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AN EMPIRICAL TEST OF AN ENHANCED AIRSPEED INDICATOR

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Analysis of airliner accidents and incidents identified a class of events in which structurally, mechanically, and electronically sound aircraft decelerated through the minimum safe operating speed to the stick-shaker activation speed. For a subset of these events the automation was *no longer actively controlling to the airspeed target*, a condition which the Primary Flight Display does not explicitly indicate. Increasing the salience of critical automation information may enhance the ability of the flight crew to detect, recognize, and diagnose when an aircraft will inappropriately decelerate, prior to a speed deviation. In the current study, we designed and tested a modification of the airspeed tape on the Primary Flight Display to explicitly annunciate the absence of active speed control. Our experiment showed that professional pilots were faster at recognizing an airspeed anomaly when using the Enhanced Airspeed Indicator as compared to the traditional air speed tape. No speed/accuracy trade-off was observed.

Modern properly functioning fully-automated airliners should not inadvertently stall. But they do. Sherry & Mauro (2014) examined 19 incidents in which mechanically and electrically sound airliners decelerated through minimum safe operating speed to stick shaker activation (5 knots above stall speed). Analysis of these events revealed that the automation was not actively controlling airspeed. In some cases, inadvertent auto-throttle (A/T) deactivation caused the airspeed target to be neglected. In several other cases, circumstances caused the automation to transition into an unexpected A/T "dormant" mode in which airspeed was not controlled. In all of these cases, the crews failed to respond in a timely manner. Typically, the events occurred while the aircraft was properly decelerating, thereby masking the inappropriate behavior of the autoflight system. These incidents of "controlled flight into stall" demonstrate two problems in the flightdeck "human-machine system." First, there is no clear indication on the flightdeck that the automation is or is not controlling airspeed. Second, pilots frequently do not fully understand the operation of their autoflight systems (Sarter & Woods, 1995). In this paper, we focus on the task of increasing the salience of automation control of airspeed (or lack thereof).

Airspeed is typically displayed on the Primary Flight Display (PFD) on nearly all modern airliners. The PFD collocates, on a single screen, indicators that were previously separate, thus allowing the pilot to obtain data about the orientation and status of the aircraft with very little eye movement. However, the PFD symbology in common use can be misleading. Airspeed is displayed on a moving "tape" on the left-hand side of the PFD (see Figure 1). The target airspeed is displayed above the tape and marked by a "bug" on the tape when that speed is within the range displayed on the tape. Current speed is displayed in a window superimposed on the tape.

This display does not indicate whether the automation is attempting to achieve the airspeed target. It only indicates that the target has been set.

To determine the state of the automation, the pilot must read and interpret the indications on the Flight Mode Annunciator (FMA) displayed at the top of the PFD (see Figure 1). Automation states are indicated by cryptic abbreviations. Changes in mode are indicated by blinking text for a few seconds. In some incidents and accidents, pilots have evidently misinterpreted the FMA abbreviations (e.g., Asiana 214, TA 1951). FMA labels are often ambiguous or overloaded (Feary, McCrobie, Alkin, Sherry, Polson, Palmer, & McQuinn, 1998) and automation control mode changes are not explicitly annunciated (Sherry, Mauro, & Trippe, 2019). Studies indicate that flight crews do not use the FMA as intended (Feary, et al., 1998; Norman, 1990, Degani, Shafto, & Kirlik, 1999). One eye-tracking study found that 62% of the pilots observed did not rely on the FMA during anticipated mode changes and 45% of the pilots did not refer to the FMA after an unanticipated change (Mumaw, Sarter, & Wickens, 2001).

Figure 1. Boeing 777 Primary Flight Display.

In this study, we examined whether pilots' abilities to determine what aspect of the autoflight system (if any) was in control of the airspeed could be improved by making small changes in the color coding and text used on the display.

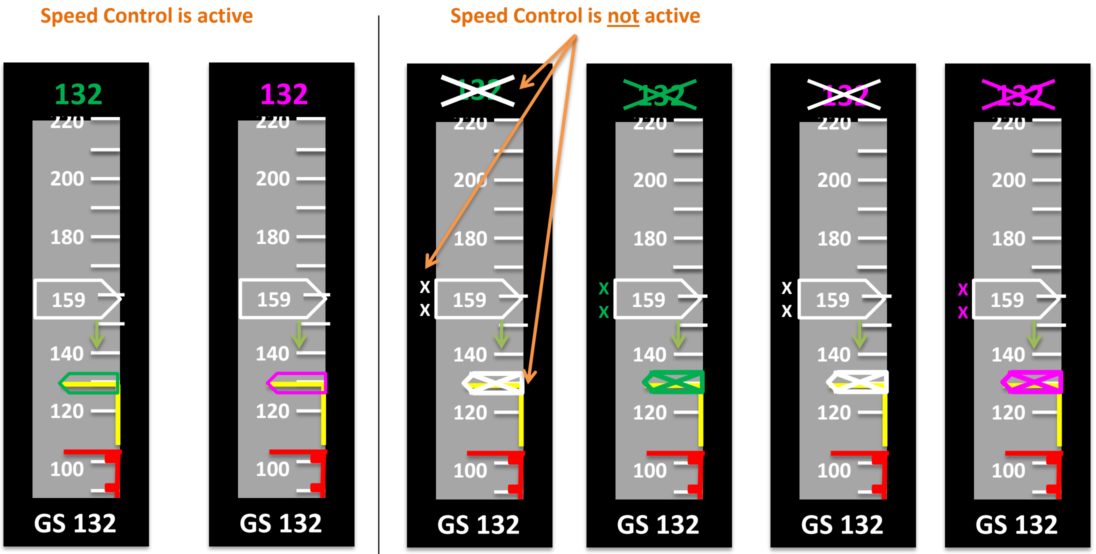
Method

Enhanced PFD design

Our goal was to design simple, relatively low-cost modifications to the existing PFD design that would substantially improve pilots' ability to determine whether the automation was in control of the aircraft's airspeed. We defined certain parameters based on previous cognitive research. Our design required explicitly indicating, in a highly salient and unambiguous manner, the current state of airspeed control. At minimum, this design needed to indicate who/what was controlling the airspeed (i.e. AFS or manual control) and what component of the system was setting the target (i.e. Mode Control Panel (MCP), Flight Management System (FMS), or none).

The design had to be easily interpretable without necessitating access to memorized rules. We also determined that it was more important for pilots to understand the need for intervention than to understand why. As noted by Vicente and Rasmussen (1988), relying on skill-based behavior rather than having to access rule-based or knowledge-based behavior could save valuable cognitive resources and time.

In addition, given the "limited real estate" of the already densely populated PFD, any modifications would have to be crafted so as not to interfere with other flight information. We determined that the most effective solution would be to locate our changes in the same place that pilots were already looking for airspeed target and control information: the middle third of the airspeed tape, using target source colors consistent with all flight deck displays (magenta = FMS, green = MCP, white = manual). Collocating this new layer of information with familiar indications would also serve to alert crews to the fact that it could not be interpreted as usual. We chose to visually block inactive target indications with Xs so that they would not be relied upon automatically (see Figure 2). Target source is indicated by the color of the target number (at top of tape) and target "bug" (on the tape). Control is indicated by color and Xs. If targets are magenta with no Xs, the AFS is controlling the airspeed to FMS targets. If the targets are green with no Xs, the AFS is controlling the airspeed to MCP targets. If the targets are X'd out, then the AFS is not controlling airspeed. Appropriately color-coded targets are visible under Xs to indicate what they would be if automation were reengaged.



Speed Control Active		Speed Control **not** Active			
A/P and A/T Engaged		A/P or A/T **not** Engaged	A/P or A/T Engaged	A/P or A/T **not** Engaged	A/P or A/T Engaged
VNAV not Engaged	VNAV Engaged	VNAV not Engaged		VNAV Engaged	
Mode controlling to Airspeed		-	Mode **not** controlling to Airspeed	-	Mode **not** controlling to Airspeed

Figure 2. Enhanced PFD Airspeed tape with explicit indication of the absence of airspeed due to engagement status or control mode. Targets and bugs X'd out and appropriately source colored.

Study design

To test the proposed Enhanced PFD, we created an online study depicting the above enhancements overlaid on a traditional Boeing 777 PFD. We then recruited 31 Boeing pilots, currently working in the 777 (12 participants), 737 (12 participants), or 767, 757 or 747 (total of 7 participants) with an average flight time of 11,733 hours (SD: 4,740).

Participating pilots were shown a series of 24 flight scenarios. Each scenario was composed of a set of 3-4 still frame “slides” depicting chronological “snap shots” of either a traditional PFD or an enhanced PFD as it would have looked at sequential time periods during a particular flight maneuver (e.g., departure, descent, localizer intercept, approach). All of the flight scenarios began with the auto-throttle in control of the airspeed. For each flight scenario, they were first shown a brief written description of the scenario along with ATC-like instructions in italics that described what would happen in the upcoming slides. For example:

VS Descent to GS (3 slides)
Inbound on LOC to KORD RWY 14R
Maintain 4000
Cleared ILS 14R

If the scenario placed the pilot’s aircraft on an approach, the participants were also shown an approach plate with the approximate vertical and lateral position of the aircraft indicated. After the description slide, there were 3 or 4 slides depicting the aircraft’s PFD at advancing time points in the flight. The pilots were allowed to control the speed with which they viewed these slides. Before the last slide in the scenario was shown, an instruction slide appeared indicating that the next slide would be the final slide and reminding the pilot of the instructions which were: “As soon as the final PFD slide in the scenario appears, please tell us as fast as possible without making mistakes whether or not there is a deviation from the intended airspeed and/or flight path. Press the "y" key for “yes, there is a problem” or the "n" key for “no, there is no problem. This slide will advance automatically after your selection.”

The pilot’s reaction time from the time that the last slide was presented until a key was pressed was recorded. Twelve scenarios depicted a normal operation and 12 scenarios depicted a problem. Two sets of 24 scenarios were produced, set “A” and set “B.” For half of the pilots, set A scenarios were depicted on a traditional PFD and set B scenarios were depicted on an enhanced PFD. For the other half of the pilots, the relation between sets and PFD type were reversed. The order of presentation was counterbalanced by PFD type.

Results

Thirty-one pilots participated in the experiment. As expected given the design and the experience level of the pilots, the pilots made very few errors. The proportion of incorrect responses did not differ by type of PFD (Traditional PFD: 10.8%, Enhanced PFD: 8.9%; X2(1)=0.703, n.s.). For 17 scenarios there was no difference in speed of responses due to type of PFD. One scenario was incorrectly presented. For 6 scenarios there was a statistically significant difference. In all of these cases, pilots were faster to respond when the scenario was presented using the enhanced PFD (see Table 1). The mean reaction time difference for these scenarios was 10.0 seconds less for the enhanced PFD, with a mean standard deviation of 6.04 seconds.

Table 1.
Significant Effect of PFD Type on Mean Log(Speed) of Correct Responses by Scenario

		Mean Reaction Time (milliseconds)		**Mean Ln(Speed)**				
		PFD Type		**PFD Type**				
Scn #	**Problem**	**Traditional**	**Enhanced**	**Traditional**	**Enhanced**	**t**	**df**	**p**
13,14	N	9416	6259	.16	.61	2.277	25	.032
15,16	N	10963	7595	-.02	.48	2.327	26	.028
17,18	N	10642	6936	.04	.51	2.404	29	.023
23,24	N	12348	7901	-.10	.47	2.263	22	.034
41,42	Y	6744	3443	.60	1.33	2.549	28	.017
45,46	Y	9965	4131	.16	1.06	3.877	26	.001

Note: Reaction times are in milliseconds. To stabilize distributions for analysis, reaction times were converted into Ln(Speed)=Ln((1/RT)*10000). Higher ln(speed) corresponds with lower reaction times. t=2-sided independent sample t-test value; df=degrees of freedom, p=probability.

Discussion

In this study we did not attempt to load the pilots or to distract them with mechanical failures or operational issues of the sorts that populate accident reports. All that the pilots needed to do was to view the PFD and determine whether the display indicated that there was a deviation from the expected path in altitude or airspeed. As would be expected, the participants, all of whom were experienced pilots, made very few errors reading their PFDs. Had many errors been observed, we would have questioned the fidelity of the study. Experienced pilots do not make many errors on such routine tasks.

To determine whether the modifications to the PFD would have any effects, we used reaction time, a measure that is much more sensitive than error rates. On most scenarios the participants were equally fast at responding to the scenarios regardless of PFD type. However, whenever there was a statistically reliable difference in speed of response, pilots were faster to respond correctly when they were using the enhanced PFD whether or not there was a problem. This pattern of results indicates that the modifications caused no problems and caused a measurable increase in performance.

The PFD modifications used in this study were designed to rely solely on relatively minor software changes to existing PFDs. Although it may be possible to achieve increased performance from other more elaborate modifications, our aim was to devise simple modifications that could be retrofitted to existing equipment at relatively minor development, certification, and implementation costs. Using this simple, easily implemented PFD enhancement that could be adapted for any platform, there was a measurable increase in pilot performance responding correctly to unexpected automation behavior. The scenarios used in this study reflected real world incidents that could easily end in catastrophes. The clear indications of lack of automated airspeed control allowed a fast skill-level response. In a time sensitive, safety critical environment, a few seconds could mean the difference between landing safely and crashing.

To be confident in the effectiveness of the modifications that we developed, the enhanced PFD used here should be compared to traditional PFDs in a flight simulator using pilots flying scenarios that tax the pilots' abilities as they are frequently taxed in actual operations and abnormal situations. If the enhanced PFD continues to demonstrate superior performance compared to traditional PFDs under these conditions, we would have greater confidence in the wisdom of making the investments required to develop, certify, and modify the PFD in existing airliners.

References

Degani, A., Shafto, M., & Kirlik, A. (1999). Modes in human-machine Systems: Constructs, representation, and classification. *International Journal of Aviation Psychology*, *9,* 125-138. Vertical Guidance Understanding. NASA/TMm1998-112217

Mumaw, R.J., Sarter, N.B., and Wickens, C.D. (2001): Analysis of Pilots´ Monitoring and Performance on an Automated Flight Deck. 11th International Symposium in Aviation Psychology. Columbus: Ohio State University.

Norman, D. A. (1990). The 'problem' with automation: inappropriate feedback and interaction, not 'over-automation.' *Philosophical Transactions of the Royal Society B: Biological Sciences*, *327*(1241), 585-593.

Sarter, N. B., & Woods, D. D. (1995). How in the world did I ever get into that mode? Mode error and awareness in supervisory control. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *37*(1), 5-19.

Sherry, L. R. Mauro (2014) Controlled Flight into Stall (CFIS): Functional Complexity Failures and Automation Surprises. 2014 Integrated Communications Navigation and Surveillance (ICNS) Conference, April 8-10, 2014

Sherry, L., Mauro, R., & Trippe, J. (2019). Design of a primary flight display (PFD) to avoid controlled flight into stall. Aviation Psychology and Applied Human Factors.

Vicente, K. J., & Rasmussen, J. (1988). On Applying the Skills, Rules, Knowledge Framework to Interface Design. *Proceedings of the Human Factors Society Annual Meeting*, *32*(5), 254–258.

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