Analysis of Eye-Tracking Data with Regards to the Complexity of Flight Deck Information Automation and Management – Inattentional Blindness, System State Awareness, and EFB Usage

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In the constant drive to further the safety and efficiency of air travel, the complexity of avionics-related systems, and the procedures for interacting with these systems, appear to be on an ever-increasing trend. While this growing complexity often yields productive results with respect to system capabilities and flight efficiency, it can place a larger burden on pilots to manage increasing amounts of information and to understand intricate system designs. Evidence supporting this observation is becoming widespread, yet has been largely anecdotal or the result of subjective analysis. One way to gain more insight into this issue is through experimentation using more objective measures or indicators. This study utilizes and analyzes eye-tracking data obtained during a high-fidelity flight simulation study wherein many of the complexities of current flight decks, as well as those planned for the next generation air transportation system (NextGen), were emulated. The following paper presents the findings of this study with a focus on electronic flight bag (EFB) usage, system state awareness (SSA) and events involving suspected inattentional blindness (IB).

Nomenclature

AOI	=	Areas of interest
CDU	=	Control display unit
CMF	=	Cockpit Motion Facility
EFB	=	Electronic flight bag
FAF	=	Final approach fix
FMA	=	Flight mode annunciator
FMS	=	Flight management system
GS	=	Glide slope
HUD	=	Head-up display
IB	=	Inattentional blindness
ILS	=	Instrument Landing System
LOC	=	Localizer
ND	=	Navigation display
NextGen	=	Next generation air transportation system
OTW	=	Out–the-window
PF	=	Pilot flying
PFD	=	Primary flight display
PM	=	Pilot monitoring
PNF	=	Pilot not flying
RFD	=	Research Flight Deck
SSA	=	System state awareness

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I. Introduction

In 2013, a flight simulation experiment aimed at investigating complexity effects was conducted using the Research Flight Deck (RFD) within NASA's Cockpit Motion Facility (CMF) at Langley Research Center (Figure 1). The RFD mimics most of the interfaces provided on the B-787 aircraft with several NextGen capabilities added. Ten two-pilot airline crews participated in the study, all of which had no less than 3000 hours of commercial airline flight experience. More than 230 simulated approaches and landings were completed in the simulator using the Memphis International Airport as the test site. The 10 crews executed a mix of 40 different approach scenarios including some that were based on one or more reference events from past accidents/incidents or studies[1,2]. Data was collected using an experimental design that allowed for the manipulation of information, operational complexity, and uncertainty across these scenarios. Flight crews were immersed in a high density traffic and adverse weather environments that included many "new" concepts either currently emerging in the industry or planned for the near future (e.g. EFBs, expanded data link services, synthetic and enhanced vision systems, and interval management automation). In addition, the study emulated off nominal (and complex) situations such as unexpected weather events, traffic deviations, equipment failures, poor data quality, communication errors, unexpected clearances, and changes to flight plans. An overview of this 2013 study and preliminary results can be found in Young[3].

Figure 1. NASA's CMF/RFD simulator.

During each of the simulated flights, eye-tracking data was collected to allow for objective evaluation of the crews' attention to the various displays and areas of interest (AOI). The nine AOIs analyzed, and reported here include: the head-up display (HUD), two primary flight displays (PFD), two navigation displays (ND), two EFBs, and out–the-window (OTW). A final AOI, the flight mode annunciator (FMA), is located within the PFD AOI. An overlay of these AOIs onto the RFD layout is given in Figure 2.

Figure 2. AOI's overlaid on RFD.

To determine the crew's attention to each of these nine AOIs, multiple analyses were performed using the eye-tracking data and other aircraft state data. The results help us to understand how pilots were choosing to observe information provided during different stages of the flights and in response to specific events that occurred within these stages. With respect to each AOI, statistics were collected to quantify their use over the full flight as well as for specific segments. These segments corresponded to initial runway alignment, reaching the final approach fix (FAF) and landing. Three analysis topics were investigated. First, because EFBs are becoming more widespread with little data yet to suggest their impact, crew usage in this experiment is analyzed and some observations are provided with respect to their implications. Second, due to the known adverse effects of crews losing automation mode awareness, engagements with the FMA during the experiment are analyzed to help in understanding "typical" interactions and attention behaviors with respect to this important element of the PFD. Lastly, 27 of the 230 simulated flights were designed to induce hazardous traffic situations, with aircraft converging ahead of ownship's path and causing a loss of safe separation. In Young[3] , it was reported that of these 27 flights, 13 resulted in manifestations of apparent inattentional blindness (IB). Based on Mack[4], a failure to notice an unexpected cue in the field of vision when other attention-demanding tasks are being performed is considered IB. During the flights resulting in apparent IB, the crews were presented with valid traffic information, but yet did not take any action to mitigate, or discuss, the loss of separation situation. Here we seek to determine via the eye-tracking data whether they were looking at the information, yet not "seeing" it (a.k.a. experiencing IB). Results for each of the above three analysis topics are presented, each suggesting the need for changes to flight deck evolution paths with respect to dealing with, and removing, complexity through novel automation and information management techniques.

II. Methodology

To collect information regarding which AOIs pilots were referring to throughout the course of each flight, the RFD platform was equipped with a Smart Eye Pro[5] head and eye-tracking system. Through the use of multiple cameras, this system produced estimates at a 50 Hz. rate for each pilot's eye location and gaze direction relative to a predetermined coordinate frame. The system provided these parameters and others, along with an associated confidence metric and an estimate of the AOI being engaged. The parameters used for this study are summarized in Table 1.

Table 1. Smart Eye Pro output parameters.

Parameter	Pilot (left seat)	Pilot (right seat)
Eye Position	(x,y,z)	(x,y,z)
Gaze Direction	unit vector (x,y,z)	unit vector (x,y,z)
Estimated AOI	AOI name	AOI name
Measurement Confidence	scale from 0:1	scale from 0:1

Raw data collected through the Smart Eye Pro system was pre-processed to eliminate outliers, reduce noise, better define the boundaries of each AOI, and yield the capability of identifying new AOIs. First, each of the eye location and gaze direction measurements were projected onto a unit surface. The results of this projection can be seen for the entirety of a single flight on the upper right quadrant of Figure 3. For further visualization and evaluation of the eye-tracking system's outputs, the lower left quadrant of Figure 3 shows the point cloud of data with corresponding AOIs overlaid. Upon comparing these results to the RFD cockpit shown on the upper left quadrant of Figure 3, it can be seen that the projected points and corresponding AOIs obtained through the eye-tracking system produce a reasonable representation of the RFD's true layout. While the raw data from the eye-tracking system produced a realistic depiction of the RFD's layout, a number of points can be observed that appear to have incorrectly identified AOIs based on their projected spatial location. To minimize the points that are either incorrectly identified or have erroneous locations, the eye-tracking data was filtered based on a set of defined heuristics. First, points were eliminated when having provided with a low confidence metric from the eye-tracking system. All points with an associated confidence less than 60% were removed. Next, points were eliminated based on their proximity to other points with common AOI identification. For each AOI, an ellipse was created around the center (i.e. spatial average) of the subset of points to encompass 98% of the points associated to that AOI. All points not contained within this ellipse were eliminated. Lastly, moving-average filters were employed to account for the motion of the pilot's gaze direction and eye location. Given the 50 Hz. update rate combined with the expected actions of the pilot, it was assumed that large excursions in motion should not be observed between samples. Therefore, a sliding window average was applied to each channel (i.e. x, y, and z) of the aforementioned parameters to help smooth out any such noise present on the measurements. This was accomplished through an implementation of equation (1) where a new measurement is formed, $p_{i,smoothed}(t_k)$, by averaging the current measurement, $p_i(t_k)$, with the previous two measurements, $p_i(t_{k-1})$ and $p_i(t_{k-2})$. The effects of the aforementioned filtering techniques are shown in the lower right quadrant of Figure 3. These results appear to be less cluttered, less noisy, and more indicative of eye-movement behavior than the raw data provided by the eye-tracking system.

$$p_{i,smoothed}(t_k) = \frac{p_i(t_k) + p_i(t_{k-1}) + p_i(t_{k-2})}{3} \tag{1}$$

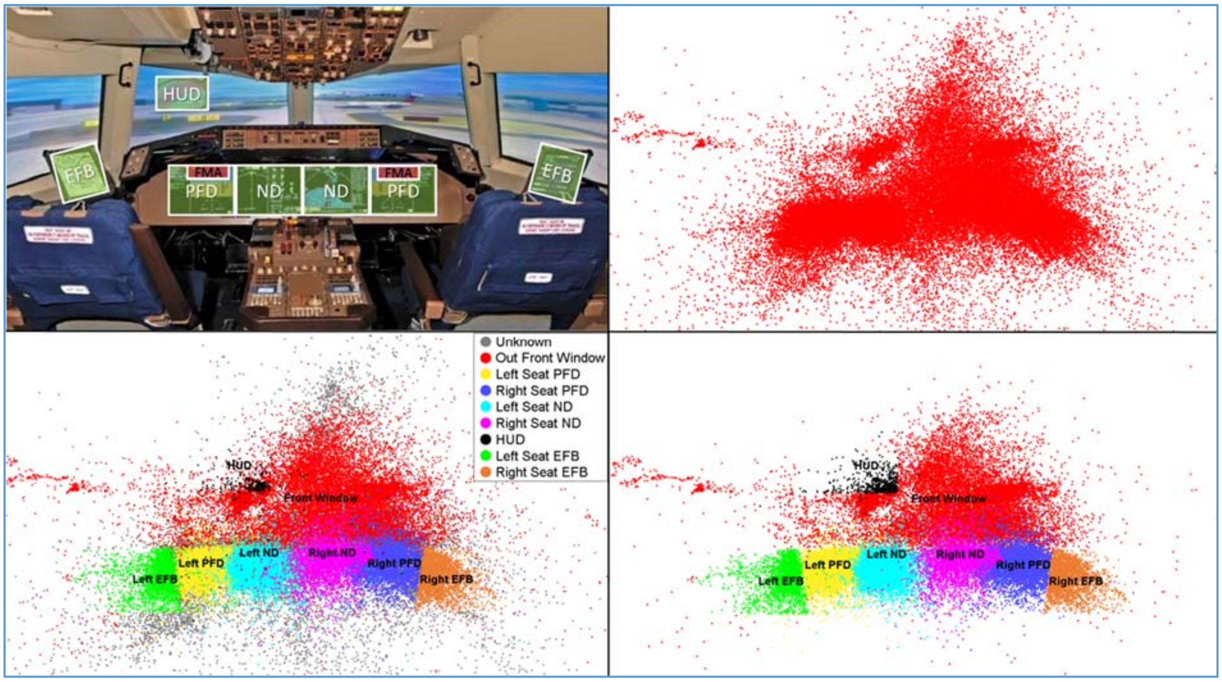

Figure 3. (a) Upper Left: AOI's overlaid on RFD; (b) Upper Right: Temporal compilation of gaze samples; (c) Lower Left: Projected gaze samples with system-identified AOIs overlaid; (d) Filtered gaze samples with overlaid AOI identification.

III. Results and Analysis

Using the method described above, each pilot's engagement with the different AOIs was tracked and evaluated across the set of flights. Of particular interest were: overall gaze distributions, EFB usage, FMA engagement during autopilot mode transitions, and ND engagement during events where IB was suspected.

For the following analysis and figures, the two pilots are distinguished based on their assigned role and using the terms pilot flying (PF) and pilot monitoring (PM). Here, we consider the PM term equivalent to the pilot not flying (PNF) term, which is also often used in the industry. These roles and terms should not be confused with seat position (left/right). In this study, a given crew took a seat position and stayed in that seat for the duration of their participation (2 days). They were, however, asked to change roles (PF/PM) occasionally, but to always complete at least two approaches consecutively before switching. Scenarios were randomly sequenced both within and across the crews with the pilot role for each seat position briefed and set prior to each flight.

A. Pilot Gaze Distributions

As previously described, the projection data from the head and eye-tracking system can be used to identify where each pilot is looking at any given time. By accruing this data for more than 230 flights, a distribution can be compiled to indicate the average amount of time per flight each pilot spent observing each AOI. The average distribution for each pilot is shown in Figure 4. From this, it can be seen that the PF spent significantly more time than the PM looking out the front window. Conversely, the PM typically spent significantly more time than the PF viewing the ND and PFD. This is consistent with the roles and responsibilities for the two pilots (i.e. PF/PM), and their training. One pilot is the PF and is expected to spend more time "eyes-out"; while the other is the PM and is expected to spend more time "eyes-in". Usage of the EFB appears comparable between the two pilots. This is most likely due to the fact that few of the crews had significant EFB experience (or training) and prescribed procedures for its use were limited in this experiment (i.e. only required to use it for data link communications).

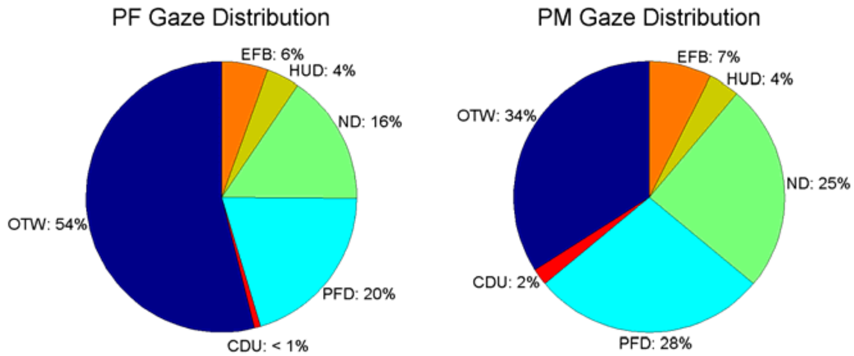

Figure 4. Average distribution of time each pilot spent looking at the specified AOIs[3].

Assessment of pilots' attention to displays is not unique to this study, however caution must be exercised when comparing the results obtained here to those of other studies due to different cockpit setups, varying functionality of devices, and training/proficiency levels. With this in mind, both the PFD and ND exhibited a decrease in usage when compared to the findings of Mumaw[6] and Huettig[7]. PFD interactions took place an average of 24% of each flight, which is substantially less than the findings of Mumaw and Huettig who observed 35% and 40% use, respectively. The percent engagement with the ND found here (20.5%) resembled the 25% and 20% results found in Mumaw and Huettig much closer than the PFD results.

Along with the average total interactions with different AOIs shown in Figure 4, the average AOI engagement can be further evaluated with respect to time. Figure 5 and Figure 6 depict the average engagement with each AOI by the PF and PM, respectively. This data indicates a substantial increase in the amount of time each pilot spends looking out the front window after reaching the final approach fix (typically 650-700 seconds into the flight). This increase in time spent looking out the front window appears to correlate with a decrease in viewing of each pilots respective ND and PFD and an increase in HUD usage. These trends appear as expected as the pilots should be looking out the front window more during final approach and landing, particularly in IMC conditions when they are looking to confirm the runway environment is in sight.

In addition to analyzing device usage over time, transitions between devices were examined in an attempt to identify scan patterns for each pilot. Figure 7 and Figure 8 show the likelihood for each pilot to transition from a specific AOI to a different AOI. The wider bars on these plots indicate the percentage of transitions away from the corresponding AOIs listed on the x-axis. The thinner bars contained within the wider bars designate the percentage of transitions away from an AOI to each of the other possible AOIs. Unfortunately, no consistent scan pattern was found across all PFs or PMs as each individual displayed unique tendencies. However, there were some lesser tendencies observed. If either pilot was interacting with the EFB, it was highly likely that they would shift next to looking at either their respective PFD or out the front window. Upon looking away from the front window, both pilots would likely move to their corresponding HUD, ND, or PFD. Transitions into and away from each pilot's ND and PFD were often reciprocal between the two displays. Except for the EFB, the most likely transition away from any device was to each pilot looking out the front window.

[3] Time spent looking at the other pilot's displays is not included in this figure, but was <1%.

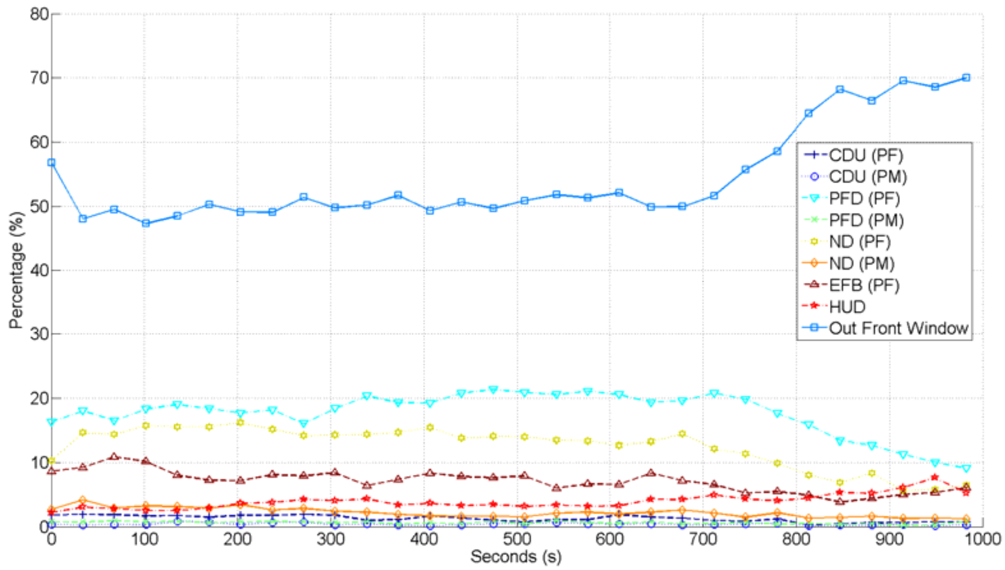

Figure 5. PF average engagement with different AOIs over time.

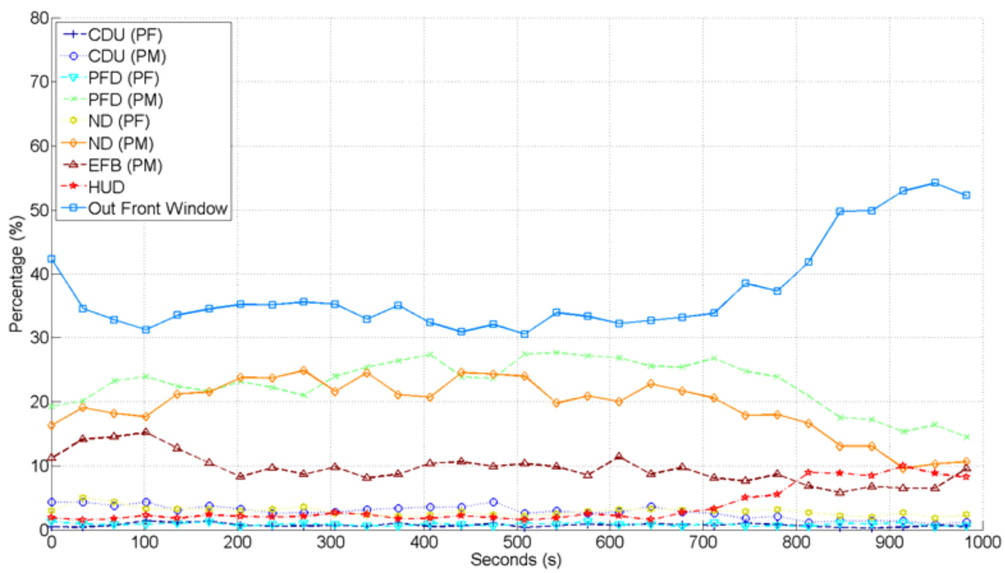

Figure 6. PM average engagement with different AOIs over time.

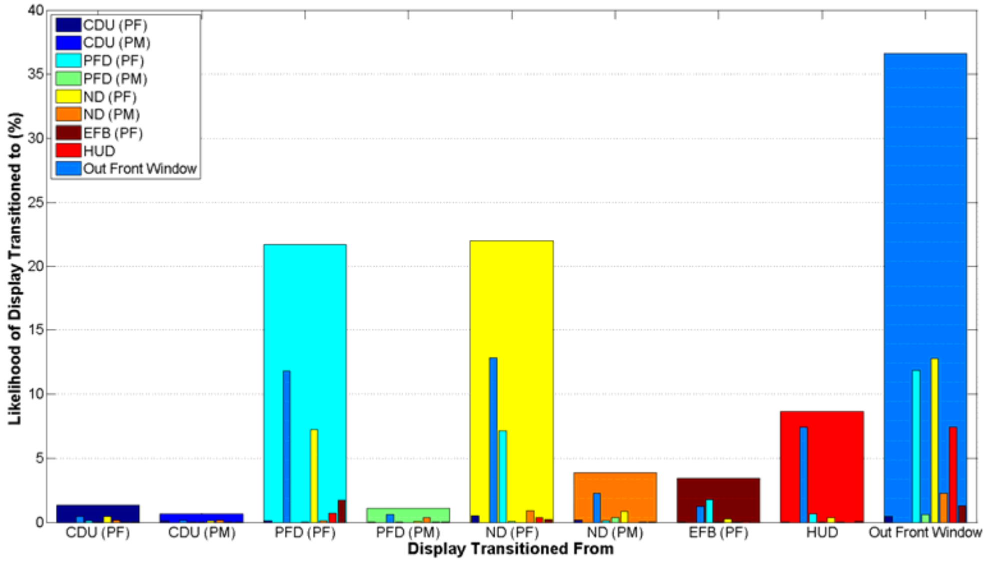

Figure 7. Likelihood of transitions between different AOIs (PF).

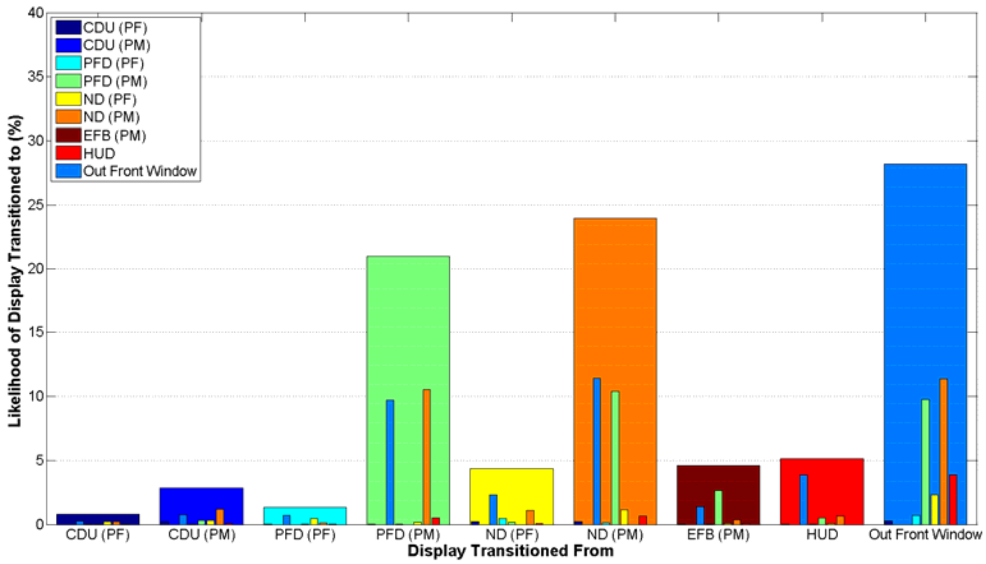

Figure 8. Likelihood of transitions between different AOIs (PM).

B. EFB Engagement

Included within this study was an increase in EFB functionality with respect to their use in current airline operations, as found in the FAA Advisory Circular 120-76B[8]. As this increase in functionality was novel to each of the pilots, and few had EFB experience at all, it is useful to analyze their respective interactions with the device. Details of the EFBs used in this work can be found in Evans[9], along with pilot questionnaire responses related to this EFB's usability.

To illustrate EFB usage during different stages of flight, Figure 9 depicts the statistics over all the flights. Upon examination of this figure it can be seen that on average at least one pilot is interacting with the EFB for ~8% of the flight. Typically, both pilots tend to spend more time on the EFB between runway alignment and the final approach fix than during any other stage of flight. It is also apparent that occasionally one of the two pilots allocated almost no attention to the EFB, but it is never fully neglected by both pilots. It should also be noted that the most significant usage of the EFB was during pre-flight (e.g. reviewing NOTAMs and weather). Analysis of eye-tracking data during this phase is not presented here.

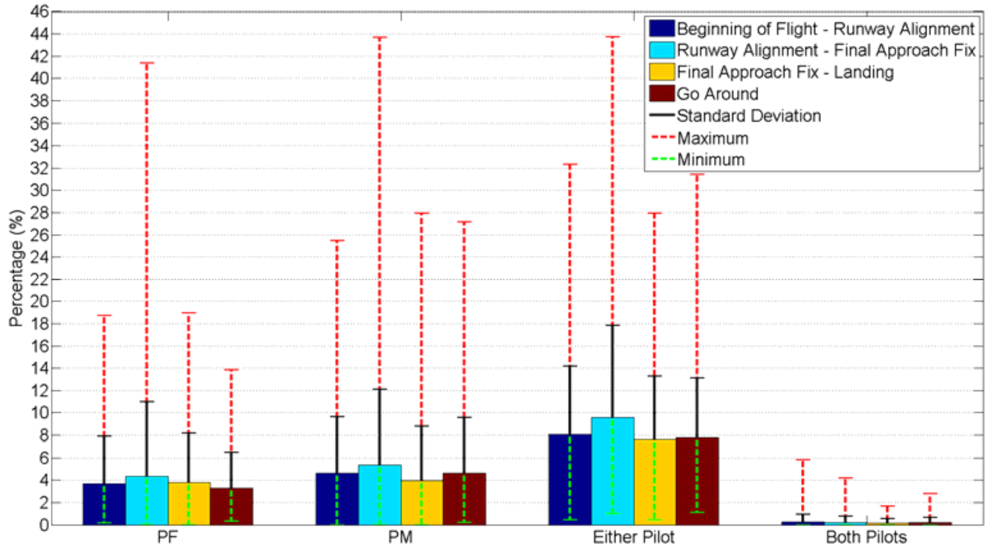

Figure 9. Average EFB usage during different phases of flight.

When the EFB is acknowledged by either pilot, it is typically often done so for a short period of time. This is reflected in Figure 10 where average interactions with the EFB are shown to last for slightly more than 2 seconds, and most interactions lasted for 4 seconds or less. Thus, even though most pilots found the enhanced EFBs useful and easy to use[9], lengthy interactions with the EFB were rare. Roughly once every 12 simulated flights an EFB was engaged for more than 10 consecutive seconds, with maximum observed dwell times of nearly 28 and 30 seconds for the PF and PM, respectively. Upon inspection, these lengthy dwell times were attributed to cycling through charts, inspecting airport maps, responding to data link messages, or asking EFB-related questions during a flight.

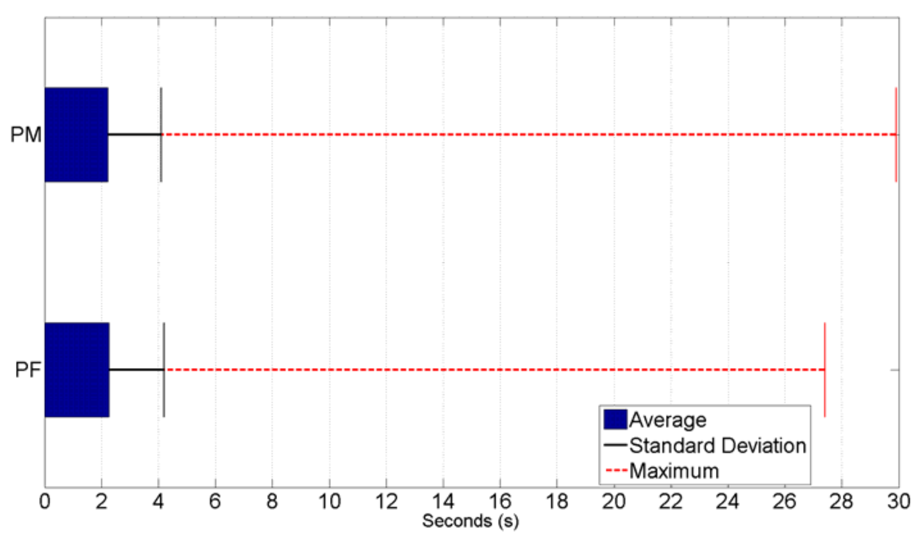

Figure 10. Average dwell time on EFB throughout flights.

C. FMA Engagement and Autopilot Mode Transitions

During manual or automatic changes of the flight system state, the FMA indicates the instantaneous mode, as seen in Figure 11. Failing to notice state changes on the FMA may result in a loss of mode awareness for the pilots. As stated in Mumaw[6], a loss of mode awareness may result in automation surprises, or actions taken or omitted based on an assumed state instead of the true state. As a loss of mode awareness has been shown to be a contributing factor in incidents and accidents in studies such as Sarter[10], and more recently the FAA[11] and CAST[2], it is important to examine the relationship between autopilot mode state (and state transitions) and attention to the FMA.

Figure 11. Identification of FMA on PFD.

Based on the data collected, average FMA reference during the different stages of flight is shown in Figure 12. This figure indicates that on average the PM looked at the FMA slightly more than the PF. Also, the FMA was typically being observed by at least one of the pilots for approximately 12% of the flight. The minimum observed interaction with the FMA over the course of a full flight was approximately 3.5% of the time.

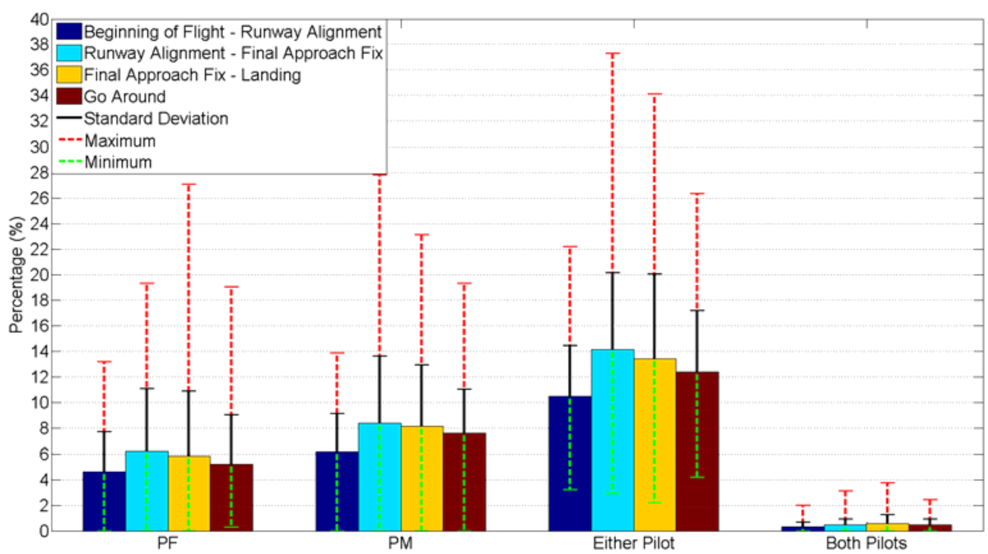

Figure 12. Average FMA usage during different phases of flight.

To better understand typical interactions with the FMA, further analysis was completed on the frequency of reference and the average dwell time. To evaluate frequency of reference, the average amount of time between discrete engagements with the FMA was calculated. The results of this are shown in Figure 13. It is important to note that for this computation, glances (i.e. interactions that lasted 0.25 – 1 seconds) were counted as distinct engagements. This figure depicts that PFs typically engaged the FMA once every 9.5 seconds and a majority of PFs averaged at least one FMA interaction every 12.1 seconds. The PMs' frequency of observation was substantially higher at an average of one engagement every 4.1 seconds and a majority averaged at least one engagement every 6.1 seconds.

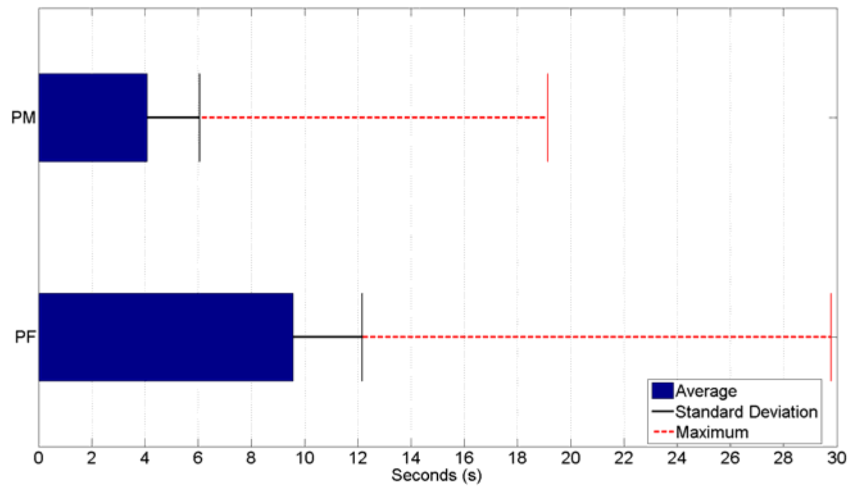

Figure 13. Frequency of FMA reference.

To breakdown the typical durations of interactions with the FMA, dwell time statistics are shown in Figure 14. For both pilots, the average interaction with the FMA lasted for less than 2 seconds and a majority of gazes lasted for less than 3 seconds. Furthermore, FMA engagements lasting longer than 8 seconds were rare, with an occurrence rate statistically beyond 4σ. These occurrences were inspected and attributed to the crew asking PFD/FMA related questions, the PM dictating state information, and AOI calibration errors. Combining these observations with the average FMA engagement shown in Figure 12, and the frequency of reference depicted in Figure 13, it appears that pilots are checking the FMA often, but in short glances. This behavior is expected as there is typically no need to dwell on the FMA for analysis of its data due to the fact that the state information on the FMA is simple to understand, albeit important.

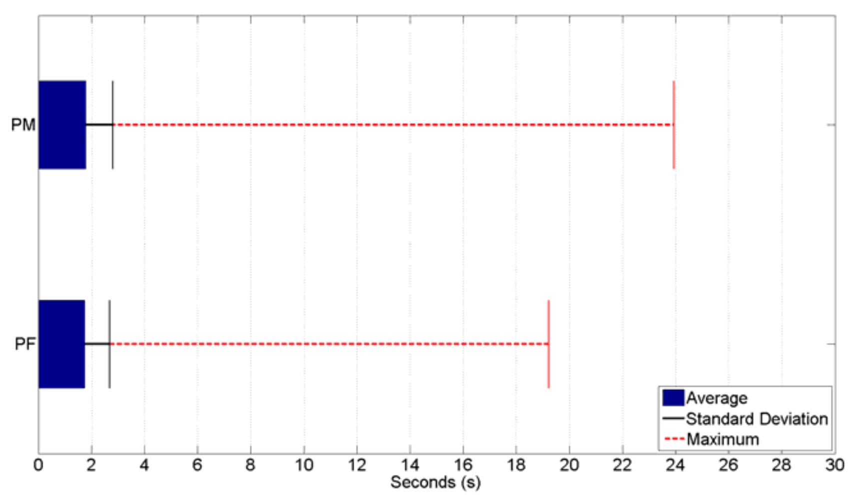

Figure 14. Average dwell time on FMA throughout flights.

To determine the extent to which pilots are observing autopilot mode changes, a comparison was performed between typical FMA references over a full flight versus FMA reference during/following autopilot mode transitions. The results of this comparison are shown in Figure 15 where the period encompassing an autopilot transition was specified to range between the 5 seconds before and after a transition occurred. This data indicates that the FMA was actually referred to slightly less often during autopilot state transitions than during regular flight. Thus, it appears likely that pilots were not witnessing visible transitions on the FMA. In general, this could be a concern as an unnoticed transition could result in a loss of mode awareness; however, in this study there were no significant effects observed in terms of safety of flight. Even with a good practice of including glances at the FMA as part of a diligent scanning pattern, the burden of detecting mode transitions remains dependent on the pilot's memory of the previous state.

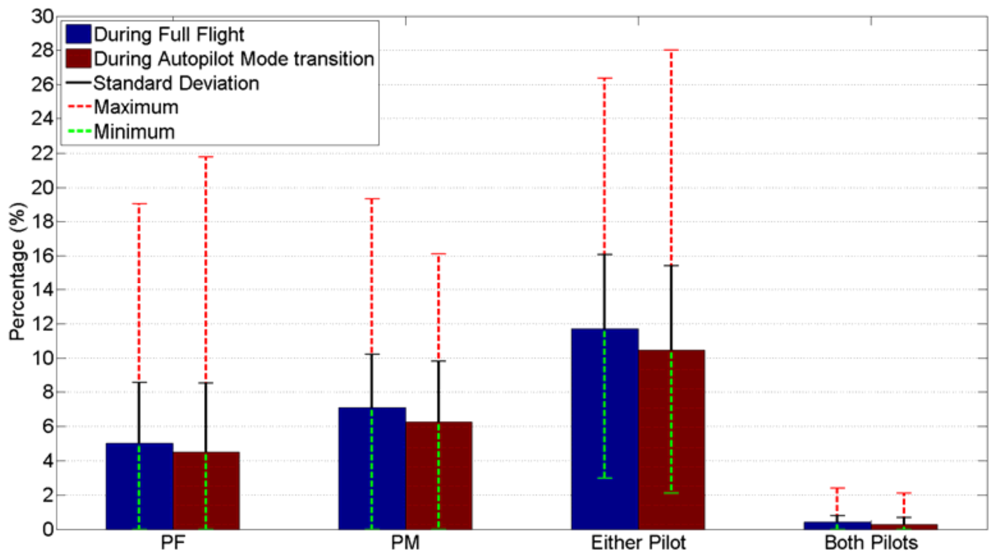

Figure 15. Average FMA usage during autopilot transitions.

D. IB to the Navigation Display During Events with Converging Traffic

Of the 40 different scenarios tested during this study, three were designed to evaluate the effect of complexity involving the ND, and the crew's ability to recognize a hazardous traffic situation by monitoring this display. Each of the three scenarios included converging aircraft ahead of ownship, which was participating in closely-spaced parallel approach operations. Instructions to the crew were to follow a particular aircraft at a specified spacing and no closer than 2 nmi (typically). Each of these scenarios had the intruder converging just after ownship passed the outer marker. The three scenarios were defined as follows:

- Scenario 2-16: Slow convergence after the merge point; emulating an intruder aircraft following the ILS LOC and GS to the wrong (parallel) runway.
- Scenario 2-17: Early convergence near merge point; emulating an intruder aircraft with the wrong runway entered into the FMS.
- Scenario 2-22: Fast convergence after the merge point; emulating an intruder aircraft on parallel approach instigating a go-around in the wrong direction, turning and passing directly in front of ownship.

Figure 16 shows an example of the ND for each of the three scenarios soon after ownship is aligned with the runway at about 4000 feet MSL. In these images, the aircraft to which the red arrow is pointing is the intruding aircraft. The yellow arrow designates the aircraft that the FIM system has designated as the aircraft to follow and upon which the speed cues are based. Ownship is represented as a white chevron at the bottom center of the image.

During these scenarios, a flight was not considered an IB event if the crew noticed the encroaching aircraft by verbal acknowledgement. Of the 28 flights with converging traffic, there were 13 events where neither pilot commented on the intrusion, which led to an assumption of IB. Of these 13 events, 7 resulted in the pilots dealing with conflicts at altitudes under 450 feet (after the aircraft in front had landed), while 6 conflicts went completely unnoticed (uncommented upon throughout the flight) despite loss of separation. The breakdown of each flight containing converging traffic is shown in Table 2.

Figure 16. Examples of ND during each scenario with converging traffic.

During these events, post experiment analysis focused on crew workload. In particular, the question of what the crews were doing while the intruding aircraft moved into ownship's path. Figure 17 shows the average use of the ND over the full flight versus a 30 second window that begins with the initiation of the traffic conflict. From this, it can be observed that ND usage does not notably change in the presence of traffic conflicts with respect to the rest of the flight. This suggests that scan patterns for each pilot were not altered when conflicts were present. Furthermore, it can be seen that at least one of the pilots was engaging the ND during ~27% of the time in which a conflict existed. Therefore, the crew was observing the ND but did not notice the intruder. Likely explanations for these apparent cases of IB are that (a) the crews focus was on some other part of the ND, (b) the conflict was not presented in an effective manner, (c) the pilots were not engaging the ND for long enough periods to do proper analysis, (d) the crew lacked adequate training on interpreting the display, or (e) the crew thought that the intruder was part of the simulation scenario or a "sim-ism". However, all of these lead to an overarching explanation that crews are expecting alerts to off-nominal conditions such as this – something more salient to draw their attention to the situation. Many concepts have been suggested (and even implemented) for detecting traffic blunders such as this, and such alerting could be an effective intervention. However, the apparent IB here may be indicative of an unintended consequence (or manifestation) of added complexity, and implies we may need to add an alerting function to any new indicators or symbols. This has been a growing trend for decades (e.g. bank angle alerting, pitch limit indicators, stall warnings, stick shakers, etc.) and may have led to such an expectation by users.

With respect to the potential circumstance of the crew not examining the ND for long enough durations to perform adequate analysis, examination of average ND dwell times appears to negate this possibility. Figure 18 shows the average dwell time on the ND during periods in which a conflict is present. During these times, average interactions with the ND lasted for 3.5 to 4 seconds. This level of engagement suggests that the pilots were looking at the ND for long enough to analyze and detect potential traffic conflicts.

Regarding the potential of the crew thinking that the intruder was part of a normal simulation scenario, analysis was performed on each of the aforementioned conflict scenarios. Figure 19 depicts the 27 flights with converging traffic with their respective ND usage and a classification of when the conflict was detected. While the sample set is small, the figure does appear to give some credence to the notion that specific scenarios could have been considered "normal" by the pilots, and therefore disregarded. The conflict in Scenario 2.22 went widely unnoticed while nearly every pilot detected the conflict in 2.17. As detection versus unnoticed conflicts was not evenly distributed between each scenario, pilots may have classified specific conflicts as "normal" and therefore, insignificant.

Table 2. Pilot detection and reaction during traffic conflict.

Scenario	Detection	Response
2.16	Detected intruder at beginning of event.	TO/GA triggered at 1900 ft.
	No commentary until traffic was visibly seen on runway.	TO/GA triggered at 380 ft.
	No commentary until traffic was visibly seen on runway.	TO/GA issued by tower at 500 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 2200 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 1400 ft.
	No commentary until traffic was visibly seen on runway.	TO/GA triggered at 420 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 1820 ft.
	No commentary until traffic was visibly seen on runway.	TO/GA triggered at 460 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 700 ft.
	No commentary until traffic was visibly seen on runway.	TO/GA triggered at 440 ft.
	Detected intruder late in event.	Pilots determined it was safe to land.
2.17	Detected intruder at beginning of event.	TO/GA triggered at 1260 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 1960 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 400 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 1960 ft.
	Detected intruder at late in event.	TO/GA triggered at 420 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 460 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 1440 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 1240 ft.
	Detected intruder at beginning of event.	TO/GA triggered at 640 ft.
	No commentary.	Pilots determined it was safe to land.
2.22	No commentary.	None.
	No commentary.	None.
	No commentary.	None.
	Detected intruder at beginning of event.	Cleared to land by tower.
	No commentary.	None.
	No commentary.	None.
	No commentary.	None.

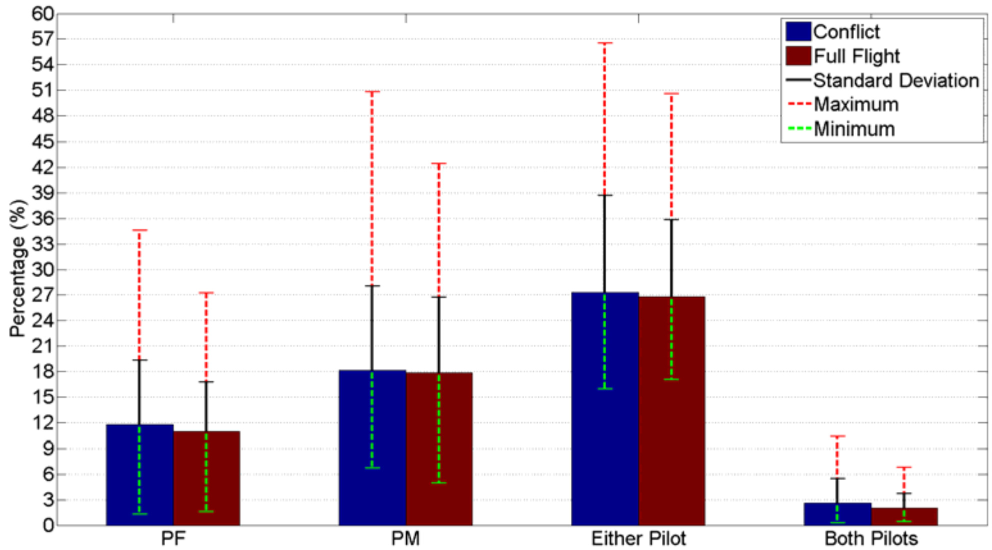

Figure 17. Average ND use during events with converging traffic.

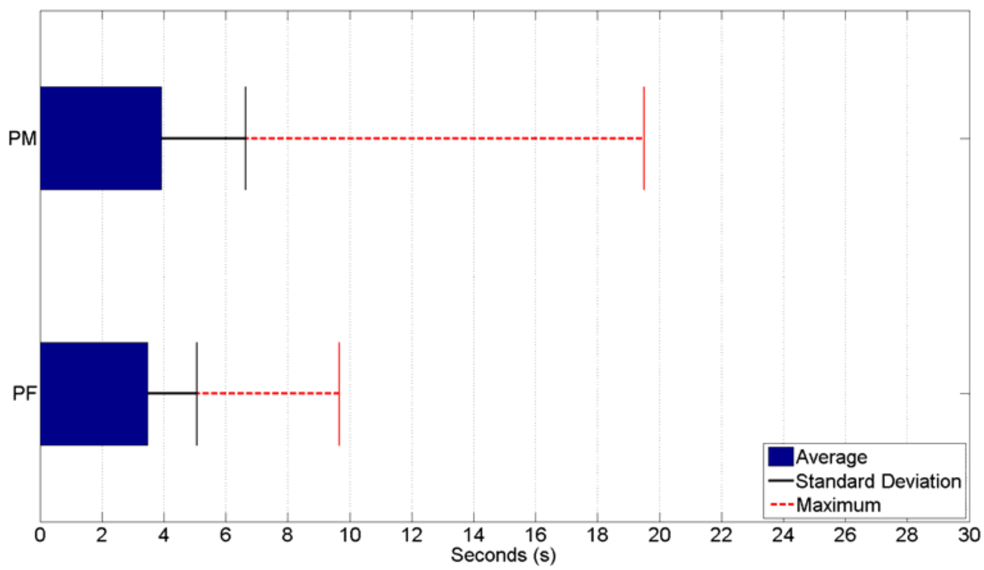

Figure 18. Average dwell time on ND display during events with converging traffic.

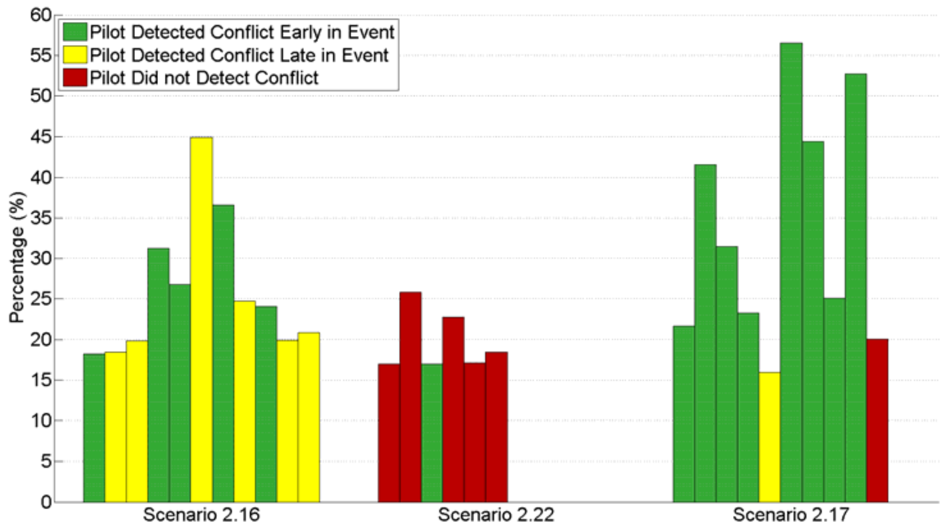

Figure 19. ND display usage with respect to individual events containing IB.

IV. Conclusions

The analysis of eye-tracking data presented in this paper is intended to help understand what pilots tend to focus their attention on and the affect that complexity can have on this tendency. While no absolute conclusions can be made from a single study, the following general observations can be made based on the evidence presented:

- Pilots found the EFB functionality used in this study useful, and the amount of time visually attending to the EFB seemed appropriate.
- During autopilot mode transitions, pilots were not monitoring the FMA any more than during periods where there were no transitions. This suggest that pilots could easily miss an autopilot mode transition, not notice that it occurred, and therefore, experience a loss of mode awareness. Given the potential risks associated with this, there may be a need for more salient notifications of transitions.
- When pilots were presented with converging traffic scenarios, a large number of events resulted in inattentional blindness; even though pilots were monitoring traffic on the ND, they did not "see" the loss of separation. Although many explanations are valid and fixes can be conceived, this finding may point to a more insidious consequence of complexity, and more evidence that we may be reaching a limit on content for effective visual scanning and monitoring in flight.

Acknowledgments

The authors would like to thank the following individuals who were key contributors to the design and execution of the 2013 simulation experiment: Capt. Daniel Kiggins (American Airlines), First Officer Marc Henegar (Alaska Airlines and ALPA), Tim Etherington (Rockwell-Collins, Inc.), Mike Norman (Boeing), and Kathryn Hoekstra (FAA). In addition, thanks to NASA LaRC's simulation development team, led by Victoria Chung and James Barnes, for their creativity and dedication.

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