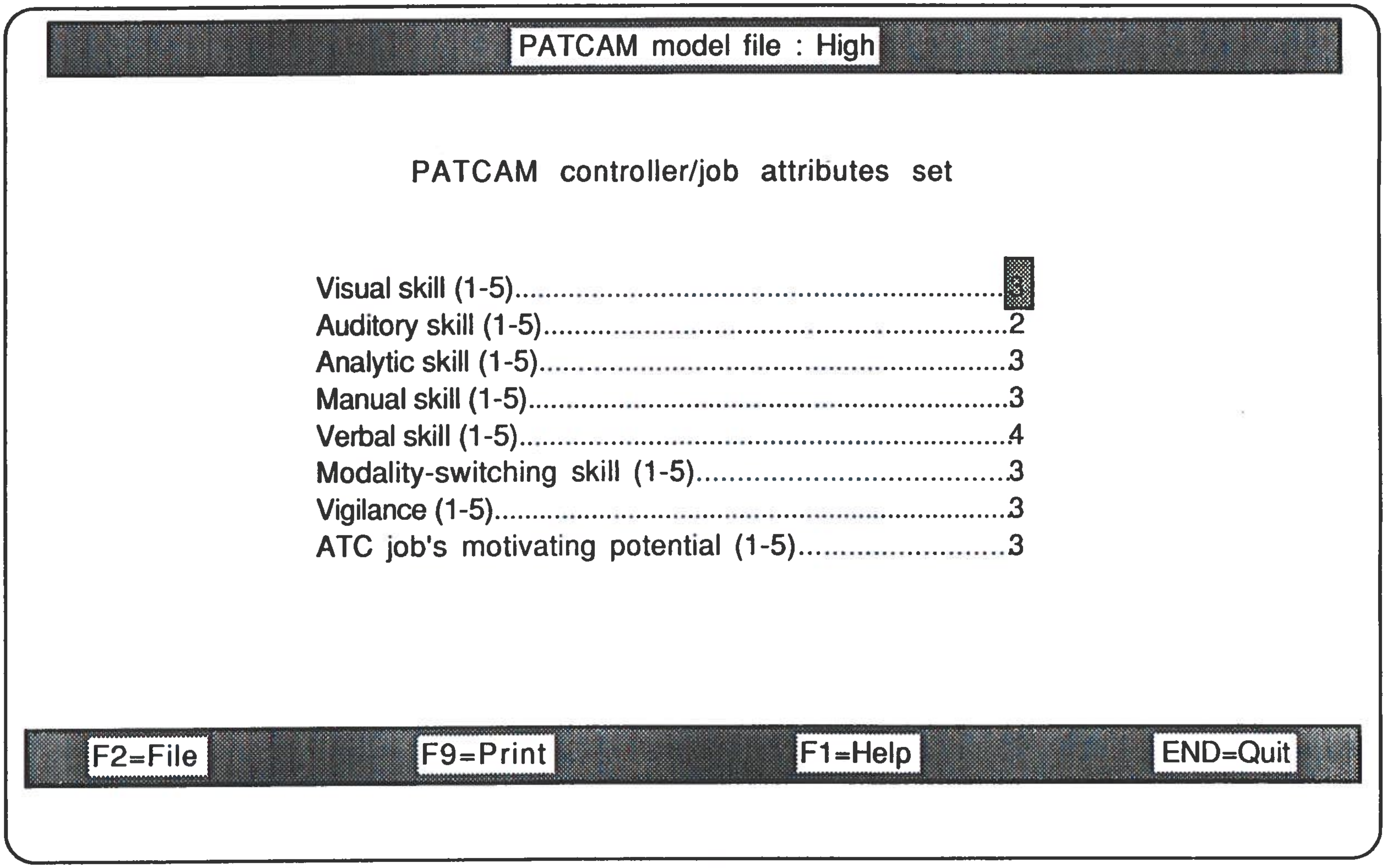
Initial number of special-use-airspace (0-10)..................0

Average travel time through sector (1-60 min.)..............20

Ratio of aircraft entering sector every x minute(s).......2.00

Type of assistance (1-5)..3

Figure E-9. Sector/assistance values display for the PATCAM model editor



PATCAM controller/job attributes set

Visual skill (1-5)..3
Auditory skill (1-5)...2
Analytic skill (1-5)..3
Manual skill (1-5)..3
Verbal skill (1-5)...4
Modality-switching skill (1-5).......................................3
Vigilance (1-5)...3
ATC job's motivating potential (1-5)...........................3

Figure E-10. PATCAM controller/job attributes set for the PATCAM model editor

4.3 Entering the Sector/Controller Attributes

Any value that the user enters will be checked to determine whether the value is within the acceptable range for that particular attribute. If the value the user enters is out of that range, PATCAM prompts the user for a new value. The acceptable value ranges are provided on the USI screens (Figure E-9 and Figure E-10).

4.4 Printing the Sector/Controller Model File

The user can print an open sector/controller file by pressing the <F9> key.

4.5 Exiting the Sector/Controller Model File

The user can quit PATCAM and return to the HOME menu by pressing the <ESC> key. If the user had made changes to an open model file, PATCAM will prompt the user to save the changes before closing the open file.

5.0 Running a Simulation

The user runs a simulation model by selecting the SIMULATOR option from the HOME menu.

5.1 Selecting the Scenario and the Sector/Controller Model

Once the user selects the SIMULATOR option from the HOME menu, PATCAM will display the directory of available Scenarios. The user can scroll through the list using the <UpArrow> and <DownArrow> keys and specify a selection by pressing <RETURN>. If the user wishes to abort the file selection, pressing <ESC> will return the user to the HOME menu.

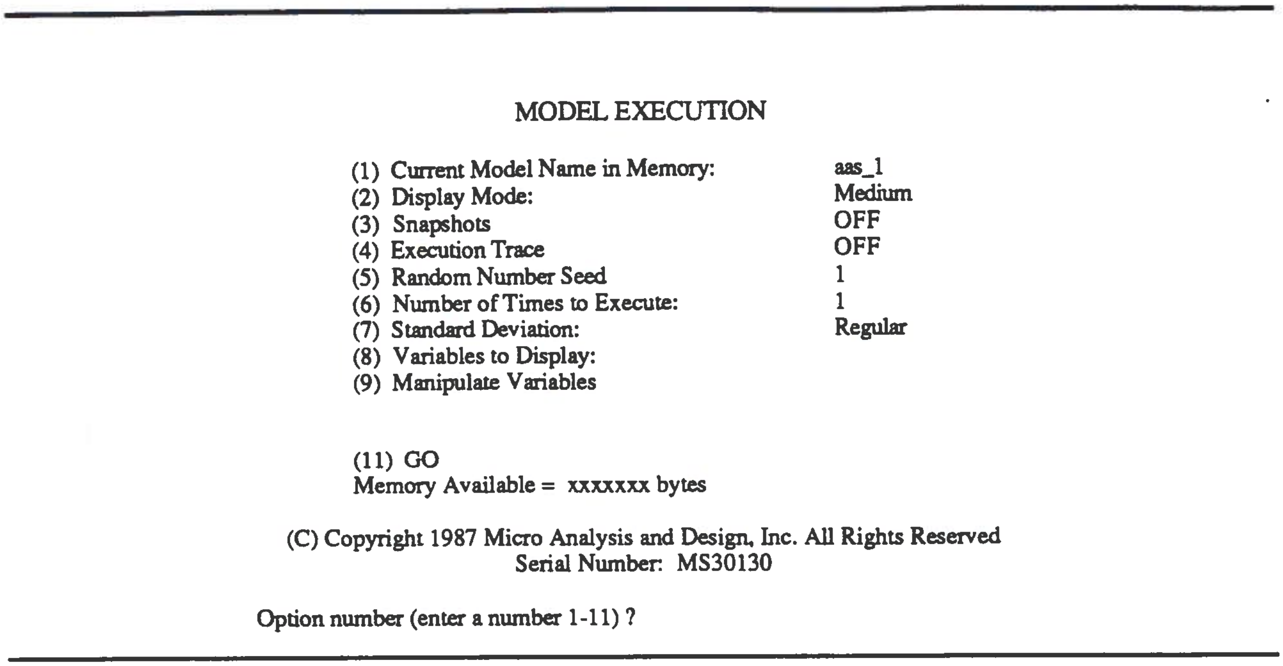
Once the user has selected a scenario file, PATCAM will display the directory of available Sector/Controller files. Again, the user can scroll through the list using the <UpArrow> and <DownArrow> keys and specify a selection by pressing <RETURN>. If the user wishes to abort the file selection, pressing <ESC> will return the user to the HOME menu.

5.2 Naming the Output File

After the user has selected the Scenario and the Sector/Controller Model, PATCAM will prompt the user for the name of a file to which the user wishes to output the results of the simulation. The user must specify a file name that is no more than seven characters long. If the user enters a reserved name, PATCAM will prompt the user for a different name.

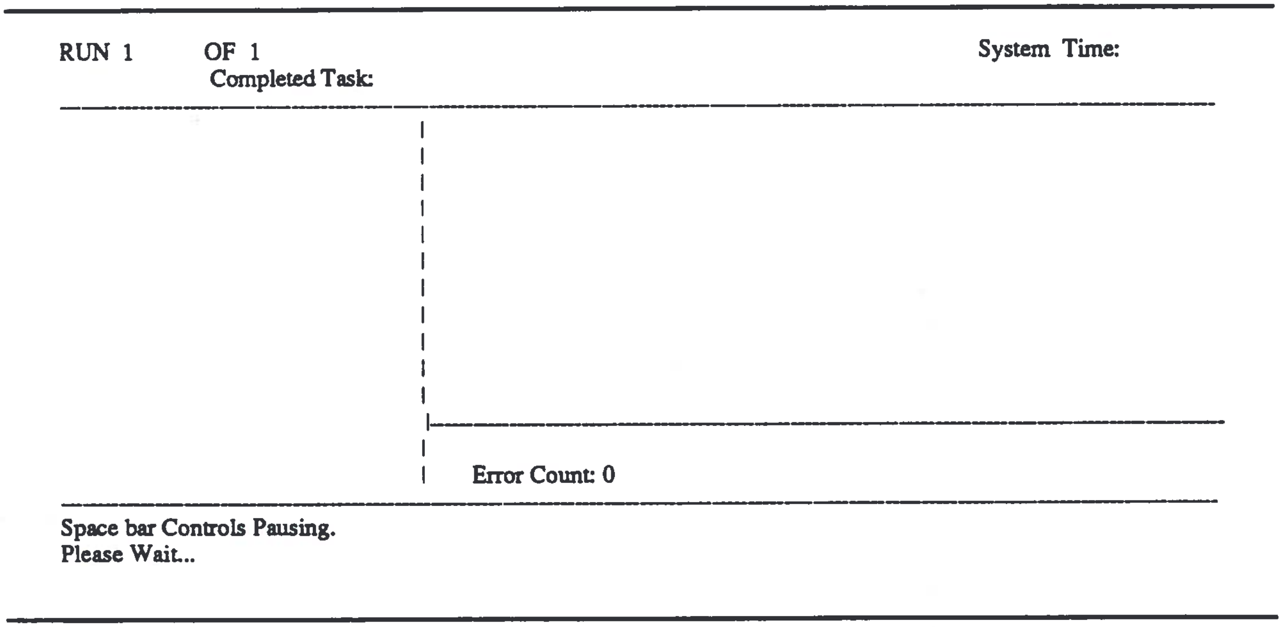
5.3 Using MicroSaint™

The MicroSAINT™ Model Execution menu, Figure E-11a, is a main menu within MicroSaint from which the user sets the parameters that create the simulation log and control the execution of the PATCAM Scenarios.



```
                         MODEL EXECUTION

        (1)  Current Model Name in Memory:        aas_1
        (2)  Display Mode:                        Medium
        (3)  Snapshots                            OFF
        (4)  Execution Trace                      OFF
        (5)  Random Number Seed                   1
        (6)  Number of Times to Execute:          1
        (7)  Standard Deviation:                  Regular
        (8)  Variables to Display:
        (9)  Manipulate Variables


        (11)  GO
        Memory Available =  xxxxxxx bytes

   (C) Copyright 1987 Micro Analysis and Design, Inc. All Rights Reserved
                        Serial Number:  MS30130

  Option number (enter a number 1-11) ?
```

Figure E-11a. MICROSaint Model Execution Menu



```
RUN  1        OF  1                                      System  Time:
               Completed Task:
----------------------------------------------------------------------
                   |
                   |
                   |
                   |
                   |
                   |
                   |
                   |
                   |
                   |
                   |
                   |
                   |---------------------------------------------------
                   |
                   |    Error Count: 0
----------------------------------------------------------------------
Space bar Controls Pausing.
Please Wait...
```

Figure 11b. EXECUTION SCREEN

1. To create the simulation log, change Snapshots to "on"from the MODEL EXECUTION menu by selecting:

   (3) Snapshots by pressing 3 <RETURN>
   (For definition of Snapshot please see the glossary in the MicroSAINT™ User's Guide).

2. At the "Turn snapshots on or off?" prompt, to select "on", enter: on <RETURN> (Use lower-case letters only).

3. To execute the controller network from the MODEL EXECUTION menu, select:

   (11) GO by typing 11 <RETURN>

Upon execution of the controller network, the MODEL EXECUTION menu, Figure E-11a will change to Figure E-11b.

As the execution occurs, the system time and completed task fields in Figure E-11b continuously change. Upon completion of the simulation run, the MicroSAINT™ Model Execution Menu (Figure E-11a) will return to the screen.

Warning: If you should strike a key on the keyboard during execution of the scenario, the simulation will pause until another key is pressed. Do not touch the keyboard until the MicroSAINT™ Model Execution menu, Figure E-11a, returns to the monitor.

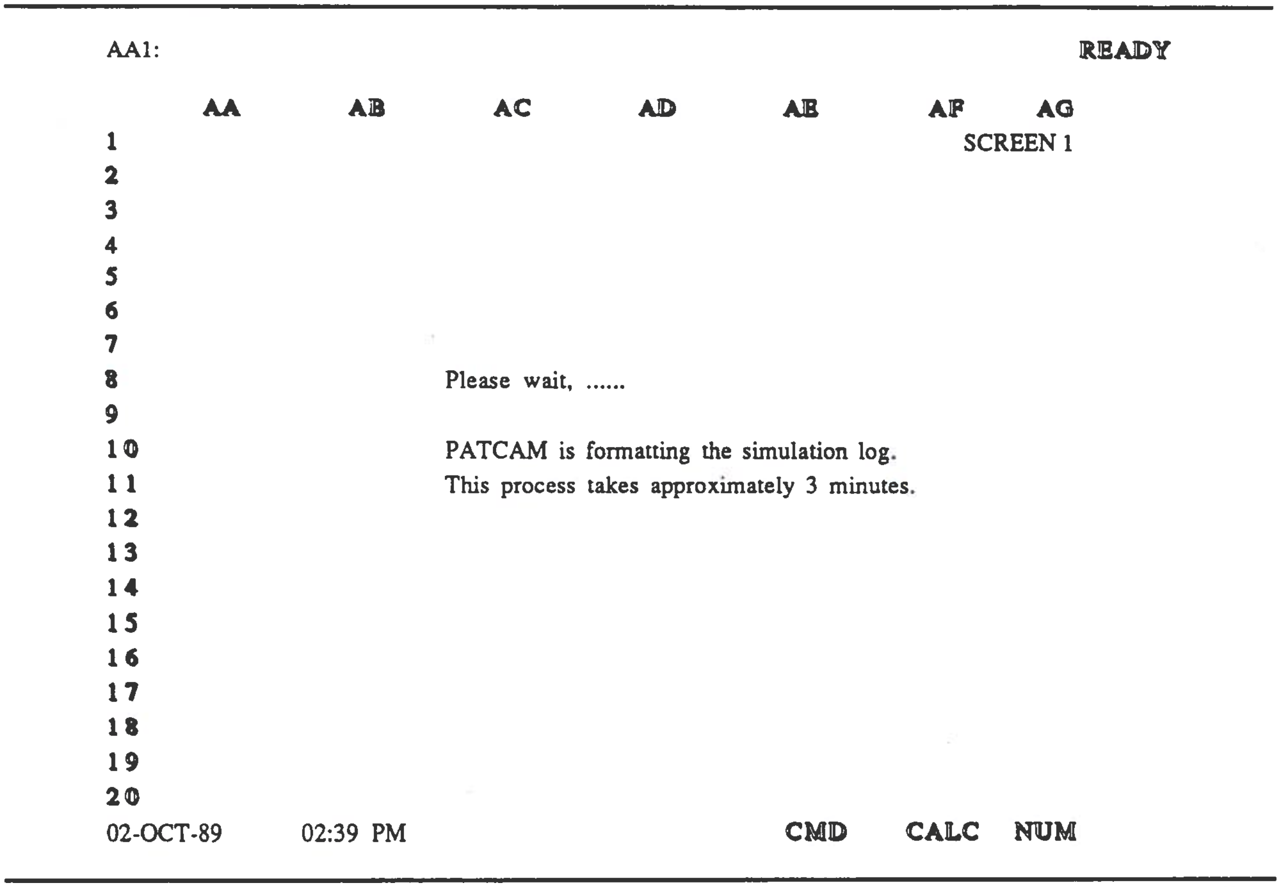
4. To exit from the MicroSAINT™ Model Execution menu type "q" <RETURN>.

After "q" has been pressed, the MicroSAINT™ Model Execution menu will again be displayed. The above three steps must be repeated exactly as performed earlier to execute the controller network a second time. The controller network is executed a second time because the simulation log created by MicroSAINT™ is unable to store all the parameter information for the chosen controller network in one run. The second run allows MicroSAINT™ to gather all the parameter information about the controller network running in the simulation.

After the completion of the second controller network, the MicroSAINT™ Model Execution menu reappears. Complete step four to exit from MicroSAINT™.

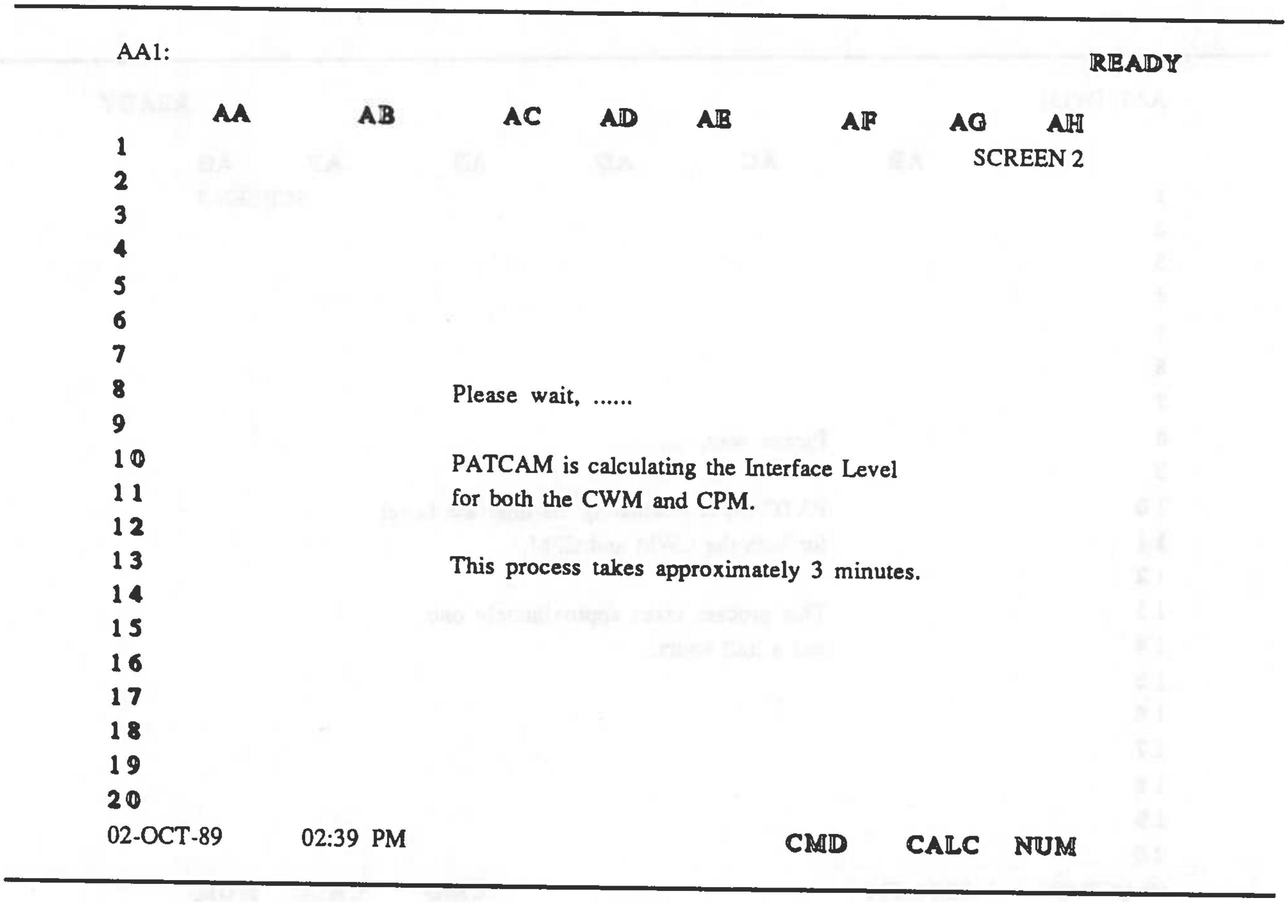
Upon exiting from MicroSAINT™, PATCAM returns control to Lotus 1-2-3™. The Lotus Screen 1 (Figure E-12), will appear on the monitor. At this point, the Lotus portion of PATCAM is formatting the simulation log into a table that can be read by the CPM and CWM. When this is completed, Lotus Screen 2 (Figure E-13) appears on the monitor. At this point, LOTUS is calculating the Interface Level of the hierarchical tree for both the CPM and CWM. The next screen that appears on the monitor is the Lotus Screen 3 (Figure E-14). Lotus is now calculating the Task Level for both the CPM and CWM. This portion of the Lotus databases takes the longest time to calculate. Calculation time is approximately one and one half to two hours. When the task levels of both the CPM and CWM are completed, Lotus Screen 4 (Figure E-15), will appear on the monitor. Lotus calculates the module, scenario, and intermediate values for the mission level at this point in the calculations.

Once MicroSaint finishes running, PATCAM will return the user to the Home menu (Figure E-1).



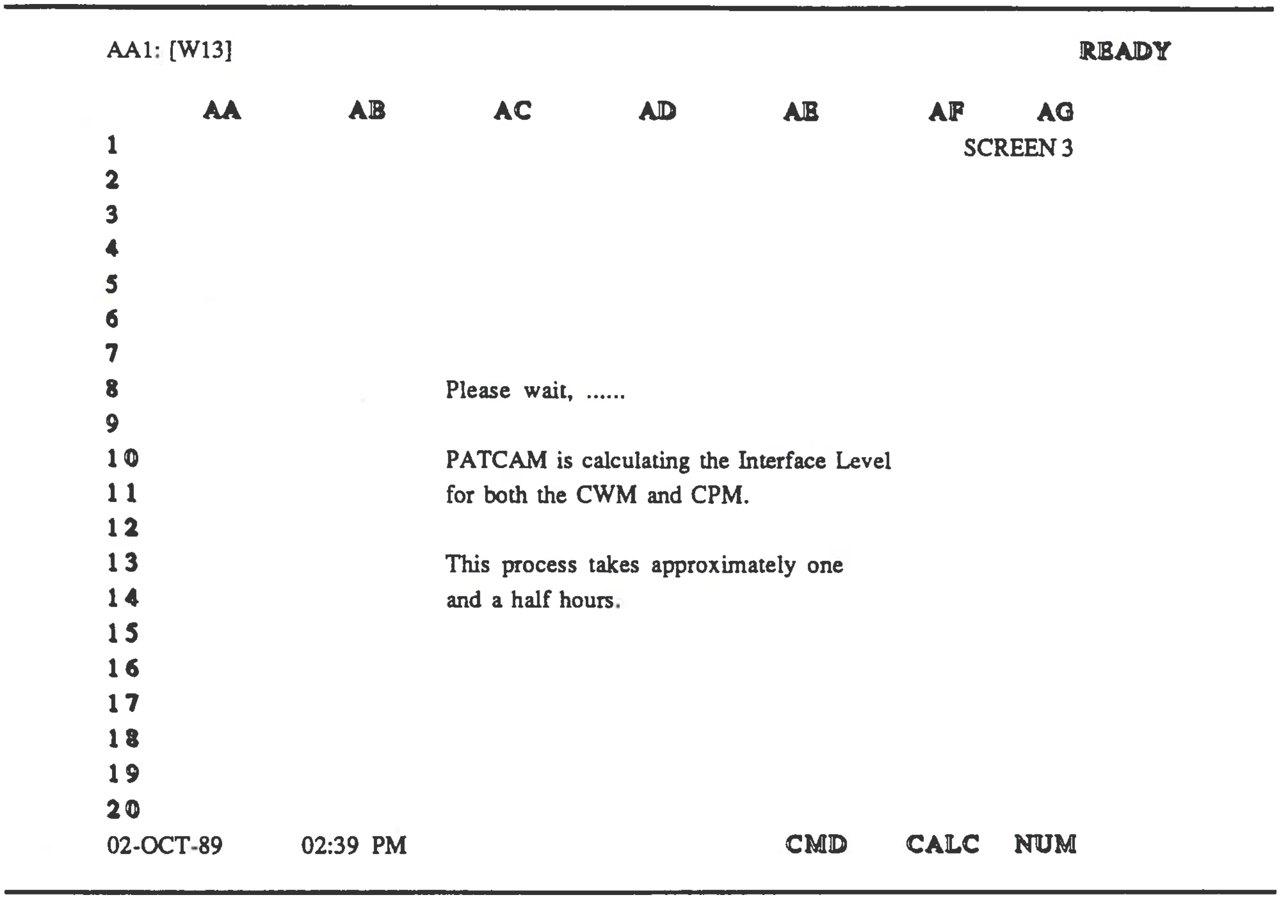
```
AA1:                                                                READY

        AA        AB        AC        AD        AE        AF      AG
1                                                              SCREEN 1
2
3
4
5
6
7
8                           Please wait, ......
9
10                          PATCAM is formatting the simulation log.
11                          This process takes approximately 3 minutes.
12
13
14
15
16
17
18
19
20
02-OCT-89     02:39 PM                             CMD      CALC   NUM
```

Figure E-12. LOTUS SCREEN 1



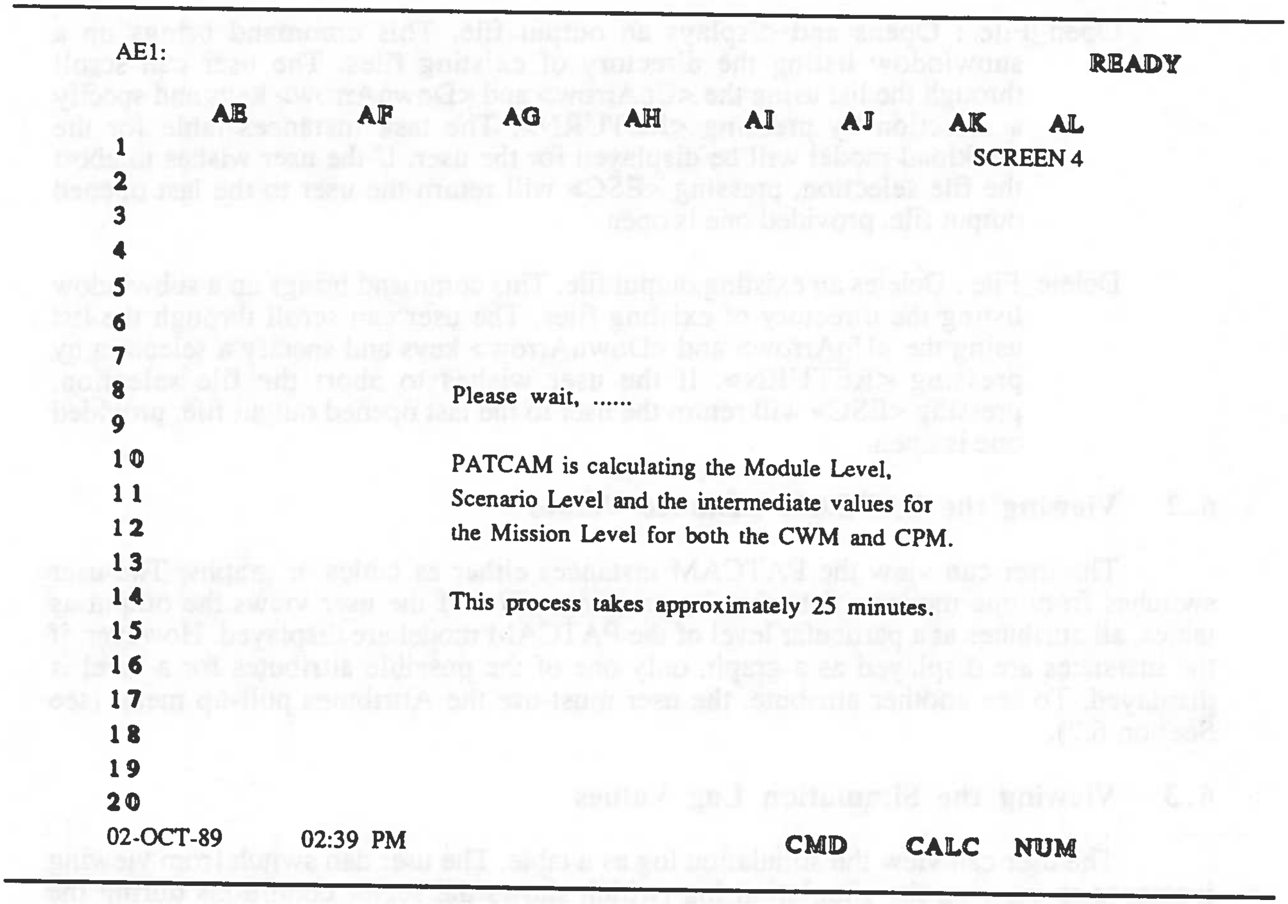
```
AA1:                                                          READY
     AA        AB        AC     AD     AE       AF     AG     AH
1                                                      SCREEN 2
2
3
4
5
6
7
8                   Please wait, ......
9
10                  PATCAM is calculating the Interface Level
11                  for both the CWM and CPM.
12
13                  This process takes approximately 3 minutes.
14
15
16
17
18
19
20
02-OCT-89     02:39 PM                          CMD     CALC    NUM
```

Figure E-13. LOTUS SCREEN 2



```
AA1: [W13]                                                        READY

        AA        AB        AC        AD        AE        AF      AG
1                                                           SCREEN 3
2
3
4
5
6
7
8                           Please wait, ......
9
10                          PATCAM is calculating the Interface Level
11                          for both the CWM and CPM.
12
13                          This process takes approximately one
14                          and a half hours.
15
16
17
18
19
20
02-OCT-89     02:39 PM                         CMD      CALC    NUM
```

Figure E-14. LOTUS SCREEN 3



```
AE1:                                                                 READY

         AE        AF        AG        AH        AI       AJ      AK      AL
1                                                                 SCREEN 4
2
3
4
5
6
7
8                           Please wait, ......
9
10                          PATCAM is calculating the Module Level,
11                          Scenario Level and the intermediate values for
12                          the Mission Level for both the CWM and CPM.
13
14                          This process takes approximately 25 minutes.
15
16
17
18
19
20
02-OCT-89      02:39 PM                              CMD      CALC    NUM
```

Figure E-15. LOTUS SCREEN 4

6.0 Viewing PATCAM Output

Selecting the OUTPUT option from the PATCAM HOME menu will place the user in the PATCAM output viewer. As shown in Figures E-16 and E-17, the PATCAM results are displayed as either tables or graphs.

6.1 Manipulating PATCAM Output Files

The user can execute one of two file manipulation commands, selected from the FILE pull-up menu, which the user accesses by pressing <F2>. Once a pull-up menu is brought up, the user scrolls to the appropriate command using the <UpArrow> and <DownArrow> keys and pressing <RETURN>. If the user wishes to abort the file manipulation command selection, pressing <ESC> will return the user to the last opened model, provided one is open. The two file manipulation commands are:

Open_File : Opens and displays an output file. This command brings up a subwindow listing the directory of existing files. The user can scroll through the list using the <UpArrow> and <DownArrow> keys and specify a selection by pressing <RETURN>. The task instances table for the workload model will be displayed for the user. If the user wishes to abort the file selection, pressing <ESC> will return the user to the last opened output file, provided one is open.

Delete_File : Deletes an existing output file. This command brings up a subwindow listing the directory of existing files. The user can scroll through the list using the <UpArrow> and <DownArrow> keys and specify a selection by pressing <RETURN>. If the user wishes to abort the file selection, pressing <ESC> will return the user to the last opened output file, provided one is open.

6.2 Viewing the PATCAM Instance Values

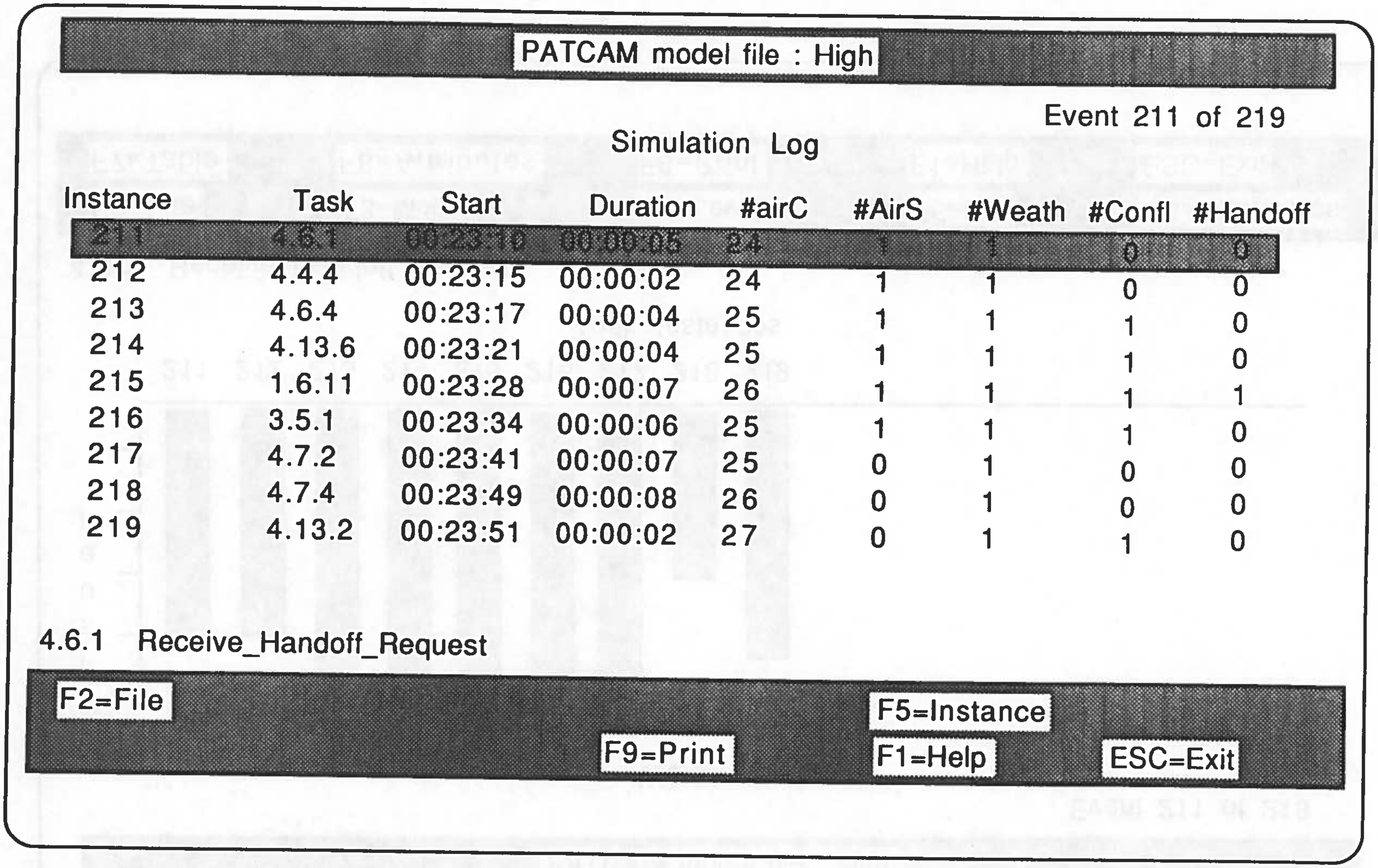
The user can view the PATCAM instances either as tables or graphs. The user switches from one mode to the other by pressing <F7>. If the user views the output as tables, all attributes at a particular level of the PATCAM model are displayed. However, if the instances are displayed as a graph, only one of the possible attributes for a level is displayed. To see another attribute, the user must use the Attributes pull-up menu (see Section 6.7).

6.3 Viewing the Simulation Log Values

The user can view the simulation log as a table. The user can switch from viewing instances to viewing the simulation log (which shows the sector conditions during the occurrence of each instance), and vice versa, by pressing the <F5> key.

6.4 Navigating the Output File

The user scrolls to a specific instance in the table using the <UpArrow> and <DownArrow>, or <RETURN> key. The instance that is displayed will be in reverse video. The name of the instance will be shown just above the bar menu at the bottom of the display. If in the graphics mode, the user can also use the <LeftArrow> and <RightArrow> key to scroll from one bar in the graph to another. The user can also page from one page to another by using the <PgUp> or <PgDn> keys.



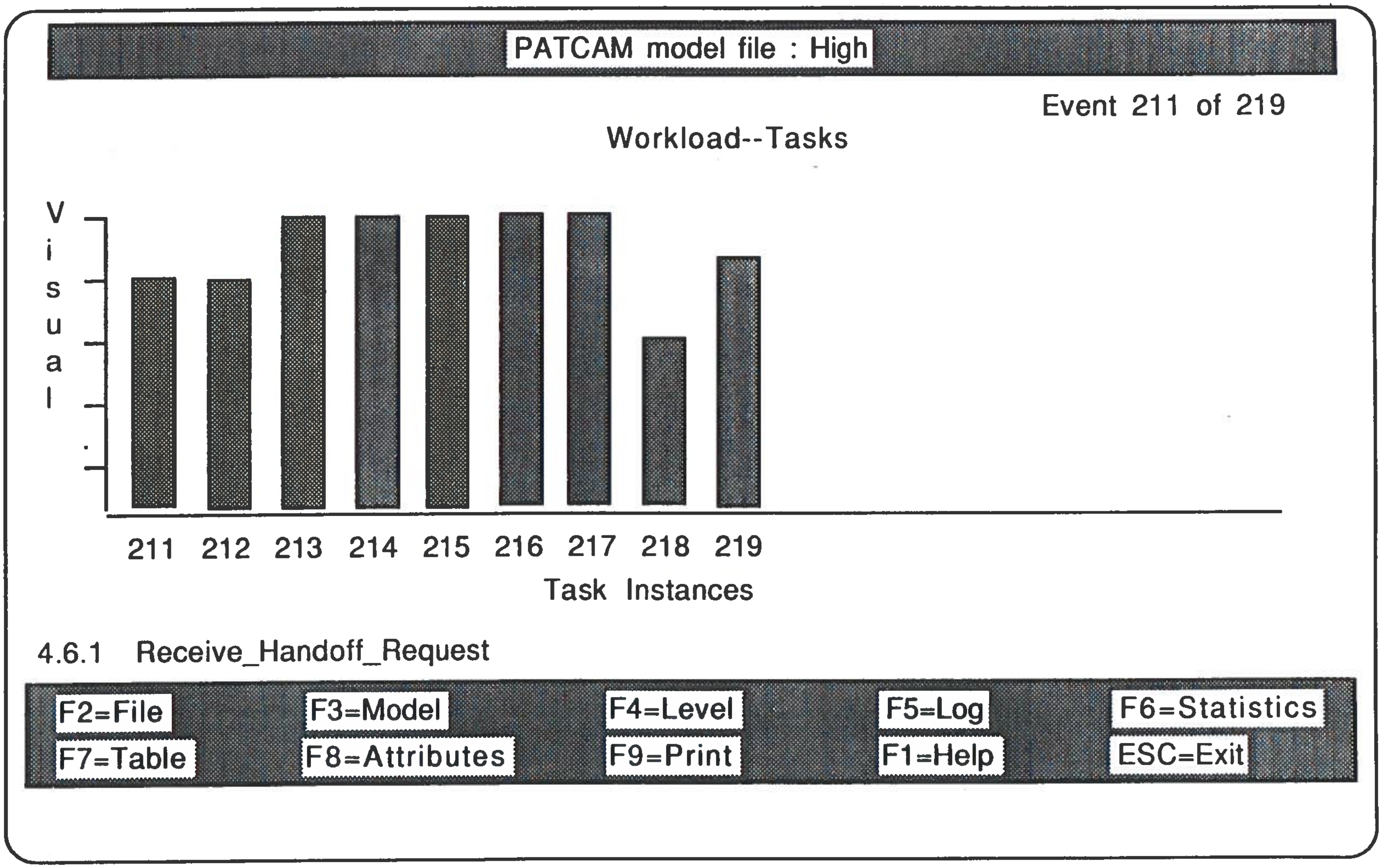
Event 211 of 219

Simulation Log

Instance	Task	Start	Duration	#airC	#AirS	#Weath	#Confl	#Handoff
211	4.6.1	00:23:10	00:00:05	24	1	1	0	0
212	4.4.4	00:23:15	00:00:02	24	1	1	0	0
213	4.6.4	00:23:17	00:00:04	25	1	1	1	0
214	4.13.6	00:23:21	00:00:04	25	1	1	1	0
215	1.6.11	00:23:28	00:00:07	26	1	1	1	1
216	3.5.1	00:23:34	00:00:06	25	1	1	1	0
217	4.7.2	00:23:41	00:00:07	25	0	1	0	0
218	4.7.4	00:23:49	00:00:08	26	0	1	0	0
219	4.13.2	00:23:51	00:00:02	27	0	1	1	0

4.6.1 Receive_Handoff_Request

Figure E-16. PATCAM instance output table



Event 211 of 219

4.6.1 Receive_Handoff_Request

Figure E-17. PATCAM instance output table

6.5 Selecting the Performance or Workload Model

The user can select either the workload or performance model by using the MODEL pull-up menu which the user accesses by pressing <F3>. Once the pull-up menu is brought up, the user scrolls to the appropriate command using the <UpArrow> and <DownArrow> keys and pressing <RETURN>.

6.6 Selecting the Level of the Model

The user can select either the task, module, or scenario level by using the LEVEL pull-up menu which the user accesses by pressing <F4>. Once the pull-up menu is brought up, the user scrolls to the appropriate command using the <UpArrow> and <DownArrow> keys and pressing <RETURN>.

6.7 Selecting the Attribute in Graphics Mode

While in the graphics mode, the user can select the attribute to display in the graph by pressing <F8>. Once the pull-up menu is brought up, the user scrolls to the appropriate command using the <UpArrow> and <DownArrow> keys and pressing <RETURN>. The contents of the attributes menu depend on the level of the workload or performance model the user is viewing.

6.8 Viewing the Statistical Output

If the user presses the <F6> key, PATCAM will display statistics for the attributes. The statistics displayed are the mean, standard deviation, and range for each of the attributes at the particular level of the performance or workload model the user is viewing.

6.9 Getting Help

The user can access the HELP window by pressing <F1>.

6.10 Printing the Output File

By pressing the <F9> key, the user can print the different levels of the output files while viewing the output on screen. The levels include the scenario, module, and task levels as well as the simulation log for both the CPM and CWM. An output file can be printed only one level at a time while that level is being viewed. This allows the user to follow on paper what is actually being seen and what has been seen on the screen.

An enhanced printout feature is also provided for the user. These printouts will look like the samples in figures E2 through E7b. This enhancement can be accessed only outside the PATCAM USI.

To print an outside file, EXIT PATCAM. At the C:\PATCAM> prompt, type one of the following commands:

1) C:\PATCAM>CPM<SPACE>output filename <RETURN>

   This prints all the levels of the CPM.

2) C:\PATCAM>CWM<SPACE>output filename<RETURN>

   This prints all the levels of the CWM.

3) `C:\PATCAM>LOG<SPACE>output filename<RETURN>`

This prints the simulation log.

The printer must be manually set to print in an elite condensed mode. This ensures that the printouts will neatly print on 8 1/2" x 11" paper.

6.11 Exiting the Output File

The user can exit the output tables and return to the HOME menu by pressing the <ESC> key.

7.0 Exiting PATCAM

The user can exit PATCAM only from the HOME menu (Figure E-1), by pressing the <END> key.

8.0 PATCAM USER'S SUPPORT

Any problems or questions encountered while using PATCAM can be directed to Janet Gresh at (301) 816-1254.

APPENDIX F

DATA COLLECTION PACKAGES

Department of Transportation (DOT)
Small Business Innovation Research (SBIR)

Data Collection:

Ratings of Task-Verb Action Demand

May, 1989

Elizabeth D. Murphy, Principal Investigator
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Rockville, MD 20852

RATINGS OF ACTION DEMANDS

Instructions:

Please rate each of the task verbs on the following charts for the action demands that they place on the controller. **Action demand** refers to the load imposed by a task's action independently of the object that is acted upon. Action demand may be imposed on a controller's visual, auditory, analytic, verbal, and/or manual resources. These resource types are the categories into which the task verbs have been sorted. Some task verbs occur in more than one category because they impose more than one type of action demand.

Please use the five-point scales provided at the top of each chart to rate action demands. Scale anchors are defined for each category of action demand.

Please rate each verb in a category in relation to the other verbs in that action demand category. A useful strategy is to first look through all the verbs in a category; find a verb that you would rate low on action demand; find another verb that you would rate high on action demand; use those verbs as reference points as you rate the other verbs in a category.

If you have any questions, please call Betty at (703) 848-2754.

Thank you very much for your participation.

RATINGS OF VISUAL ACTION DEMAND

SCALE:

1	2	3	4	5
Low	Low-Mod	Moderate	Mod-High	High
Survey Visual Display				Perceive symbols, numbers, words

VERB	DEFINITION	RATING
CHECK	Visually examine a hardware item to establish its operational state or condition.	
DETECT	Discern visually a newly occurring fact or item (not being watched for, i.e., not the object of preceding attention), usually from a visual display, such as the action of an aircraft target symbol.	
FLIGHT-FOLLOW	Provide advice and information to assist pilots in conduct of a flight not otherwise being controlled, to include tracking that flight on the Situation Display.	
OBSERVE	Take notice visually or watch attentively something or somewhere for an expected message, object, event, or occurrence of something.	
PERCEIVE	Recognize an action or situation as it evolves over time in the absence of any specific indicator, such as an aircraft deviation or a tracking fault.	
QUICK-LOOK	Temporarily produce for observation on one's own display the data or visual presentations that are available from another workstation.	
READOUT	Acquire information from the computer on a specific item, such as range/bearing/time from an aircraft to a fix.	
RECEIVE	Acquire transmitted messages by seeing without necessarily taking action to express approval or receipt.	
REVIEW	Look over and study conditions or situations, or reexamine something, as in reviewing the completeness of a flight plan. Also appropriate for absorbing information to maintain a dynamic picture of present and/or future traffic, or the status of some equipment.	
SEARCH	Scan/look over a display or area to locate something, such as a particular Flight Data Entry.	

RATINGS OF AUDITORY ACTION DEMAND

SCALE:	1	2	3	4	5
	Low	Low-Mod	Moderate	Mod-High	High
	Monitor Audio Channel				Attend/Focus on one signal among multiple signals

VERB	DEFINITION	RATING
CONTACT	Establish communications via radio or telephone with another person, informing them of or discussing matters of concern, as in contacting a pilot to verify arrival intentions.	
DETECT	Discern aurally a newly occurring fact or item (not the object of preceeding attention), usually from an auditory display, such as an alarm indicator.	
DISCUSS	Exchange information/ideas on a particular topic with one or more others, typically not involving a resolution of differences.	
NEGOTIATE	Confer in order to come to a mutually acceptable agreement, as when negotiating with a pilot the technique to be used for accomplishing a flight delay.	
RECEIVE	Acquire transmitted messages by listening, without necessarily taking action to express approval or receipt.	
REPLAY	Electronically recreate a prior situation, such as a traffic situation, from a computer recording.	

RATINGS OF ANALYTIC ACTION DEMAND

SCALE:	1	2	3	4	5
	Low	Low-Mod	Moderate	Mod-High	High
	Simple mental arithmetic, pattern recognition				Assess, perform complex mental conversions or transformations

VERB	DEFINITION	RATING
CHOOSE	Make a mental decision on a course of action or mentally pick one of several alternatives, as in choosing a desired flow sequence.	
COMPARE	Relate one item to another to note relative similarities and/or differences, as in comparing a maintenance request to a maintenance schedule.	
DETERMINE	Process information mentally to reach a decision about a situation, state of affairs, or timing of action.	
EVALUATE	Examine and judge the merits of an action or situation for a definite purpose and to reach a decision.	
FLIGHT-FOLLOW	Provide advice and information to assist pilots in conduct of a flight not otherwise being controlled, to include tracking that flight on a Situation Display.	
FORMULATE	Mentally compose or prepare the content of a verbal or computer input message or plan, including all required or pertinent elements thereof, such as an advisory or clearance.	
PERCEIVE	Recognize an action or situation as it evolves over time in the absence of any specific indicator, such as an aircraft deviation or a tracking fault.	
PROJECT	Mentally extend or estimate the position and/or path of one or more mobile objects, such as aircraft or ground vehicles, in time and space.	
REVIEW	Look over and study conditions or situations, or reexamine something, as in reviewing the completeness of a flight plan. Also appropriate for absorbing information to maintain a dynamic picture of present and/or future traffic, or the status of the equipment.	
VALIDATE	Determine that an automatic altitude readout varies less than 300 feet from pilot-reported or known altitude.	
VERIFY	Establish the truth of an activity or matter by confirming that a particular situation or matter is in the expected state. For example, verifying pilot compliance with a clearance, or confirming the occurrence of specific computer actions during transition stages.	

RATINGS OF VERBAL ACTION DEMAND

SCALE:	1	2	3	4	5
	Low	Low-Mod	Moderate	Mod-High	High
	One word message to convey a single meaning				Continuous speech for non-proceduralized situations

VERB	DEFINITION	RATING
ACCEPT	Respond to an originating controller or computer message, indicating that the receiving controller assumes complete or partial responsibility for the requested action, as appropriate.	
ACKNOWLEDGE	Respond to an originating controller or computer message indicating a call or message has been received, without further commitment as to what action will be taken.	
APPROVE	Respond favorably to a request as a person in authority, as in approving a clearance request.	
ASSIGN	Designate or commit an item such that the computer can act on it, as in assigning a beacon code to an aircraft. Also, modify personnel responsibilities, as in designating a controller to take over a particular control position.	
ATTEMPT	Try a course of action without predicting the results, as when trying to establish communications with an aircraft.	
BRIEF	Give concise preparatory information concerning all sector or position activities and operational situation to another person, as when turning over responsibility for a position.	
BROADCAST	Transmit a recording or voice message to a general audience (as opposed to contacting a specific person) via radio.	
CONDUCT	Accomplish a series of related actions to achieve a definite goal, as in conducting a radio/radar search for an aircraft.	
CONTACT	Establish communications via radio or telephone with another person, informing them of or discussing matters of concern, as in contacting a pilot to verify arrival intentions.	
DECLARE	State with emphasis that a situation exists, as in declaring the existence of an emergency event.	
DENY	Refuse to grant a request.	
DIRECT	Issue instructions or a directive to a controller, directing that a certain action be taken.	
DISCUSS	Exchange information/ideas on a particular topic with one or more others, typically not involving a resolution of differences.	

RATINGS OF VERBAL ACTION DEMAND

SCALE:	1	2	3	4	5
	Low	Low-Mod	Moderate	Mod-High	High
	One word message to convey a single meaning				Continuous speech for non-proceduralized situations

VERB	DEFINITION	RATING
EXCHANGE	Replace, transfer, or modify personnel responsibilities; designate a controller to a position.	
FLIGHT-FOLLOW	Provide advice and information to assist pilots in conduct of a flight not otherwise being controlled, to include tracking that flight on the Situation Display.	
FORWARD	Send information verbally to another position.	
INFORM/NOTIFY	Impart information to another person.	
INITIATE	Begin an action or sequence, as in initiating a handoff.	
ISSUE	Distribute or communicate information as guidance to a pilot or vehicle operator by radio, as in issuing clearances, alerts, and advisories.	
NEGOTIATE	Confer in order to come to a mutually acceptable agreement, as when negotiating with a pilot the technique to be used for accomplishing a flight delay.	
QUERY	Inquire of another person to gain information to remove doubt, as in querying a pilot about some element of a flight plan.	
RECALL	Summon or otherwise return personnel to their workstations.	
RELINQUISH	Turn over legal responsibility for controlling an aircraft to another controller who is able to assume control.	
REQUEST	Ask another individual for information on, approval of or for receipt of something.	
RETRACT	Take back, negate, or withdraw the start of an action already begun, such as a handoff.	
REVERT	Go to the use of an alternate procedure, such as backup operations.	
SUGGEST	Offer another course of action for consideration when a request is not feasible, such as clearance alternatives to a clearance request.	

RATINGS OF MANUAL ACTION DEMAND

SCALE:	**1**	**2**	**3**	**4**	**5**
	Low	**Low-Mod**	**Moderate**	**Mod-High**	**High**
	Activate a discrete control				**Manipulate discrete controls in a prescribed format**

VERB	DEFINITION	RATING
ACCEPT	Respond to an originating controller or computer message, indicating that the receiving controller assumes complete or partial responsibility for the requested action, as appropriate.	
ACKNOWLEDGE	Respond to an originating controller or computer message indicating a call or message has been received, without further commitment as to what action will be taken.	
ADJUST	Change or fine-tune a data base, controls, display, and/or communication control.	
APPROVE	Respond favorably to a request as a person in authority, as in approving a clearance request.	
ASSIGN	Designate or commit an item such that the computer can act on it, as in assigning a beacon code to an aircraft. Also, modify personnel responsibilities, as in designating a controller to take over a particular control position.	
ATTEMPT	Try a course of action without predicting the results, as when trying to establish communications with an aircraft.	
BROADCAST	Transmit a recording or voice message to a general audience (as opposed to contacting a specific person) via radio.	
CONDUCT	Accomplish a series of related actions to achieve a definite goal, as in conducting a radio/radar search for an aircraft.	
DELETE	Remove an information item (as in deleting the highlights of an item on a display) or cancel a previous action (as in canceling a request for pilot position reports). This includes verbal actions as well as computer information.	
DENY	Refuse to grant a request.	
DIRECT	Issue instructions or a directive to a controller, directing that a certain action be taken.	
EMPHASIZE	Provide prominence to an item on display.	
ENTER	Insert data, text, or a system message into the computer system.	

RATINGS OF MANUAL ACTION DEMAND

SCALE:	1	2	3	4	5
	Low	Low-Mod	Moderate	Mod-High	High
	Activate a discrete control				Manipulate discrete controls in a prescribed format

VERB	DEFINITION	RATING
EXCHANGE	Replace, transfer, or modify personnel responsibilities; designate a controller to a position.	
FORCE	Compel the display of something, as in forcing a Full Data Block or Flight Data Entry that otherwise would not be presented.	
FORWARD	Send information electronically to another position.	
INFORM	Impart information to another person.	
INHIBIT	Prevent the occurrence of a machine function, as in inhibiting an alert function.	
INITIATE	Begin an action or sequence, as in initiating a handoff or starting a track.	
ISSUE	Distribute or communicate information as guidance to a pilot or vehicle operator by radio, as in issuing clearances, alerts, and advisories.	
OFFSET	Relocate the position of a Data Block in adapted increments in relation to its associated target on the display.	
QUERY	Inquire of a computer to gain information to remove doubt.	
QUICK-LOOK	Temporarily produce for observation on one's own display the data or visual presentations that are available from another workstation.	
READOUT	Acquire information from the computer on a specific item, such as range/bearing/time from an aircraft to a fix.	
REASSOCIATE	Reposition a Data Block with its intended target when it has become disassociated from it.	
RECORD	Make a permanent or written note of an event or observation, as in recording a weather observation.	
REDIRECT	Retract handoff initiated to one controller and reinitiate it to another controller.	
RELINQUISH	Turn over legal responsibility for controlling an aircraft to another controller who is able to assume control.	

RATINGS OF MANUAL ACTION DEMAND

SCALE:	1	2	3	4	5
	Low	Low-Mod	Moderate	Mod-High	High
	Activate a discrete control				Manipulate discrete controls in a prescribed format

VERB	DEFINITION	RATING
REPLAY	Electronically recreate a prior situation, such as a traffic situation, from a computer recording.	
REQUEST	Direct the system to provide a function such as route readout or beacon code.	
RESEQUENCE	Rearrange the order of Flight Data Entries displayed.	
RESTORE	Bring back into being or remove an inhibit of a function such as MSAW or the display of certain information.	
RETRACT	Take back, negate, or withdraw the start of an action already begun, such as a handoff.	
RETRIEVE	Display for reconsideration a stored item, such as a previously stored trial plan.	
REVERT	Go to the use of an alternate procedure, such as backup operations.	
SELECT	Single out an item in preference to others on a display or panel, or pick one of several available system options or items, such as a Flight Data Entry Sorting Priority scheme, and inform the system of the choice.	
SET UP	Adjust equipment for proper functioning	
SIGN OFF	Carry out a standard procedure to inform the system that one is no longer operating at a particular control workstation.	
SIGN ON	Carry out a standard procedure to establish oneself as operating at a particular control workstation.	
SKETCH	Draw on an electronic display, as in specifying new sector airspace other than an adapted airspace.	
SUPPRESS	Curtail the display of an item, such as a Full Data Block after a pointout. Such display may be restored at some later time.	
SWITCH	Change a given system condition to another available condition, as when switching communications to a backup frequency.	

RATINGS OF MANUAL ACTION DEMAND

SCALE:

1	2	3	4	5
Low	Low-Mod	Moderate	Mod-High	High
Activate a discrete control				Manipulate discrete controls in a prescribed format

VERB	DEFINITION	RATING
TERMINATE	Bring an action to an end, as in terminating radar service to an aircraft.	
TRANSFER	Direct the system to convey a Flight Data Entry from one control position to another for display and action at the latter location.	
UPDATE	Change or modify text or data to make it more up-to-date, as in updating electronic reminder notes.	

Department of Transportation (DOT)
Small Business Innovation Research (SBIR)

Data Collection:

Ratings of Interface Complexity

May, 1989

Elizabeth D. Murphy, Principal Investigator
CTA INCORPORATED
6116 Executive Boulevard
Rockville, MD 20852

RATINGS OF INTERFACE COMPLEXITY

Background and Definitions:

Each interface in the list is categorized as a **data display** (DD), **input message** (IM), or **mental model** (MM). Contents of the data displays and input messages are defined in Appendix C of FAA Air Traffic Control Operations Concepts, Vol. II: ACF/ACCC Terminal and EnRoute Controllers, Change 1 (July 1988).

Contents of the mental models are defined as follows:

Current Mental Traffic Picture = an integrated mental image of number of aircraft and their positions in the sector, aircraft routes through the sector, any existing conflict situations, traffic patterns and complexity, and weather as it affects current traffic.

Decision-making Criteria = strategies and techniques, based on training and experience, which the controller employs in problem solving and selection of alternative courses of action.

Projected Mental Traffic Picture = the controller's mental prediction of the traffic picture as it would exist at some point in the future if allowed to develop without intervention or if acted upon in some way by the controller.

Sector Workload Picture = the controller's mental image of current or projected sector workload, based on variables such as number of aircraft, traffic complexity, necessary air-to-ground communication, weather, and number of conflict situations.

Please indicate here whether or not you agree that these four mental models and their definitions describe significant cognitive aspects of the controller's role in air traffic control:

☐ **Agree** ☐ **Disagree**

If you disagree, please provide an explanation on the back of this page. Thank You.

Interface complexity refers to the level of information loading that a particular interface places on the controller's physical and/or mental resources. In this context, we consider the mental models as another kind of interface. Interface complexity results from the interplay between the **amount of information** input to or output by the controller and the **implied processing** or effort that is required for the controller to understand the information, manipulate it mentally, and make a decision based on it.

The **categories of interface complexity** are as follows:

Visual complexity - information loading on the controller's visual attention (e.g., due to visual display of data).

Auditory complexity - information loading on the controller's audditory attention (e.g., from auditory alerts).

Analytic complexity - information loading on the controller's problem solving and decision-making resources; amount of mental manipulation the controller must perform to interpret an interface (e.g., due to need to integrate information from multiple sources).

Verbal complexity - information loading on the controller's resources for verbal production (e.g., due to level of detail in a clearance).

Manual complexity - information loading on the controller's resources for manual interaction with the automated system (e.g., due to amount and sequencing of expected data entry).

Instructions:

Please rate each of the Advanced Automation System (AAS) interfaces on the rating form for the appropriate categories of complexity. Use numbers from 1 to 5 corresponding to the scale below:

Scale 1 2 3 4 5
Low **Moderate** **High**

The scale anchors and the midpoint are defined as follows:

- **Low (1)** - the interface is easily perceived, integrated, or mentally manipulated.
- **Moderate (3)** - the interface is more complicated and is noticeably more difficult to perceive, interpret, or mentally manipulate.
- **High (5)** - the interface has multiple aspects, requires a series of complex mental transformations, or needs the controller's full attention.

Please fill in all the empty cells ("boxes") on the rating form. A dash already entered in a cell means that a category of complexity does not apply to a particular interface. For example, we assume that data displays do not impose any manual loading on the controller. If you disagree with a dash, please feel free to enter a rating.

Please base your ratings on your understanding of **AAS requirements** as they are described in the AAS operations concept and the system-level specification.

Again, please call if you have any questions, and thank you for participating.

RATINGS OF INTERFACE COMPLEXITY (INFORMATION LOADING ON CONTROLLER)

Scale 1 Low — 2 — 3 Moderate — 4 — 5 High

INTERFACE	TYPE*	VISUAL	AUDITORY	ANALYTIC	VERBAL	MANUAL
AERA Alert Display	DD				–	–
AERA Alert Display Manipulations	IM		–		–	
Aeronautical and Meteorological Data Changes	IM		–		–	
Aeronautical and Meteorological Data Display	DD		–		–	–
Aeronautical and Meterological Display Manipulations	IM		–		–	
Airport Environmental Data Display	DD		–		–	–
Airport Environmental Data Display Manipulations	IM		–		–	
Alert and Resolution Display	DD				–	–
Alert and Resolution Display Manipulations	IM				–	

* DD = Data Display; IM = Input Message; MM = Mental Model

INTERFACE	TYPE*	VISUAL	AUDITORY	ANALYTIC	VERBAL	MANUAL
Automation Processing Messages	IM					
Controller Notepad Display	DD		–		–	–
Controller Notepad Display Manipulations	IM		–		–	
Current Mental Traffic Picture	MM	–	–		–	–
Data Block Manipulations	IM		–		–	
Decision-Making Criteria	MM	–	–		–	–
Flight Data Changes	IM		–		–	
Flight Data Display	DD		–		–	–
Flight Data Display Manipulations	IM		–		–	
General Display Functions	IM		–		–	
Interim Altitude	IM		–		–	
Message Composition and Response Display	DD		–		–	–
Message Manipulations	IM		–		–	
Parameter Adjustments	IM		–		–	
Pointout Actions	IM		–		–	

* DD = Data Display; IM = Input Message; MM = Mental Model

INTERFACE	TYPE*	VISUAL	AUDITORY	ANALYTIC	VERBAL	MANUAL
Projected Mental Traffic Picture	MM	–	–		–	–
Sector Workload Display	DD		–		–	–
Sector Workload Picture	MM	–	–		–	–
Sector Workload Prediction	IM		–		–	
Separation Assurance Control	IM		–		–	–
Sign On/Sign Off	IM		–		–	
Situation Display	DD		–		–	–
Situation Display Adjustments	IM		–		–	
Special Lists	DD		–		–	–
Special Lists Manipulations	IM		–		–	
Static Information Display	DD		–		–	–
Static Information Display Manipulations	IM		–		–	
Suppressed Display List Display	DD		–		–	–
System Status Changes	IM		–		–	
System Status Data Display	DD		–		–	–
System Status Data Display Manipulations	IM		–		–	

* DD = Data Display; IM = Input Message; MM = Mental Model

INTERFACE	TYPE*	VISUAL	AUDITORY	ANALYTIC	VERBAL	MANUAL
Transfer of Control Message	IM		–		–	
Voice Switching and Control System Display	DD/IM					
Weather Display	DD		–		–	–
Weather Display Manipulations	IM		–		–	

* DD = Data Display; IM = Input Message; MM = Mental Model

APPENDIX G

RATING SCALES FOR CONTROLLER SKILLS, MOTIVATING POTENTIAL, AND VIGILANCE

RATING SCALE FOR CONTROLLER SKILLS

Skill-level Definitions

Each of the following skill levels assumes that skills at the previous level(s) have been mastered. For example, Level 3 assumes the capabilities of Levels 1 and 2 to begin with.

(1) **Minimally Acceptable:**

This minimal capability level can be met by all personnel in the seven skill categories: visual, auditory, analytic, verbal, manual, multiplexing, and modality switching.

(2) **Generally Acceptable:**

Perception (visual and auditory): Sense a non-precise indication; distinguish primary colors, noise or no noise, movement or no movement.

Analytic: Perform successfully in positions requiring relatively slow and noncomplex decision-making in an ATC facility of less-than-average complexity;

Psychomotor (manual and verbal): Perform nonprecise physical manipulations (e.g., move the cursor using a trackball); communicate with others using a mixture of standard and non-standard phraseology.

Multiplexing (timesharing): Timeshare no more than two noncomplex task elements using different resources (e.g., a visual search for altitude information on one aircraft and auditory monitoring of one voice channel).

Modality switching: Switch between no more than two resources in performing a task (e.g., from visual search for altitude information to analytic evaluation of that information for correctness).

(3) **Satisfactory:**

Perception (visual and auditory): Accurately sense and/or coordinate one or more fixed variable indications, such as quantity indications of an instrument; distinguish relative positions of objects, shapes of objects, relative frequency, and rates of movement.

Analytic: Perform mental arithmetic correctly; understand and be able to evaluate the geometry of routine traffic situations; maintain an accurate mental picture of the current traffic situation; perform successfully in all required positions in an ATC facility of average complexity.

Psychomotor (verbal and manual): Perform coodinated and precise motions to achieve efficient and effective results (e.g., a pilot executing an instrument approach or a controller positioning the cursor accurately and entering information on a data block with the trackball/keyboard; communicate with others using standard phraseology.

Multiplexing (timesharing): Timeshare several non-complex task elements using different resources (e.g., visual search, analytic evaluation, and auditory monitoring).

Modality switching: Switch between several resources in performing a task (e.g., from visual search to analytic evaluation to manual data entry).

(4) **Above-average:**

Perception (visual and auditory): Accurately sense and/or coordinate several fixed variable indications (e.g., quality indications of an object, relative motion, degrees of comparison, simultaneous or time critical events, shades and brightness of colors, volume of sound, and the frequency, rate, and direction of movement).

Analytic: Project current variables mentally into the future (e.g., develop a projected mental picture); evaluate and resolve complex traffic situations on the basis of established procedures; perform successfully in all required positions in an ATC facility of greater-than-average complexity.

Psychomotor (manual and verbal): Perform precise, coordinated motions in variable sequences; maintain a high level of accuracy in data entry and object manipulation; communicate concisely and clearly in complex situations, using standard phraseology.

Multiplexing (timesharing): Timeshare several simple and complex task elements drawing from at least two resource pools (e.g., visual search in combination with analytic evaluation and decision making).

Modality switching: Switch comfortably between multiple resources in performing a task (e.g., from visual search, to verbal communication, to analytic evaluation, and manual data entry).

(5) **Superior:**

Perception (visual and auditory): Accurately sense and integrate several dynamic variable indications (e.g., trends over time in complex conflict geometry; content of simultaneous audio transmissions).

Analytic: Develop and maintain a strategy for the sector; resolve conflict situations for which no predefined procedures exist; make decisions successfully in all required positions in the busiest and most complex ATC situations.

Psychomotor (manual and verbal): Perform extensive manual data entry without error; reduce criticality of situation by issuing clear, concise instructions using standard phraseology.

Multiplexing (timesharing): Timeshare several task elements drawing from at least three resource pools (e.g., visual search; analytic evaluation; data entry).

Modality switching: Switch effectively and efficiently between multiple resources in performing a task (e.g., from auditory monitoring, to analytic evaluation, to verbal communication, to visual search, to manual data entry).

RATING SCALE FOR MOTIVATING POTENTIAL

The term "Motivating Potential" is a construct developed by organizational psychologists at Yale University (Hackman & Oldham, 1980). It refers to the motivational characteristics of the job, not of the person. It is defined as the extent to which a job supports the internal, intrinsic motivation of the worker. Job characteristics such as task identity and importance, skill variety, and feedback from supervisors are contributors to Motivating Potential. The following definitions of rating scale anchors can be used by the PATCAM analyst in selecting a value for Motivating Potential to be used by the PATCAM algorithms:

LOW (1) -- Job characteristics rarely support consistently strong internal work motivation; job characteristics generally contribute to poor morale and low job satisfaction.

LOW-TO-MODERATE (2) -- Job characteristics sometimes support strong internal work motivation; job characteristics may vary widely from day to day, sometimes being supportive, and other times being unsupportive.

MODERATE (3) -- Job characteristics often support consistently strong internal work motivation; on the average, job characteristics are supportive.

MODERATE-TO-HIGH (4) -- Job characteristics usually support consistently strong internal work motivation; the worker generally experiences a sense of beginning and finishing an important task; the job allows the worker to exercise a variety of skills; feedback is generally offered as constructive and contributing to the worker's professional development.

HIGH (5) -- Job characteristics fully support consistently strong internal work motivation; the worker always feels that he/she is contributing to an important undertaking; the worker is encouraged to exercise current skills and to develop new skills; even when negative, feedback is offered immediately, fairly, constructively, and with a sincere interest in the worker's well being; job characteristics, including organizational climate, contribute to high morale.

RATING SCALE FOR VIGILANCE

In the psychological literature (e.g., Wickens, 1984), vigilance is a technical term referring to the ability of a human monitor to maintain accuracy in a tracking or pursuit task. This ability is characterized by a severely limited time boundary, in that the performance of human monitors degrades significantly after thirty minutes. This degradation is a characteristic of the human cognitive system; it is not intentional on the part of the human monitor; and it cannot be eliminated by training or experience.

We use the term here in a slightly less technical sense, to refer to the controller's level of alertness. Since the controller functions as an active agent rather than a full-time monitor, he/she is able to maintain alertness for more than 30 minutes. However, extended periods of passive monitoring will tend to degrade performance in the same sense that vigilance performance degrades with extended monitoring.

Scale-level definitions:

LOW (1) -- Due to the boredom and fatigue associated with extended monitoring, the controller is distracted and inattentive to the ATC situation.

LOW-TO-MODERATE (2) -- As the situation becomes slightly more demanding, the controller is sometimes able to remain alert and attentive.

MODERATE (3) -- With a generally moderate level of task demand (workload), the controller is typically alert and attentive.

MODERATE-TO-HIGH (4) -- With a consistently moderate level of task demand (workload), the controller is consistently alert and attentive.

HIGH (5) -- When presented with a complex or critical situation, the controller's attention is fully focused on the problem at hand; this level of vigilance is extremely demanding to maintain; long periods of high vigilance can lead to cognitive narrowing or "cognitive tunnel vision" (Sheridan, 1981), which can cause the controller to overlook significant information or keep trying an unproductive line of reasoning.

APPENDIX H

AERA 2 TASK ELEMENTS

AERA 2 TASK ELEMENTS

TASK	INTERFACE	TASK ELEMENT
1.1.53 Request Display of Future Situation	Automation Processing Messages	Initiate Request Future Situation Display message
		Execute Request Future Situation Display message
	Future Situation Display (FSD) Decision-making Criteria (DMC)	Detect appearance of FSD
1.1.54 Evaluate Displayed Future Situation	FSD DMC	Extract potential effects of current plans and trial plans from the FSD
	Situation Display	Extract information about the current situation from the Situation Display
	Projected Mental Traffic Picture (PMTP)	Synthesize extracted information into a projected mental traffic picture of the future situation as compared to the current situation
	Sector WL Display DMC	Evaluate impact of projected future situation on sector workload
	DMC	Determine the proper course of action
1.1.55 Select Trial Plan to Use in Display of Future	Automation Processing Messages	Initiate Select Trial Plan message
		Execute Select Trial Plan message
	DMC	Detect appearance of projected effects
1.1.56 Review Data Block for Alert Indications	Situation Display	Acquire alert indications in Data Block on Situation Display
	DMC	Determine validity of alerts
		Recognize existing or potential problem

		Determine need for additional information
1.1.57 Review Alert(s) of Predicted Problems	Alert & Resolution Display DMC	Determine validity of alert(s) displayed on Alert & Resolution Display
	Planning Display DMC	Determine validity of alert(s) displayed on Alert & Resolution Display
	Situation Display DMC	Assess current overall situation
	FSD DMC	Assess projected future situation
	Sector WL Display DMC	Assess impact of current and future situation on workload
	DMC	Determine proper course of action

1.1.58 = AAS 1.1.1 Review Flight Data Display for present/future Aircraft Separation

2.7.50 Receive Alert of Predicted Problem	Alert & Resolution Display	Acquire alert type and alert condition on Alert and Resolution Display A/O
	Planning display	Acquire Flight Plan Alert or Trial Plan Alert and Plan ID on Planning Display
	DMC	Recognize meaning of alert
2.7.51 Evaluate Alert of Predicted Problem	Flight Data Display	Acquire Flight Plan Data on Flight Data Display for information pertaining to predicted problem
	Alert & Resolution Display DMC	Determine validity of alert information
	Projected Mental Traffic Picture	Synthesize extracted information into a projected mental traffic picture with regard to predicted problem
	Planning Display DMC	Assess contents of Flight Plan alert or Trial Plan alert

	Situation Display DMC	Compare alert information to current overall situation
	DMC	Determine proper course of action
2.7.53 Receive Resolutions to Predicted Problem	Alert & Resolution Display A/O	Acquire APR results on A&R Display
	Planning Display	Acquire APR constraints currently in effect/problem information/resolutions generated by CAR process
	DMC	Decide whether to request additional information
2.7.54 Evaluate Resolutions to Predicted Problem	Alert & Resolution Display DMC	Assess machine resolutions presented on A&R Display
	Situation Display DMC	Assess resolutions with regard to the current overall situation displayed on the Situation Display
	Projected Mental Traffic Picture	Project current situation into a parameter time in the future to assess potential effects of resolutions
	Future Situation Display DMC	Assess future situation with each resolution implemented, in priority order
	DMC	Determine proper course of action
2.7.55 Request Rationale for Maneuver Type/Ranking	Automation Processing Messages	Initiate Request Rationale Message
		Execute Request Rationale Message
	Planning Display	Acquire rationale for maneuver type/ranking
	DMC	Recognize meaning of rationale

2.7.56 Evaluate Rationale for Maneuver Type/Ranking	Planning Display	Assess displayed rationale
	DMC	
	Situation Display DMC	Assess current overall situation
	Future Situation Display DMC	Assess projected effect of maneuver type
	Projected Mental Traffic Picture	Estimate effects of any conditions not known to the automation
	DMC	
	DMC	Determine that rationale clarifies the resolution or that further planning is needed
2.7.62 Request Resolutions to Predicted Problems	Automation Processing Messages	Initiate Request Resolutions Message
		Execute Request Resolutions Message
	Alert & Resolution Display	Acquire resolution information on A&R Display
	DMC	Recognize meaning of resolution information
2.9.51 Receive Notice of Aircraft No Longer Affected by Flow/ Airspace	Planning Display	Acquire notice of aircraft no longer affected by flow/ airspace restriction
	Current Mental Traffic Picture (CMTP)	Integrate acquired information in CMTP
	DMC	Determine proper course of action
3.2.52 Request Display of Conformance Bounds	Situation Display Adjustments	Initiate Request Display of Conformance Bounds Message
	Situation Display	Acquire conformance bounds on Situation Display
	DMC	Recognize relationship between conformance bounds and aircraft position

3.2.53 Evaluate Display of Conformance Bounds	Situation Display DMC	Assess conformance of aircraft
	Flight Data Display DMC	Assess current plan for aircraft
	DMC	Determine proper course of action
4.10.50 Select Plan as Current Plan	Planning Display	Choose plan ID displayed on Planning Display
	Automation Processing Messages	Initiate Make Current Message
		Execute Make Current Message
	DMC	Infer that flight plan has been amended or that new plan has been created by machine
4.11.55 Select Plan as Pending Plan	Planning Display	Choose plan ID displayed on Planning Display
	Automation Processing Messages	Initiate Make Pending Message
		Execute Make Pending Message
	DMC	Infer that plan will be subject to periodic problem detection
4.11.60 Select Plan for Automated Coordination	Planning Display	Choose plan ID for automated coordination
	Special Lists (Automated Coordination)	Initiate automated coordination message(enter/choose sector ID)
		Execute automated coordination message
	DMC	Infer that plan will be transferred to designated sector/ Traffic Management Coordinator
4.11.62 Request Display of Specified Plan(s) for Aircraft	Planning Display	Extract Plan IDs and Plan Types to be Requested
	Flight Data Display	Extract Flight ID for subject aircraft

	Automation Processing Messages	Initiate Request Display of Specified Plan(s) for Aircraft Message
		Execute Message
	DMC	Recognize display of plan(s) for possible use
4.11.63 Update/Revise Retrieved Plan	Planning Display	Enter plan revisions
	DMC	Infer that a new useable plan will be created
4.11.64 Review Stored Plan for Correctness to Traffic Situation	Planning Display	Acquire stored plan on Planning Display
	Situation Display DMC	Assess stored plan in relation to current overall situations
	FSD PMTP DMC	Assess stored plan in relation to projected future situation
	Sector Workload Display DMC	Assess stored plan in relation to current/projected situation
	DMC	Determine whether plan is suitable to current need or whether modification is required
4.1.56 Receive Automated Coordination Response	Special Lists (Automated Coordination)	Acquire automated coordination response
	DMC	Recognize that clearance may be implemented
6.8.50 Request Display of Sector Workload Factor	Automation Processing Messages	Initiate Request Sector Workload Measures Graphic Display message by entering Time Period and Workload Measure Type
		Execute message
	Sector Workload Display DMC	Detect appearance of requested Sector Workload Factor

6.8.51 Evaluate Displayed Sector Workload Factor	Sector Workload Display Sector Workload Picture (SWPIC) CMTP Situation Display PMTP FSD	Assess displayed Sector Workload Factor in relation to current overall situation and projected future situation
	DMC	Determine proper course of action

APPENDIX I

VALIDATION PACKAGES

CWM VALIDATION

MEMORANDUM

From: Betty Murphy EDM
Date: May 19, 1989
Subject: Instructions for Completing Scenario-Based Demand Ratings

This exercise is part of the data collection for the Department of Transportation (DOT)/Small Business Innovation Research (SBIR) project on controller workload. As you know, the purpose of the research is to develop a method of estimating potential workload effects of ATC transition states prior to design.

Please complete the following steps:

1. **Review the attached operational scenario sector airspace diagram, the sector's normal conditions, and the scenarios (Attachment A).** Note that the tasks performed within each scenario are grouped into sets of tasks preceded by a bold-faced heading. For example, the scenario for En Route High-Altitude Sector Normal Monitoring is divided into four segments: **Aircraft Enters Sector, Monitoring for Conflicts, Aircraft Leaves Sector**, and **Housekeeping.** The rating forms ask you to provide demand estimates for scenario segments, for each scenario as a whole, and for selected tasks within the context of their scenario segments. The forms also ask you to estimate controller workload across the scenarios.

2. **Review the definitions of the demand categories (Attachment B).** If you have any questions about these definitions, please do not proceed until your questions have been answered. (Call Betty Murphy (301) 816-1262 with questions.)

3. **Using the five-point scale provided on the rating forms, fill in your estimates for each box or "cell" on the rating forms (Attachment C).** For example, considering the first segment of En Route High-altitude Sector Normal Monitoring, please supply a rating for the Visual Perception Demand associated with an aircraft entering the sector. If you conclude that a particular demand category is not applicable, please enter a dash (--) in that cell. **Please check to make sure that you have entered a rating value or a dash in each cell.**

4. **Fill in your estimates of average task-performance time in seconds for the AAS tasks listed in Attachment D.**

Please return the completed forms in the enclosed envelope by **June 1**, if at all possible.

Thank you for your participation in this research.

ATTACHMENT A

AAS SCENARIOS

BASELINE OPERATIONAL SCENARIOS

Two baseline operational scenarios and a monitoring macro for an en route, high altitude sector are provided. The scenarios were built from the expanded operational scenarios in the July 1987 edition of the *FAA Air Traffic Control Operations Concept* (DOT/FAA/AP-87-01, Vol. II, Appendix H). These scenarios focus on ATC subactivities and tasks that may be considered for support by increased automation. They will be used as baselines for estimating demand on controller resources.

The scenarios should be viewed independently; activity, weather, etc., in one scenario have no bearing on the other baseline scenario. The routine, on-going monitoring tasks that a controller performs are presented separately, before either of the scenarios.

The scenarios concern sector 80, an en route, high altitude sector at a fictitious Denver Center. This sector exchanges traffic with four adjacent high-altitude sectors (Sectors 90, 91, 92, and 93) and three low-altitude sectors (Sectors 71, 72, and 77). Included in the sector are VORTAC's ESB and HLA. Figure 1 shows the fictitious airspace structure assumed for these scenarios.

Note: The scenarios and the monitoring macro have been reviewed and validated by the Sector Suite Requirements Validation Team (SSRVT).

The task durations, given in seconds, are estimates provided by the SSRVT.

The A1 prefix is understood to precede all task numbers.

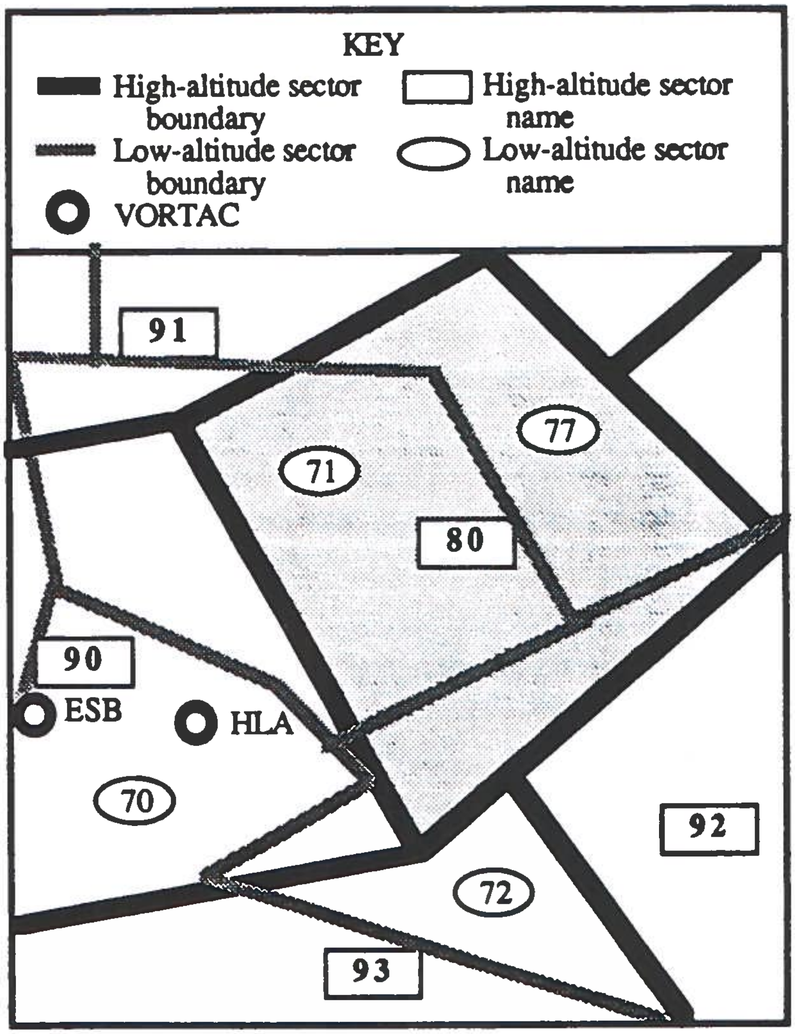

Figure 1. Operational scenario sector airspace diagram adapted from (DOT/FAA/AP-87-01, Vol. I, pg. B-1)

Following is a list of conditions that are "normal" to the imaginary sector:

- traffic is 20 aircraft under the sector's control;
- typically, 20 minutes are required to traverse the sector;
- on the average, one aircraft enters the sector, and another leaves every minute;
- handoffs are normally initiated automatically and always accepted;
- all aircraft are Mode C (transponder) equipped.
- data blocks are automatically suppressed when aircraft leave the sector

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: NORMAL MONITORING

DUR*	SITUATION OR TASK	
	Aircraft Enters Sector	
1-2	4.6.1	Receive handoff request
2	4.6.6	Determine response to handoff request
2	4.6.4	Accept automatic handoff
5	4.13.6	Receive initial radio contact from pilot
10	1.6.11	Enter FDE notations
5	3.5.1	Validate Mode C altitude
	Monitoring for Conflicts	
5	1.1.1	Review Flight Data Display for present and/or future aircraft separation
5	1.1.2	Review Situation Display for potential violation of aircraft separation standards
10	1.6.11	Enter FDE notations
5	1.1.4	Project mentally an aircraft's future position/ altitude/path
5	1.1.12	Review Situation Display for potential violation of airspace separation standards
5	1.1.13	Review display for potential violation of flow restriction
5	1.1.14	Review display for potential violation of conformance criteria
5	1.1.7	Determine whether aircraft may be separated by less than prescribed minima
5	1.1.16	Determine whether conformance criteria may be violated
5	1.1.15	Determine whether airspace separation standards may be violated
5	1.1.17	Determine whether flow restrictions may be violated
	Aircraft Leaves Sector	
1-2	4.7.2	Observe automatic initiation of handoff
5	4.7.4	Receive handoff acceptance
2	4.13.4	Determine frequency in use by receiving sector

* Duration in Seconds

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: NORMAL MONITORING

DUR*	SITUATION OR TASK	
10	4.13.5	Issue change of frequency to pilot
10	1.6.11	Enter FDE notations
10	4.7.8	Verify aircraft leaving sector
	Housekeeping	
3-5	1.6.1	Offset a data block

* Duration in Seconds

SCENARIO 1

The following scenario is for a controller in an en route, high altitude sector. The tasks are listed in order of occurrence with a time line. At the beginning of the scenario, there is no significant weather. However, there is a restricted airspace.

Flight UA522 conflicts with a restricted airspace, requiring the controller to resolve the conflict. After resolving the airspace conflict, the controller evaluates his workload. The controller detects a potential aircraft conflict between EA124 and CA024, but before the conflict can be resolved, another flight, UA105, encounters severe air turbulence and requests a change in altitude. The controller issues clearance to UA105. The controller amends the aircraft's flight plan and passes on the weather information. The controller detects and resolves Flight AA321 lateral nonconformance using trial planning. The aircraft conflict between EA124 and CA024 is also processed using trial planning. The controller clears a change in altitude with controller(s) of nearby sector(s), along the immediate flight path of CA024 before issuing clearance. A special use airspace in the sector becomes unrestricted, allowing the controller to provide Flight UA005 with a previously denied user-preferred route.

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK	
	Scenario Begins	
		(Monitoring 1-3 minutes)
15	**H-4:: Flight UA522 Conflicts with Airspace**	
5	4.11.12	Receive alert of predicted problem with specified plan
10	2.3.6	Determine validity of airspace conflict notice or indication
5	2.1.7	Review potential conflict situation for resolution
15	4.11.7	Request Quick Trial Planning
15	4.11.17	Request Airspace Conflict Display
15	2.3.8	Determine appropriate action to resolve airspace conflict situation
15	4.10.4	Formulate clearance with appropriate instructions
15	4.10.5	Issue clearance and instructions to pilot
15	4.5.3	Enter Flight Plan Amendment
15	1.6.11	Enter FDE Notations
15	4.10.7	Verify aircraft compliance with clearance
		(Monitoring 1-2 minutes)
	Managing Personal Workload	
15	6.8.2	Evaluate workload factors not included in automated information
15	6.8.5	Request sector workload predictions
10	6.8.6	Evaluate sector workload predictions
15	6.8.1	Determine impending controller overload
		(Monitoring 1-1.5 minutes)
	Controller detects potential Aircraft (EA124) to Aircraft (CA024) Conflict	
10	2.1.9	Perceive potential aircraft conflict situation
10	2.1.7	Review potential conflict situation for resolution

*Duration in Seconds

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK	
	(Monitoring 0-.5 minutes)	
	H-7:: Aircraft (UA105) Encounters Severe Turbulence and Requests Altitude Change.	
10	5.1.8	Receive PIREP on weather
10	4.1.2	Receive clearance request from pilot
40	1.1.4	Project mentally an aircraft's future position/altitude/path
60	4.1.17	Evaluate mental flight plan projection for appropriateness
15	4.1.5	Request clearance/approval from another controller *(controller for sector 92)*
15	4.10.4	Formulate a clearance with appropriate instructions
10	4.10.5	Issue clearance and instructions to pilot
15	1.6.11	Enter FDE Notations
15	4.10.7	Verify aircraft compliance with clearance
10	5.1.4	Enter PIREP into system
	(Monitoring 1-2 minutes)	
	Looking for Aircraft (EA124) to Aircraft (CA024) Conflict Resolution	
10	2.1.7	Review potential conflict situation for resolution
	(Monitoring 0-.5 minutes)	
	H-9:: Processing (Lateral) Non-Conformance of Flight AA321	
5	3.2.6	Detect lateral/altitude non-conformance indication
10	3.2.11	Evaluate lateral non-conformance indication for action needed
15	4.10.8	Query pilot regarding conformance with clearance
5	3.2.7	Request Reconformance Aid
15	3.2.8	Evaluate trial plan generated by reconformance aid for appropriate atitude/route
10	3.2.3	Determine maneuver to establish/restore flight plan conformance

*Duration in Seconds

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK	
25	4.10.4	Formulate clearance with appropriate instructions
20	4.10.5	Issue clearance and instructions to pilot
10	4.5.3	Enter Flight Plan Amendment
15	4.10.7	Verify aircraft compliance with clearance
		(Monitoring 0-.5 minutes)
	Processing Aircraft (EA124) to Aircraft (CA024) Conflict	
15	2.1.7	Review potential conflict situation for resolution
20	2.1.8	Determine appropriate action to resolve conflict situation
10	4.11.1	Determine need for Trial Planning
30	4.11.2	Request specified plan(s) for aircraft (CA024)
10	4.11.3	Review retrieved plan(s) for correctness/appropriateness to traffic situation
5	4.11.6	Enter Trial Plan Amendment
15	4.11.13	Receive trial plan notice of no conflict/restriction violation
10	4.11.9	Evaluate trial planning results for correctness/ appropriateness to traffic situation
10	4.11.15	Enter Trial Plan save
	Processing Pointout and APREC for EA124 and CA024 (who will be in Sector 92)	
15	4.8.1	Initiate Pointout
10	4.8.4	Receive acceptance of pointout
10	4.12.1	Inhibit automatic handoff for designated tracks (EA124 and CA024)
25	4.10.4	Formulate a clearance with appropriate instructions (for CA024)
5	4.10.1	Select Trial Plan for implementation

*Duration in Seconds

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK	
15	4.1.5	Request clearance/approval from another controller (controller for sector 92)
15	4.1.6	Receive clearance approval/clearance restriction from another controller *(controller for sector 92)*
	Issuing Clearance to CA024 to resolve conflict	
15	4.10.5	Issue clearance and instructions to pilot (CA024)
15	1.6.11	Enter FDE Notations
15	4.10.7	Verify aircraft compliance with clearance
	Manual Handoff of EA124 and CA024 to Sector 92	
5	4.7.9	Detect manual handoff mode indication
10	4.7.1	Initiate handoff function (EA124)
10	4.7.4	Receive handoff acceptance
10	4.7.1	Initiate handoff function (CA024)
10	4.7.4	Receive handoff acceptance
	(Monitoring .5-1 minute)	
	Restriction on Special Use Airspace is Lifted	
5	3.3.5	Observe display of Airspace Restriction Status change
	Processing Aircraft (UA005) User-Preferred Route	
5	4.11.1	Determine need for trial plan
5	4.11.2	Request specified plan(s) for aircraft
15	4.11.4	Review retrieved plan(s) for correctness/appropriateness to traffic situation
15	1.1.4	Project mentally an aircraft's future position/altitude/path
15	4.1.17	Evaluate mental flight plan projection for appropriateness

*Duration in Seconds

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK	
15	4.1.11	Determine appropriate mental or automated plan for aircraft c clearance
30	4.10.4	Formulate clearance with appropriate instructions
5	4.10.1	Select trial plan for implementation
15	4.10.5	Issue clearance and instructions to pilot
10	1.6.11	Enter FDE Notations
10	4.10.7	Verify aircraft compliance with clearance
	(Monitoring 0-3 minutes)	
	Scenario Ends	

*Duration in Seconds

SCENARIO 2

The following scenario is for a controller in an en route, high altitude sector. The tasks are listed in order of occurrence with a time line.

Flight UA111 has a predicted noncompliance with a flow restriction. The controller uses trial planning to resolve the flow restriction noncompliance. Testing of the trial plan indicates an aircraft conflict, requiring the trial plan to be amended using quick trial planning. The controller detects and resolves non-conformance for Flight NE120. The controller also processes a user-preferred route for aircraft NJ225. However, approval is sought from the controller of sector 90 before clearance is granted. The controller is warned of an imminent aircraft conflict between flights AA221 and NJ532. The conflict is resolved by issuing clearance to change altitude of NJ532.

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK	
	Scenario Begins	
		(Monitoring 1-3 minutes)
	Processing Flow Restriction Nonconformance for UA111	
5	4.11.12	Receive alert of predicted problem with specified plan
15	3.1.15	Determine validity of flow restriction violation indication
5	3.1.4	Review options to bring aircraft into conformance with traffic management restrictions
5	4.11.1	Determine need for trial plan
5	4.1.17	Evaluate mental flight plan projection for appropriateness
10	4.11.2	Request specified plan(s) for aircraft
5	4.11.6	Enter trial plan amendment
5	4.11.12	Receive alert of predicted problem with specified plan
5	4.11.11	Evaluate alert of predicted problem with specified plan against flight plan/traffic/weather
5	4.11.17	Request Airspace Conflict Display
5	4.11.7	Request Quick Trial Planning
5	4.11.9	Evaluate trial planning results for correctness/ appropriateness to traffic situation
20	4.11.15	Enter trial plan save
25	4.1.11	Determine appropriate mental or automated plan for aircraft clearance
5	4.10.4	Formulate clearance with appropriate instructions
10	4.10.1	Select trial plan for implementation
15	4.10.5	Issue clearance and instructions to pilot
15	4.5.3	Enter Flight Plan Amendment
10	4.10.7	Verify aircraft compliance with clearance

*Duration in Seconds

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK	
	(Monitoring 1-2.5 minutes)	
	H-18:: Managing Personal Workload	
15	6.8.2	Evaluate workload factors not included in automated information
5	6.8.5	Request sector workload predictions
15	6.8.6	Evaluate sector workload predictions
15	6.8.1	Determine impending controller overload
	(Monitoring .5 minute)	
	Computer-Generated Reminders of Needed Actions for UA111	
5	4.1.9	Receive computer-generated reminder notice on clearance
15	4.10.4	Formulate clearance with appropriate instructions
15	4.10.5	Issue clearance and instructions to pilot
25	1.6.11	Enter FDE notations
10	4.10.7	Verify aircraft compliance with clearance
	(Monitoring 2-3.5 minutes)	
	Processing Nonconformance of Flight NE120	
5	3.2.6	Detect lateral/altitude nonconformance indication
15	3.2.11	Evaluate lateral nonconformance indication for action needed
5	3.2.9	Request Display of FDE for flight plan
15	3.2.10	Evaluate flight data to determine future course of action
15	4.10.8	Query pilot regarding conformance with clearance
5	3.2.7	Request Reconformance Aid
15	3.2.8	Evaluate trial plan generated by reconformance aid for appropriate altitude/route
15	3.2.3	Determine maneuver to establish/retsore flight plan conformance
10	4.10.4	Formulate clearance with appropriate instructions
15	4.10.1	Select trial plan for implementation

*Duration in Seconds

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK	
25	4.10.5	Issue clearance and instructions to pilot
10	4.10.7	Verify aircraft compliance with clearance
		(Monitoring 1-2 minutes)
	Processing User-Preferred Route for Flight NJ225	
5	4.5.11	Receive requested flight plan change
5	4.11.1	Determine need for trial plan
5	4.11.2	Request specified plan(s) for aircraft
15	4.11.4	Review retrieved plan(s) for correctness/appropriateness to traffic situation
15	1.1.4	Project mentally an aircraft's future position/altitude/path
15	4.1.17	Evaluate mental flight plan projection for appropriateness
5	4.1.16	Formulate controller plan of action for clearance generation
15	4.1.5	Request clearance/approval from another controller
15	4.1.6	Receive clearance/approval from another controller
20	4.10.4	Formulate clearance with appropriate instructions
15	4.10.5	Issue clearance and instructions to pilot
15	1.6.11	Enter FDE Notations
10	4.10.7	Verify aircraft compliance with clearance
		(Monitoring 3-4 minutes)
	H-19:: Processing Aircraft (AA221) to Aircraft (NJ532) Conflict	
5	2.1.1	Detect aircraft conflict alert indication
5	2.1.2	Determine validity of potential aircraft conflict notice or indication
5	2.1.8	Determine appropriate action to resolve conflict situation
5	4.10.4	Formulate a clearance with appropriate instructions (NJ532)
10	4.10.5	Issue clearance and instructions to pilot (NJ532)

*Duration in Seconds

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK	
25	4.5.3	Enter Flight Plan Amendment (NJ532)
15	4.10.7	Verify aircraft compliance with clearance
		(Monitoring 2-3 minutes)
	Scenario Ends	

*Duration in Seconds

ATTACHMENT B

DEFINITIONS OF DEMAND CATEGORIES

DEFINITIONS OF DEMAND CATEGORIES

Analytic Demand--the combined demand across all the segments in a scenario for analytic processing (e.g., mental projection or transformation of data, problem solving, decision making.

Analytic Processing Demand--problem-solving and decision-making load for a segment of a scenario, based on analytic loading for the tasks in that segment.

Auditory Perception Demand--listening load for a segment of a scenario, based on listening load for the tasks in that segment.

Controller Workload--the degree of demand placed on the controller's resources by perceptual, analytic, verbal, and manual procedures and operations, as well as by the need to parallel process (timeshare) or switch between modes (e.g., from analytic to manual to visual).

Manual Response Demand--physical load for a segment of a scenario, based on physical loading for the tasks in that segment.

Modality-Switching Management Demand--the degree to which attention must be shifted sequentially from one perceptual, processing, or responding resource to another (e.g., from visual to analytic to verbal) in completing a segment of a scenario.

Multiplexing (Timesharing) Management Demand--the need to provide sufficient attentional resources when parallel processing or timesharing of resources is necessary in completing a segment of a scenario.

Perceptual Demand--the combined demand, across all the segments in a scenario, for visual and auditory perception.

Resource Management Demand--the combined demand, across all the segments in a scenario, for efficient and effective allocation of attentional resources when multiplexing and/or modality-switching are required.

Response Demand--the combined level of Verbal Response Demand and Manual Response Demand for all the segments in a scenario.

Verbal Response Demand--outgoing communication load for a segment of a scenario, based on need to generate outgoing communications for the tasks in that segment.

Visual Perception Demand--loading on visual resources for a segment of a scenario, based on visual loading for the tasks in that segment.

ATTACHMENT C

RATING FORMS

Demand Ratings for En Route High-Altitude Sector Scenario Segments: Full AAS Environment

SCALE:

1	2	3	4	5
Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Scenario Segment	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
Normal Monitoring: Aircraft enters sector							
Normal Monitoring: Monitoring for conflicts							
Normal Monitoring: Aircraft leaves sector							
Normal Monitoring: Housekeeping							
Scenario 1: Flight UA522 conflicts with airspace							
Scenario 1: Managing personal workload							

Demand Ratings for En Route High-Altitude Sector Scenario Segments: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Scenario Segment	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
Scenario 1: Controller detects potential aircraft (EA124) to aircraft (CA024) conflict							
Scenario 1: Aircraft (UA105) encounters severe turbulence and requests altitude change							
Scenario 1: Looking for aircraft (EA124) to aircraft (CA024) conflict resolution							
Scenario 1: Processing (lateral) non-conformance of Flight AA321							
Scenario 1: Processing aircraft (EA124) to aircraft (CA024) conflict							

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Demand Ratings for En Route High-Altitude Sector Scenario Segments: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Scenario Segment	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
Scenario 1: Processing pointout and APREC for EA124 and CA024							
Scenario 1: Issuing clearance to CA024 to resolve conflict							
Scenario 1: Manual handoff of EA124 and CA024 to Sector 92							
Scenario 1: Restriction on Special Use airspace is lifted							
Scenario 1: Processing aircraft (UA005) User-preferred route							

Demand Ratings for En Route High-Altitude Sector Scenario Segments: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Scenario Segment	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
Scenario 2: Processing flow restriction non-conformance for UA111							
Scenario 2: Managing personal workload							
Scenario 2: Computer-generated reminders of needed actions for UA111							
Scenario 2: Processing non-conformance of Flight NE120							
Scenario 2: Processing aircraft (AA221) to aircraft (NJ532) conflict							

Demand Ratings for En Route High-Altitude Sector Scenario Segments: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Scenario	Perceptual Demand	Analytic Demand	Response Demand	Resource Management Demand	Controller Workload
Normal Monitoring					
Scenario 1					
Scenario 2					
Normal monitoring + Scenario 1 + Scenario 2					

Demand Ratings for En Route High-Altitude Sector Tasks: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Task (in Context of Scenario Segment)	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
4.6.6. Determine response to handoff request (Normal Monitoring: Aircraft enters sector)							
1.1.2. Review situation display for potential violation of aircraft separation standards (Scenario 1: Monitoring for conflicts)							
1.1.16. Determine whether conformance criteria may be violated (Scenario 1: Monitoring for conflicts)							
1.6.11. Enter FDE notations (Scenario 1: Aircraft leaves sector)							
1.6.1. Offset a data block (Scenario 1: Housekeeping)							

Demand Ratings for En Route High-Altitude Sector Tasks: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

	Demand Categories						
Task (in Context of Scenario Segment)	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
2.3.8. Determine appropriate action to resolve airspace conflict situation (Scenario 1: Flight UA522 conflicts with airspace)							
6.8.2. Evaluate workload factors not included in automated information (Scenario 1: Managing personal workload)							
2.1.7. Review potential conflict situation for resolution (Scenario 1: Controller detects potential aircraft (EA124) to aircraft CA024) conflict)							
4.10.4. Formulate a clearance with appropriate instruction (Scenario 1: Aircraft (UA105) encounters severe turbulence and requests altitude change)							

Demand Ratings for En Route High-Altitude Sector Tasks: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Task (in Context of Scenario Segment)	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
3.2.8. Evaluate trial plan generated by Reconformance Aid for appropriate altitude/route (Scenario 1: Processing (lateral) non-conformance of Flight AA321)							
4.11.1. Determine need for trial planning (Scenario 1: Processing aircraft (EA124) to aircraft (CA024) conflict)							
4.10.1. Select trial plan for implementation (Scenario 1: Processing pointout and APREC for EA124 and CA024)							
4.10.7. Verify aircraft compliance with clearance (Scenario 1: Issuing clearance to CA024 to resolve conflict)							
4.7.1. Initiate handoff function (EA124) (Scenario 1: Manual handoff of EA124 and CA024 to Sector 92)							

Demand Ratings for En Route High-Altitude Tasks: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Task (in Context of Scenario Segment)	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
4.1.11. Determine appropriate mental or automated plan for aircraft clearance (Scenario 1: Processing aircraft (UA005) user-preferred route)							
4.11.11. Evaluate alert of predicted problem with specified plan against flight plan/traffic/weather (Scenario 2: Processing flow restriction non-conformance for UA111)							
6.8.2. Evaluate workload factors not included in automated information (Scenario 2: Managing personal workload)							
4.10.5. Issue clearance and instructions to pilot (Scenario 2: Computer-generated reminders of needed actions for UA111)							

Demand Ratings for En Route High-Altitude Sector Tasks: Full AAS Environment

SCALE:	1	2	3	4	5
	Low (Minimal Demand)	**Low-Mod**	**Moderate** (Average Demand)	**Mod-High**	**High** (Unusually Severe Demand)

Demand Categories

Task (in Context of Scenario Segment)	Visual Perception Demand	Auditory Perception Demand	Analytic Processing Demand	Verbal Response Demand	Manual Response Demand	Multiplexing (Timesharing) Demand	Modality-Switching Demand
4.10.8. Query pilot regarding conformance with clearance (Scenario 2: Processing nonconformance of Flight NE120)							
4.1.5. Request clearance/approval from another controller (Scenario 2: Processing user-preferred route for Flight NJ225)							
4.10.7. Verify aircraft compliance with clearance (Scenario 2: Processing aircraft (AA221) to aircraft (NJ532) conflict)							

ATTACHMENT D

ESTIMATED TASK-PERFORMANCE TIMES

ESTIMATED TASK-PERFORMANCE TIMES

Instructions: Please fill in your estimates of average task-performance time in seconds for the AAS tasks listed. (The A1 prefix is understood in each case.)

Task #	Task statement	Est. performance time (task duration **in seconds**)
3.3.1	Advise pilot of airspace restriction release	______
4.1.2	Receive clearance request from pilot	______
4.4.8	Query pilot about flight plan	______
4.6.5	Determine that aircraft is entering sector	______
4.6.7	Receive control of aircraft	______
4.7.8	Determine that aircraft is leaving sector	______
4.7.12	Inform controller of relinquished control of aircraft	______
4.11.5	Enter trial plan	______
4.11.10	Formulate trial plan mentally	______
4.11.17	Request Airspace Conflict Display	______
4.14.1	Observe target entering radar coverage	______
4.14.2	Inform pilot that radar contact is established	______
4.14.3	Conduct radar identification procedures	______

CPM VALIDATION

MEMORANDUM

From: Betty Murphy
Date: August 18, 1989
Subject: Estimated Workload and Performance Ratings

Please complete the enclosed forms and return them to me as soon as possible.

Forms to be completed:

1) Estimated Values for Workload Variables: AAS En Route High Altitude Sector

2a) Estimated Controller Performance Ratings: AAS En Route High Altitude, Scenario 1: Processing Aircraft (EA 124) to Aircraft (CA024) Conflict

b) Estimated Controller Performance Ratings: AAS En Route High Altitude, Scenario 1: Processing Aircraft (UA005) User-Preferred Route

c) Estimated Controller Performance Ratings: AAS En Route High Altitude, Scenario 2: Processing Flow Restriction Nonconformance for UA111

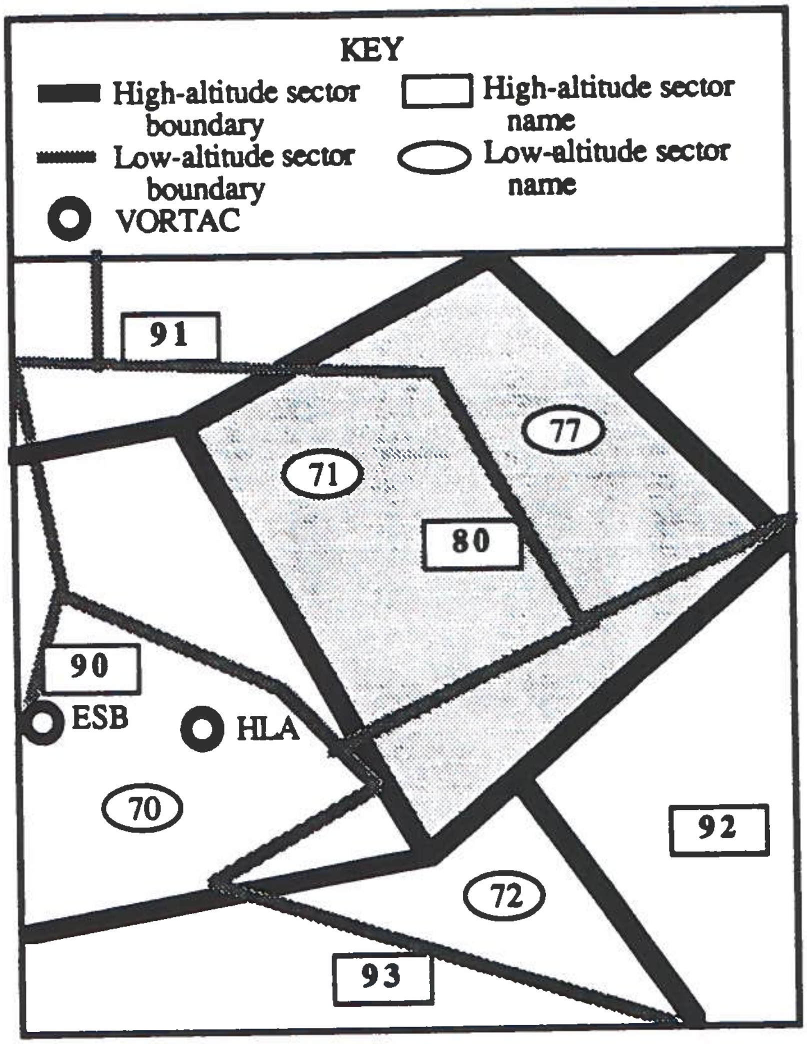
Directions for completing the forms are attached.

The following supporting materials are included in your package:

- o Map of the generic sector
- o Scenario segments (context for the performance ratings)
- o Definitions of skills and skill levels
- o Definitions of performance categories

Thanks for your help with this exercise. Your input will be

Map of Generic Sector



Operational scenario sector airspace diagram adapted from (DOT/FAA/AP-87-01, Vol. I, pg. B-1)

Directions for Completing Form 1:

Estimated Values for Workload Variables:
AAS En Route High Altitude Sector

Please supply one value in each empty "box" on the form. The values you supply in the first column should represent your estimation of a **low workload** situation. In the second column, values should represent **moderate workload**; and, in the third column, they should represent **high workload.**

You are asked to estimate values for the following ATC variables:

- **Number of aircraft in the sector:** please enter a value from one to fifty.
- **Number of weather elements in the sector:** please enter a value from zero to five.
- **Rate at which aircraft enter the sector:** please enter a rate within a slow-to-fast range. A slow rate would be "one aircraft every ten minutes." A fast rate would be "one aircraft every thirty seconds."
- **Average time to traverse the sector:** Please enter a value for "average time" an aircraft spends in the sector, corresponding to low workload, moderate workload, or high workload.
- **Level of automated assistance:** Please enter one of the following scale values:

    1 - Low automated assistance; PVDs but no decision aiding or conflict alert.

    2 - Low-to-moderate automated assistance; corresponds to today's system; two-minute conflict alert.

    3 - Moderate automated assistance; corresponds to AAS with AERA 1; 20-minute conflict alert, but no automated resolutions.

    4 - Moderate-to-high automated assistance; corresponds to AAS with AERA 2 capabilities; automated problem resolution; automated coordination.

    5 - High automated assistance; corresponds to AAS with AERA 3; automated data link.

Form 1

Estimated Values for Workload Variables: AAS En Route High Altitude Sector

Workload Variables	**Estimated Values**		
	Low Workload	Moderate Workload	High Workload
Number of Aircraft (1 - 50)			
Number of Weather Elements (0 - 5)			
Rate at which aircraft enter sector (1 every ten minutes to 1 every 30 seconds)			
Average time to traverse sector (in minutes)			
Level of automated assistance (Low = 1; Moderate = 3; High = 5)			

Directions for Completing Form 2:

Estimated AAS Controller Performance Ratings, AAS En Route High-Altitude Sector

There are three versions of this form, corresponding to different scenario segments. The appropriate scenario segment is attached to each version of the form.

Please complete these forms according to the following procedure:

1. **Review the scenario segment** to get an understanding of the demands on the controller.
2. **Review the skill and skill-level definitions** for an understanding of the different available skills, as listed in the column headed "Controller Attributes": Superior visual skill; Satisfactory auditory skill; Above-average analytic skill; Satisfactory verbal skill; Superior manual skill; Minimally acceptable multiplexing skill; and Above-average modality-switching skill.
3. **Compare the specific demands of the scenario with the available skills** to arrive at a scale value for performance. For example, compare the scenario segment's demands for visual perception with the available visual skill (superior), and estimate the level of controller visual perception performance **across all the tasks in the scenario segment.**
4. **Please enter your selected performance-scale values** in the appropriate boxes on the form. The performance scale appears at the top of each form.

Note that performance estimates should be based on a demand-skill comparison across all the tasks in a scenario segment.

THANKS FOR YOUR PARTICIPATION!

Form 2 a

Estimated AAS Controller Performance Ratings
AAS En Route High Altitude, Scenario 1:

Processing Aircraft (EA124) to Aircraft (CA024) Conflict

Performance Scale

1	2	3	4	5
Minimally Acceptable	Generally Acceptable	Satisfactory	Above Average	Superior

Controller Attributes	Performance Categories						
	Visual Perception	Auditory Perception	Analytic Processing	Verbal Response	Manual Response	Multiplexing Management	Modality-Switching Management
Superior Visual Skill		____	____	____	____	____	____
Satisfactory Auditory Skill	____		____	____	____	____	____
Above-Average Analytic Skill	____	____		____	____	____	____
Satisfactory Verbal Skill	____	____	____		____	____	____
Superior Manual Skill	____	____	____	____		____	____
Minimally Acceptable Multiplexing Skill	____	____	____	____	____		____
Above-Average Modality-Switching Skill	____	____	____	____	____	____	

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK	
	Processing Aircraft (EA124) to Aircraft (CA024) Conflict	
15	2.1.7	Review potential conflict situation for resolution
20	2.1.8	Determine appropriate action to resolve conflict situation
10	4.11.1	Determine need for Trial Plan.
30	4.11.2	Request specified plan(s) for aircraft (CA024)
10	4.11.3	Review retrieved plan(s) for correctness/appropriateness to traffic situation
5	4.11.6	Enter Trial Plan Amendment
15	4.11.13	Receive trial plan notice of no conflict/restriction violation
10	4.11.9	Evaluate trial planning results for correctness/ appropriateness to traffic situation
10	4.11.15	Enter Trial Plan save

*Duration in Seconds

Form 2 b

Estimated AAS Controller Performance Ratings
AAS En Route High Altitude, Scenario 1:

Processing Aircraft (UA005) User-Preferred Route

Performance Scale	1	2	3	4	5
	Minimally Acceptable	Generally Acceptable	Satisfactory	Above Average	Superior

Controller Attributes	**Performance Categories**						
	Visual Perception	Auditory Perception	Analytic Processing	Verbal Response	Manual Response	Multiplexing Management	Modality-Switching Management
Superior Visual Skill		____	____	____	____	____	____
Satisfactory Auditory Skill	____		____	____	____	____	____
Above-Average Analytic Skill	____	____		____	____	____	____
Satisfactory Verbal Skill	____	____	____		____	____	____
Superior Manual Skill	____	____	____	____		____	____
Minimally Acceptable Multiplexing Skill	____	____	____	____	____		____
Above-Average Modality-Switching Skill	____	____	____	____	____	____	

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 1

DUR*	SITUATION OR TASK	
	Processing Aircraft (UA005) User-Preferred Route	
5	4.11.1	Determine need for trial plan
5	4.11.2	Request specified plan(s) for aircraft
15	4.11.4	Review retrieved plan(s) for correctness/appropriateness to traffic situation
15	1.1.4	Project mentally an aircraft's future position/altitude/path
15	4.1.17	Evaluate mental flight plan projection for appropriateness
15	4.1.11	Determine appropriate mental or automated plan for aircraft clearance
30	4.10.4	Formulate clearance with appropriate instructions
5	4.10.1	Select trial plan for implementation
15	4.10.5	Issue clearance and instructions to pilot
10	1.6.11	Enter FDE Notations
10	4.10.7	Verify aircraft compliance with clearance

*Duration in Seconds

`Form 2 c`

Estimated AAS Controller Performance Ratings
AAS En Route High Altitude Sector, Scenario 2:

Processing Flow Restriction Nonconformance for UA111

Performance Scale	1	2	3	4	5
	Minimally Acceptable	Generally Acceptable	Satisfactory	Above Average	Superior

Controller Attributes	**Performance Categories**						
	Visual Perception	Auditory Perception	Analytic Processing	Verbal Response	Manual Response	Multiplexing Management	Modality-Switching Management
Superior Visual Skill		___	___	___	___	___	___
Satisfactory Auditory Skill	___		___	___	___	___	___
Above-Average Analytic Skill	___	___		___	___	___	___
Satisfactory Verbal Skill	___	___	___		___	___	___
Superior Manual Skill	___	___	___	___		___	___
Minimally Acceptable Multiplexing Skill	___	___	___	___	___		___
Above-Average Modality-Switching Skill	___	___	___	___	___	___	

AAS-EN ROUTE HIGH-ALTITUDE SECTOR: SCENARIO 2

DUR*	SITUATION OR TASK	
	Processing Flow Restriction Nonconformance for UA111	
5	4.11.12	Receive alert of predicted problem with specified plan
15	3.1.15	Determine validity of flow restriction violation indication
5	3.1.4	Review options to bring aircraft into conformance with traffic management restrictions
5	4.11.1	Determine need for trial plan
5	4.1.17	Evaluate mental flight plan projection for appropriateness
10	4.11.2	Request specified plan(s) for aircraft
5	4.11.6	Enter trial plan amendment
5	4.11.12	Receive alert of predicted problem with specified plan
5	4.11.11	Evaluate alert of predicted problem with specified plan against flight plan/traffic/weather
5	4.11.17	Request Airspace Conflict Display
5	4.11.7	Request Quick Trial Planning
5	4.11.9	Evaluate trial planning results for correctness/ appropriateness to traffic situation
20	4.11.15	Enter trial plan save
25	4.1.11	Determine appropriate mental or automated plan for aircraft clearance
5	4.10.4	Formulate clearance with appropriate instructions
10	4.10.1	Select trial plan for implementation
15	4.10.5	Issue clearance and instructions to pilot
15	4.5.3	Enter Flight Plan Amendment
10	4.10.7	Verify aircraft compliance with clearance

*Duration in Seconds

Skill-level Definitions

Each of the following skill levels assumes that skills at the previous level(s) have been mastered. For example, Level 3 assumes the capabilities of Levels 1 and 2 to begin with.

(1) **Minimally Acceptable:**

This minimal capability level can be met by all personnel in the seven skill categories: visual, auditory, analytic, verbal, manual, multiplexing, and modality switching.

(2) **Generally Acceptable:**

Perception (visual and auditory): Sense a non-precise indication; distinguish primary colors, noise or no noise, movement or no movement.

Analytic: Perform successfully in positions requiring relatively slow and noncomplex decision-making in an ATC facility of less-than-average complexity;

Psychomotor (manual and verbal): Perform nonprecise physical manipulations (e.g., move the cursor using a trackball); communicate with others using a mixture of standard and non-standard phraseology.

Multiplexing (timesharing): Timeshare no more than two noncomplex task elements using different resources (e.g., a visual search for altitude information on one aircraft and auditory monitoring of one voice channel).

Modality switching: Switch between no more than two resources in performing a task (e.g., from visual search for altitude information to analytic evaluation of that information for correctness).

(3) **Satisfactory:**

Perception (visual and auditory): Accurately sense and/or coordinate one or more fixed variable indications, such as quantity indications of an instrument; distinguish relative positions of objects, shapes of objects, relative frequency, and rates of movement.

Analytic: Perform mental arithmetic correctly; understand and be able to evaluate the geometry of routine traffic situations; maintain an accurate mental picture of the current traffic situation; perform successfully in all required positions in an ATC facility of average complexity.

Psychomotor (verbal and manual): Perform coodinated and precise motions to achieve efficient and effective results (e.g., a pilot executing an instrument approach or a controller positioning the cursor accurately and entering information on a data block with the trackball/keyboard; communicate with others using standard phraseology.

Multiplexing (timesharing): Timeshare several non-complex task elements using different resources (e.g., visual search, analytic evaluation, and auditory monitoring).

Modality switching: Switch between several resources in performing a task (e.g., from visual search to analytic evaluation to manual data entry).

(4) **Above-average:**

Perception (visual and auditory): Accurately sense and/or coordinate several fixed variable indications (e.g., quality indications of an object, relative motion, degrees of comparison, simultaneous or time critical events, shades and brightness of colors, volume of sound, and the frequency, rate, and direction of movement).

Analytic: Project current variables mentally into the future (e.g., develop a projected mental picture); evaluate and resolve complex traffic situations on the basis of established procedures; perform successfully in all required positions in an ATC facility of greater-than-average complexity.

Psychomotor (manual and verbal): Perform precise, coordinated motions in variable sequences; maintain a high level of accuracy in data entry and object manipulation; communicate concisely and clearly in complex situations, using standard phraseology.

Multiplexing (timesharing): Timeshare several simple and complex task elements drawing from at least two resource pools (e.g., visual search in combination with analytic evaluation and decision making).

Modality switching: Switch comfortably between multiple resources in performing a task (e.g., from visual search, to verbal communication, to analytic evaluation, and manual data entry).

(5) **Superior:**

Perception (visual and auditory): Accurately sense and integrate several dynamic variable indications (e.g., trends over time in complex conflict geometry; content of simultaneous audio transmissions).

Analytic: Develop and maintain a strategy for the sector; resolve conflict situations for which no predefined procedures exist; make decisions successfully in all required positions in the busiest and most complex ATC situations.

Psychomotor (manual and verbal): Perform extensive manual data entry without error; reduce criticality of situation by issuing clear, concise instructions using standard phraseology.

Multiplexing (timesharing): Timeshare several task elements drawing from at least three resource pools (e.g., visual search; analytic evaluation; data entry).

Modality switching: Switch effectively and efficiently between multiple resources in performing a task (e.g., from auditory monitoring, to analytic evaluation, to verbal communication, to visual search, to manual data entry).

Definitions of Controller Attributes (Skill categories):

Analytic Processing Skill: available capability for problem-solving and decision making

Auditory Skill: available capability for accurate aural perception (hearing and listening)

Manual Skill: available capability for efficient and effective physical action (e.g., data entry)

Modality-Switching Skill: available capability for switching attention rapidly between perceiving, processing, and responding (e.g., from recognizing a potential aircraft-to-aircraft conflict, to deciding on a resolution, to issuing instructions to a pilot)

Multiplexing Skill: available capability for time-sharing or parallel processing (e.g., in performing more than one task simultaneously, as in scanning a display for aircraft-to-aircraft conflicts while issuing instructions to a pilot)

Verbal Skill: available capability for effective and efficient oral communication

Visual Skill: available capability for accurate visual perception (recognition of displayed objects)

Definitions of Performance Categories:

Analytic Processing Performance: degree of success in problem solving and decision making, across all the tasks in a scenario segment

Auditory Perception Performance: degree of accuracy in hearing and listening, across all the tasks in a scenario segment

Manual Response Performance: degree of efficiency and effectiveness in executing physical actions, across all the tasks in a scenario segment

Modality-Switching Management Performance: degree of efficiency and effectiveness in switching attention between perceiving, processing, and responding, across all the tasks in a scenario segment

Multiplexing Management Performance: degree of efficiency and effectiveness in time-sharing or parallel processing portions of more than one task, across all the tasks in a scenario segment

Verbal Response Performance: degree of speed and accuracy in communicating orally with others (e.g., pilots, other controllers), across all the tasks in a scenario segment

Visual Perception Performance: degree of speed and accuracy in recognizing data objects that are displayed visually, across all the tasks in a scenario segment

Performance Scale Levels:

1 -- Minimally acceptable

2 -- Generally acceptable

3 -- Satisfactory

4 -- Above-average

5 -- Superior

APPENDIX J

MATERIALS FOR INVESTIGATION OF MENTAL INTERFACES

CONTROLLER VALIDATION STUDY

Job Category: ____________________

Years of Experience: ____________________

INSTRUCTIONS

Each of the following terms are elements of Air Traffic Control:

- aircraft type
- ATC procedures
- aircraft position
- projected proximity between aircraft and special use airspace
- weather
- equipment status
- current traffic volume
- aircraft destination
- projected proximity between aircraft and sector boundaries
- aircraft altitude
- type of sector
- expected traffic volume
- separation standards
- flow restrictions
- aircraft route
- sector operating procedures
- projected proximity between aircraft

You will be rating the similarity or relatedness of these terms from an ATC operational perspective. For example, you might be asked to consider the relationship between "weather" and "frequency congestion". How related are these items? Choose a rating from 1 to 7 that best represents the relatedness of terms; "1" means "not related" and "7" means "highly related".

e.g., weather frequency congestion

not related highly related

1 2 3 4 5 6 7

Circle the number that you think best describes the extent to which pairs of terms are related. Do not dwell on the terms, but instead just give your first impression of their relatedness.

CONTROLLER VALIDATION STUDY

aircraft route — aircraft altitude

not related ________________ highly related

1 2 3 4 5 6 7

aircraft type — sector operating procedures

not related ________________ highly related

1 2 3 4 5 6 7

expected traffic volume — separation standards

not related ________________ highly related

1 2 3 4 5 6 7

aircraft destination — weather

not related ________________ highly related

1 2 3 4 5 6 7

aircraft altitude — expected traffic volume

not related ________________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

weather sector operating procedure

not related highly related

1 2 3 4 5 6 7

aircraft destination projected proximity between aircraft

not related highly related

1 2 3 4 5 6 7

aircraft altitude current traffic volume

not related highly related

1 2 3 4 5 6 7

projected proximity between aircraft and sector boundaries ATC procedures

not related highly related

1 2 3 4 5 6 7

weather type of sector

not related highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

flow restrictions — equipment status

not related ______ highly related

1 2 3 4 5 6 7

aircraft type — expected traffic volume

not related ______ highly related

1 2 3 4 5 6 7

aircraft route — projected proximity between aircraft

not related ______ highly related

1 2 3 4 5 6 7

projected proximity between aircraft and sector boundaries — weather

not related ______ highly related

1 2 3 4 5 6 7

type of sector — separation standards

not related ______ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft altitude — sector operating procedures

not related — highly related

1 2 3 4 5 6 7

projected proximity between aircraft and special use airspace — type of sector

not related — highly related

1 2 3 4 5 6 7

aircraft type — ATC procedures

not related — highly related

1 2 3 4 5 6 7

aircraft destination — equipment status

not related — highly related

1 2 3 4 5 6 7

projected proximity between aircraft — type of sector

not related — highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

projected proximity between aircraft and special use airspace	ATC procedures

not related	highly related

1 2 3 4 5 6 7

aircraft route	separation standards

not related	highly related

1 2 3 4 5 6 7

projected proximity between aircraft and sector boundaries	current traffic volume

not related	highly related

1 2 3 4 5 6 7

aircraft destination	sector operating procedures

not related	highly related

1 2 3 4 5 6 7

projected proximity between aircraft and special use airspace	separation standards

not related	highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft altitude — projected proximity between aircraft

not related ______ highly related

1 2 3 4 5 6 7

expected traffic volume — current traffic volume

not related ______ highly related

1 2 3 4 5 6 7

aircraft type — aircraft route

not related ______ highly related

1 2 3 4 5 6 7

projected proximity between aircraft and sector boundaries — sector operating procedures

not related ______ highly related

1 2 3 4 5 6 7

flow restrictions — type of sector

not related ______ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft route

weather

not related — highly related

1 2 3 4 5 6 7

projected proximity between aircraft and special use airspace

projected proximity between aircraft and sector boundaries

not related — highly related

1 2 3 4 5 6 7

flow restrictions

ATC procedures

not related — highly related

1 2 3 4 5 6 7

aircraft type

current traffic volume

not related — highly related

1 2 3 4 5 6 7

aircraft position

projected proximity between aircraft and sector boundaries

not related — highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft destination aircraft altitude

not related ________ highly related

1 2 3 4 5 6 7

expected traffic volume type of sector

not related ________ highly related

1 2 3 4 5 6 7

aircraft route flow restrictions

not related ________ highly related

1 2 3 4 5 6 7

projected proximity between aircraft weather

not related ________ highly related

1 2 3 4 5 6 7

separation standards sector operating procedures

not related ________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

current traffic volume	equipment status

not related ________ highly related

1 2 3 4 5 6 7

flow restrictions	sector operating procedures

not related ________ highly related

1 2 3 4 5 6 7

aircraft position	type of sector

not related ________ highly related

1 2 3 4 5 6 7

ATC procedures	separation standards

not related ________ highly related

1 2 3 4 5 6 7

projected proximity between aircraft and sector boundaries	flow restrictions

not related ________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft route — current traffic volume

not related ________ highly related

1 2 3 4 5 6 7

projected proximity between aircraft — expected traffic volume

not related ________ highly related

1 2 3 4 5 6 7

weather — equipment status

not related ________ highly related

1 2 3 4 5 6 7

current traffic volume — ATC procedures

not related ________ highly related

1 2 3 4 5 6 7

aircraft type — projected proximity between aircraft and special use airspace

not related ________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft position — sector operating procedures

not related — highly related

1 2 3 4 5 6 7

aircraft destination — separation standards

not related — highly related

1 2 3 4 5 6 7

projected proximity between aircraft — equipment status

not related — highly related

1 2 3 4 5 6 7

weather — ATC procedures

not related — highly related

1 2 3 4 5 6 7

sector operating procedures — type of sector

not related — highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft position — ATC procedures

not related _______________ highly related

1 2 3 4 5 6 7

aircraft route — projected proximity between aircraft and sector boundaries

not related _______________ highly related

1 2 3 4 5 6 7

aircraft destination — current traffic volume

not related _______________ highly related

1 2 3 4 5 6 7

projected proximity between aircraft — separation standards

not related _______________ highly related

1 2 3 4 5 6 7

expected traffic volume — ATC procedures

not related _______________ highly related

1 2 3 4 5 6 7

CONTROLLER WORKLOAD STUDY

aircraft route

expected traffic volume

not related ____ highly related

1 2 3 4 5 6 7

projected proximity between aircraft and sector boundaries

equipment status

not related ____ highly related

1 2 3 4 5 6 7

aircraft altitude

type of sector

not related ____ highly related

1 2 3 4 5 6 7

aircraft altitude

projected proximity between aircraft and special use airspace

not related ____ highly related

1 2 3 4 5 6 7

aircraft route

aircraft position

not related ____ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft type

projected proximity between aircraft

not related ________ highly related

1 2 3 4 5 6 7

aircraft destination

expected traffic volume

not related ________ highly related

1 2 3 4 5 6 7

aircraft position

aircraft route

not related ________ highly related

1 2 3 4 5 6 7

equipment status

ATC procedures

not related ________ highly related

1 2 3 4 5 6 7

current traffic volume

sector operating procedures

not related ________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

projected proximity between aircraft	current traffic volume

not related _____ highly related

1 2 3 4 5 6 7

aircraft position	aircraft altitude

not related _____ highly related

1 2 3 4 5 6 7

expected traffic volume	sector operating procedures

not related _____ highly related

1 2 3 4 5 6 7

aircraft destination	flow restrictions

not related _____ highly related

1 2 3 4 5 6 7

projected proximity between aircraft	projected proximity between aircraft and special use airspace

not related _____ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft altitude — ATC procedures

not related ________________ highly related

1 2 3 4 5 6 7

aircraft position — separation standards

not related ________________ highly related

1 2 3 4 5 6 7

aircraft destination — projected proximity between aircraft and sector boundaries

not related ________________ highly related

1 2 3 4 5 6 7

aircraft type — aircraft position

not related ________________ highly related

1 2 3 4 5 6 7

aircraft route — equipment status

not related ________________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft type	projected proximity between aircraft and sector boundaries

not related — highly related

1 2 3 4 5 6 7

aircraft position	current traffic volume

not related — highly related

1 2 3 4 5 6 7

projected proximity between aircraft and special use airspace	projected proximity between aircraft

not related — highly related

1 2 3 4 5 6 7

aircraft altitude	weather

not related — highly related

1 2 3 4 5 6 7

expected traffic volume	equipment status

not related — highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

weather type of sector

not related ______ highly related

1 2 3 4 5 6 7

separation standards sector operating procedures

not related ______ highly related

1 2 3 4 5 6 7

type of sector ATC procedures

not related ______ highly related

1 2 3 4 5 6 7

current traffic volume flow restrictions

not related ______ highly related

1 2 3 4 5 6 7

aircraft type type of sector

not related ______ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft position

expected traffic volume

not related ________ highly related

1 2 3 4 5 6 7

projected proximity between aircraft and special use airspace

weather

not related ________ highly related

1 2 3 4 5 6 7

type of sector

equipment status

not related ________ highly related

1 2 3 4 5 6 7

weather

separation standards

not related ________ highly related

1 2 3 4 5 6 7

type of aircraft

projected proximity between aircraft

not related ________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft altitude — equipment status

not related ______ highly related

1 2 3 4 5 6 7

aircraft position — weather

not related ______ highly related

1 2 3 4 5 6 7

projected proximity between aircraft and special use aircraft — sector operating procedures

not related ______ highly related

1 2 3 4 5 6 7

aircraft position — aircraft destination

not related ______ highly related

1 2 3 4 5 6 7

ATC procedures — aircraft type

not related ______ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft destination	ATC procedures

not related ______ highly related

1 2 3 4 5 6 7

projected proximity between aircraft	sector operating procedures

not related ______ highly related

1 2 3 4 5 6 7

equipment status	separation standards

not related ______ highly related

1 2 3 4 5 6 7

aircraft type	type of sector

not related ______ highly related

1 2 3 4 5 6 7

aircraft route	projected proximity between aircraft and special use airspace

not related ______ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

projected proximity between aircraft and special use airspace	flow restrictions

not related ______________ highly related

1 2 3 4 5 6 7

type of sector	sector operating procedures

not related ______________ highly related

1 2 3 4 5 6 7

current traffic volume	separation standards

not related ______________ highly related

1 2 3 4 5 6 7

aircraft type	weather

not related ______________ highly related

1 2 3 4 5 6 7

projected proximity between aircraft and sector boundaries	type of sector

not related ______________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft destination

projected proximity between aircraft and special use airspace

not related — highly related

1 2 3 4 5 6 7

expected traffic volume

weather

not related — highly related

1 2 3 4 5 6 7

aircraft altitude

flow restrictions

not related — highly related

1 2 3 4 5 6 7

equipment status

sector operating procedures

not related — highly related

1 2 3 4 5 6 7

aircraft position

flow restrictions

not related — highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

projected proximity between aircraft — flow restrictions

not related — highly related

1 2 3 4 5 6 7

aircraft altitude — separation standards

not related — highly related

1 2 3 4 5 6 7

projected proximity between aircraft sector boundaries — expected traffic volume

not related — highly related

1 2 3 4 5 6 7

ATC procedures — sector operating procedures

not related — highly related

1 2 3 4 5 6 7

aircraft type — flow restrictions

not related — highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

current traffic volume
type of sector

not related ——— highly related

1 2 3 4 5 6 7

projected proximity between aircraft
ATC procedures

not related ——— highly related

1 2 3 4 5 6 7

aircraft type
separation standards

not related ——— highly related

1 2 3 4 5 6 7

aircraft altitude
projected proximity between aircraft and sector boundaries

not related ——— highly related

1 2 3 4 5 6 7

aircraft route
aircraft destination

not related ——— highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

projected proximity between aircraft and special use airspace

current traffic volume

not related ________________ highly related

1 2 3 4 5 6 7

weather

flow restrictions

not related ________________ highly related

1 2 3 4 5 6 7

type of sector

ATC procedures

not related ________________ highly related

1 2 3 4 5 6 7

aircraft type

equipment status

not related ________________ highly related

1 2 3 4 5 6 7

aircraft destination

current traffic volume

not related ________________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

projected proximity between aircraft	projected proximity between aircraft and sector boundaries

not related ____________ highly related

1 2 3 4 5 6 7

aircraft position	equipment status

not related ____________ highly related

1 2 3 4 5 6 7

aircraft destination	type of sector

not related ____________ highly related

1 2 3 4 5 6 7

weather	current traffic volume

not related ____________ highly related

1 2 3 4 5 6 7

projected proximity between aircraft	projected proximity between aircraft and special use airspace

not related ____________ highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

flow restrictions — separation standards

not related						highly related
1	2	3	4	5	6	7

aircraft route — type of sector

not related						highly related
1	2	3	4	5	6	7

aircraft type — aircraft altitude

not related						highly related
1	2	3	4	5	6	7

projected proximity between aircraft and special use airspace — equipment status

not related						highly related
1	2	3	4	5	6	7

expected traffic volume — flow restrictions

not related						highly related
1	2	3	4	5	6	7

CONTROLLER VALIDATION STUDY

flow restrictions	type of sector

not related — highly related

1 2 3 4 5 6 7

aircraft position	projected proximity between aircraft and special use airspace

not related — highly related

1 2 3 4 5 6 7

aircraft route	sector operating procedures

not related — highly related

1 2 3 4 5 6 7

aircraft type	aircraft destination

not related — highly related

1 2 3 4 5 6 7

separation standards	projected proximity between aircraft and sector boundaries

not related — highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

aircraft route   ATC procedures

not related   highly related

1 2 3 4 5 6 7

equipment status   flow restrictions

not related   highly related

1 2 3 4 5 6 7

projected proximity between aircraft and sector boundaries   separation standards

not related   highly related

1 2 3 4 5 6 7

projected proximity between aircraft and special use airspace   expected traffic volume

not related   highly related

1 2 3 4 5 6 7

CONTROLLER VALIDATION STUDY

1. Rate the importance of the following terms to your "mental picture" of the traffic

	not important						very important
aircraft type	1	2	3	4	5	6	7
ATC procedures	1	2	3	4	5	6	7
aircraft position	1	2	3	4	5	6	7
projected proximity between aircraft and special use airspace	1	2	3	4	5	6	7
weather	1	2	3	4	5	6	7
equipment status	1	2	3	4	5	6	7
current traffic volume	1	2	3	4	5	6	7
aircraft destination	1	2	3	4	5	6	7
projected proximity between aircraft and sector boundaries	1	2	3	4	5	6	7
aircraft altitude	1	2	3	4	5	6	7
type of sector	1	2	3	4	5	6	7
expected traffic volume	1	2	3	4	5	6	7
separation standards	1	2	3	4	5	6	7
flow restrictions	1	2	3	4	5	6	7
aircraft route	1	2	3	4	5	6	7
sector operating procedures	1	2	3	4	5	6	7
projected proximity between aircraft	1	2	3	4	5	6	7

CONTROLLER VALIDATION STUDY

2. Rate the importance of the terms to the development of a traffic management plan or strategy.

	not important						very important
type of sector	1	2	3	4	5	6	7
aircraft position	1	2	3	4	5	6	7
weather	1	2	3	4	5	6	7
equipment status	1	2	3	4	5	6	7
current traffic volume	1	2	3	4	5	6	7
aircraft destination	1	2	3	4	5	6	7
projected proximity between aircraft and sector boundaries	1	2	3	4	5	6	7
aircraft altitude	1	2	3	4	5	6	7
ATC procedures	1	2	3	4	5	6	7
projected proximity between aircraft and special use airspace	1	2	3	4	5	6	7
expected traffic volume	1	2	3	4	5	6	7
separation standards	1	2	3	4	5	6	7
flow restrictions	1	2	3	4	5	6	7
aircraft route	1	2	3	4	5	6	7
sector operating procedures	1	2	3	4	5	6	7
projected proximity between aircraft	1	2	3	4	5	6	7
aircraft type	1	2	3	4	5	6	7

CONTROLLER VALIDATION STUDY

3. Rate the extent to which the following terms contribute to controller workload.

	low workload						high workload
ATC procedures	1	2	3	4	5	6	7
expected traffic volume	1	2	3	4	5	6	7
projected proximity between aircraft and special use airspace	1	2	3	4	5	6	7
equipment status	1	2	3	4	5	6	7
aircraft destination	1	2	3	4	5	6	7
projected proximity between aircraft and sector boundaries	1	2	3	4	5	6	7
aircraft altitude	1	2	3	4	5	6	7
weather	1	2	3	4	5	6	7
type of sector	1	2	3	4	5	6	7
aircraft type	1	2	3	4	5	6	7
current traffic volume	1	2	3	4	5	6	7
aircraft position	1	2	3	4	5	6	7
separation standards	1	2	3	4	5	6	7
flow restrictions	1	2	3	4	5	6	7
aircraft route	1	2	3	4	5	6	7
sector operating procedures	1	2	3	4	5	6	7
projected proximity between aircraft	1	2	3	4	5	6	7