Hooey, B. L., Gore, B. G., Wickens, C. D., Scott-Nash, S., Socash, C., Salud, E., & Foyle, D. C. (2010). Modeling Pilot Situation Awareness. In C. Cacciabue et al., (Ed.) *Human Modelling in Assisted Transportation*. Heidelberg: Springer.

Modeling Pilot Situation Awareness

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Abstract

The Man-machine Integration Design and Analysis (MIDAS) human performance model was augmented to improve predictions of multi-operator situation awareness (SA). In MIDAS, the environment is defined by situation elements (SE) that are processed by the modeled operator via a series of sub-models including visual attention, perception, and memory. Collectively, these sub-models represent the situation assessment process and determine which SEs are attended to, and comprehended by, the modeled operator. SA is computed as a ratio of the Actual SA (the number of SEs that are detected or comprehended) to the Optimal SA (the number of SEs that are required or desired to complete the task).

A high-fidelity application model of a two-pilot commercial crew during the approach phase of flight was generated to demonstrate and verify the SA model. Two flight deck display configurations, hypothesized to support pilot SA at differing levels, were modeled. The results presented include the ratio of actual to optimal SA for three high-level tasks: Aviate, Separate, and Navigate. The model results verified that the SA model is sensitive to scenario characteristics including display configuration and pilot responsibilities.

1 Introduction

In the Next Generation [7] of aviation operations, it is anticipated that there will be substantially more information available to pilots on the flight deck (e.g., weather, wake, terrain, traffic trajectory projections) to support more precise and closely coordinated operations. Safe and efficient task performance within complex sociotechnical systems depends on operators acquiring and maintaining appropriate levels of situation awareness (SA) [9], and as such, a critical issue is how well the flight deck will support the pilots' ability to acquire and maintain SA of relevant information in the NextGen environment.

Arguably, the most commonly accepted definition of SA is that offered by Endsley [1] who defined 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. To date, efforts to computationally model and predict SA have been few [but see 8, 13, 14].

This paper describes recent enhancements to the Man-machine Integration Design and Analysis System (MIDAS) to enable improved predictions of pilot SA. MIDAS is a human performance modeling and simulation environment that facilitates the design, visualization, and computational evaluation of complex human-machine system concepts [3, 4, 5]. MIDAS links a virtual human, comprised of a physical anthropometric character, to a computational cognitive structure that represents human capabilities and limitations. The cognitive component includes decision-making, task management, perception, visual attention, and memory mechanisms.

2 Modeling Situation Assessment and Situation Awareness

The MIDAS SA model was first developed by Shively, Brickner, and Silbiger [11] and is augmented here to enable improved predictions of multi-operator SA in NextGen aviation concepts. In MIDAS, the *situation context* defines what information is important to the modeled operator in the situation [11]. At a minimum, in NextGen applications, the context is defined by the phase of flight (taxi, departure, cruise, approach, or land), but may be broken down to finer levels of granularity, or along other dimensions such as nominal and off-nominal operations. For each context, the operators' high-level tasks are defined. For NextGen aviation models, the default high-level tasks adhere to the following hierarchy of task importance[1]: Aviate, Separate, Navigate, Communicate, and Systems Management [see 10]. For SA, these can be subdivided; for example, the task of Separate can be divided into "Separate from traffic" and "Separate from terrain". The importance of each task is defined (as high, medium, or low) for each operator and each context.

Within each context, the environment is broken down into '*Situational Elements*' (SEs), which are pieces of information that are necessary to support the operator's high-level tasks [11]. For example, for the task of 'Aviate', the SE 'attitude' is *required*, but the SE 'angle of attack' (which is a display that presents the angle of the wing relative to the wind and warns of stall conditions) is *desired*. Although angle of attack supports pilot performance and makes the task easier, it is not strictly necessary, or required. The *accessibility* of each SE is defined by the analyst using a set of design heuristics that address: display modality (visual, auditory), legibility (size, contrast), permanence (always visible, automatically presented, requires key strokes), and format (text, graphical). For example, spatial information that is conveyed by a text display would be classified as less accessible than information that is conveyed graphically.

In the current implementation of MIDAS, perception is a three-stage (undetected, detected, comprehended), time-based perception model for objects inside the workstation (e.g., an aircraft cockpit). The model computes the upper level of detection that can be achieved by the average unaided eye if the observer dwells on it for a requisite amount of time. Once an SE is comprehended, the operator is assumed to have acquired SA of the SE. An SE with low accessibility requires longer time to comprehend, and thus has a corresponding decrement in SA. After an SE is comprehended, it is subject to the constraints of the memory sub-model, which degrades SA as a function of time since last accessed. The memory model in MIDAS causes the perception level of a 'comprehended' display to drop to 'detected' after the retrievability threshold of working memory (5 sec) has been surpassed, and perception drops fully to 'undetected' after the retrievability threshold of long-term working memory (300 sec) has been surpassed. As the maximum perception level for an SE drops, there is a corresponding drop in SA.

The information in the environment flows through the situation assessment process (including visual attention, perception, and memory sub-

[1] Schutte & Trujillo (1996) define a four-level workload management hierarchy: Aviate, Navigate, Communicate, and Systems Management. Separate is added here to accommodate new flight-deck responsibilities anticipated in the NextGen environment

models) and yields a metric of SA for each operator's high-level task (Aviate, Separate, Navigate, Communicate, and Systems Management. The SA metric in MIDAS computes the ratio of SEs that are detected or comprehended (Actual SA) to the SEs that define the ideal state (Optimal SA).

Actual SA. For each high-level task (*i*), at time (*t*), Actual SA (See Equation 1) is calculated as the weighted sum of *m* Required SEs and *n* Desired SEs multiplied by the perception level (*p*). Note that if an SE is available on more than one display simultaneously, the highest perception level attained is applied. For SEs within the cockpit, *p* has values of 0 if the SE is undetected, .5 if detected, and 1.0 if comprehended. *Required* SEs have a weight of 2 and *desired* SEs have a weight of 1.

$$SA_{Actual}(t_i) = \underbrace{\sum_{r=1}^{m} 2 \bullet p_{irt}}_{\text{required SEs}} + \underbrace{\sum_{d=1}^{n} 1 \bullet p_{idt}}_{\text{desired SEs}} \tag{1}$$

Where p_{irt} and p_{idt} have values: 0 for undetected SEs, 0.5 for detected SEs, and 1.0 for comprehended SEs.

Optimal SA. Optimal SA (see Equation 2) reflects awareness the operator would have if he/she comprehended all the information that is required and desired for the task at any given moment. Therefore, for each high-level task (*i*), at time (*t*), Optimal SA is the weighted sum of *m* Required SEs and *n* Desired SEs multiplied by *p*; where *p* is always equal to 1.0. Required SEs have a weight of 2 and Desired SEs have a weight of 1.

$$SA_{Optimal}(t_i) = \underbrace{\sum_{r=1}^{m} 2 \bullet p_{irt}}_{\text{required SEs}} + \underbrace{\sum_{d=1}^{n} 1 \bullet p_{idt}}_{\text{desired SEs}} \tag{2}$$

Where p_{irt} and p_{idt} have values of 1.0.

SA Ratio. SA Ratio (See Equation 3) is the ratio of Actual SA to Optimal SA. It yields a value from 0 (no SA) to 1(maximal SA) that reflects the proportion of SEs of which the operator has awareness.

$$SA_{Ratio}(t_i) = SA_{Actual}(t_i) / SA_{Optimal}(t_i) \qquad (3)$$

3 Application Scenario

A high-fidelity model of a two-pilot crew flying an approach into an airport was developed. The model included pilot tasks such as manipulate flight controls, monitor flight instruments, maintain separation from traffic, monitor aircraft system status, and communicate with ATC. For the purposes of this model, the Captain was assumed to be the pilot flying (left seat) and the First Officer was the pilot-not-flying (right seat). The scenario started with the aircraft at 2200 ft altitude on a normal approach into Dallas/Fort Worth International Airport. The scenario was run with two configurations (Current-day and Augmented) that varied both the flight deck display configuration and pilot responsibilities in a manner expected to impact the time to comprehend information, and, in turn, SA.

Current-day Configuration. The flight deck was equipped with a minimal set of current-day glass-cockpit displays including a Primary Flight Display (PFD) that depicted altitude, speed, pitch, bank, and heading and a Navigation Display (ND) that graphically depicted the current and commanded flight path. Consistent with current-day operations, both pilots shared the same hierarchy of importance for the tasks of Aviate, Separate, Navigate, Communicate and Systems.

Augmented Configuration. The Captain was equipped with a head-up display (HUD) that superimposed primary flight instruments and a highway-in-the-sky (HITS) display over the out-the-window view [2] and a current-day ND. The First Officer was equipped with a current-day PFD and an advanced 3-D ND [6] allowing for improved visualization and predictive information about traffic and weather trajectories. Each pilot had a unique task hierarchy. The Captain's emphasis was placed on the tactical task of Aviate and Separate (from immediate hazards). The First Officer's main responsibility was the strategic planning tasks of Navigate and Separate (from global hazards).

3.1 Results

Figure 1 presents the SA ratio for the tasks of Aviate, Separate (*from* hazards), and Navigate (*to* waypoints) in the Current-day and Augmented configurations. In the Current-day configuration, there were only negligible differences between the Captain and First Officer's SA for each of the three high-level tasks. This was expected, since both pilots shared a similar display configuration and shared equal responsibility for maintaining awareness of all SEs in the environment.

The Augmented configuration demonstrated a different pattern of results, again consistent with expectations. Recall that in the Augmented scenario, it was assumed that the Captain would place highest priority on the tactical tasks of Aviate and Separate from immediate hazards as supported by a HUD with a HITS display. This is clearly reflected in the Captain's SA for the Aviate task, which was higher in the Augmented condition than the Current Day condition. Likewise, in the Augmented condition, the Captain's SA of the Aviate task was higher than that of the First Officer. Further, recall that in the Augmented scenario, the First Officer had an advanced 3-D ND that supported strategic Navigate and Separate tasks. This is reflected in the First Officer's increased SA for the tasks of Separate and Navigate, relative to the Captain, in the Augmented configuration.

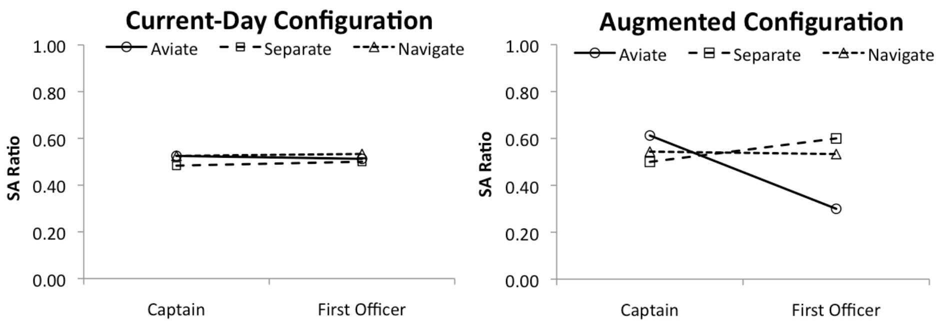

Fig. 1 Captain and First Officer SA ratio for the tasks of Aviate, Separate and Navigate as a function of display configuration (Current day, left and Augmented, right). SA ratio is presented on a scale from 0 (no awareness) to 1.0 (maximum awareness)

Comparing the Current-day to Augmented configurations, it is clear that the distribution of SA has changed in a manner consistent with expectations as a function of the procedural and display manipulations in the Augmented conditions. System-wide, the Augmented configuration enabled a higher level of SA for the task of Aviate (by the Captain) and Separate (by the First Officer) than was attained in the Current-day scenario.

4 Conclusion

The MIDAS model was augmented yielding improved predictions of multi-operator SA. The SA metric was augmented to allow for the prediction of SA as a function of the operator's high-level tasks (such as shown above, Aviate, Separate, and Navigate). The model also allows for SEs to be characterized according to their level of importance for task completion (required or desired) and for SA to be degraded as a function of information accessibility. It is acknowledged that this model is limited in it's focus to the first of Endsley's three stages of SA [1] – specifically, the perception of elements in the environment. Future research efforts will be aimed at addressing the subsequent two stages of SA: comprehension and projection.

The SA model was verified using a high-fidelity simulation model of a two-pilot crew conducting an approach into an airport. The model output revealed that the SA model was sensitive to differences in display configurations and pilot responsibilities. While future efforts will undertake a formal validation of this model by comparing the model output to human-in-the-loop data, this work represents preliminary steps toward the development of a model-based tool that can be used to predict operator SA as a function of procedures and display configurations.

Acknowledgments

This research was funded by the National Aeronautics and Space Administration (NASA) Aviation Safety (AvSAFE) Program (Integrated Intelligent Flight Deck Technologies (IIFTD) / System Design & Analysis (SDA) project).

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