PILOT SITUATION AWARENESS: THE CHALLENGE FOR THE TRAINING COMMUNITY

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ABSTRACT

The ability of the military pilot to maintain situation awareness (SA) has been recognized in the pilot community as crucial to mission success and survival. Traditionally, pilot training has focused on instruction in the operation of on-board technologies, procedural information for normal flight and emergency conditions, and deployment tactics. These programs alone are not enough, however. Training programs that focus directly on the development of pilot SA are greatly needed. A cognitive model and formal definition of SA are presented as a basis for several SA-based training approaches. The Situation Awareness Global Assessment Technique (SAGAT), an objective measure of pilot SA, is discussed as a means of evaluating the impact of training techniques on pilot SA.

INTRODUCTION

Traditionally, pilot training has focused on instruction in the operation of on-board technologies, procedural information for normal flight and emergency conditions, and deployment tactics. Further training programs, such as Blue Flag and Top Gun, seek to build upon basic skills and knowledges with the objective of developing and honing warfighter capabilities through continued tactics development and flight experience.

Courtice [2] has expounded upon the limitations of current training efforts. During simulations it was found that qualified combat pilots experienced difficulty in integrating multiple tasks during air-to-air engagements, "including difficulty in operating multiple systems and accomplishing complex procedures simultaneously, coordinating teamed tactics, and in creating and selecting optimal tactics for engagements." Courtice attributed this to the fact that each of these skills were taught and evaluated as a separate unit in the training program. No support was provided for the development of the higher order cognitive skills required to operate in the tactical/operational environment. Courtice states: "no training system in the Air Force today can objectively account for the combat needs of the warfighter and thereby be a reliable indicator and/or predictor of the warfighter's ability to support national military objectives."

The questions to be answered by the training community are: what are these higher order cognitive skills, and how can a training experience be structured to facilitate the pilot's use of his technological systems and appropriate knowledge bases in combat?

THE ROLE OF SITUATION AWARENESS

A model of pilot decision making is presented in Figure 1 to provide a basis for answering these fundamental questions. It is the pilot's situation awareness (SA), his mental model of the world around him and his place in it, that directs his decision making and tactical performance. SA was cited as the single most important factor in improving mission effectiveness at a conference attended by representatives from nine of the major branches of the Air Force [13]. Walker [16] cited that 80 percent of aircraft killed in combat did not even see their attacker. Clearly, SA is critical to pilot performance and survivability in the combat environment.

The SA construct can be broken down as is depicted in Figure 1. The pilot first perceives that some element (e.g. an aircraft, a mountain, a warning light) is present in the environment, along with its relevant characteristics (e.g. color, size, speed, location). This is Level 1 SA. Based upon his knowledge of these elements, particularly when put together to form patterns with the other elements (gestalt), the pilot forms a holistic picture of the environment, comprehending the significance of objects and events (Level 2 SA). For example, the pilot not only detects that a red light has appeared on the warning panel, but he also comprehends that the appearance of that light indicates the failure of a particular system which is life threatening. He comprehends that the appearance of three enemy aircraft within a certain proximity of each other and in a certain geographical location indicates certain things about their objectives, which, in turn, leads to a projection of possible future scenarios. The ability to project the future

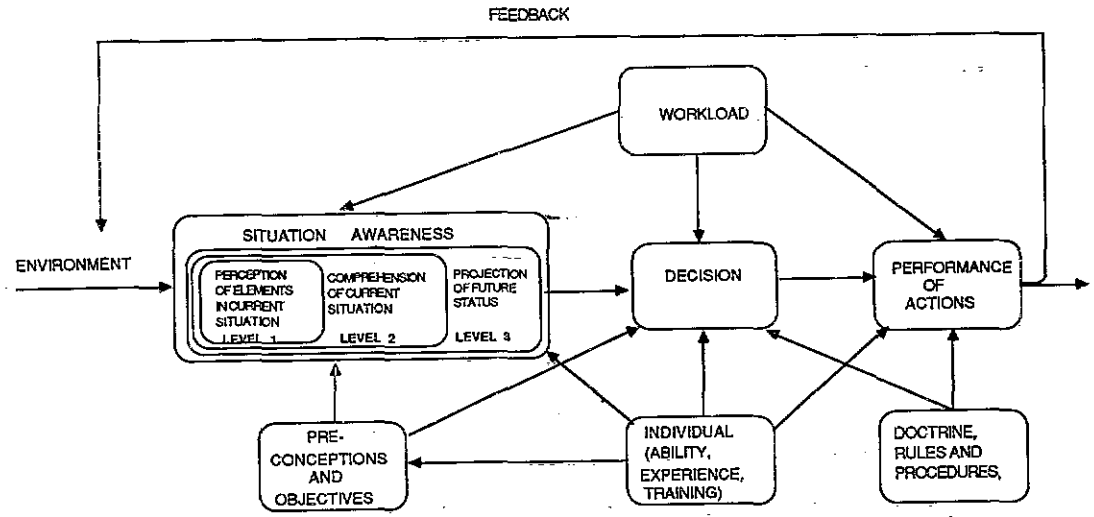

FIGURE 1 PILOT DECISION MAKING MODEL

actions of the elements in the environment, at least in the very near term, forms the third and highest level of situation awareness, Level 3 SA. For example, knowing that a threat aircraft is currently offensive and is in a certain location allows the pilot to project that the threat aircraft is likely to attack in a given manner. This gives him the knowledge (and time) necessary to decide on the most favorable course of action to meet his objectives.

From this description, SA is defined formally as:

> *"the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning, and the projection of their status in the near future".*

The elements in this definition have been explicitly defined for air-to-air tactical missions, and fall into the following categories:

1) knowledge of ownship, friendlies, and enemies, including their location, spatial and system attributes;

2) knowledge of ground forces, terrain, features and reference points;

3) knowledge of airborne missiles, their location and status;

4) higher level comprehension of the situation such as priority/imminence of threats, advantages/disadvantages, threat knowledge, capabilities and objectives; and

5) projection of friendly and threat actions in the near future.

The perception elements, comprehension and projection requirements can also be described explicitly for different missions and aircraft types.

A schematic description of the hypothesized role of short term sensory memory, perception, working memory and long term memory in the SA process is shown in Figure 2. The environment is initially processed preattentively by the pilot through parallel iconic and echoic memory stores (sensory registers for visual and audio input to the brain). Certain properties will be observed at this stage, providing cues for further focalized attention. The pilot may choose to direct his attention towards certain objects in the environment based upon location, shape, color or movement characteristics.

Further processing will typically be directed by the saliency of these objects/features with respect to the goals, objectives and tasks active in working memory and by their saliency in light of pertinent schema active in long term memory. These schema are memory stores which organize bodies of knowledge into integrated meaningful frameworks. Schema can provide coherent frameworks of understanding encompassing highly complex system components, states and

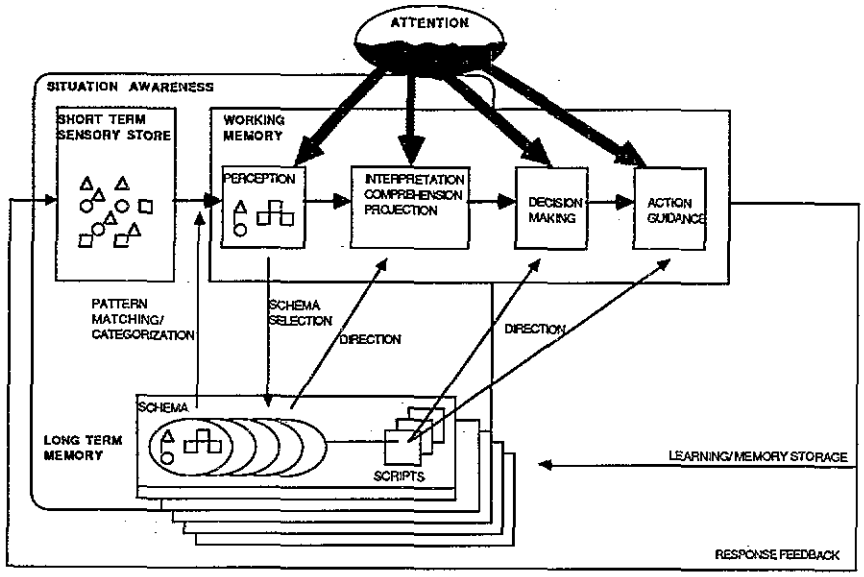

FIGURE 2 MECHANISMS OF SITUATION AWARENESS

functioning. For instance, a schema for "missile employment" might include: dynamic relative positions of own and threat aircraft (location, altitude, airspeed, heading, flight path) and current weapon selection including weapon envelope/capabilities, current Pk, and rate of Pk change. If this schema was active, the pilot would be inclined to seek out and process those portions of the environment which were required by the schema.

Hayes, Waterman and Robinson [10] and Robinson and Hayes [15] found that schema will be used to make judgements concerning which information is relevant to a problem. Hinsley, Hayes and Simon [11] found that people will categorize information almost immediately into a schema that directs problem solving.

In addition, the pilot SA/decision making process can be viewed as a dual process whereby active schema and scripts are dictating which information to focalize attention on (conceptually driven), and simultaneously the presence of certain objects or attributes in the environment will activate new schema in long-term memory (data driven) [1]. If the pilot detected a new threat, for example, he might cease to operate on the "missile employment" schema and a "threat assessment" schema might be activated.

The schema selected, when detailed enough, can be used to direct situation comprehension, future projection, and decision making. A "threat assessment schema" might include information as to what patterns of threats and threat movements constitute offensive versus defensive activities, for example. Future threat movements might be predictable from the schema through a classification of current threat movements into known tactics. Appropriate tactics for countering given threat actions might also be resident in the schema, greatly simplifying decision making.

Ties to scripts, sequences of appropriate actions for task performance, will also greatly facilitate the cognitive process. The pilot will not have to actively decide on appropriate actions at every turn, but will automatically know the actions to take for a given situation.

When schema are not present to draw upon, working memory will be heavily loaded, as active processing will be required to comprehend, project, and carry-out decision activities. Fracker [8] has hypothesized that working memory constitutes the main bottleneck for situation awareness. Hartman and Secrist [9] have proposed that highly experienced pilots will use largely automated processes (such as an automated perception/action sequence directed by long term memory) to circumvent the limitations of working memory.

Whereas novice pilots may have to rely on simple rules and heuristics (rules-of-thumb),

the expert pilot will typically have a much richer base of information to draw upon, expressed in schema in long-term memory. These schema, detailing the relevant system components, attributes, and functioning in such a way as to provide cues for pattern matching to the schema, can provide predictability of dynamics, and ties to appropriate scripts for situational outcomes. SA will be largely dependent, therefore, upon the existence of well developed representations in long-term memory, detailing a model of the functioning of objects alone and with others in the environment and providing for the projection of future actions of that object. When such schema do not exist, SA will be limited by the constraints of working memory.

In the complex environment of the fighter pilot, attentional demands due to informational overload, complex decision making and multiple tasks can quickly exceed limited cognitive resource capacities. Problems with non-optimal *information sampling, visual dominance, and* attentional narrowing under such high demands also seriously limit pilot SA.

Kahneman [14] has proposed that attentional resources can be increased to some degree by physiological arousal mechanisms. Further relief to the limitations dictated by finite cognitive attention resources can be met through the capability of people to divide their attention under certain circumstances. Damos and Wickens [3] have found that sharing of attentional resources is a skill which can be learned and at which some people excel over others.

In summary, situation awareness is a complex process of perception and pattern matching greatly limited by working memory and attentional capacities. Several mechanisms, attentional sharing and automated processing, may serve to alleviate these limitations to some degree. Overall, it can be seen that the combat pilot must develop SA on the basis of well founded and detailed schema or mental models of the environment if he is to be successful in his tasks.

Through his situation awareness, the pilot organizes the world around him. Skills and knowledge bases are called up internally by the *pilot as required by his SA. Subsequent decisions* and actions are all directed by his SA. As situation awareness serves as a critical foundation for organizing pilot knowledge and cognitive processes, it is imperative that training efforts be oriented towards SA.

DETERMINANTS OF SA

Situation awareness will be affected by two major factors: The aircraft design, determining how much and which kind of information the pilot is receiving, and the individual pilot.

AIRCRAFT SYSTEM DESIGN - The first major determinant of SA is the quality and quantity of information that is available to the pilot. The ability of the aircraft system to present the required SA information will largely determine how good that pilot's SA can be. As the amount of information needed is great and workload can be a serious problem, the manner of information presentation is critical. The attributes of the aircraft system for deriving, managing and presenting SA information will greatly influence pilot SA. [5]

PILOT ABILITIES - A second major determinant of SA resides with the capabilities of the individual pilot. Individuals vary in their ability *to search out, assimilate and comprehend* situation awareness information. These individual differences stem from a combination of expectations, inherent attributes, training and experience.

PILOT EXPECTATIONS - SA will be influenced by what is expected. A pilot will typically go into the mission with some expectations of what is to come. Expectations are developed through pre-mission briefings, the flight plans, mission folders and past experience with the environment. Resulting expectations can be conceived of as active schema into which events and information during the mission may be filtered and interpreted.

INDIVIDUAL ATTRIBUTES - No direct information exists on the exact attributes that differentiate between individual's abilities in SA, however, several can be hypothesized.

1) Spatial abilities - the degree to which an individual can mentally visualize and manipulate objects spatially as well as one's own orientation relative to the objects (spatial mapping).

2) Perceptual abilities - including vigilance, perceptual speed, encoding speed, and pattern recognition.

3) Attention abilities - including selective attention capacity, and attention sharing ability.

4) *Logical abilities - including general*

analytic capabilities, and capabilities for predicting system functioning and assessing and diagnosing patterns.

5) Personality factors - Specifically, cognitive complexity and field-independence, since these have been related to problem solving and workload management.

6) Memory - including short-term memory capacity and quantity and quality of long-term memory stores.

Each of these factors may be useful for the development of SA in a given context and for the development of schema with experience. More research is needed to determine which of these factors is actually most critical to SA. An identification of specific individual attributes which differentiate the aces from the general population will provide a wealth of knowledge for pilot selection and training.

EXPERIENCE - Experience should be instrumental in improving an individual's SA through a variety of mechanisms, including:

1) Experience should lead to the development of a large body of episodic memories which can latter be drawn upon.

2) Increased experience should lead to the formation of relevant schema for organizing the functioning of objects in the environment.

3) Schema should become richer with experience to include relationships, functioning, and cause and effect information, to the point of allowing for the projection of future states and the development of appropriate response scripts.

4) Important environmental cues, signifying relevant schema, will be learned (either consciously or unconsciously) by the pilot.

5) Experience should lead to the development of more accurate and manipulable cognitive maps (internal maps of the specific spatial environment).

6) Increased experience should lead to a decreased requirement for attention to individual tasks and an increase in attention sharing among tasks.

TRAINING - Training can be a useful mechanism for developing pilots with superior SA abilities by facilitating the experience process. Situation awareness can be incorporated into training programs in several ways.

1) SA TRAINING CRITERION - If good SA is a desired training outcome, then pilot SA should be made a training criterion. The Situation Awareness Global Assessment Technique (SAGAT), has been developed as an objective measure of pilot SA in manned simulations [4], [6], [7]. SAGAT provides a comparison of the real situation (as it exists in the simulator) to the situation that the pilot perceives, his SA. SAGAT assesses pilot SA in the following manner:

• The pilot flies a mission scenario using a specified aircraft system in man-in-the-loop simulations.

•. At random points, the simulation is stopped and the cockpit and out-the-window displays are blanked.

• The pilot is asked a series of questions to determine his knowledge of the situation at that exact moment in time. The questions correspond to the pilot's specific SA requirements inclusive of perception, comprehension and projection elements. The SAGAT queries are currently programmed on a Macintosh computer, available at each pilot station, to allow for the rapid input and storage of highly spatial information.

• As it is impossible to query the pilot about all of his SA requirements in a given stop, a portion of the SA questions are randomly selected and asked of the pilot each time. This random sampling method allows consistency and statistical validity, thus allowing SA scores to be easily compared across trials, pilots, systems and missions. Some of the questions in any particular query pertain to highly important SA information and some of the questions pertain to more secondary SA information.

• At the completion of the trials, the query answers are evaluated on the basis of what was actually happening in the simulation. This is accomplished by comparing the pilot's answers to data collected from the simulation computers. (Where necessary this may be augmented by subjective evaluations from a team of expert pilots, e.g. for a determination of the priority threat.) The comparison of the real and perceived situation provides an objective measure of pilot SA.

Thus, SAGAT provides an objective, global measure of the pilot's SA. It is inclusive of a pilot's knowledge of his ownship status and

his awareness of the location and attributes of his opponents, his higher level comprehension of the situation, and his ability to project future states of the tactical environment. By objectively evaluating pilot SA, and using this as a training criterion, we can assess how well different training programs help pilots achieve SA, and how well each pilot is accomplishing this objective.

2) SA ORIENTED TRAINING PROGRAMS - Current training efforts could be greatly enhanced by incorporating training that focuses specifically on the development of pilot SA. Training programs can be developed that instruct pilots in the components of important schema, the dynamics and functioning of the tactical elements, and projection of future actions based on these dynamics. Salient cues pointing to the schema and appropriate responses should be tied to the instruction.

In order for such instruction to be internalized meaningfully, it needs to be coupled with experiences that can be provided in simulators and/or actual aircraft. Humphress and Hartman [12] have proposed the "Intentional Tutor", a simulator program for leading the crew member through a structured set of experiences where he can receive immediate feedback on the consequences of his actions. This type of program could also be used to present tactical elements and their dynamic interaction patterns, enhancing the development of schema. Such experiences should be presented in a structured manner, tied to the pilot's comprehension and projection needs.

Several important issues need to be resolved to realize an SA- oriented training program.

- The necessary schema need to be explicitly defined, including their components, attributes, dynamics and relevant cues.

- The SA construct needs to be fully explored in order to understand in what way the SA of superior pilots is better than that of others.

- Research is also needed to determine how higher level SA (comprehension and projection) is generated from lower level data elements.

- Means need to be developed for helping individuals to develop good schema and for instructing pilots in the recognition and interpretation of relevant cues the environment.

- The skills necessary for acquiring SA from the environment need to be determined.

3) STUCTURED FEEDBACK - Feedback is critical to the learning process. If pilots are to learn to improve their SA, they must receive feedback on it. In mission simulations, intermittent feedback can be used to allow the crew member to compare his perceived SA to the actual state of the environment using a tool such as SAGAT. SA feedback should be useful in helping him to fine-tune his schema and his SA acquisition behaviors, greatly enhancing the benefits of experience in developing complex schema.

4) HIGHER ORDER COGNITIVE SKILLS TRAINING - Other types of training may also be useful. Training programs devoted specifically to teaching attention sharing may enhance a crew member's ability to deal with the large volumes of information in the cockpit. Training that focuses on information acquisition strategies should also be useful. For instance, information sampling, holistic processing and information filtering may all be teachable. The exact cognitive skills that are most critical to SA need to be determined.

5) INTENSIVE PRE-MISSION BRIEFINGS - As the acquisition and interpretation of information will be highly focused by a person's expectations, the pre-mission briefing can be a useful tool for enhancing pilot SA. Obviously, the quantity and quality of locational and tactical information provided about what to expect will be important. A simulator tool that allows the pilot to actively experience the expected combat environment by flying through it may also prove to be extremely valuable for developing pilot SA.

CONCLUSIONS

Situation awareness is an extremely important component of the pilot's cognitive processes in the combat environment. It is through his SA that he strives to understand his aircraft's status and the world around him, forming his tactics and decisions accordingly. The training community has before it a great challenge. The development of training programs oriented to the SA and decision making demands of the complex combat environment are a must if we are to prepare fighter pilots who can function at their best in this strenuous environment. At the core of such programs is the need to define and objectively measure situation

awareness, and to incorporate this existing knowledge into a working training program.

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ACKNOWLEDGMENTS

The author wishes to thank Mr. Chuck Semple for his detailed comments on a previous version of this paper.

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