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THE INFLUENCE OF COCKPIT WEATHER AUTOMATION ON PILOT PERCEPTION AND DECISION-MAKING IN SEVERE WEATHER CONDITIONS

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ABSTRACT

This research examines situations in which a pilot either chooses to use, or refrains from using weather-related automation systems, and how the presence of such systems influences a pilot's decision-making, performance and ability to perceive danger in severe weather conditions. Results indicate that the influence of automation on a pilot's perception and decision-making process is dependent upon the pilot's ability to perform manual flight tasks, independent of the automation. Pilots are more likely to continue flight into severe weather conditions and less likely to identify hazardous weather changes when an imbalance exists between a pilot's flight experience, confidence in ability to manually operate the aircraft, and reliance on automation systems.

LITERATURE REVIEW

Reliance on advanced cockpit technologies, more specifically weather radar systems, has led researchers to question whether such technologies improve or hinder a pilot's decision-making performance and ability to perceive danger in severe weather conditions. Madhavan and Lacson (2006) state that "poor pilot decision-making in deteriorating weather is the leading cause of a significant percentage of fatalities arising from aviation accidents in the last two decades" (p. 47). Although an appropriate level of training may have been completed, the presence of weather automation may enhance or hinder the pilot's performance and decision-making process. High-tech cockpits integrate information quickly and efficiently, decreasing the pilot's

workload and the time it takes the pilot to make decisions. Thus, overreliance on automation, specifically weather automation systems, may increase erroneous behavior and ultimately lead to aircraft accidents. This research focuses on the pilot's reliance on weather automation, versus the pilot's ability to perform without weather automation, when assessing the safety of weather conditions and determining whether to continue flight. Mosier, Skitka, Heers, and Burdick (1998) indicated that although pilots are trained to use the systems of the aircraft, new technologies are being developed to take on cognitive flight tasks for the pilot. Concurrently, pilots who use automated weather systems have shown an overreliance on the data provided by these displays. These advancements have been proven to have a positive affect on a pilot's performance and decision-making process; however, confusion pertaining to automation and weather displays has also been documented.

The article *Performance Consequences of Automation-Induced Complacency* by Parasuraman, Molloy, and Singh (1993) explained that one form of confusion, known as *complacency*, is "one potential negative effect of automation relevant to monitoring performance" (p. 2). Parasuraman, Molloy, and Singh (1993) go on to explain that:

Crew attitudes such as overconfidence in automation may not be sufficient in themselves to lead to complacency, but may only indicate a potential for complacency. Complacent behavior may arise only when complacency potential occurs jointly with other conditions such as high workload brought about by poor weather, heavy traffic, or fatigue due to poor sleep or long flights. The combination of the crew's attitude toward automation (e.g., overreliance) and a particular situation (e.g., fatigue) may lead to complacent behavior. One index of complacent behavior (among other possibilities) could be reduced accuracy or delay in detecting a failure in the automated control of a flight task. (p. 3)

It can be determined that certain human factors or flying conditions (weather, traffic, fatigue, etc.) may cause pilots to rely more heavily on automated weather systems, in comparison to situations in which such human factors or conditions do not occur. Such confidence in weather displays may result in poor monitoring performance. While relying on the weather systems, pilots may neglect to monitor the systems for danger, malfunctions, or failure, which could ultimately lead to an incident or accident. It is important that an appropriate balance exists between the accuracy of the pilot's performance and the reliance upon the accuracy of the automated weather systems. Muthard and Wickens (2003) recognize the limitations of some automated weather systems, noting that pilots were less likely to detect threatening weather changes and were therefore more likely to continue flying hazardous routes. They also found that "pilots would seek cues that confirm the belief that the originally filed flight path was safe and ignore cues that refute the belief" (Muthard & Wickens, 2003, p. 858). This is an indication of substantial reliance on weather automation and deficient information processing. Pilots who rely on already limited automation are more likely to continue flight into unsafe conditions, which increases the risk of erroneous behavior and the possibility of calamity.

In *Humans and Automation: Use, Misuse, Disuse, Abuse*, the relationship between pilots and **automation** is examined and further defined as the "engaging or disengaging, overreliance, neglect, and omission of consequences of, or pertaining to automation" (Parasuraman & Riley, 1997, p. 230). When automation is implemented in flight operations, it is important that the system is easy to operate, responds quickly, and that proper training is received to ensure its appropriate use and to reduce the risk of operator errors (Parasuraman & Riley, 1997). Parasuraman and Riley (1997) discuss the importance of the pilot's ability to recognize an overreliance on automation and the tendency to use automation cues as heuristics for decisions. They report that "operational monitoring can be efficient" with favorable ergonomics, steady workloads, and a counterbalance between pilots and automation performance (p. 249). Furthermore, an operator's mistrust of auto-

mation will decrease when the automation meets standard requirements for function. Equally, automation abuse will decrease when the operator has responsibilities and capabilities not solely based on the functions of the automation (Parasuraman & Riley, 1997). Contrarily, a study by Moiser et al. (1998) reported that:

Pilots who reported an internalized perception of “accountability” for their performance and strategies of interactions with the automation were significantly more likely to double-check automated functioning against other cues and less likely to commit errors than those who do not share this perception. Pilots were also likely to erroneously “remember” the presence of expected cues when describing their decision-making processes. (p. 47-48)

These studies suggest that although some pilots maintain a balance between their ability to fly the aircraft and their reliance on automation, there are pilots who do not maintain this balance, relying solely on automation to complete cognitive flight tasks. The imbalance between flight experience and automation reliance identified in both of these studies documents the influence of automation on pilot perception and decision-making. Based on this research, the influence of automation can be positive or negative, depending on the pilot’s ability to assume responsibility for completing cognitive flight tasks, independent of automation. A study by Wiggins and Bollwerk (2006) suggests that the presence of automation within the cockpit helps pilots make safe decisions and perform flight tasks correctly, in accordance with high-risk situations in which pilots make strategic decisions based on time and their ability to maintain personal control of the aircraft, as opposed to completing all flight tasks with a sole reliance on automation. Furthermore, Wiggins and Bollwerk (2006) report that:

- (a) Different operators prefer to acquire information using different heuristic-based strategies;
- (b) the selection of an information acquisition strategy

is not predicted by task-related experience; (c) and the strategy that appears most appealing is also one that demands a significant amount of time to ensure that sufficient information is acquired prior to the selection of an alternative. Successful decision support systems are therefore likely to be those that enable users to exercise control over their own individual approach to decision making, and present the required information within a time period that enable the generation and execution of a response. (p. 745)

Wiggins and Bollwerk's (2006) study examined pilot decision-making relative to perception and personal stimuli, with little dependency on weather automation. Similarly, a study by Wiegmann, Goh, and O'Hare (2002) examined pilot decision-making in severe weather conditions relative to weather encounters and available weather information. Wiegmann et al. (2002) reported that pilots who encountered severe weather early in a flight were more likely to "go take a look," while pilots who experienced weather changes later in a flight were more likely to rely on their senses and personal experience before making a decision to diverge from their original flight plan. They further reported that these analyses were a result of situation assessment. Wiegmann et al. (2002) explained that early weather encounters influenced pilots to continue flight (or "go take a look") due to a contradiction between prior weather briefing information and automated weather data. Furthermore, later weather encounters quickly influenced pilots to divert from the original flight plan due to the lack of accuracy and reliability of the previous weather briefing information.

O'Hare and Smitheram (1995) report that "one of the most significant factors in general aviation fatalities is the continuance of visual flight rules (VFR) flight into deteriorating weather" (p. 351). In "Human Factors Analysis of Accidents Involving Visual Flight Rules Flight into Adverse Weather," Goh and Wiegmann (2002a) hypothesize that "pilots risk pressing on into deteriorat-

ing weather simply because they do not realize they are doing so” (p. 817). In this study, Goh and Wiegmann (2002) also hypothesize that pilots may continue VFR flight into instrument meteorological conditions (IMC) when they “are overconfident in their abilities and do not fully appreciate the risks of flying into adverse weather” (p. 817). Data support both hypotheses above, where pilots may be too confident or do not realize the deteriorating weather, ultimately leading to an incident or accident (Goh & Wiegmann, 2002a, p. 821). Goh and Wiegmann (2002a) report that:

It was found that the median flight hours of pilots involved in VFR-IMC accidents was significantly lower than that of pilots involved in other types of GA accidents. Pilots involved in VFR-IMC accidents had less training (certification) and were less likely to have instrument ratings. Therefore, these pilots may have less experience interpreting real-time weather and may make more erroneous evaluations. (p. 821)

Pilots appear to rely on automation, as well as their own ability to perceive danger, to complete cognitive flight tasks in high-risk situations; however, flight experience and familiarity of the automation significantly affect the outcome of a flight. Further research has identified how pilots apply decision-making to the performance of cognitive tasks in weather related situations with the use of automated weather systems. Latorella and Chamberlain (2002) evaluate pilots’ notion of *tactical* (to do, evaluate, maneuver, and control) and *strategic* (to plan, think, anticipate, prioritize) planning in severe weather, and report that “pilots need tactical weather information” (p. 105). Latorella and Chamberlain (2002) report that “subjects indicated that knowing cell intensities’ (colored graphics), proximity to weather (cell locations and aircraft location), and having weather radar and observations for alternates and destinations supported tactical use” (p. 104). This study indicates that although pilots can operate aircraft without tactical weather-related information from weather radar systems, pilots need such information for

better performance and safer decision-making. Without weather radar systems in the cockpit, a pilot may evaluate the safety of a flight using personal stimuli and knowledge to strategically plan a diversion. However, with weather radar systems in the cockpit, a pilot is able to use both tactical and strategic planning to form a safer flight plan in critical situations.

A study by Beringer and Ball (2004) examines the effects of weather automation and direct weather viewing on a pilot's perception and decision-making in severe weather. Thirty-two pilots participated in this study, flying a simulator using NEXRAD weather radar, while visual-performance data, flight-performance data, and post-flight data were collected. Visual-performance data correspond to how long the pilots accessed the data; flight-performance data correspond to how close to the weather the pilots flew, and how long they deferred the decision to continue flight; post-flight data correspond to the response of the pilots to weather data, equivalent to that of the simulator in a non-flight environment (Beringer & Ball, 2004). Data showed that:

Physical separation maintained from convective cells suggests that the pilots with higher resolution NEXRAD imagery or no NEXRAD imagery tended to fly closer to the convective cells than is recommended by the AIM (7-1-27). It recommends "avoiding by at least 20 miles any thunderstorm identified as severe or giving an intense radar echo." Note that 17 (53.2%) of the pilots flew inside this recommended distance. Additionally, the AIM (7-1-27) suggests not taking off or landing in the face of an approaching thunderstorm and to not attempt to fly under the thunderstorm even if you can see through the other side. However, 7 (21.9%) pilots attempted to fly through or under the thunderstorm to land. (p. 6)

Their results show that pilots exhibited both an overreliance on weather automation and a deficient professional judgment

while flying through severe weather conditions. When no weather automation is present, a pilot may still continue near or through inclement weather, without indication of the presence or severity of storm cells. When weather automation with high resolution (indicating more accuracy) is present, the pilot may opt to continue flight near or through inclement weather. Such reliance on automated weather systems can be burdensome on the pilot and may affect the outcome of the flight. Beringer and Ball (2002) state that “NEXRAD has a number of limitations that most pilots do not take into account in their usage of the data” (p. 1). Beringer and Ball (2004) proceed to explain that:

NEXRAD data received in the cockpit are always time-delayed from the actual observation at least 6 to 7 minutes following the actual radar scan. This means that an image on a cockpit display may be as old as 12 to 14 minutes before it is updated. This fact gives rise to the legitimate concern that pilots might be trying to make tactical decisions based upon “old” data. There is also the question of how much degradation is acceptable in the resolution of the data before pilots no longer feel that the displayed image is representative of the weather phenomena. (p. 1)

This report significantly supports the hypothesis of pilots’ overreliance on weather displays, where both too much and too little use of these systems can have a negative effect on pilot performance and the overall safety of flight. A significant amount of training on weather automation, and the ability to fly without this automation, could exponentially decrease the number of accidents and incidents that result from severe weather. Concurrently, a study by Latorella and Chamberlain (2001) examines General Aviation (GA) pilots’ use of aural, external, and sensor-based avionics to make flight decisions. Latorella and Chamberlain (2001) identify “out-the-window,” Flight Service Station, Flightwatch, Air Traffic Control, Stormscope, and Strikefinder as the avionics used to determine the pilots’ in flight decision-making processes. In correlation to these weather systems, they note that

information available from these sources is limited and, when weather becomes a problem, the frequencies used to obtain this information become saturated, making this information inaccessible at exactly the time it is most needed... While these systems show severe local weather to avoid, they do not provide the more comprehensive weather picture required to fully support strategic planning or avoidance maneuvers. More accessible, complete, and usable weather information would benefit pilots' situation awareness, decision-making, and safety. (p. 1)

The importance of the presence of weather automation, as well as pilot input pertaining to both strategic and tactical planning in hazardous conditions, is well documented. While weather automation does exhibit limitations to the amount and accuracy of data it provides, in high-risk situations the presence of these automated aids is more helpful than not. However, when the weather displays are most needed, the data may not be obtainable, which becomes a limitation to pilots. Furthermore, pilots should not rely solely on these systems under the assumption that when approaching hazardous weather, the technology will always be available. Pilots must be trained to operate aircraft, independent of the automated weather systems. The skills required for tactical flight should be well ingrained into pilot training. If such skills exist for pilots operating in hazardous weather conditions, the level of risk and calamity associated with inclement weather can be mitigated.

Wiggins and O'Hare (1995) state that "weather-related crashes continue to account for a significant proportion of general aviation (GA) accidents ... Weather-related crashes are one of the most common causes of GA fatalities" (p. 305). In their study, Wiggins and O'Hare (1995) recruited forty pilots, separated by levels of experience, to be tested on decision-based scenarios, observing results with indication of information acquisition, performance, decision-making, pilot experience (flight hours), and confidence. When examining the strategies of pilot information acquisition, it was determined that "experienced pilots accessed

significantly fewer information screens, made fewer information recursions and spent relatively less time examining the information screens than inexperienced pilots” (p. 316). Their data suggest that pilots with more experience rely less on automation when flying through hazardous weather, while less experienced pilots rely more heavily on automation to complete flight operations in hazardous weather.

These results reflect the effects automation reliance has on pilots with lower confidence in performing. When pilots have low confidence in their ability to perform, they will rely more heavily on automation, which may not be the best choice. Inexperienced pilots might not trust automated systems to provide sufficient information pertaining to the surrounding environment; they might, however, rely on automation to guide them through inclement weather because of their uncertainty about their own ability to perform flight operations safely. Contrarily, more experienced pilots may be over-confident in their ability to perform operations with little to no automation, which in certain weather-related situations may not be the best decision. However, less reliance upon automation may reflect a positive outcome, as the more experienced pilots take into account the limits of the systems and instead choose to apply their own experience in flight operations.

A balance between the pilots’ confidence in their abilities to perform, their knowledge and training, and use of automation must exist to ensure overall flight safety in inclement or deteriorating weather conditions. Wiggins and O’Hare (1995) report that an “analysis of the decisions indicated that pilots in the intermediate and experienced groups were significantly more likely to continue toward their destinations than to divert. By contrast, pilots in the inexperienced group chose with greater frequency to return to the point of take-off” (p. 317). It is important to note that “the decision to return to the point of departure, in most scenarios used, is ill-advised” (p. 317). Again, the more experienced pilots are more confident in both their own performance, as well as the uses of automation to complete flight operations, while the less experienced pilots are not as confident in their ability to complete flight opera-

tions. This study supports the importance of accurate training and trust in automation to meet standard operation requirements, and the effects they can have on decreasing erroneous decision-making, as well as accidents. Wiggins and O'Hare (1995) write that

A qualitative distinction was observed between both the information search and problem-solving strategies used by inexperienced and experienced pilots. This was interpreted as qualified support for the notion that through task-specific experience, individuals develop procedures that can be generalized and applied subsequently to a variety of situations. Quantitative differences were also observed between the information search strategies of inexperienced and experienced pilots, with the former accessing a greater number of information screens; making a greater number of information recursions; and spending more time examining the information screens than the latter. Inexperienced pilots also exhibited greater response latency in selecting from a forced choice: whether to continue to the destination or return to the point of take-off. (p. 318)

Additionally, the study by Wiggins and O'Hare (1995) addresses the importance and need for weather-related decision-making in pilot training initiatives. "Weather-related decision-making (WRDM) can be defined as those skills necessary to recognize and avoid meteorological phenomena that present a hazard to the flight" (p. 305). WRDM training could provide pilots with insight on how to take advantage of the weather automation resources within the cockpit to make accurate decisions based on safety in a timely manner.

A study by Beringer and Schvaneveldt (2002), *Priorities of Weather Information in Various Phases of Flight*, reports that 71 pilots (26 experienced, 45 novice) provided questionnaire responses about weather related priorities at different phases of flight. The

phases of flight observed in the study include preflight planning, pre-departure, taxi, takeoff, climb, transition to cruise, cruise, in-flight planning, descent, approach and landing (p. 87). Additionally, there were 28 weather factors that included, but were not limited to rain, hail, snow, turbulence, updrafts, downdrafts, lightning, windshear, clouds, and static atmospheric pressure (p. 87).

Beringer and Schvaneveldt (2002) asked pilots to rate certain factors between VFR and IFR flight, where “1 = *critical and/or frequently accessed*, 2 = *important and/or usually accessed*, 3 = *relevant and/or sometimes accessed*, and 4 = *not relevant and/or rarely accessed*” (p. 87). Data from this study indicate that experienced pilots rated weather information as more important than did the novice pilots. This study aimed to examine pilot use of weather automation in hazardous weather conditions; it reported that pilots with more training and flight experience utilized the weather information provided by the automated weather systems, but also maintained a sense of necessity to perform flight operations and detect danger, independent of the weather displays. Beringer and Schvaneveldt (2002) add that, “for pilots to maintain (or quickly attain) good situation awareness, they must have access to and be aware of these critical information elements, whether they are actively in control or not” (p. 87).

The Beringer and Schvaneveldt study identifies the positive effects of automated weather systems on pilot perception and decision-making in hazardous weather. Weather automation provides the pilot with crucial information in relation to the surrounding environment, quickly and efficiently, decreasing the time it takes pilots to identify hazards, make decisions, and perform the most optimal and safe flight operations.

In *Relating Flight Experience and Pilots' Perceptions of Decision-Making Skill*, Goh and Wiegmann (2002b) report that

Recognizing the weather has changed does not imply a pilot will generate the most optimal plan to deal with it. Being able to diagnose how serious this weather change is and the options available given the constraints of the situation (e.g., the weather

change precludes the option of returning to the origin), are highly important. Therefore, in the event that a pilot encounters situations that are not easily defined in emergency procedures (e.g., inadvertently encountering adverse weather), the pilot will need to rely on his or her own abilities to diagnose the problem quickly and accurately. (p. 84)

This study reinforces the importance of a pilot's confidence, and independence from weather automation, to perceive danger and act accordingly. While automated weather aids assist pilots in identifying severe weather and route planning, the weather data are limited. Thus, it is important that pilots retain a crucial amount of skill, allowing for flight operations independent of automated weather displays. Such abilities will assist a pilot to, first, identify dangerous weather conditions, and then to act accordingly, with accuracy and speed.

Correlating to pilot decision-making in severe weather conditions, Krozel, Penny, Prete, and Mitchell (2007) examine the influence weather automation has on optimal planning in the transition airspace during weather related events. This study examined three automated route generators for weather avoidance: navigation aids (Nav aids), flow-based route planners, and free-flights. The Nav aids examined in this study were used to determine standard terminal arrival routes (STARs). The flow-based route planners provide a set of routes that minimize the distance traveled. Free-flights are generated to avoid weather and separate other en-route aircraft, using the safest path within a two-hundred nautical mile range. They state that "compared with today's routing practices, these methods demonstrate improved throughput with increased safety during hazardous weather events in the transition airspace" (Krozel et al., p. 152). This statement suggests the reliability and positive effects automated systems can have when aiming to avoid or fly through severe weather. Yet they note that

Flow-based techniques are less computationally intensive, as a single synthesized route may apply

to many aircraft. A controlled version of free-flight (using required times of arrival for aircraft) can perform on par with the highest performing flow-based techniques. However, free-flight requires routes to be generated for each aircraft that simultaneously avoid hazardous weather and aircraft conflicts, therefore requiring great computational time. Further, free-flight techniques exhibit greater complexity than flow-based techniques, and therefore imply greater workload to monitor. (p. 152)

While all three of these automated methods of severe weather avoidance provide safe and efficient routes within the airspace, some methods are quicker and more efficient than others. Studies such as this are vitally important in determining the best form of weather automation systems to be implemented within the cockpit. As it is the industry's goal to develop and implement the most proficient and accessible automation for flight operations, improving the performance of both pilot and the automation will provide insight about the most appropriate automated weather systems.

Madhavan and Lacson (2006) discuss the effects of automation on pilot decision-making in their study "Psychological Factors Affecting Pilots' Decision to Navigate in Deteriorating Weather." This study identifies the influences of automated systems on pilot decision-making in high-risk situations. These technologies improve, speed up, and at times fully complete flight operations and decision-making situations for pilots. It is reported that

Higher levels of automation may be beneficial in situations where it is extremely difficult or even impossible for the pilot to independently assess the overall state of the system (in this case the aircraft in critically deteriorating weather conditions)... These automated systems assist, support or even perform the last stages of decision-making for the pilot, namely functions as-

sociated with risk assessment, decision-making and action selection... Decision-making models can help determine the causes of VFR into IMC incidents by delineating the variables that typically affect quality of decisions at various stages of the navigating process. Consequently, solutions to improve pilot decision-making can be found through cognitive aspects of training, displays allow for easy detection and integration of cues, as well as automated tools to assess and formulate courses of action. (p. 58-59)

This study shows that automated decision-making yields difficulties in determining probable causes in aviation accidents, supports pilots in making decisions, and at times completes flight operations for the pilot, providing pilots with information pertaining to flight operations, and in some cases preventing aircraft accidents by decreasing the time needed in the decision-making process. Such yields are most beneficial in high-risk situations with an absolute need for automated weather aids.

CONCLUSION

Too much or too little attention given to automated weather aids may prevent a pilot from recognizing the severity of weather conditions and choosing the best response to the situation. This research concludes that the influence of weather automation on pilot perception and decision-making, whether it is positive or negative, is significantly dependent upon the pilot's training and flight experience. For the best performance and completion of cognitive tasks in severe weather, there must be a balance between a pilot's knowledge of flight operations, ability to complete flight operations and a pilot's reliance upon weather automation. Safer decision-making and high performance between pilots and automated weather systems will help reduce erroneous behavior and, ultimately, aircraft accidents.

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