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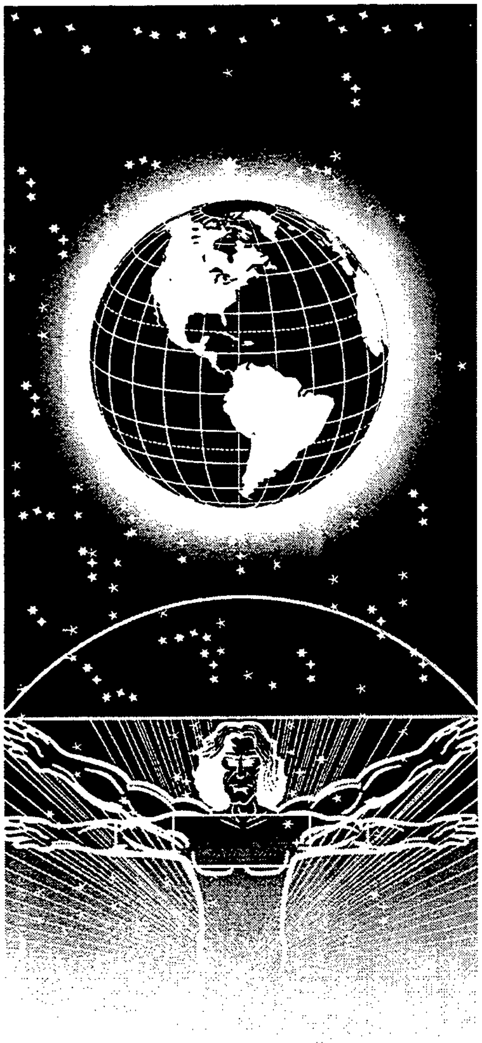

UNITED STATES AIR FORCE RESEARCH LABORATORY

ABAIS: AFFECT AND BELIEF ADAPTIVE INTERFACE SYSTEM

Eva Hudlicka
John Billingsley

PSYCHOMETRIX ASSOCIATES, INC.
8 SILVER HILL ROAD
LINCOLN MA 01773

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Human Effectiveness Directorate
Crew System Interface Division
2255 H Street
Wright-Patterson AFB OH 45433-7022

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Deputy Chief, Crew System Interface Division
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13. ABSTRACT *(Maximum 200 words)*

We describe an Affect and Belief Adaptive Interface System (ABAIS) designed to compensate for performance biases caused by users' affective states and active beliefs. The ABAIS architecture implements an adaptive methodology consisting of four steps: sensing/inferring user affective state and performance-relevant beliefs; identifying their potential impact on performance; selecting a compensatory strategy; and implementing this strategy in terms of specific GUI adaptations. ABAIS provides a generic adaptive framework for exploring a variety of user assessment methods (e.g., knowledge-based, self-reports, diagnostic tasks, physiological sensing), and GUI adaptation strategies (e.g., content- and format-based). The ABAIS performance bias prediction is based on empirical findings from emotion research, and knowledge of specific task requirements. The initial ABAIS prototype is demonstrated in the context of an Air Force combat task, uses a knowledge-based approach to assess the pilot's anxiety level, and modifies selected cockpit instrument displays in response to detected increases in anxiety levels.

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Summary

Purpose As decision-support systems (DSS) and associated user interface (UI) technologies mature and proliferate into mission-critical applications, and increasingly heterogeneous user populations, it becomes particularly important that they accommodate individual user characteristics. While some progress has been made in user-modeling and adaptive user interfaces, the majority of existing systems continue to assume normative performance, and fail to adapt to the individual characteristics of particular users, whether those that are relatively stable over time, or those that are susceptible to situational influences. This is particularly true for adaptation with respect of the user's affective state.

Current lack of accommodation of individual variations in performance in most human-machine systems can lead to non-optimal behavior at best, and critical errors with disastrous consequences at worst.

The purpose of this Phase I effort was to develop an Affect and Belief Adaptive Interface System, ABAIS, capable of assessing the user's affective and belief state and adapting the user interface to prevent potential performance biases.

Brief Description The ABAIS prototype implements a four step adaptive methodology consisting of: 1) sensing/inferring the individual's affective state and performance-relevant beliefs (e.g., high level of anxiety; aircraft is under attack); 2) identifying their potential impact on performance (e.g., focus on threatening stimuli, biasing perception towards identification of ambiguous stimuli as threats); 3) selecting a compensatory strategy (e.g., redirecting focus to other salient cues, presentation of additional information to reduce ambiguity); and 4) implementing this strategy in terms of specific UI adaptations (e.g., highlighting relevant cues or displays).

The ABAIS architecture consists of four modules, each module implementing the corresponding step of the adaptive methodology. For the Phase I ABAIS prototype, we focused on a knowledge-based assessment approach, applied to assessment of anxiety levels, to demonstrate the feasibility of the overall adaptive methodology. The knowledge-based assessment approach assumes the existence of multiple types of data (e.g., individual history, personality, task context, physiological signals), and from these data derives the likely anxiety level. Anxiety was selected both because it is the most prevalent affect during crisis situations, and because its influence on cognition has been extensively studied and empirical data exist to support specific impact prediction and adaptation strategies.

The ABAIS prototype was demonstrated in the context of an Air Force sweep mission. The prototype is integrated with a flight simulation environment, containing both an interactive and scripted fighter aircraft simulation, and an analyst interaction module. The latter supports the

definition of task elements, the specification of knowledge about the user which forms the basis of the adaptation, and specification of ABAIS run-time parameters. The key element of the simulation, the pilot's user interface, consists of a subset of the cockpit instruments, a heads-up display (HUD), radar, and two windows showing incoming communications and alarms, respectively.

Findings Development of the Phase I ABAIS proof-of-concept demonstrated feasibility of the overall adaptive methodology and its implementation. The four modules comprising the ABAIS architecture were able to assess the user state using a knowledge-based approach and information from a variety of sources (e.g., static task context, dynamic external events occurring during the task, pilot's individual history, pilot's personality traits, pilot's training and proficiency, and simulated physiological data), predict the effects of this state in the context of the demonstration task, and suggest and implement specific GUI adaptation strategies, based on the pilot's individual information presentation preferences.

Results of this demonstration indicate the feasibility of the approach in general, and of knowledge-based affect assessment and GUI adaptation in particular. The implementation allows the specification of highly-individualized baseline pilot profiles, which are used to infer individual reactions to a variety of specific events, based on the pilot's background, personality, and individual history, and selected physiological data. A key finding was demonstration of the feasibility of using electronic data about the task environment as basis for both affect and belief assessment.

We believe that the key requirements for a successful ABAIS system are: 1) limiting the number, type, and resolution of affective; 2) using multiple, complementary methods and multiple data sources for affective state assessment; 3) providing individualized user data, including details of past performance, individual history, personality traits, and physiological data; 4) constraining the overall situation in terms of situation assessment and behavioral possibilities; 5) providing a wide variety of task-specific data in an electronic format; 6) fine-tuning the rule-bases and inferencing to "personalize" the system to the individual user-task context; and 7) implementing 'benign' adaptations, that is, GUI / DSS modifications that at best enhance and at worst maintain current level of performance.

Future Applications A number of application areas exist where adaptation to affect and belief induced biases would help improve performance, and where the implementation of an ABAIS-type system would be feasible. These include both commercial and government applications, falling into three broad areas: 1) real-time, crisis-prone, high-risk decision-making environments; 2) infotainment and edutainment industry; and 3) training environments for emotional and cognitive disabilities and disorders.

Abstract

Currently, the majority of decision-support systems assume normative performance and fail to adapt to individual differences. This is particularly true with respect to affective states and individual beliefs, which can have profound impact on performance, particularly in complex, crisis situations. We developed an Affect and Belief Adaptive Interface System (ABAIS) capable of compensating for performance biases caused by users' affective states and active beliefs. The ABAIS architecture implements an adaptive methodology consisting of four steps: sensing/inferring user affective state and performance-relevant beliefs; identifying their potential impact on performance; selecting a compensatory strategy; and implementing this strategy in terms of specific GUI adaptations. ABAIS provides a generic adaptive framework for exploring a variety of user state assessment methods (e.g., knowledge-based, self-reports, diagnostic tasks, physiological sensing), and GUI adaptation strategies (e.g., content- and format-based). The ABAIS performance bias prediction is based on existing empirical findings from emotion research and knowledge of specific task requirements. ABAIS was developed in JAVA and C++, and its functionality was demonstrated in the context of an Air Force sweep task. The focus of this Phase I effort was on adapting selected cockpit instruments to the pilot's level of anxiety and associated beliefs. Adaptation to a heightened level of obsessiveness was also explored.

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Glossary of Terms

General

ABAIS	Affect and Belief Adaptive Interface System
AI	Artificial Intelligence
CTA	Cognitive Task Analysis
COTS	Commercial Off the Shelf
DSS	Decision Support System
GUI	Graphical User Interface
KE	Knowledge Elicitation
SME	Subject Matter Expert
UI	User Interface

Physiological Sensing

BVP	Blood Volume Pressure
EMG	Electromyogram
GSR	Galvanic Skin Response

AF Sweep Task

BVR	Beyond Visual Range
EID	Electronic Identification
IFF	Identification Friend Foe
NCTR	Non-cooperative target recognition
RWR	Radar Warning System
TWS	Track while Scan

1. Introduction

1.1 The Challenge: Adaptive Affective Interfaces

As decision-support systems (DSS) and associated user interface (UI) technologies mature and proliferate into mission-critical applications, and increasingly heterogeneous user populations, it becomes particularly important that they accommodate individual user characteristics. While some progress has been made in user-modeling and adaptive user interfaces, the majority of existing systems continue to assume normative performance, and fail to adapt to the individual characteristics of particular users, whether those that are relatively stable over time, or those that are susceptible to situational influences. This is particularly true for adaptation with respect of the user's affective state and individual, possibly idiosyncratic, beliefs.

To the extent that adaptation does exist, it is generally limited to "novices" vs. "power-users" (Shneiderman, 1997), and thus addresses a narrow range of domain- or system-specific differences among users. The more subtle differences in skill levels, individual histories and beliefs, decision-making and cognitive styles, not to mention affective states, go largely unacknowledged. This is in spite of accumulating evidence that both affective states and individual differences in knowledge, beliefs, and cognitive styles have a major impact on performance (Williams et al., 1997; Eysenck, 1997; Mineka & Sutton, 1992; Isen, 1993; LeDoux, 1992; Hammond et al., 1987; Deckert et al., 1994; Lussier et al., 1992; Fallesen, 1993). Such lack of accommodation of individual variations in performance can lead to non-optimal behavior at best, and critical errors with disastrous consequences at worst, as evidenced, for example, by the high rate of fratricide in recent military operations (Steinweg, 1995) and aircraft accidents and incidents, both civilian and military (e.g., USS Vincennes).

Fortunately, these limitations of existing systems are beginning to be recognized and addressed in recent work in human-computer interaction, particularly in the emerging agent technologies. There is increasing interest in the recognition of, and accommodation to, individual differences by practitioners in the relevant disciplines, including human-computer interaction (HCI), artificial intelligence (AI), and cognitive science. This is evidenced in increasing research efforts in understanding individual information and display requirements across a variety of tasks and individual characteristics, ranging from domain expertise, through cognitive abilities and individual beliefs, to physical limitations (Ackerman et al., 1989; Michel & Reidel, 1988; Egan, 1988; Edwards, 1995). These efforts are aided by a parallel increased interest in the study of individual differences by psychologists (Revelle, 1995), and by the burgeoning interest in the scientific study of emotion in AI and cognitive science (Picard, 1997; Hudlicka & Fellous, 1998), psychology (Williams et al., 1997; Davidson, 1992), and cognitive neuroscience (LeDoux, 1992). In AI and cognitive science, this interest takes a number of forms, including the use of emotions to develop more realistic agents (Reilly, 1996; Picard, 1997), investigation of basic mechanisms of emotion and cognition (Araujo, 1993; Scherer, 1993), investigations of how emotions arise from an integrated cognitive architecture (Sloman, 1987), and models of how specific emotions impact performance (Hudlicka, 1997; Pew and Mavor, 1998).

1.2 The Solution: Affect and Belief Adaptive Interface System

To help address the existing shortcomings in the accommodation of individual affective and belief states, we propose to design and demonstrate an adaptive user interface (UI) framework. This framework will be capable of adapting both to the users' affective state, and to the relevant individual beliefs that might influence performance. The proposed approach is based on a four step methodology, summarized in table 1.2-1. The methodology consists of: 1) sensing/inferring the individual's affective state and performance-relevant beliefs; 2) identifying their potential impact on performance; 3) selecting a compensatory strategy; and 4) implementing this strategy in terms of specific UI adaptations; that is, presenting additional information, or presenting existing information in a format that facilitates recognition and assimilation, thereby enhancing situation awareness (Endsley, 1995). We illustrate this approach with an example from a frequent Air Force combat activity, the sweep task, described below.

Table 1.2-1: Methodology for Proposed Adaptive Framework

METHODOLOGY STAGE	EXAMPLE
1. ASSESS USER STATE • Identify affective state • Identify individual beliefs	• Affective state: Anxious • Belief: Result of individual history of failures/successes
2. PREDICT IMPACT (generic & task specific) • Predict impact of affective states • Predict impact of individual beliefs	*Generic* • Anxiety Impacts Attention & Perception - Increased focus on threatening stimuli - Perception of ambiguous signals as threats • Indiv. history creates biases in expectations of outcome *Specific* • Focus on threat ID & neglect other tasks • Bias towards identifying signals as threats • Over- or underestimation of the likelihood of failure • Possible premature engagement / fratricide
3. SELECT STRATEGY • Select compensatory strategies to prevent biased performance	• Present reminders to prevent neglect of tasks • Present broader evidence to counteract threat-estimation bias • Present contrary evidence to counteract failure-driven confirmation bias
4. ADAPT AIDING INFO TYPE & PRESENTATION • Provide additional data about ambiguous signals • Select info format enhancing detection and assimilation	• Direct an associated DSS to present additional data about ambiguous signals • Present explicit estimates of times required for task completion to prevent premature engagement • Use multi-modal, customized attention-capturing presentation to assure detection

Consider a situation where a 4-aircraft F-15 wing is conducting a sweep mission at night and in bad weather. The lead pilot must conduct a number of parallel tasks, including aviating, navigating, coordinating with the other pilots, and radar-based search and visual lookout for target enemy aircraft (bogeys). As the wing is entering the engagement phase, hampered by reduced visibility and bad weather, one of the engines on the lead pilot's aircraft fails, thus further contributing to his level of stress and anxiety, already heightened because of the combat situation, lack of sleep, and combat fatigue.

A number of empirical studies provide evidence that the primary effect of anxiety is on attention and perception, causing attention to be focused on threatening stimuli and causing perception to favor interpretation of ambiguous stimuli as threatening (MacLeod & Hagan, 1992). In this case, the resulting increased anxiety is likely to cause the pilot to pay increased attention to threatening stimuli, possibly neglecting the other critical tasks of aviating, navigating, and coordinating with the other members of his wing. The heightened anxiety also contributes to the pilot's tendency to interpret ambiguous signals as threatening, which may lead to misidentification of bogeys or even fratricide. Suppose further, that the pilot's individual history includes several episodes of similar circumstances where a failure to react to such ambiguous stimuli had disastrous consequences (e.g., being shot down by enemy aircraft). The pilot is therefore biased from several sources (affective state and activated beliefs based on individual history) to identify ambiguous targets as a bogey and to enter the engagement phase of the sweep task prematurely, contributing to misidentification of aircraft as enemy and possible fratricide.

To compensate for this potentiality, we envision an aiding system which would embed the proposed methodology within a generic affective, adaptive framework. This system would be capable of *detecting the pilot's state*, both affective state and current predominant beliefs (i.e., increased anxiety and expectations of failures when engagement was avoided or delayed), *identifying the potential impact* of his affective and belief states (i.e., possible neglect of aviating and coordinating tasks, increased threat estimation, and increased likelihood of premature engagement), *selecting a compensatory strategy* (e.g., presentation of additional information to reduce ambiguity or slowing down decision-making to prevent a mistaken hasty decision), and *adapting the user interface* by providing additional information in a customized format designed to enhance fast recognition and assimilation (i.e., directing an associated DSS to collect additional information about the suspected target, suggesting that the pilot further confer with the other pilots to conduct a positive identification, guiding the pilot's attention to additional radar data that may disconfirm his original suspicions, etc.).

The proposed framework will be able to accommodate a variety of complementary methods for identifying a range of affective states (e.g., anxiety, depression, anger, etc.), and beliefs (e.g., intuitive knowledge gathered from individual experience, preferred knowledge and procedures, beliefs about current situation, etc.). Candidate methods will be discussed in more detail in section 3. The framework will use knowledge-based methods (e.g., rule-based reasoning (RBR) and case-based reasoning (CBR)) to derive the most likely impact of the detected affective and belief state, to select a compensatory strategy, and to suggest user interface adaptations implementing the selected strategy.

The overall objective will be to develop a generic framework, within which a variety of specific methods of assessment, impact prediction, and adaptation can be explored. This flexible design will then facilitate the implementation of an exploratory testbed during Phase II, that would support modular implementation of a variety of specific techniques and their flexible combination to address a range of task scenarios.

For the purposes of the Phase I effort, we limited the demonstration to the assessment of the user's level of anxiety, via rule-based reasoning, and the assessment of a limited set of beliefs relevant to outcome estimation, via a staged process of domain ontological analysis using direct knowledge elicitation methods, followed by on-line dynamic belief assessment using rule-based reasoning. Anxiety was selected in part because it is the most likely predominant affect displayed during crisis situations, and in part because its impact on attention and perception is well-documented from existing empirical studies (Williams et al., 1997; MacLeod & Hagan, 1992). A follow-on Phase II effort would then expand this initially limited scope to include additional affective states and personality characteristics, additional means of identifying these states and characteristics, and enhanced adaptation strategies, in both individual and team settings.

1.3 Technical Objectives

The primary objective of the Phase I effort was to assess the feasibility of the proposed four-step affect and belief adaptive methodology. In the Phase I, we designed and developed a framework for affective interfaces in complex, crisis situations, capable of adapting to a variety of user affective and belief states. This framework implemented the adaptive methodology described in table 1.2-1 within a workstation architecture: the Affect and Belief Adaptive Interface System (ABAIS). ABAIS was demonstrated in the context of a sweep task, and focused on adapting the user interface output to the pilot's current level of anxiety and beliefs resulting from individual experiences. In the Phase I effort, we demonstrated a knowledge-based approach to the problem, based on a detailed characterization of the effects of a variety of affective states, personality factors, and knowledge schemata on flight performance. Basic questions addressed during in this Phase I effort included:

- **Impact of Affective States on Performance:** How do different affective states impact perception and decision-making? How do the effects of the emotional states vary across individuals and across tasks? Which of these effects are most relevant in crisis situations?
- **Nature of Beliefs and their Impact on Performance:** When do individual beliefs emerge during performance and how do they impact perception and decision-making? How are these beliefs related to different affective states?
- **Methods of Affect and Belief Assessment:** What are the best methods for identifying affective states and individual intuitive beliefs? Which of these methods can be applied in real-time and which are limited to off-line use? How can complementary assessment methods be combined and incorporated into an adaptive user interface to enhance intelligent aiding?
- **Compensatory Strategies for Affect- and Belief-Induced Biases:** How can we distinguish between affect- and belief-induced biases which are adaptive, from those that are counterproductive? What are the best ameliorative and compensatory strategies for counteracting the deleterious impact of specific affective states and beliefs?
- **Decision-Support and Display Strategies:** What specific additional information is necessary to counteract affect- and belief-induced biases? What are the best methods of presenting this information to the user in a timely and efficient manner? What specific displays and UI methods are most effective in counteracting the limitations of affect-induced processing and belief-induced cognitive biases? How do these vary across individual preferences and tasks?
- **Prototype Fidelity and Full-Scope Development:** What level of prototype fidelity and scenario complexity are required to demonstrate the basic operation of the envisioned adaptive framework? How can we effectively transition the prototype to a full-scope demonstrator of adaptive affective decision-aiding in crisis situations?
- **Commercial Applications:** What commercial areas are most likely to benefit from this type of adaptive decision-aiding and what is the likelihood of market success in these areas? How can the ABAIS framework and workstation best be applied to a variety of federal government and commercial settings?

By addressing these questions under the Phase I effort, and demonstrating feasibility of the approach, we will be in a position to specify detailed requirements for a Phase II effort directed at full-scope development and testing of an adaptive, affective interface system.

1.4 Technical Approach

The approach taken under this effort focused on the proof-of-concept demonstration of an Affect and Belief Adaptive Interface System (ABAIS). ABAIS assists the user (e.g., pilot) in the detection of, and adaptation to, user affective states (e.g., anxiety), dominant personality characteristics (e.g., obsessiveness), and current set of beliefs that may influence performance (activated knowledge schemata) (e.g., pilot belief he is under attack by hostile aircraft), in an attempt to counter the associated performance biases. Seven specific tasks comprised our effort:

- Defining a scenario for ABAIS demonstration
- Identifying generic effects of affective states and decision-making biases resulting from intuitive, idiosyncratic beliefs from existing research literature
- Identifying specific likely effects of affective states and examples of individual, idiosyncratic beliefs that might influence performance from knowledge elicitation interviews with expert Air Force pilots and research personnel
- Developing knowledge bases for each of the four modules comprising the ABAIS system architecture
- Designing and implementing a prototype ABAIS architecture
- Demonstrating the proof-of-concept of the ABAIS framework and prototype in the context of selected test scenarios
- Defining requirements for Phase II development and commercialization

The activities performed under each of these tasks are summarized in the paragraphs below.

We first **defined a scenario for ABAIS demonstration** through a series of knowledge elicitation interviews with subject matter experts (SME's) (USAF and Navy fighter pilots and psychologists). The objective was to define a scenario which would provide adequate complexity to allow the demonstration of the adaptive methodology and yet be feasible to implement within the short time available for the Phase I effort. The scenario had to provide opportunities for application of the ABAIS methodology by providing situations where different affective states, personality factors, and beliefs could have varying effects on situation assessment and decision making. The scenario also had to be of sufficient complexity and difficulty to include situations likely to induce varying levels of anxiety. A fighter pilot context was selected to provide a scenario where stress levels are likely to be high, accurate situation assessment is critical, and consequences of affect- and belief-induced performance biases can be catastrophic or at best expensive. After considering several options of tasks and task contexts (e.g., instrument failures and intercept geometries to induce anxiety), we selected the sweep task and a series of BVR air-to-air combat encounter events to demonstrate the ABAIS adaptive methodology in a real-time, dynamic context.

We then **identified generic effects of affect- and belief-induced performance biases** by reviewing empirical literature from four areas: 1) experimental, cognitive, and applied psychology; 2) personality theory; 3) human factors; and 4) cognitive engineering. The findings were then evaluated for their potential in providing information about the effects of affect-, personality trait- and belief-induced biases on performance. The literature search focused both on the basic research in the effects of affective states on performance, and on the more applied research in the effects of beliefs and selected affective, personality factors (e.g., anxiety, obsessiveness) on situation awareness and decision making.

We then **identified specific likely effects of affective states, selected personality factors, and individual beliefs on flight performance** in the context of the demonstration task described above. Given the relative paucity of empirical studies in this area, the primary means of identifying these effects were knowledge elicitation interviews with pilots and other aviation subject matter experts (SME's). Part of this effort was also focused on identifying likely personality traits and affective profiles by reviewing existing literature on personality testing of the Air Force pilot population.

We then **developed knowledge bases** for each of the four modules comprising the ABAIS system: User State Assessment, Impact Prediction, Strategy Selection, and GUI/DSS Adaptation. The information contained in these knowledge bases was derived both from the literature search and from knowledge elicitation interviews with SME's, and focused on knowledge required for the selected demonstration scenario. The rule base of each ABAIS module captures the domain knowledge necessary to perform each of the four steps of the adaptive methodology. The rules, and the associated inference engine, assume the existence of a variety of data providing background information about the pilot (individual history, personality characteristics, physiological data), and dynamic, real-time information about the task (via datalink and variety of on-board detection instruments).

For the *User State Assessment,* this effort consisted first of identifying the multiple categories of factors necessary to infer the user's affective state, personality trait, and predominant beliefs, and second, of constructing the rules mapping these factors onto the space of possible affective and belief states. For the Phase I effort we focused on anxiety, obsessiveness, and beliefs corresponding to knowledge schemata likely to be active during the demonstration task (e.g., "lead aircraft under attack", "hostile aircraft approaching", "Lead at maximum firing range", etc.). We reviewed multiple methods of user state assessment and selected a knowledge-based approach for this Phase I demonstration, as providing the best means for feasibility assessment of the overall approach.

For the *Impact Prediction* module, this effort consisted of constructing rules that mapped the identified affective state, personality trait, or active belief onto the most likely effects on various elements of the sweep task performance. Again, focusing on the effects of anxiety and obsessiveness, we mapped these factors onto their corresponding specific effects within the demonstration task (e.g., anxiety predisposes towards interpretation of "unknown" NCTR as hostile and narrowing of attention on highest-threat task, high obsessiveness predisposes towards lengthy echoing of communications and checking of instruments, etc.). Key element of this effort was the incorporation of the reciprocal influence between affect and belief, with the potential for a performance bias due to a positive feedback between an anxiety state and an anxiety-induced belief.

For the *Strategy Selection* module, we developed rules mapping the specific performance bias (e.g., task neglect, cue misinterpretation, checking behavior) onto a corresponding series of compensatory strategies counteracting these biases (e.g., redirecting focus onto neglected data, reminders of increasing vulnerability due to a delayed decision).

Finally, for the *GUI / DSS Adaptation* Module, we developed rules implementing specific modifications of the pilot cockpit instrument displays corresponding to the suggested strategy (e.g., highlighting information to capture pilot's attention, displaying additional information to counter predicted biases, etc.). The specific GUI modifications also took into consideration information about the individual pilot preferences for information presentation, encoded in customized user preference profiles.

We then **designed and implemented a prototype ABAIS architecture** using COTS products and existing software to the extent possible. The architecture consists of the four modules described above and is embedded within a simulation testbed environment. This environment contains both an interactive and scripted fighter aircraft simulation, and an analyst interaction module. The latter supports the definition of task elements, the specification of user knowledge used to drive the adaptation, and specification of ABAIS run-time parameters. JAVA was used to construct the ABAIS graphical user interface (GUI) in the Jbuilder development environment. The GUI consists of selected cockpit instruments (HUD, radar, and a notification window for alarms etc.), and includes a variety of windows showing dialog boxes for defining the background information required by ABAIS (e.g., pilot preference profile, pilot individual history), and dialog boxes for specifying the system run time parameters (e.g., what windows should be visible for monitoring system performance). Charles River Analytics SD_PVI C++ routines were used as a model for the aircraft flight dynamics. C++ was used to implement the overall scenario simulation, the rule-based reasoning, and to integrate the individual system components described above. The flight instruments were modeled on commercially-available

F-15 and F-22 simulator games.

JAVA was selected because its object-oriented model supports rapid prototyping and the development of reusable code. JAVA also has excellent cross-platform portability. Borland's JBuilder 2.0 was selected as the development environment to support rapid design and development of GUI's. JBuilder was selected because it provides one of the best available GUI design environments and offers a full suite of JAVA objects. The original plan called for integration of ABAIS with the Charles River Analytics SD_PVI system (Mulgund et al., 1997). However, it was determined that due to platform and software incompatibilities, as well as the focus of the current effort, the ABAIS demonstration was better served through a custom-coded GUI and simulation environment. The SD_PVI system from Charles River Analytics thus served primarily as a model for the flight dynamics required for the flight simulation. The original plan called for using JESS, a JAVA version of the CLIPS rule based shell. However, it was determined that the complexity of the Phase I rule bases did not justify the effort required to integrate JESS within the ABAIS simulation environment. A custom-coded rule-based inferencing engine was therefore used for the Phase I demonstration.

We **designed, constructed, integrated, and evaluated a wireless heart rate monitor.** Although not originally planned for the Phase I effort, we designed and constructed a wireless heart rate monitor as a means of prototyping the wearable technology necessary for physiological affect assessment. The monitor consists of a light-weight belt worn around the torso and an associated wireless transmitter. In our initial demonstration we integrated the monitor with simple ABAIS GUI adaptations to demonstrate ABAIS' capability to detect and respond to changing physiological signals. The prototyped system ensemble provides foundations for extensive physiological assessment under the proposed Phase II.

We then **demonstrated the proof-of-concept of the ABAIS framework** and prototype in the context of selected task scenarios. ABAIS performance was evaluated by simulating several pilot profiles, represented by specific personality, individual history, and training data, in the context of the demonstration scenarios, with and without adaptation. The different pilot profiles generated different affective and belief states at different points of the scenario. The resulting GUI / DSS adaptations were derived via the ABAIS adaptive methodology, using the rules in the four ABAIS modules. The output of the GUI / DSS Adaptation recommendations was then shown on the corresponding cockpit instruments.

The ABAIS implementation supports two modes of system operation: 1) *pilot-as-user* mode, where the user actually flies the aircraft and interacts with a simulated environment consisting of enemy aircraft, other friendly aircraft, and missiles; and 2) *analyst-as-user,* where the analyst watches a scripted task and monitors the scripted pilot's performance, and the rule-based inferencing. These modes are not entirely mutually exclusive. In other words, the analyst and / or the pilot can specify pilot and system parameters, the pilot can they "fly" the aircraft, and both can watch the system output on simulated cockpit instruments and ABAIS system monitoring windows.

Due to the precise coordination required to fly the demonstration script, it was determined that the best method of demonstrating the ABAIS performance under Phase I would be in the analyst-as-user mode, where the aircraft is controlled by a script that emulates the desired pilot behavior. However, we did demonstrate the human-in-the-loop mode during the integration of the heart rate monitor with the ABAIS system. Under this mode a user (e.g., pilot) wears the remote monitor and the real-time physiological signals are used as input to the ABAIS GUI adaptation logic.

Finally, we **defined requirements for Phase II full-scope development and commercialization.** To define specifications for ABAIS in military environments, we focused on identifying further development and demonstration requirements to be met for a full-scope affective adaptive user interface for a variety of real-time, dynamic environments (e.g., AWACS tasks). We focused on environments requiring team coordination, as these are becoming increasingly common and provide a rich context in which to demonstrate the proposed ABAIS methodology. To define commercialization requirements, we identified promising commercial market areas and particular market segments that could benefit from the development of a suitably specialized affective, adaptive interface and decision support tool.

1.5 Summary of Results

The primary result of this study was a proof-of-concept demonstration of an Affect and Belief Adaptive Interface System (ABAIS), designed to provide individualized GUI and DSS adaptations based on the user's affective and belief state. Specific results are outlined below, first for the effort as a whole, and then organized by the individual subtasks conducted.

Overall ABAIS Adaptive Methodology Framework Development of the Phase I ABAIS proof-of-concept demonstrated feasibility of the overall adaptive methodology and its implementation. The four modules comprising the ABAIS architecture were able to assess the user state using a knowledge-based approach and information from a variety of sources (e.g., static task context, dynamic external events occurring during the task, pilot's individual history, pilot's personality traits, pilot's training and proficiency, and simulated physiological data), predict the effects of this state in the context of the demonstration task, and suggest and implement specific GUI adaptation strategies (e.g., modify an icon or display to enhance visibility), based on the pilot's individual information presentation preferences.

Results of this demonstration indicate the feasibility of the approach as a whole, and of knowledge-based affect assessment and GUI adaptation. The implementation allows the specification of highly-individualized baseline pilot profiles, which can be used to infer individual reactions to a variety of specific events, based on the pilot's background, personality, and individual history (i.e., specific events in recent past), and selected physiological data. A key finding was demonstration of the feasibility of using electronic data about the task environment as basis for both affect and belief assessment (e.g., radar contacts).

Specifically, we believe that the key requirements for its success are: 1) availability of highly individualized data about the system user, including details of past performance, individual history, personality traits, and physiological data; 2) availability of a wide variety of task-specific data in an electronic format; 3) use of multiple methods and multiple sources of data for assessing the user's affective and belief state; and 4) ability to fine-tune the rule-bases and inferencing to "personalize" the system to the individual user-task context.

The specific findings supporting these conclusions, and the detailed findings under each of the seven tasks comprising the Phase I effort, are summarized below.

Scenario Definition A sweep task scenario was developed involving two friendly fighter aircraft engaging several unknown and presumed hostile aircraft in the course of a sweep task. Multiple variations within this basic structure provide opportunities to demonstrate varying affective states (e.g., low vs. high anxious), varying personality traits (e.g., low vs. high obsessive), and differences in individual history and training with consequent variations in performance. The aircraft instrumentation is loosely modeled on the F-15 fighter aircraft which is assumed to be equipped with a HUD and datalink connections between the lead, wingman, and an AWACS. Critical data are thus shared between the lead, wingman and the AWACS pilots. The ABAIS system is demonstrated in the context of the lead's cockpit and is assumed to be tightly coupled with the detection instruments and the radar and HUD displays. The ABAIS system thus has access to any data appearing on the radar, whether obtained directly from the aircraft sensors, or indirectly from wing man or AWACS via datalink. ABAIS uses these data as the basis for its dynamic inferencing to assess the pilot's affective and belief state, implement the adaptation strategy, and perform the GUI adaptation.

Effects of Affect, Personality Traits, and Beliefs on Performance We reviewed a variety of literature sources to identify effects of affect-, personality trait- and belief-induced performance biases. *Affect and personality traits:* Recent experimental psychology research provides increasing evidence for the existence of consistent biases in attention, perception, and variety of inferencing associated with different affective states and personality factors. Experimental psychology literature thus represented a good source of data for identifying generic effects of a variety of affective states and personality traits. Anxiety was selected as the primary affect and obsessiveness was the primary personality trait for the Phase I effort. This selection was made in part because much is known about both of these factors and their effect on performance, and because both factors can play a role in dynamic, real-time environments of interest to the Air Force. The following effects were identified: 1) effects of anxiety on attention (bias towards threat, narrowing, attentional shifts) and perception (bias towards interpretation of ambiguous signals as threatening); and 2) effects of obsessiveness on decision making (delaying of decision making due to "checking behaviors", reduced recall of recent events, narrow conceptual categories). *Belief:* The research literature in human error and judgment proved to be a good source of information for assessing potential effects of individual beliefs. Research literature in the more applied area of situation assessment and situation awareness also provided a variety of data about the effects of individual knowledge and biases on performance, specifically on situation assessment. One of the more interesting outcomes of this search was the identification of generic situation assessment and decision selection biases that can result from active beliefs. These include confirmation bias, overgeneralization, availability, order effects, internal coherence, consistency, and representativeness. Together, these findings provided data about the generic effects of affect and belief on performance, specifically on situation assessment.

Once the generic effects of the selected factors were identified, we surveyed the literature to identify empirical studies documenting these effects in aviation-related contexts, specifically, in the fighter pilot context. However, given the relative paucity of available empirical data, we focused instead of knowledge elicitation interviews with SME's to obtain information about possible specific effects of these factors in the context of the demonstration scenarios. These interviews provided both an informal confirmation of the generic effects identified in the empirical literature, and specific instances of these effects in the context of the demonstration task. Namely, instances of specific effects of anxiety on attention and perception, obsessiveness on decision making, and other factors such as aggressiveness, impulsivity, and risk taking on situation assessment and performance in general.

We also reviewed results of recent studies in the psychological assessment of the fighter pilot population. These results helped identify critical personality traits necessary to define representative pilot profiles for the simulation.

User State Assessment User state assessment consisted of assessing both the affective state and dominant personality trait, and identifying the likely belief state (i.e., dominant knowledge schemata influencing situation assessment and subsequent performance). The affective state selected for the Phase I demonstration was the level of anxiety, which was assessed to be at one of several qualitative values (e.g., low, medium, high), using a variety of background and real-time data about the pilot. The personality trait was obsessiveness, which was specified a priori and assumed to manifest itself more prominently under conditions of heightened anxiety. The belief states were defined in terms of the task context to reflect the pilot's interpretation of the current dynamic data (e.g., contact is unknown or hostile) and situation assessment (e.g., enemy aircraft are attacking). A rule-based approach to this problem was implemented, which used information about the pilot's training, personality, and individual history background specified by the analyst prior to a simulation run, and simulated physiological data and dynamic environment data as generated dynamically during a simulation run. The knowledge-based approach to this problem feasible provided that the following criteria are met: 1) detailed information about the pilot's individual history, training, and personality factors is available; 2) real-time physiological measures are available; 3) variety of task-relevant data are available in electronic form (e.g., enemy radar information, enemy aircraft identification and characteristics, etc.); 4) ability to fine-tune and customize the rule-bases to reflect the individual user-task context. In general, the identification of a belief state is more difficult than identification of an affective state, due to the large numbers of possible knowledge schemata. However, in highly constrained task contexts where the space of possible cues, situations, and actions is limited, belief assessment appears feasible. The ability to identify the user's dominant affective state, personality trait, and currently active belief, then provided input to the next stage of the adaptive methodology: predicting the influence of these factors on performance.

Impact Prediction Impact of the user state on performance was predicted based on knowledge about both generic and specific effects of anxiety and obsessiveness, and potential effects specific belief states (e.g., "aircraft under attack", "hostile aircraft approaching", etc.). This knowledge was used to as basis for a detailed affective / cognitive task analysis. This method of task analysis focused on generating a broad set of possible behaviors based on the collection of specific performance biases resulting from the identified affective, personality, and belief states. A rule-base was then constructed which mapped particular user states onto specific performance biases (e.g., heightened anxiety predisposes towards a threat estimation bias, resulting in the possible misinterpretations of unknown contacts as hostile). A generic version of this approach would be difficult, in other words, it would be difficult to predict the effects of arbitrary beliefs and affective states on performance across arbitrary contexts. However, constrained environments, where information is available about both the task details and the user, provide a sufficiently narrow scope within which the necessary space of possibilities can be generated (e.g., targets can only be interpreted as unknown, hostile, or friendly; weapons can be deployed or not; etc.). The ability to predict the influence of the affective state, personality trait, and currently active belief, on performance then provided input to the next stage of the adaptive methodology: selecting a compensatory strategy.

Strategy Selection As with the impact prediction, the successful selection of a compensatory strategy was possible given the highly focused task context, within which only a small number of alternative behaviors exist (e.g., focus on radar vs. focus on HUD; present reminders of neglected tasks; remind of consequences of delayed firing decision, etc.), and the assumed availability of a wide variety of electronic data supporting the instantiation of the identified strategies (e.g., provide more evidence for or against a particular target interpretation). The identified compensatory strategy then provided input to the final stage of the adaptive methodology: implementing the selected strategy in terms of the pilot's GUI.

GUI / DSS Adaptation Finally, the successful GUI adaptation was possible given the assumed "glass cockpit" environment and the possibility of modifying selected cockpit instrument displays as needed, to implement the suggested adaptation strategy (e.g., enhance icon visibility, present additional information about target, display notification or warning text, etc.). The adaptation was further enhanced by taking into consideration the pilot's preference profile, which defined the pilot's preferred information presentation format. In this way the selected strategy was optimized for the individual user.

Design and Implementation of ABAIS Prototype The COTS-based, object-oriented development approach produced a working prototype implementing the adaptive methodology and consisting of the four modules described above, the aircraft simulation, an analyst module supporting interactive specification of task scripts, pilot information required for the assessment, pilot preference profiles, and the monitoring of system performance. JAVA proved to be a good environment for the development of the required GUI's and provided a flexible means of implementing the necessary GUI adaptations.

Demonstration of ABAIS ABAIS performance was demonstrated across multiple sequences of events in the context of the sweep task scenario. The scenario was defined in terms of a task script matrix, which defined the sequence of dynamic events (e.g., communications between lead, wingman, and AWACS; appearance of contacts on radar; RWR signals, etc.). The ABAIS system then instantiated these dynamic data, together with the background knowledge about the pilot, within the individual module knowledge-bases. The rules in the individual modules than implemented the adaptive methodology, deriving first the user's anxiety level (e.g., high-anxious) and dominant belief (e.g., hostile aircraft approaching, aircraft under attack); predicting their effects on performance (e.g., misinterpretation of unknown contacts as hostile, assumption aircraft is under attack); selecting a compensatory strategy (e.g., notify pilot of recent change in contact status from unknown to friendly); and finally selecting and implementing a corresponding GUI adaptation (e.g., redirect attention to radar display, enhance recent change in contact status).

Full-scope Development Based on the successful feasibility demonstration, we specified the requirements for a full-scope ABAIS development and evaluation, under a Phase II design, development, and evaluation effort. The Phase I objective was to establish feasibility; under Phase II, we would considerably expand the scope, increase the functionality of the individual modules, incorporate limited physiological sensing in a closed-loop demonstration, and fully explore and evaluate ABAIS effectiveness in a human-in-the-loop, dynamic team task environment. The system architecture design would thus follow the architecture developed during this Phase I effort, but the functionality of the individual modules and corresponding rule-bases would be considerably expanded.

Commercialization Potential We have identified a number of potential market areas for the application of the adaptive methodology developed during this Phase I effort. Three broad areas of applications were identified: real-time decision making environments, characterized by information overload, decision-making under uncertainty, and high-risk, potential for crisis situations; training and therapeutic environments, designed to address specific cognitive biases, learning disabilities, or affective disorders; and the emerging infotainment and edutainment industries.

We believe that these results demonstrate the basic features of the ABAIS concept for affect and belief adaptation, particularly as applied in a real-time, dynamic setting relevant to Air Force operations. The study was specifically structured to be narrow in scope, but to provide sufficient depth to ensure the reliable specification of requirements for a full-scope system.

1.6 Report Outline

Chapter 2 provides technical background on related research and current technologies most relevant to this Phase I effort. Section 2.1 provides a brief overview of the status of emotion research and some key recent findings, while section 2.2 summarizes the effects of emotion on cognition and performance. Section 2.3 reviews relevant work in individual differences and personality research. Section 2.4 reviews theory and methods for assessing affective states. Section 2.5 summarizes research on situation awareness and its relevance to assessing and adapting to the user's belief state. Finally, section 2.6 summarizes the relevant technologies, including wearable computing, knowledge elicitation techniques, rule-based reasoning, COTS products for software development, and existing systems relevant to this effort.

Chapter 3 provides a description of the ABAIS prototype. Section 3.1 defines the system architecture and provides a general overview of system functionality. Sections 3.2 through 3.5 then describe the four key modules of this architecture: User Assessment, Impact Prediction, Strategy Selection, and GUI / DSS Adaptation. Section 3.6 describes the ABAIS GUI and section 3.7 describes the simulation environment.

Chapter 4 demonstrates ABAIS functionality by illustrating its adaptation strategies across several scenarios. Section 4.1 provides an overview of the adaptation process. Section 4.2 then describes the demonstration scenarios used. Section 4.3 illustrates the sequence of steps and the ABAIS adaptation, via a series of screen shots taken from the system display.

Chapter 5 summarizes the key tasks conducted under this effort, and presents the major conclusions.

2. Background

This chapter provides technical background on existing research and current technologies most relevant to our effort to develop an ABAIS concept prototype. Section 2.1 provides a brief overview of the status of emotion research and some key recent findings, while section 2.2 summarizes the effects of emotion on cognition and performance. Section 2.3 reviews relevant work in individual differences and personality research. Section 2.4 reviews theory and methods for assessing affective states. Section 2.5 summarizes research on situation awareness and its relevance to assessing and adapting to the user's belief state. Each of the above sections concludes with an "Implications for ABAIS system" paragraph, which highlights the relevance of the discussed findings for the ABAIS adaptive methodology and system. Finally, section 2.6 summarizes the relevant technologies, including wearable computing, COTS products for software development, and existing systems relevant to this effort.

2.1 Emotion Research

Although central to human development and functioning, emotions have, until recently, had a somewhat marginal status in both cognitive science and neuroscience. The study of emotions was generally equated with such ineffable phenomena as qualia and consciousness, and it was not clear how these problems could be addressed or in what way the study of emotions could help elucidate the nature of human behavior and information processing. Another problem faced by emotion researchers was the association of emotion with psychopathology and maladaptive behavior, and the consequent lack of acknowledgment of emotional processing as integral part of human performance.

Over the past 10 years, however, important discoveries in neuroscience and experimental psychology have contributed to an interest in the scientific study of emotion. A growing body of evidence from neuroscience research points to the existence of circuitry processing emotionally-relevant stimuli (i.e., stimuli that threaten or benefit the survival of the organism or its species) (LeDoux, 1989). LeDoux and colleagues have studied fear conditioning in rats and identified a number of key results: 1) existence of dedicated circuitry processing stimuli that threaten or benefit organism or species survival; 2) evidence that emotional circuitry performs fast, less differentiated processing and behavior selection (e.g., freezing behavior in rats); 3) evidence that this processing is mediated by connections linking sensory organs directly to emotional circuitry in the brain, specifically, the amygdala (LeDoux, 1992). Studies in experimental psychology have identified memory systems with distinct processing characteristics (explicit and implicit memory) (Schacter, 1987) analogous to the characteristics of the neural circuitry identified by LeDoux; namely, fast and less differentiated processing versus slower, more refined processing.

Cognitive psychologists have described a variety of appraisal processes involved in inducing a particular emotional state in response to a situation (Frijda, 1986; Lazarus, 1991) and several models have been proposed (Ortony et al. 1988), some of which have been implemented in computational models (Reilly, 1996; Scherer, 1993; Bates et al., 1992; Frijda and Swagerman, 1987). Damasio and colleagues have studied humans with brain lesions and identified the role of emotion in human information processing and decision-making (Damasio, 1994). Damasio suggests that emotions "prune" the search spaces generated through cognitive processing by selecting only those paths associated with previously rewarding experiences. Damasio's "somatic marker hypothesis" suggests that this selection is guided by "somatic markers", that is, learned associations between a particular affective state and specific cognitive content.

Recent research thus provides evidence for the impact of emotion on cognitive processing and the central role of emotion in the control of behavior. The emerging findings also begin to blur the distinction between what has traditionally been thought of as the separate realms of cognition and emotion.

Specific Roles of Emotions Psychologists and sociologists suggest that emotions play both an intrapersonal (intrapsychic) and interpersonal (social) roles, functioning as signals that communicate the status of the organism's goals both internally and externally (Oatley and Jenkins, 1992).

In the *intrapsychic realm*, emotions are thought to be associated with processing required to *coordinate activities aimed at satisfying multiple-goals* in an uncertain and unpredictable environment (Oatley and Johnson-Laird, 1987). Emotions are involved in the *monitoring and regulation of goal-directed behavior* and are closely linked with motivation and preparation for behavior. Emotions are also involved in *resource allocation*, particularly during high-demand tasks (e.g., stress-producing situations) (Humphreys and Revelle, 1984). Emotions provide *behavior heuristics* by linking distinct emotional states to distinct desired behaviors and thereby function to improve the organism's chances for survival (Plutchik, 1991).

Neuroscience and psychological research demonstrates that emotional processing is an integral part of adaptive behavior across species. Emotions represent a phylogenetically older (LeDoux, 1987), more primitive yet powerful information processing mechanisms, designed to both mediate behaviors which are particularly adaptive for the organism and to make behaviors more adaptive, by facilitating both simple reflexive responses and complex cognitive processing. Recent research in neuroscience and psychology indicates that emotional information processing is intimately linked with all functions we currently understand to be involved in cognition, namely attention, perception, learning, reasoning, and memory storage and retrieval.

Neuroscience and experimental psychology studies of emotional processing have identified the following functions and characteristics of emotions:

- Capability to quickly identify stimuli in the environment which are dangerous or beneficial to the organism's survival. Emotions are often associated with hardwired and highly specific responses (e.g., rats responding to squeaks of certain frequencies emitted by pups in danger).
- Capability to induce processing states which bias the organism towards specific types of behaviors over long periods of time.
- Reliance on pre-wired circuitry to accomplish fast and long lasting learning, when necessary.
- Capability to quickly allocate appropriate resources in critical situations and thereby focus attention and delay less critical processing.

In the *interpersonal realm*, behavioral manifestations of emotions serve to *communicate behavioral tendencies* (e.g., imminent attack or withdrawal) among individuals across a number of species and help *coordinate group behaviors* and social interaction. Key to this is the ability to express emotion on the one hand, and recognize others' emotional states on the other. This is accomplished through a variety of mechanisms, including posture and gestures, as well as facial expressions. The latter have been extensively studied and are discussed in more detail in section 2.4.3 below.

Basic Emotions The question of the existence of basic emotions addresses the issue of how many distinct "primitive" emotions exist (e.g., fear, anger), which serve as basis for the more complex emotions (e.g., shame and guilt) (Ekman and Davidson, 1994). Much of emotion research has focused on identifying this set of basic emotions. While the exact number of the emotions considered basic varies, the general agreement is that there are between six and ten such basic, or primary, emotions. The most commonly agreed-upon set includes: fear, anger, joy, sadness, disgust and surprise. The existence of basic emotions is relevant both for identifying distinct emotional states, in other words, identifying methods and distinct physiological correlates for these emotions, and for identifying the distinct behaviors and information processing and performance characteristics of these emotional states (see also discussion section 2.2 below).

Fundamental Dimensions Characterizing Emotions In contrast to the basic emotion research described above, other efforts, including neurophysiological studies, aim to identify more fundamental emotional systems and dimensions, which could serve to reduce the complexity of the emotion space. These 'unified theories of emotion' typically map the variety of observed or described emotional states onto a two dimensional space. Different conceptualizations of this two dimensional space exist. Russel (1978) uses affective valence and intensity. Thayer (1989) uses energetic arousal and tense arousal. Watson and Tellegen (1985) use the terms positive affect and negative affect. In each case, this 2-dimnesional conceptualization of emotions allows locating particular emotional and mood states (e.g., sadness, anxiety, joy, calm, etc.) within a simplified space. One of the advantages of these two dimensional models is the correspondence between the distinct dimensions and specific neurophysiological systems mediating the associated. Empirical evidence suggests that two separate neurophysiological systems exist mediating positive and negative affect, and there is evidence for two independent systems mediating approach and avoidance behaviors (behavioral inhibition system or BIS and behavioral approach system or BAS).

Implications for ABAIS Aside from the motivation to understand emotional processing for its own sake, as an integral component of human information processing, studying emotion and its impact on information processing and behavior has wider implications. Specifically, in cognitive engineering and human-centered system design, understanding the impact of emotions on cognition and behavior can help design better decision-support and training systems, by adapting the system functionality and user interface to a variety of emotional states, and by helping to counteract emotion-induced cognitive biases. In team research and applications, understanding the emotion-mediated coordination behaviors, and the effect of emotion on team performance can significantly enhance team effectiveness. In intelligent agent research, understanding the role of emotions in motivation and communication can help produce more believable agents, more efficient means of coordination among multiple agents, and improved adaptive systems in general.

Examples of specific implications of this research for ABAIS include:

- Basic emotions imply different behaviors, therefore different effects on performance, therefore different adaptations required to compensate for potential biases.
- Basic emotions suggests how many and which emotions ABAIS should address.
- Resource allocation research in emotion helps identify specific performance influences and effects of emotional states, and suggests compensatory strategies.
- Two-dimensional conceptualizations of emotion, and corresponding physiological mechanisms, provide basis for physiological assessment of the basic affective components of behavior (arousal and valence).
- Interpersonal, communication goals of emotions are particularly critical in team environments, and provide an additional important application of the ABAIS methodology in team settings.

2.2 Effect of Emotion on Cognition and Performance

Cognitive and clinical psychologists have observed the differential impact of various emotional states on cognition; for example, increased attention to threatening stimuli in states of anxiety, increased elaboration of material in positive affective states, and the general phenomenon of mood-congruent recall (Williams et al., 1997; Mineka and Sutton, 1992; Bower, 1981; Blaney, 1986; Isen, 1993). A number of affective states and personality traits have been studied extensively: anxiety, and depression[2], obsessiveness, extraversion, and impulsivity. These factors influence a number of perceptual and cognitive processes, including attention, perceptual categorization, memory, and general inferencing and judgment. The findings of these studies are briefly summarized below and in table 2.2-1.

Anxiety The primary impact of anxiety is on attention. Specifically, anxiety narrows the focus of attention, predisposes towards the detection of threatening stimuli, and predisposes towards the interpretation of ambiguous stimuli as dangerous (Williams et al., 1997; Mineka and Sutton, 1992).

Depression The primary impact of depression is on memory. Perhaps the best documented phenomenon is mood-congruent recall in memory (Bower, 1981; Blaney 1986); that is, the observation that a particular affective mood induces recall of similarly valenced memories (e.g., depressed mood enhances recall of negative experiences in the past, including negative self-appraisals). Depression has also been studied in the context of particular inferencing tasks, such as judgment and decision-making. In these tasks depression appears to lower estimates of the degree of control (Isen, 1993).

Obsessiveness A number of studies have documented the impact of high-obsessiveness, characterized by "checking" behavior, on cognitive processing. Among the primary effects identified are the following: lack of confidence in own attention apparatus to capture salient features in the environment (Broadbent et al., 1986); narrow conceptual categories (Reed, 1969; Persons and Foa, 1984); poor memory for previous actions and a general lack of certainty about own ability to distinguish between events that occurred vs. those that were planned or imagined (Sher et al., 1989), and slower decision-making speed related to obsessive gathering of confirming information (Sher et al., 1989).

Emotional stability Emotional stability is linked to a predisposition to experience positive or negative affect. Low emotional stability correlates with higher rates of anxiety and depression. Studies indicate that high anxiety leads to deficits following failure while low

[2]The impact of positive states has also been studied but less extensively. For example, Isen (1993) has found that positive affective states induce greater degree of elaboration of material in memory.

anxiety leads to increased effort following failure (Revelle, 1990).

Extraversion Extraversion correlates with positive affect, interacts with stress to affect performance, and is associated with deficits in sustained performance (Revelle, 1997).

Impulsivity Impulsivity appears to have an inverse correlation with arousal; less impulsive individuals have a higher state of arousal. This facilitates sustained performance over time, but apparently hinders performance on tasks requiring retention of high amounts of information over brief time periods. Low impulsives show lower sensitivity to rewards and are slower in initiating new tasks but show increased persistence once the task is begun (Revelle, 1987). Results of empirical studies reveal complex patterns of interactions indicating effects of impulsivity on performance that varies with stress level, task demands, and time of day. Specifically, impulsivity seems to affect both short and long term memory, persistence in behavior following failure, and ability to maintain sustained information transfer (Revelle, 1997).

The research summarized above provides evidence for the ubiquitous impact of emotion on cognitive processing, and the central role of emotion in the control of behavior. The emerging findings also begin to blur the distinction between what has traditionally been thought of as the separate realms of cognition and emotion.

Table 2.2-1: Impact of Emotion and Personality Traits on Cognition: Summary of Empirical Findings

Anxiety and Attention
Narrowing of attentional focus
Predisposing towards detection of threatening stimuli
Mood and Memory
Mood-congruent memory phenomenon - particular affective state induces recall of similarly valenced material
Obsessiveness and Performance
Delayed decision-making
Reduced ability to recall recent activities
Reduced confidence in ability to distinguish among actual and imagined actions and events
Narrow conceptual categories
Affect and Judgment & Perception
Depression lowers estimates of degree of control
Anxiety predisposes towards interpretation of ambiguous stimuli as threatening
Emotional Stability
Low emotional stability correlates with higher incidence of depression and anxiety
Low emotional stability correlates with decreased effort following failure
Extraversion
Correlates negatively with ability to sustain performance
Correlates positively with positive affect
Impulsivity
Correlates negatively with arousal
Low-impulsives show lower sensitivity to rewards
Low-impulsives show decreased ability to initiate tasks but increased ability to sustain performance over time

Implications for ABAIS Existing evidence summarized above provides an empirical basis for predicting the generic effects of emotional states and personality traits on performance. These generic effects can be used in the absence of specific information, and also serve as guiding principles for the affective / cognitive task analysis required to generate specific performance effects, in the context of particular situations.

2.3 Individual Differences and Personality Research

Two additional areas of psychological research relevant to assessment of, and adaptation to, affective states are the individual differences literature and the personality theory literature. Each of these areas is discussed below.

2.3.1 Individual Differences Research

Recent years have witnessed a renewed interest in individual differences research (Revelle, 1995), and its application to military environments (Pew and Mavor, 1998; Deckert et al., 1994; Illgen, Zacharias, Hudlicka et al., 1997; Fallesen, 1993). For example, in military tactical environments, empirical studies have identified a number of differences among individuals in terms of level of expertise, cognitive abilities (specifically, ability to perform mental 'what-if' simulations), ability to visualize situations from multiple perspectives, ability to abstract relevant information, and preferred style of information presentation (e.g., textual vs. visual, abstract vs. concrete, etc.) (Hammond, Hamm, Grassia & Pearson, 1987; Deckert, Entin, Entin, MacMillan & Serfaty, 1994; Badre, 1978). Studies of tactical planning and command decision-making identify features that characterize expert performance and thus distinguish between expert and novice tactical planners (Lussier et al., 1992; Tolcott et al., 1989; Fallesen, 1993). These include factors relating to situation awareness (awareness of uncertain assumptions, better use of available information, active seeking of confirming and disconfirming evidence, greater awareness of enemy activities, and awareness of more critical factors), and decision-making (more flexible planning, more elaborate war-gaming, explicit prediction of events, explicit consideration of adverse alternatives and plan failures). A number of additional domain-independent individual differences in cognitive styles can be found in Hudlicka (1997) and Illgen et al. (1997).

Recent research in the area of individual differences focused on the investigation of the biological basis of fundamental dimensions of personality (Revelle, 1995; 1997). This research focused specifically on how individual differences moderate the effects of situational manipulations on subsequent cognitive performance. An integrated model was developed of how individual differences in approach and avoidance motivation interact with situational manipulations such as time of day, time on task, stimulant drugs, and incentives, to affect working memory, subsequent retrieval from long term memory, and sustained performance

(Humphreys and Revelle, 1984). Recent efforts focused on demonstration of how stable individual differences in diurnal rhythms can be measured by both basal body temperature and by self report measures of energetic and tense arousal, and how these latter measures, in turn, predict individual patterns of changes over the day of reaction time (Revelle et al., 1997). The multilevel analysis techniques developed can be applied to fit performance on a variety of tasks across the day including measures of basic cognitive performance such as working memory and reaction time as well as affective judgments. Individual parameters of arousal amplitude, phase, and coherence have been shown to be stable across several weeks and to show predictable relationships with other aspects of individual differences.

Implications for ABAIS The evidence for broad variations in behavior based on individual differences underscores the importance of using detailed individual histories and baseline performance data for both impact prediction and strategy selection. The specific results help identify which data should be collected.

2.3.2 Personality Theory Research

Personality research has had a long and controversial history in academic psychology. The desire to predict human behavior and to classify the complexities of human nature into a small number of categories has existed in folk psychology since antiquity. The first known classification of personalities is attributed to Hippocrates around 400 BC, who classified individuals into four temperaments: choleric, phlegmatic, sanguine, and melancholic. During this century, personality theories and personality research reflect the evolution of ideas in psychological theory and research in general, specifically the controversy between behaviorism and environmentally-determined behavior on the one hand, and the more individually-focused theories of behavior on the other. Three major schools of psychological thought have influenced personality research in the 20th century and gave rise to the major theories of personality structure and development: 1) Freud's psychoanalytic school and the tri-partite theory of the psyche (id, ego, and superego); 2) behaviorist theories and their emphasis on learning and environmentally-reinforced behavior; and 3) humanistic psychology and its emphasis on the unique enduring characteristics of the individual and the interaction between individual and environment (McCrae & Costa, 1990).

Of these theories, the latter two are the more relevant for the current effort, since they provide both theoretical detail and empirical justification for application to the analysis human decision-making behavior, especially in military contexts. While personality research has been an active area for a number of years, with a number of journals devoted specifically to this topic, it should be kept in mind that many of the most fundamental questions asked about personality remain open research issues and subjects of much debate. These include the following basic questions:

- To what extent is behavior predictable across situations?
- To what extent can personality change over lifetime?
- What are the basic personality traits?
- How do personality traits cluster together into types?
- What are the best indicators of the different personality types?
- How do personality traits interact with situational variables?
- How do personality traits affect cognition and decision-making?

The personality research field has, until recently, been polarized into two camps: the *trait theorists*, emphasizing the importance of stable, persistent personality traits across situations, and the *situationists or social learning theorists*, emphasizing the importance of situational variables in determining individual behavior. Like many other false dichotomies, the trait-vs.-situation controversy fueled psychological debate over several decades in the 60's, 70's and early 80's. More recently, a compromise position seems to have been reached, termed the interactionist view (Revelle, 1995; Krahe, 1990). We will summarize current personality research below by presenting the extreme positions for expository purposes. The reader should keep in mind that few contemporary researchers adhere to either extreme point of view.

2.3.2.1 Trait Theories

The pure trait theory point of view posits the existence of fixed personality predispositions for behavior, the personality traits, which are stable across time and across situations. The number, and to some extent the nature, of the basic traits vary, generally between three and seven but in some cases going up to sixteen distinct traits. Table 2.3.2.1-1 includes examples of traits identified by various psychologists.

Table 2.3.2.1-1: Personality Traits

Hippocrates (400 BC)	**Jung (20's-40's)**	**Eysenck (60's-80's)**	**Costa and McCrae (80's-90's)**
Choleric Melancholic Phlegmatic Sanguine	Extroverted vs. Introverted Sensing vs. Intuiting Thinking vs. Feeling Judging vs. Perceiving	Neuroticism Extroversion vs. Introversion Psychoticism	Neuroticism vs. Emotional Stability Extroversion vs. Introversion Openness Conscientiousness Agreeableness

The traits are generally identified by a factor analysis of self-report data collected from subjects who fill out a variety of personality inventory instruments. Subjects are asked to answer a number of questions about how they have or might react in certain situations, how they feel and what they think about different aspects of themselves, others, and their lives. Other data are also used as sources, including observations of behavior in naturalistic life situations and observations of behavior in situations designed for experimental purposes.

To the extent that the personality traits can be identified, behavior of an individual can be predicted in a given situation. Not only has the number and type of the traits varied over the years, but different researchers have constructed various categorizations, depending on the focus of their research and their findings. For example, Allport and Cattell distinguish traits by frequency of occurrence and identify common and unique traits. Cattell also distinguishes between source traits, which are more fundamentally causal, and surface traits, which are the manifested effects of the source traits (Mischel, 1976). Examples of source traits are dominance vs. submissiveness, and ego strength vs. emotionality and neuroticism. Examples of surface traits are integrity and altruism vs. dishonesty and undependability, and thoughtfulness vs. foolishness. Cattell also categorizes traits by their contribution to behavior. Thus he identifies dynamic traits as those relevant in initiating action and behavior, ability traits describe specific skills used in satisfying the individual's goals, and temperament traits are traits related to emotional reactivity. Cattell also categorized traits as to their source as environmental-mold vs. constitutional, and their stability across situations (general vs. specific). In this latter categorization he foresaw the eventual merging of the trait theory and situational-social learning theory points of view.

Recent trait theory research, exemplified by the work of Costa and McCrae (1989), shows evidence for five traits that remain stable in individuals across the lifetime. This five factor personality model, known as the "Big 5", and its associated instrument, the NEO-PI, has become the most widely accepted trait theory model with significant supporting empirical evidence. The NEO-PI also seems to adequately account for traits identified by other models and inventories (McCrae& Costa, 1989; McCrae & Costa, 1990).

A more biologically-oriented model has been suggested by Eysenck (1967; 1991) and posits three dimensions: extraversion, neuroticism, psychoticism, with psychoticism being related to aggressiveness. This model is often referred to as the "Giant 3".

While academic psychologists have struggled with fundamental questions such as the number and nature of the basic personality traits, and to what extent personality can change over lifetime, on the more applied side management consultants, career counselors, and human resource professionals have focused on the application of one model and its associated instrument: the Jungian-psychology based Myers Briggs Type Indicator. This instrument has been applied primarily in work settings for team management, team composition, team training, and career counseling. The MBTI is based on the Jungian dimensions of personality and Jung's conception that opposing tendencies exist in the personality which are eventually integrated in the well-functioning individual. Jung identified several categories of dimensions, the four used most commonly are: 1) introversion vs. extraversion - describing individual's orientation towards others; 2) thinking vs. feeling - describing individual's orientation toward emotions; 3) sensing vs. intuition - describing individual's orientation towards stimuli and information processing; and 4) judging vs. perceiving - describing the individual's attitude toward structure. The MBTI has not been as widely investigated in academic circles, possibly due to its origins by a non-psychologist mother-daughter team. There is however an organization promoting its use, the Association for Psychological Types, which holds annual conferences and publishes a quarterly research journal: The Association for Psychological Types Research Journal. In spite of its marginal status in psychological research, several studies of the MBTI have been conducted (Druckman & Bjork, 1991) and a number of researchers have made comparisons of the MBTI to the Big 5 and other factor models, indicating close correspondences between the two (McCrae and Costa, 1990).

2.3.2.2 Situationist Models and Social Learning Theories

In part as a natural consequence of the behaviorist tradition based on learning theories, and in part as a reaction to the often contradictory data evident in the trait models, situationist and social learning theories suggest an alternative model. They propose that the individual's behavior is determined by situational variables and by the individual's experience in similar situations in the past (reinforcement), rather than by a stable predisposition to act in a certain way across situations. Thus the observations of consistent behavior across situations, observations which could lead to the inference of stable traits, can in fact be interpreted as the result of learned and previously reinforced behavior in similar situations (Mischel, 1976). Thus an aggressive behavior need not be interpreted as a result of a hostile personality but rather as the result of previously reinforced aggressive behavior. The initial radical behaviorist position that situational variables and reinforcement history were solely responsible for behavior, was later modified to include individual variables. Individual variables include specific abilities and competencies (IQ, skills, etc.), encoding strategies (selecting attention, interpretation and categorization), internal mental representations, expectations about outcomes resulting from previous learning, subjective values, and current goals and plans. Perhaps the major contribution of social learning theories is that the best predictor of future behavior is past behavior.

Much as the trait theorists' acknowledgment that situational variables play a role in behavior, in addition to the individual's predispositions to behave, think and feel in a particular way, the social learning theorists' acknowledgment that individual variables play a role in behavior is a step towards the eventual reconciliation of the two extreme views. This view, the interactionist view (Krahe, 1990), represents a modern synthesis of the earlier extreme views and promises to enrich personality research by its broader focus that includes both the individual and the situation, and the interaction between the behavior triggering stimuli and the individual personality traits.

2.3.2.3 Fighter Pilot Personality Assessment

As is the case in many fields, personality assessment in the Air Force "has a long and controversial history" (Callister et al., 1997, p. 1). Personality measures show mixed ability to predict performance. On the one hand, they seem to fail to predict completion of initial training, on the other hand, they do appear to predict ratings of pilots in commercial settings and retention of USAF pilots (Callister et al., 1997). The identification of an 'ideal pilot' personality is similarly controversial. For example, early World War I studies suggest that both a "high-spirited and happy-go-lucky" and "quiet and methodical" represent ideal pilot profiles (Callister et al., 1997, p. 1). It is interesting to note that as the military environment changes from individual-based to increasingly team-based, the "ideal" personality types for a variety of tasks may change as well, from the more independent, individually-oriented type to a more socially-oriented type of personality.

A number of recent studies exist assessing the pilot population in terms of a variety of standard psychological assessment instruments (e.g., NEO-PI-R, MMPI, etc.) (Callister et al., 1997), as well as instruments specialized for the fighter pilot population (e.g., ALAPS (Retzlaff et al., 1997)). In one study, Callister and colleagues (1997) tested 1301 USAF student pilots (92% male) using the NEO-PI-R inventory based on the Big 5 personality factors (neuroticism, extraversion, openness, agreeableness, and conscientiousness). The scores were compared with those of general population. The results indicate that both males and females differ on the extraversion (higher than general population) and agreeableness dimension (lower than general population), as well as in assertiveness, and excitement-seeking (higher than general population). In addition, the female USAF component of this sample shows a higher score on openness than the general population.

While studies using standard psychological instruments are useful, they often fail to focus on the specific traits relevant to specific USAF tasks, or do not meet the desirable psychometric norms. To help address these shortcomings, a specialized instrument has been developed at Armstrong Laboratory to assess the aviation population. This instrument, the Armstrong Laboratory Aviation Personality Survey (ALAPS), consists of 240 true or false items divided into 15 subscales. ALAPS is described in greater detail in section 2.4 below.

Implications for ABAIS Personality research provides a number of relevant contributions for ABAIS. *First,* it confirms to a large extent the folk psychology notion that the best predictor of future behavior is past behavior. This underscores the importance of gathering as much information as possible about the ABAIS user's past performance and using this information as part of the individual history category of factors to assess affect and belief states, and to predict likely and performance biases. *Second,* it helps identify a set of personality traits to use as part of the ABAIS user profile description. The traits, while not strictly orthogonal, do provide a good coverage for a broad range of personalities and help predict generic classes of behaviors. The traits selected for the Phase I ABAIS user profile were derived from a combination of the Big 5 and the "Giant 3", and filtered by their potential relevance to the USAF tasks in general, and the Phase I demonstration task in particular. The selected traits are: emotional stability, impulsiveness, risk tolerance, aggressiveness, and obsessiveness. *Third,* the findings from interactionist theories suggest the importance of including in the individual history specific trait-situation interactions (e.g., anxiety only occurs during defensive maneuvers but not during offensive maneuvers for a particular pilot) and use this type to predict pilot behavior in similar situations. *Fourth,* these findings help identify specific expressions of a particular trait (e.g., anxiety causes physical symptoms but has no impact on cognitive abilities) and use this information to predict the impact of particular affective states on the pilot's decision-making. *Fifth,* personality theory offers a series of standardized clinical instruments to identify specific affective states and temperamental traits, as discussed in section 2.4.3 below.

2.4 Assessment of Affective States

2.4.1 Self reports and Psychological Instruments

While a seemingly countless number of personality inventories exist, they can be divided into two broad categories: those targeted at measuring personality structure in terms of the small number of factors identified by the various trait theories, and those focusing on psychopathology in general or on a particular set of symptoms. We discuss both categories below.

Personality Assessment Personality inventories exist for each of the factor models mentioned discussed in section 2.3.2. However, the two inventories used most frequently are the NEO-PI (Costa and McCrae, 1989), based on Costa and McCrae's Big 5 model, and the MBTI (Briggs and Myers, 1977), based on Jung's model of personality. The NEO-PI-R is more broadly accepted in the academic community and has been subjected to extensive validation studies. NEO-PI-R consists of 240 items evaluated on a 5-point Likert scale ("strongly agree", "agree", "neutral", etc.). The test provides scores for each of the Big 5 factors – neuroticism, extraversion, openness, agreeablenes, and conscientiousness. Each of these major scores consists of six subscales (see table 2.4.1-1).

Table 2.4.1-1: NEO-PI-R Personality Assessment Scales and Subscales

Neuroticism	Extraversion	Openness	Agreeableness	Conscientiousness
Anxiety	Warmth	Fantasy	Trust	Competence
Angry Hostility	Gregariousness	Aesthetics	Straighforwardness	Order
Depression	Assertiveness	Feelings	Altruism	Dutifulness
Self-Consciousness	Activity	Actions	Compliance	Achievement Striving
Impulsiveness	Excitement-Seeking	Ideas	Modesty	Self-Discipline
Vulnerability	PositiveEmotioanility	Values	Tenderness	Deliberation

The MBTI is generally used in more applied settings for management purposes, career counseling, and team training, as well as in popular psychology (e.g., matchmaking). The MBTI consists of 126 items and the result consists of eight scores, corresponding to each of the eight poles of the Jungian personality model: Introverted-Extraverted; Sensing-Intuitive; Thinking-Feeling; and Judging-Perceiving.

Of particular interest is the aviation-oriented instrument developed by USAF psychologists, the Armstrong Laboratory Aviation Personality Survey (ALAPS). ALAPS consists of 240 true or false items divided into 15 subscales. The subscales cover personality, psychopathology, and crew interaction (Retzlaff et al., 1997). Summary of the instrument is shown in table 2.4.1-2. This instrument has been successfully validated and is currently being used in on-going personality assessment research.

Table 2.4.1-2: Aviation-Oriented ALAPS Personality Assessment Instrument

Confidence / Narcissism	Affective Lability	Deference / Submissiveness
Socialness	Anxiety	Team Orientation
Aggressiveness	Depression	Organization
Orderliness / Compulsivity	Alcohol Abuse	Impulsivity
Negativity	Dogmatism / Authoritarianism	Risk Taking

Psychopathology Assessment Probably the most widely used instrument in clinical setting is the Minnesota Multiphasic Personality Inventory (MMPI) (Hathaway and McKinley, 1989), which consists of 567 items and classifies individuals into ten scales: hysteria, depression, psychopathic deviate, masculinity-femininity, paranoia, psychasthenia, schizophrenia, social introversion. The MMPI also includes three control scales to detect consistent biases in the data: lie scale, defensiveness scale, careless/confused.

In addition to the broadly-oriented MMPI, there is a vast and ever increasing number of questionnaires focusing on specific affective states. These include anxiety (The State-Trait Anxiety Scale, The Manifest Anxiety Scale), panic attack and phobia sensitivity (Anxiety Sensitivity Index (Peterson & Reiss, 1987)), negative emotionality (Positive and Negative Affect Scales – PANAS (Watson, Clark, Tellegen, 1988)), depression (Beck Depression Inventory), stress coping strategies, locus of control, eating disorders and a number of others.

Implications for ABAIS Both personality theory and psychopathology offer a series of standardized and validated clinical instruments to identify specific affective states and temperamental traits from self-report data. While the pathologically-oriented instruments are less relevant for the USAF population, particularly the fighter pilots, the personality instruments in general do provide useful data about specific relevant traits and potential susceptibility to specific affective states. These instruments can be used in two ways as part of the self-assessment procedure in ABAIS. *First*, during an off-line, initial assessment, to provide background information and suggest generic effects on performance. *Second*, during brief on-line assessment, where one or two items would be presented to the user *during* task performance, to provide a specific, targeted assessment of their current affective state. This latter application of self-reports would need to be compatible with the task context and would not be appropriate in all situations.

2.4.2 Physiological Methods

The fundamental questions regarding physiological assessment of affective states is this: Do different emotions exhibit unique physiological manifestations? From a historical perspective, the answer to this question evolved over the past 100 years (Ekman and Davidson, 1994). According to William James (1890), the answer was a 'yes': "distinct emotions associated with unique patterns of skeletal muscle and physiological changes since our experience of the emotion is a direct function of feedback from the periphery" (Davidson, 1994, p. 237). In the predominantly cognitively-oriented 60's and 70's, Schachter and Singer's (1962) answer was 'no' and their two-factor theory of emotion suggested that the same state of undifferentiated arousal can lead to different emotions, depending on the activated cognitions. Contemporary researchers vary in their response to this question and the answer appears to be a qualified 'yes, sometimes' and 'yes, if you look in the right place (i.e., the brain not the peripheral nervous system) and using the correct tool (e.g, electrodes, fMRI, PET scans, etc.). "To the extent emotions are associated with different action tendencies, they should differ in their autonomic patterns" (Davidson, 1994, p. 241). This summary will be elaborated in more detail below.

The vast majority of efforts to identify unique physiological signatures for specific emotions have focused on the autonomic nervous system and facial muscles, although some work has also been done using data from the endocrine system, EEG, and, more recently brain scan data are being studied, such as fMRI and PET scans. The most frequently studied ANS signals include: heart rate, heart rate variability, respiration rate, EEG, skin conductance (GSR), pupillary dilation, and blood volume pressure (BVP). Facial EMG is used to detect muscle movement and eye blinks. While a number of these measures successfully assess arousal (heart rate, skin conductance, pupillary dilation) and valence (facial EMG - corrugator & zygomatic muscles), the results in further differentiation among the different affective states are mixed.

When considering the 2-dimensional model of emotion discussed above, that is, arousal and valence, a variety of signals appear to reliably reflect high and low states of arousal, and positive and negative valence. Specifically, heart rate, skin conductance measures, and pupillary dilation correlate with arousal; activity of the corrugator and zygomatic muscle groups correlates with valence. Although these dimensions can be successfully assessed in principle, many practical issues exist in applying the physiological affect assessment methods in practice. These include: intrusiveness of the measurement apparatus (e.g., skin conductance and facial EMG sensors), restrictions of the subject's movement (e.g., EEG sensors), task environment which may interfere with the measurement (e.g., perspiration interfering with collection of skin conductance data), difficulty gathering the required data in the task context (e.g., pupil dilation detection in a fighter pilot cockpit (Callan, 1998)), individual differences in physiological reactivity, and day-to-day and diurnal variations in physiological activity in general. This type of variability further underscores the importance of adequate baseline data for each individual, to accurately map the subject's affective signals onto a specific state.

The picture is not as clear when considering the more complex space of emotions, such as the basic emotions. While some researchers report results indicating the ability to differentiate between positive and negative emotions (Levenson et al., 1990), others have been unable to duplicate these efforts (Ekman and Davidson, 1994, p. 261-262). Levenson and colleagues (1990) report data that differentiate between the following emotions: disgust, fear, anger, sadness, happiness. The theoretical explanations of these data suggest that these findings are due to different metabolic requirements for the different types of behaviors associated with these emotions. Thus fear and anger require higher metabolic activity than disgust and sadness. Anger and fear produce larger heart rate acceleration than happiness, presumably because they must prepare the organism for flight-or-flight in the former case, but not in the latter. Positive emotions have been hypothesized by Levenson to function as "undoers" of the autonomic arousal and metabolic behavioral preparations caused by the more negative emotions; that is, positive emotions function to rapidly return organism to its pre-arousal state.

Several researchers suggest that past failures to identify unique physiological correlates may be a function of having "looked in the wrong places" (Gray, 1994). Future work will focus on the brain and use new technologies (neuroimaging, single-cell & cell cluster recordings, neuropeptide analysis), taking advantage of recent findings in neuroscience. For example, left anterior prefrontal cortex appears to be associated with positive-affect and approach behaviors, while the right prefrontal cortex is associated with negative-affect and withdrawal (Davidson, 1992); the amygdala neurons and neuronal clusters appear to differentiate between rewarding and non-rewarding situations (LeDoux, 1994); different neuropeptides associated with different emotions (Panksepp, 1994) such as anxiety, aggressiveness, social processes, playfulness, fearfulness. While these findings promise to provide much more detailed reflections of affective states, many technical problems must be overcome before recordings and signal analysis from these areas can be applied in real-time settings for the detection of, and adaptation to, a variety of affective states.

Implications for ABAIS While a number of experimental methods are theoretically available, results of the literature search reveal that most reliably assessed affective measures are arousal and valence. The best *practical* signal for arousal detection is heart rate (Hugdahl, 1995; Orr, 1998; Hofmann, 1998; Cacioppo et al., 1993). Other measures of arousal, such as galvanic skin response, pupil size, blood volume pressure, etc., either do not provide additional data and / or are not as readily assessed. While skin conductance measures represent a better direct measure of anxiety, the requirement of finger or palm sensors makes these impractical in computerized, automated environments. Heart rate variability is a highly useful measure, but is more concerned with tonic arousal rather than the temporary, phasic arousal due to transient anxiety states, which are of interest in the proposed task context (Cacioppo et al., 1993; Orr, 1998; Hofmann, 1998). The best means of assessing valence is facial EMG, using the corrugator and zygomatic muscle groups. This approach will be discussed in greater detail in section 2.4.3 below.

2.4.3 Facial Recognition

Successful use of facial recognition as an affect assessment method is predicated on two assumptions. *First*, that distinct emotions produce distinct configurations of the facial musculature. *Second*, that these configurations can be recognized, either through the use of electromyograms or using computer vision pattern recognition methods. Both of these issues are discussed below.

Distinct Facial Expressions as Emotion Markers The area of facial expression of emotion has been studied extensively, beginning with Tomkins' work and continuing with contemporary work of Ekman and colleagues and Izard (Cacioppo et al., 1993). In fact, much of the evidence for the existence of basic emotions comes from facial expression research. Strong empirical evidence exists supporting the existence of cross-cultural regularities in the expression of a number of emotions.

The primary muscle groups of interest in emotion expression are the corrugator ("eyebrow muscle") and the zygomatic ("smile muscle"). Negative emotions such as fear, sadness, and anger are reflected in higher corrugator muscle activity. Positive emotion (i.e., happiness) is reflected in higher zygomatic muscle activity. While these methods appear to be robust, there are issues about data interpretation. For example, some problems are associated with interpreting the zygomatic movement however, since some negative emotions also cause movement in that muscle group. It is not clear whether this is due to "distress smiling" or cross-talk between muscle groups (Cacioppo et al., 1993).

A number of coding schemes exist for classifying emotions based on facial expression, the Facial Action Coding System (FACS) developed by Ekman and colleagues being the most comprehensive (Ekman and Friesen, 1975).

Recognition of Facial Expressions Two methods used for facial expression recognition are facial EMG and computer vision pattern recognition. Facial EMG involves the attachment of either electrodes or some other sensor (e.g., piezoelectric tape) to key locations of the face, so that minute muscle movements can be identified as they cause changes in the facial skin configuration. A recent example of the use of piezoelectric tape is work by Riseberg and Picard (1999), where the corrugator muscle movement was used to differentiate between interest and surprise ("upward" movement of the muscle), and confusion and frowning ("downward" movement). While the work is still in progress, initial data show promise in the ability to discriminate between these emotion categories, using a relatively non-intrusive assessment method.

Computer vision pattern recognition uses a camera to identify distinct emotions from either still images or short video segments. Generally, video segments are preferred over still images for facial recognition, as more temporal information is provided which helps disambiguate the data (Picard, 1997). Several recent efforts have successfully discriminated among different affective states, with a high degree of accuracy. For example, Essa and Pentland (1997), and Yacoob and Davis (1996), report discriminations between the basic emotions with up to 98% accuracy. However, several factors limit the applicability of these results to a real-time affective adaptive interface. First, the number of subjects in both cases was small (8-12), bringing into question the robustness of the results; second, the emotions that were recognized were artificial, in the sense that the individuals were asked to display a particular emotion in one case, and faces of TV actors were used in the other case; third, the time required for recognition was too long for real-time assessment (up to 5 minutes per face).

Implications for ABAIS While pattern recognition approach is theoretically possible and promising work exists in the area, this approach is both computationally intensive, and not sufficiently robust at this stage for real-time affective assessment. More promising is the assessment of valence via facial EMG, specifically, via the movement of the corrugator and zygomatic muscle groups. These approaches are promising, especially given the emerging non-intrusive technologies such as piezoelectric tapes. While it is difficult to reliably differentiate among a large set of emotions, the physiological assessment valence appears via facial EMG.

2.5 Situation Awareness

Much recent research in decision making and skilled human performance, particularly in dynamic, real-time settings, has focused on the concept of situation assessment and situation awareness (Endsley, 1995). Briefly, situation awareness refers to the individual's ability to rapidly identify salient cues in the incoming data and map those cues onto a small set of relevant situations, which then guide further action selection. A series of extensive studies of situation assessment in the military and other real-time settings have been conducted by Klein and colleagues (1989). Klein has labeled this process *recognition-primed decision-making* (RPD), and identified RPD as a key element in tactical planning.

To the extent that affective state and personality traits influence attention, perception, and cognition, they play a major role in influencing all aspects of recognition-primed decision-making and situation assessment; from cue identification and extraction, to situation classification, and finally decision-selection. In the battlefield management and tactical planning domain, several studies of human performance have identified a number of types decision errors and biases in tactical situation assessment (Tolcott, Marvin & Lehner, 1989; Fallesen, 1993) which contribute to the inadequate development of tactical alternatives, or to the selection of an inappropriate final course-of-action (COA).

Empirical studies of tactical planning and decision-making indicate that certain categories of failures are common, resulting in inadequate COA development and selection (Fallesen, 1993). Fallesen divides these failures into categories according to the stage of the COA development process (e.g., situation assessment, formulation of alternative COAs, comparison of these alternatives, wargaming, etc.). For each category he then identifies the most critical factors that contribute to ineffective and non-optimal performance. Examples of these factors are failures to use systematic comparison strategies for alternative COAs, failures to verify uncertain information, failures to develop adequate action/reaction trees due to inadequate wargaming, failures to consider all factors, failures to verify assumptions, failures to assess information quality, failures to interpret available information, and failures to make predictions for situation assessment. Other research indicates that knowledge of enemy activities is particularly critical and often neglected by tactical planners.

Of particular importance is the *primacy bias*, that is, selecting an *a priori* option and then looking for confirmatory evidence and ignoring disconfirming evidence for that option. Another common bias is *success orientation*, that is, the overconfidence in friendly plans and underestimation of possible enemy activities that could jeopardize projected friendly activities (Fallesen & Michel, 1991; Lussier, Solick & Keene, 1992).

The general area of cognitive biases has been studied extensively in laboratory settings, and is particularly relevant to situation assessment. Cognitive biases result from use of cognitive heuristics, many of which may be unconscious (Tversky & Kahneman, 1974). The following types of cognitive biases have been identified:

- Availability - Items (e.g., events, entities, relations) most easily retrieved from memory are considered most important
- Order effects - Recency/Primacy bias - Initial or most recent information is considered most important
- Representativeness - Likelihood of events is judged by their similarity to typical events, rather than by statistical frequency
- Internal coherence - Information consistent with previous experience and beliefs is preferred
- Consistency - Preference for consistent information and exclusion of important evidence to the contrary
- Confirmation bias (cognitive hysteresis, set, functional fixation) - Search for information that confirms existing belief / hypothesis
- Overgeneralization - generalizing from few cases or from non-representative cases

Implications for ABAIS The belief assessment component of ABAIS corresponds to the situation assessment discussed above, in that the currently active beliefs and knowledge schemas influence all stages of the situation assessment process. The assessment of a user's belief state thus amounts to the identification of his/her set of knowledge schemas that guide situation assessment. The situation assessment literature helps identify both the distinct stages of situation assessment, and the role that specific knowledge plays in this process. The cognitive bias literature helps identify the set of specific performance errors that can result from cognitive biases. Both of these sources provide a systematic basis for identifying possible belief states, for analyzing individual history information and applying it to dynamic belief assessment, and for identifying the relationships between specific affective states and cognitive biases.

2.6 Enabling Technologies

This section summarizes the relevant technologies, including wearable computing, knowledge elicitation techniques, rule-based reasoning, COTS products for software development, and existing systems relevant to this effort.

2.6.1 Wearable Computers

Wearable computers represent one of the latest trends in portable computing. As the name implies, 'wearables' are distinguished from the more traditional desktops, laptops, and palmtops by the fact that they can actually be worn. This characteristic implies a number of features regarding weight and input/output devices. Wearable computers have the following characteristics (Rhodes, http://wearables.www.media.mit.edu/projects/wearables/):

- Light-weight and unobtrusive (possibly embedded in clothing or even jewelry (http://www.media.mit.edu/affect/AC_research/projects/affective_jewelry.html)
- Portable while operational, allowing computing while user is walking or going about other daily activities
- Non-traditional input-output devices (e.g., heads-up displays, chording keyboard input devices)
- Allowing hands-free use by facilitating speech input/output and heads-up display
- Attention-capturing mechanisms allow user notification when events of interest occur (e.g., e-mail)

Aside from their size and portability, the key distinguishing features of wearables are the non-traditional input-output (I/O) devices. For text input, the Twiddler chorded keyboard can be used, which allows rapid, one-handed text input. Additional input devices include video cameras, microphones for speech, and a variety of physiological sensors (see also discussion below). For output, the Private Eye LED display has been used which produces a monochrome 720x780 image. Wearable processors range from the older 486 through more current Pentium processors.

Another feature of wearables is the presence of wireless communication devices, for interconnecting the wearables on a single individual (personal area network), for data transfer between individuals, and for communicating with the Web and mail servers.

The applications of wearables range from personal assistants which facilitate information management and Web access, through job aids such as troubleshooting and maintenance (Columbia University KARMA system), to individual physiological monitoring systems for military applications (BBN's Pathfinder).

Because of their unobtrusiveness and "perpetual presence", wearable computers are ideal for the type of physiological signal collection necessary for reliable affective assessment. The ability to collect data throughout the day and across multiple activities facilitates collection of the variety of baseline physiological measures necessary for personalized affective assessment. Much progress has been made in the wearable technology over the past 5 years, both in commercial settings, and in university laboratories. Many off-the-shelf systems are available for sensing a variety of physiological signals. For example, the Polar heart rate monitor detects heart rate and downloads the data to a PC. Its cost is between $150 and $500. Thought Technologies ProComp and FlexComp systems provide 8 channels A/D converters and a variety of sensors (e.g., BVP, respiration, heart rate, EKG,EEG, EMG, temperature) which can be interfaced with a PC. The cost ranges from $1,500 to $2,500 for the system plus about $200 per sensor. Another off-the-shelf system is Biopak Systems' MP100WSW that provides an interface card and plug-ins for a variety of amplifiers and sensors. The basic system is $3,500, and sensors are between $100-200 each. Sensors include the standard heart rate, EMG, GSR, skin temperature, blood pressure, respiration, EEG, etc. A wireless transmitter is also available for up to 12 feet.

Laboratory systems include MIT Affective Computing Laboratory's galvanic skin response sensors embedded in shoes, rings, and bracelets. GSR provides a good measure of arousal and anxiety, but traditional GSR measures are often impractical, since they require sensors that attach to a finger and thus interfere with other activities. The wearable GSR sensors developed at MIT thus promise to take advantage of the diagnosticity of this signal, while eliminating many of the practical issues that prevented its application with more traditional sensors. Other systems developed at MIT include MicroOptical eyeglasses or Private Eye, Hand-held chording keyboard (Twiddler), and ProComp sensing system with custom sensors (jewelry, shoes, PAN (personal area network).

2.6.2 Knowledge Elicitation Techniques

KE techniques have been developed by psychologists and artificial intelligence researchers to access human knowledge structures, whether in the context of memory and expertise research (Olson & Biolsi, 1990), or in the more applied setting of knowledge-based system construction (Gaines & Boose, 1988) and mental model research (Klein, 1989; Rouse & Miller, 1986). Multiple KE methods exist and a number of variations of these methods have been described in the literature. A variety of KE techniques exist and have been extensively described in the KE literature (Cooke, 1995). In spite of the recent proliferation of specific KE techniques, the basic methods can be grouped into three broad categories: direct, indirect, and observational.

Direct techniques are based on the assumption that the subject matter experts (SME's) are able to articulate their problem solving knowledge in response to direct questions.

- *Simple interview*, where subjects are asked a series of questions about the task. Interviews can vary in the degree of structure from completely open "Tell me about the mission planning process" to very specific "Why did you decide to use an active missile?"

- *Protocol analysis* (Ericsson & Simon, 1984), where subjects are asked to think-aloud while performing a task and these data are later analyzed to identify knowledge structure and inferencing processes.
- *Interruption analysis,* where subjects are interrupted during a critical moment, usually immediately prior to or after an important decision has been made, and is asked why they made a particular decision.
- *Critical decision method* (Klein et al., 1989), a form of retrospective analysis where subjects are presented with an unusual or particularly complex incident or situation and asked a series of questions designed to elicit factors influencing their situation assessment and decision-making processes.
- *Inferential flow analysis*, where subjects are asked a series of "why" and "how" questions to elicit the domain causal models underlying of their reasoning.

While the direct techniques represent methodologies for knowledge elicitation and knowledge acquisition, they have several drawbacks as techniques for obtaining the expert's underlying mental models and details of the reasoning processes. *First,* only data accessible to conscious awareness can be reported. There is an on-going debate as to whether the data reported in fact represent the *actual* underlying thought processes or whether they are reconstructed by the expert and have little to do with the actual mental models and processes.[1] Psychological literature contains many experiments reporting exactly such reconstructions (Nisbett & Wilson, 1977) . There is evidence that truly expert knowledge is difficult to articulate and that what is being reported by the expert is *intermediate expertise* level of reasoning (Schmidt, Boshuizen & Hobus, 1988; Berry, 1987). *Second*, even if we accept introspection as a reliable means of accessing internal processing, direct verbal techniques have applicability only in situations where expert problem-solving is verbally mediated or at least when it can be expressed in terms of language. This is not typically the case for tasks which rely on perceptual and motor processing, which are often performed on an almost reflexive basis, and are difficult, if not impossible, to articulate. To the extent that such processing forms the basis of higher-level reasoning, such as that used in complex tactical pattern recognition in battlefield management, a different set of techniques must be used to augment the purely verbal ones. *Third*, even when their knowledge can be articulated in principle, in practice experts may not be able to articulate all of the reasoning underlying their decision making when asked a direct question. *Finally,* experts may

[1] Note that when we question whether data are accessible via introspection we are speaking here about the detailed mental models and reasoning, not about the basic, general knowledge of the task and the domain, which can clearly be articulated and obtained via interviews.

not be willing to express their knowledge, due to fear of "giving away" private knowledge or, sometimes, embarrassment because of the idiosyncratic nature of this knowledge.

To address these problems, **indirect techniques** have been developed. These techniques do not rely on the assumption that all expert knowledge can be readily articulated in response to direct questions and specific probes. The indirect methods attempt to by-pass this limitation by accessing elements of the internal structures through a series of simpler questions, for example, obtaining lists of similarities and differences among salient domain entities. The more complex domain structures and basis for inferencing are then reconstructed from these knowledge elements. These techniques thus do not rely on simple introspection, nor are they limited to data that are easily verbalized. This latter attribute is particularly important in domains where visualization-based problem solving is critical, such as battlefield situation assessment.

Indirect methods include a variety of *proximity scaling techniques*, which first elicit similarity ratings among domain entities (e.g., "On a scale of 1 to 10, how similar are COA 1 and COA 2?") and from these data construct a specific representational structure using some type of multivariate statistical analysis method. The structures include *graphs* (Pathfinder algorithm (Cooke et al., 1987)), *hierarchies* (hierarchical clustering (Johnson, 1967)), or a *plots* in a continuous multi-dimensional space (multi-dimensionsal scaling (Shiffman et al., 1981)). The nodes in these representations represent the domain entities and the connecting links or spatial distribution represents some relation among these entities. The structures can then be analyzed further to identify desired domain characteristics. While powerful psychological research instruments, proximity scaling methods are not always practical for KE, due to the time, effort, and complex software required.

A powerful alternative technique is *repertory grid analysis* (RGA), a method adapted from a psychological theory of personality and cognition (Kelly, 1955) and widely used in clinical settings. RGA is based on eliciting similarities and differences among salient domain entities (e.g., "List all similarities and differences between COA 1 and COA 2."). RGA consists of three steps. First, domain entities are identified (these form the column labels of the repertory grid matrix). Second, the entities are compared two or three at a time to obtain similarities and differences (these form the row labels of the repertory grid matrix). Third, each entity is rated along each attribute on some scale (e.g., "On a scale of 1 to 10, how 'risky' is COA 1?"). The filled-in grid can then be analyzed via a number of methods, including all of the methods used for proximity scaling techniques.

2.6.3 Rule-Based Reasoning

Rule-based reasoning (RBR) is an established method of knowledge-based inferencing. An RBR system consists of a knowledge-base, represented in terms of if-then production rules; data or facts describing the current situation, represented in terms of variables matched against the rule antecedents; and an inference engine, which performs the fact / rule-base matching, selects the highest matching rules, and instantiates these rules and applies their consequents. Rule-based systems can vary along several dimensions including the type of inferencing (forward chaining vs. backward chaining), the type of matching strategies (fuzzy vs. exact matches), and the type of control implemented through the rule-selection process (breadth, depth, or heuristic).

2.6.4 COTS Products

The ABAIS workstation demonstration prototype was developed using COTS packages as much as possible to minimize the implementation effort. A brief description of the tools used for the Phase I effort, as well as relevant tools for Phase II, are included below.

JAVA JAVA was selected as the core development language. JAVA is a general purpose, object-oriented, high-level programming language, similar to C++, but having several advantages over C++. First, JAVA uses a syntax simpler than C++, while still maintaining the pure object-oriented paradigm. JAVA provides a large number of GUI primitives and there is large number of JAVA-based GUI builder tools. In addition, the increasing size of the JAVA user group provides a good source of freeware GUI elements. JAVA supports good cross-platform compatibility. JAVA also supports links to VRML for future embedding within virtual reality environments.

Borland Jbuilder 2.0 Borland's JBuilder 2.0 was selected as the development environment to support rapid design and development of GUI's. JBuilder was selected because it provides one of the best available GUI design environments and offers a full suite of JAVA objects.

JESS JESS is a rule-based system shell that implements the NASA-developed CLIPS public domain rule-base system within JAVA. JESS will be used to develop the rule-based reasoning components of the individual ABAIS modules.

Hugin is a COTS product supporting the development of Bayesian belief nets. Hugin has a full GUI, supporting the graphical construction and execution monitoring of belief nets.

2.6.5 Existing Relevant Systems

VIEW is a knowledge elicitation workstation developed at Charles River Analytics (Hudlicka et al., 1999) which provides an integrated toolkit for interactive, visualization-based knowledge elicitation. VIEW supports both direct KE methods (e.g., protocol analysis, critical decision method, inferential analysis, etc.) and indirect methods (e.g., repertory grid analysis). VIEW facilitates the construction of KE scripts designed to administer any combination of specific KE techniques. VIEW is well-suited for supporting off-line knowledge elicitation effort required to identify the factors necessary for both affect and belief assessment.

3. System Description

This chapter provides a description of the ABAIS prototype. Section 3.1 describes the system architecture and provides a general overview of system functionality. Sections 3.2 through 3.5 then describe the four key modules of the ABAIS prototype: user state assessment (section 3.2), impact prediction (section 3.3), strategy selection (section 3.4), and graphical user interface / decision support system (GUI/DSS) adaptation (section 3.5). Section 3.6 describes the ABAIS GUI and section 3.7 describes the simulation component.

3.1 System Architecture and Functional Overview

The ABAIS architecture implements the adaptive methodology summarized in table 3.1-1 and consists of four modules: 1) *user state assessment,* which identifies the user's affective state and task-relevant beliefs; 2) *impact prediction,* which identifies the effect user state on performance; 3) *strategy selection,* which selects a compensatory strategy; and 4) *GUI* /DSS *adaptation,* which modifies the user interface content and format to enhance detection, recognition, and assimilation of incoming data; that is, to enhance situation awareness. The ABAIS framework architecture implementing this methodology is shown in figure 3.1-1. Since no single reliable method currently exists for affect assessment, the ABAIS workstation design provides facilities for the flexible combination of multiple methods of user state assessment (e.g., diagnostic tasks, self reports, multiple physiological measures, individual training and history, etc.).

The original plan called for integration of ABAIS with the Charles River Analytics SD_PVI system (Mulgund et al., 1997). However, it was determined that due to platform and software incompatibilities, as well as the focus of the current effort, the ABAIS demonstration was better served through a custom-coded GUI and simulation environment. The SD_PVI system from Charles River Analytics thus served primarily as a model for the flight dynamics required for the flight simulation.

ABAIS Run-Time Execution Modes The core ABAIS framework is integrated within a dynamic flight simulation environment and supports two modes of system operation: 1) *pilot-as-user* mode, where the user actually flies the aircraft and interacts with a simulated environment consisting of other friendly aircraft, enemy aircraft, radars, and weapons; and 2) *analyst-as-user,* where the analyst watches a simulation of a scripted task and monitors the (scripted) pilot's performance, and the system run-time performance (i.e., results of the rule-based inferencing).

Table 3.1-1: Methodology for Proposed Adaptive Framework

METHODOLOGY STAGE	EXAMPLE
1. ASSESS USER STATE • Identify affective state • Identify individual beliefs	• Affective state: Anxious • Belief: Belief that approaching aircraft are hostile
2. PREDICT IMPACT (generic & task specific) • Predict impact of affective states • Predict impact of individual beliefs	*Generic* • Anxiety Impacts Attention & Perception - Increased focus on threatening stimuli - Perception of ambiguous signals as threats • Indiv. history creates biases in expectations of outcome *Specific* • Focus on threat detection & weapons deployment. neglecting communication info from wingman • Bias towards interpreting unknown returns as threats
3. SELECT STRATEGY • Select compensatory strategies to prevent biased performance	• Present reminders to prevent neglect of tasks • Present broader evidence to counteract threat-estimation bias • Present contrary evidence to counteract failure-driven confirmation bias
4. ADAPT AIDING INFO TYPE & PRESENTATION • Provide additional data about ambiguous signals • Select info format enhancing detection and assimilation	• Direct an associated DSS to present additional data about ambiguous signals • Present explicit estimates of times required for task completion to prevent premature engagement • Use multi-modal, customized attention-capturing presentation to assure detection

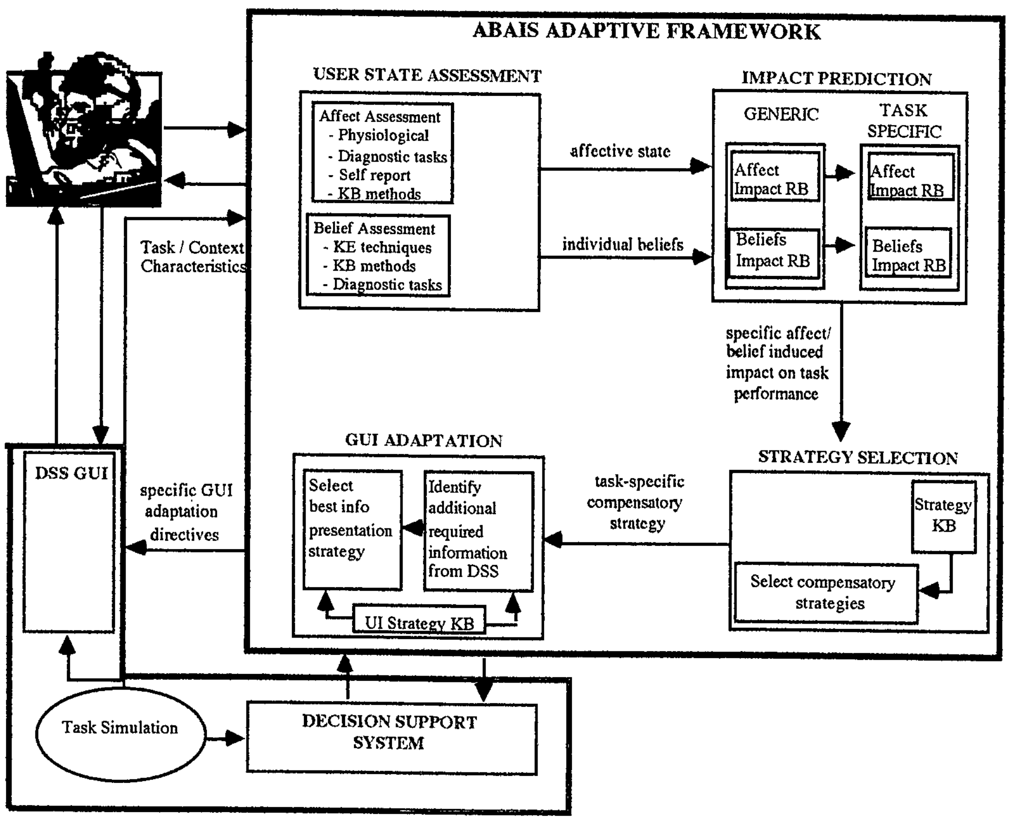


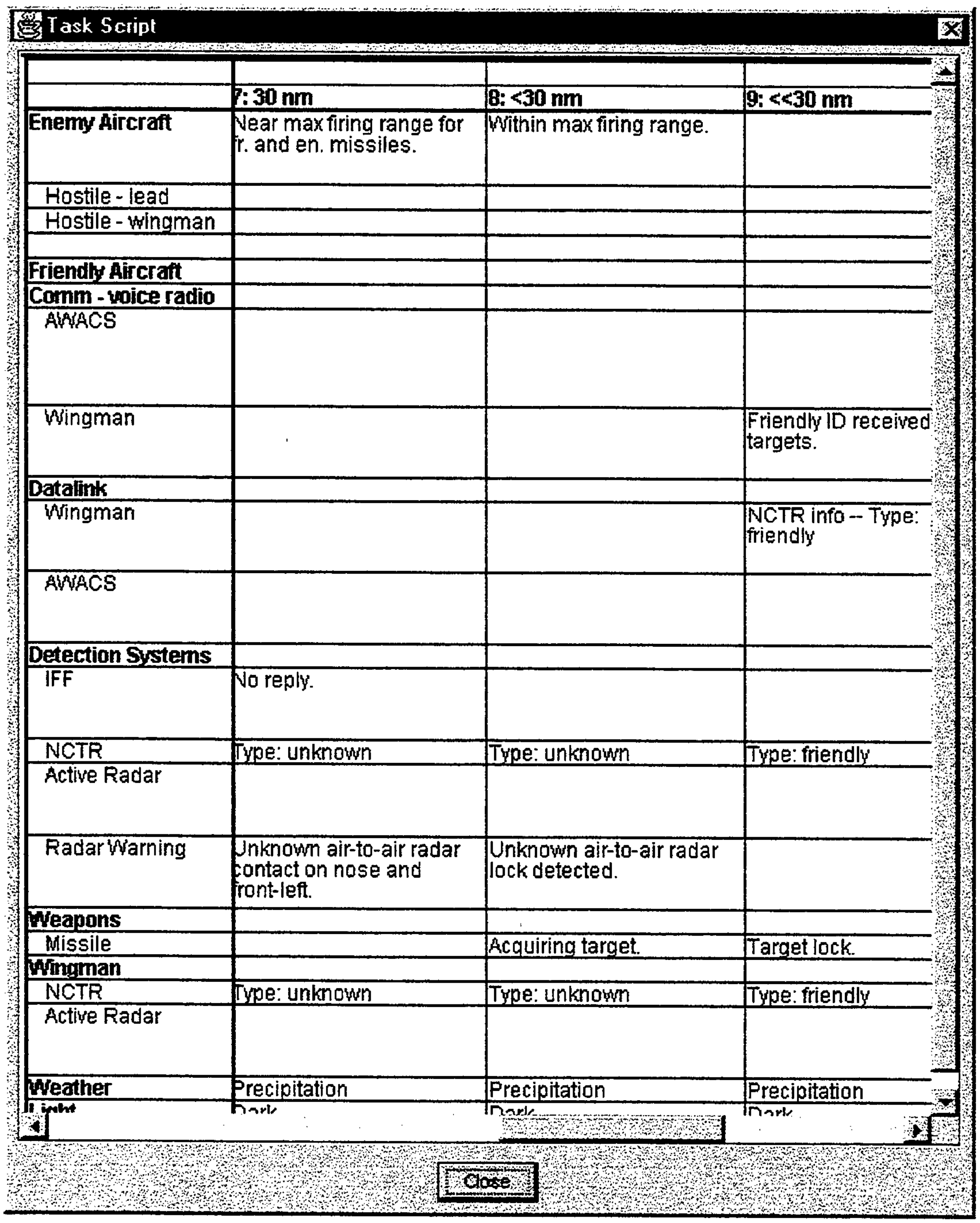
Figure 3.1-1: ABAIS Architecture Implementing the Adaptive Methodology

Both modes include a pilot GUI, which simulates key cockpit displays relevant to the task: the HUD, a radar display showing all sensor data, and two windows showing incoming communications and alarms, respectively. To support these two modes of operation, the ABAIS simulation environment supports both human-in-the-loop flight simulation, and script-based agent simulation. The design includes a script definition functionality which allows the interactive graphical specification of customized scripts via a variety of pop-up menus associated with the individual cells. Figure 3.1-2 shows a segment of the task script matrix for the demonstration task.

User Profiles During a given run, ABAIS uses pilot profiles defining critical features and information required for the affect and belief assessment, and for adaptation strategy selection and implementation. User profiles include information about the pilot's personality (e.g., anxiety-tolerant vs. anxiety-prone), training and proficiency (e.g., experienced vs. novice), individual history (e.g., recent failures or successes), etc. This information forms the basis of the dynamic affect and belief assessment during a scenario run. User profiles also include information about the individual pilots' preferences for information presentation, which allows customized adaptations based on the pilot's specific information processing preferences (e.g., visual vs. auditory modality for alarms, specific colors and attention capture graphics, etc.). The highly individualized profiles represent a critical component of the adaptive methodology, and provide the necessary background information that allows the assessment of the pilot's current affective state and likely belief, during the course of the task.

ABAIS Demonstration Task ABAIS functionality was demonstrated in the context of a sweep task, focusing on adaptation with respect to a single user (i.e., a single pilot). The primary ABAIS demonstration used the analyst-as-user mode, due to the precise coordination required to "fly" the sweep task demonstration script and simulate the desired sequence of events to demonstrate real-time adaptation. In this mode, the aircraft is controlled by a script that simulates the pilot behavior (e.g., "centering the dot" on a HUD) and the dynamic task environment (e.g., changes in radar contact status due to incoming IFF data). The pilot-as-user (human-in-the-loop) mode was demonstrated separately, during an evaluation of physiological user state assessment. This evaluation involved the design and development of a wearable heart rate sensor, whose output is linked directly into the ABAIS GUI / DSS Adaptation module to provide GUI modifications in response to specific changes in the user's heart rate. The successful implementation of this sensor demonstrated the feasibility of using real-time physiological data to drive the adaptation logic.

The ABAIS Testbed Environment A key objective of the overall effort is to develop a flexible testbed for the exploration of multiple affective assessment methods and adaptation strategies. To support this objective, we developed an analyst GUI enabling the flexible specification of background information about the pilot, selection of run time parameters controlling the simulation, and system performance monitoring. The analyst GUI displays include a variety of windows containing dialog boxes for defining the background information necessary for the knowledge-based user assessment (e.g., pilot preference profile, pilot individual history); dialog boxes for specifying the system run time parameters (e.g.,



	7: 30 nm	8: <30 nm	9: <<30 nm
Enemy Aircraft	Near max firing range for fr. and en. missiles.	Within max firing range.	
Hostile - lead			
Hostile - wingman			
Friendly Aircraft			
Comm - voice radio			
AWACS			
Wingman			Friendly ID received targets.
Datalink			
Wingman			NCTR info -- Type: friendly
AWACS			
Detection Systems			
IFF	No reply.		
NCTR	Type: unknown	Type: unknown	Type: friendly
Active Radar			
Radar Warning	Unknown air-to-air radar contact on nose and front-left.	Unknown air-to-air radar lock detected.	
Weapons			
Missile		Acquiring target.	Target lock.
Wingman			
NCTR	Type: unknown	Type: unknown	Type: friendly
Active Radar			
Weather	Precipitation	Precipitation	Precipitation
Light	Dark	Dark	Dark

Figure 3.1-2: Segment of a Script Matrix Defining the Demonstration Task

what windows should be visible for monitoring system performance); and windows allowing monitoring of system performance (e.g., rule base and rule instantiation, physiological data, inferred pilot affective state).

The remainder of this section describes in detail the individual modules of the core ABAIS architecture (sections 3.2 through 3.5), the graphical user interface (section 3.6), and simulation (section 3.7).

3.2 User State Assessment Module

The overall functionality of this module is summarized in figure 3.2-1. The *User State Assessment Module* receives a variety of data about the user and the task context and from these data identifies the user's predominant affective state and individual beliefs and preferences, as they relate to, and potentially influence, task performance. The assessment methods are discussed in detail below.

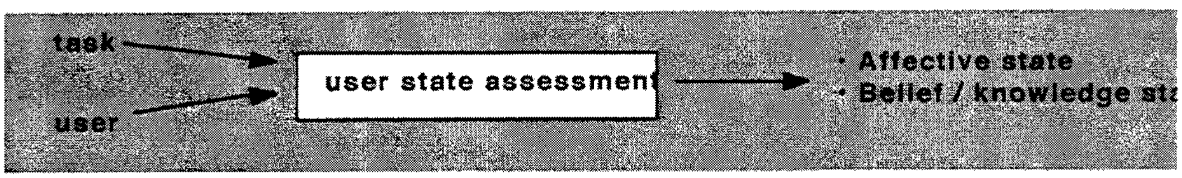


Figure 3.2-1: Functionality of the User State Assessment Module

3.2.1 Affective Assessment

Since no single reliable method currently exists for affective assessment, the User Assessment module provides facilities for the flexible combination of multiple methods. A number of such complementary methods exist. These include:

- Sensing of physiological signals (e.g., galvanic skin response (GSR), heart rate, heart rate variability, blood volume pressure, muscle tension, etc.);
- Recognizing the affective state from facial expression or pupil size changes;
- Use of diagnostic tasks (e.g., test tasks such as the detection rate and interpretation accuracy of a particular sequence of stimuli);
- Self-reports (i.e., subjective answers to specific questions about the user's state, such as those used in workload estimation); and
- Use of AI knowledge-based methods (e.g., rule-based reasoning (RBR), CBR (case-based reasoning), belief nets, etc.)) to derive likely affective state based on factors from current task context, personality traits, and individual history.

Each of these methods has its associated advantages and disadvantages, and none alone is currently sufficient for reliable affective state identification. The key to successful affect assessment is therefore the coordinated use of multiple methods. The overall ABAIS framework thus calls for the coordinated use of all of these methods, to improve reliability of the affective state assessment.

For the Phase I effort, we focused on a knowledge-based approach, which combines data from all categories of user information and allows the demonstration of the feasibility of the overall adaptive framework. Under a Phase II effort, a broader scope of methods would be implemented, including limited physiological sensing, self-reports, and diagnostic tasks. Under the Phase I effort, the primary focus of demonstration was anxiety assessment and adaptation, with a secondary focus on the assessment of, and adaptation to, a heightened state of obsessiveness, resulting from a combination of increased anxiety and a specific personality trait (conscientiousness from the "Big 5" factor group). Under a Phase II, a broader range of affective states and personality traits would be assessed, although the primary focus would continue to be on anxiety. Anxiety was selected both because it is the most prevalent affect during crisis situations, and because its influence on cognition has been extensively researched, and empirical data exist to support specific impact prediction and adaptation strategies.

A variety of factors contribute to an individual's affective state and the expression of particular personality traits (see figure 3.2.1-1). Examples of such specific factors, in the context of the Phase I demonstration task, are shown in table 3.2.1-1. The user assessment module uses knowledge from each of these categories of factors to derive the user's affective state or relevant personality trait, using a rule-based reasoning approach (see figure 3.2.1-2). The assessment process implements a fuzzy rule-based approach consisting of four stages. *First*, a user profile is specified in terms of static and dynamic data, representing task-relevant factors about the user (see table 3.2.1-2 and figure 3.2.1-3, which shows the ABAIS dialog boxes for user profile specification). *Second*, the data in this profile are matched against the rules in the user assessment rule-base, following the standard rule-based reasoning algorithms and using fixed weights for conflict resolution (see figure 3.2.1-4 for examples of rules). *Third*, each relevant factor, represented by an instantiated rule, contributes a numerical weight component to the overall score of the corresponding affect. (This is the anxiety weight factor, or AWF, shown in the rules.) Individual factors or categories of factors may be weighted differently, to reflect their differential influence on the overall affective state (e.g., static task factors will typically have a lower weight than dynamic factors and real-time physiological signals). *Finally*, after all relevant rules are instantiated, the overall anxiety level is computed and the resulting value is mapped onto a three-valued qualitative variable indicating a low, medium, or high anxiety level. Examples of specific factors in each of the relevant categories are discussed below.

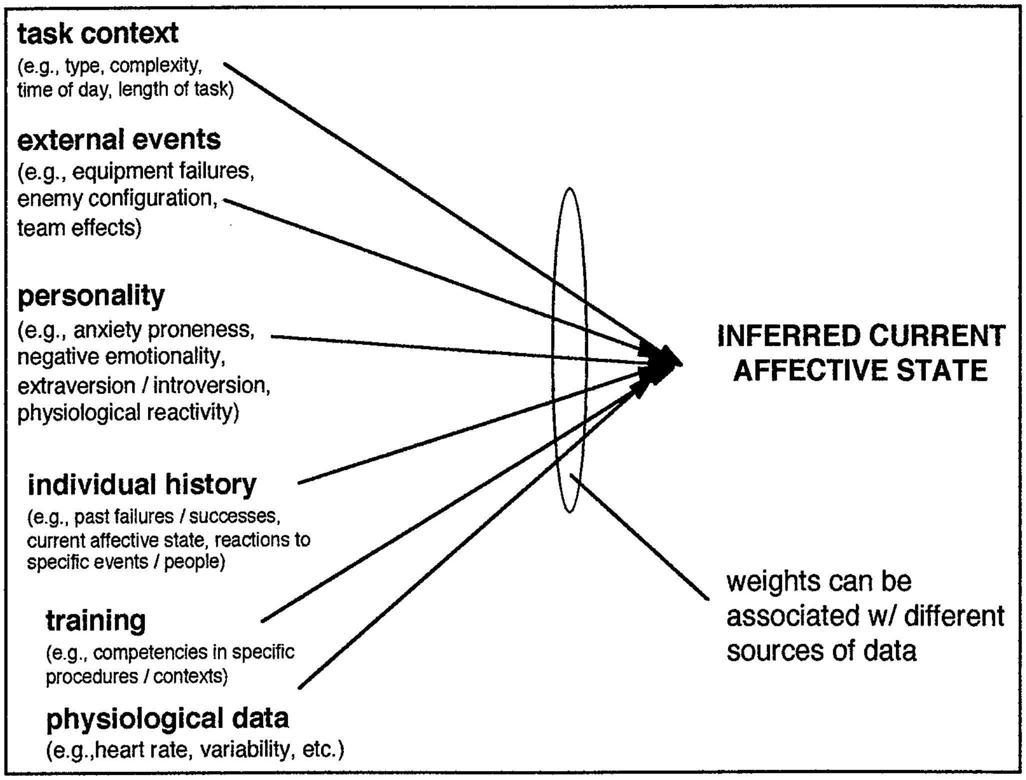


Figure 3.2.1-1: Sources of Information for Deriving Pilot's Affective State

Table 3.2.1-1: Examples of Task Specific Factors for Contributing to the Pilot's Affective State

External Event Factors	
Equipment failures	:== {engine, nozzle indicator, IFF, RWR, NCTR, EID}
Target distance	:== {not detected I BVR I WVR}
Target distance change	:== {closing I opening}
Firing status	:== {cleared to fire I not cleared to fire}
NCTR output	:== {none I unknown I friendly I hostile}
IFF output	:== {friendly I no response}
RWR output	:=={air-to-air unknown I air-to-air hostile I SAM }
Number of hostile a/c	:== {2 I 4 I 6 I > 6}
Number of unknown a/c	:== {2 I 4 I 6 I > 6}
Active radar output	:== {unknown I hostile I friendly}
Individual History Factors	
Successful situations in past	:== {Planning I Detection I Commitment I Sorting I Engagement I Egress I Evasion I Hit I enemy radar lock - evasion I enemy radar lock - hit I unknown radar lock - evasion I unknown radar lock - hit}
Failure situations in past	:== {Planning I Detection I Commitment I Sorting I Engagement I Egress I Evasion I Fratricide I enemy radar lock - evasion I enemy radar lock - hit I unknown radar lock - evasion I unknown radar lock - fratricide repeated unsuccessful IFF interrogations followed by fratricide}
Affective reactions to specific events	:== (unknown NCTR type = (anxiety weight factor=8))

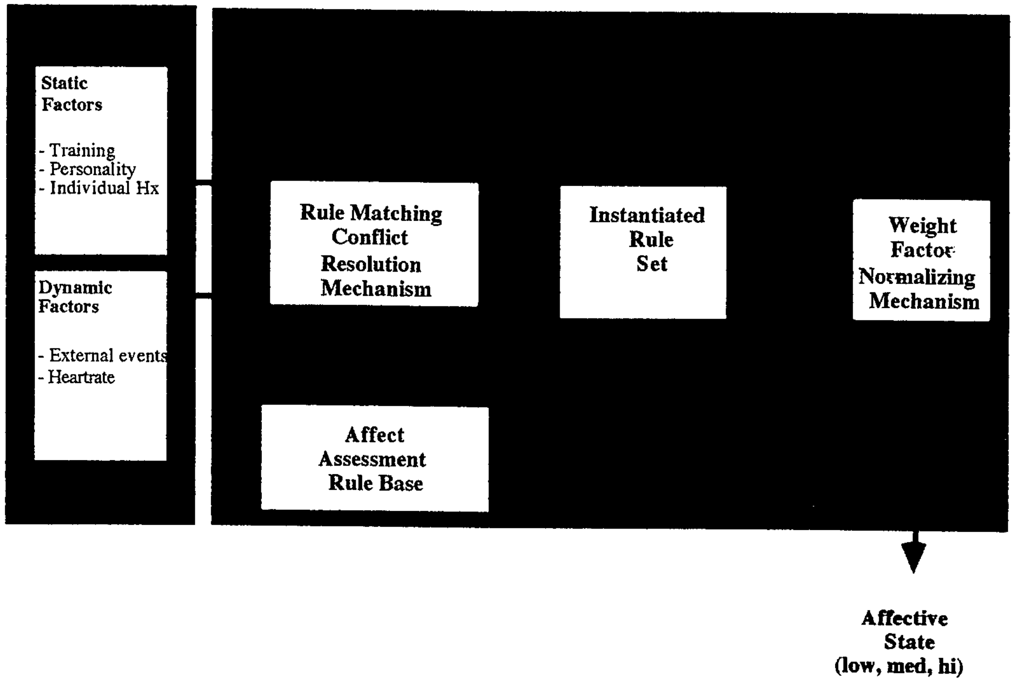


Figure 3.2.1-2: Rule-Based Approach to Affect Assessment

**Table 3.2.1-2: User Profile Example:
Anxiety Prone (High-Anxious) Pilot Profile**

Personality factors

Emotional stability = low

Training / Proficiency factors

air combat hours = low
air combat exercises hours = medium
training hours = low
recency of air combat = low
recency of air combat exercises = low
recency of training = medium

Specific events in individual history contributing to anxiety

Cleared to fire
Unknown type from NCTR
Unsuccessful IFF interrogation
Unknown RWR radar lock
SAM lock
"Centering the dot"

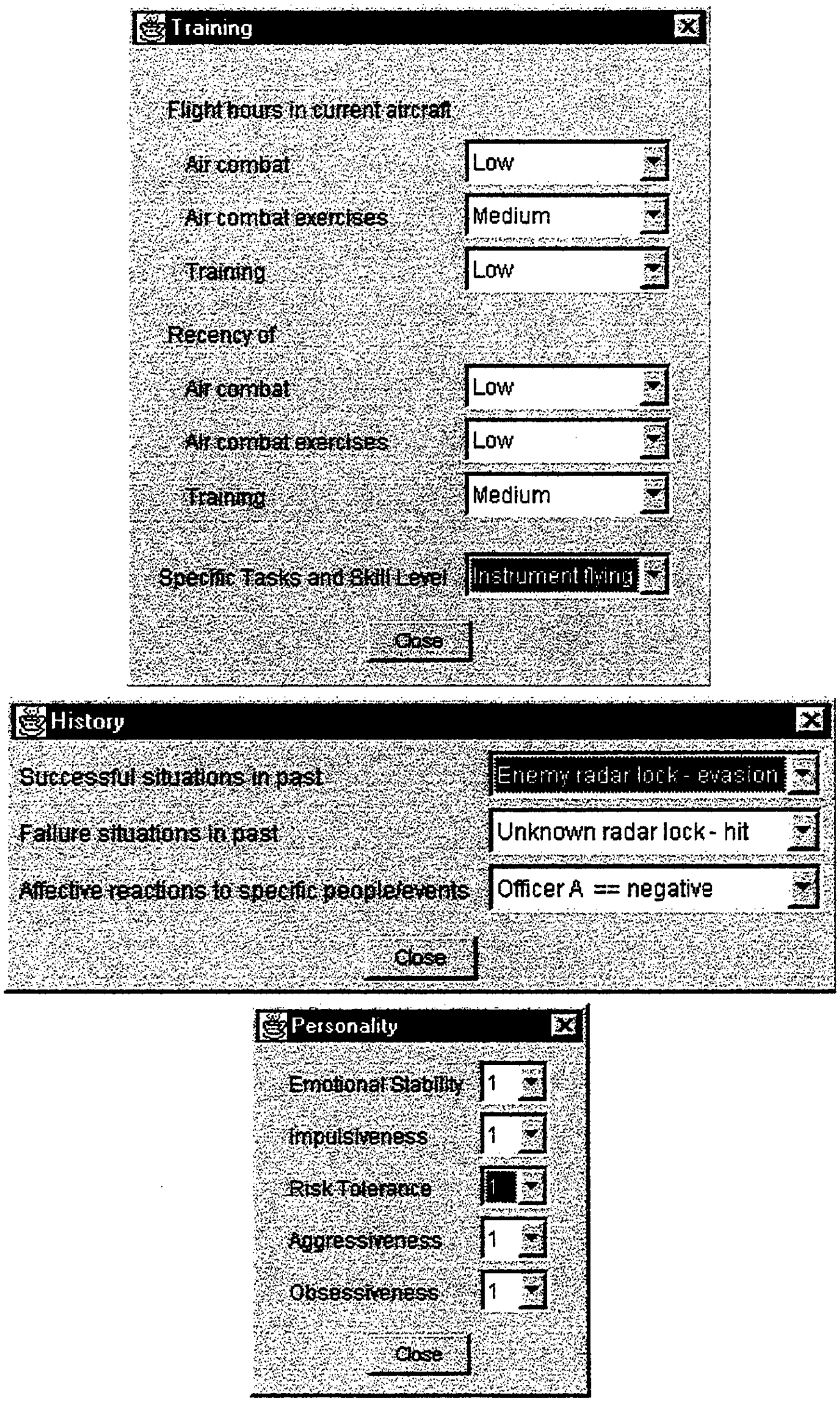


Figure 3.2.1-3: Dialog Boxes for the Interactive Specification of User Profile Information

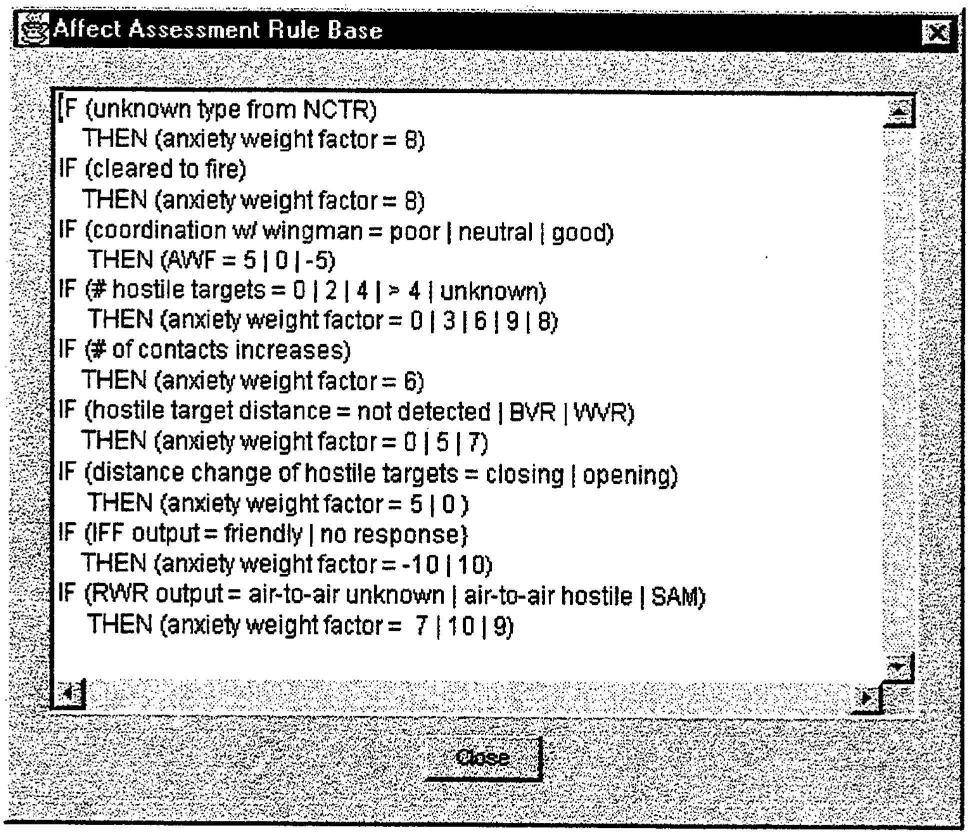


Figure 3.2.1-4: Examples Rules Using External Events Factors to Derive User Affective State

The factors contributing to the pilot's affective state fall into two broad categories: *static and dynamic*. The *static factors* represent influences that remain constant throughout the task, that is, the background level of task difficulty, pilot's training and proficiency level, pilot's personality characteristics, and pilot's individual history. The values of these factors are specified prior to a particular simulation and the resulting affect weight factors is calculated once, before the simulation begins. In contrast to this, the values the *dynamic factors* represent the changing external environment (e.g., incoming data from sensors such as radar contacts) as well as the changing state of the pilot (e.g., changes in particular physiological signals such as heart rate). These values are provided to the affective assessment rules throughout course of the simulation, allowing dynamic computation of the affect weight factor.

For the Phase I effort only first-order effects were represented; in other words, contributions of individual factors to an overall affective state (e.g., anxiety) score were calculated independently.

Specific factors, their corresponding values, and example rules using these factors to derive an affective state are discussed below. It is important to keep in mind that the factors, their values, and the corresponding rules are specified in the context of a specific task and can be changed depending on the particulars of the tasks and the individual. In fact, a key feature of the ABAIS system design is precisely this ability to modify these factors, their values, and their weights, to allow individualized adjustment of system performance. Such individualized system calibration is key to successful adaptation, given the large space of possible influences of affective and belief states on performance.

Static Factors *Task context* factors define the overall difficulty of the task. These are in effect the static, a priori factors that contribute to the overall level of task difficulty and thus exert a potential indirect effect on the overall affective state (e.g., anxiety). The specific values are obtained from experts via direct knowledge elicitation methods and can be further customized to reflect the particular user's experience (i.e., for a particular pilot the subjective complexity for specific task types may vary, etc.). Examples of these factors, and their possible values in the context of the Phase I demonstration task, are summarized in table 3.2.1-3. Examples of rules using these factors to derive an affective state are shown in table 3.2.1-4.

Table 3.2.1-3: Summary of Task Context Factors Used During User State Assessment

Type_1	:== {Offensive, Defensive}
Type_2	:== {air-to-air, air-to-ground}
Type_3	:== {intercept, CAP, sweep}
Phase	:== {Planning, Detection, Commitment, Sorting, Engagement, Egress}
Complexity	:== {1-10}
Weather	:== {clear, cloudy, fog, precipitation}
Light conditions	:== {light, dusk, dark}

Table 3.2.1-4: Examples Rules Using Task Context Factors to Derive User Affective State

<table>
<tr><td>IF (phase = Planning | Detection | Commitment | Sorting | Engagement | Egress)</td><td>THEN (anxiety weight factor = 1 | 3 | 5 | 7 | 10 | 3)</td></tr>
<tr><td>IF (task type_2 = offensive | defensive)</td><td>THEN (anxiety weight factor = 5 | 10)</td></tr>
<tr><td>IF (task complexity = low | med | high)</td><td>THEN (anxiety weight factor = 1/5/10)</td></tr>
<tr><td>IF (weather = clear | cloudy | fog | precipitation</td><td>THEN (anxiety weight factor = 0 | 2 | 3 | 3)</td></tr>
<tr><td>IF (light conditions = light | dusk | dark)</td><td>THEN (anxiety weight factor = 0 | 3 | 2)</td></tr>
</table>

Training and proficiency factors represent the individual's training and educational background, as well as the current proficiency level. Training refers to the total number of flight hours, combat experience and combat exercises, as well the specific type of training (e.g., type of aircraft or simulator, specific types of missions, etc.). Skill level or proficiency depend on recent experience or "currency", which is a function of type and frequency of *recent* training (e.g., in simulator vs. during actual exercises or combat missions) and actual tasks. All of these factors influence the overall skill level and specific competencies and shortcomings in performance. Skill level and proficiency are particularly critical in assessing the level of automaticity, which determines the degree to which task performance may degrade under conditions of heightened anxiety. The selected training and proficiency factors, and their possible values in the context of the Phase I demonstration task, are summarized in table 3.2.1-5. Examples of rules using these factors to derive an affective state are shown in table 3.2.1-6.

Table 3.2.1-5: Summary of Training and Proficiency Factors for User State Assessment

Flight hours in current aircraft:	
Air combat	:== {low I medium I high}
Air combat exercises	:== {low I medium I high}
Training	:== {low I medium I high}
Recency of	
Air combat	:== {low I medium I high}
Air combat exercises	:== {low I medium I high}
Training	:== {low I medium I high}
Specific tasks and skill level	:== {radar I instrument flying I dogfighting}

Table 3.2.1-6: Examples Rules Using Training and Proficiency Factors to Derive User Affective State

IF (air combat hours = low I med I high)	THEN (AWF = 6 I 3 I 0)
IF (air combat exercises hours = low I med I high)	THEN (AWF = 7 I 4 I 0)
IF (training hours = low I med I high)	THEN (AWF = 4 I 2 I 0)
IF (recency of air combat hours = low I med I high)	THEN (AWF = 9 I 5 I 0)
IF (recency of air combat exercises hours = low I med I high)	THEN (AWF = 7 I 4 I 0)
IF (recency of training hours = low I med I high)	THEN (AWF = 6 I 3 I 0)

Personality factors represent a relatively stable set of characteristics of the user's personality that may contribute to his/her affective state (e.g., emotional stability correlates with anxiety tolerance) and may influence behavior in general (e.g., obsessiveness, aggressiveness). The selection of the specific personality factors below was guided by the following criteria:

- Empirical evidence for existence of factor as a distinct personality characteristic
- Empirical evidence or knowledge elicitation data indicating specific effects of the personality factor on performance, particularly in the context of aviation and air combat tasks
- Likelihood of the personality factor playing a role in the selected demonstration task

A number of studies exist assessing the pilot population in terms of a variety of standard psychological assessment instruments (e.g., NEO-PI-R, MMPI, etc.) (Callister et al., 1997), as well as instruments specialized for the fighter pilot population (e.g., ALAPS (Retzlaff et al., 1997)). However, little systematic empirical work has been done in the general area of linking personality factors to specific performance influences and biases, at a level of analysis that would provide the type of detail necessary for real-time adaptation. This type of research, while critical for improved understanding of pilot performance, is both methodologically difficult, and somewhat controversial in nature.

The selection of the ABAIS personality factors was therefore based on general personality research results (e.g., "Big 5", "Giant 3" – see section 2.4 above), and on knowledge elicited from domain experts, either pilots or USAF psychologists and scientists. The objective was to capture personality traits that: 1) are likely to exist in the pilot population, and 2) exert a pronounced influence on behavior during the performance of the demonstration task. The selected personality factors, and their possible values in the context of the Phase I demonstration task, are summarized in table 3.2.1-7. Emotional stability was the primary factor of interest under the Phase I effort, since it is this factor that correlates with anxiety tolerance. The rule capturing this influence in shown in table 3.2.1-8.

Table 3.2.1-7: Summary of Personality Factors for User State Assessment

Emotional stability	:== {1-10}
Impulsiveness	:== {1-10}
Risk tolerance	:== {1-10}
Aggressiveness	:== {1-10}
Conscientiousness	:== {1-10}

Table 3.2.1-8: Example Rule Using a Personality Factor to Derive User Affective State

IF (emotional stability = low I med I high) THEN (anxiety weight factor = 10 I 5 I 0) AND (mood weight factor = 0 I 5 I 10)

Individual history factors represent specific events from the user's history that may influence the current affective state. Given the importance of an individualized approach to affective and belief state assessment, these factors are among the most critical, particularly so since personality research indicates that the most reliable predictor of future behavior is past behavior. A variety of individual history factors exist and must be selected for the specific task context. Accordingly, the factors used during the Phase I ABAIS are customized for the demonstration task and were obtained primarily through direct interview knowledge elicitation methods from domain experts. The selected individual history factors, and their possible values in the context of the Phase I demonstration task, are summarized in table 3.2.1-9. Examples of rules using these factors to derive an affective state are shown in table 3.2.1-10.

Table 3.2.1-9: Summary of Individual History Factors for User State Assessment

Successful situations in past	:== {Planning I Detection I Commitment I Sorting I Engagement I Egress I Evasion I Hit I enemy radar lock - evasion I enemy radar lock - hit I unknown radar lock - evasion I unknown radar lock - hit}
Failure situations in past	:== {Planning I Detection I Commitment I Sorting I Engagement I Egress I Evasion I Fratricide I enemy radar lock - evasion I enemy radar lock- hit I unknown radar lock - evasion I unknown radar lock - fratricide I repeated unsuccessful IFF interrogations followed by fratricide}
Affective reactions to specific people / events	:== {(flight member <name> = positive I negative) I (unknown NCTR type = (Anxiety Weight Factor=8)) }

Table 3.2.1-10: Examples Rules Using Individual History Factors to Derive User Affective State

IF (<current-situation> member-of <past-failures>)	THEN (AWF = 10) AND (mood factor = -5)
IF (<current- situation> member-of <past-successes>)	THEN (AWF = -5) AND (mood factor = +5)
IF (unknown type from NCTR)	THEN (anxiety weight factor = 8)
IF (cleared to fire)	THEN (anxiety weight factor = 8)
IF (confidence in wingman = poor / neutral / good)	THEN (AWF = 5 / 0 / -5)

Dynamic Factors *External events* factors represent more dynamic factors that can contribute to the task difficulty and, again, influence the overall affective state. These include a variety of factors relating to the state of the aircraft, task specific factors such as the geometry of the intercept, any data appearing on the radar systems, as well as specific and non-specific team effects. Examples of these factors, and their possible values in the context of the Phase I demonstration task, are summarized in table 3.2.1-11. Examples of rules using these factors to derive an affective state are shown in table 3.2.1-12.

Physiological data factors represent specific physiological measures collected from the user during the course of the task. Due to the high degree of individual variations in physiological signals, as well as within-individual variations over time and habituation, these measures must be normalized based on the user's baseline responsiveness measures, and baseline measures for the task and the current day. While a variety of measures are theoretically possible, see discussion on physiological sensing in section 2.3.4, the most reliable measures of state anxiety appear to be those related to arousal, that is: heart rate and skin conductance measures. Although these measures reflect general arousal, rather than anxiety per se, it is assumed that during crisis situations in general, and during the demonstration scenario sweep task in particular, this arousal would be a likely indication of anxiety. GSR may not be a practical measure in the fighter pilot setting, both due to intrusive monitoring devices (i.e., finger sensors), and because the fighter pilot task environment may interfere with the data collection (i.e., finger sensors may obstruct other activities). During the Phase I effort we therefore focused on heart rate as the most reliable and practical measure of arousal, using estimates derived from existing empirical literature and interviews with fighter pilots. Examples of assessment rules using physiological data are shown in table 3.2.1-13.

Table 3.2.1-11: Summary of External Events Factors for User State Assessment

Equipment failures	:== {engine, nozzle indicator, oil pressure, fuel valve failures, IFF, RWR, NCTR, EID}
Intercept geometry	:== {single side offset I bracket I wall}
Visual contact w/ wingman	:== {good I poor}
Target distance	:== {not detected I BVR I WVR}
Target distance change	:== {closing I opening}
Firing status	:== {cleared to fire I not cleared to fire}
NCTR output	:== {none I unknown I friendly I hostile}
IFF output	:== {friendly I no response}
RWR output	:=={air-to-air unknown I air-to-air hostile I SAM }
Number of hostile a/c	:== {2 I 4 I 6 I > 6}
Number of unknown a/c	:== {2 I 4 I 6 I > 6}
Active radar output	:== {unknown I hostile I friendly}
Team effects	
Non-specific	:== {team coherence factors}
Specific	:=={familiar team members I unfamiliar team members I liked team members I disliked team members}

Table 3.2.1-12: Examples Rules Using External Events Factors to Derive User Affective State

IF (# hostile targets = 0 I 2 I 4 I > 4 I unknown)	THEN (anxiety weight factor = 0 I 3 I 6 I 9 I 8)
IF (# of contacts increases)	THEN (anxiety weight factor = 6)
IF (hostile target distance = not detected I BVR I WVR)	THEN (anxiety weight factor = 0 I 5 I 7)
IF (distance change of hostile targets = closing I opening)	THEN (anxiety weight factor = 5 I 0)
IF (IFF output = friendly I no response}	THEN (anxiety weight factor = -10 I 10)
IF (RWR output = air-to-air unknown I air-to-air hostile I SAM)	THEN (anxiety weight factor = 7 I 10 I 9)
IF (NCTR output = friendly I unknown I hostile)	THEN (anxiety weight factor = 0 I 5 I 10)
IF (# of equipment failures > 1)	THEN (anxiety weight factor = 5)
IF (engine failure or flameout)	THEN (anxiety weight factor = 7)
IF (fuel system failure)	THEN (anxiety weight factor = 3)
IF (nozzle indicator failure)	THEN (anxiety weight factor = 3)
IF (intercept geometry = wall I single side offset I bracket)	THEN (anxiety weight factor = 5 I 7 I 9)
IF (visual contact w/ wingman = good I poor)	THEN (anxiety weight factor = 0 I 5)

Table 3.2.1-13: Examples of Physiological Factors for User State Assessment

IF (heart rate = normal I high)	THEN (AWF = 0 I 10)
IF (respiration rate = normal I high)	THEN (AWF = 0 I 10)
IF (blood pressure = normal I high)	THEN (AWF = 0 I 10)
IF (skin conductance = normal I high)	THEN (AWF = 0 I 10)

3.2.2 Belief / Knowledge Assessment

For the discussion below, we assume a working definition of "belief", where belief state represents the currently active or preferred set of knowledge constructs, schemata, or procedures, resulting from a combination of training, individual history, and personality and cognitive style differences. For example, a combination of pilot's training, recent events, and affective state might predispose him towards a particular interpretation of existing ambiguous data (e.g., unknown radar is hostile, approaching unknown aircraft are friendly, etc.), a pilot's training might predispose him/her toward a particular cockpit instrument scanning pattern, and individual experience might predispose him to a specific set of expectations regarding the outcome of a particular engagement. In other words, the current belief state represents the currently active situation schemata and reflects the pilot's situation assessment and situation awareness. Belief assessment in this context thus corresponds to what is generally referred to as situation assessment in the literature; that is, the identification of the most likely current interpretive schemata guiding situation interpretation and subsequent action selection.

Given this definition of beliefs, the following problems must be addressed to identify a belief state and its potential effects on performance. *First,* the possible set of beliefs relevant for a particular task context must be identified; in other words, the situation taxonomy for the task domain must be defined. *Second,* the factors contributing to the instantiation of a particular set of beliefs during situation assessment must be identified; these can then be used to dynamically assess the pilot's belief state. *Finally,* a dynamic assessment must be performed during the task execution to determine the individual's most likely set of active schemata, that is, the dominant belief state and corresponding situation assessment. These three problems, and the corresponding solutions during this Phase I effort, are discussed below.

3.2.2.1 Identifying the Task Domain Situation Taxonomy

The first problem requires a detailed ontological analysis of the task domain, identifying critical cues, a taxonomy of possible situations, and space of possible actions. This problem is best addressed through a standard set of knowledge elicitation (KE) techniques and cognitive task analysis (CTA) methods (Cooke, 1995; COADE, 1995). A variety of these methods exist, including the direct methods of protocol analysis, inferential analysis, and dynamic situation assessment, and a variety of indirect techniques. Indirect techniques are particularly appropriate in this case, since they are well-suited for identifying intuitive knowledge that characterizes individual, possibly idiosyncratic, beliefs, that are often difficult to articulate directly. A number of these techniques exist, including multi-dimensional scaling, hierarchical clustering, Pathfinder algorithm, and repertory grid analysis (Hudlicka, 1996).

During the Phase I effort we addressed the initial domain ontological analysis problem through the use of scenario-based, direct interview knowledge elicitation methods and associated cognitive and affective task analysis. The domain characterization (a partial ontological analysis), yielded the cues, situations, and actions summarized in table 3.2.2.1-1 and figure 3.2.2.1-1. For a more extensive elicitation effort required for a Phase II, other methods would be used, including repertory grid analysis, which has been shown to be an efficient method for eliciting large numbers of individual knowledge constructs and schema components (Hudlicka, 1996; Hudlicka et al., 1999).

Table 3.2.2.1-1: Examples of Salient Cues and Possible Situations

Cues

- Datalink - friendly | unknown | hostile
- IFF - friendly | unknown
- NCTR - <aircraft type>
- RWR - no radar contact | hostile radar contact | friendly radar contact | SAM radar contact | unknown radar contact |
- Active radar - friendly | unknown | hostile
- Targets - closing | opening
- Cleared to fire notification

Situations

- Hostile aircraft closing
- Hostile aircraft opening
- Presumed hostile aircraft closing
- Presumed hostile aircraft opening
- Unknown aircraft closing
- Unknown aircraft opening
- Cleared to fire
- Cleared to fire w/ positive EID
- Not cleared to fire
- At maximum firing range for <weapon>
- Beyond maximum firing range for <weapon>
- Within firing range of hostile aircraft - vulnerable
- Under attack from hostile aircraft
- Attacking hostile aircraft

Actions

- Fire weapon
- Initiate intercept
- Initiate evasive action
- Communicate w/ wingman
- Communicate w/ AWACS
- Focus on particular instrument {HUD | radar | etc.}

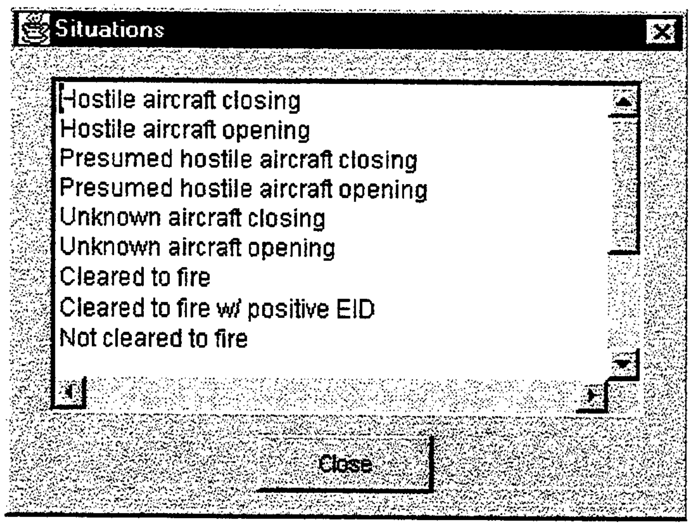


Figure 3.2.2.1-1: Belief Assessment Rules and Resulting Beliefs (i.e., Situations) Instantiated in the Current Task Context

3.2.2.2 Factors Contributing to a Particular Belief State

A variety of factors contribute to the activated belief state (see figure 3.2.2.2-1). Each factor contributes some piece of knowledge or evidence to establish, confirm, or refute a particular belief about the current situation (e.g., unknown target is friendly or hostile). The sum total of these influences then determines the pilot's overall belief state, reflecting his/her assessment of the current situation. There is significant overlap in the knowledge and rules used to assess the affective state and those used to infer the belief state.

A critical aspect of the belief state assessment is the inclusion of the pilot's presumed affective state. This in effect allows the implicit modeling of the influence of specific affective states on cognition and distinguishes the current approach to belief / situation assessment from existing situation assessment methods (e.g., SD_PVI (Zacharias et al., 1996; Pew and Mavor, 1998)). The knowledge-based belief assessment approach implemented during Phase I uses knowledge from each of these categories to derive the user's belief state. As with affect assessment described above, this approach in effect emulates an expert observer, familiar with both the task and the specific individual.

Again, as with the affective state assessment, it is important to keep in mind that the factors, their values, and the corresponding rules, are specified in the context of the current individual-task and can be changed as that context changes. In fact, such individualized tailoring of the ABAIS knowledge-bases is the key to its successful adaptation for a particular individual, or group of individuals in a team setting.

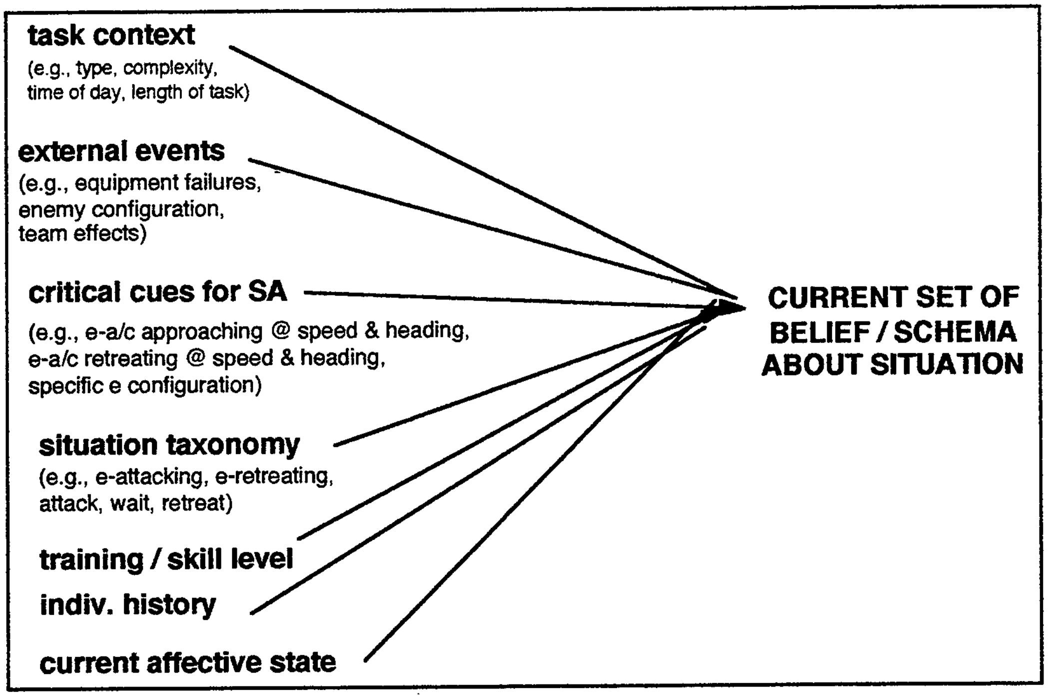


Figure 3.2.2.2-1: Sources of Information Used to Derive Pilot's Belief State

3.2.2.3 Dynamic On-Line Belief Assessment

The process of dynamic belief assessment is the final step of user belief state assessment. During this phase the current knowledge factors contributing to the activation of particular beliefs are instantiated to derive the most likely set of activated schemata, that is activated beliefs reflecting the current situation. This process essentially simulates, at the input-output level, the pilot's own situation assessment processes. In the context of the current demonstration scenario, the pilot's belief state is reflected in the pilot's assessment of the current situation from the available salient cues. While in theory a large number of situations are possible, in practice the set of situations for a particular task is generally limited (e.g., attacking vs. being attacked, approaching aircraft are friendly or hostile, etc.). In the context of the Phase I demonstration scenario we therefore limit the possible situations to those identified through initial knowledge elicitation and cognitive task analysis (see table 3.2.2.1-1). Specifically, the primary cues are the radar returns and datalink information available on the aircraft's detection systems; that is, the active TWS air-to-air radar, NCTR, IFF, and RWR. The critical situations then consist of the identity, distance, and course of identified targets, whether or not the aircraft is within a weapons range, whether or not the aircraft is vulnerable, and whether or not the pilot is cleared to fire.

The most common existing approaches to belief and situation assessment are AI knowledge-based methods using one of a variety of knowledge representation formalisms and associated inferencing methods (e.g., rule based reasoning, case based reasoning, Bayesian belief nets, or various hybrid combinations thereof) (Pew and Mavor, 1998).

Under the Phase I effort, we selected a rule-based approach for belief assessment. As was the case with affective state assessment discussed above, the knowledge used to dynamically derive the pilot's belief state was encoded in terms of production rules. The actual belief state was then derived from a combination of static, a priori information about the pilot and the task, and from dynamic data reflecting the changing task environment and pilot state, including the pilot's affective state. The most critical categories of factors were: 1) external events (i.e., cues); 2) individual history; and 3) current affective state. These are described in detail below.

External events External events represent the dynamic task environment and include both events on the aircraft itself (e.g., instrument failures), and events in the task environment (e.g., behavior of other aircraft, both friendly and enemy; incoming sensor radar data). Examples of external events are listed in table 3.2.2.1-1 above and in figure 3.2.2.3-1 below.

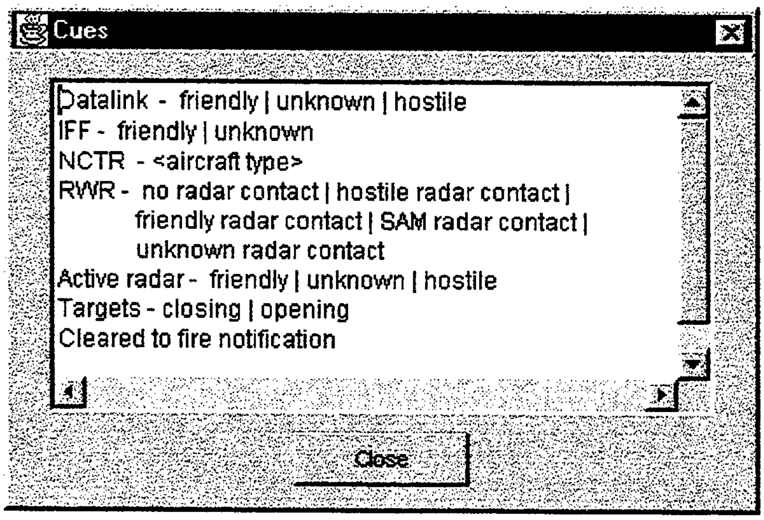


Figure 3.2.2.3-1: Examples of Cues Used as Input for Belief State Assessment

Individual history combines the training and skill factors with specific experiences that influence the pilot's situation assessment and decision-making. In other words, specific successful or unsuccessful experiences that tend to predispose the pilot towards or against certain situations and maneuvers. For example, in the current demonstration scenario, occurrence of specific recent situations may bias the interpretation of current data; i.e., if the pilot has recently experienced a situation where a number of unsuccessful IFF interrogations were followed by a final identification of that aircraft as hostile, s/he may be predisposed to conclude that if an aircraft does not respond to IFF interrogations it is in fact hostile.

Current affective state The pilot's affective state plays a critical role in his/her situation assessment. By taking into account the current affective state, the ABAIS User Assessment module in effect implicitly models the potential biasing influences of the different affective states and provides a structure which allows the explicit representation of the positive feedback between cognition and affect that is often seen in crisis situations. In other words, increased anxiety contributes to a particular situation assessment (e.g., aircraft is being attacked by hostile aircraft), which then limits the processing of data that could give rise to alternative interpretations and further increases the anxiety level. Examples of rules for belief assessment are shown in figure 3.2.2.3-2 and table 3.2.2.3-1. These rules map the combinations of cues representing external events, individual history, and affective state onto the set of possible situations, which are summarized in table 3.2.2.3-2.

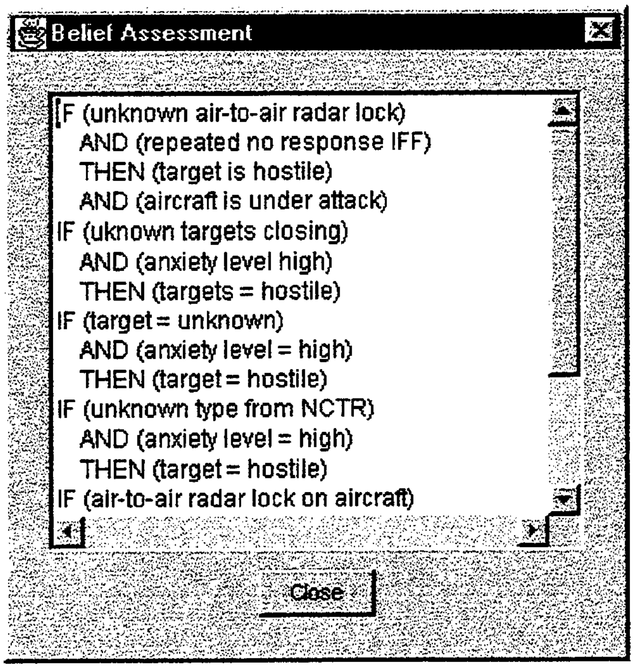


Figure 3.2.2.3-2: Examples of Belief Assessment Rules

Table 3.2.2.3-1: Examples of Rules Deriving Pilot's Belief State

IF (unknown contacts closing) AND (anxiety level > low)	THEN (contacts = hostile)
IF (unknown contacts closing) AND (anxiety level = low)	THEN (contacts = unknown)
IF (cleared to fire) AND (unknown contacts closing)	THEN (contacts = hostile)
IF (unknown type from NCTR) AND (anxiety level = > low)	THEN (contact = hostile)
IF (unknown type from NCTR)	THEN (contact = hostile)
IF (unknown air-to-air radar lock) AND (repeated no response IFF) THEN (target is hostile) AND (aircraft is under attack)	
IF (unknown targets closing) AND (anxiety level high)	THEN (targets = hostile)
IF (target = unknown) AND (anxiety level = high)	THEN (target = hostile)
IF (air-to-air radar lock on aircraft) AND (anxiety level = high)	THEN (radar lock = hostile)
IF (unknown air-to-air radar lock on aircraft) AND (hostile SAM lock on aircraft) THEN (aircraft is under attack)	

Table 3.2.2.3-2: Examples of Belief Assessment Output: Possible Situations

for each	
target on active radar	= {hostile I unknown I friendly}
for each	
radar warning signal	= {hostile I unknown I friendly}
cleared to fire	= {yes I no}
under attack	= {yes I no I unknown}
at max firing range for <weapon>	= {yes I no}
vulnerable	= {yes I no I unknown}

3.3 Impact Prediction Module

The overall functionality of *Impact Prediction Module* is summarized in figure 3.3-1. The *Impact Prediction Module* receives as input the identified affective and belief states and determines their most likely influence on task performance.

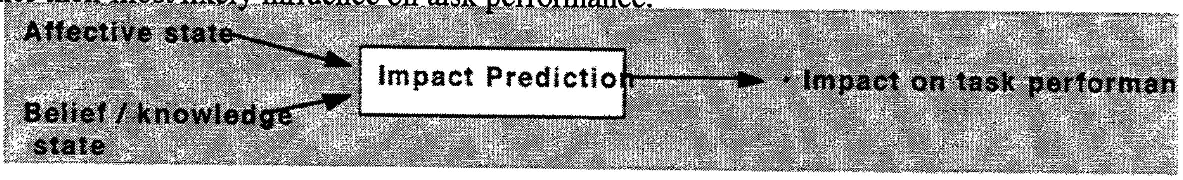


Figure 3.3-1: Functionality of the Impact Prediction Module

The goal of the impact prediction module is to predict the influence of a particular affective state (e.g., high anxiety) or belief state (e.g., "aircraft under attack", "hostile aircraft approaching", etc.) on task performance. Impact prediction thus represents an essential component of the overall adaptation strategy. Impact prediction process implemented under Phase I uses rule-based reasoning (RBR) and takes place in two stages. First, the *generic effects* of the identified affective state are identified, using a knowledge-base that encodes empirical evidence about the influence of specific affective states on cognition and performance. Next, these generic effects are instantiated in the context of the current task to identify *task-specific effects*, in terms of relevant domain entities and procedures (e.g., task prioritization, threat assessment). The knowledge encoded in these rules is derived from a detailed cognitive / affective task analysis, which predicts the effects of different affective states on performance in the current task context. Such a task analysis is a critical component of building the impact prediction knowledge base, since the state-of-the-art of theoretical understanding and empirical research in personality and emotion do not allow accurate prediction of these influences in a generic, domain-independent manner. The separation of the generic and specific knowledge enhances modularity and simplifies knowledge-based adjustments.

3.3.1 Effects of Affective States and Personality Traits on Performance

Generic Effects Primary source of evidence for the generic (i.e., domain independent) impacts of affective states on performance was empirical literature in experimental and cognitive psychology. Several affective states and personality traits have been studied extensively in laboratory settings. Empirical findings consistently indicate that anxiety affects attention and perception; mood affects recall, prediction of future outcomes, and a sense of locus of control, and obsessiveness affects decision making speed and recall of recent events. Table 3.3.1-1 summarizes findings from experimental psychology regarding the generic effects of selected affective states and personality traits on performance. The remainder of this section discusses in more detail both the generic effects, and their specific instantiations in the context of the demonstration task.

Table 3.3.1-1: Summary of Generic Effects of Selected Affective States and Personality Traits on Performance

Anxiety and Attention (Williams et al., 1997; Mineka and Sutton, 1992; Eysenck, 1997)
Narrowing of attentional focus
Predisposing towards detection of threatening stimuli
Mood and Memory (Bower, 1981; Blaney, 1986)
Mood-congruent memory phenomenon - particular affective state induces recall of similarly valenced material
Obsessiveness and Performance (Broadbent et al., 1986; Persons & Foa, 1984; Sher et al., 1989)
Delayed decision-making
Reduced ability to recall recent activities
Reduced confidence in ability to distinguish among actual and imagined actions and events
Narrow conceptual categories
Affect and Judgment & Perception (Isen, 1993)
Depression lowers estimates of degree of control
Anxiety predisposes towards interpretation of ambiguous stimuli as threatening

Specific Effects Although there appears to be an increasing interest in linking specific personality traits and affective states with performance, there are surprisingly few systematic empirical studies investigating these effects, at a level of detail necessary for a knowledge-based adaptation system such as ABAIS. In other words, while studies have been conducted that attempt to correlate training success or career performance with broad personality measures (e.g., "Big 5"), little work has been done in identifying specific performance biases induced by transient states of anxiety and other affects, or by systematic biases due to dominant personality traits. Due to the paucity of systematic empirical studies in this area, the primary source of knowledge for the identification of specific effects under Phase I were SME's (i.e., experienced fighter pilots). Knowledge elicitation interviews with multiple SME's provided information about the likely effects of a variety of affective states and personality traits on pilot performance. The results of these interviews are summarized below.

Anxiety - Attention and Perception: The *generic effects of anxiety* on attention include narrowing of attentional focus, difficulty focusing attention (i.e., inability to select an action and consequent delayed reaction time), and increased attention to threatening stimuli. This narrowing of attention may result in task neglect for other critical tasks, and a failure to detect other relevant cues.

Given this generic knowledge, a detailed cognitive / affective task analysis is then used to predict situations where these biases may influence performance. In other words, the cognitive / affective task analysis identifies task segments where parallel signals may occur (e.g., two signals on radar from two different sources, radar and engine instruments, etc.) and identify points where parallel tasks take place. These then allow predictions as to which of these tasks is likely to be neglected during a state of increased anxiety (e.g., pilot is more likely to pay attention to radar signals than engine instruments or radio).

The generic effect of anxiety on perception is to bias perception towards interpretation of ambiguous signals as threats. Since the primary perceptual bias is the misinterpretation of cues, the cognitive / affective task analysis required to identify specific possible instances must focus on potential instances of ambiguous cues, and cues likely to be misinterpreted as threats, and identify from these candidates for likely misinterpretation as threats.

This type of task analysis, based on knowledge elicitation data from SME's, identified a number of *specific effects* of the generic anxiety-induced biases discussed above. These include:

- Focussing on target on radar display and failing to notice incoming communication from other sources (e.g., radio voice communication from wingman, AWACS, etc.).
- Focussing on target information on HUD and failing to notice new information on radar.
- Focussing on "centering the dot" and failing to notice a change in icon indicating a change in target identification (from hostile or unknown to friendly).
- Interpreting any of the various ambiguous signals on radar as threats. This includes ambiguous IFF signals, RWR signals that do not indicate whether the aircraft is being 'painted' by a hostile or friendly radar; NCTR which provides information about the type of aircraft but not necessarily whether it is hostile or friendly; unknown NCTR signal.[3]
- Focussing on information on radar and failing to notice cockpit warnings of aircraft system malfunctions.

Examples of specific rules constructed from this knowledge are shown in table 3.3.1-2.

[3]For example, a MIG fighter aircraft could be owned by a friendly ally or an adversary. Thus an indication that an aircraft is a MIG may not indicate whether it is friendly or hostile.

Table 3.3.1-2: Example Rules Predicting the Effect of Anxiety on Performance

Anxiety-Induced Narrowing of Attention
IF (multiple targets on radar) THEN (focused on signals representing unknowns or threats)
IF (multiple unknown / threats targets on radar) THEN (focused on nearest / fastest-approaching targets)
IF (data arriving on multiple cockpit instrument) THEN (attention focused on radar or HUD)
IF (data arriving on HUD and radar) THEN (attention focused on HUD)
Anxiety-Induced Misinterpretation of Cues
IF (unknown or ambiguous targets on radar I NCTR exist) THEN (assume targets are hostile)
IF (unknown air-to-air radar lock on RWR) THEN (assume under attack)
IF (no reply from IFF) THEN (assume targets are hostile)

Mood - Memory and Judgment: The *generic effects of mood* on memory and judgment include the mood-congruent recall phenomenon and mood-congruent outcome prediction. In mood congruent recall the individual's mood determines the type of information recalled; in other words, positive mood favoring the recall of positively-valenced information (e.g., successful past situation), and negative moods favoring the recall of negatively-valenced information (e.g., failures from the past). In mood-congruent prediction of future outcomes, positive moods favor positive estimates of outcomes and negative mood favor negative estimates of outcomes. The exact content of the recalled events is of course a function of the individual-task context.

In the context of the sweep task scenario, these generic effects of mood on memory and judgement may result in the following *specific effects*:

- A pilot in a negative mood may avoid a particular situation, action, or maneuver because it reminds him/her of past failures and because s/he anticipates a negative outcome.
- Conversely, a pilot in a positive mood may initiate a particular action or maneuver because it reminds him/her of successful situations from the past and because s/he anticipates successful outcome.

An example of the former situation is a lead pilot who has recently experienced a situation where he became separated from his wingman while attempting to change formation, lost sight of his wingman, and subsequently the wingman was shot down. There is an increased likelihood that this pilot will avoid similar maneuvers in the future, particularly when in a negative mood, which increases the likelihood of recalling this "negative" situation from the past.

To successfully instantiate these effects, detailed description of the pilot's individual history is required, where specific situations from the past are linked with their associated affective valence (i.e., positive or negative).

Obsessiveness - Decision-Making: The *generic effects of obsessiveness* on decision making include delayed decision-making, reduced ability to recall recent events, narrow conceptual categories, and inability to adapt to new and unanticipated situations.

In the *context of fighter pilot tasks*, these generic effects may produce what is known as a "checklist" mentality, which may, in some situations, take up valuable time and lead to delayed decision making. A cognitive / affective task analysis of the sweep task indicates that the generic effects of obsessiveness on decision making described above may result in any of the following *specific effects*:

- Failing to recall recent events may result in repetition of procedure steps or assumption that the steps have already been performed
- Repeated IFF interrogations
- Rechecking the weapon switches (e.g., master arm switch, weapon selection switch, radar mode)
- Repeating verbatim messages from AWACS rather than simply acknowledging them by saying "Roger"
- Repeating messages received from AWACS to wingman, even though wingman also receives all AWACS communication.
- Verifying wingman's sort even though wingman in principle remembers this from pre-flight briefings and executes this correctly during flight.

These "checking" behaviors may then delay decisions such as committing, initiating a maneuver such as changing formation, firing a weapon, or turning to commit.

Impulsivity and Performance: Empirical evidence indicates that high-impulsives seek out conditions of high arousal and tend to perform better under conditions of high arousal. In contrast, low impulsivity tends to be associated with preference for familiar situations and possible a lower degree of adaptability.

Contrary to what one might intuitively expect, impulsivity does not necessarily result in riskier behavior per se, but rather in faster decisions made on the basis of less evidence, which may or may not be 'risky'.

In the *context of fighter pilot tasks*, these generic effects of high impulsivity may result in any of the following:

- Faster, 'snap', decisions and judgements made on the basis of less information
- Increased likelihood of identifying an ambiguous return as hostile
- Increased likelihood in performing more aggressive maneuvers.

3.4 Strategy Selection Module

The overall functionality of the *Strategy Selection Module* is summarized in figure 3.4-1. The *Strategy Selection Module* receives as input the predicted specific effects of the affective and belief states and selects a compensatory strategy to counteract performance biases resulting from these effects.

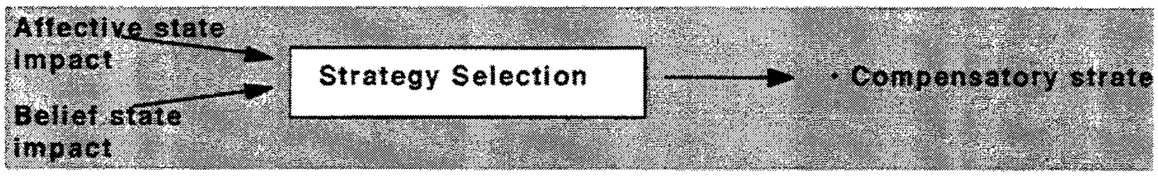


Figure 3.4-1: Functionality of the Strategy Selection Module

Strategy selection is accomplished by rule-based reasoning. The knowledge-base contains mappings between specific performance biases identified by the *Impact Prediction Module* (e.g., task neglect, threat-estimation bias, failure-estimation bias, etc.) and associated compensatory strategies (e.g., present reminders of neglected tasks, present broader evidence to counteract threat-estimation bias, present contrary evidence to counteract failure-driven confirmation bias, etc.). As was the case with impact prediction, the strategy selection module relies on a detailed analysis of the task context that identifies specific strategies available to counteract the possible biases. This analysis then allows the construction of the strategy selection knowledge bases. Again, the process is divided into generic and task specific components, to facilitate KB editing and modification. Generic strategies map the generic performance bias (e.g., task neglect) into a generic compensatory strategy (e.g., present reminders of neglected tasks). Table 3.4-1 lists examples of these generic strategy rules.

The generic strategies are then instantiated in the specific strategy rules, based on knowledge about the task context and detailed cognitive / affective task analysis. Examples of specific rules for compensatory strategy selection are shown in table 3.4-2.

Table 3.4-1: Examples of Generic Rules for Compensatory Strategy Selection

Anxiety effects

IF (<task> importance = high) AND (pilot's assessment of <task> importance = low)
THEN (present reminders for <task>) AND (direct attention to neglected instruments / data)

IF (threat estimation bias = high)
THEN (collect all available evidence regarding radar signal identity)

IF (confirmation bias = high)
THEN (obtain any contradictory evidence) AND (enhance display of evidence)

Obsessiveness effects

IF (obsessiveness = high)
THEN (remind of consequences of delayed decisions)
(remind that no data exist that will provide additional information)
(remind of most recent tasks accomplished – present explicit checklists)
(display task timeline and current position within timeline)

Table 3.4-2: Examples of Specific Rules for Compensatory Strategy Selection

Anxiety effects

IF (recent change in radar target status) THEN
(emphasize change in status of return)

IF (attention focus = HUD) AND (incoming radar data) THEN
(redirect focus to radar)

IF (attention focus = radar) AND (incoming radio call) THEN
(redirect focus to radio)

IF (attention focus = non-radar instruments) AND (incoming radar data) THEN
(redirect focus to radar)

IF (likelihood of task neglect for <instrument> = high) & (has-critical-info? <instrument>)
THEN (emphasize <instrument> visibility)

IF (target = unknown) AND (target belief = hostile) THEN
(emphasize unknown status) AND (collect more data)

Aggressiveness effects

IF (likelihood of premature attack = high) THEN
(display all available info about enemy a/c) AND
(enhance display of enemy a/c info)

Obsessivness effects

IF (likelihood of delayed attack = high) THEN
(display all available info about enemy a/c) AND
(display likelihood of attack by enemy a/c) AND
(display envelope of vulnerability around own aircraft) AND
(display reminders for attack tasks)

3.5 GUI / DSS Adaptation Module

The *GUI/ DSS Adaptation Module* performs the final step of the adaptive methodology by implementing the selected compensatory strategy in terms of specific GUI modifications. The overall functionality of this module is summarized in figure 3.5-1. A rule-based approach is used to encode the knowledge required to map the specific compensatory strategies onto the necessary GUI / DSS adaptations.

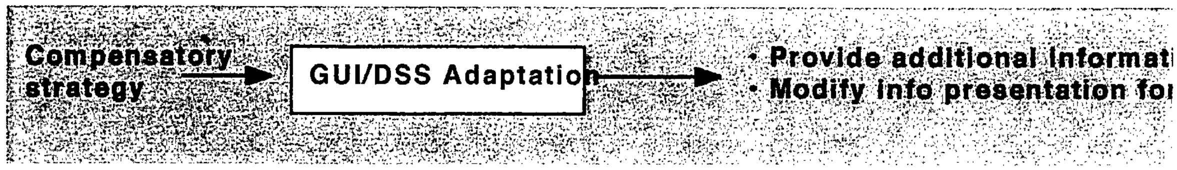


Figure 3.5-1: Functionality of the GUI/DSS Adaptation Module

Modes of Adaptation In general, two broad categories of adaptation are possible:

- Content-Based adaptations, which *provide additional information,* and
- Format-Based adaptations, which *modify the format of available information.*

Content-based adaptation involves the collection and display of additional data or knowledge to prevent a particular performance bias. For example, providing additional data about an ambiguous radar signal may help prevent an anxiety-induced confirmation bias to identify the signal as a threat. In the Phase I ABAIS demonstration scenario, this type of adaptation was demonstrated in the context of demonstration scenario #2, focusing on adaptations due to obsessive behavior. In this case, a compensatory strategy was selected to counteract the pilot's obsessive "checking" behavior which was delaying his decision to fire. The content-based adaptation strategy first identified additional relevant information (i.e., the fact that the friendly aircraft was now within the hostile aircraft's missile range), and then displayed this information in a prominent manner, to warn the pilot of consequences of further delaying his decision to fire (see figure 3.5-2). The red triangle overlaid on the radar display indicates the range of the hostile missile. The fact that the aircraft is within this triangle indicates that the pilot is vulnerable.

Format-based adaptation involves the presentation of existing data in an alternative format, to enhance visibility and / or to draw attention to neglected displays, and, in general, to facilitate fast detection, recognition, and assimilation, thereby improving situation awareness. In the Phase I ABAIS demonstration scenario, this type of adaptation was demonstrated in the context of demonstration scenario #1, focusing on adaptations due to high levels of anxiety. In this scenario, a compensatory strategy was selected to counteract the pilot's narrowed attention and inaccurate situation assessment. Namely, his failure to note a recent change in status of a contact from presumed unknown to friendly, and his consequent failure to cease preparation for firing a missile. The format-based adaptation first identified possible strategies for enhancing the neglected information (i.e., highlighting the radar contact whose status has recently changed), and then implemented these strategies in terms of specific modifications of the pilot's displays (see figure 3.5-2). Namely, highlighting the contact in question on the pilot's HUD (blue box) and highlighting the status information on the radar display (blinking blue text message box in lower left corner of radar display).

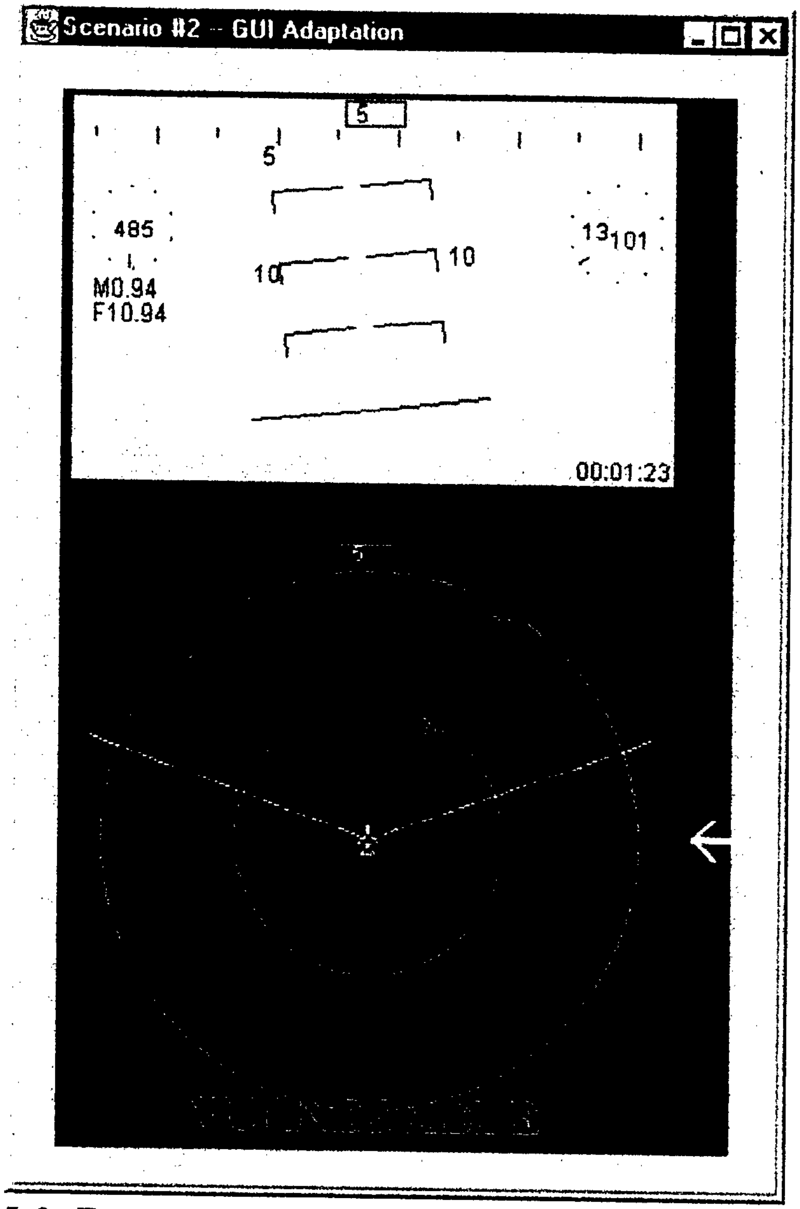


Figure 3.5-2: Example of a Content-Based Adaptation Aiming to Compensate for an Obsessive Delaying of the Decision to Fire

The arrow on right indicates pilot's current focus. The red triangle indicates the area of vulnerability from hostile aircraft missile. The blue, blinking notification string further emphasizes the friendly's vulnerability.

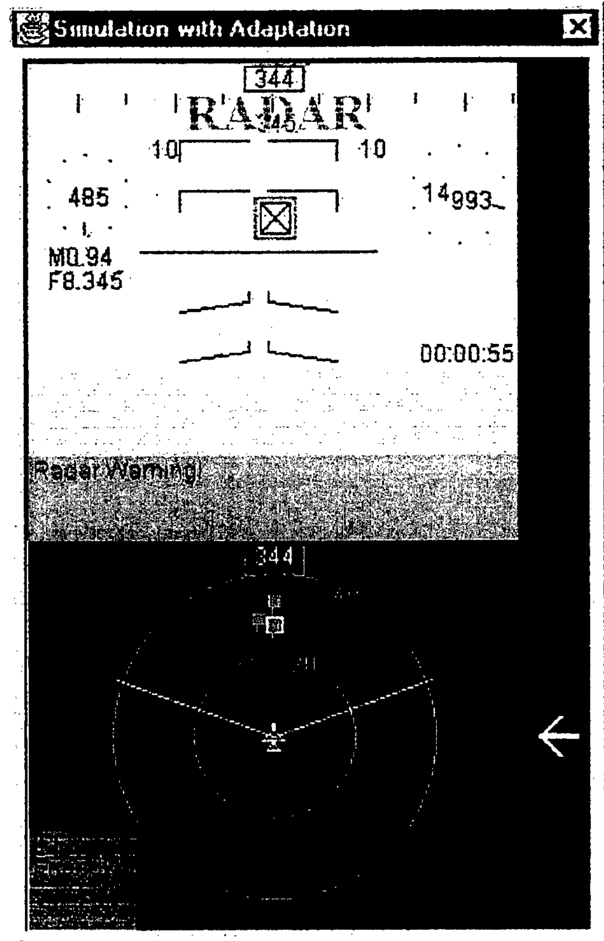


Figure 3.5-3: Example of a Format-Based Adaptation Aiming to Compensate for an Anxiety-Induced Narrowing of Attention and Perception Bias

The arrow on right indicates pilot's current focus. The blinking, enlarged, blue contact icon on the HUD indicates a change in status. The blinking, blue contact icon on the radar indicates a change in status, with details provided in the text box in lower left corner of the radar display.

Level of Adaptation Regardless of the method chosen, adaptation eventually results in a modification of specific user interface (UI) attributes. These include changes in overall format, different choice of icons, or changes in UI elements, including color, location, size, orientation, modality, motion of stimulus, motion on periphery to re-direct attention by pre-attentive processes. Adaptation can thus take place at any of the four levels below:

- Icon level
- Display level
- Notification level

- User Interface level

Each of these levels affords different alternatives and is more or less suitable for a given situation, depending on the task, task context, and the individual. The different levels of adaptation are discussed below.

Icon level adaptation involves modifications to the individual icons within a particular display. For example, changing the size or appearance of an icon in some way to enhance its visibility (e.g., highlighting, changing its location within a display, changing color or size, etc.). It can also include modifying the icon proper, for example, making it less abstract or more graphical, to eliminate the presentation of complex alpha-numeric data and associated perceptual and cognitive load when the user's resources are limited due to increased levels of anxiety.

Display level adaptation involves modifications of the display as a whole, rather than the individual icons within the display. Examples of display level adaptations are changing the size or location of a selected display (e.g., moving a critical display to a central location of the overall UI), changing the appearance of a display (e.g., range setting on radar), or changing the contents of a display (e.g., decluttering a display).

Notification level adaptation involves inserting new, or modifying existing, alarms and alert notifications. Examples of notification level adaptations include adding a notification string regarding desired focus of attention (see for example "RADAR" on the HUD display in figure 3.5-3 or "VULNERABLE" string on the radar display in figure 3.5-2), or adding an icon to a display to represent new information (see "vulnerability" triangle in figure 3.5-2).

Finally, *UI level adaptation* involves global changes to the user interface as a whole or insertion of display elements designed to focus attention on particular areas of the overall UI. Examples of UI level adaptations include a reconfiguration of the entire set of instruments on the UI to reflect a different system mode, increasing the redundancy of warnings (e.g., adding an auditory warning to a visual one, etc.), or the insertion of attention-capturing and attention-directing elements designed to direct the user's attention to a particular icon or display.

Individualized Adaptation All of these strategies are further enhanced and customized by taking into account the user's (e.g., the pilot's) display and modality preferences and implementing the suggested GUI adaptation accordingly. This element is critical to any adaptive approach, due to the large individual differences that exist in human information processing and decision-making. ABAIS allows the specification of multiple pilot information preference profiles, which indicate the individual preferences for presenting information. For example, knowing that a particular pilot has a high-sensitivity to auditory signals, ABAIS suggests that auditory warnings be used to capture attention. In another case, a particular pilot might have a preferred means of capturing attention, for example, by motion on the periphery towards the desired area. Examples of specific pilot profile information from the Phase I demonstration are shown in figure 3.5-4 and table 3.5-1.

Under Phase I this included preferred modality for alarms and notifications, preferred modes of attention capture. The same mechanism can be extended to include preferences for particular icons, particular displays, and display configurations.

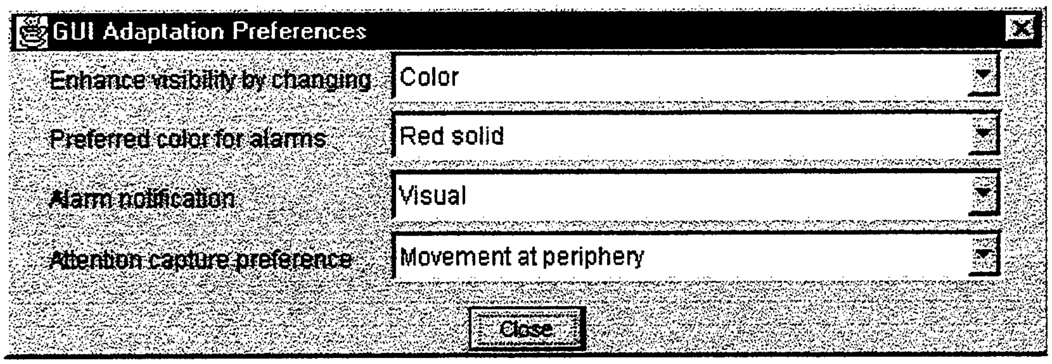


Figure 3.5-4: Pilot Information Preference Profile Dialog Box

Table 3.5-1: Pilot Information Preference Profile

Enhance visibility by changing:	color I size I blinking
Preferred color for alarms:	red solid I red outline
Alarm notification:	visual I auditory
Attention capture preference:	movement at periphery I shift display to foveal region I enhance visibility of icon / display I display arrow pointing to desired icon / display I superimpose blinking icon / display over foveal area

The GUI / DSS adaptation strategies are expressed in abstract terms, and are instantiated within the particular user-task context, taking into consideration the user preference profiles. The GUI/ DSS Adaptation Module performs three sequential functions:

- Identifies additional information required based on selected compensatory strategy
- Selects best information presentation format
- Applies individual information presentation preferences and capabilities (e.g., modality preference, color blindness, etc.).

Examples of specific adaptation rules from the Phase I demonstration are shown in figure 3.5-5.

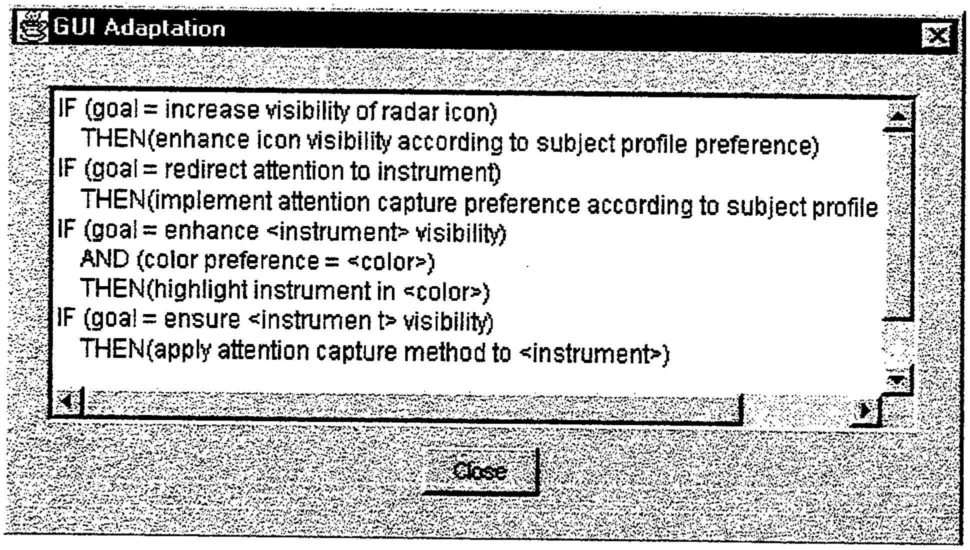


Figure 3.5-5: Examples of ABAIS GUI / DSS Adaptation Rules

3.6 ABAIS Graphical User Interface (GUI)

The ABAIS graphical user interface (GUI) consists of two sets of displays: those representing the cockpit instruments (the pilot's GUI), and those used by the analyst to specify the background information required by ABAIS, to define the run-time parameters, and to monitor system performance during a simulation – adaptation run.

3.6.1 Pilot's GUI

The pilot's GUI (figure 3.6.1-1) consists of four displays, corresponding to the heads-up-display (HUD) (upper portion of the display), a window showing current incoming communication (middle pink window), an alert notification window (middle green window), and the sensor display (bottom portion of display), which combines information from active radar, IFF, NCTR, and RWR, as well as datalink from other friendly aircraft. The arrow on the right side of the display indicates the pilot's presumed current attention focus. These displays, and their associated symbology, are described in detail below.

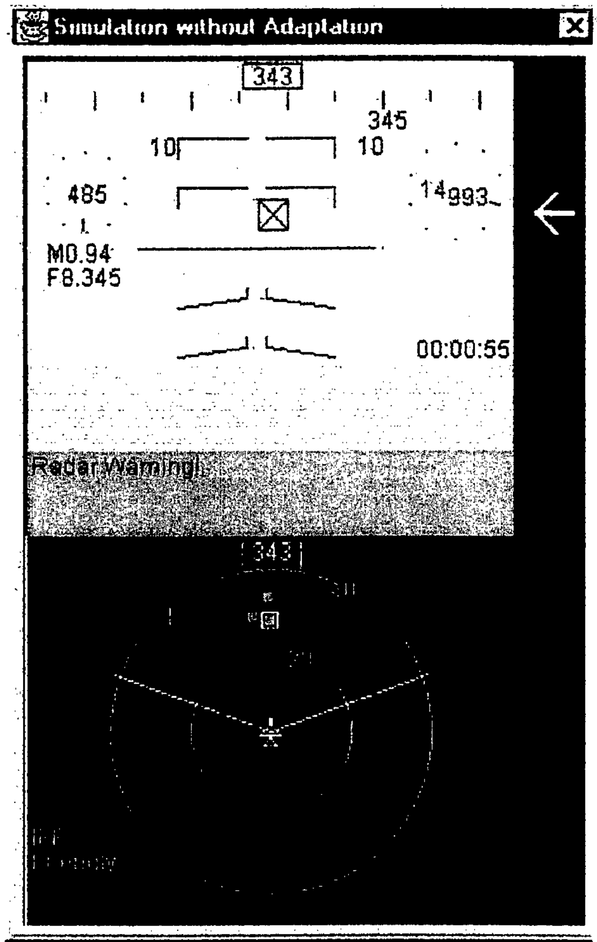


Figure 3.6.1-1: Screenshot of the ABAIS Pilot GUI

HUD Display The heads-up display combines a variety of navigation and sensor information within a single display. The top scale represents the heading indicator and heading ruler. The vertical scale on the left represents the airspeed indicator, showing both knots and a spinning dial, to indicate rate of change in airspeed. Under the speed indicator is the MACH speed, and under the mach speed indicator is the fuel indicator, showing fuel in thousands of pounds. On the right top is the altimeter, with height in feet, and a displacement, surrounded by another spinning dial, again to indicate rate of change in altitude. At the bottom is a clock, indicating current simulation time. A red box near center indicates the location of the current target.

Communication Window Display The communication window displays incoming communication as text strings.

Alert Notification Window Display The alert notification window displays current alarms and notifications as text strings.

Radar Window Display The radar window display combines information from the on-board sensors (active TWS radar, NCTR, and IFF). The own aircraft is shown in the center, with the concentric rings indicating range in miles, using standard radar symbology. The contacts are displayed as filled circles when data are arriving from on-board sensors, and as hollow circles when data are arriving via datalink. The heading of the individual contacts is indicated by the associated lines, with the line lengths corresponding to the contact speed. The sensor display can also show radar locks, both those originating from the friendly aircraft, and those originating from hostile or unknown radars, and appear on the radar as inward-pointing triangles shown on the outer circle of the display. Ground-based radar emitters are shown as rectangles on the outside of the radar display.

Specific contact symbology is depicted as follows: rectangular ship icon means unknown/enemy; circular ship icon means friendly; green ship icon means friendly, red ship icon mean enemy, yellow ship icon means unknown; white box around ship icon indicates that user is targeting that ship. Friendly missiles are represented by white dots, with a radar-lock line pointing from the missile icon to its target.

3.6.2 Analyst's GUI

The analyst's GUI serves three functions:

- It allows specification of all ABAIS *system run-time parameters*, including task script editing and selection, adaptation thresholds, and execution monitoring windows.
- It allows specification of all necessary *background pilot information*.
- It allows display and monitoring of ABAIS *simulation and run-time data*

These are discussed in detail below.

The ABAIS system run begins with the analyst defining the necessary system parameters, specifying any relevant pilot information, and defining the task. The initial ABAIS menu bar is shown in figure 3.6.2-1. This menu provides access to the top level set of commands. The 'File' and 'Window' commands support the definition of task information, task script, and subject profile. 'Simulation Parameters' allow the specification of run-time parameters, controlling display contents and configuration, and the task and subject profile selection. Commands associated with the 'Run' menu control the simulation itself. The parameters are described in more detail below.

Figure 3.6.2-1: Initial ABAIS Menu Bar

ABAIS System Run-Time Parameters System parameters allow the analyst to specify the ABAIS GUI configuration during a system run, and to select and define the task script. The analyst may select which background pilot information is visible during execution (e.g., pilot personality profile, training, individual history, etc.). The analyst also selects which rule bases s/he wishes to see during execution, and specifies the adaptation threshold, which determines, indirectly, whether or not adaptation will take place. Figures 3.6.2-2 shows screen shots of the ABAIS GUI windows that allow the definition of these run-time parameters, and indicates specific parameter values selected.

Prior to a simulation run, the analyst must also select or define a task scenario and associated task parameters. This is done by defining a *task script*, which specifies which events occur during the task and their timing. Several related task parameters are also defined, such as task type and complexity. In the Phase I demonstration, the task script is largely fixed, allowing only a limited selection of specific values from the available possibilities. The task script definition window is used primarily to demonstrate its functionality in a full-scope ABAIS (see figure 3.6.2-3). In a full-scope system, each of the task script cells would allow the selection of specific values from the available set, thereby allowing the definition of a wide variety of experimental scenarios.

The task script defines the entire simulation dynamic environment. That is, the behavior of both the lead pilot and the wingman, the lead pilot's aircraft (i.e., any instrument failures, etc.), enemy aircraft, and any weapon deployment. In the full-scope implementation, each cell in the matrix would have an active associated listbox, which would provide the set of possible values for that cell.

Background Pilot Information Prior to a run, the analyst must specify background information about the pilot. This is a necessary component of the type of individualized adaptation implemented by the ABAIS system. In this Phase I demonstration, these values are entered by the analyst. In a full-scope system, some of these parameters might be entered by the pilot (e.g., self-reports and individual history information), gathered during training tasks (e.g., baseline physiological or diagnostic task data), or collected automatically during an actual system run (e.g., actual physiological signals or diagnostic task results). The analyst must specify the background information necessary for the assessment of the pilot's affective and belief state, and must define the pilot's GUI adaptation profile. This profile specifies the pilot's

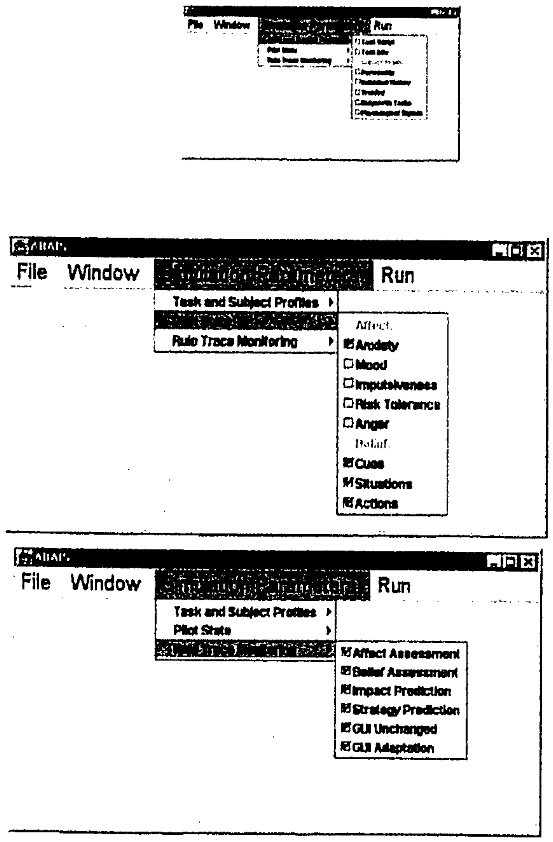


Figure 3.6.2-2: Analyst's GUI Menus Specifying ABAIS System Run-Time Parameters

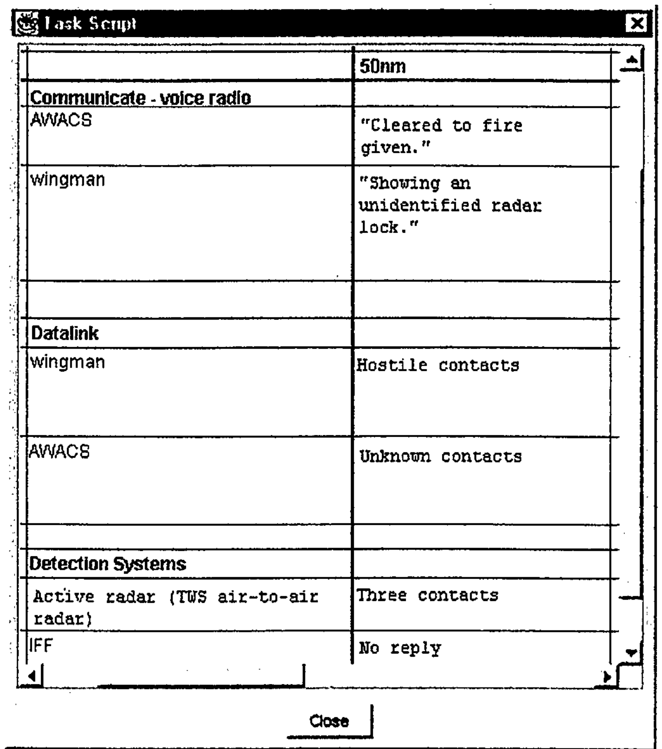


Figure 3.6.2-3: Task Script Definition Window

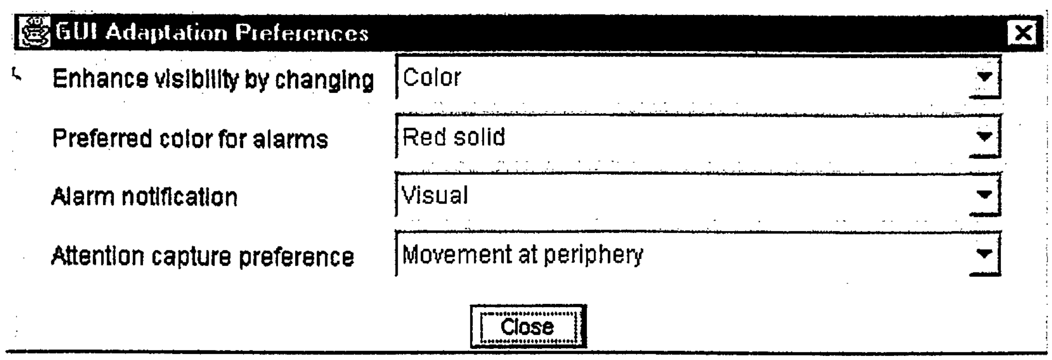


Figure 3.6.2-4: Background Pilot Information: Information Preference Profile

preferred modality and other UI parameters that guide the selection of the specific adaptation method (e.g., use of pilot's preferred sensory modality for notifications, preferred icons and display formats, etc.). Figures 3.6.2-4 and 3.6.2-5 show screen shots of the ABAIS GUI windows that allow specification of this information.

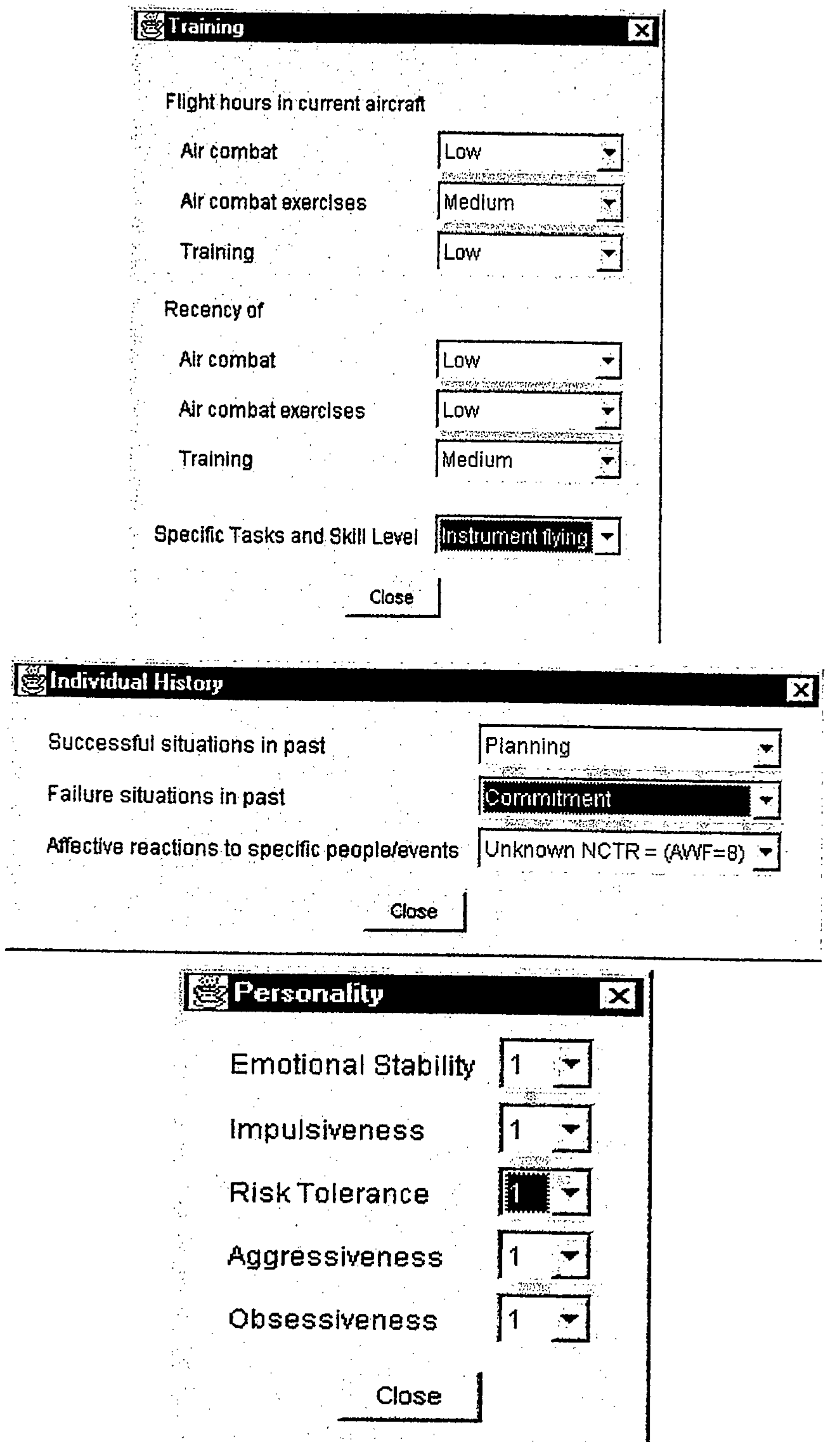


Figure 3.6.2-5: Background Pilot Information: Training, Individual History, and Personality

3.7 Simulation Module

To demonstrate the ABAIS adaptive methodology in the context of an AF sweep task, we integrated the core ABAIS architecture with a flight simulation module. Two modes of simulation are possible: 1) *pilot-as-user* mode, where the user actually flies the aircraft and interacts with a simulated environment consisting of enemy aircraft, other friendly aircraft, and missiles; and 2) *analyst-as-user*, where the analyst watches a scripted task and monitors the scripted pilot's performance, as well as the rule-based inferencing results. Due to the precise timing required to demonstrate the adaptation GUI changes, the emphasis under Phase I was on developing the analyst-as-user mode and the associated script-based simulation, which allows precise control over the external task events necessary to demonstrate the real-time adaptation.

The simulation module output is shown on two windows representing the pilot's GUI, as described in detail in section 3.7 above. One window shows the simulated cockpit displays without adaptation, the other window displays the ABAIS-derived adaptations on the same set of cockpit displays. During a simulation run, these two sets of cockpit displays are synched to the same moment of simulation-time, allowing the analyst to compare and contrast the two as the adaptations take effect during the run.

A third window contains a simple set of run-time controls and is used to control the simulation during the run. The run-time controls allow the analyst to pause the simulation at any point for a more leisurely study of the simulation displays, and of the rule-based inferencing mediating the adaptation.

Modeling of the environment is done within the simulation proper, with the dynamic characteristics of all aircraft (e.g., speed, location, heading), and the instrumentation of the pilot displays, incremented on a continuous basis as time in the simulation progresses. The required aerodynamic calculations, simplified for scripted control, are used to model the scenario aircraft. Instrumentation is a simulation-generated reflection of the environment, with communication, data links and special events introduced as specified by the task script. Scripted events take place at discrete times, modifying the behavior of the friendly and enemy pilots or introducing new elements into the simulation.

Although the demonstration analyst-as-user mode follows a precise script, the simulation is also designed to allow real-time interactive control of the friendly aircraft by the user and non-scripted response by the enemy aircraft.

4. System Operation and Demonstration

The objective of the full-scope ABAIS system is to provide an experimental testbed implementing the generic adaptive methodology. Such a testbed would facilitate the exploration of a variety of assessment and adaptation strategies across a range of task scripts. The system would support both the definition of specific task scripts and rule-bases, and the application of these rules to the selected task script to demonstrate the system adaptive methodology.

During the Phase I effort a limited subset of this functionality was developed, focusing on the analyst's graphical user interface, to provide a look-and-feel of the envisioned system. In this chapter we illustrate the ABAIS system by demonstrating its functionality in the context of the selected scenarios. The ABAIS demonstration runs include the analyst's interaction both prior to a simulation run, where the analyst selects or edits a task script, specifies the necessary pilot information, and defines the system run-time parameters, and during the simulation run, where the analyst monitors system performance via a customized GUI showing the selected rule bases and pilot profile parameters. ABAIS system functionality is demonstrated by illustrating the inferencing supporting system adaptation in the context of the demonstration scenarios. The scenarios were designed to demonstrate multiple points at which a particular affective state, personality trait, or belief can bias processing. ABAIS performance is illustrated by showing the system output, in terms of the pilot GUI's, for several pilot profiles, with and without adaptation, as determined by different adaptation thresholds. The pilot profiles vary in terms of personality characteristics, individual history, training, and simulated physiological signals. The different pilot profiles thus generate different affective and belief states at different points of the scenario. The pilot profiles also specify different preferences for GUI features, resulting in different formats of the information provided as a result of the adaptation.

The demonstration illustrates the ABAIS system functionality across all stages of the adaptive process. The specific GUI / DSS adaptations are derived from a sequence of instantiated rules from the four ABAIS modules. The output of the GUI / DSS adaptation recommendations is shown on the corresponding cockpit instruments.

The ABAIS implementation supports two modes of system operation: 1) *pilot-as-user* mode, where the user actually flies the aircraft and interacts with a simulated environment consisting of enemy aircraft, other friendly aircraft, and missiles; and 2) *analyst-as-user*, where the analyst watches a scripted task and monitors the scripted pilot's performance as well as the rule-based inferencing results. These modes are not entirely mutually exclusive. In other words, the analyst and / or the pilot can specify pilot and system parameters, the pilot can they "fly" the aircraft, and both can watch the system output on simulated cockpit instruments and ABAIS system monitoring windows. Due to the precise coordination required to fly the demonstration script, the ABAIS performance is demonstrated in the analyst-as-user mode, where the aircraft is controlled by a script that emulates the desired pilot behavior.

This chapter is organized as follows. Section 4.1 discusses the affective state, personality characteristics, and beliefs chosen for demonstration of the adaptive methodology. Section 4.2 describes the demonstration scenarios. Section 4.3 illustrates the sequence of steps and the ABAIS adaptation, via a series of screenshots from the ABAIS GUI.

4.1 Selection of Affective States, Personality Characteristics, and Belief States

Anxiety was selected as the primary affect and obsessiveness as the primary personality trait for the Phase I effort. This selection was made in part because much is known about both of these factors and their effect on performance, and in part because both factors can play a role in the types of dynamic, real-time environments that are of interest to the Air Force. Although the fighter pilot population is certainly not in general characterized by a propensity towards anxiety, anxiety can and does occur during combat and can severely influence performance, as evidenced by a number of documented aviation mishaps.

Obsessiveness represents a combination of anxiety and one of the "Big 5" personality traits: the conscientiousness dimension. The effects of obsessiveness on performance have also been studied and provide interesting possibilities for adaptation.

The pilot's relevant belief set is defined by the possible set of situations as described in table 3.2.2.1-1 in section 3.2.2 above. In the specific context of the demonstration scenarios, the possible belief states include identity of contacts (unknown, hostile, friendly), status of own aircraft (under attack or not), status of weapon deployment (attacking or not). This set of beliefs was selected because it adequately represents the possible situations and likely actions in the constrained behavior space of the demonstration scenario.

4.2 Demonstration Scenarios

Key element of a successful ABAIS system demonstration was the selection of an appropriate demonstration scenario. The scenario should satisfy the following criteria:

- **Adequacy** The scenario should provide adequate opportunities for demonstrating key ABAIS affect, personality, and belief assessment and adaptation features.
- **Credibility** The scenario should provide a credible context within which to effectively demonstrate the ABAIS adaptation features. The scenario situations should be capable of inducing varying levels of anxiety and provide opportunity for performance biases due to

selected personality traits and likely beliefs. The scenario should also provide credible opportunities for prediction of likely performance biases and for subsequent adaptation.

- **Feasibility** The scenario implementation must be feasible within the time available for the Phase I effort.
- **Relevance** Last, but not least, the selected scenario should demonstrate ABAIS in an environment of interest to the USAF, and demonstrate its ability to improve decision making performance.

In addition, the task environment as a whole must provide relevant data in an electronic format, to facilitate the type of inferencing necessary for implementing the user assessment and adaptation.

To satisfy these requirements, we have selected a fighter pilot context, and a defined a sweep task scenario within this context. A sweep task represents a situation where stress levels are likely to be high, accurate situation assessment is critical, and consequences of affect- and belief-induced performance biases can be catastrophic, or at best expensive. Two sequential scenario segments within this general contexts were defined, each designed to demonstrate adaptation to a particular combination of affect, personality, or belief-induced performance bias.

The scenario sequence involves two friendly fighter aircraft engaging several unknown and presumed hostile aircraft in the course of a sweep task. Multiple variations within this basic structure provide opportunities to demonstrate varying affective states (e.g., low vs. high anxiety), varying expressions of particular personality traits (e.g., low vs. high obsessive / conscientious), and differences in individual history and training with consequent variations in performance. The aircraft instrumentation is loosely modeled on the F-15 fighter aircraft which is assumed to be equipped with a HUD and datalink connections between the lead, wingman, and an AWACS. Critical data are thus shared between the lead, wingman, and the AWACS pilots.

The ABAIS system is demonstrated in the context of the lead's cockpit and is assumed to be tightly coupled with the detection instruments and the radar and HUD displays. The ABAIS system thus has access to any data appearing on the radar, whether obtained directly from the aircraft sensors, or indirectly from wingman or AWACS via datalink. ABAIS uses these data as the basis for its dynamic inferencing when assessing the pilot's affective and belief state, inferring the adaptation strategy, and implementing the GUI adaptation.

The two scenario segments are described in detail below. Each description is followed by a highlighting of the features that are most relevant for the ABAIS adaptation demonstration.

4.2.1 Scenario #1 - Anxiety-Induced Attention and Perception Bias

The scenario description below is excerpted from Shaw (1998a).

Two aircraft are conducting a sweep mission under the control of AWACS. The aircraft are equipped with track-while-scan (TWS) air-to-air radar, radar warning receiver (RWR), IFF interrogation capability for friendly aircraft, a non-cooperative target recognition (NCTR) capability providing aircraft type identification, and air-to-air datalink among both fighters and AWACS.

This is the first day of the air campaign and the first combat mission for both pilots, so the anxiety level is high. The pilots have been briefed to expect strong enemy fighter opposition. Enemy fighters have long-range radar-guided missiles of capability similar to that of the F-15s. There are also likely to be aircraft of the allied coalition in the area, so either an electronic- or visual identification or clearance from AWACS will be required before any attacks.

AWACS notifies lead pilot by voice radio of unknown number of "probable hostile contacts" 100nm north, headed south at high speed, medium altitude. A datalink target generated by AWACS is displayed on both fighter radars beyond normal radar contact range. The fighters vector north toward the contacts and attempt to acquire radar contacts.

At 70nm range AWACS notifies that contacts are "presumed hostile fighters", continuing on same course at same heading, altitude, airspeed and that the friendly aircraft are cleared to fire with a positive electronic identification (EID) (i.e., IFF or NCTR) . Same information shows up on datalink as before.

At 50nm the lead pilot obtains radar contact with a single target on the nose. This information is provided to the AWACS and the wingman, both verbally and automatically via datalink. The wingman does not yet have radar contact but gets a radar display from information provided by lead via datalink, indicated as datalink targets by hollow icons, in contrast to actual sensor contacts which are solid.

Lead pilot initiates IFF interrogation of target and gets no reply. This may indicate either a faulty IFF interrogator, inoperative friendly target IFF, or hostile aircraft. At 40nm the lead's radar identifies multiple aircraft in the target group: first 2, then 4 separate aircraft. Simultaneously, the wingman calls radar contact with the group, also indicating that he sees 4 aircraft. Another IFF interrogation is attempted with the same negative results. The lead instructs his wingman to attempt IFF interrogation.

At 35nm, approaching maximum missile[4] firing range for both the F-15s and the presumed enemy fighters, the wingman reports "sorted" on the target group, indicating that he has selected the targets in the group that he has been instructed in the brief to target, and negative IFF interrogation.

The automated NCTRs of both aircraft have been operating, but have not yet resolved the target aircraft type. Up to now the targets are identified as "Unknown Type."

At 30nm, just as maximum firing range is reached, the lead's RWR indicates an "Unknown Air-to-Air Radar" lock on the nose, followed shortly by indication of an enemy SAM radar lock-on on the left-front quarter. This information is not transmitted automatically via data link to either the AWACS or the wingman.

The wingman calls, in a high-pitched voice, that he too is targeted by the SAM. Through the blaring RWR audio the lead hears the AWACS controller issue a "cleared to fire." The last part of the transmission is difficult to understand because the wingman makes a simultaneous transmission on the other radio notifying the lead that his NCTR has just provided a "Friendly" ID on one of the targets in the group. Which exact target is not specified and the implication is that all other targets in the group are also friendly.

The above information is also provided to lead's radar automatically via datalink, in addition to the voice radio communication from wingman. The lead is busy "centering the dot" for his missile shot, attempting to target the enemy leader or the first enemy on his side, depending on the established sort, and does not grasp the significance of the wingman's radio call. As the lead aircraft's first missile leaves the rail, the wingman calls "Cease fire, cease fire!"

4.2.1.1 Key Features of Scenario #1

This scenario was designed to demonstrate adaptation to the pilot's heightened state of anxiety and thus provides multiple opportunities for demonstrating the effect of anxiety on attention and perception. These include the presence threatening stimuli (i.e., presumed hostile aircraft, RWR warnings), and the presence of multiple unknown stimuli (e.g., unknown aircraft approaching, RWR warnings). The large number of unknown (i.e., ambiguous) signals provide both a source of anxiety, potential for anxiety- and belief-induced performance bias, and consequent opportunities for adaptation. The ambiguous signals include:

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[4] The friendly missiles are assumed to be AMRAAM missiles, which are guided by the fighter's radar for the first part of a long-range shot. Once the missile is close to its target, it becomes "active" (turns on its own radar) and tracks the target independently. Enemy missiles are assumed to be the AA-12 or equivalent, which are similar in capability and operation to the AMRAAM.

- Both friendly aircraft are being targeted by a SAM
- A number of unknown but presumed hostile aircraft are approaching
- The lead aircraft indicates an unknown air-to-air radar lock
- Unknown but presumed hostile aircraft
- Unknown NCTR
- Unknown IFF signals (no response)
- Unknown RWR

The most critical moment in this scenario occurs when the lead is about to launch a weapon at an approaching friendly aircraft which he has mistaken as hostile. The last sequence of events is as follows:

1. Lead pilot hears the AWACS radio "Cleared to fire" transmission

2. Simultaneously the wingman radios that his NCTR has just provided a friendly ID on one of the targets in the approaching, 'presumed hostile' aircraft - this critical transmission is not heard by the lead.

3. The wingman's' friendly ID NCTR info is provided to the lead via a datalink and appears on his radar.

4. Not expecting this information, and focusing on centering the dot, the lead fails to take notice of this and fires a missile at the friendly aircraft due to his heightened anxiety level.

The ABAIS objective is to prevent the fratricide, by detecting its possibility and adapting the pilot's cockpit GUI to assure that the pilot notices the changed status of the unknown contact from presumed hostile to friendly.

4.2.2 Scenario #2 - Obsessiveness-Induced Performance Bias

The scenario description below is excerpted from Shaw (1998b).

Two aircraft are conducting a sweep mission under the control of AWACS. Aircraft are equipped with track-while-scan (TWS) air-to-air radar, radar warning receiver (RWR), IFF interrogation capability for friendly aircraft, a non-cooperative target recognition (NCTR) capability providing aircraft type identification, and air-to-air datalink among both fighters and AWACS.

This is the second week of the air campaign and the second combat mission for the Lead pilot, while the Wingman has completed several combat missions and been credited with one confirmed "Kill." On the Lead's first combat mission, he had fired a missile at a friendly aircraft by mistake. Ambiguous and inconclusive electronic identification (EID) data had contributed to this mishap. Following that mission the pilot had been grounded and forced to endure a formal Board of Inquiry. He was absolved of total responsibility for the incident, primarily because he had been given firing clearance from his AWACS controller, but the pilot still had received a "letter of reprimand" for his premature decision to fire without a confirmed Hostile EID.

The pilots have been briefed that the enemy fighter force had been severely weakened through attrition and evacuation to a neighboring country, so strong opposition was not expected. Some remaining enemy fighters, however, may still have long-range radar-guided missiles of capability similar to that of the F-15s. There are also likely to be aircraft of the Allied Coalition in the area, so either an electronic- or visual identification will again be required before any attacks.

AWACS notifies lead pilot by voice radio of "possible hostile contacts" 100nm northwest, headed southwest at high speed, low altitude. The Lead confirms, "Roger, Limbo 01 Flight understands possible hostile contacts 330, 100nm, low altitude, high aspect. Turning 330, searching." A datalink target generated by AWACS is displayed on both fighter radars beyond normal radar contact range. The fighters vector 330 degrees toward the contacts and attempt to acquire them on radar.

At 70nm range AWACS notifies that contacts "presumed hostile fighters" and that the friendly aircraft are cleared to fire with a positive electronic identification (EID). The Lead responds, "Limbo 01 Flight understands targets presumed hostile and cleared to fire with positive EID."

At 50nm the lead obtains radar contact with a single target on the nose. This information is provided to the AWACS and the wing both verbally and automatically via datalink. The Wing does not yet have radar contact.

Lead initiates IFF interrogation of the target and gets no reply. This may indicate either faulty IFF interrogator, inoperative friendly target IFF, or hostile aircraft. IFF interrogation is again attempted at 45nm range.

At 40nm the lead's radar identifies two aircraft in the target group, echeloned west. Simultaneously, the Wingman calls radar contact with the group. Another IFF interrogation is attempted with the same negative results. The Lead acknowledges the Wingman's radar contact and instructs him to attempt IFF interrogation.

At 35nm, approaching maximum missile firing range for both friendly aircraft and the presumed enemy fighters, the Wingman reports "sorted" on the target and negative IFF interrogation. The Lead calls the Wingman to "Confirm azimuth sort;" and the Wingman replies in the affirmative. The Leader attempts another IFF interrogation and rechecks his weapons switches, which were set some time previously when entering hostile airspace. The automated NCTRs of both friendly aircraft have been operating, but have not yet resolved the target aircraft type. Up to now the targets are identified as "Unknown Type."

At 30nm, just as maximum firing range is reached, the lead's RWR indicates an "Unknown Air-to-Air Radar" lock on the nose. The Wingman calls on VHF tactical frequency that he too is "spiked." Near simultaneously, on the UHF receiver, Lead hears the AWACS controller issue a "cleared to fire with positive ID." The last part of the transmission is difficult to understand because it is "stepped on" by the Wingman's radio call, so the Lead responds on VHF, "Roger 2, understand spiked." He then queries the AWACS controller on UHF, "Limbo 01 Flight, understand cleared to fire with positive EID. Negative EID at this time." Simultaneously, the Lead attempts another IFF interrogation.

At 25nm the Wingman reports Hostile EID on one target aircraft. The Leader responds, "Roger 2, understand Hostile. Negative ID here." The Lead attempts another IFF interrogation. Although technically now cleared to fire, the Leader hesitates in order to confirm the ID with his own EID systems. IFF interrogation is repeated again at 20nm, just as the Wingman repeats, with added urgency, "Limbo 01, repeat! Limbo 02 has POSITIVE Hostile ID on target. Recommend FOX 3!" Before the Leader can respond, he receives a blaring audio warning from his RWR indicating a hostile air-to-air missile targeted at this aircraft.

4.2.2.2 Key Features of Scenario #2

Scenario #2 was designed to provide opportunities for adaptation to the pilot's heightened obsessiveness, and thus provides multiple opportunities for demonstrating the effect of obsessiveness on decision making. The primary effect here is excessive checking behavior and delayed decision making, which manifest itself in repeated and lengthy confirmations of communication transmissions. Again, as with scenario #1 above, the large number of unknown or ambiguous stimuli provide ample opportunities for expressions of the checking behaviors.

- Possible hostile contacts at 100 nm result in lengthy echoing of information by lead.
- Presumed hostile aircraft at 70 nm and clearance to fire results in another lengthy echoing of status by lead.
- At 35 nm, when wingman reports "sorted", lead asks for unnecessary confirmation of sort type and repeats IFF interrogation. The lead also rechecks his weapons.
- At 30 nm, which is also the maximum firing range, both lead and wingman are spiked by a presumed enemy radar and lead engages in yet another lengthy confirmation of the 'cleared to fire' order from the AWACS.
- Although cleared to fire, at 25 nm lead attempts yet another IFF. Simultaneously wingman

reports positive hostile id on one target aircraft. Leader responds, indicating that his own id remains negative.

- At 20, wingman repeats his positive id and suggests that lead deploy weapon. Simultaneously, the lead receives an RWR warning that he is being attacked by an air-to-air missile.

There are thus a number of points during this scenario where extensive checking behavior occurs, delaying the pilot's decision to deploy the aircraft weapon, and culminating in the most critical moment in this scenario which occurs when the lead aircraft is targeted by an enemy aircraft.

The ABAIS objective is to prevent this situation, by detecting its possibility and adapting the pilot's cockpit GUI to attempt the reduce the checking behavior and induce the pilot to initiate timely weapons deployment.

4.3 System Demonstration: Scenario #1

This section describes in detail the ABAIS simulation for scenario #1. The ABAIS system performance is demonstrated by describing the rule-based reasoning comprising the adaptation sequence, starting with user assessment and culminating with the GUI / DSS adaptations. The scenario is divided into discrete time frames, and ABAIS inferencing and resulting GUI output on the cockpit displays are shown for each time frame. The ABAIS simulation walk-through also illustrates the flexibility of the adaptation, which is controlled by: 1) specific settings of the pilot background information profile to generate varying levels of anxiety (see tables 4.3-1 and 4.3-2); 2) thresholds controlling the level of anxiety required before adaptation is triggered; and 3) specific pilot preference profiles, representing different the pilot information presentation preferences (see table 4.3-3). These parameters give rise to a series of variations, which differ in the number and types of adaptations suggested, as well as the specific formats of these adaptations on the pilot GUI.

The simulation run is presented as a series of discrete frames, where each frame corresponds to a specific time segment of the scenario (see tables 4.3-4 and 4.3-5). Both affect and belief states are derived at each point of the scenario, from both static factors (e.g., personality structure, training, individual history) and dynamic factors (e.g., current number and type of hostile or unknown aircraft, etc.). The rules used to perform the user assessment are shown for each frame.

Two pilot profiles are specified for the demonstration: one representing an anxiety-prone (high-anxious) pilot, the other representing an anxiety tolerant (low-anxious) pilot. These profiles are shown in tables 4.3-1 and 4.3-2. Briefly, the low-anxious pilot is more highly trained, has a more stable personality structure, has less reactive heart rate measures, and an individual history that does not predispose him to anxiety. In contrast to this, the high-anxious pilot has less training and recency, has a less stable personality structure as reflected in both a lower score on the emotional stability scale and a more reactive physiological profile, and has an individual history that predisposes him to anxiety in particular situations.

In addition to specifying background information allowing the assessment of the pilot's affective and belief states, pilot profiles also allow the specification of GUI presentation preferences. Thus the same recommended adaptation (e.g., "Enhance unknown target display") can appear in multiple formats, depending on the pilot's presentation preference (e.g., highlight icon in a particular color, change icon size, generate an auditory notification, etc.). Examples of presentation profiles used for the demonstration are shown in table 4.3-3.

Table 4.3-1: Anxiety Tolerant (Low-Anxious) Pilot Profile

Personality factors
Emotional stability = high
Training / Proficiency factors
air combat hours = high
air combat exercises hours =high
training hours = high
recency of air combat hours = high
recency of air combat exercises hours = high
training hours = high
Specific events in individual history contributing to anxiety
SAM lock
Centering the dot

Table 4.3-2: Anxiety Prone (High-Anxious) Pilot Profile

Personality factors
Emotional stability = low
Training / Proficiency factors
air combat hours = low
air combat exercises hours = low
training hours = low
recency of air combat hours = low
recency of air combat exercises hours = low
training hours = low
Specific events in individual history contributing to anxiety
Cleared to fire
Unknown type from NCTR
Unsuccessful IFF interrogation
Unknown RWR radar lock
SAM lock
"Centering the dot"

Table 4.3-3: Examples of Different Pilot Presentation Preference Profiles

Profile #1	
Enhance visibility by changing:	color
Preferred color for alarms:	red solid
Alarm notification:	visual
Attention capture preference:	display over foveal area
Profile #2	
Enhance visibility by changing:	size
Preferred color for alarms:	red outline
Alarm notification:	visual
Attention capture preference:	display arrow pointing to icon
Profile #3	
Enhance visibility by changing:	color and size
Preferred color for alarms:	red solid
Alarm notification:	visual and auditory
Attention capture preference:	movement at periphery

The scenario is summarized in two tables, highlighting different aspects of the demonstration. These tables provide overview of ABAIS processing during the demonstration scenario, indicating critical external events and corresponding ABAIS processing for each time frame of the script. Table 4.3-4 shows the incoming data which serve a primary cues for belief derivation and also as input to the affect assessment rule base. This table also indicates the pilot's physiological signals (i.e., heart rate measures) and shows the ABAIS inferred belief and affective state for both the low and the high-anxious pilot. Table 4.3-5 summarizes the scenario again, this time showing the system output for the high-anxious pilot and indicating the inferred affect and belief state, predicted impact of these states on performance, selected adaptation strategy, and specific GUI / DSS modifications implementing this strategy, and specific format of the GUI modifications as defined by the pilot presentation preference profile. The actual pilot's GUI (selected cockpit instruments), and the analyst GUI for the last critical frames where adaptations occur, are shown in ABAIS screenshots. Each of these frames thus shows the analyst GUI with the selected information (e.g., task script events, rule base monitors, pilot physiological signals, etc.), cockpit instruments indicating the incoming data on the corresponding displays (e.g., approaching hostile targets, etc.), the inferred pilot affective and belief states, and the GUI adaptations, if any.

Table 4.3-4: Summary of Demonstration Scenario: Incoming Cues and Pilot's Physiological Signals, Inferred Belief and Affective States for Low and High-Anxious Pilot

Time Frame	New data / cues	Heart rate signals		Inferred Belief		Affective State	
		Low anxious	*High anxious*	*Low anxious*	*High anxious*	*Low anxious*	*High anxious*
1: 100 nm	AWACS: probable hostile contacts	HR nml	HR nml	Unknown contacts	Unknown contacts	low	low
2: 70 nm	AWACS: probable hostile contacts; cleared to fire w/ pos EID	HR nml	HR inc	Unknown contacts	Hostile contacts	low	low-med
3: 50 nm	own: active radar single contact; NCTR unk; attempt IFF	HR nml	HR inc	Probable hostile contacts	Hostile contacts	low	low-med
4: 40 nm	own: active radar 4 targets; NCTR unk	HR inc	HR inc	Probable hostile contacts	Hostile contacts	low	med
5: 37 nm	NCTR unk; attempt IFF - no reply;	HR nml	HR inc	Probable hostile contacts	Hostile contacts	low	med
6: 35 nm	wing: negative IFF own: NCTR unk	HR nml	HR inc	Probable hostile contacts	Hostile contacts	low	med
7: 30 nm	own: RWR unk air-to-air radar lock; hostile SAM lock	HR inc	HR inc	Hostile contacts	Hostile contacts; Under attack	low-med	med-high

Table 4.3-4: Summary of Demonstration Scenario: Incoming Cues and Pilot's Physiological Signals, Inferred Belief and Affective States for Low and High-Anxious Pilot (cont.)

Time Frame	New data / cues	Heart rate signals		Inferred Belief		Affective State	
		Low anxious	*High anxious*	*Low anxious*	*High anxious*	*Low anxious*	*High anxious*
8: < 30nm	own: RWR unk air-to-air radar lock AWACS: cleared to fire wing: unk air-to-air radar lock	HR inc	HR inc	Hostile contacts	Hostile contacts; Under attack	low-med	med-high
9: <<30nm	own: RWR unk air-to-air radar lock; **centering the dot** AWACS: cleared to fire wing: friendly ID on target	HR inc	HR max	Hostile contacts; Under attack	Hostile contacts; Under attack	low-med	high
10: <<< 30	**own:** ***low anx*** **- notice friendly ID** ***high anx*****- fire missile** wing: "Cease fire, Cease fire"	HR inc	HR max	Friendly contacts	Hostile contacts; Under attack; Attacking	low-med	high

Table 4.3-5: Summary of Demonstration Scenario: Inferred Belief and Affective States and Predicted Influence, Compensatory Strategy, and GUI / DSS Adaptation

Time Frame	Inferred Belief	Affective State	Predicted Impact	Selected Strategy	GUI / DSS Adaptation
		Anxiety			
1: 100 nm	Unknown contacts	low			
2: 70 nm	Hostile contacts	low-med			
3: 50 nm	Hostile contacts	low-med			
4: 40 nm	Hostile contacts	med			
5: 37 nm	Hostile contacts	med			
5: 35 nm	Hostile contacts	med			
6: 30 nm	Hostile contacts	med-high	Threat estimation bias (unknown NCTR; neg IFF) selects threat interpretation (i.e., hostile contacts)	Emphasize unknown target status	Subject Profile #1: Enlarge icon size Subject Profile #2: Highlight icon w/ color
7: < 30nm	Hostile contacts; Under attack	med-high	Threat estimation bias (unknown RWR) selects threat interpretation (i.e., under attack)	Emphasize unknown target status;	Subject Profile #1: Enlarge icon size Subject Profile #2: Highlight icon w/ color Both subjects: Display that aircraft is NOT within range of enemy missiles

Table 4.3-5: Summary of Demonstration Scenario: Inferred Belief and Affective States and Predicted Influence, Compensatory Strategy, and GUI / DSS Adaptation (cont.)

Time Frame	Inferred Belief	Affective State	Predicted Impact	Selected Strategy	GUI / DSS Adaptation
8: <<30nm	Hostile contacts; Under attack	high	Narrowed focus on HUD; Miss incoming "friendly ID"	Redirect focus to radar; Emphasize change in status or target	Subject Profile #1: - Display string over HUD to look at radar - Change target to friendly icon, enlarge size Subject Profile #2: - Display arrow over HUD pointing towards radar - Change target to friendly icon, display string "Changed status"
9: <<< 30	Hostile contacts; Under attack; Attacking	high			

The remainder of this section shows the rules used to derive the ABAIS output at each stage of the adaptation process, the associated data driving the inferencing, and the actual GUI modifications, for each frame of the simulation.

The detailed description below is organized to follow the sequence data flow through the ABAIS system modules. The description is provided from the point of view of the lead aircraft for the high-anxious pilot and indicates the source of cues when these are arriving from other than the lead's own sensors. *First,* the salient cues arriving from the dynamic task environment are listed, followed by a description of the affect and belief assessment, showing examples of instantiated rules used for the assessment. *Second,* the rules that map the resulting identified affect and belief states onto their predicted effects on performance are listed. *Third,* the rules that map the predicted effects on performance onto selected strategy are listed. *Finally,* the rules that map the selected strategy onto an specific adaptation are listed. These rules are combined with the pilot information preference profile to arrive at the final set of GUI modifications displayed to the pilot. The resulting cockpit instrument GUI is then shown.

Recall that the User Assessment rules use the following information as the basis for inferencing:

- *Static factors* provided by analyst or pilot prior to run and calculated at the beginning of the simulation run (task context factors, personality factors, training / proficiency)
- *Dynamic factors* , generated during the run based on dynamic task environment and / or information known about pilot (external events factors, individual history, physiological signals)

Rules using *static factors* are instantiated once, at the beginning of the task script, to determine the contribution of the static factors to the overall anxiety level. The contributions of these rules to the overall anxiety level of belief state remains constant throughout a given scenario. Rules using *dynamic factors* are instantiated at each frame of the task script, to determine their contribution to the anxiety weight factor during that frame. The static rules for this scenario are shown in table 4.3-6. The dynamic rules, and their associated triggering cues, are shown in the respective time frames in the detailed simulation description below.

Table 4.3-6: Static Factors User Assessment Rules

Task context factors	
IF (task type = Detection)	THEN (anxiety weight factor = 3)
IF (task complexity = med)	THEN (anxiety weight factor = 5)
IF (weather = clear)	THEN (anxiety weight factor = 0)
IF (light conditions = light)	THEN (anxiety weight factor = 0)
Personality factors	
IF (emotional stability = low)	THEN (anxiety weight factor = 10)
Training / Proficiency factors	
IF (air combat hours = low)	THEN (anxiety weight factor = 6)
IF (air combat exercises hours = low)	THEN (anxiety weight factor = 7)
IF (training hours = low)	THEN (anxiety weight factor = 4)
IF (recency of air combat hours = low)	THEN (anxiety weight factor = 9)
IF (recency of air combat exercises hours = low)	THEN (anxiety weight factor = 7)
IF (training hours = low)	THEN (anxiety weight factor = 6)

The critical time segments of the scenario, that is, those demonstrating the ABAIS GUI adaptations, begin at frame 7, which occurs at 30 nautical miles. During this segment of the scenario the wingman datalink provides a "Friendly ID" on one of the contacts in the presumed-hostile contact group. The high-anxious pilot does not notice this information and, in the non-adapted version, deploys the weapon against the presumed hostile aircraft. In the adapted version, this fratricide is prevented by implementing the ABAIS-recommended GUI adaptations; namely, emphasizing the IFF return and directing the pilot's attention to the radar display, away from the limited HUD display and from readying the weapon.

The discussion below describe in detail the ABAIS performance for each frame during a simulation involving a high-anxious pilot. For each frame, representative screenshots are shown, displaying the incoming cues, subsets of the instantiated rule sets for affect and belief assessment, impact prediction, strategy selection, and GUI adaptation. For those frames where adaptations are generated, both the adapted and the non-adapted pilot GUI's are shown, otherwise only one pilot GUI is shown. Note that not all states of anxiety induce visible GUI adaptations in the discussion below, since the actual display of the GUI / DSS adaptations is controlled by the adaptation threshold, whose value is set by the analyst prior to each run. In other words, if the adaptation threshold is set of 'high', then adaptations will only be displayed when anxiety level reaches the 'high' value.

Figure 4.3-1 shows the pilot's GUI at the beginning of the scenario simulation. (Since at this point there is no difference between the adapted and the non-adapted GUI, only one screenshot is shown.)

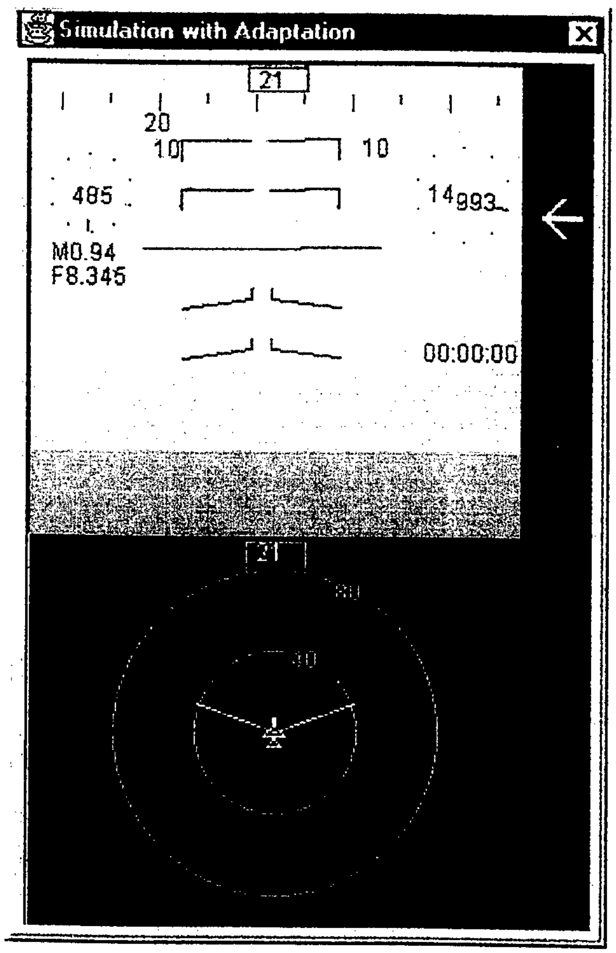

Figure 4.3-1: Pilot's GUI at the Start of the Simulation Run

The remainder of this section describes in detail the simulation run implementing Scenario #1. Refer to tables 4.3-4 and 4.3-5 for summaries of the arriving cues, and the affect and belief states of the low- and high-anxious pilots.

4.3.1 Scenario 1 - Frame 1 - 100 nm

Figure 4.3.1-1 shows a screenshot of the ABAIS cue monitoring window, showing the cues arriving during frame 1. These cues, along with pilot background information, provide the data for the affect and belief assessment rules. Figure 4.3.1-2 shows a subset of the affect assessment rules instantiated during frame 1. Figure 4.3.1-3 a subset of the belief assessment rules instantiated during frame 1. Table 4.3.1-1 shows the actual environment and the pilot's belief and anxiety level, as assessed by ABAIS. Finally, figure 4.3.1-4 shows the pilot's GUI during frame 1. Again, since at this point there is no difference between the adapted and non-adapted GUI, only one screenshot is shown.

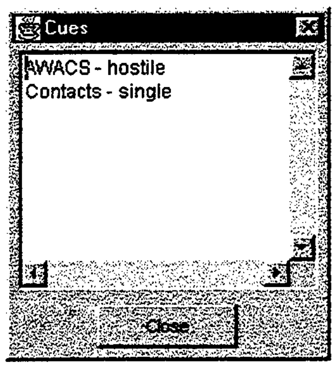

Figure 4.3.1-1: Cues Arriving During Frame 1 of Simulation Run

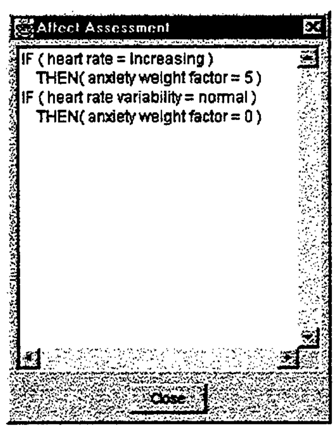

Figure 4.3.1-2: Subset of Affect Assessment Rules Instantiated During Frame 1 of Simulation Run

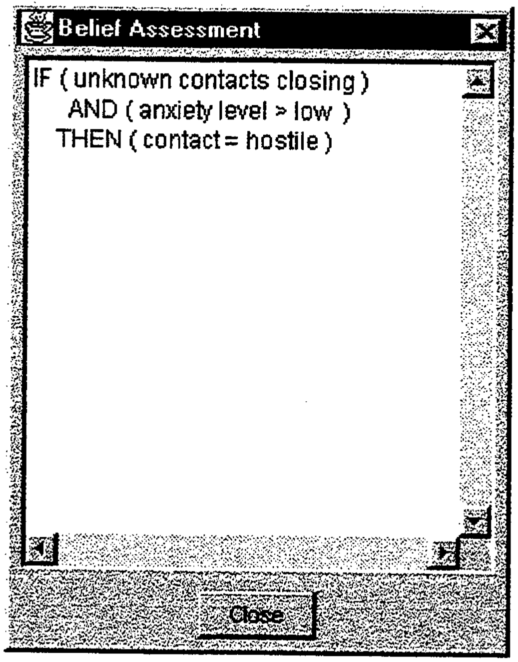

Figure 4.3.1-3: Subset of Belief Assessment Rules Instantiated During Frame 1 of Simulation Run

Table 4.3.1-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Anxiety State
Probable hostile contacts	Unknown contacts	Low

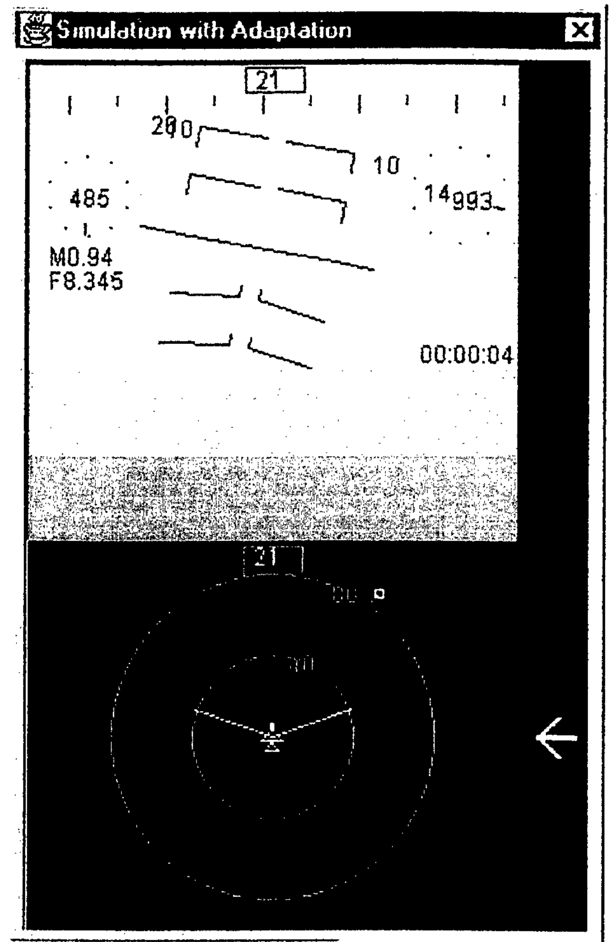

Figure 4.3.1-4: Pilot's GUI at Frame 1 of Simulation Run

4.3.2 Scenario 1 - Frame 2- 70nm

Figure 4.3.2-1 shows a screenshot of the ABAIS cue monitoring window, showing the cues arriving during frame 2. These cues, along with pilot background information, provide the data for the affect and belief assessment rules. Figure 4.3.2-2 shows a subset of the affect assessment rules instantiated during frame. Figure 4.3.2-3 shows a subset of the belief assessment rules instantiated during this frame. Table 4.3.2-1 shows the actual environment and the pilot's belief and anxiety level, as assessed by ABAIS. Finally, figure 4.3.2-4 shows the pilot's GUI during frame 2. Again, since at this point there is no difference between the adapted and non-adapted GUI, only one screenshot is shown.

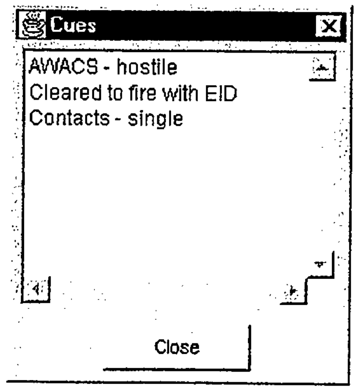

Figure 4.3.2-1: Cues Arriving During Frame 2 of Simulation Run

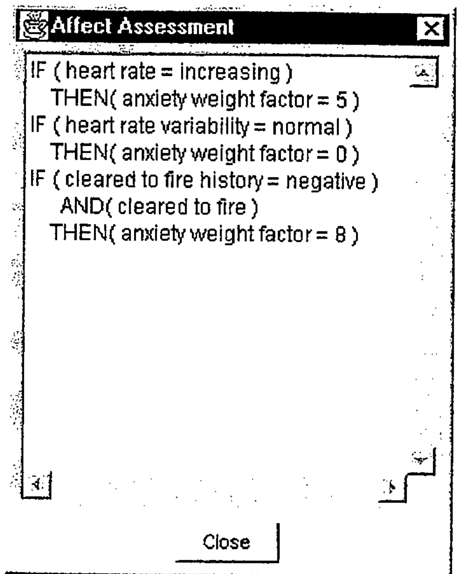

Figure 4.3.2-2: Subset of Affect Assessment Rules Instantiated During Frame 2 of Simulation Run

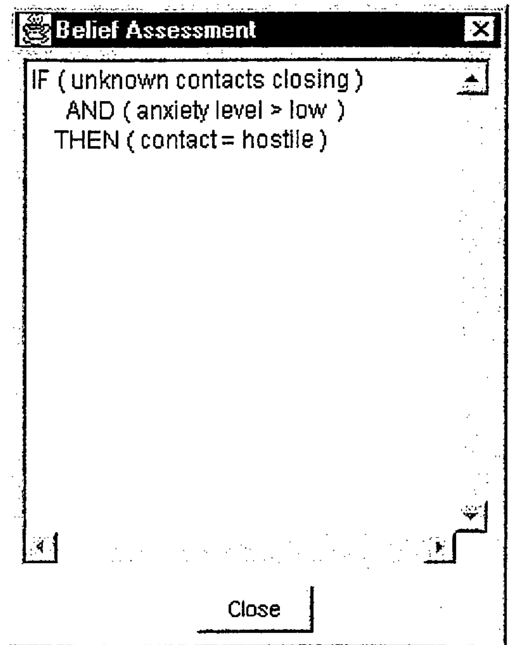

Figure 4.3.2-3: Subset of Belief Assessment Rules Instantiated During Frame 2 of Simulation Run

Table 4.3.2-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Affective State
Probable hostile contacts	Hostile contacts	Low-med

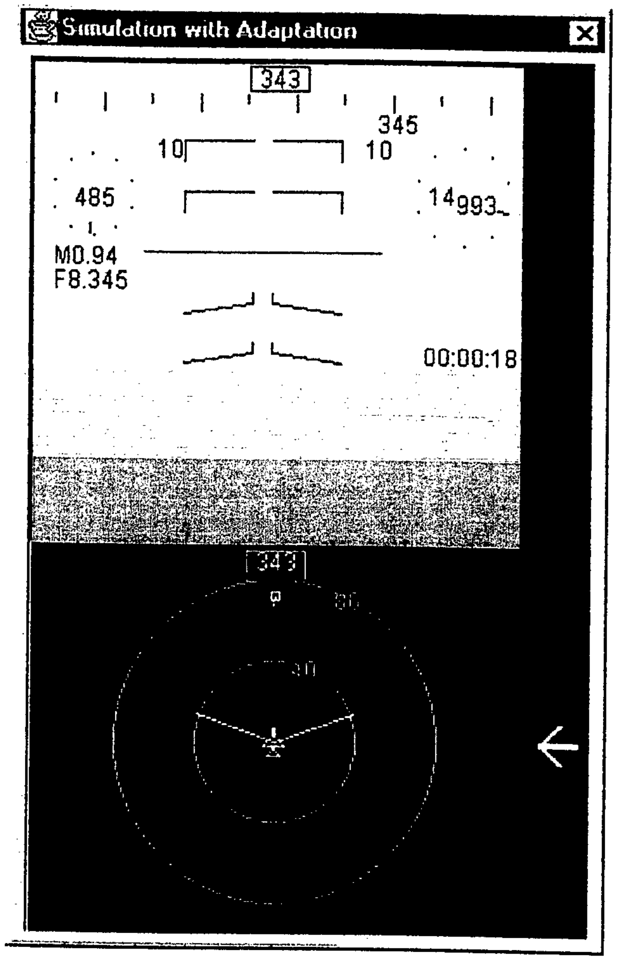

Figure 4.3.2-4: Pilot's GUI at Frame 2 of Simulation Run

4.3.3 Scenario 1 - Frame 3 - 50 nm

Figure 4.3.3-1 shows a screenshot of the ABAIS cue monitoring window, showing the cues arriving during frame 3. These cues, along with pilot background information, provide the data for the affect and belief assessment rules. Figure 4.3.3-2 shows a subset of the affect assessment rules instantiated during frame 3. Figure 4.3.3-3 a subset of the belief assessment rules instantiated during frame 3. Table 4.3.3-1 shows the actual environment and the pilot's belief and anxiety level, as assessed by ABAIS. Finally, figure 4.3.3-4 shows the pilot's GUI during frame 3. Again, since at this point there is no difference between the adapted and non-adapted GUI, only one screenshot is shown.

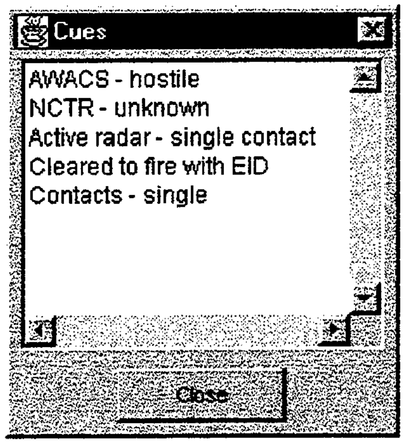

Figure 4.3.3-1: Cues Arriving During Frame 3 of Simulation Run

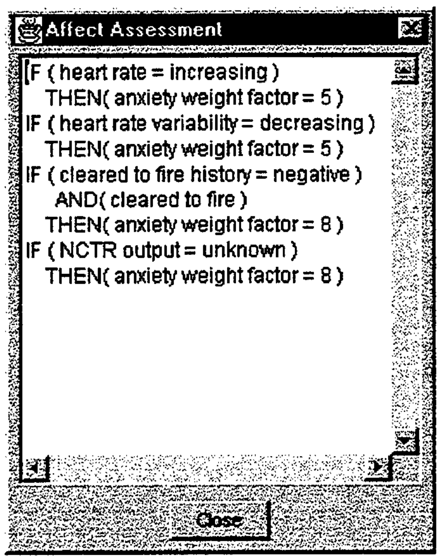

Figure 4.3.3-2: Subset of Affect Assessment Rules Instantiated During Frame 3 of Simulation Run

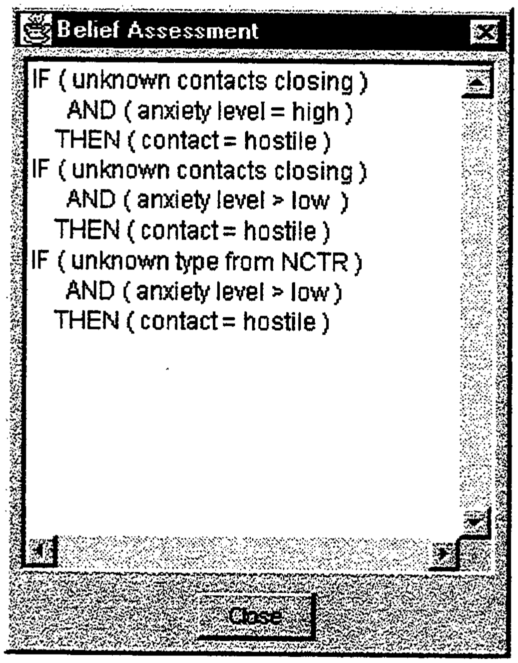

Figure 4.3.3-3: Subset of Belief Assessment Rules Instantiated During Frame 3 of Simulation Run

Table 4.3.3-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Affective State
Probable hostile contacts	Hostile contacts	Low-med

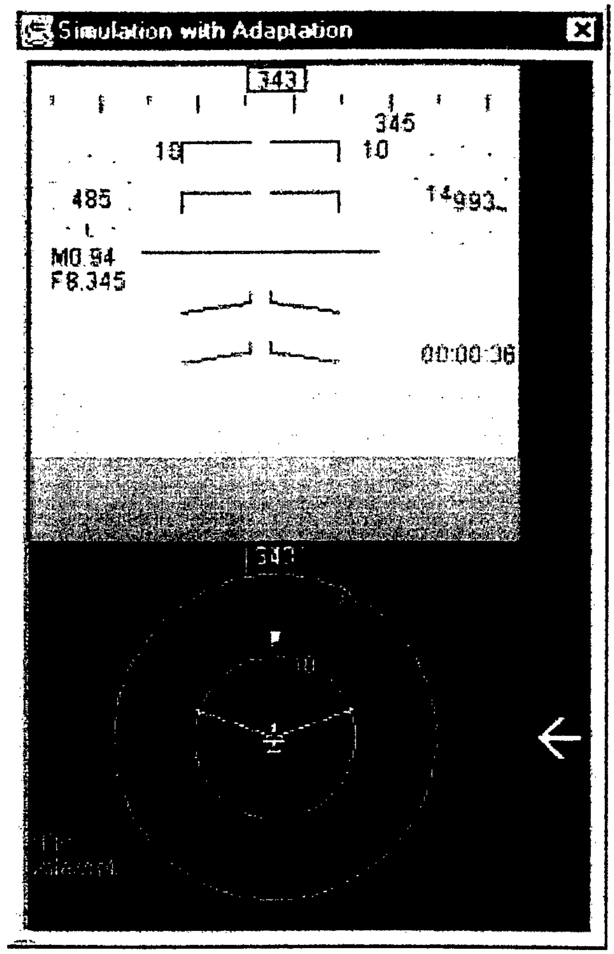

Figure 4.3.3-4: Pilot's GUI at Frame 3 of Simulation Run

4.3.4 Scenario 1 - Frame 4 - 40 nm

Figure 4.3.4-1 shows a screenshot of the ABAIS cue monitoring window, showing the cues arriving during frame 4 of the simulation run. These cues, along with pilot background information, provide the data for the affect and belief assessment rules. Figure 4.3.4-2 shows a subset of the affect assessment rules instantiated during frame 4 of the simulation run, and figure 4.3.4-3 shows a subset of the belief assessment rules. Table 4.3.1-1 shows the actual environment and the pilot's belief and anxiety level, as assessed by ABAIS. Figure 4.3.2-4 shows a subset of the impact prediction rules instantiated during this frame, and figure 4.3.4-5 shows a subset of the strategy selection rules. Finally, figures 4.3.4-6 and 4.3.4-7 show the pilot's GUI, the non-adapted and the adapted versions, respectively.

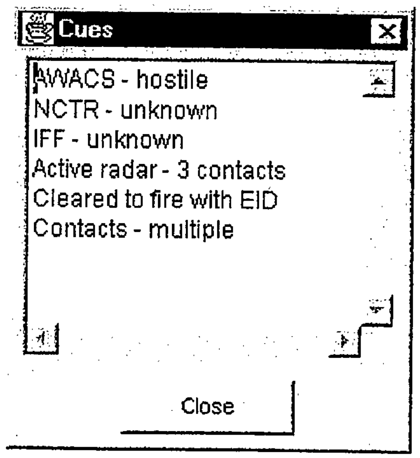

Figure 4.3.4-1: Cues Arriving During Frame 4 of Simulation Run

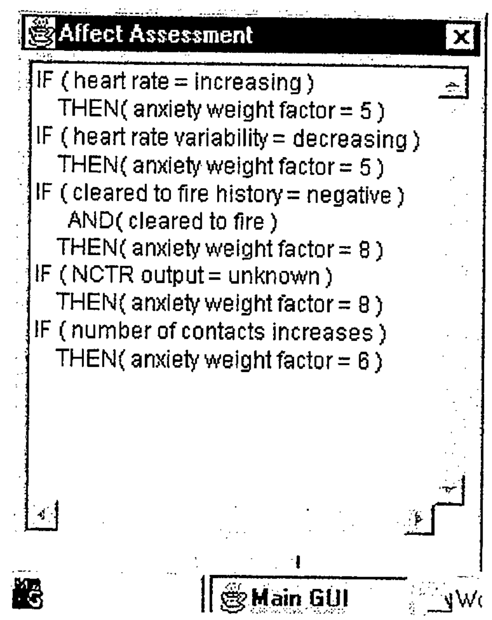

Figure 4.3.4-2: Subset of Affect Assessment Rules Instantiated During Frame 4 of Simulation Run

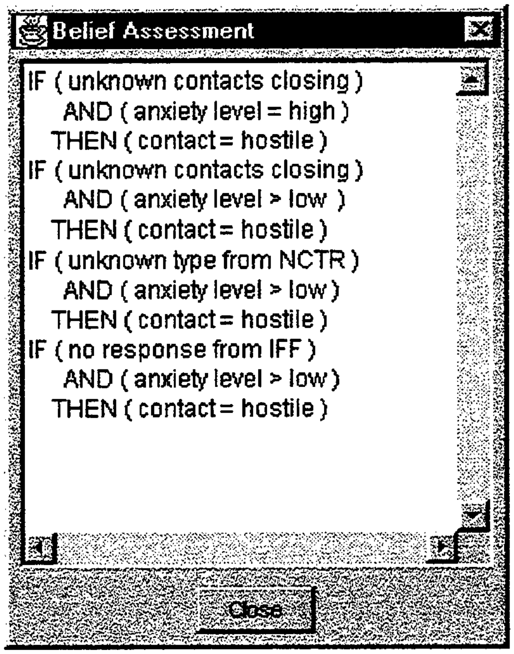

Figure 4.3.4-3: Subset of Belief Assessment Rules Instantiated During Frame 4 of Simulation Run

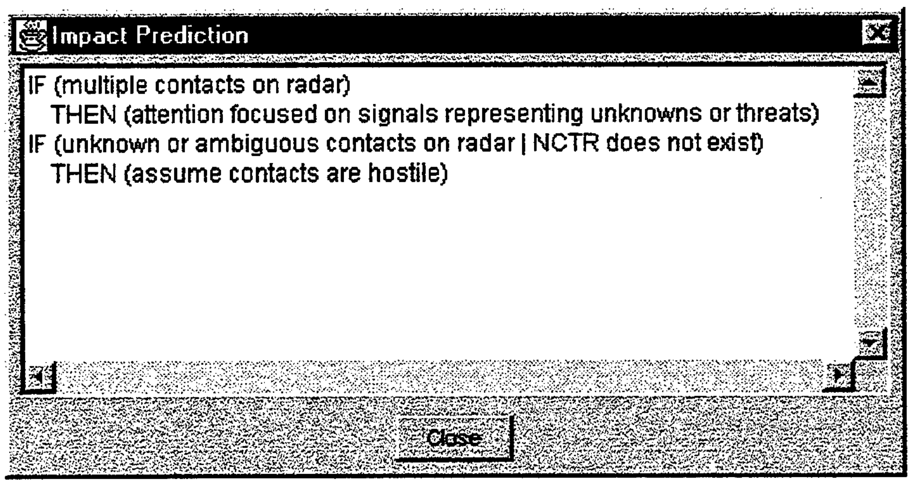

Figure 4.3.4-4: Subset of Impact Prediction Rules Instantiated During Frame 4 of the Simulation Run

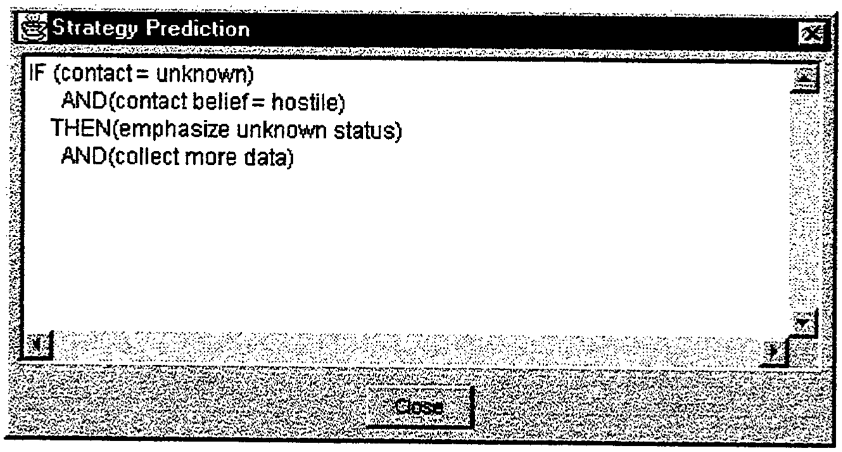

Figure 4.3.4-5: Subset of Strategy Selection Rules Instantiated During Frame 4 of Simulation Run

Table 4.3.4-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Affective State
Probable hostile contacts	Probable hostile contacts	Med

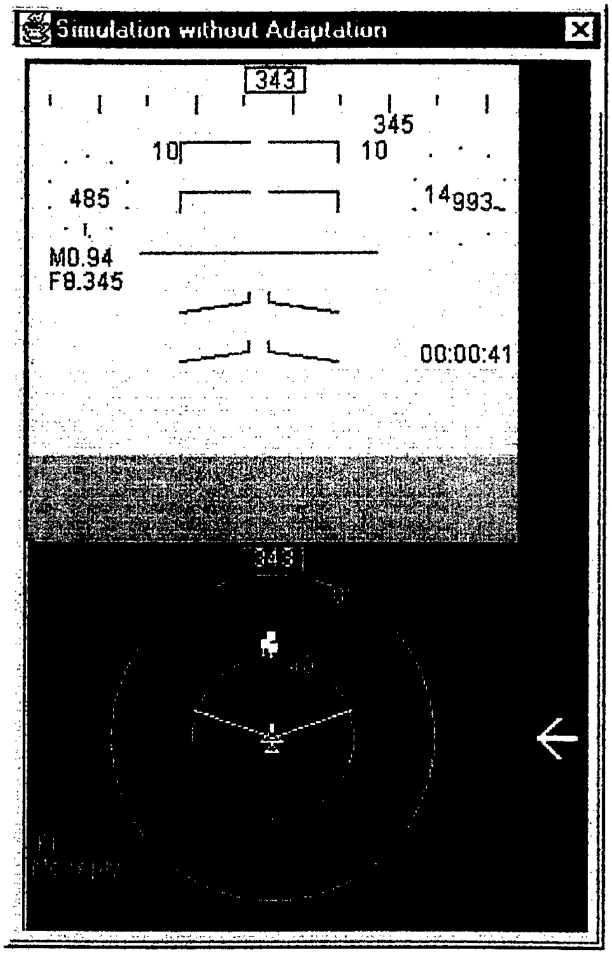

Figure 4.3.4-6: Pilot's GUI at Frame 4 of Simulation Run: Non-Adapted Version

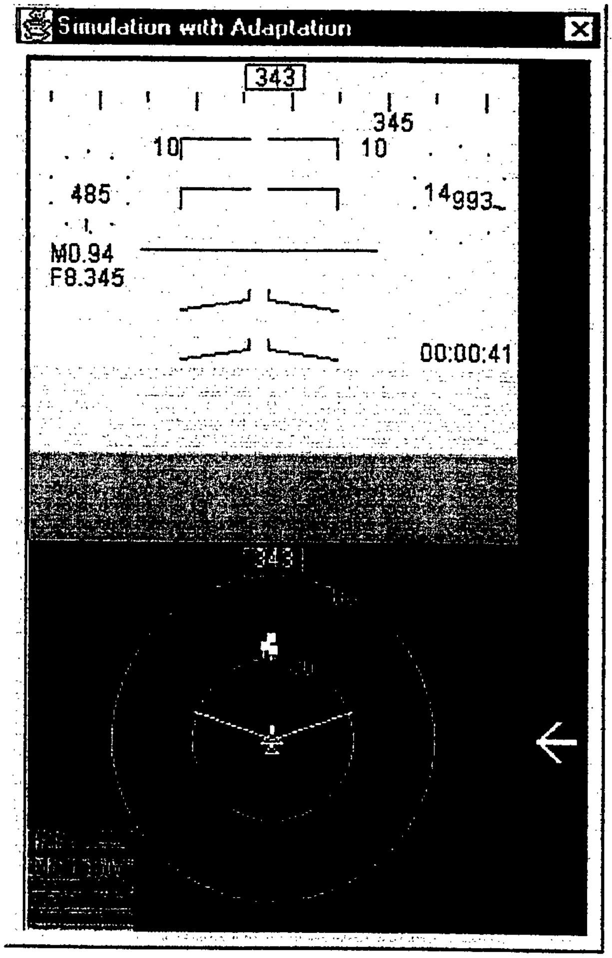

Figure 4.3.4-7: Pilot's GUI at Frame 4 of Simulation Run: Adapted Version

4.3.5 Scenario 1 - Frame 5 - 37nm

ABAIS inferencing and GUI remain largely unchanged during this frame. The pilot's anxiety level remains at 'medium', his belief state remains at 'hostile contacts'; in other words, the pilot is interpreting the unknown probable hostile contacts as in fact hostile. Table 4.3.5-1 shows the actual environment and the pilot's belief and anxiety level, as assessed by ABAIS. The cockpit instruments remain unchanged from those shown in frame 4 above.

Table 4.3.5-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Affective State
Probable hostile contacts	Hostile contacts	Med

4.3.6 Scenario 1 - Frame 6 - 35 nm

ABAIS inferencing and GUI remain largely unchanged during this frame. The pilot's anxiety level remains at 'medium', his belief state remains at 'hostile contacts'; in other words, the pilot is interpreting the unknown probable hostile contacts as in fact hostile. Table 4.3.6-1 shows the actual environment and the pilot's belief and anxiety level, as assessed by ABAIS. The cockpit instruments remain unchanged from those shown in frame 4 above.

Table 4.3.6-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Affective State
Probable hostile contacts	Hostile contacts	Med

4.3.7 Scenario 1 – Frame 7 - 30 nm

Figure 4.3.7-1 shows a screenshot of the ABAIS cue monitoring window, showing the cues arriving during frame 7. These cues, along with pilot background information, provide the data for the affect and belief assessment rules. Figure 4.3.7-2 shows a subset of the affect assessment rules instantiated during frame 7. Figure 4.3.7-3 a subset of the belief assessment rules instantiated during frame 7. Table 4.3.7-1 shows the actual environment and the pilot's belief and anxiety level, as assessed by ABAIS. Figure 4.3.7-4 shows a subset of the strategy suggestion rules instantiated during this frame. At this stage the pilot's attention is focused on the alert window, informing him of a radar lock. The adaptation rules direct ABAIS to emphasize the unknown status of the IFF, to prevent possible task neglect. Figures 4.3.7-5 and 4.3.7-6 show the pilot's GUI, the non-adapted and the adapted versions, respectively.

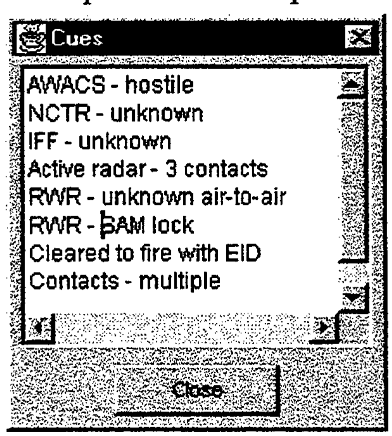

Figure 4.3.7-1: Cues Arriving During Frame 7 of Simulation Run

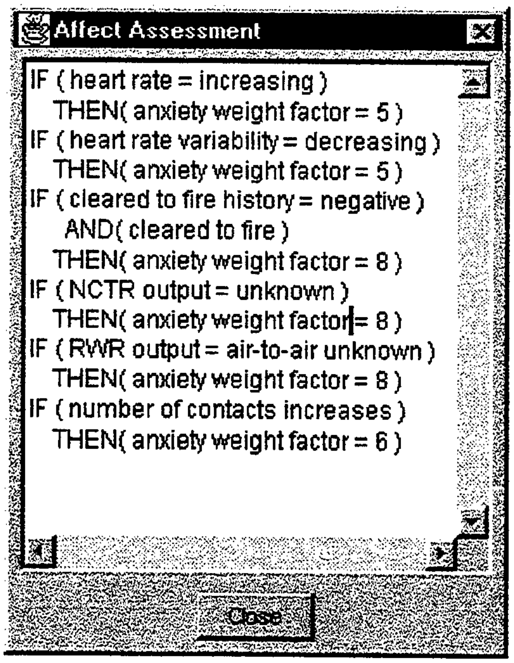

Figure 4.3.7-2: Subset of Affect Assessment Rules Instantiated During Frame 7 of Simulation Run

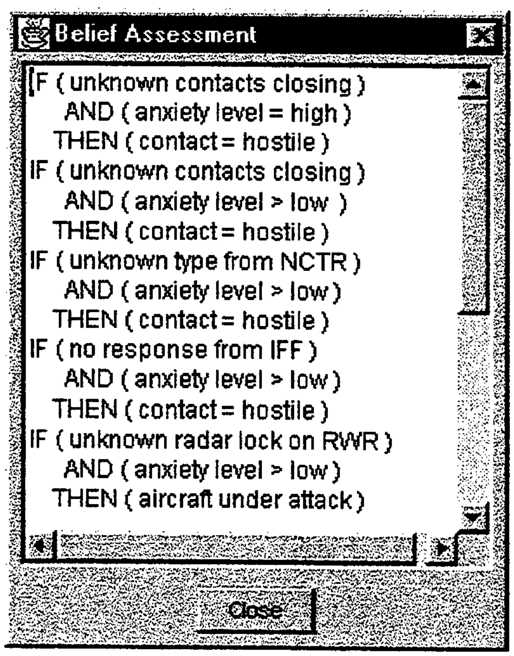

Figure 4.3.7-3: Subset of Belief Assessment Rules Instantiated During Frame 7 of Simulation Run

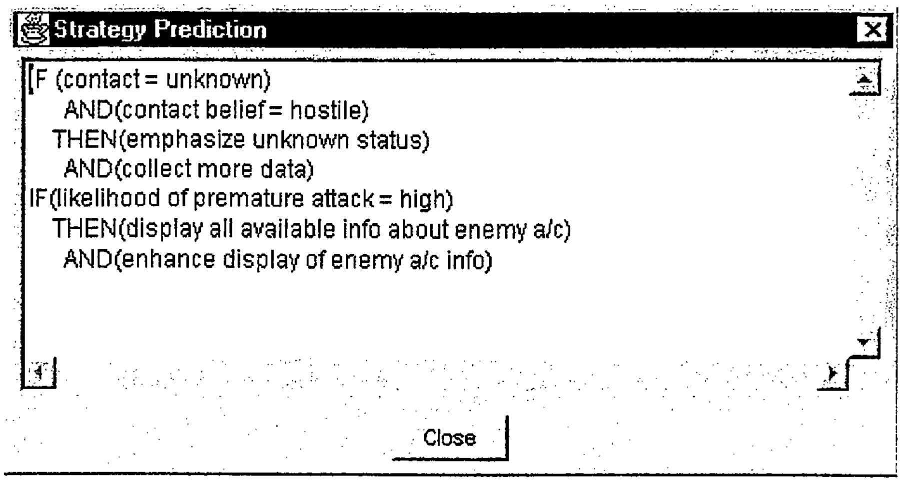

Figure 4.3.7-4 Subset of Strategy Suggestion Rules Instantiated During Frame 7 of Simulation Run

Table 4.3.7-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Affective State
Probable hostile contacts	Hostile contacts Under attack	Med-high

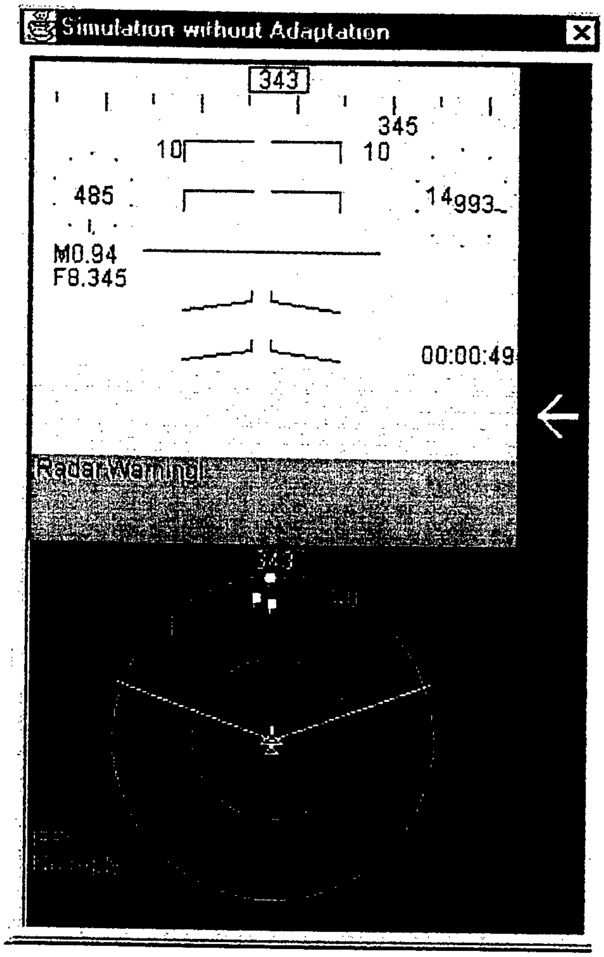

Figure 4.3.7-5: Pilot's GUI at Frame 7 of Simulation Run: Non-Adapted Version

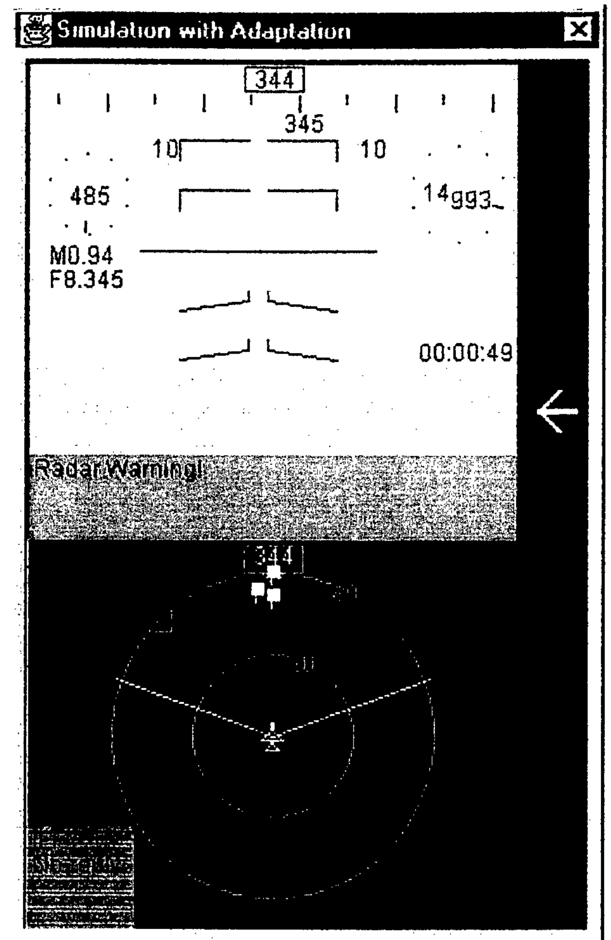

Figure 4.3.7-6: Pilot's GUI at Frame 7 of Simulation Run: Adapted Version

4.3.8 Scenario 1 - Frame 8 < 30 nm

Figure 4.3.8-1 shows a screenshot of the ABAIS cue monitoring window, showing the cues arriving during frame 8. Figure 4.3.8-2 shows the actions being performed by the pilot during this frame. Figure 4.3.8-3 a subset of the belief assessment rules instantiated during frame 8. Figure 4.3.8-4 shows a subset of the impact prediction rules instantiated during this frame and figure 4.3.8-5 shows a subset of the strategy selection rules instantiated. Figure 4.3.8-6 shows a subset of the GUI Adaptation rules instantiated during this frame. At this point during the scenario the pilot's attention is focused on the HUD, where he is 'centering the dot' in response to his belief that he is under attack from a closing hostile aircraft. The adaptation rules suggest that the pilot direct his attention to the radar display, and suggest that the system emphasize the unknown status of the IFF to prevent possible fratricide. Figures 4.3.8-7 and 4.3.8-8 show the pilot's GUI, the non-adapted and the adapted versions, respectively.

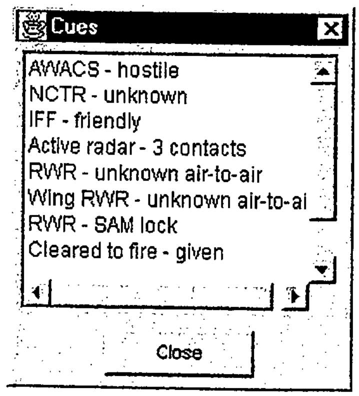

Figure 4.3.8-1: Cues Arriving During Frame 8 of Simulation Run

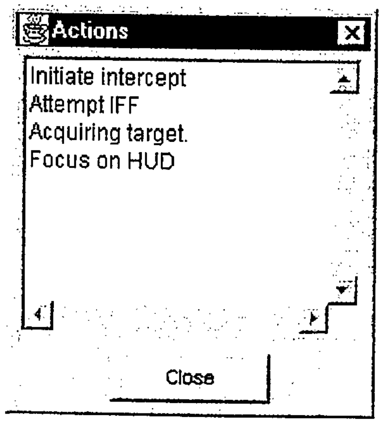

Figure 4.3.8-2: Pilot's Actions During Frame 8 of the Simulation Run

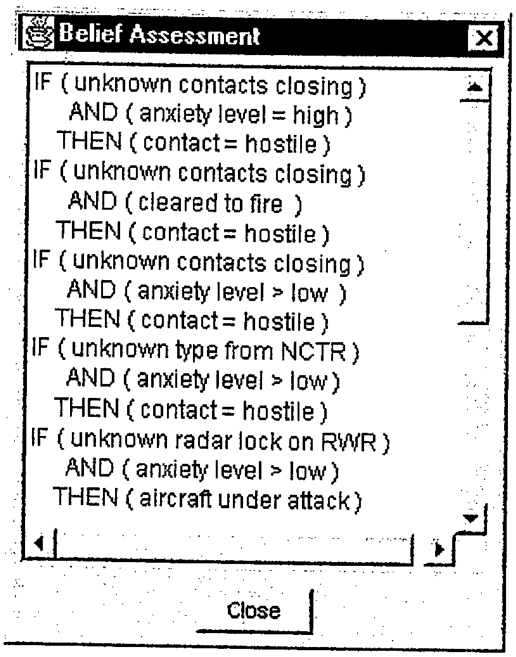

Figure 4.3.8-3: Subset of Belief Assessment Rules Instantiated During Frame 8 of Simulation Run

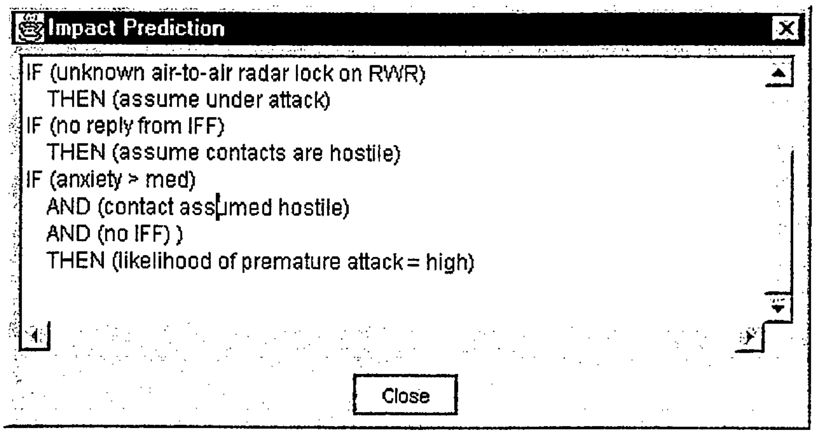

Figure 4.3.8-4: Subset of Impact Prediction Rules Instantiated During Frame 8 of the Simulation Run

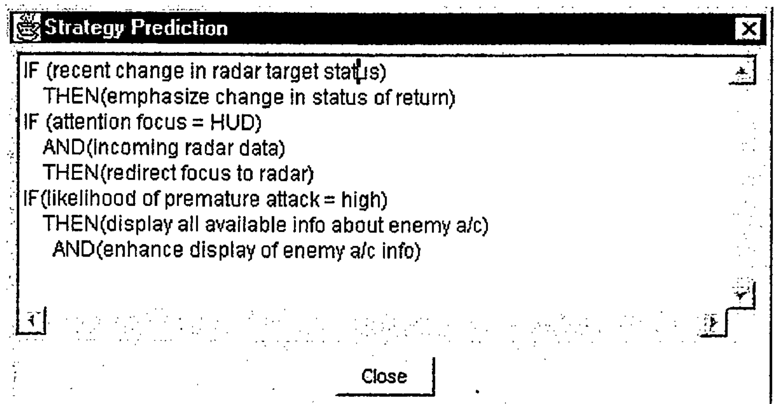

Figure 4.3.8-5: Subset of Strategy Selection Rules Instantiated During Frame 8 of Simulation Run

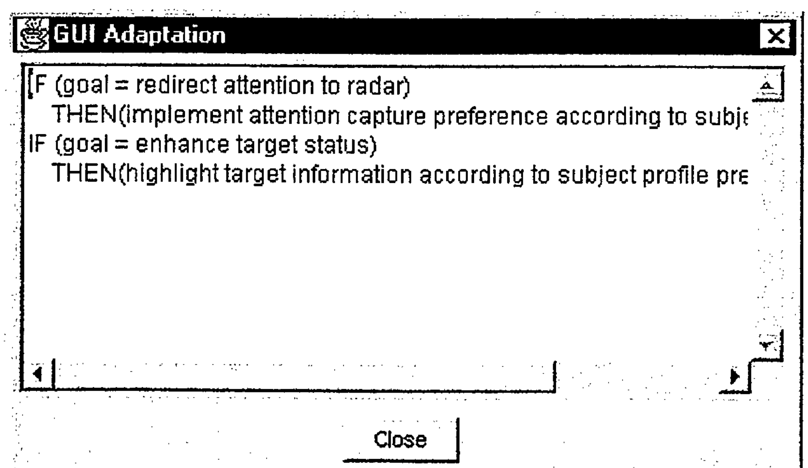

Figure 4.3.8-6: Subset of GUI Adaptation Rules Instantiated During Frame 8 of Simulation Run

Table 4.3.8-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Affective State
Probable hostile contacts	Hostile contacts Under attack	Med-high

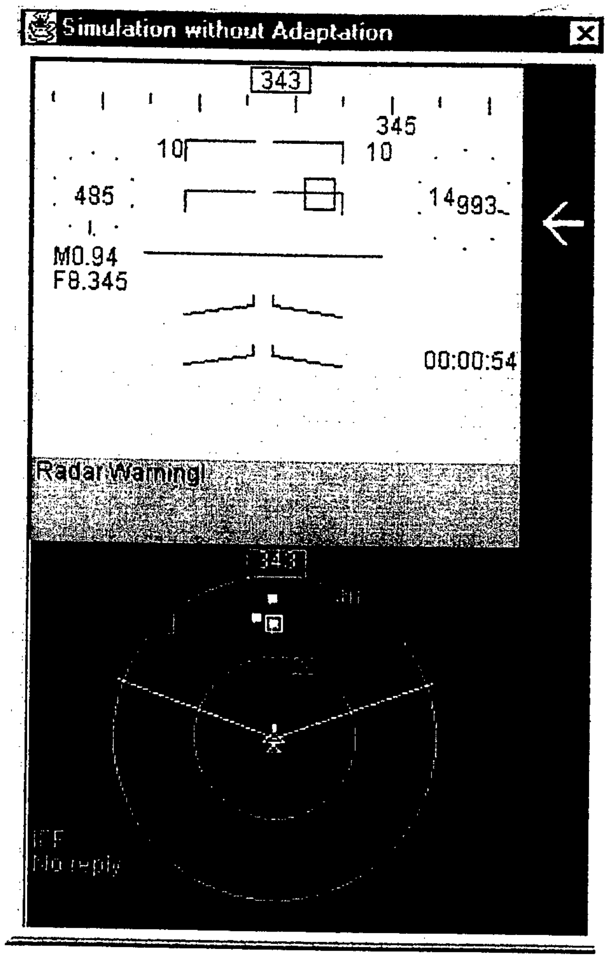

Figure 4.3.8-7: Pilot's GUI at Frame 8 of Simulation Run: Non-Adapted Version

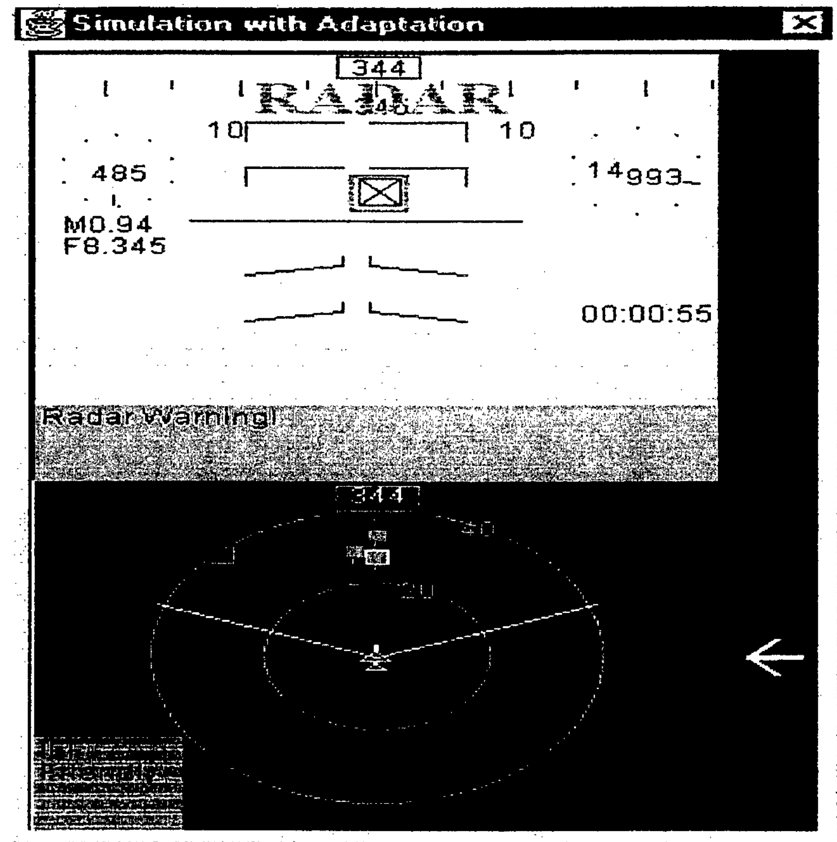

Figure 4.3.8-8: Pilot's GUI at Frame 8 of Simulation Run: Adapted Version

4.3.9 Scenario 1 - Frame 9- << 30 nm

Figure 4.3.9-1 shows a screenshot of the ABAIS cue monitoring window, showing the cues arriving during frame 9. Figure 4.3.9-2 shows a subset of the impact prediction rules instantiated during this frame and figure 4.3.9-3 shows a subset of the strategy selection rules instantiated. Figure 4.3.9-4 shows a subset of the GUI Adaptation rules instantiated during this frame. At this point during the scenario the pilot's attention is focused on the HUD, where he is 'centering the dot' in response to his belief that he is under attack from a closing hostile aircraft. The adaptation rules suggest that the pilot should direct his attention to the radar display, and suggest that the system emphasize the unknown status of the IFF to prevent possible fratricide. Figures 4.3.9-5 and 4.3.9-6 show the pilot's GUI, the non-adapted and the adapted versions, respectively.

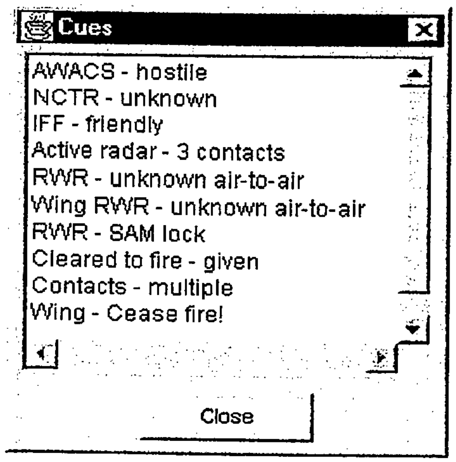

Figure 4.3.9-1: Cues Arriving During Frame 9 of Simulation Run

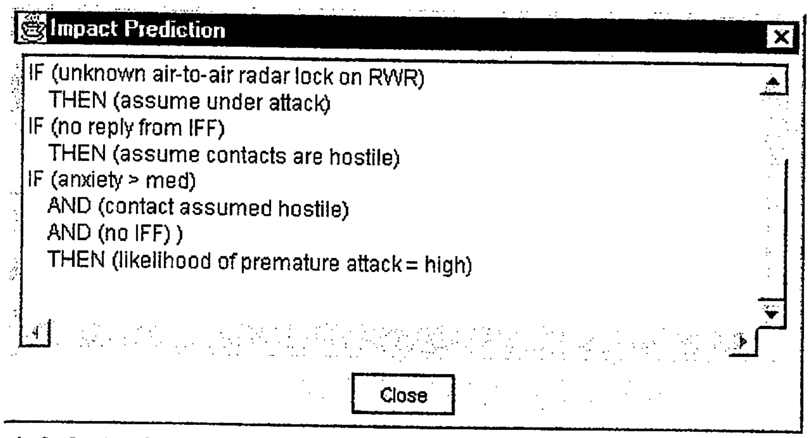

Figure 4.3.9-2: Subset of Impact Prediction Rules Instantiated During Frame 9 of the Simulation Run

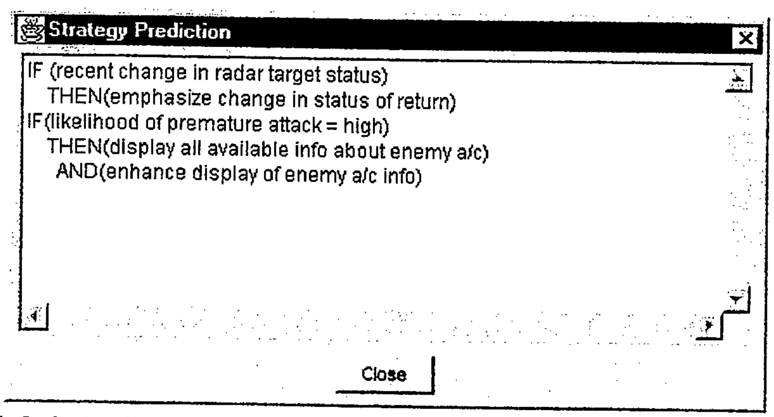

Figure 4.3.9-3: Subset of Strategy Selection Rules Instantiated During Frame 9 of Simulation Run

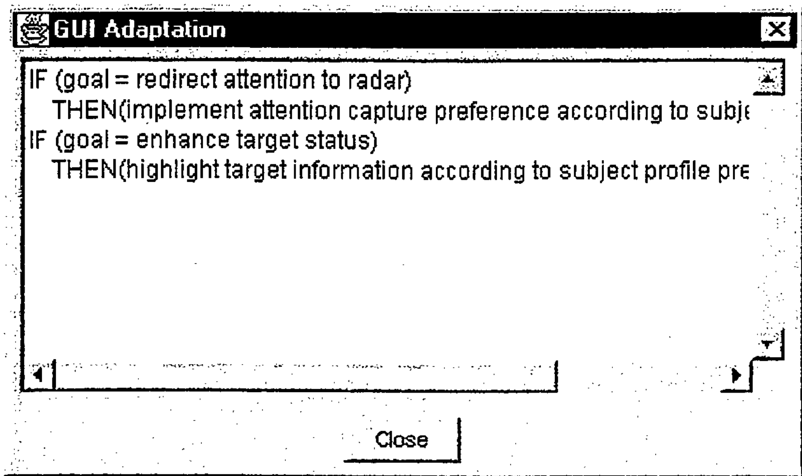

Figure 4.3.9-4: Subset of GUI Adaptation Rules Instantiated During Frame 9 of Simulation Run

Table 4.3.9-1: Scenario Environment and Pilot's Belief and Anxiety State

Actual Ground Truth	Pilot's Belief State (Situation Assessment)	Pilot's Affective State
Probable hostile contacts	Hostile contacts Under attack	High

Rules deriving belief state:

IF (unknown radar lock on RWR) AND (anxiety level = > low)	THEN (contact = hostile)
IF (unknown radar lock on RWR) AND (anxiety level = > low)	THEN (aircraft under attack)
IF (cleared to fire) AND (unknown radar lock on RWR)	THEN (aircraft under attack)

Rules deriving affective state:

Individual history factors	
IF (cleared to fire)	THEN (anxiety weight factor = 8)
External event factors	
IF (unknown radar lock on RWR)	THEN (anxiety weight factor = 8)
IF (wing unknown radar lock on RWR)	THEN (anxiety weight factor = 8)
Physiological factors	
IF (heart rate = increasing)	THEN (AWF = 5)

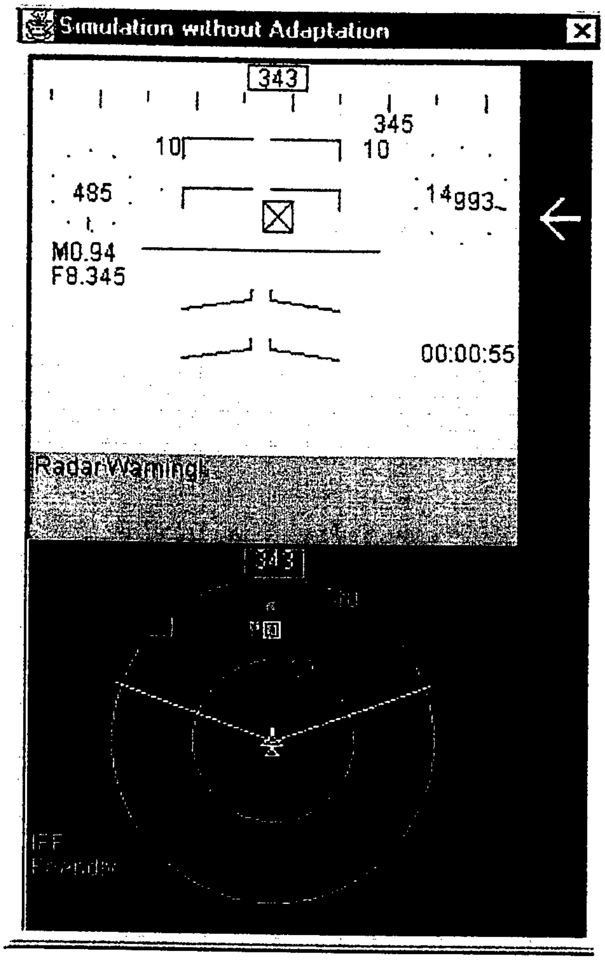

Figure 4.3.9-5: Pilot's GUI at Frame 9 of Simulation Run: Non-Adapted Version

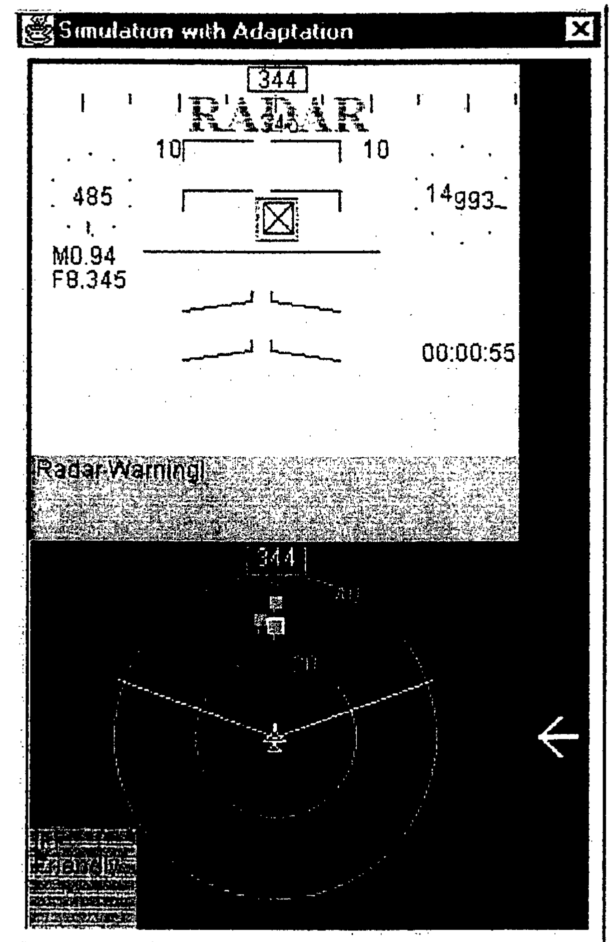

Figure 4.3.9-6: Pilot's GUI at Frame 9 of Simulation Run: Adapted Version

5. Summary, Conclusions, and Recommendations

This chapter summarizes the key tasks conducted under this effort and presents the major conclusions.

5.1 Summary

The approach taken under this effort focused on the proof-of-concept demonstration of an Affect and Belief Adaptive Interface System (ABAIS). ABAIS assists the user (e.g., pilot) in the detection of, and adaptation to, user affective states (e.g., anxiety), dominant personality characteristics (e.g., obsessiveness), and current set of beliefs that may influence performance (activated knowledge schemata) (e.g., pilot's belief that he is under attack by hostile aircraft), in an attempt to counter the associated performance biases. Seven specific tasks comprised our effort:

- Defining a scenario for ABAIS demonstration
- Identifying generic effects of affective states and decision-making biases resulting from intuitive, idiosyncratic beliefs from existing research literature
- Identifying specific likely effects of affective states and examples of individual, idiosyncratic beliefs that might influence performance from knowledge elicitation interviews with expert Air Force pilots and research personnel
- Developing knowledge bases for each of the four modules comprising the ABAIS system architecture
- Designing and implementing a prototype ABAIS architecture
- Demonstrating the proof-of-concept of the ABAIS framework and prototype in the context of selected test scenarios
- Defining requirements for Phase II development and commercialization

The activities performed under each of these tasks are summarized below.

We first **defined a scenario for ABAIS demonstration** through a series of knowledge elicitation interviews with subject matter experts (SME's) (USAF and Navy fighter pilots and psychologists). After considering several options of tasks and task contexts (e.g., instrument failures and intercept geometries) to induce anxiety, we selected the sweep task and a series of BVR air-to-air combat encounter events to demonstrate the ABAIS adaptive methodology in a real-time, dynamic context.

We then **identified generic effects of affect- and belief-induced performance biases** by reviewing empirical literature in four areas: 1) experimental, cognitive, and applied psychology; 2) personality theory; 3) human factors; and 4) cognitive engineering. The findings were then evaluated for their potential in providing information about the effects of affect-, personality trait-, and belief-induced biases on performance.

We then **identified specific likely effects of affective states, selected personality factors, and individual beliefs on flight performance** in the context of the demonstration scenario described above. Given the relative paucity of empirical studies in this area, the primary means of identifying these effects were knowledge elicitation interviews with pilots and other aviation subject matter experts (SME's).

We then **developed knowledge bases** for each of the four modules comprising the ABAIS system from the knowledge derived both from the literature search, and from knowledge elicitation interviews with SME's. For the *User State Assessment,* this effort consisted first of identifying the multiple categories of factors necessary to infer the user's affective state, personality trait, and predominant beliefs, and second, of constructing the rules mapping these factors onto the space of possible affective and belief states. For the *Impact Prediction* module, this effort consisted of constructing rules that mapped the identified affective state, personality trait, or active belief onto the most likely effects on various elements of the sweep task performance. For the *Strategy Selection* module, we developed rules mapping the specific performance bias (e.g., task neglect, cue misinterpretation, checking behavior) onto a corresponding series of compensatory strategies counteracting these biases (e.g., redirecting focus onto neglected data, reminders of increasing vulnerability due to a delayed decision). Finally, for the *GUI / DSS Adaptation* module, we developed rules implementing specific modifications of the pilot cockpit instrument displays corresponding to the suggested strategy (e.g., highlighting information to capture pilot's attention, displaying additional information to counter predicted biases, etc.).

We **designed, constructed, integrated, and evaluated a wireless heart rate monitor.** The monitor consists of a light-weight belt worn around the torso and an associated wireless transmitter. In our initial demonstration we integrated the monitor with simple ABAIS GUI adaptations to demonstrate ABAIS' capability to detect and respond to changing physiological signals.

We then **demonstrated the proof-of-concept of the ABAIS framework** and prototype in the context of selected task scenarios. The distinct pilot profiles generated different affective and belief states at different points of the scenario. The resulting GUI / DSS adaptations were derived via the ABAIS adaptive methodology, using the rules in the four ABAIS modules. The output of the GUI / DSS Adaptation recommendations was then shown on the corresponding cockpit instruments.

Finally, we **defined requirements for Phase II full-scope development and commercialization.** We focused on identifying further development and demonstration requirements to be met for a full-scope affective adaptive user interface for a variety of real-time, dynamic environments (e.g., AWACS tasks). We focused on environments requiring team coordination, as these are becoming increasingly common and provide a rich context in which to demonstrate the proposed ABAIS methodology. To define commercialization requirements, we identified promising commercial market areas and particular market segments that could benefit from the development of a suitably specialized affective, adaptive interface and decision support tool.

5.2 Conclusions

The primary result of this study was a proof-of-concept demonstration of an Affect and Belief Adaptive Interface System (ABAIS), designed to provide individualized GUI and DSS adaptations based on the user's affective and belief state. Specific results are outlined below, first for the effort as a whole, and then organized by the individual subtasks conducted.

Overall ABAIS Adaptive Methodology Framework Development of the Phase I ABAIS proof-of-concept demonstrated feasibility of the overall adaptive methodology and its implementation. The four modules comprising the ABAIS architecture were able to assess the user state using a knowledge-based approach and information from a variety of sources (e.g., static task context, dynamic external events occurring during the task, pilot's individual history, pilot's personality traits, pilot's training and proficiency, and simulated physiological data), predict the effects of this state in the context of the demonstration task, and suggest and implement specific GUI adaptation strategies (e.g., modify an icon or display to enhance visibility), based on the pilot's individual information presentation preferences.

Results of this demonstration indicate the feasibility of the approach as a whole, and of knowledge-based affect assessment and GUI adaptation. The implementation allows the specification of highly-individualized baseline pilot profiles, which can be used to infer individual reactions to a variety of specific events, based on the pilot's background, personality, and individual history (i.e., specific events in recent past), and selected physiological data. A key finding was the demonstration of the feasibility of using available electronic data about the task environment (e.g., radar contacts) as basis for both affect and belief assessment

Specifically, we believe that the following factors represent the key requirements for the development of an adaptive, affective interface:

- Availability of highly individualized data about the system user, including details of past performance, individual history, personality traits, and physiological data;

- Availability of a wide variety of task-specific data in an electronic format;
- Use of multiple methods and multiple sources of data for assessing the user's affective and belief state;
- Ability to fine-tune the rule-bases and inferencing to "personalize" the system to the individual user-task context.

The specific findings supporting these conclusions, and the detailed findings under each of the seven tasks comprising the Phase I effort, are summarized in detail in section 1.5.

5.3 Recommendations

On the basis of these Phase I results, a Phase II effort is recommended which focuses on the design, development, and evaluation of a full-scope Affect and Belief Adaptive Interface (ABAIS) system and testbed environment. The overall functionality of the system, and its key features, are briefly outlined below.

Core ABAIS Architecture The core ABAIS architecture implements an adaptive methodology, summarized in table 3.1-1, and consists of four modules: 1) *user state assessment,* which identifies the user's affective state and task-relevant beliefs; 2) *impact prediction,* which identifies effects of the user state on performance; 3) *strategy selection,* which selects a compensatory strategy; and 4) *GUI adaptation,* which modifies the user interface content and format to enhance detection, recognition, and assimilation (i.e., to improve situation awareness). The ABAIS architecture implementing this methodology, in the context of the Phase I demonstration environment, is shown in figure 3.1-1. *Under Phase I* we successfully prototyped both the methodology and the architecture. *Under Phase II,* we would build upon the existing ABAIS architecture by providing the following: 1) additional modules to handle explicit task parameter and knowledge-base modification; 2) enhanced connectivity among individual ABAIS modules to provide feedback to the user assessment module, thereby enhancing the assessment process; and 3) instrumentation of ABAIS with the necessary features to function in a team setting (i.e., ability to instantiate multiple ABAIS copies on separate workstations and communication among these, multiple user assessment, etc.). The implementation of ABAIS within a team context would also require the definition and maintenance of multiple ABAIS user profiles, and support for real-time interaction among these, to provide the basis of coordinating adaptation across multiple team members.

ABAIS Run-Time Execution Modes *Under Phase I,* the core ABAIS framework was integrated within a dynamic flight simulation environment and supported two modes of system operation: 1) *pilot-as-user* mode, where the user actually flies the aircraft and interacts with a simulated environment consisting of other friendly aircraft, enemy aircraft, and missiles; and 2) *analyst-as-user,* where the analyst watches a scripted task and monitors the scripted pilot's performance, as well as the rule-based inferencing results. To support these two modes of operation, ABAIS was integrated with a simulation environment supporting both human-in-the-loop flight simulation, and script-based agent simulation. The script definition functionality allowed the interactive graphical specification of customized scripts within the general sweep task context, consisting of varying number of aircraft with associated autonomous behaviors, via a variety of pop-up menus associated with the individual cells.

Under Phase II, we plan to maintain the two-mode operation to provide maximum flexibility in the testing and evaluation of a full-scope ABAIS within a team context. However, the focus will be on the full-scope development and support of a human-in-the-loop mode, to provide opportunities for closed-loop assessment and adaptation in actual dynamic team tasks.

User Profiles *Under Phase I,* profiles of representative users (e.g., anxiety-tolerant and anxiety-prone pilots) were constructed and used as basis for performing the dynamic affect assessment during the demonstration sweep task. *Under Phase II,* we would still support the construction of profiles for scripted task executions, but the emphasis will be on the real-time assessment of a variety of dynamic factors, including diagnostic task data (e.g., time and accuracy measures of performance), self-assessment reports (e.g., indication whether or not the user feels anxious at a particular stage of the task), and physiological measures (i.e., heart rate).

ABAIS Demonstration Task *Under Phase I,* we demonstrated ABAIS functionality in the context of a sweep task, focusing on adaptation with respect to a single user (i.e., a single pilot). The primary ABAIS demonstration used the analyst-as-user mode, due to the precise coordination required to "fly" the sweep task demonstration script and simulate the desired sequence of events to demonstrate real-time adaptation. In this mode the aircraft is controlled by a script that simulates the pilot behavior (e.g., "centering the dot" on HUD) and the dynamic task environment (e.g., changed contact status due to incoming IFF data). The pilot-as-user (human-in-the-loop) mode was demonstrated separately, during an evaluation of physiological user state assessment. This evaluation involved the design and development of a wearable heart rate sensor, whose output is linked directly into the ABAIS GUI / DSS Adaptation module to provide modified GUI's in response to specific changes in the user's heart rate. The successful implementation of this sensor demonstrated the feasibility of using real-time physiological data to drive the ABAIS adaptation logic.

Under Phase II, the scope of demonstration will be extended to a synthetic team task environment, the Distributed Dynamic Decision-Making (DDD). This environment, developed by Aptima, Inc., has been successfully used for a variety of empirical evaluations of human-in-the-loop design issues. As such, it provides a flexible tool for the exploration of ABAIS adaptations across multiple team tasks. As mentioned above, this extension will involve the capability to instantiate multiple "copies" of ABAIS across separate workstations, the ability to specify multiple profiles and assess of multiple user states, and the ability to provide the necessary communication mechanisms to ensure adaptation to multiple users. The team task was selected based on the increasing importance of team environments in the USAF, and recent results indicating critical affect-induced team effects and biases. Specifically, several recent studies focus on stress related decision making deficits which include psycho-social factors (i.e., intra-crew tensions). The impact on decision was found to be most extreme in complex decisions with high consequence. Both perceptual narrowing and failure to note disconfirming data were observed (Prince et al., 1994; Driskell and Salas, 1991).

Individual vs. Team Adaptations *Under Phase I*, individual adaptations were implemented and explored in the context of the sweep task. Specifically, selected cockpit instruments (e.g., HUD, radar) were simulated and adaptations were implemented within these displays by enhancing icons or redirecting attention to critical incoming data. *Under Phase II*, we would: 1) continue individual adaptations but would implement ABAIS in the context of a distributed team task environment; 2) would enhance the level of adaptation; 3) would explore a variety of specific applications of the user state assessment.

The ABAIS Testbed Environment A key objective of the overall effort is to develop a flexible testbed for the exploration of multiple affective assessment methods and adaptation strategies. *Under Phase I*, we developed an analyst GUI supporting the flexible specification of background pilot information, selection of run time parameters, and system performance monitoring. The analyst displays include a variety of windows showing dialog boxes for defining the background information necessary for the knowledge-based user assessment (e.g., pilot preference profile, pilot individual history); dialog boxes for specifying the system run time parameters (e.g., what windows should be visible for monitoring system performance); and windows allowing monitoring of system performance (e.g., rule base and rule instantiation, physiological data, inferred pilot affective state).

Under Phase II, we would build upon this existing functionality to enhance the analyst GUI and interaction facilities. Specifically, we would include a capability for dynamical monitoring of, and interaction with, the knowledge-based inferencing, and will provide a means of flexibly combining the complementary affect assessment methods and adaptation strategies across multiple task scenarios. We would integrate these facilities with the existing DDD software environment, to provide support for exploration of ABAIS across multiple team tasks and team configurations.

6. References

Ackerman, P.L., Sternberg, R.J. and Glaser, R. (1989). *Learning and individual differences*. New York: W.H.Freeman.

Araujo, A.F.R. (1993). Emotions Influencing Cognition In *WAUME '93: Workshop on Architectures Underlying Motivation and Emotion*. Birmingham, UK: The University of Birmingham.

Badre, A. N. (1978). *Selecting and Representing Information Structures for Battlefield Decision Systems* ARI Technical Report 79-A20.

Bates, J., Loyall, A.B., and Reilly, W.S. (1992). Integrating Reactivity, Goals, and Emotion in a Broad Agent. In *Proceedings of the 14th Meeting of the Cognitive Science Society*.

Berry, D. (1987). The problem of implicit knowledge. *Expert Systems,* 4, 144-151.

Blaney, P.H. (1986). Affect and Memory. *Psychological Bulletin*, 99 (2), 229-246.

Bower, G.H. (1981). Mood and Memory. *American Psychologist,* 36, 129-148.

Briggs, K.C. and Myers, I.B. (1977). Myers-Briggs Type Indicator. Palo Alto, CA: Consulting Psychologists Press, Inc.

Broadbent, D.E., Broadbent, M.H.P, and Jones, J.L. (1986) Performance correlates of self-reported cognitive failure and obsessionality. *British Jnl. of Clin. Psych.*, 25, 285-299.

Cacioppo, J.T., Klein, D.J., Bernston, G.G., and Hatfield, E. (1993). The Psychophysiology of Emotion. In *Handbook of Emotions*, M. Lewis and J. Haviland, eds. New York: Guilford.

Callan, D. (1998). Personal communication.

Callister, J.D., King, R.E., Retzlaff, P.D., and Marsh, R.W. (1997). *Using the NEO-PI-R to Assess the Personality of US Air Force Pilots.* AL/AO-TR-1997-0097. Brooks AFB, TX: Aerospace Medicine Directorate.

COADE: A Framework for Cognitive Analysis, Design, and Evaluation. Final Report, Panel 8 on the Defense Applications of Human and Bio-Medical Sciences RSG.19 on Decision Aids in Command and Control NATO Defense Research Group. Tech Report AC/243 (Panel 8) TR/17.

Cooke, N. M. (1995). Varieties of Knowledge Elicitation Techniques. *International Journal of Human-Computer Studies*, 41(6), 801-849.

Cooke, N.M. and McDonald, J.E. (1987). The Application of Psychological Scaling to Knowledge Elicitation for Knowledge-Based Systems. *International Journal of Man-Machine Studies*, 74, 1422-1430.

Costa, P.T. Jr. and McCrae, R.R. (1989). The NEO-PI/NEO-FFI manual supplement. Odessa, FL. Psychological Assessment Resources.

Damasio, A.R. (1994). *Descrates' Error: Emotion, Reason and the Human Brain*. New York: G.P. Putnam's Sons.

Davidson, R.J. (1994). Complexities in the Saerch for Emotion-Specific Physiology. In *The Nature of Emotion: Fundamental Questions*. P. Ekman and R.J. Davidson, eds. New York: Oxford University Press.

Davidson, R.J. (1992). Prolegomenon to the Structure of Emotion: Gleanings from Neuropsychology. Cognition and Emotion, 6 (3/4), 245-268.

Deckert, J. C., Entin, E. B., Entin, E. E., MacMillan, J., & Serfaty, D. (1994). *Military Command Decisionmaking Expertise* (Report 631). Burlington, MA: Alphatech, Inc.

Driskell, J. E. and E. Salas (1991). Overcoming the effects of stress on military performance: Human Factors Training and Selection Strategies. *Handbook of Military Psychology*, 183-193.

Druckman, D. and Bjork, R.A. (1991). In the mind's eye: Enhancing Human Performance. Washington, DC: National Academy Press.

Edwards, A.D.N. (1995). *Extra-Ordinary Human-Computer Interaction: Interfaces for Users with Disabilities*. Cambridge, UK: Cambridge University Press.

Egan, D.E. (1988). Individual Differences in human-computer interaction. In M. Hellander, ed. *Handbook of human-computer interaction*. Amsterdam: Elsevier.

Ekman, P. and Davidson, R.J. (1994). *The Nature of Emotion: Fundamental Questions*. New York: Oxford University Press.

Ekman, P. and Friesen, W.V. (1975). *Unmasking the Face*. Englewood Cliffs, NJ: Prentice Hall.

Endsley, M. R. (1995). Measurement of Situation Awareness in Dynamic Systems. *Human Factors*, 37(1).

Ericsson, K.A. and Simon, H.A. 1984. Protocol Analysis: Verbal Reports as Data. Cambridge, MA: The MIT Press.

Essa, I. and Pentland, A. (1997). Coding, analysis, interpretation and recognition of facial expressions. *IEEE T-PAMI*, 19(7), 757-763.

Eysenck, HJ. (1991a). Dimensions of personality: 16: 5 or 3? criteria for a taxonomic paradigm. *Personality and Individual Differences*, 12, 773-90.

Eysenck, M.W. (1997). *Anxiety and Cognition: A Unified Theory*. Hove, East Sussex: Psychology Press, Publishers.

Eysenck, H. J. (1967). *The biological basis of personality*. Springfield, IL: Charles C. Thomas.

Fallesen, J. J. (1993). *Overview of Army Tactical Planning Performance Research* (Technical Report 984): US ARI for Behavioral and Social Sciences.

Fallesen, J. J., & Michel, R. R. (1991). *Observation on Command and Staff Performance During CGSC Warrior '91* (Working Paper LVN-91-04): US ARI for Behavioral and Social Sciences.

Frijda, N.H. and Swagerman, J. (1987). Can Computers Feel? Theory and Design of an Emotional System. *Cognition and Emotion,* 1 (3), 235-257.

Frijda, N.H. (1986). The emotions. Cambridge, UK: Cambridge University Press.

Gaines, B. and Boose, J. 1988. *Knowledge Acquisition for Knowledge-Based Systems*. New York: Academic Press.

Gray, J.A. (1994). Three Fundamental Emotion Systems. In *The Nature of Emotion*, P. Ekman and R. Davidson, eds. New York: Oxford University Press.

Hammond, K. R., Hamm, R. M., Grassia, J., & Pearson, T. (1987). Direct Comparison of the Efficacy of Intuitive and Analytical Cognition in Expert Judgment. *IEEE Trans. on Systems, Man & Cybernetics*, 17(5), 753-770.

Hathaway, S.R. and McKinley, J.C. (1989). MMPI-2: Minnesota Multiphasic Personality Inventory - 2. Minneapolis, MN: The University of Minnesota Press.

Hofmann, S. (1998). Personal communication.

Hudlicka, E., Burge, J. E., Black. E.H., Klinzing, K.J., and Zacharias, G.L.(1999). VIEW: Visualization and Interactive Elicitation Workstation. Technical Report R95431. Cambridge, MA: Charles River Analytics.

Hudlicka, E. and Fellous, J-M. (1998). Review of Computational Models of Emotion. Submitted to the *AAAI Magazine*.

Hudlicka, E., Burge, J., Zacharias, G., and Lussier, J. (1997). An Integrated Methodology and Environment for Cognitive Task Analysis. Submitted to *Human Factors*.

Hudlicka, E. (1997). *Modeling Behavior Moderators in Military HBR Models*. TR 9716. Lincoln, MA: Psychometrix Associates, Inc. (see also Pew and Mavor, 1998)

Hudlicka, E. (1996). Requirements Elicitation with Indirect Knowledge Acquisition Techniques: A Comparison of Three Techniques. In *Proceedings of the 2nd International Conference on Requirements Engineering*. Los Alamitos, CA: IEEE Computer Society Press, 4-11.

Hudlicka, E. (1994). *Toward a Computational Model of Attention.* BBN Report. No. 7791.

Hugdahl, K. (1995). *Psychophysiology and* Cambridge, MA: Harvard University Press.

Humphreys, M.S. and Revelle, W. (1984). Personality, Motivation, and Performance. *Psychological Review*, 91 (2), 153-184.

Illgen, C., Zacharias, G.L. Rinkus, G., Hudlicka, E., O'Neil, V. and Carley, K. (1997). A Decision-Aid for Command and Control Warfare. Report No. R96421. Cambridge, MA: Charles River Analytics, Inc.

Isen, A.M. (1993). Positive Affect and Decision Making. In *Handbook of Emotions*, J.M. Haviland and M. Lewis, eds. New York, NY: The Guilford Press.

James, W. (1890/1950). Principles of Psychology. New York: Dover.

Johnson, S.C. (1967). Hierarchical Cluster Analysis, *Psychometrika,* 32, No. 3.

Kelly, G. (1955). The Psychology of Personal Constructs. New York: Norton.

Klein, G. A. (1989). Recognition-Primed Decisions. *Advances in Man-Machine Systems Research*, 5, 47-92.

Klein, G.A., et. al. 1989b. "Critical Decision Method for Eliciting Knowledge." IEEE Trans. on Systems, Man and Cybernetics, Vol. 19, No. 3: 462-472.

Krahe, B. (1990). Situation Cognition and Coherence in personality: An individual-centered approach. Cambridge, UK: Cambridge University Press.

Lazarus, R.S. (1991). *Emotion and Adaptation*. New York, NY: Oxford University Press.

LeDoux, J.E. (1994). Emotion Specific Physiological Activity. In *The Nature of Emotion: Fundamental Questions*. P. Ekman and R.J. Davidson, eds. New York: Oxford University Press.

LeDoux, J.E. (1992). Brain Mechanisms of Emotion and Emotional Learning. *Current Opinion in Neurobiology*., 2(2), 191-197.

LeDoux, J.E. (1989). Cognitive-Emotional Interactions in the Brain. *Cognition and Emotion*, 3(4), 267-289.

Levenson, R.W., Ekman, P., and Friesen, W.V. (1990). Voluntary facial action generates emotion-specific autonomic nervous system activity. *Psychophysiology*, 27, 363-384.

Lussier, J. W., Solick, R. E., & Keene, S. D. (1992). *Experimental Assessment of Problem Solving at the Combined Arms Services Staff School* (Research Note 92-52): US ARI.

Lussier, J. W., Solick, R. E., & Keene, S. D. (1992). *Experimental Assessment of Problem Solving at the Combined Arms Services Staff School* (Research Note 92-52): US ARI for Behavioral and Social Sciences

MacLeod, C. and Hagan, R. (1992). Individual differences in the selective processing of threatening information. *Behav. Res. Ther.*, 30, 151-161.

McCrae, Robert R. and Costa, Paul T. Jr. (1990). Personality in Adulthood. NY: The Guilford Press.

McCrae, Robert R. and Costa, Paul T. Jr. (1989). Re-interpreting the Myers-Briggs Type Indicator from the Perspective of the Five-Factor Model of Personality. *Journal of Personality*, 57(1), 17-40.

Michel, R.R. and Reidel, S.K. (1988). *Effects of Expertise and Cognitive Style on Information Use in Tactical Decision Making*. US ARI Report 806.

Mineka, S. and Sutton, S.K. (1992). Cognitive Biases and the Emotional Disorders. *Psychological Science*, 3(1), 65-69.

Mischel, W. (1976). *Introduction fo Personality*. NY: Holt, Rinehart and Winston.

Mulgund, S.S., Rinkus, G.J., Illgen, C., Zacharias, G. (1997). *A Situation-Driven Workload-Adaptive Pilot/Vehicle Interface*. TR R96051, Cambridge, MA: Charles River Analytics, Inc.

Nisbett, R.E. and Wilson, T.D. 1977. "Telling More than We Know: Verbal Reports on Mental Processes." *Psychological Review*, Vol. 84: 231-259.

Oatley, K. and Jenkins, J.M. (1992). Human Emotions: Function and Dysfunction. *Annual Review of Psychology*, 43:55-85.

Oatley, K. and Johnson-Laird, P.N. (1987). Towards a Cognitive Theory of Emotions. *Cognition and Emotion*, 1(1), 29-50.

Olson, J.R. and Biolsi, K. 1990. *Techniques for Representing Expert Knowledge*. University of Michigan - Cognitive Science and Machine Intelligence Laboratory. Technical Report 34.

Ortony, A., Clore, G.L., and Collins, A. (1988). *The Cognitive Structure of Emotions*. NY: Cambridge University Press.

Orr, S. P. (1998). Personal communication.

Panskepp, J. (1994). The Closest Physiological Distinctions Between Emotions Will Be Found Among the Circuits of the Brain. In *The Nature of Emotion*, P. Ekman and R. Davidson, eds. New York: Oxford University Press.

Persons, J.B. and Foa, E.B. (1984). Processing of fearful and neutral information by obsessive-compulsives. *Behavior Res. Ther.*, 22, 260-265.

Peterson, R.A. and Reis, S. (1987). Test Manual for the Anxiety Sensitivity Index. Orland Park, IL: International Diagnostic Systems.

Pew, R.W. and Mavor, A.S. (1998). *Representing Human Behavior in Military Simulations*. Washington, DC. National Academy Press.

Picard, R. (1997). *Affective Computing*. Cambridge: MIT Press.

Plutchik, R. (1991). Emotions and Evolution. In K.T. Strongman, (ed.), International Review of Studies on Emotion (Vol. 1). Chichester, UK. Wiley Publishers.

Prince, C., Bowers, C. and Salas, E.(1994). Stress and Crew Perforance: Challenges for Aeronautical Decision Making Training. (in N. Johnston, N. McDoanld and R. Fuller, Eds.) *Aviation Psychology in Practice*. Avebury Technical.

Reed, G.F. (1969). Under-inclusion - a characteristic of obsessional personality. *British Journal of Psychiatry*, 115, 781-785.

Reilly, W.S.N. (1996). Believable Social and Emotional Agents. Ph.D. Dissertation. Report No. CMU-CS-96-138. Pittsburgh, PA: Carnegie Mellon University.

Retzlaff, P.D., Callister, J.D., and King, R.E. (1997). *The Armstrong Laboratory Aviation Personality Survey (ALAPS): Norming and Cross-Validation*. AL/AO-TR-1997-0099. Brooks AFB, TX: Aerospace Medicine Directorate.

Revelle, W. (1997) Extraversion and Impulsivity. In Nyborg, H. (Ed.) *The scientific study of human nature: Tribute to Hans J. Eysenck at eighty*. Elsevier Science Press.

Revelle, W. (1995). Personality Processes. *Annual Review of Psychology*, 46, 295-328.

Revelle, W. (1995). Individual differences in personality and motivation. In *Attention: Selection, Awareness, and Control.* Baddeley, A. ed. Oxford: Clarendon Press.

Revelle, W. & Loftus, D. (1990) Individual differences and arousal: implications for the study of mood and memory. *Cognition and Emotion*, 4, 209-237.

Rouse, W.B. and Miller, N.M. 1986. On Looking into the Black Box: Prospects and Limits in the Search for Mental Models. *Psychological Bulletin*, Vol. 100, No. 3: 349-363.

Russel, J.A. (1978). Evidence of convergent validity on the dimensions of affect. *Journal of Personality and Social Psychology*, 36, 1152-1168.

Schachter, D.L. (1987). Implicit Memory: History and Current Status. *Jnl. of Experimental Psychology: Learning, Memory, and Cognition*, 13, 501-513.

Schachter, S. Singer, J.E. (1962). Cognitive, social, and physiological determinants of emotional state. *Psychological Review*, 69, 379-399.

Scherer, K. (1993). Studying the Emotion-antecedent appraisal process: The expert system Approach. *Cognition and Emotion*, 7, 325-355.

Schmidt, H.G., Boshuizen, H.P.A. and Hobus, P.P.M. 1988. Transitory Stages in the Development of Medical Expertise: The 'Intermediate Effect' in Clinical Case Representation Studies. *10 Annual Conference of the Cognitive Science Society*. Montreal, Canada.

Shaw, Robert L. (1998a). Task Scenario. FCI Memo PS98001. Dayton, OH: FCI Associates, Inc.

Shaw, Robert L. (1998b). Task Scenario. FCI Memo PS98002. Dayton, OH: FCI Associates, Inc.

Sher, K.J., Frost, R.O., Kushner, M., Crews, T.M. and Alexander, J.E. (1989). Memory deficits in compulsive checkers. *Behavior Res. Ther.*, 27, 65-69.

Schiffman S., Reynolds, L. , and Young, F.W. (1981). *Introduction to Multi-Dimensional Scaling: Theory, Methods, and Applications*. NY, NY: Academic Press.

Shneiderman, B. (1997). *Designing the User Interface*. Reading, MA: Addison Wesley Longman.

Sloman, A. (1987). Motive Mechanisms and Emotions. *Cognition and Emotion*, 1(3), 217-234.

Steinweg, K.K. (1995). Dealing Realistically With Fratricide. *Parameters*, Spring, 4-29.

Thayer, R.E. (1989). *The biopsychology of mood and arousal*. New York: Oxford.

Tolcott, M. A., Marvin, F. F., & Lehner, P. E. (1989). *Expert Decisionmaking in Evolving Situations. IEEE Trans. on Systems, Man & Cybernetics*, 19(3), 606-615.

Tversky, B. and Kahneman, D. (1974). Judgements under Uncertainty: heuristics and biases. *Science*, 185, 1124-1131.

Watson, D., Clark, L.A., and Tellegen, A. (1988). Development and validation of brief measues of positive and negative affect: The PANAS Scales. *Journal of Personality and Social Psychology*, 54, 1063-1070.

Watson, D. and Tellegen, A. (1985). Toward a consensual structure of mood. *Psychological Bulletin*, 98, 219-235.

Weiner, E. (1989) *Human Factors of Advanced Technology (Glass Cockpit) Transport Aircraft.* NASA Contractor Report 177528.

Williams, J.M.G., Watts, F.N., MacLeod, C., and Mathews, A. (1997). *Cognitive Psychology and Emotional Disorders*. NY: John Wiley.

Yacoob, Y. and Davis, L.S. (1996). Recognizing human facial expressions from log image sequences using optical flow. *IEEE T-PAMI*, 18(6), 636-642.

Zacharias, G.L. (1996). SAMPLE: Situation Awareness Model for Pilot-in-the-Loop Evaluation. Final Report R95192. Cambridge, MA: Charles River Analytics.