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An Integrated Decision-Making Model for Categorizing Weather Products and Decision Aids

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List of Acronyms

AHAS	Airborne Hazard Awareness System
AIRMET	Airman's Meteorological Advisory
ASOS	Automated Surface Observation System
ATM	Automatic Teller Machine
ATC	Air Traffic Control
AWARE	Aviation Weather Analysis and Reporting Enhancements
AWC	Aviation Weather Center
AWIN	Aviation Weather Information
AWOS	Automated Weather Observing System
CAT	Clear Air Turbulence
CCT	Cognitive Continuum Theory
CIP	Current Icing Potential
DTF	Diagnostic Turbulence Forecast
EWxR	Enhanced Weather Radar
FA	Area Forecast
FAA	Federal Aviation Administration
FGC	Fireground Commanders
FIP	Forecasted Icing Potential
FW	Flight Watch
GA	General Aviation
ITFA	Integrated Turbulence Forecast Algorithm
METAR	Aviation Routine Weather Report
MFD	Multi-Function Display
NAS	National Airspace System
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Center for Environmental Prediction
NCWF	National Convective Weather Forecast
NEXRAD	Next Generation Radar
NWS	National Weather Service
PIREPS	Pilot Reports
RPD	Recognition Primed Decision-making
RVR	Runway Visual Range
RUC	Rapid Update Cycle
SA	Situation Awareness
SIGMET	Significant Meteorological Information
SLD	Supercooled Liquid Droplets
SPECI	Aviation Selected Special Weather Report
SRK	Skills Rules Knowledge
TAF	Terminal Aerodrome Forecast
TCWF	Terminal Convective Weather Forecast
UTC	Coordinated Universal Time
VFR	Visual Flight Rules
WA	AIRMET
WS	Domestic SIGMET
WST	Convective SIGMET
WxAP	Weather Accident Prevention

ABSTRACT

The National Airspace System's working capacity, especially in general aviation, is expected to witness considerable growth in the next few decades. Weather is one component that adversely affects safe air travel, accounting for approximately 30% of general aviation accidents. With the expected increase in air travel, the FAA and NASA have embarked on a grand objective: to develop new technologies that display the multi-dimensional characteristics of weather (e.g., information representation) in a fashion that efficiently supports situation awareness and optimizes pilot decision-making for avoiding hazardous weather. Understanding the intricacies of situation awareness and naturalistic decision-making is an important step in achieving this goal. Information representation (i.e., spatial and temporal uncertainty) and time stress of the situation greatly influence the person's attentional resource allocation and working memory capacity, potentially obstructing accurate situation awareness assessments. Three naturalistic decision-making theories (Rasmussen's Skills-, Rules-, and Knowledge-Based Reasoning; Klein's Recognition Primed Decision-Making; and Hammond and Hamm's Cognitive Continuum Theory) were integrated to provide a comprehensive understanding of the various levels of decision-making incorporated in three situations (e.g., pre-operational planning, operational planning, and operational immediate) and in two conditions (e.g., collaborative or autonomous). The task characteristics (e.g., time stress and taskload) associated with each phase of flight govern the level of situation awareness attained and the decision-making processes utilized. Weather products were classified on the basis of the product's efficacy to support situation awareness and decision-making. The weather product's attributes and the situations' task characteristics combine to classify the weather product according to the decision-making processes best supported given the phase of flight. In addition, a graphical interface is described that affords intuitive selection of the appropriate weather product relative to the pilot's current flight segment.

1.0 Introduction

According to the Federal Aviation Administration (FAA), air travel will witness substantial growth during the next few decades, potentially affecting one billion passengers in 2015. Along with an increase in the number of commercial aircraft to accommodate the proliferation of air travel, general aviation (GA) aircraft are projected to witness considerable growth also. New technologies can aid the air transportation system's capacity and improve safety. Without the continuous development of these new technologies, future commercial and GA aircraft will increase the already overburdened capacity of the air transportation system (2001 FAA National Aviation Research Plan).

1.1 Weather

Weather is one problem that threatens the safety of air travel, especially in GA. Adverse weather has been attributed as the cause of nearly 30% of GA accidents (Chamberlain & Latorella, 2001; Latorella, Pliske, Hutton, & Chrenka, 2001). As a result, the National Aeronautics and Space Administration (NASA) along with the FAA, in compliance with the U.S. President's 1997 movement to reduce the aviation accident rate by 80% in ten years (Latorella et al., 2001; McAdaragh, 2002), initiated the Weather Accident Prevention (WxAP) project. One component of this endeavor, the Aviation Weather Information (AWIN) element, was created to develop new technologies specifically to support optimal pilot decision-making in avoiding hazardous weather during en-route phases of flight.

Within the National Airspace System (NAS), dynamic, unpredictable weather is a critical element that technology can detect and intuitively display to attenuate GA accidents and facilitate safe flying. However, displaying the multi-dimensional characteristics of weather in a manner that supports accurate situation awareness assessments and optimizes decision-making is a grand objective.

Currently, pilots' situation awareness (SA) is obtained through weather information from weather products on the ground and in the flight deck (McAdaragh, 2002). However, the pilot's weather SA is limited by the amount of uncertainty associated with the weather information (e.g., mental workload may be strained in order to determine the exact location of a storm), the reliability of the weather information (e.g., detection and projection of the weather phenomena is only as accurate as the sensors and computer algorithms), time stress (e.g., some decisions must be made and executed without much cognitive deliberation) and so on (Latorella et al., 2001). Even as technology advances the detection and prediction capabilities for adverse weather, these technological achievements do not automatically facilitate weather SA and optimize the pilot's decision-making ability. Because monitoring weather information is one of many complicated environmental pieces of information that pilots must mentally integrate with other cues to arrive at optimal decision-making *in situ* (McAdaragh, 2002), the attributes in which the information is presented must receive focus.

Understanding how decision-making can be improved with display design can greatly attenuate mental workload, allowing more cognitive resources to be devoted to supporting SA and optimizing decision-making. The attributes (i.e., characteristics) of the weather products will be evaluated relative to the level of SA and decision-making support the weather product yields for different segments of flight. NAS operators typically formulate decisions concerning hazardous weather avoidance behaviors in three different situations: 1) pre-operational planning, 2) operational planning, and 3) operational immediate. In addition to these decision-making situations are two decision-making conditions: autonomous operation and collaboration with other NAS operators (McAdaragh, 2002). Generally, decision-making situations involve the operator's SA relative to his/her status in the NAS while decision-making conditions involve the collaboration with various weather service providers or not. Before discussing the decision-making situations and the decision-making conditions, the following sections will discuss SA and the appropriate decision-making theories constituting an integrated model that will be used as a benchmark for categorizing some existing weather products and decision-aids.

2.0 Decision Making

Wickens, Gordon, and Liu (1998) define decision-making as a task where "(a) a person must select one choice from a number of choices, (b) there is some amount of information available with respect to the choices, (c) the time frame is relatively long (longer than a second), and (d) the choice is associated with uncertainty; that is, it is not clear which is the best choice" (p. 184). From this definition, one can clearly discern that decision-making involves risk – the "best" course of action is not always readily apparent to the decision-maker. However, "good" decision makers can competently assess the risks and outcomes associated with each choice (Wickens et al., 1998). Flying in the NAS with adverse weather has levels of risk that vary in severity (especially for GA pilots); flying through mist is less dangerous than flying through a large thunderstorm. Effective decision-aiding tools can assist pilots in selecting executable actions that attenuate the level of risk associated with the situation (e.g., displaying current flight path and surrounding weather).

In many domains, including GA, economic rationality provides a normative standard for how decisions should be made. Decision process models based on economic rationality (e.g., Multi-attribute Utility Technology) assume decision makers have access to all needed information, unlimited time to make a choice, perfect knowledge, and infinite computational prowess. Simon et al. (1987) compared economic rationality (expected utility maximization) to a theory of ideal gases, frictionless planes, and vacuums—how decisions should be made in a "perfect world" with no constraints. The GA environment, however, is not so perfect and not so simple. For these reasons, some researchers have argued that utility maximization is an inappropriate standard for decision quality in general (see Simon, 1956; Gigerenzer & Todd, 1999), and aviation in particular (see Hunter, Driskill, Weissmuller, Quebe, Hand, & Dittmar, 1995). For instance, Driskill et al. (1997) argued that a compensatory decision model to integrate weather information (i.e., an economic model where one good weather factor can compensate for a bad one) was not appropriate in many circumstances and could even lead to dangerous choices by pilots. Many decision theorists have become dissatisfied with economic theory's inability to describe how people make decisions in dynamic complex environments. Therefore, this paper will focus upon decision-making theories applicable to dynamic settings.

2.1 Naturalistic Decision-Making

Decision-making frequently occurs in real-world, dynamic, and complex environments. As a result, naturalistic decision-making tasks performed in a multifaceted environment typically encompass the following characteristics: (a) ill-structured problems, (b) information uncertainty, (c) dynamic environmental cues, (d) shifting or competing goals, (e) time stress, (f) high risk levels, and (g) collaboration between people (Zsambok, 1997). GA pilots, especially those flying in the NAS and confronted with adverse weather, formulate decisions in environments that highly correlate with the characteristics of naturalistic decision-making. Such dynamic environments require pilots to identify and integrate multiple sources of information, manage attentional resources, identify appropriate courses of action, predict potential obstacles, manage information from other decision makers, and perform a controlled action. Furthermore, all of these tasks are typically performed under some level of time stress. Thus, making decisions, while flying an aircraft in adverse weather, is difficult and takes great skill, training, and experience to perform well.

2.1.1 Information Representation. Naturalistic decision-making typically begins when the pilot acquires cues (i.e., pieces of information) directly from the environment or from a display that illustrates environmental information. According to Garner (1962), "information is something we get when some person or machine tells us something we didn't know before" (p.2). However, due to the dynamic characteristics of the environment, the perceived cues may have some grade of uncertainty.

The uncertainty of the information may be the result of our perception that important information from the environment is missing or that the information displayed is unreliable. In fact, Baron (1994) points out that in any situation of uncertainty, the perceiver believes that some information is either missing or unreliable. That is, the cues that signal a potential problem are not always straightforward. If the situation is uncertain, the decision is more difficult to justify than if the situation is clear-cut, which may work against a decision to change the course of action. Additionally, uncertain situations require more cognitive effort to define the nature of the problem, seek out problem-indicating cues, and make a decision (Orasanu & Fischer, 1997). For example, weather forecasts provide probabilistic information concerning the future position of a weather system. Because these predictions are fallible, uncertainty is introduced into the decision strategy. For the most part, people tend to avoid choices that involve uncertain cues and select options with information that is perceived to be certain (Baron, 1994).

2.1.2 Spatial Uncertainty. Sometimes the uncertainty of the information can be spatial and/or temporal. Spatial uncertainty refers to a display's resolution or fidelity of the illustrated surrounding environment. For example, let's say a display shows a large red square indicating a severe thunderstorm, yet the display's resolution dictates that one square represents a 50 x 50 km area. The exact location of the storm is spatially uncertain. Recently, Novacek, Burgess, Heck, and Stokes (2001) found that, absent an out-the-window view, pilots routinely flew clear of adverse weather when provided lower spatial resolution displays (8 x 8 km) rather than higher spatial resolution displays (4 x 4 km). People avoid uncertainty (Baron, 1994). That is, lower spatial resolution increased the uncertainty of the storm's location, thus forcing the pilots to take a wider berth around a weather system. Higher display fidelity and resolution can support more accurate and reliable assessments of the surrounding environment, especially when it is necessary to directly navigate around the weather system.

2.1.3 Temporal Uncertainty. Conversely, temporal uncertainty refers to the rate at which information is updated. For instance, let's say a weather display updates every four hours. In order to accurately assess the situation, the pilot must know how old the data is and from this time stamp, estimate the weather system's future location. Research has demonstrated that people are not accurate at predicting future states, especially the future states of dynamic environments (see Wickens et al., 1998). Therefore, low temporal resolution dictates that pilots must first obtain an initial weather report, store a mental image of the storm's position relative to the last update, attempt to project the storm's path, and wait for the next report to confirm the predictions. All this processing occurs in working memory (to be discussed below). Recent or recently updated weather reports are more informative than old reports

(Wickens et al., 1998) as the strain on working memory resources is reduced. The pilot's decision to proceed with a flight in uncertain weather (either spatial or temporal) contains a high amount of risk; it is difficult to predict in advance what impact the adverse weather will have on flight safety. Technological advances in atmospheric sensors and decision-aids can facilitate assessments of adverse weather.

2.2 TIME STRESS

Time stress has a critical influence on the decision process (Svenson & Maule, 1993; Cook & Woods, 1994; Reason, 1990). The level of time stress within a situation dictates the level of mental processes incorporated into the decision process. Relative to the amount of information presented, Wright (1974) notes that under high time stress, decision-making performance deteriorates when more rather than less information is provided. In high time stress situations, people tend to restrict their range of focus on the environmental cues (Svenson & Maule, 1993). Also, in situations marked by high time stress, people attend more on information sources that are visible, readily interpretable, and directly in their forward field of view (Wickens et al., 1998). This implies that for pilots working under high time stress, less information presented in a perceptually intuitive manner can facilitate decision-making (i.e., less is more). In addition, it has been found consistently that high time stress leads people to abandon analytical strategies (e.g., painstakingly integrating multiple sources of information) in favor of more intuitive strategies, like simple pattern matching. These decision-making approaches will be discussed later.

2.2.1 STRATEGIC PLANNING. As noted above, the level of time stress of the situation dictates the type of planning the operator can incorporate into the decision-making process. Strategic planning, also known as molar plans, can be described in terms of one's overall goals (Benjafield, 1992). These overall goals contain long-term responses related to resource availability. That is, strategic plans are fairly stable, general ideations that must be established in order to complete a mission (Tolman, 1948; Keel, Stancil, Eckert, Brown, Gimmestad, & Richards, 2000). For example, the strategic plan for a pilot flying in adverse weather is to execute a safe flight. The overall strategic goal is to perform a safe flight by avoiding hazardous weather systems at all costs. An important feature of strategic planning is that the overall molar goal can be accomplished in a variety of ways (i.e., "There's more than one way to skin a cat"). This is a precursor to tactical operations.

2.2.2 TACTICAL OPERATIONS. Tactical operations contain quick, reactive responses that enable the person to accomplish his/her goals (Benjafield, 1992). Specifically, a tactical operation refers to the small-scale molecular actions (i.e., specific processes) that can be incorporated to achieve the molar goal (i.e., strategic plan). That is, tactical operations are short-lived specific actions or operations that must be completed to satisfy the molar goal (Tolman, 1948; Benjafield, 1992). For instance, if the pilot finds himself/herself in the midst of an adverse weather system to his/her left, then he/she needs to turn the aircraft to the right in order to avoid the weather system. Information that elicits tactical operations may consist of textual or graphical cues that suggest immediate course correction (Keel et al., 2000) in order to avoid a hazardous situation.

The difference between strategic and tactical operations is fairly straightforward; strategic plans are molar, general actions that satisfy the overall goal (e.g. a safe flight) while tactical operations are molecular, specific actions that are completed to suit the overall goal (Tolman, 1948; Benjafield, 1992). For example, Apollo 11's goal of landing on the moon was a strategic, molar plan. In order to achieve this goal, many smaller scale tactical, molecular actions needed to take place (e.g., the Apollo astronauts executed many fine flight adjustments to land the spacecraft safely on the moon).

3.0 Situation Awareness

To execute optimal decisions successfully in dynamic environments, decision-makers must deduce and assimilate the perceived cues in working memory (i.e., short-term memory) in order to create a relatively accurate awareness of the current and evolving situation (Endsley, 1997; Wickens & Hollands, 2000). For example, in order to plan a safe yet efficient flight, it would aid the pilot if he/she perceived and comprehended the weather cues along the flight path to avoid hazardous areas. From the environmental cues and through executive processes involved in working memory, people interpret and integrate these cues to comprehend the current state of their surroundings (Wickens et al., 1998). This cognitive process is regularly termed situation awareness (Endsley, 1997).

Endsley (1995) defines situation awareness (SA) 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” (p. 36). SA, therefore, involves perceiving critical environmental cues (level 1 SA); understanding the meaning behind those environmental cues relative to the person’s goals (level 2 SA); and at the highest level, the prediction of potential future events in the system (level 3 SA). All three levels vary in cognitive complexity with perceiving environmental cues being the simplest and projecting future status being the most complex (Endsley, 1995).

3.1 Levels of Situation Awareness

3.1.1 Level 1 SA – Perception of Environmental Cues. As stated in the definition, the first step in obtaining an accurate SA is to perceive the dynamics of the relevant environmental cues. For instance, in level 1 SA, the pilot needs to perceive the important elements in the environment (Endsley, 1997) such as terrain, other aircraft, warning lights, as well as adverse weather along the flight path. Along with perceiving these cues, the pilot must understand the relevant characteristics associated with each cue (e.g., the necessary safe altitude to avoid flying into the terrain).

3.1.2 Level 2 SA – Comprehension of Current Situation. Understanding the current situation is founded upon the amalgamation of the environmental cues. Level 2 SA includes a comprehension of those environmental cues relative to one’s goals. Incorporating the data attained from perceiving the cues, the decision-maker integrates this information to create a holistic picture of the situation, attaching meaning to the cues (Endsley, 1997). For example, let’s say the pilot recognizes that a large thunderstorm is straight ahead, crossing his/her current flight path. A large thunderstorm spells trouble for GA aircraft. If the pilot’s goal is safe flying, he/she will need to make a course correction to avoid the thunderstorm. Effective diagnosis of the situation is dependent upon the integration and comprehension of multiple environmental cues (Wickens et al., 1998).

3.1.3 Level 3 SA – Predicting Future Status. The aptitude to project the future status of environmental cues forms the third and highest level of SA (Endsley, 1997). This level is accomplished through knowledge of the dynamics of the cues as well as a comprehension of the current situation (obtained from level 1 and 2 SA knowledge). For instance, knowing that a thunderstorm is straight ahead and is traveling in a definite direction permits the pilot to choose an appropriate course of action that meets his/her overall strategic goal. Thus, by mentally simulating where the storm will be in the future from available cues, the pilot can make an appropriate course correction (i.e., tactical operation).

As Endsley (1997) points out, SA involves far more than simply perceiving environmental cues. SA includes an integrated understanding of the perceived environmental cues and projecting possible future states of the dynamic situation. The higher levels of SA are particularly important for effective decision-making in many information-rich environments (Endsley, 1997).

3.2 LIMITED ATTENTION AND WORKING MEMORY

Humans' limited attentional resources and working memory capacity constrain the process of developing accurate SA as well as processes incorporated in decision-making, especially in dynamic, high time-stressed tasks. Direct attention is required for perceiving and processing the environmental cues in order to initiate the formation of SA as well as for selecting and executing actions (Endsley, 1997). In dynamic environments, task complexity, multiple tasks, and information overload can quickly exceed a person's attention capacity. Because of the person's limited attentional resources, other environmental cues may receive more attention than others; some cues may not be attended to at all. As Neisser (1976) points out, a person's expectations influence what information is attended to; people attend to information they expect to see. This limited attentional fixation can drastically affect a person's SA as not all the environmental cues are perceived, which can result in poor decisions, potentially leading to human error.

Similarly, working memory capacity can hinder the development of accurate SA also. Active processing (i.e., awareness) of the evolving environmental cues resides in working memory. New information must be integrated with existing knowledge from long-term memory to develop a composite image of the situation (level 2 SA). A projection of future status (level 3 SA) also occurs in working memory. However, working memory can only process and maintain approximately $7^{\pm}2$ chunks of information at a given time (Miller, 1956). As a result, working memory degrades as more resources are allocated to competing tasks. That is, due to the limitations of working memory, people can only incorporate a small number of chunks in order to develop a mental picture of the situation. This can lead to an inaccurate assessment of the situation. Because flying is a complex task with many environmental cues that must be interpreted and integrated, the amount of information presented can directly influence decision-making (Cook & Woods, 1994; Reason, 1990).

Too much information can quickly overload working memory, which can lead to an increase in mental workload (Wickens et al., 1998). In times of high mental workload and time stress, people seem to lose their SA. That is, they fail to track the current state of the world (Waag & Bell, 1997). For pilots, this may mean a spatial disorientation of their relative position (Wickens et al., 1988). Therefore, working memory may constitute the primary bottleneck for SA and can seriously constrain the decision-making process (Endsley, 1997). Analog displays can counteract this bottleneck. Analog displays (i.e., graphical displays) that visually integrate several environmental cues into one display can be used effectively in order to counter the limitations of working memory (Cook & Woods, 1994; Reason, 1990). Stone, Yates, and Parker (1997) suggest that the conversion of arithmetic calculations or confusing language to graphical form can attenuate the strain on working memory.

4.0 NATURALISTIC DECISION-MAKING THEORIES

4.1 SKILL-, RULE-, AND KNOWLEDGE-BASED DECISION-MAKING

Rasmussen's (1983) Skills-, Rules-, and Knowledge-Based (SRK) information processing model illustrates three levels of cognitive control incorporated in the decision-making process. Depending upon the characteristics of the task and the operator's amount of experience with the situation, people typically function at one of the three levels (Rasmussen, 1983; 1986; 1993). In addition, depending upon the level of familiarity, the person can switch between levels of cognitive control in the decision-making process. The cognitive processing at the skill-based level, the rule-based level, or the knowledge-based level dictates how information can be processed and how information is used in the decision-making process. Information interpretation and integration, mediated by the intentions and expectations of the person, has three levels: signals, signs, and symbols.

4.1.1 SKILL-BASED. People who have a great deal of experience with a particular task will process the information and make decisions at the skill-based level. This level of decision-making is characterized by automatically reacting to the environmental cues at a subconscious level (i.e., without awareness). The information is perceived as signals – people do not need to consciously interpret and integrate the cues or think of possible controlled actions; rather pure stimulus-response associations govern behavior (Rasmussen, 1983). For instance, let's say the pilot perceives a thunderstorm straight ahead that interferes with the current flight path. The pilot simply reacts to this environmental cue by executing a course correction to avoid the storm. Because the pilot's behavior is relatively automatic, drain on attentional resources is minimal, allowing the operator to spread monitoring resources to other flight systems. The skill-based level of decision-making is where experts typically perform. Errors at the skill-based level are usually caused by misdirected attention (e.g., attends to other information that would suggest a deviation from the normal course of action but operator still performs the automatic behavior) or by focusing attention on the task, which then interrupts an automated sequence of behavior (Wickens et al., 1998).

4.1.2 RULE-BASED. Operators who are familiar with the task, but lack extensive experience, process the information and execute decisions at the rule-based level. At this level of decision-making, the cues are processed as signs. Information perceived as signs activate learned controlled responses associated with signals, generally labeled by names that refer to states of the environment or a particular situation. These signs are compared to IF-THEN rules accumulated from past experiences. These IF-THEN rules follow strong associations between cue sets (e.g., groups of information) and the appropriate actions (Rasmussen, 1983). Let's say that there is a convective system to the right of the pilot's flight route. If the storm compromises the flight path, then the appropriate action would be to turn to the left to avoid the storm. However, if the storm fails to move across the flight path, then no course correction is needed. There is more cognitive processing in the rule-based decision-making process than skill-based decision-making. Essentially, the behavior of the cue set determines the operator's course of action. Errors made in decision-making at the rule-based level tend to result from the misclassification of the cue sets, which leads to an application of the wrong rule followed by the wrong action (e.g., thinking the storm would <u>not</u> move across the flight path when eventually it does).

4.1.3 Knowledge-Based. People in novel situations cannot retrieve any rules accumulated from previous experience. Therefore, these people process the information and formulate decisions at the knowledge-based level. This level is characterized by highly analytical processing using conceptual information. The information at this decision-making level takes the form of symbols, mental representations of the information's functional properties (i.e., what the person thinks the information means after much deliberation) (Rasmussen, 1983). After the person interprets and integrates the symbols to develop a mental representation of the situation, he/she processes this information in accordance with rules and goals stored in working memory. However, without rules to govern behavior in unfamiliar situations, the person must adapt by generating new rules. These new rules are based on logical reasoning and symbolic representation of the problem state. If new rules cannot be generated, the operator must change their goals. Effortful analysis and memory retrieval support problem solving and strategic planning activities. Mental models are often used to run cognitive simulations in evaluating a planned course of action. For instance, the pilot may consult weather reports and other NAS operators to formulate a mental model of the situation. In order to verify the mental model, the pilot would conduct mental simulations, making predictions about future states of the weather environment. Once the cognitive simulation has been conducted, the pilot can evaluate the outcome relative to his/her goals. Errors made at the knowledge-based level are the result of factors associated with analytical thinking, such as limited working memory capacity to interpret and integrate environmental cues (Reason, 1988).

4.2 Recognition-Primed Decision-Making

Due to the constraints that time stress places on attentional resources and working memory, the SA model suggests that optimal decision-making is dependent upon pattern matching between critical environmental cues and the person's mental model of the situation. The recognition-primed decision-making (RPD) model describes what people actually do under time stress situations, uncertain information, and dynamic conditions (Klein, 1989). The RPD model contains three levels of cognitive functioning: simple pattern matching, pattern discrimination, and mental simulation.

The RPD model was developed out of frustration with the inability of traditional decision theory to describe the decision process of urban fireground commanders (FGCs) as well as other experts who work in complex dynamic environments. The traditional decision tree representation did not adequately describe the decision processes of such experts. Traditional decision theory assumes that decision makers generate all relevant alternative courses of action, compare all courses of action, and choose the course of action with largest expected utility. The FGCs, however, did not characterize their roles as making choices, generating alternatives, comparing alternatives, or assessing probabilities (Klein & Calderwood, 1991). In contrast, experienced FGCs described themselves as acting or reacting on the basis of prior experience, monitoring, planning, and modifying plans to meet specific and changing constraints (Klein & Calderwood, 1991). Thus, the RPD model was developed to describe the way that expert decision makers make real world high-stakes decisions.

4.2.1 Simple Pattern Matching. During the simple pattern matching stage of decision-making, the person identifies a pattern encompassed within the environmental cues and reacts accordingly. The goals are straightforward (e.g., execute a safe flight), the critical cues are being attended to, and a course of action is recognized and readily executed. Simple pattern matching is fast and accurate, which makes this type of decision-making process robust to time stress and other stressors (Klein, 1993). For instance, if a pilot is in a high time-stress situation and sees on a display (or out the window) that a thunderstorm is directly ahead, then he/she can make a course correction without much cognitive processing; the action is relatively automatic. When people match patterns of environmental cues to an appropriate action, rapid and optimal decision-making can occur (Klein, 1989).

4.2.2 Pattern Discrimination. The pattern discrimination stage of decision-making attempts to link multiple observed patterns to causal factors in order to obtain an explanation for the events. The purpose of pattern discrimination is to evaluate an uncertain assessment of the situation by comparing cue patterns and respective actions. Recognizing the difference between cue patterns is important because it can largely determine the course of action adopted. For example, consider a pilot who recognizes a thunderstorm close to the current flight path. At least two patterns must be evaluated; the storm could move away from the current flight path or the storm could cross the current flight path. If the pilot determines that the storm does not cross the current flight path, then that cue pattern informs the pilot to take no action. However, if the pilot determines that the storm will cross the current flight path, then that cue pattern signifies that a course correction is required. In this situation, the pilot must discriminate between the two patterns in order to determine the appropriate course of action. Often decision-makers will spend more time and mental effort trying to distinguish between different patterns than comparing different courses of action associated with each pattern. The pattern discrimination stage is typically initiated in response to uncertainty about the nature of the situation, especially if more time is available (Klein, 1989).

4.2.3 Mental Simulations. Mental simulation is a more complex decision-making stage than simple pattern matching or pattern discrimination. Conducting a mental simulation is necessary to determine if a course of action will encounter any difficulties and whether these difficulties can be remedied, or whether an entire new course of action is needed. Mental simulations are analytical processes that deliberately assess the viability of available courses of actions. Mental simulations are used to project a course of action forward in time. For example, when conducting a mental simulation, the pilot, during pre-flight, may consult many weather reports (or other groundside personnel), construct a mental model, and make a prediction regarding the storm's location before the next weather report update. If the update matches what the pilot predicted, then the mental model is not modified; the pilot continues with his/her original flight plan. If the update does not match the pilot's prediction however, then the mental model is amended, possibly altering the original flight plan.

According to Wickens et al. (1998), in order to accomplish accurate SA, the person must recognize key environmental cues that map onto key features in the mental model; the mental model must match the environmental information. An accurate mental model can then provide for higher levels of SA (e.g., comprehension and projection) without drastically draining attentional resources and loading working memory (Endsley, 1997). In spite of the prevalence of rapid pattern-recognition decisions, there are cases where decision makers will use highly analytical methods. If uncertainty exists and time is adequate, additional analyses are performed to assess the current situation, modify the retrieved action plan, or generate alternative action plans (Wickens et al., 1998).

4.3 Cognitive Continuum Theory

Hammond (1980; 1993) and Hamm's (1988) cognitive continuum theory (CCT) suggests that decision-making processes occur within a continuum ranging from intuitive processes to analytical processes. Low cognitive control, low conscious awareness, and automatic information processing exemplify intuitive processes (Hammond, 1993). During intuitive processing, environmental cues are simply sensed and automatically responded to accordingly. Beyond that, there is no further demand on cognitive resources. Conversely, higher levels of cognitive control and slower deliberate processing characterize analytical processes. The area that lies between complete intuitive processing and complete analytical processing is called quasi-rational. Quasi-rational processes represent the cognitive compromise between intuitive processing and analytical processing. Essentially, a person enters quasi-rational processing when full analysis of the situation is impossible and full intuition would not be acceptable. For example, when calculating how long an automobile trip may take, the driver might engage in the analytical process by looking up the actual number of miles but then guess the average speed necessary to make the destination within a certain amount of time.

The region along the cognitive continuum where a person will operate is mediated by time stress. If there is high time stress to make a decision, then the operator will shift toward the intuitive pole. Conversely, if there is time to think about plausible explanations for an event, then the operator will be driven toward analytical processing. Analytical cognitive processes are analogous to knowledge-based processing—the person must painstakingly interpret and integrate all the environmental cues to develop a mental image of the situation while intuitive cognitive processing corresponds to skill-based processing. Additionally, quasi-rational processing correlates to rule-based processing.

5.0 An Integrated Model of Naturalistic Decision Making

While each of the aforementioned naturalistic decision-making models provide a unique explanation of the decision-making processes, all can be integrated into a single decision-making model. Rasmussen's cognitive control theory provides the framework for the integration model. Through the integrated model, the decision-making strategies that operate at each level of SA can be described. Figure 1 illustrates how the various levels of decision-making specified by each theory map onto the integrated model. Table 1 provides a simplified representation of the integrated naturalistic decision-making model.

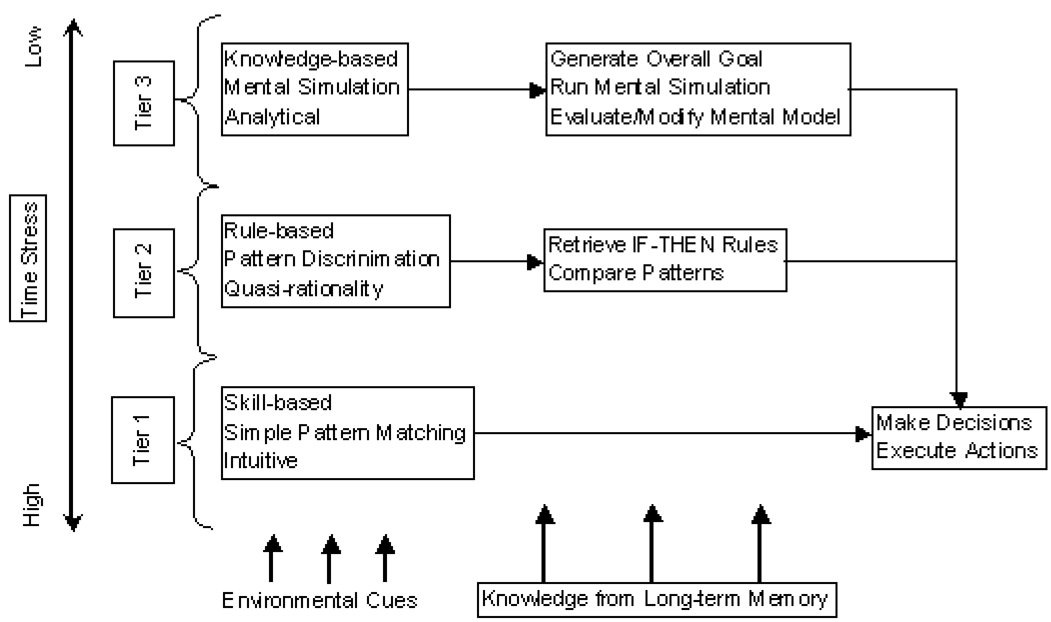

Figure 1: An integrated model for naturalistic decision-making.

Table 1
The SRK, RPD, and CCT Theories Combined into a Naturalistic Decision-Making Model

	Tier 1	Tier 2	Tier 3
SRK	Skill-based	Rule-Based	Knowledge-Based
RPD	Pattern Matching	Pattern Discrimination	Mental Simulation
CCT	Intuitive	Quasi Rationality	Analytical

As illustrated in Figure 1, the integrated model of naturalistic decision-making illustrates the processes that occur in working memory, with information captured from the environmental cues and knowledge extracted from long-term memory. According to this model, information enters the system, is processed, and decisions are made at one of three tiers depending upon the characteristics of the situation (e.g., taskload and time stress). Tier 1 decision-making consists of CCT's intuitive decision-making, SRK's skill-based decision-making, and RPD's pattern matching decision-making while Tier 2 decision-making consists of CCT's quasi rationality decision-making, SRK's rule-based decision-making, and RPD's pattern discrimination decision-making. Finally, Tier 3 decision-making consists of CCT's analytical decision-making, SRK's knowledge-based decision-making, and RPD's mental simulation decision-making.

5.1 Tier 1

Tier 1 decision-making occurs when decision makers have enough time to perceive the environmental cues as signals and react to those signals. Tier 1 processes are robust when time stress is high or when cognitive resources are strained. Thus, Tier 1 processes (e.g., skill-based decisions, decisions based on simple pattern matching, and decisions based on intuitive processes) are the only ways that pilots can process information when under high time stress or high taskload. Tier 1 processes, however, are limited in that they can only interact with information that can be processed as signals. Tier 1 processes are not amendable to information other than signals (e.g., signs and symbols), which are left unattended when there is insufficient time or cognitive resources for higher-level analytical processes to operate (i.e., Tier 2 and Tier 3 decision processes).

When decision makers are under time stress, Tier 1 processes correspond closely to level 1 SA. The environmental cues (i.e., signals) are simply acquired and perceived from the environment. Time stress is not the only reason why decision makers employ Tier 1 processes, as experience may elicit these processes. For instance, consider a chess master with extensive knowledge and experience playing chess. Chess positions (i.e., cues) do not require much cognitive processing for chess masters to reach a good decision; rather the appropriate action (i.e., move) is quickly retrieved and executed (Chase & Simon, 1973). Essentially, highly experienced operators associate the pattern of the environmental cues automatically with the appropriate cue-action rules from long-term memory, which specify the desired action sequence to be executed (Gordon, 1992).

5.2 Tier 2

Tier 2 decision processes require more time and cognitive resources than Tier 1 processes. When time and resources allow, decision makers can integrate and assign meaning to the signs. Tier 2 processes are only amendable to information that can be processed as signs. Other forms of information (e.g., symbols) are left unattended even under conditions of moderate time stress. When Tier 2 decision processes can be engaged, the pilot can rely upon rule-based IF-THEN strategies to discriminate between cue patterns (i.e., pattern discrimination). In addition, Tier 2 decision processes are quasi-rational (i.e., some cues can be processed analytically and others intuitively).

In situations characterized by moderate time stress, Tier 2 processes parallel level 2 SA – development of an integrated understanding of the state of the world, including amendments or refinements to mental models. A mixture of strategic and tactical operations can occur in this situation. The pilot still maintains a molar goal of safe flight. In the event the pilot's safety may be compromised, the pilot can make a course correction (i.e., molecular action to satisfy the molar goal).

5.3 Tier 3

Tier 3 decision-making processes necessitate more time and mental resources than Tier 2 or Tier 1 processes. Given ample time and resources, the person can integrate, assign meaning, and project the future behavior of the information (i.e., symbols). Because Tier 3 is characterized by low time stress, however, other information (e.g., signals and signs) can still be integrated into the decision-making process. Tier 3 processes are engaged when Tier 1 and Tier 2 processes do not provide a satisfactory solution or decision and time is available; the decision-making process will shift toward a more deliberate analytical process (Wickens et al., 1998). The pilot can use knowledge-based reasoning and run mental simulations, based on symbols, to confirm or amend mental models of his/her weather SA. A more strategic approach can be incorporated into the decision-making process where the molar goal of safe flight is developed.

Tier 3 decision-making processes correspond to level 3 SA; a mental model is developed and the future state of the environment is projected. Under ordinary circumstances, even with analytical processing, a decision-maker will generate only one mental model and generate one overall goal along with the necessary sequence of steps to satisfy the goal (Wickens et al., 1998). The decision-making process in Tier 3 relies heavily on running mental simulations to help assess the validity of the mental model (Orasanu, 1993). When conducting mental simulations, the decision-maker typically searches the environment for further data to confirm the mental model (Wickens et al., 1998). The use of mental simulations to generate ideas about additional cues to be obtained would explain why people tend to look for confirming evidence. This is because only the generation and running of false mental models would yield disconfirming cues to search for. This seems unlikely to occur in many situations, especially those with time urgency (Wickens et al., 1998).

6.0 Collaborative and Autonomous Decision Making

So far, this discussion has primarily focused on naturalistic decision-making theories relating to individual decision-making. However, as noted in the definition of decision-making, naturalistic decision-making can also occur within a team structure (Zsambok, 1997). Zsambok (1997) points out that individuals who contribute to good team decision-making monitor their performance and self-correct; offer feedback to others; maintain awareness of roles and functions and take action consistent with that knowledge; adapt to changes in the task or the team; communicate effectively; converge on shared understanding of their situation and course of action; anticipate each other's needs or actions; and coordinate their actions. In order to optimize collaborative decision-making, team members must share a common mental model of the situation (Orasanu & Salas, 1993; Salas, Cannon-Bowers, & Johnston, 1997).

One way to facilitate a shared mental model is to use similar equipage to present the environmental cues (Orasanu & Salas, 1993). If time permits and the team members have the cognitive resources available, then collaborative decision-making can take place. During times of reduced mental workload, team members can share information regarding the situation, goals, emergency strategies, and so forth (Salas et al., 1997). This way, when the team encounters an emergency, they can use the shared information for implicit coordination that does not require extensive communication. There usually is a status difference between two operators who must share and exchange information (i.e., the pilot and Flight Watch (FW) specialist) as one has more knowledge and experience with forecasting weather (Wickens & Hollands, 2000). For instance, FW specialists are trained to nowcast weather systems and relay their interpretation, whereas pilots are not trained to perform this task.

However, some conditions do not support collaborative decision-making. Inter-member decision-making can be severely constrained during periods of high time stress, strained cognitive resources, and when team members do not use similar equipment (Orasanu & Salas, 1993). Without the ability to develop and share a common mental model, collaborative decision-making breaks down. This type of scenario is called an autonomous decision-making condition (i.e., the pilot is the sole person making the decisions). During autonomous decision-making, the pilot does not have sufficient time and mental resources to convey or receive information regarding his/her situation from groundside personnel. Rather, the pilot is focusing his/her mental resources on the task at hand. Because of the limited cognitive resources available for communication, autonomous decision-making typically occurs in situations of tactical operations.

7.0 Phases of Flight

As noted above, GA pilots typically make decisions for avoiding hazardous weather in three different phase of flight situations: pre-operational planning, operational planning, and operational immediate (McAdaragh, 2002). Idiosyncratic tasks, mental processes incorporated into the decision-making process, and requirements for weather decision aids in order to support SA characterize each of these situations. It should be stated that in all phases of flight, the pilot's behavior is assumed to be goal directed. That is, it is assumed the pilots' intentions are to fly a route that satisfies safe flight.

7.1 Pre-Operational Planning

During the pre-operational phase, the pilot plans for future operations along the intended flight route within the NAS. The pilot examines many operational variables, including appropriate weather products (McAdaragh, 2002). At this time, the pilot initiates the formulation of a mental model of the weather along the intended flight route (i.e., SA begins to develop). The pre-operational planning stage is characterized by more available time than subsequent phases of flight; therefore the pilot has the freedom to allocate mental resources (i.e., working memory and attention) for weather SA development (McAdaragh, 2002). The pre-operational planning phase has the following task characteristics:

- *Low time stress*: Because the pilot is on the ground, he/she can take as much time as needed to thoroughly examine weather reports; sufficient time can be devoted to constructing of a mental model of the weather surrounding the intended flight path. The pilot has the luxury to mentally forecast future weather status and confirm those predictions.

- *Strategic planning*: Due to the low time stress of the situation, the pilot can construct a relatively stable, molar goal that provides a general plan to satisfy safe flight (i.e., the pilot can be proactive and plan ahead to select a safe route).
- *Actions*: Once the strategic plan has been tested and re-tested, the pilot then files a flight plan, one that satisfies safe flight.
- *Collaborative decision-making*: While groundside, the pilot may consult various weather reports along the intended flight path. Also, the pilot can discuss the convective weather conditions with other NAS operators (e.g., airline dispatchers, meteorologists, ATC weather service units) in order to develop a comprehensive weather SA mental model.

As can be derived from these characteristics, low time stress supports strategic planning as well as collaborative decision-making between NAS operators enabling the pilot to perceive, understand, and predict the future status of the convective weather system. As a result, the task characteristics associated with the pre-operational planning phase afford the following decision-making processes and SA level:

- *Level 3 SA*: The pilot can examine many weather reports and/or discuss surrounding weather with groundside NAS personnel (level 1 SA), comprehend the meaning behind the weather information (i.e., creating a mental model of the weather situation along the intended flight path; level 2 SA), and predict the future status of the weather system (level 3 SA). Once the weather forecasts have been made, the pilot can compare their predictions to the latest weather updates. After completing this process, the pilot can modify the mental model accordingly and predict future convective weather activity, incorporating the most recent weather data. Broad attention can be used to integrate many sources of weather information during mental model construction.
- *Decision-making processes*: Because of the low time stress associated with this situation, the pilot can spend sufficient time analyzing the weather reports and constructing a mental model of the weather environment. As a result of much deliberation over weather reports, the decisions made under these circumstances conform to knowledge-based decision-making. Within the mental model, the pilot perceives, comprehends, and predicts the behavior of the weather system. This is a very analytical approach to decision-making as the weather information is carefully mulled over. In addition, the low time stress offers the pilot time to conduct mental simulations to determine if his/her mental model fits the environmental information and requires modification.

7.1.1 Weather Product Requirements: Due to low time stress where working memory and attentional resources can be fully utilized to develop a mental model of the weather situation, according to McAdaragh (2002), any weather products approved by the FAA can be appropriate for the pre-operational planning phase. Pilots, as well as groundside operators, have access to these products. In addition, any decision aids that integrate approved FAA weather information may be used in the pre-operational planning phase also (McAdaragh, 2002).

7.2 Operational Planning

During the operational planning phase, the pilot incorporates weather information in order to plan future operations for the aircraft while operating in the NAS. The pilots' decisions are based upon extrapolations and official forecasts along the flight route (McAdaragh, 2002). The pilot's SA in the operational planning stage is characterized by integrating information to confirm the current mental model of the weather situation or make amendments to the intended flight plan while operating in the NAS. These decisions are made in a dynamic, multi-tasking environment. The operational planning phase has the following characteristics:

- *Moderate time stress*: The pilot is now operating in the NAS where the multi-tasking nature of the situation divides available time and attention between completing various tasks and comprehending many sources of information. The pilot has less time to study weather information than he/she did in the pre-operational phase. That is, less time is available for the pilot to estimate future weather states and confirm those predictions.
- *Strategic/Tactical operations*: As a result of the moderate time stress associated with the situation, the pilot can still conform to the molar plan (i.e., proactive behavior of obtaining information, possibly planning to alter course) of executing a safe flight. However, the pilot may need to incorporate tactical operations (i.e., reactive behavior), performing molecular course corrections to avoid hazardous weather systems, satisfying safe flight.
- *Actions*: Up-linked cockpit data can be used to evaluate the current mental model of the situation. An executed course correction suggests the pilot amended his/her mental model while maintaining present course implies the mental model was simply confirmed.
- *Collaborative decision-making*: Even though the pilot is under moderate time stress when operating in the NAS, he/she has ample time and cognitive resources to discuss convective weather conditions along the intended flight path with groundside personnel. When collaborating with groundside NAS operators (e.g., Flight Watch (FW) specialists), pilots can discuss information regarding their current situation along the flight path and share plans for safely avoiding convective weather systems.

The operational planning phase is a dynamic situation, with attentional resources and working memory distributed over many tasks and many sources of information. However, moderate time stress still permits strategic planning (tactical operations can occur if necessary), modifications of mental models, and collaborative decision-making. Due to increased time stress associated with the task, level 2 SA can be attained and the following decision-making processes are most likely utilized:

- *Level 2 SA*: Even though the pilot is under more time stress with attentional and working memory resources spread over several tasks, he/she still has enough attentional (i.e., focused attention) and working memory resources to perceive and comprehend surrounding weather systems. Although level 3 SA can be implemented, given the amount of time stress however, it seems unlikely the pilot will spend much time forecasting future activity and locations of weather systems; level 2 SA seems to be where the pilot will spend most of the time during this phase of flight. The pilot can collaborate with groundside NAS operators to discuss current weather activity along the flight path. The pilot can make minor modifications to the mental model of the convective weather situation either through weather information received from cockpit displays or from groundside personnel. This information can be incorporated into the decision to maintain current flight path or to deviate.

- *Decision-making processes*: The moderate time stress in this phase (due to the multi-tasking nature of flying in the NAS) allows the pilot to make slight modifications to the mental model. Subsequently, the pilot incorporates rule-based reasoning in the decision-process, relying on IF-THEN rules between the perceived groups of information and the appropriate course of action. The groups of information form patterns. These patterns are compared against each other (i.e., pattern discrimination). Cues that follow a particular pattern elicit a specific course of action. For instance, if the pilot recognizes that a thunderstorm interferes with the current flight path (i.e., cue pattern), the pilot will make a course correction to avoid the hazardous weather system. Neither full analytical processing nor full intuitive processing of the weather system is available; therefore the pilot incorporates quasi-rationality in the decision-process.

7.2.1 Weather Product Requirements: According to McAdaragh (2002), to optimally support decision-making in the operational planning phase of flight, FAA approved weather products must be compatible with dynamic, multi-tasking situations. Thus, these weather products should incorporate algorithms that integrate and provide accurate short-term depictions of future convective weather hazards (i.e., nowcasted data). Weather decision-making would be enhanced if the weather information displayed were temporally current and spatially accurate. The interfaces for these weather products should support rapid interpretation and understanding at a glance, thereby attenuating the mental resources needed to analyze and interpret weather data. Finally, these weather products should display all relevant convective weather systems along the intended route of the aircraft to efficiently support decision-making in the operational planning phase (McAdaragh, 2002).

7.3 Operational Immediate

During the operational immediate phase, the pilot uses ”information to directly navigate the aircraft around weather hazards within the current flight environment” (McAdaragh, 2002, p. 7). That is, pilots use weather information for rapid decision-making efforts to route the aircraft around weather hazards. The pilot is no longer planning weather avoidance, but now uses weather information to take immediate action. As a result, the operational immediate phase is characterized by the following:

- *High time stress*: The pilot is directly navigating around the convective weather system; therefore the pilot is under great time stress, needing to perceive the environmental cues quickly and make decisions rapidly in a fast moving environment. Sufficient time is not available for the pilot to predict the future status of the weather system.
- *Tactical operations*: Because the pilot is under high time stress, he/she needs to execute small-scale molecular actions immediately. In order to satisfy the strategic goal of safe flight, the pilot needs to respond in ways that inhibit the potential for flying into the hazardous weather system.
- *Actions*: Due to the pilot's inability to thoroughly process the weather information, the pilot is required to perceive and react accordingly by executing immediate course corrections to avoid the hazardous weather.
- *Autonomous decision-making*: The high time stress greatly reduces the pilot's ability to discuss his/her situation with groundside NAS personnel. As a result,

the pilot is forced to make decisions regarding the optimal route to navigate around the weather system solely on the basis of the information attained from looking out the cockpit window and/or from flightdeck weather displays.

In the operational immediate phase of flight, the pilot is under great time stress. Subsequently, the pilot switches from strategic planning to tactical operations and from collaborative decision-making to autonomous decision-making. Therefore, level 1 SA is attained and the following processes are incorporated into the decision-making procedure:

- Level 1 SA: The pilot is under high time stress, causing attention to narrow (i.e., attentional tunneling) to the specific task of navigating around the hazardous weather system. As a result, the pilot can only perceive (level 1 SA) the weather information. High time stress and lack of sufficient mental resources do not permit the pilot to comprehend or predict future status of the weather system. Rather the pilot simply reacts to the weather information.
- Decision-making processes: Due to the high time stress of the situation, the pilot is limited to simply perceiving the environmental cues and reacting accordingly. Insufficient time inhibits the pilot's ability to make modifications to the mental model. People can process patterns of information quickly and intuitively; therefore the decision-making process is expedited. If the pilot recognizes a pattern within the attended critical cues (i.e., simple pattern matching), then he/she can process this pattern automatically and make a reflexive response to the information. This decision-making process is analogous to skill-based reasoning.

7.3.1 Weather Product Requirements: Because the operational immediate phase is an extremely high time stressed condition, with attention and cognitive resources spread over many tasks, weather information must be presented that supports flexibility in the pilot's attention as well as rapid interpretation. In order to satisfy the decision-making requirements in the operational immediate phase, approved weather products must support optimal decision-making in dynamic, multi-tasking, real-time situations (McAdaragh, 2002). Such weather products must have high spatial accuracy and high temporal resolution in order to accurately represent the current weather conditions. In addition, these weather products should display the convective weather information in an integrated graphical manner to facilitate quick interpretation of the surrounding situation. Data being used to make decisions in the situation must be considered real-time data (McAdaragh, 2002).

8.0 CLASSIFICATION OF WEATHER PRODUCTS AND DECISION-AIDS

8.1 WEATHER PRODUCTS

The following section discuses the taxonomy of some of the available weather products relative to the level of decision-making the product supports. While this may not be an exhaustive list, this section should provide guidance to the reader on how to classify future weather products on the basis of the products' attributes (e.g., spatial fidelity, temporal resolution, and weather integration capability) and the characteristics of the task. Hopefully, the reader will see that the weather products' attributes and the situation's (i.e., phase of flight) time stress together contribute to the categorization process. More information about the weather products can be found in the sections below and in Appendix A. It should be noted that some weather products have attributes that afford classification into multiple categories (i.e., some weather products can be used in the pre-operational planning and operational planning phases of flight). These weather products are indicated in Table 2. Note: convective weather activity can move fast with rapidly changing conditions – requiring rapid updates for current reports. Icing and turbulence cover widespread areas and typically do not change or move rapidly – updates do not need to be as rapid.

Table 2
Categorization of Weather Products Relative to Phase of Flight.

	Phases of Flight			
	Pre-Operational Planning		**Operational Planning**	**Operational Immediate**
Weather Products	Terminal Aerodrome Forecast (TAF)	Area Forecast (FA)	Current Icing Potential (CIP)*	On-Board Radar
	Aviation Routine Weather Report (METAR)	Next Generation Weather Radar (NEXRAD)	Terminal Convective Weather Forecast (TCWF)*	
	Convective SIGMET (WST)	AIRMET (WA)	Integrated Turbulence Forecast Algorithm (ITFA)*	
	Domestic SIGMET (WS)		National Convective Weather Forecast (NCWF)*	

Note: Those products that can be used in the pre-operational planning and operational planning phases of flight are indicated by an "" (i.e., forecasting ability was classified as pre-operational planning while reporting short-term integrated forecasts was classified as operational-planning). Any FAA approved weather product can be used in the pre-operational planning phase.*

8.1.1 Pre-Operational Planning. As the pre-operational planning phase is strongly associated with low time stress, the weather products listed in Table 2 can support decision-making during this phase. With the exception of METAR, TAF, and NEXRAD, the remaining weather products have relatively low spatial resolution (i.e., the weather information presented covers a large area – approximately 3000 square miles); the pilot must put forth great mental effort in order to determine the precise location of the convective weather system relative to his/her intended flight plan. Such efforts could entail consulting with other groundside NAS personnel or other weather reports. In addition, with the exception of METAR, NEXRAD, and WST, the remaining weather products have slow temporal update cycles (e.g., most updates are longer than one hour), thereby requiring extensive pilot attention and working memory processing to interpolate, integrate, and project the weather system's future location and travel rate. Following this last notion, *all* of these weather products *do not* provide nowcasts less than three hours, inhibiting the ability to readily confirm or amend the mental model. That is, these weather products require the pilot to develop his/her own mental model of the weather situation and wait for the next available update to test the mental model appropriately.

However, because the pilot is groundside and operating under little time stress, he/she has the availability and cognitive resources to thoroughly analyze a variety of weather products before developing a mental model of his/her weather SA and filing a flight plan. That is, the pilot can spend the necessary time and mental resources to perceive, understand, predict, and evaluate future actions of weather systems before deciding a safe route. Accordingly, these products support Tier 1 decision-making processes. In addition, it is very likely that both the pilot and groundside NAS personnel have access to the same weather equipment/information; hence these weather products support collaborative decision-making. Time availability permits the pilot to utilize the necessary attentional and working memory resources in order to interact with groundside personnel when building a comprehensive mental model of his/her SA. The following describes the attributes associated with each of the weather products classified under the pre-operational planning phase.

Terminal Aerodrome Forecast (TAF). Terminal Aerodrome Forecast (TAF) is a forecast weather product prepared by the National Weather Service (NWS) office. The TAF forecast is updated four times per day (000 UTC, 0600 UTC, 1200 UTC, and 1800 UTC). These forecasts are valid for 24 hours. The forecasts depict specific weather information within five statute miles of the terminal area. The weather information includes: wind, visibility, weather phenomena, sky conditions, and wind shear. Forecast amendments are issued to reflect significant changes in atmospheric conditions. Amended forecasts may be issued at non-scheduled times.

Aviation Routine Weather Report (METAR). The NWS forecast office also provides an Aviation Routine Weather Report (METAR). This report contains current weather information about surface conditions at the airport. The METAR reports weather information derived from airport weather observations and from Automated Weather Observing Systems (AWOS) or Automated Surface Observations Systems (ASOS). METAR reports provide weather information on winds, visibility, runway visual range (RVR), weather phenomena, sky conditions, dewpoint, temperature, and altimeter settings. The METAR reports are updated hourly, which is valid until the next update. If weather conditions significantly degrade at the terminal area, an Aviation Selected Special Weather Report (SPECI) is issued as soon as the criteria for degraded weather conditions are met.

Convective SIGMET (WST). The Convective SIGMET (WST), issued by the Aviation Weather Center (AWC) to alert all categories of pilots about hazardous convective weather, provides current and forecasted weather information. WST reports are updated hourly and the forecasts are valid for two hours. WST reports have a coverage area of approximately 3000 square miles. Weather information reported includes severe surface weather (e.g., surface wind greater than 50 knots, hail larger than 3/4 of an inch in diameter, and tornadoes), severe thunderstorms, embedded thunderstorms, and lines of thunderstorms.

Domestic SIGMET (WS). The Domestic SIGMET (WS) is also issued by the AWC to warn all categories of pilots of hazardous weather conditions. The WS provides current and forecasted weather conditions that apply to approximately 3000 square miles. WS reports are updated every four hours; the forecasts are valid for 4 hours. Weather information reported includes severe icing, severe or extreme turbulence, duststorms and/or sandstorms reducing visibility to less than three miles, and volcanic ash.

AIRMET (WA). The AIRMET (WA) is a current and forecasted weather product issued by the AWC to warn of atmospheric conditions that may be hazardous to pilots flying under visual flight rules (VFR) or light/single engine planes. WA reports are updated every six hours or as conditions warrant. This weather product covers areas of 3000 square miles. Three different WAs can be issued; Sierra refers to ceilings (less than 1000 feet) and visibility (less than three miles); Tango refers to moderate turbulence and surface winds (exceeding 30 knots); Zulu refers to moderate icing and freezing levels. Amendments to WA reports are issued as conditions warrant.

Area Forecast (FA). Area Forecasts (FA) is issued by the AWC for the 48 contiguous states. The FA is a current and forecasted (forecasts can be made up to12 hours) weather product that contains information on cloud cover and general weather conditions within a 3000 square mile area. The FA is issued three times per day and is updated every eight hours. Amendments to the FA report are issued as conditions warrant.

Next Generation Weather Radar (NEXRAD). Next Generation Weather Radar (NEXRAD) is provided by the NWS. NEXRAD is capable of detecting the location, severity, and movement of hazardous weather phenomena. NEXRAD is a current weather product with a five-minute update rate. However, these updates are typically 6-7 minutes old or older upon receipt. The accuracy of NEXRAD weather information can vary (2km, 4km, 8km, and 64km).

8.1.2 Operational Planning. Moderate time stress distinguishes the operational planning phase. See Table 2 for those weather products cataloged under this phase of flight. Most of these weather products have higher spatial resolution than the weather products categorized in the pre-operational planning phase (e.g., NCWF can depict the location of convective weather within 4 km). Hence the need to mentally determine the convective weather's location is reduced. Also, these weather products have faster update rates (e.g., between 5 minutes to one hour) than the previously mentioned weather products. The delay time to update the mental model based on current weather information is attenuated. Recently updated, spatially accurate weather information can enhance the pilot's SA (Wickens et al., 1998) while operating in the NAS. Importantly, the one attribute that sets these weather products apart is their ability to provide nowcasted weather information. Nowcasting capability integrates several sources of weather information (e.g., NEXRAD and lightning data are combined in one weather product) and provides a short-term forecast (e.g., less than 3 hours) of the weather system's future location. As a result, the task of integrating weather information and projecting its future behavior is completed by the system, not the pilot, thereby eliminating the cognitive resources associated with these mental tasks. These weather products' attributes combine to attenuate the cognitive resources necessary to resolve the uncertainty of determining the weather system's current location, discerning the weather system's future location, and modifying the mental model. Such attributes are important in a multi-tasking environment. As a result, these weather products support decision-making processes positioned in Tier 2.

Despite the notion that the pilot is multi-tasking and operating under moderate time stress, collaborative decision-making can still be supported. As with the pre-operational planning weather products, it is likely that groundside NAS personnel will have access to these types of weather products, facilitating the construction of a shared mental model of the weather situation. The pilot should also have sufficient cognitive resources available to communicate and integrate weather information with groundside personnel. The following sections describe the weather products that best support decision-making in the operational planning phase.

Current Icing Potential (CIP). The Current Icing Potential (CIP) is an integrated and nowcasted weather product that uses sensors and numerical models to provide a diagnosis of the icing environment. The CIP provides current icing conditions while the FIP provides four icing forecasts (e.g., 3, 6, 9, and 12-hour). These forecasts are updated hourly. CIP forecasts are 80% accurate and cover areas approximately 40 x 40 km with an 18,000 ft ceiling (3000 ft intervals). CIP reports depict all icing and Supercooled Liquid Droplet (SLD) icing conditions. Water drops larger than 50 micrometers in diameter characterize SLD icing conditions; these conditions include freezing drizzle and freezing rain aloft. PIREP symbols are overlaid if the PIREP report is within 1500 ft vertically and 75 minutes temporally.

Integrated Turbulence Forecast Algorithm (ITFA). The Integrated Turbulence Forecast Algorithm (ITFA) is an integrated and nowcasted weather product. The ITFA begins with the Diagnostic Turbulence Forecast (DTF) algorithm. This algorithm models jet stream, mountain induced, and convective induced turbulence. Using artificial intelligence fusion of the DTF, *in-situ* sensing, and remote sensing, the ITFA is produced. The ITFA also incorporates forecasts from the National Centers for Environmental Prediction (NCEP) Rapid Update Cycle (RUC-2) aviation forecast model and turbulence observations within the last 1 1/2 hours. All this weather data is combined to produce turbulence forecasts. The ITFA provides four Clear Air Turbulence (CAT) forecasts (e.g., 3, 6, 9, and 12-hour forecast). These forecasts are updated every one to two hours. The ITFA also provides current turbulence conditions. The ITFA covers an area approximately 20 x 20 km with a 45,000 ft ceiling (3000 ft intervals).

Terminal Convective Weather Forecast (TCWF). MIT Lincoln Laboratories developed the Terminal Convective Weather Forecast (TCWF). The TCWF is an integrated (e.g., NEXRAD and lightning data) and nowcasted weather product. The TCWF is a unique weather product in that it provides current weather information around the terminal area. The range, however, can be extended out to 200 nautical miles from the airport. Current weather information is updated every 5-6 minutes. The TCWF provides 30 and 60-minute forecasts (shown in 10-minute increments) of the convective weather's growth and decay. TCWF has the capability to loop 30 minutes of past weather with a 30 or 60-minute projection of forecasted weather. In addition, TCWF provides an accuracy indicator by comparing what was predicted to what actually happened.

National Convective Weather Forecast (NCWF). The National Convective Weather Forecast (NCWF) product, designed by the National Center for Atmospheric Research (NCAR), is an integrated (e.g., precipitation and lightning) and nowcasted weather product that provides current convective weather hazards and one-hour forecasts of weather hazard locations. The current weather illustration and forecasted weather location are update every five minutes. The NCWF can show convective weather activity within 4 km.

8.1.3 Operational Immediate. Due to the high time stress associated with the operational immediate phase, on-board radar is the weather product that can effectively aid pilot decisions when he/she is directly navigating around the weather system (see Table 2). On-board radar has high spatial fidelity and temporal resolution (e.g., a radar can complete a scan in 3-4 seconds). On-board radar presents weather information in a track-up manner; therefore its attributes can attenuate the mental resources necessary for discerning the exact location of the weather system (i.e., the pilot does not need to mentally rotate the image to match his/her out-the-window view). However, because the pilot is in the midst of the convective weather system, all attentional and working memory resources are directed to the task of navigating around the weather system. As a result, collaborative decision-making breaks down for two reasons: (1) the pilot does not have the cognitive resources to communicate with groundside personnel, and (2) because the radar display is typically track-up, a common mental model is unlikely to develop (i.e., the displays for groundside personnel are typically north-up). Accordingly, the combination of the task characteristics of the situation and the unique fidelity and orientation of on-board radar, autonomous decision-making processes in Tier 1 are supported.

On-board Radar. On-board radar has the unique advantage of illustrating real-time or near real-time (e.g., 3-4 second scan rate with 60°-90° scan angle) convective weather information (e.g., precipitation rate, precipitation related turbulence detection, and windshear detection) from echo returns in front of the aircraft. On-board radar can provide the pilot with directly sensed precipitation data to aid the pilot in deciding the location of hazardous weather in real-time (McAdaragh, 2002). This high temporal resolution ideally supports tactical course corrections in close vicinity of hazardous weather systems, enhancing SA, improving decision-making, and allowing the pilot to directly navigate around the weather system or through a break in the line of thunderstorms. However, on-board radar suffers from its inability to detect hazardous weather systems at great distances, thus strategic planning breaks down.

8.2 WEATHER DECISION-AIDS

The following section discusses two cockpit weather decision-aiding tools (e.g., Rockwell Collins' AWARE and EWxR systems) and classifies them according to the level of decision-making best supported. According to Zachary (1988), a decision-aiding tool is any interactive system that is designed specifically to improve the decision-making of its users by enhancing the user's cognitive abilities. That is, these decision-aiding tools incorporate technology that can help overcome limitations of the pilot's attentional and working memory resources (Woods & Roth, 1988) by integrating weather information into one display. Decision-aids can overcome the pilot's cognitive limitations by providing external memory aids and look-ahead simulation tools, highlighting critical information, and alerting the pilot when variables exceed safe operating parameters. It has been established that decision-aids that transform heavily cognitive and analytical tasks to simpler perceptual ones, expedite the decision-making process (Klein, 1989).

Aviation Weather Analysis and Reporting Enhancements (AWARE). The Aviation Weather Analysis and Reporting Enhancements (AWARE) is a cockpit weather decision-aid created out of Rockwell Collins' Airborne Hazard Awareness System (AHAS). This is a weather display that illustrates weather along the current flight path. The AWARE integrates METAR (if the reporting station is within one hour of the aircraft's current position), TAF, SIGMET, PIREPS, and NEXRAD weather data into the system's interface. Rockwell Collins intended this product to be used as a strategic planning aid. With the exception of NEXRAD, the remaining weather products have slower update rates (e.g., 5-6 minutes vs. hourly or greater) and larger resolution areas (e.g., 2 km vs. terminal areas or greater). Accordingly, the classification model suggests that this decision-aid best supports pilot decision-making in the pre-operational planning phase. The pilot needs to expend a lot of mental effort to comprehend, integrate, and project the future location of the weather system.

Enhanced Weather Radar (EWxR). The Enhanced Weather Radar (EWxR) is another a cockpit weather decision-aid created out of Rockwell Collins' AHAS project. The EWxR can predict future convective weather system location as well as depict ownship future location. The EWxR combines NEXRAD weather data with on-board radar echo returns in a track-up orientation. Three display formats can be selected: on-board weather radar only, on-board weather radar plus NEXRAD, and NEXRAD only. Storm information, such as tops and velocity, can be displayed.

The ability to display three formats gives this weather decision-aid a unique classification. If the pilot selects the on-board weather radar only format, then the EWxR can support Tier 3 decision-making because of on-board radar's ability to provide spatially accurate rapid echo weather returns in a track-up fashion. However, if the pilot selects either the on-board weather radar with NEXRAD or the NEXRAD only format, the EWxR can optimally support Tier 2 decision-making. At best, NEXRAD can be updated every 5-6 minutes. This update performance level requires the pilot to mentally calculate the storm's future location and develop decisions accordingly. However, the EWxR calculates the storm's future location and the aircraft's future location, thus allowing the pilot to quickly confirm or amend the mental model. Even though in one format, NEXRAD is paired with on-board radar, the weather information that requires the most cognitive resources dictates the decision-making processes utilized.

9.0 Weather Product Selection Interface

The following section describes a graphical interface for a GA weather information display that intuitively affords selecting the appropriate category of weather information tools for the decision-making situation being encountered. It should be noted that this interface is not intended to show weather information until the pilot has selected the actual weather information icon he/she wishes to be displayed. Therefore, the proposed interface will be the first window on a weather display when the pilot accesses weather information on a multi-function display (MFD). Figure B1 in Appendix B provides a general schematic of the proposed interface for selecting operational planning weather products.

9.1 Multi-level Menu Structure

To conform to the notion of top-down processing for display design (Wickens et al., 1998), the proposed interface will reflect a multi-level menu structure similar to menus found in most windows based software programs[1]. Consistent interface appearance will facilitate understanding of the correct interactions with a new interface (Benjafield, 1992). Top-down processing in human factors display design postulates that learning a new interface can be expedited if the interface conforms to the users' expectations. That is, if the user is familiar with interfaces on a windows operating platform, top-down processing will support transference to the new interface (Wickens et al., 1998).

The first level of the menu structure will consist of three icons representing the three decision-making conditions (e.g., pre-operational planning [PP], operational planning [OP], operational immediate [OI]). The proposed number of first-order menu items falls within the optimal range for menu items (Lee & MacGregor, 1985). In order to facilitate structured search, where each item is examined in a systematic order (Wickens & Hollands, 2000), these main menu items will be presented horizontally to comply with normal reading behavior. Once the pilot has selected weather for a phase of flight (see section below on input device), the corresponding icon will be shaded in gray and those weather tools/information that fall within this category will be displayed. Note: the default for this interface will be weather information corresponding to the pre-operational planning phase.

The second level will consist of icons for weather information (e.g., NEXRAD). Actual weather product acronyms should be used to facilitate comprehensibility of the icons (Wickens et al., 1998). According to Lee and MacGregor (1985), menu structures should be designed to facilitate minimum access time by incorporating few sub-levels within the menu hierarchy. These will appear vertically on the left side of the display (i.e., these targets are somewhat similar to drop-down menus found on most computer interfaces). When an icon is selected, it will be shaded gray and the corresponding weather information will be displayed. To deselect the weather information, the pilot simply needs to touch the icon again to remove the gray shading. In order to keep the pilot informed of weather updates, when an update has been issued, the computer can notify the changes in the system state by causing the corresponding

[1] It is assumed that most GA pilots are familiar with windows based programs.

icon to begin flashing. In order to bring the updated weather information to the multifunction display, the pilot can select the corresponding icon. Blinking targets (i.e., salient target) in static displays can effectively direct the pilot's attention to new information (Fisher & Tan, 1989; Wickens & Hollands, 2000). Notification that important variables have changed results in heightened SA (Wickens et al., 1998)

9.2 Input Device

The input device for the proposed interface's menu structure will incorporate touch screen technology. Touch screen technology has many utilities, ranging from extreme environments such as weightlessness in space to fairly stable environments, such as cash registers and automatic teller machines (ATMs). In addition, according to Sears and Shneiderman (1991), a natural way to select a target/icon is to physically touch it. Relative to aviation, Adolf and Holden (1996) noted that touch screens can be well suited for aircraft flight decks, stating that touch screens are easier to learn than conventional input devices (e.g., a mouse). Adolf and Holden (1996) also examined touch screen utility in simulated zero gravity and discovered that Space Shuttle pilots preferred the touch screen for targets with large areas. Dillon, Edey, and Tombaugh (1990) reported that selection of touch screen items was significantly faster and more accurate (i.e., less deviation errors) than using a mouse; touch screen attenuated fine motor movements.

Sears and Shneiderman (1991) stated that touch screens can be utilized for selecting targets as small as 4 pixels in size. Hall, Cunningham, Roache, and Cox (1988) reported that accuracy asymptotes for targets approximately 26 mm per side. This latter finding coincides nicely with Fitt's Law (Fitts & Peterson, 1964); the smaller the target, the longer it will take to acquire because of the fine motor movements involved. This is especially relevant when selecting targets during turbulent weather conditions. Therefore, it is recommended that the targets displayed on the interface be larger than 4 pixels per side but smaller than 2 cm per side.

10.0 Conclusion

During the next few decades, NAS operations are expected to grow substantially, possibly compromising safe flight for commercial and GA aircraft. Adverse weather adds to the already overburdened air transportation system. In order to attenuate the number of GA accidents attributed to weather, NASA and the FAA have embarked on a joint effort to develop and evaluate new technologies specifically designed to support decision-making when avoiding hazardous weather. The first step toward achieving this effort however, requires an understanding of the cognitive processes that constitute SA development and contribute to the decision-making process.

Naturalistic decision-making is characterized by uncertain information. That is, the manner in which the information (e.g., environmental cues) is presented does not readily depict a problem. Information representation (e.g., spatial and/or temporal) and the level of time stress can greatly influence a person's SA and mental processes utilized in decision-processes. Consequently, information with low spatial and temporal fidelity requires the person to expend more energy and cognitive resources to resolve the uncertainty. If the environmental cues are uncertain and the situation promotes high time stress, the person does not have time to initiate the cognitive processes necessary to comprehend and calculate the future behavior of the environmental cues. Limited attentional resources and working memory capacity are constrained under situations of high time stress. Low time stress, however, affords effective utilization of attentional resources and working memory in order to develop a comprehensive understanding of his/her SA. Additionally, in low time stress situations, people have the luxury to initiate strategic planning (e.g., molar goals) whereas in high time stress situations, people typically incorporate tactical operations (e.g., molecular actions).

By integrating three naturalistic decision-making theories, one can explain the decision-making processes within the various phases of flight. Tier 1 decision-making typically occurs in high time stress situations where cognitive resources are constrained. These decision-making processes correspond to level 1 SA; the person simply perceives the signals (i.e., environmental cues) and reacts accordingly. Under Tier 2 decision-making, the person has more time and cognitive resources available to assign meaning and develop an understanding of the signs (i.e., level 2 SA). The lowest time stress and most cognitive resources available characterize Tier 3 decision-making. Accordingly, the person can devote the time and mental resources necessary to formulate an accurate conception of the surrounding environment from symbols (i.e., level 3 SA).

Pilots typically make decisions in three situations (e.g., pre-operational planning, operational planning, and operational immediate) and two conditions (e.g., collaborative and autonomous). The pre-operational planning phase is a low time stress situation that affords strategic planning and collaborative decision-making. As a result, the pilot can reach level 3 SA and incorporate decision-making processes associated with Tier 3. The operational planning phase is a moderate time stress, multi-tasking situation that allows the pilot to initiate strategic planning and tactical operations as well as collaborative communication with groundside NAS personnel. Thus, the pilot can accomplish level 2 SA and exploit Tier 2 decision-making processes. The operational immediate phase is a high time stress situation where the pilot is directly navigating around the hazardous weather system employing tactical operations. Therefore, the pilot obtains level 1 SA and incorporates Tier 1 decision-making processes (i.e., autonomous decision-making is initiated).

A combination of the task characteristics (i.e., time stress and taskload) correlated with each phase and the weather products' attributes (e.g., spatial and temporal fidelity) contribute to product classification under the phase of flight the weather product best supports pilot decision-making (see Figure 2). Situations characterized by low time stress allow for weather products with low spatial accuracy and slow temporal updates cycles to support SA and decision-making within the pre-operational planning phase. Conversely, moderately time-stressed, multi-tasking situations require weather products with moderate spatial accuracy and moderate temporal updates which include short-term outlooks to optimize SA and decision-making within the operational phase. Finally, high-stress situations necessitate weather products with high spatial resolution and high temporal update rates to best support SA and decision-making in the operational immediate phase.

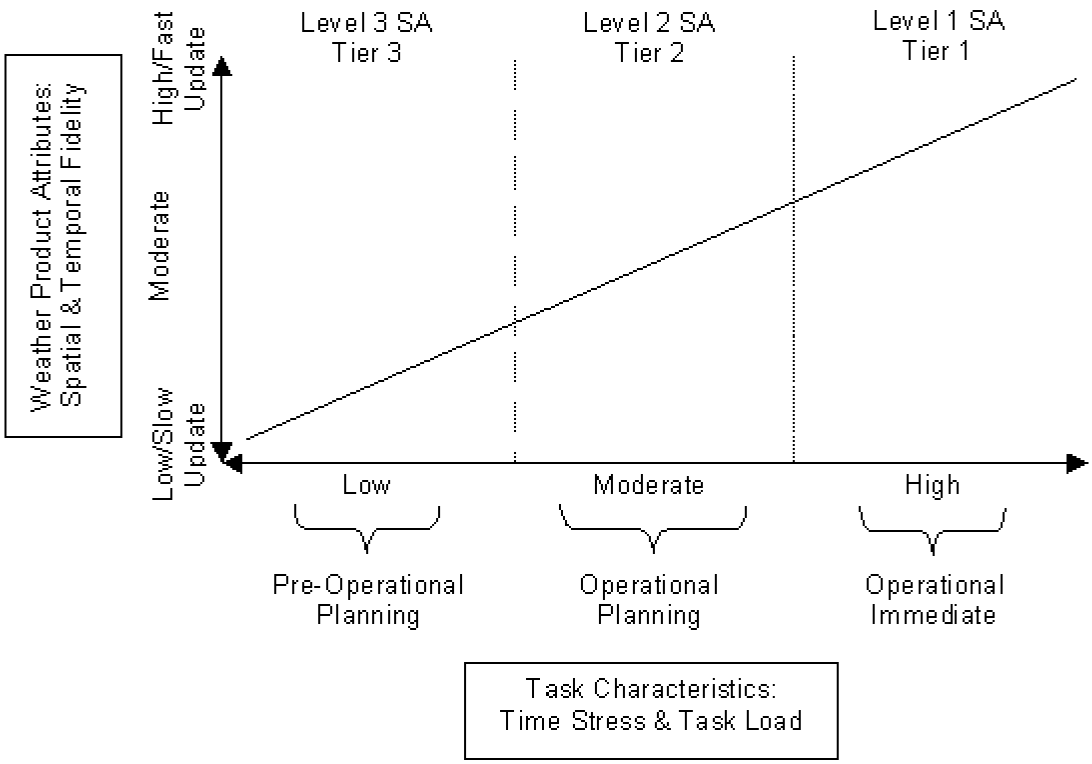

Figure 2: An illustration of the level of SA and decision-making achieved is dictated by the relationship between task characteristics and the weather products' attributes.

Finally, a graphical interface with a compact menu structure that conforms to windows-based operating menu systems and informative icons intuitively affords selecting the appropriate weather product given the situational phase of flight. This interface on the MFD incorporates touch screen technology in order to ensure the proper weather product is selected even in turbulent flying conditions.

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APPENDIX A

PRE-OPERATIONAL PLANNING WEATHER PRODUCTS

Weather Product Name	Terminal Aerodrome Forecast (TAF)
Type	Forecast
Update Rate	Updated 4 times per day (000 UTC, 0600 UTC, 1200 UTC, and 1800 UTC) or as conditions warrant; updates are valid for 24 hours
Coverage Area	Forecasts conditions within 5 miles of the terminal area
Comments	A forecast prepared by the NWS for an airport; report included winds, visibility, weather phenomena, sky conditions, and wind shear.

Weather Product Name	Aviation Routine Weather Report (METAR)
Type	Current conditions at airport
Update Rate	Hourly; reports are valid for 1 hour; a SPECI is issued if conditions warrant
Coverage Area	Terminal area, measurement site (e.g., AWOS or ASOS)
Comments	Contains information about surface conditions at the airport; report includes winds, visibility, RVR, weather phenomena, sky conditions, dewpoint, temperature, and altimeter settings

Weather Product Name	Convective SIGMET (WST)
Type	Current and forecast conditions
Update Rate	Hourly; reports are valid for 2 hours
Coverage Area	Areas of 3000 square miles
Comments	Issued by AWC to alert all categories of pilots about hazardous convective weather; report includes severe weather, severe thunderstorms, embedded thunderstorms, and lines of thunderstorms

Weather Product Name	Domestic SIGMET (WS)
Type	Current and forecast conditions
Update Rate	Every 4 hours; reports are valid for 4 hours
Coverage Area	Areas of 3000 square miles
Comments	Issued by AWC to alert all pilots about hazardous conditions; reports include severe icing, severe or extreme turbulence, duststorms and/or sandstorms reducing visibility to less than 3 miles, and volcanic ash

Weather Product Name	AIRMET (WA)
Type	Current and forecast conditions
Update Rate	Every 6 hours or as conditions warrant; reports are valid for 6 hours
Coverage Area	Areas of 3000 square miles
Comments	Issued by AWC to warn of atmospheric conditions that may be hazardous to pilots flying VFR or light/single engine planes; Sierra (ceiling and visibility), Tango (moderate turbulence and surface winds), Zulu (moderate icing and freezing levels)

Weather Product Name	Area Forecast (FA)
Type	Current and forecast conditions; 12 hour forecast with 6 hour outlook
Update Rate	Every 8 hours or as conditions warrant
Coverage Area	Areas of 3000 square miles
Comments	Issued by AWC and contains information on cloud cover and general weather conditions

Weather Product Name	Next Generation Weather Radar (NEXRAD)
Type	Near-time (6-10 minutes old upon receipt)
Update Rate	Every 5 minutes
Coverage Area	2 or 4 or 8 or 64 km accuracy
Comments	Issued by NWS; report includes location, severity, and movement of hazardous weather phenomena

OPERATIONAL PLANNING WEATHER PRODUCTS

Weather Product Name	Current Icing Potential (CIP)
Type	Forecast (80% accurate)
Update Rate	Hourly
Coverage Area	40 x 40 km
Comments	An integrated and nowcasted weather product; CIP provides current icing conditions while FIP provides 4 forecasts (3, 6, 9, 12 hour); integrates SLD icing conditions and PIREP reports

Weather Product Name	Terminal Convective Weather Forecast (TCWF)
Type	Current and forecast (1-2 hour forecast in 10 minute increments); loop 30 minutes of past and 30 or 60 minutes of forecasted weather; provides accuracy of forecast by comparing what it predicted to what actually happened each time NEXRAD updates (i.e., 75-85% accuracy is displayed)
Update Rate	5-6 minute updates
Coverage Area	Terminal area
Comments	Integrates NEXRAD and lightning data; view range can be extended out to 200 miles from airport

Weather Product Name	Integrated Turbulence Forecast Algorithm (ITFA)
Type	Forecast (3, 6, 9, and 12 hour forecast)
Update Rate	Every 1 to 2 hours
Coverage Area	20 x 20 km (uses RUC 20)
Comments	An integrated and nowcasted weather product based on an algorithm that fuses data from DTF, *it situ* sensing, and remote sensing, providing CAT forecasts

Weather Product Name	National Convective Weather Forecast (NCWF)
Type	Forecast; produce 1 hour convective product
Update Rate	Every 5 minutes
Coverage Area	4 km accuracy
Comments	Issued by NCAR; report integrates precipitation and lightning data; provides short-term nowcast of convective weather

WEATHER DECISION-AIDS

Weather Decision Aid	Aviation Weather Analysis and Reporting Enhancements (AWARE)
Manufacture	Rockwell Collins [Airborne Hazard Awareness System (AHAS)]
Integrated Weather Information	METAR (if reporting station is within 1 hour of forecast), TAF, SIGMETS, PIREPS, NEXRAD
Comments	Depicts weather along the flight path; intended for strategic planning

Weather Decision Aid	Enhanced Weather Radar (EWxR)
Manufacture	Rockwell Collins [Airborne Hazard Awareness System (AHAS)]
Integrated Weather Information	Combined NEXRAD with on-board weather data
Comments	Predicts storm and aircraft future positions; intended for tactical operations

APPENDIX B

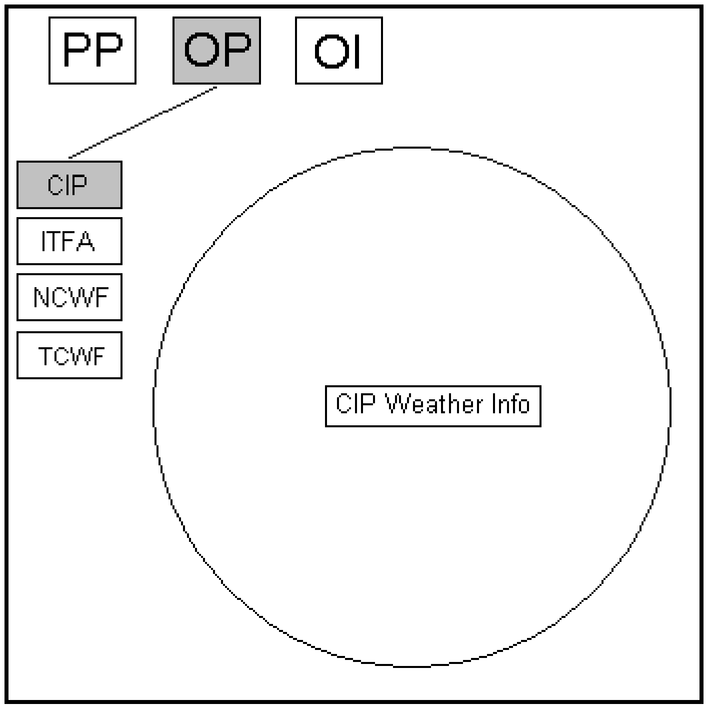

Figure B1: A proposed interface for selecting weather products for each phase of flight.

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14. ABSTRACT The National Airspace System's capacity will experience considerable growth in the next few decades. Weather adversely affects safe air travel. The FAA and NASA are working to develop new technologies that display weather information to support situation awareness and optimize pilot decision-making in avoiding hazardous weather. Understanding situation awareness and naturalistic decision-making is an important step in achieving this goal. Information representation and situation time stress greatly influence attentional resource allocation and working memory capacity, potentially obstructing accurate situation awareness assessments. Three naturalistic decision-making theories were integrated to provide an understanding of the levels of decision making incorporated in three operational situations and two conditions. The task characteristics associated with each phase of flight govern the level of situation awareness attained and the decision making processes utilized. Weather product's attributes and situation task characteristics combine to classify weather products according to the decision-making processes best supported. In addition, a graphical interface is described that affords intuitive selection of the appropriate weather product relative to the pilot's current flight situation.							
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