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Beyond 2020 NextGen Compliance: Human Factors and Cognitive Loading Issues for Commercial and General Aviation Pilots

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Beyond 2020 NextGen Compliance: Human Factors and Cognitive Loading Issues for Commercial and General Aviation Pilots

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Abstract. As previously identified by the authors, digitized flight decks have realigned SHELL model components and introduced cognitive overload concerns. Considering changes from implementing Next Generation air traffic management requirements in 2020, the authors assess digitized interfaces associated with cockpit displays of information integral to performance based navigation and similar operations. Focus is placed on Automatic Dependent Surveillance Broadcast, digitized communications, and expanded electronic flight bags. The ADSB (In) cockpit display will enable pilots to have flight visual awareness on aircraft, terrain, weather and hazards to flight through live satellite updates every second. Increased optical demands and cognitive loading are anticipated for general aviation and commercial pilots, beyond operational levels for those currently using advanced technologies. With nearly continuous cognitive processing and embedded information in the enhanced SHELL model by the authors, potential overload and concerns of situational awareness become likely candidates for human factors problems. Addressing these concerns, areas of emphasis for transition to NextGen 2020 operations are delineated, potential risks among increased cognitive disparities identified, and suggested foci recommended.

Keywords: SHELL · Digitized flight deck · Human factors · Working memory
Crew resource management

1 Introduction

The next generation of Air Traffic Control (ATC) technological is slowly becoming a reality for controlling the airspace over the United States (U.S.). NextGen as it is called will modernize the old ATC system in the U.S. by switching it from land-based technologies to satellite based technologies. The increased gains in efficiency and safety have tremendous potential. NextGen aircraft technologies will not be interrupted by signal intervals like previous equipment, but instead will be constant. Pilots will now receive continuous output on other aircraft, terrain and weather from the more accurate satellite fed devices. They will be able to fly more direct and efficient routes by using Global Positioning Satellite (GPS) data from the satellites and will no longer have to rely on a ground system of antiquated Navigation Aides to keep them on

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highways in the sky. NextGen will also boast of a better way of keeping track of all aircraft in airspace through ADSB (Out) technology that continuously puts out the aircrafts position every second through the use of satellites. This will act as a new form of transponder to let air traffic controllers and pilots know exactly where other aircraft are. The Federal Aviation Administration (FAA) has now mandated that all aircraft flying in the U.S. be equipped with ADSB (Out) equipment by 2020. The goal of this mandate is make the NextGen system fully functional. In the process of NextGen becoming fully functional, pilots will have options to use ADSB (In) and Datalink technologies to enhance their information. ADSB (In) will allow pilots to actually know where the other participating aircraft are along with being made aware of where the closest terrain is and how the weather will affect the flight. In addition, Datalink will allow digitalized text communication in flight. With NextGen imminent starting in 2020, there is currently only an outlook of relief as the skies over the United States are forecasted to get more crowded over the next 20 years and the current system cannot handle that forecasted growth. While NextGen is the long awaited ATC infrastructure for US airspace moving into the future, it is not without some serious questions to be answered in the area of computer information and automation concerning Nextgen cockpit technologies. How will these technologies affect both General Aviation and Commercial pilots flying in the future US airspace?

2 Analyzing the Increase of Computer Usage on Human Factors and Potential Human Error

The increase of computer information and automation in U.S. Commercial Cockpits has been well documented over the last 30 years. What started with automated flight controls, auto throttle and flight management systems designed to gain maximum fuel efficiency in flight soon shifted to improved flight navigation flight navigation systems and safety devices like Ground Proximity Warning Systems (GPWS), Traffic Collision Avoidance Systems (TCAS), and Onboard Weather Radar. All these technologies related to computer information and automation have greatly increased fuel efficiency, flight navigation, while at the same time greatly enhancing aviation safety. However, with the introduction of Electronic Flight Bags along with NextGen specific ADSB (In) and Datalink communications devices working their way into the cockpit, there has been a serious shift in how much computer information and automation is now available to pilots. All this addition of technology sounds good until it can have potential negative effects on the human performance in flight. Analysis of aviation accident reports that involved some kind of computer information and automation in the past 20 years indicates that the effects the computer information and automation on pilots show potential deficiencies in the four following areas: (1) Complacency in relying on computers, (2) Confusion and not understanding the computers, (3) Becoming overly focused on a computer and distracted from flying, and (4) Using the computer as optical inside only with little outward scanning. In Fig. 1, the SHELL diagram for human factors analysis was updated in 2017 [1] to take into account the increase of computer information and automation in the cockpit while including NextGen technologies. In this SHELL 2017 model, the potential for possible human

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factors issues that could lead to human error can be seen more clearly. The Hardware (H)-Liveware (L) and the Environment (E)-Liveware (L) linkages show the original areas of the computer being introduced in the cockpit. The Software (S)-Liveware (L), the Liveware (L)-Liveware (L) along with the Environment (E)-Liveware (L) show the new areas that computers have been introduced into the cockpit in the form of EFB, Datalink digitalized texting and ADSB (In) communications. The first important observation made clearly visible in this model is that the computer information and automation have become interfaces between what used to be direct linkages. In the evolution of flight, the SHELL interfaces were originally direct linkages to the human (Liveware (L)) at the center of the SHELL. However, in 2017 version of the SHELL, the evolution of infused computer technologies in aircraft cockpits has created clear computer interfaces in each linkage. Another important issue that is seen in the SHELL Model 2017 is that the new computers (EFB and Datalink) added in the Software (S)-Liveware (L) and Liveware (L)-Liveware (L) interfaces introduced in the last 15 years have now made every computer interface concatenated so that they can potentially overlap with one another. The most important observation in the SHELL Model 2017 is that those interface areas that have been newly created computer interfaces will grow in use in the Software (S)-Liveware (L)-Liveware (L)-Liveware (L) and the Environment (E)-Liveware (L) as NextGen becomes more functional in 2020 and beyond.

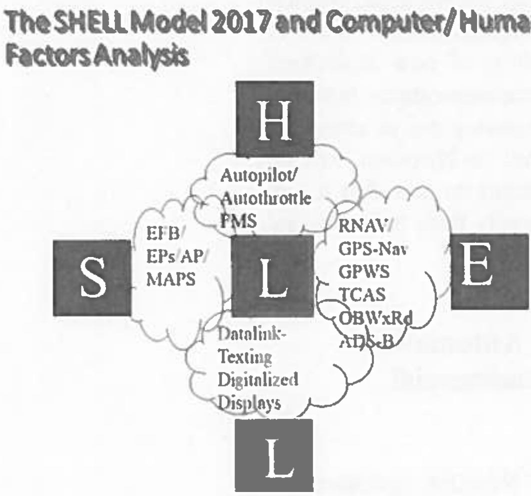

Fig. 1. The SHELL model 2017 and computer/human factors analysis [1]

3 NextGen Cockpit Equipment and the Effect of the Computer in the Cockpit in 2020 and Beyond

As shown in red in Fig. 1, within the Environment (E)-Liveware (L) linkage, the ADSB (In) will become a much greater tool for pilots in the cockpit as it will give constant visual updates to the pilots of the whereabouts of other terrain, other aircraft,

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and weather, all on a small screen built into the ADSB- (In) equipment. With that, navigation equipment will be linked to continuously updated satellite data to fly precise inputted automated routes that can also fly around updated weather. To support this the Software (S)-Liveware (L) linkage will continue to grow in use of the EFB. It is assumed at this juncture of the FAA's ADSB (Out) mandate by 2020 that the vast majority of U.S. pilots both Commercial and in General Aviation will switch to the efficiency gained from carrying an aviation oriented computerized tablet loaded with pubs, maps and procedures that will update electronically. As this trend continues to grow, there will also be another trend of EFBs and similar cockpit computer devices directly hooking up to cockpit displays in 2020 and beyond. Pilots of NextGen will use ADSB (In) data along with precision satellite navigation automation to fly with maps and instrument approach plates that are computer generated from their EFB. Where the NextGen equipment radically departs from normal aviation operations is in the area of communications. Where once pilots observed gauges together and discussed the readings with each other and the crew over cockpit radio, they have slowly changed to observing digital readouts of similar information over the computer screen. Pilots who once spoke to maintenance personnel or dispatchers via radio can now communicate with them via a digitized electronic text format. NextGen in 2020 and beyond will also favor more communications with ATC through a digitized text format called Datalink. Although there are many pros and cons as to how much and when Datalink will be ultimately used in the new ATC system, it has certainly already shown great promise by being used at selected over-crowded airports in the U.S. for Standardized Departures and Routing along with IFR Departure Clearances. Regardless of how digitalized communication evolves in flight within the cockpit or with communications from the cockpit to the ground, it will surely continue to grow. The growing use of computer information and automation in U.S. cockpits directly related to NextGen will be enormous in 2020 and beyond, but it is important at this juncture to note that it will affect the majority of the U.S. Commercial pilots much differently from their General Aviation counterparts.

4 The Influence of Computer Information and Automation from Nextgen Cockpit Equipment on U.S. Commercial Pilots in 2020 and Beyond

From a U.S. Commercial Pilot's perspective, the advent of NextGen equipment or related equipment like the EFB is inevitable and in many cases already happening. In the case of the ADSB (In) technology, it is presumed that all the Major Commercial Operators will be eventually equipped and gain the extra benefits for pilots that the ADSB (In) gives in the form of a visual display for the aircraft's relation to terrain, other aircraft and updated weather. The human factors ergonomic issue related to this is that U.S. CFR Part 121 carriers already have these three benefits in their cockpit layouts in the form of GPWS, TCAS and Onboard Weather Radar. In fact, the integration and improvement of these technologies over the last 30 years has brought the U.S. Commercial Industry to its highest levels of safe operations in the last decade. The problem with the addition of ADSB (In) for U.S. Commercial pilots is how to integrate the ADSB (In) visual display of terrain to work with the GPWS. Similarly, how to integrate the ADSB visual display of other aircraft into using the current TCAS system. Also important is how to use the ADSB (In) live weather display with the Onboard Weather Radar system. While the ADSB (In) seems like an immediate great addition of redundant systems in a visual form to boost safety margins in aviation, at the same time the three major technologies that ADSB (In) will support take a great deal of training and crew coordination to use properly. With ADSB (In), new human factors guidelines will need to be determined for the appropriate use of the ADSB (In) in U.S. commercial cockpits. In particular how to use ADSB (In) with each system optimally will also need to be determined. Will a priority still be given to respond to a TCAS alert if there is no threat observed on the ADSB-in or vice versa? Along with new human factors guidelines, training will also be imperative to integrate the use of ADSB (In) in simulators and Crew Resource Management. In the cases of the Software (S)-Liveware (L) linkage of the SHELL 2017, many companies have already been standardizing and upgrading their EFB devices for years. Though EFB and its informational software like maps and approach plates are not FAA mandated NextGen cockpit devices, they are certainly technologies that have been developing as strong supportive devices for NextGen flight. As these EFB devices become more powerful and integrate more into the cockpit displays, they will also call for more standardization and more training from each U.S. Commercial carrier. The last perspective from Liveware (L)-Liveware (L) linkage of the SHELL 2017 Model is related to communications and in the increase use of digitized texting in the cockpit. Many U.S. carriers have already installed Datalink and have capabilities of digitized texting in the cockpit. For the U.S. Commercial industry this will mean finding a consensus on when and where to use such digitized texting to communicate safely while at the same time finding where efficiencies and safer operations can be gained without jeopardizing efficient radio communications that already exist. The U.S. Commercial industry and their pilots should be the benefactor of the NextGen related computer technologies in the cockpit as long as the appropriate human factors guidelines are set along with the appropriate training for their integration to avoid human error.

5 The Influence of Computer Information and Automation from NextGen Cockpit Equipment on U.S. General Aviation Pilots in 2020 and Beyond

The General Aviator in the U.S. will be affected much differently through the implementation of NextGen cockpit technologies. Assuming that the ADSB (In) technology will someday be reasonably affordable, General Aviation enthusiasts will welcome the safety gains immediately attained by installing the ADSB (In) component in their cockpit to go with the mandatory ADSB-out component. Unlike their Commercial Airline counterparts, the vast majority of General Aviation enthusiasts do not have extra safety equipment in the cockpit to help them with deal with the Environment (E)-Liveware (L) linkage in the SHELL 2017 Model. In fact, very few General Aviation

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aircraft in the United States have GPWS, TCAS or Onboard Weather Radar in their cockpits. Most General Aviators simply are made aware of the terrain by looking at it or using maps. They keep separation from other aircraft by scanning more outward, while sometimes working with ATC. For in flight weather, General Aviators use the forecast and then are expected to use good judgement should the weather deteriorate. Coming from a standpoint of having nothing to enhance safety, to now having something that covers all three of the most dangerous parts of the aviation environment is certainly a great boost for the General Aviator, but this upwelling of new tools for the General Aviator could come with a human factors penalty. The penalty stems from the fact that most General Aviators fly single piloted and are not in team trained crews like their Commercial counterparts. Suddenly installing a magic video box in the form of ADSB (in) within a General Aviation cockpit will give pilots the visual tools immediately to help them avoid terrain, see other aircraft and work better with the weather, but this will come at a cost of looking visually more inside instead of having a primary scan outside. Experienced pilots with terrific scans could become overly focused while looking at the smaller ADSB (In) screen and less outside the cockpit where their eyes belong. Training General Aviators on how to integrate the ADSB (In) information into their flying properly will be ongoing in 2020 and beyond. In the Software (S)-Hardware (H) linkage in the SHELL 2017, General Aviators are not far behind their commercial counterparts when it comes to EFBs. In fact, companies like Jeppesen have come up with excellent EFB equipment for General Aviators that is far superior to the former method of carrying maps and approach plates. This has been a major enhancement for General Aviators over the past decade. This technology of cockpit computer information is a tremendous help as long as the General Aviator is able to operate the EFB device efficiently and not becoming overly focused on it while flying. Efficient ways of using such EFBs for General Aviators will be the key if they are also operating ADSB (In) equipment simultaneously. In the Liveware-Liveware (L) linkage of the SHELL 2017, the General Aviator will be at a disadvantage of being single piloted and trying to communicate through digitized text messaging while flying at the same time. Although some advantages could be gained in the form of using digitalized texting communications for copying taxi instructions, Standard Departures or copying IFR clearances, the General Aviator will have to exercise extreme caution while attempting to communicate digitally while taxing or in flight as the same human factors that have deemed texting dangerous while driving a car could also be at work in a single piloted aircraft as well. Although the General Aviation pilot will realize gains in safety and efficiency through NextGen cockpit equipment, without proper human factors standards and training, the General Aviator being often single piloted could fall prey to human error caused by NextGen cockpit equipment.

6 NextGen Computer Technology in the Cockpit Could Lead to Declines in Situational Awareness

The most important thing any pilot will learn related to situational awareness is to prioritize to fly the aircraft in safe parameters first, navigate the aircraft second and then communicate last. Aviate, navigate, communicate is an age old aviation adage that

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keeps pilots safe and alive by prioritizing situational awareness while flying. The first computers in aircraft aimed to increase situational awareness by helping keep that 'aviate' a priority by being directly integrated with the flight controls as depicted in the SHELL Model 2017 under the Liveware (L)-Liveware (L) linkage. Computers were added to the Liveware (L)-Environment (E) to help pilots improve their situational awareness to navigate better, avoid terrain, other aircraft and bad weather in the process. This was the older paradigm of using computers inflight to enhance efficiency in the cockpit and increase situational awareness around the "aviate and navigate' priority. The new paradigm introduces more efficient ways to communicate through computer technologies. In the new millennium cockpit, computer technologies have been introduced: in the Environment (E)-Liveware (L) linkage though ADSB (In) to communicate visually to pilots about terrain, other aircraft and weather, in the Software (S)-Liveware (L) linkage using EFB to communicate information visually to fly with and in Liveware (L)-Liveware (L) using Datalink and texting to communicate visually with digitized written language to others. This new paradigm of computers in the cockpit is about communicating visually with pilots. Referring back to the old adage of 'Aviate, Navigate and Communicate', the prioritizing situational awareness word of 'Communicate' was deemed the last priority in keeping overall situational awareness, but now could suddenly become a higher priority with these new NextGen cockpit computer technologies. Is it possible that 'Aviate and Navigate" could be affected by these new paradigm visual communication devices? Could these devices cause visual communications to sometimes interfere and overwhelm the 'Aviate and Navigate' situational awareness priorities?

Figure 2 is a simple Risk Assessment Matrix [2] that exposes the potential for problems with NextGen computer technologies in U.S. cockpits in 2020 and beyond. Across the top of the Matrix from right to left shows the slow increase of usage of computer information and automation in cockpits from 1980 to the 2020 FAA NextGen mandate and beyond. Once 2020 occurs, so begins the common use of all the new computer communications devices (ADSB (In), EFB and Datalink) in the cockpit. Due to cost affordability, the fast growth in these NextGen cockpit technologies will not happen immediately, but these communications computer tools for the cockpit will increase in usage beyond 2020 and eventually the sheer numbers of this growth will increase the probability of the occurrence of a loss of situational awareness related to Aviate, Navigate and Communicate; especially if human factors standards and training are not addressed. However, even with a herculean effort of human factors training and safety campaigning by the FAA, the most critical area of 'Aviate' (flying the aircraft safely) related to situational awareness could be left vulnerable on the left 'Severity' side of the Risk Assessment Matrix. This is because the lower priority of 'Communicate' in terms of the NextGen equipment could become visually overwhelming. The main reason why this should be concerning is because we are at a juncture in using all these new computerized cockpit tools together while having very little understanding of how they work with the human mind in flight cognitively.

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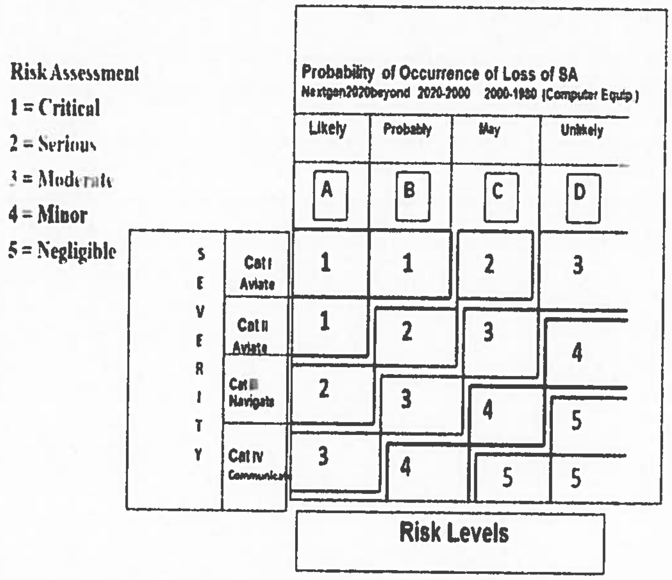

Fig. 2. Risk Assessment Matrix of the loss of situational awareness from the increased use of computer information and automation in modern cockpits versus (Aviate, Navigate and Communicate) [2]

7 NextGen 2020 Cognitive Processing Challenges

Previously discussed was the aspect that text information will replace audio, and that digitized information will require looking down (inviting other issues), including the tendency to turn off information feeds to reduce confusion and overload. Some potential deficiencies in cognitive processing that pilots are likely to encounter when adopting the new technology and procedures include confusion when interpreting the digital output, distraction and excessive loading in working memory, and reduced outward scanning for situational awareness. Since ADSB (Out) will be required in Airspace Classes A, B, C, and E (above 10,000 feet), services like TIS-B (traffic information) and FIS-B (flight information) will add to the cognitive processing requirements for pilots, some of whom may not be familiar with these flight demands. With regard to ADSB requirements now in effect in Europe, and required in 2020 within the U.S., potential cognitive differences may include latency in communications, alerts, symbology, colors, selection of traffic by crew, and integrating TCAS alert symbology. Other concerns [3] illuminate variations in electronic charting, e.g., terrain, airspace, approach paths, and landing systems. With requirements for digitized information and display increasingly mandatory in aircraft, the ability to discern similarities and differences accurately could present a challenge for some general aviation pilots. With standardization of display information elusive among manufacturers, this could well present a problem into the foreseeable future.

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An earlier convention was that humans process information at a set rate, although later evidence showed the rate varies based on individual skills and type of information involved. Limited capacity theory suggests a limit to how much information can be allocated to performance, influenced by task complexity, and the allocation for primary and secondary tasks. The serial process is sequential, the parallel process provides for two or more channels operating simultaneously (although independently), and a hybrid variant that may process serially and in parallel with convergence, but can produce bottlenecks. In naturally occurring channels for vision or symbols these flow smoothly in parallel channels. However, where multiple visual signals are moving in the same channel, capacity is reached more readily and cognitive slowing may result [4]. This suggests that working memory might take a parallel processing track as opposed to sequential, which doubles the neural resources required and accelerates onset of compromised cognitive processing. As the growth in visualized digital data increases on the flight deck and in cockpits, the susceptibility for such delay in cognitive processing increases.

The term multitasking describes performing multiple tasks at once, although the evidence does not address adequately the issue of how people designate primary and secondary tasks. This has prompted a concept of task-switching to explain how multitasking is effective. Wickens [5] has determined that performance decrement rests on whether more than one task is performed simultaneously calling upon the same perceptual, cognitive, and psychomotor resources. Since most tasks are performed in stages, resources are adequate for demands made, however, an individual's load capacity may be reached where a single, large task becomes paramount. This might be the case where deconfliction decision making takes precedence with a less experienced operator in the NextGen 2020 environment.

8 Cognitive Loading and NextGen 2020

Cain [4] defined mental workload as measures that characterize task performance relative to operator capability. Earlier views that workload was principally additive, with demands on undifferentiated resources, has been replaced by the perspective that information processing comprises multiple resources operating differentially according to task complexities. The inference of cognitive loading initially was measured by direct observation of performance and use of rating scales and similar instruments to gauge decrements in task execution. As psychophysiological measures have entered the literature in greater emphasis, the point has been made that physiological methods do not measure imposed load, and instead provide information of individual responses to load. With less experienced operators entering the ADS-B environment, unaccustomed cognitive loading may tax some pilots and crewmembers.

Variable capacity theory [6] provides for operator intentions in setting task priorities and expanded channel capacity as workload increases, although fixed limits do not appear to be reliably predictable. Coping and resilience have been suggested as explanations for variable capacity and, along with several other proposed explanations for adaptive responses, have opened the investigation into variable capacities subject to

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situational relevance and individual states [7]. Fatigue, for instance, has been shown to reduce speed of output [8]. In high task situations this will be further exacerbated.

A comparison to studies of text messaging brings to bear a directly relevant issue with digitized cockpit communications. A comparison of heavy truck operation [9] and aircraft suggests that elevated risk for crash or near-crash increases 2300% over non-texting operations. Where ADS-B is initiated in single pilot operations, with no second crew member available, it is prudent to assess the potential for a similar elevated risk potential. Accompanying elevated risk invites increased anxiety, which increases attention to threat-related stimuli that can arise from confusion while attempting to comprehend the ADS-B information for less experienced pilots [10]. Recognition primed decision making applies where a learned optimal response has been successfully employed (often in emergencies) and can quickly be evaluated to meet a situation [11]. In such events, very experienced operators who regularly rehearse emergency events can evaluate a situation more rapidly with coherence and have the benefit of RPD, where general aviation pilots might be less able to develop a comparable level of skill.

Essentially, the adoption of ADS-B introduces several added degrees of freedom in cognitive processes as a result of NextGen procedures [12]. When considering Wickens' [5] concept for rearrangement of cognitive channels, where variable upper limits exist, the potential for elasticity is enhanced. In the case of general aviation pilots, however, not acquiring the associated task selection and sequencing skills actually reduces the degrees of freedom and invites potentially catastrophic outcomes. With added ATM and ADS-B requirements, general aviation pilots are more likely to reach a fixed upper limit of channel capacity and resulting notable decline in performance. A further consideration is the difficulty when bifurcation becomes imminent, as with a critical decision point. The influence of ensuing instability in cognitive processes suggests that pilots with high or excessive cognitive loading may alter a behavior pattern that could set into action an undesired sequence of events.

Further study of potential areas for concern in meeting the NextGen 2020 environment is needed. Task performance is situationally dependent, however, changes and response time are normally generalizable. A minus is that analysis may not indicate the unobserved part of the process. Still unresolved is the issue of whether mental workload is a scalar or vector quantity, particularly in regard to predictive modeling. As a scalar measure, cognitive loading is approached as a one-dimensional measurement (magnitude) of a single quantity. A vector approach, on the other hand, can have two measures (e.g., magnitude and direction) associated with a quantity. The relevance to cognitive workload is in determining relationships among vector measures and subsequent reliability and validity for prediction of cognitive processing and behaviors [4]. The effect is somewhat obvious when considering the added cognitive loading for NextGen 2020 ADS-B and allied demands for new or less experienced pilots.

Operators with poor understanding of a situation are prone to errors. Where this is attributable to lack of awareness rather than proficiency failure, a question of cognitive ability has been investigated. Working memory and spatial memory have been areas of special interest, along with cognitive style characteristics [13]. With added cognitive load, this could precipitate earlier onset of fatigue, which is reflected in the CUSP model, described operationally as a decrement in work capacity over time. With added cognitive workload associated with NextGen 2020, fatigue occurs earlier and memory and perception are the first to degrade [14]. This can be illustrated with the complexities the general aviation pilot might encounter when ADSB (In) becomes a requirement. The U.S. FAA has mapped this system and complexities in Advisory Circular 172-B.

In summary, the growing optical and cognitive workloads for pilots in a digitized environment, represented in SHELL Model 2017, will likely be challenged further with implementation of NextGen 2020 and ADS-B. That, and increasing use of electronic flight bags, accelerates risk of cognitive overload, confusion, fatigue, and loss of situational awareness. Regulators, manufacturers, operators, and pilots might take notice of these impending threats and address them in upgraded training and procedures.

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