A New Interface to Cope With Unreliable Airspeed Indications

A Behavioral and Eye-Tracking Study

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Abstract: When unreliable airspeed events occur, the pilot flying (PF) is required to fly the aircraft using the thrust and the pitch parameters that are displayed in two distanced locations of the flight deck. The Sycopaero interface was designed to limit the PF's workload by automatically displaying thrust and pitch values specific to aircraft configuration on the primary flight display. Participants performed a simulated flight scenario in which they lost airspeed information during take-off with and without the Sycopaero interface. Both behavioral and ocular results demonstrate that the Sycopaero interface significantly lowers the mental workload of PFs and improves their monitoring performance. Taken together, these results suggest that the Sycopaero interface may be a suitable solution to safely handle airspeed failures.

Keywords: Sycopaero, unreliable airspeed event, aviation, workload, pilot flying

Over the past few decades, the automatization and complexity of aircraft have increased drastically (Lee, 2006). While this evolution helped significantly improve air safety (Boeing, 2012), it also led to the emergence of new types of accidents linked to breakdowns in human–automation coordination, where pilots lack knowledge and have trouble understanding the current and future state of automation (e.g., Dehais et al., 2015; Parasuraman & Manzey, 2010; Sarter et al., 2007), as it sometimes happens when an unreliable airspeed event (UAE) occurs (Silva & Nicholson, 2012).

Most of the time, UAEs translate into abnormally large Mach number or indicated airspeed fluctuations and differences between the indications for the two pilots. In the worst-case scenario, all pitot probes are affected at the same time, which makes the detection of the failure more difficult as the information between the sources seems consistent. Abnormal behavior of the autothrust and/or the autopilot can also be observed (e.g., disconnection), which triggers a reversion of the flight control laws resulting in a lower flight envelope protection compared to a nominal flight situation. As a failure of the autopilot and/or the autothrust can trigger a total loss of control of the aircraft, UAEs have to be quickly detected and properly handled (BEA, 2012; Silva & Nicholson, 2012).

When the pilots detect a UAE, the pilot flying (PF) is required to disconnect the autothrust, the autopilot, and the flight directors, resulting in a decreased automation level. The PF also has to manually adjust the thrust and the pitch of the aircraft according to predefined settings that can be found in the flight crew operating manual and are usually provided by the pilot monitoring (BEA, 2012). In Airbus 320 aircraft, the thrust information (N1) is displayed in the electronic centralized aircraft monitor (ECAM) located in the middle of the flight desk, while the pitch of the aircraft is displayed in the primary flight display (PFD) located in front of the pilots. UAEs were found to significantly increase airline pilots' stress, both because they feel less protected due to the sudden drop in automation and because they are not always able to understand what is happening (BEA, 2012). They also trigger a sudden increase in workload, due to (1) the effort associated with the understanding of the failure and (2) the operation of the aircraft in degraded conditions (e.g., the recovery procedure and the repeated switch of attention between the ECAM and the PFD; Fitts et al., 1949; BEA, 2012). Workload and stress are likely to affect the pilots' cognitive skills, to undermine their reasoning and piloting performances; and therefore to negatively affect flight safety (Goode, 2003; Sarter et al., 1997). Even though the airspeed failure is properly handled by the pilots, the increased workload and stress associated with the operation of the aircraft in degraded conditions are likely to trigger fatigue in the mid and long term and substantially increase the risk of action selection errors and execution errors (Silva & Nicholson, 2012), which are the main causes of accident in these conditions (e.g., BEA, 2012; DGAC, 1996; DGATP, 1996; NTSB, 1975; Wiegmann & Shappell, 2017).

While one's first reaction may be to blame the pilots for not always being able to handle UAEs, it is important to ask the question as to the extent to which an appropriate interface could have supported the pilots in these very stressful and hazardous conditions and prevented these terrible accidents (Silva & Nicholson, 2012). The lesson to be learned from these accidents is that the human operator is not always considered as being part of the overall system when designing automated systems, thus, these problems are the result of a failure to design for a coordinated team effort across human and machine agents as one cooperative system (Sarter et al., 1997). Instead, the human operator is considered as a providential who will take over when automation fails (Gateau et al., 2016). Unfortunately, the technological response to these accidents often consists in implementing even more automation rather than improving the integration of the human in the control and decision loop (Billings, 1996; Chialastri, 2012). However, in the case of unreliable airspeed indication, human-centered solutions could be designed and based on basic flying procedures that are taught to pilots from their ab initio training.

In reaction to the accident of Air France Flight 447 (BEA, 2012), Airbus developed a system called "Back-Up Speed Scale" (BUSS©) designed to cope with the potential danger of UAEs. The BUSS© consists of displaying speed information based on the angle of attack as a function of the slat/flap configuration. While this system was recently found to be useful to handle UAEs (ATSB, 2018), the EASA still advises against its use above flight level 250 and recommends referring to the pitch and thrust tables in case of strong turbulence (EASA, 2018a). Moreover, the BUSS© was found to be likely to display erroneous information when two angle-of-attack sensors are affected by icing conditions at the same time, making its use potentially dangerous in these specific conditions (EASA, 2018a). A simpler and more reliable solution may be to display the thrust and pitch values presented in the flight manual directly into the PFD, as a function of the altitude, the weight, the flight phase, and the configuration of both flaps and slats of the aircraft.

The present study aimed at evaluating the impact of the Sycopaero interface on PFs in the occurrence of an identified UAE. This interface consisted of displaying both the pitch and the thrust indications corresponding to the four flight configurations (i.e., TOGA for Take Off/Go-Around, climb, level off, and descent/final approach) into the PFD to facilitate both the monitoring and the aircraft operation. Participants had to perform a simulated flight scenario as PF (in which the airspeed information was lost in a collision with birds during take-off, forcing them to return to the departure airport) with (i.e., Sycopaero scenario) and without (i.e., control scenario) [the Sycopaero interface]. The subjective mental workload of the participants was assessed in each scenario using the NASA-TLX questionnaire (Hart, 2006). The mean speed and the speed variations were measured in both scenarios. Participants' ocular activity was also measured with a remote eye-tracker set up in the flight simulator. This technique is particularly suited to investigate the attentional processes of the operators (Helleberg & Wickens, 2003; Peysakhovich et al., 2018), as it provides objective and quantitative evidence of the user's visual and (overt) attentional processes reflecting their mental processes (Duchowski, 2002). Consequently, it appeared to be the most suitable technique for assessing the extent to which the Sycopaero interface modulates the attentional processes of the PFs. We predicted that the loss of reliable airspeed would be associated with a lower perceived mental demand and lower speed variability in the Sycopaero flight scenario than in the control scenario. We also predicted that the participants would spend less time monitoring the thrust information using the ECAM indicator (N1) and retrieve this information from the thrust indicator duplicated in the PFD (N1d). Consequently, we expected to observe, respectively, an increase and a decrease in dwell time percentages for the N1d and the ECAM. Furthermore, we also expected to observe a decrease in transition rate between the attitude indicator (AI) and the N1d and a decrease in transition rates between the AI and the ECAM.

Method

Participants

A total of 20 professional pilots (11, five, and four pilots operating, respectively, Airbus, Boeing and ATR/MEP aircraft); and two student pilots (Pilatus PC-12) who completed their training the same week took part in this study (22 males; age: *M* = 34.67 years, *SD* = 9.21). Overall, 13 had an Airline Transport Pilot License and the remaining nine had a Commercial Pilot License (flight hours: *M* = 4,328, *SD* = 3,052). They all had a previous experience in an Airbus simulator. They were recruited via advertisement and received no financial compensation for their participation. All had a normal or corrected-to-normal vision. None of them reported a prior history of neurological disorder.

Ethics Statement

All participants were informed of their rights and gave written informed consent for participation in the study

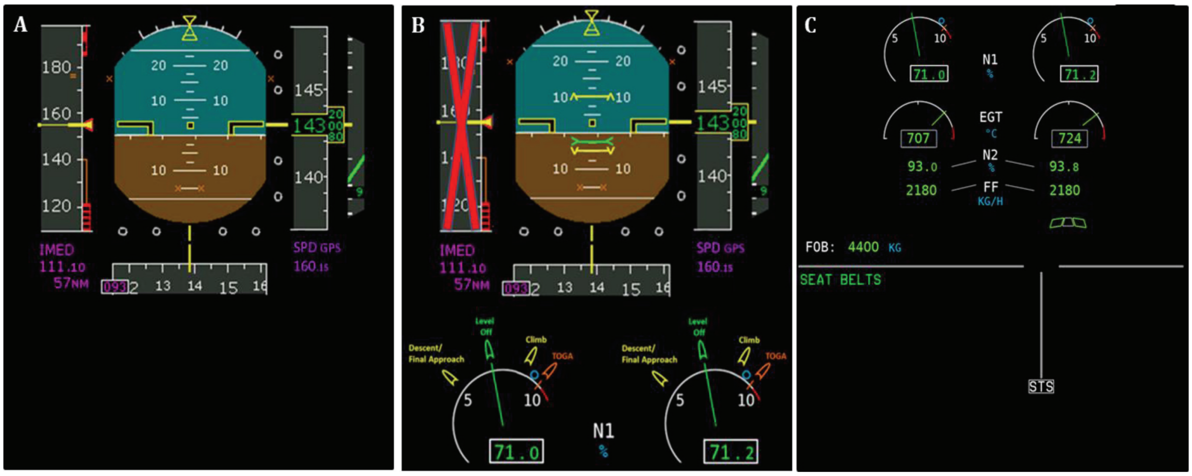


Figure 1. Illustrations of the PFD in (A) the control scenario and (B) the Sycopaero scenario. In the Sycopaero scenario, the airspeed indicator was crossed out to indicate that the airspeed was unreliable and the thrust indicator was duplicated at the bottom of the PDF (N1d) to facilitate the joint monitoring of the thrust and the attitude. (C) Illustration of the ECAM in both scenarios.

according to the Helsinki Declaration. The experimental protocol was reviewed and approved by a regional ethics committee (CERNI no. 2018-108).

Material

Interfaces

In this experiment, we compared the performances of the participants in a flight scenario performed with the Sycopaero interface (Figure 1B) with the performances in the same flight with the interface that is currently displayed when an unreliable speed event occurs (i.e., control interface; Figure 1A). The Sycopaero interface consisted of displaying the pitch and the thrust values for the climb, cruise (i.e., level off), descent, and approach phases as a function of the current aircraft, flap/slat configuration, landing gear configuration, and estimated weight of the aircraft (see Figure 1B). The pitch values are symbolized by three colored lines with two arrowheads at their extremities and displayed directly on the PFD: The pitch value of the level-off is a green line with the arrowheads pointing to the center of the line, while the climb and the descent pitch values are yellow lines with the arrowheads pointing up and down, respectively. The pitch value of TOGA was not displayed as pilots know this value by heart. The thrust information (N1) is displayed on the ECAM (see Figure 1C). As the latter is quite far from the PFD (see Figure 3), we decided to duplicate the N1 (i.e., N1d) and to place it directly into the PFD in order to minimize the workload associated with monitoring (i.e., only one area to monitor instead of two). Four notches were placed around the half-circles representing the thrust in the N1d (see Figure 1B). The color code of the notches is the same as the pitch value lines: The notch representing the cruise thrust value is colored in green, the notches representing the thrust values of descent and climb are colored in yellow, and the notch representing the TOGA thrust value is colored in amber. The color code recommended by the EASA (2018b; see Part 25.1321) and the FAA (2010; see Part 25.1322) for flight deck design was applied. Yellow and amber inks were used to indicate marginal conditions or to alert of situations where caution, recheck, or unexpected delay is necessary. Green was used to indicate that monitored equipment/processes are within tolerance or a condition is satisfactory and that it is all right to proceed with an operation or transaction. Finally, the airspeed indicator was crossed out in order to prevent the pilots from consulting it. The design process is described in detail in the Electronic Supplementary Material, ESM 1.

Flight Simulator

The experiment was conducted in a simplified A320 flight simulator called Pegase at ISAE-Supaero in France.

Eye Tracker

A Smart Eye Pro (Smart Eye AB, Gothenburg, Sweden) remote eye-tracking system, with a 60-Hz sampling rate and five-camera set-up with two IR flash illuminators was used in the present study. Eleven points were used for calibration.

Procedure

After they gave their written consent, participants were handed a booklet describing four different new interfaces/warning systems. Only one of them was the Sycopaero

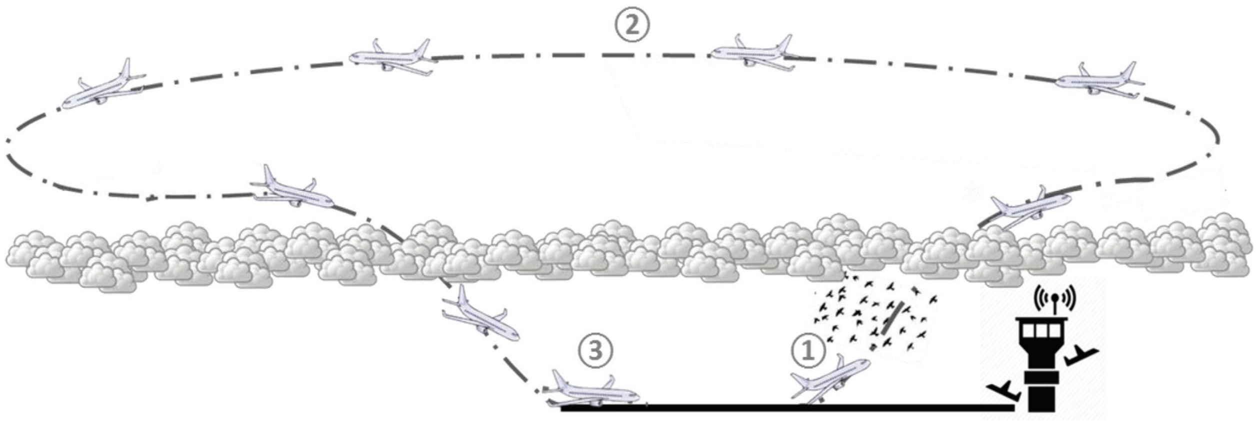


Figure 2. Illustration of the flight scenario with ① the bird-strike following take-off, ② go-around at 3,000 feet, and ③ touch-down.

interface that was going to be tested during the experiment. The three remaining interfaces/systems were fictional (see ESM 1) and were presented to the participants in order to prevent them from predicting the failure they would have to handle during the experiment. Participants took the left seat of the PEGASE flight simulator. They were then asked to perform one landing procedure and one take-off procedure to become acquainted with the PEGASE flight simulator. Once they felt at ease, the eye-tracker was calibrated. Participants were asked to look at the 11 different calibration points located around the flight deck and the exterior. Each participant was calibrated to reach an overall accuracy of at least 1.5°. This level of accuracy ensured a sufficient level of precision to detect the subparts of the PFD (13° × 17°) with: the speed and altitude indicators (3.5° × 10°), the AI (6° × 10°), and the N1d area (i.e., the lower part of the PFD; 5° × 13°). Once the calibration was completed, the experiment started. Just after take-off, participants who performed the flight as PF heard a loud noise. The experimenter who served as a "pseudo" pilot monitoring, informed participants that the aircraft had just collided with birds, which resulted in the destruction of all pitot probes (see Figure 2). Then the former provided participants with the thrust and the pitch values to be applied (which could also be retrieved in the flight crew operating manual) and informed them that (1) they had been cleared by the ATC to perform a go-around procedure and to land on the same runway they took off and that (2) no other aircraft was present in the area in which they were operating the aircraft. They had to perform a go-around procedure at an altitude of 3,000 feet to return to the departure airport and land on the same runway they took off from. A thick cloud layer between 1,000 and 2,000 feet prevented the pilots from flying by sight, forcing them to rely on the flight instruments only. Participants had to perform this flight scenario twice: once with the Sycopaero interface (i.e., Sycopaero scenario) and once with the control interface (i.e., control scenario). Half of the participants started the experiment with the Sycopaero scenario, while the other half started with the control scenario.

In the control scenario, participants had to perform the rest of the flight with the basic instrumentation found in Airbus aircraft (i.e., the BUSS© was not part of the instrumentation), while in the Sycopaero scenario, the thrust and pitch values were directly displayed into the PFD (see Figure 1B). Participants' ocular activity was recorded in both scenarios. After each flight scenario, participants filled out the NASA-TLX questionnaire aimed at evaluating the subjective mental demand (Hart, 2006). At the end of the experiment, participants were debriefed and asked to give their views on the interface and how they thought it could be improved.

Results

Behavioral Results

Speed Variations

The speed of the aircraft and the standard deviations of the speed were measured in both scenarios from the moment the aircraft took off to the moment it touched the runway for landing. After ensuring that the data were normally distributed, two two-tailed paired Student t tests were conducted on the mean speeds and the standard deviations of the speed measured in the Sycopaero scenario and the control scenario. The analysis revealed no significant differences in mean speed, $t(21) = .20$, $p = .84$, $d = .05$; control scenario: $M = 148.93$ knots, $SD = 9.22$; Sycopaero scenario: $M = 149.40$ knots, $SD = 8.24$, or in speed standard deviation, $t(21) = -.48$, $p = .63$, $d = .06$; control scenario:

Table 1. Means and standard deviations of the NASA-TLX

	Control		Sycopaero	
NASA-TLX	*M*	*SD*	*M*	*SD*
Total	47.00	21.32	32.23	13.07
Mental demand	10.41	4.11	6.73	3.13
Physical demand	6.45	3.90	5.09	3.28
Temporal demand	5.50	4.82	4.81	2.86
Performance	6.05	2.80	4.95	3.60
Effort	10.82	4.49	7.55	4.57
Frustration	5.77	4.23	3.09	2.24

M = 9.74 knots, SD = 5.45; Sycopaero scenario: M = 9.21 knots, SD = 4.31.

NASA-TLX

Two-tailed paired Student t tests and Wilcoxon signed-rank tests were conducted on the raw NASA-TLX data when the latter were, respectively, normally and nonnormally distributed. For clarity, the means and standard deviations are reported in Table 1. Overall, the analysis revealed a significant decrease in perceived workload when the scenario was performed with the Sycopaero interface, $t(21) = 4.17$, $p < .001$, $d = .79$, than with the control interface.

The analysis of the NASA-TLX sub-scales revealed lower perceived mental demand, $t(21) = 5.30$, $p < .001$, $d = .92$, physical demand, $t(21) = 2.81$, $p < .05$, $d = .28$, effort, $t(21) = 4.46$, $p < .001$, $d = .67$, and frustration, $T = 15$, $z = -2.564$, $p < .05$, in the Sycopaero scenario than in the control scenario. No significant differences were found in perceived temporal demand, $T = 44$, $z = -1.248$, $p = .212$, and perceived performance, $T = 62$, $z = -1.620$, $p = .105$, (see Figure 3).

Postexperimental Debriefing

During the debriefing, all 22 participants reported that the interface was very natural to use, well-designed, and that it made them feel safer in this very stressful situation. All reported that they thought crossing-out the airspeed indicator was a good idea, because it helped them remember that this information – they are used to monitor continuously – was no longer valid, which lowered their cognitive charge. Except for one pilot who declared that he had some difficulty adapting to the N1d, the remaining 21 pilots reported that duplicating the N1 in the PFD made the monitoring easier and lessened their workload. They were pleased that the N1 was not removed from the ECAM when the Sycopaero interface appeared. They found it reassuring that the Sycopaero interface did not upset their routine, allowing them to continue monitoring the thrust in the ECAM if they wished to.

Oculometric Results

Dwell Times

In order to compare the ocular activity of the pilots during the two versions of the flight scenario, six areas of interest (AOIs) were created (see Figure 4). They corresponded to the main flight instruments: the ECAM, the navigator display (ND), the flight control unit (FCU), and the exterior (EXT). As the introduction of the Sycopaero interface had modified the PFD, we divided the PFD into two separate areas: one area corresponding to the Sycopaero interface (SYC) comprising the N1d and the AI in the center of the PFD, and an area comprising the remaining parts of the PFD (PFDr).

The dwell time percentages to the six AOIs and the area of "non-interest" (i.e., the area regrouping the zones of the

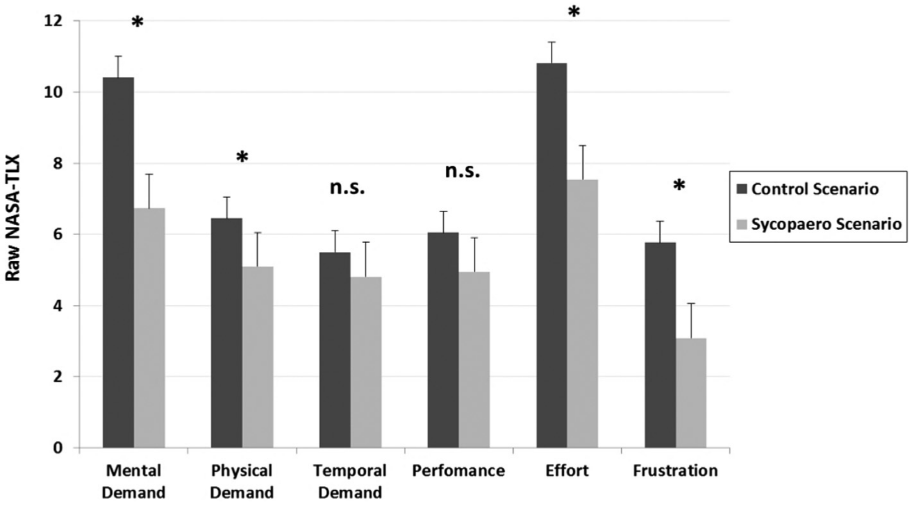


Figure 3. Illustration of the raw NASA-TLX subscales for the control scenario (dark gray) and the Sycopaero scenario (light gray).

Figure 4. Illustration of the PEGASE flight deck with the six areas of interest.

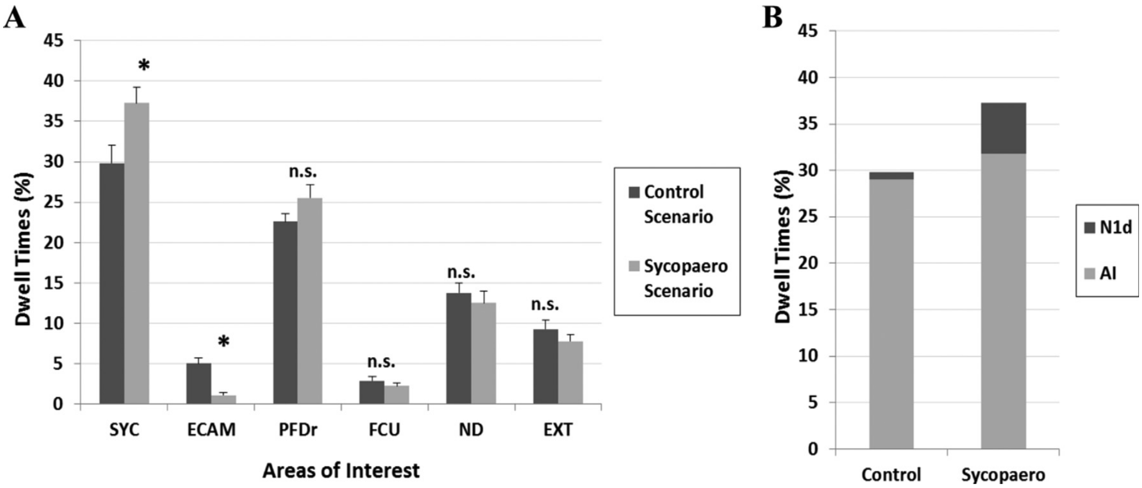
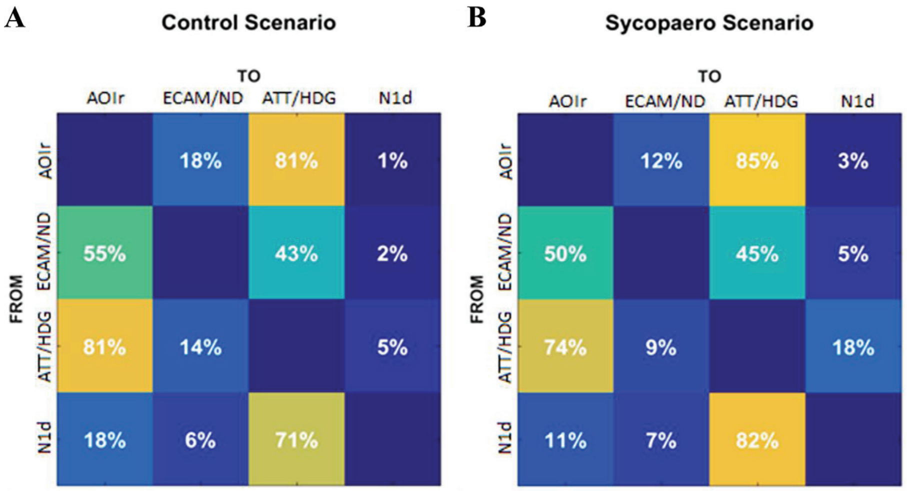


Figure 5. Illustrations of the dwell times as a function of the duration of the flight scenario (%): (A) for the six areas of interest and in total and for the control scenario (dark gray) and the Sycopaero scenario (light gray); (B) for the N1d and the AI composing the Sycopaero area in the control scenario (left) and the Sycopaero scenario (right).

cockpit not included in the AOIs) were measured in the control scenario and the Sycopaero scenario from the moment the aircraft took off to the moment it touched the runway for landing. A 2 × 6 – Scenario (Sycopaero; control) × AOIs (SYC, ECAM, PFDr, ND, FCU, EXT) – ANOVA was performed with Tukey–HSD post hoc tests conducted on the dwell times. A significant main effect of scenario, $F(1, 21) = 7.56$, $p < .05$, $\eta_p^2 = .26$, was found with longer dwell times on the AOIs in the Sycopaero scenario (M = 14.40%, SD = 28.55) compared with the control scenario (M = 13.88%, SD = 26.61). The analysis revealed a significant Scenario × AOIs interaction, $F(5, 105) = 17.20$, $p < .001$, $\eta_p^2 = .45$ (see Figure 5A), with longer dwell times on the Sycopaero Area (SYC) and shorter dwell times on the ECAM in the scenario with the Sycopaero interface (SYC: M = 37.25 %, SD = 9.27; ECAM: M = 1.09%, SD = 1.18) than in the control scenario (SYC: M = 29.82%, SD = 10.42, $p < .001$; ECAM: M = 5.01%, SD = 3.18, $p < .01$). No significant differences were found for the remaining AOIs between the scenario with the Sycopaero interface



A Control Scenario

FROM \ TO	AOIr	ECAM/ND	ATT/HDG	N1d
AOIr		18%	81%	1%
ECAM/ND	55%		43%	2%
ATT/HDG	81%	14%		5%
N1d	18%	6%	71%	

B Sycopaero Scenario

FROM \ TO	AOIr	ECAM/ND	ATT/HDG	N1d
AOIr		12%	85%	3%
ECAM/ND	50%		45%	5%
ATT/HDG	74%	9%		18%
N1d	11%	7%	82%	

Figure 6. Transition matrices for the four areas of interest: the ECAM and ND merged area (ECAM/ND), the AI and heading merged area (ATT/HDG), the N1d and the AOIr in (A) the control scenario and (B) the Sycopaero scenario.

and the control scenario (Figure 5A). The analysis also revealed a main effect of AOIs, $F(1, 21) = 97.22$, $p < .001$, $\eta_p^2 = .82$. For the sake of clarity, the details of these results are reported in ESM 1 (see Tables E1 and E2). A 2 × 2 – Scenario (Sycopaero; control) × AOIsyc (N1d; AI) – ANOVA was also performed on the dwell times and revealed a main effect of scenario, $F(1, 21) = 39.78$, $p < .001$, $\eta_p^2 = .65$ (see Figure 5B) with longer dwell times on the two AOIs composing the SYC area (AOIsyc) with the Sycopaero interface ($M = 18.62\%$, $SD = 15.53$) than without it ($M = 14.91\%$, $SD = 16.25$).

The analysis also revealed a main effect of AOIsyc, $F(1, 21) = 123.95$, $p < .001$, $\eta_p^2 = .85$, with more time spent on the AI ($M = 30.43\%$, $SD = 10.71$) than on the N1d ($M = 3.11\%$, $SD = 3.94$). The Scenario × AOIsyc interaction, $F(1, 21) = 1.03$, $p = .32$, $\eta_p^2 = .05$, did not reach significance.

Transitions Between the Areas

Complementary analyses were conducted to investigate the transitions between the three AOIs: N1d, the ECAM, and the AI; and an area covering the remaining AOIs in order to investigate how the introduction of the N1d impacted the joint monitoring of the thrust and the attitude. As the ND is located next to the ECAM and the pilots' gaze had to pass through the ND to access the ECAM, this may have interfered with the measurements of the saccades between the ECAM and the remaining AOIs. To prevent this, a unique area merging the ECAM and the ND was created, assuming that introducing the Sycopaero interface would not modify the number of transitions between the ND and the remaining AOIs. A 2 × 12 – Scenario (Sycopaero; control) × Transition (AOIr → ECAM/ND; AOIr → AI; AOIr → N1d; ECAM/ND → AOIr; ECAM/ND → AI; ECAM/ND → N1d; AI → AOIr; AI → ECAM/ND; AI → N1d; N1d → AOIr; N1d → ECAM/ND; N1d → AI) – ANOVA was conducted on the data, revealing a significant Scenario × Transition interaction, $F(11, 231) = 7.26$, $p < .001$, $\eta_p^2 = .26$ (see Figure 6), with an increase in AI → N1d transitions ($M = 82.47\%$, $SD = 9.86$, $p < .01$) and N1d → AI transitions ($M = 17.72\%$, $SD = 10.23$, $p < .001$) in the Sycopaero scenario compared to the control scenario (AI → N1d: $M = 70.81\%$, $SD = 23.07$; N1d → AI: $M = 5.06\%$, $SD = 4.91$). Tukey-HSD post hoc analysis revealed no significant differences in transition rates for the remaining AOIs between the Sycopaero scenario and the control scenario (all $p > .36$).

The details of this analysis are presented in ESM 1 (see Table E4. The analysis also revealed a main effect of transitions, $F(11, 231) = 239.46$, $p < .001$, $\eta_p^2 = .91$. The details of this result are reported in ESM 1 for sake of clarity (see Table E3). The main effect of condition did not reach significance, $F(1, 21) = 1.00$, $p = .32$, $\eta_p^2 = .05$.

Discussion

The present study aimed at testing a new interface called Sycopaero, designed to support the PFs and lower their workload in the event of an identified airspeed failure. All pilots were able to safely land the aircraft in both scenarios. No differences in mean speed or speed standard deviation were found between the Sycopaero scenario and the control scenario. These results are reassuring as they demonstrate the effectiveness of the intensive training pilots receive to manage this type of failure since the accident of Air France flight 447 (BEA, 2012). Interestingly, participants reported that they perceived their performance as being similar in both scenarios (i.e., performance sub-scale of the NASA-TLX), suggesting that they were able to accurately evaluate their performance. Despite the absence of difference in flight performance, participants reported during the postexperimental debriefing that the interface was very natural to use, well-designed and that it made them feel safer in this very stressful situation. The analysis of the raw NASA-TLX data (Hart, 2006) revealed that overall participants estimated that the Sycopaero interface significantly reduced their mental workload. More specifically, participants reported lower mental demand, physical demand, effort, and frustration in the Sycopaero scenario than in the control scenario. Taken together, these results suggest that the Sycopaero interface was very well accepted by the participants operating as PF and lowered their mental workload, which is a key point when facing a UAE (Silva & Nicholson, 2012).

Participants' ocular activity was analyzed in order to assess how the Sycopaero interface impacted the way PFs allocate their attentional resources in the occurrence of a UAE with and without the Sycopaero interface (Duchowski, 2002). Proportionally to the duration of the flight scenarios, participants were found to spend significantly more time monitoring the AOI (i.e., main flight instruments) with the Sycopaero interface than with the control interface. In case of a UAE, the thrust and the pitch values corresponding to the current condition of the aircraft (i.e., altitude, weight, and flap/slat configuration) are required to maintain the balance of the aircraft and to prevent it from stalling. This information has to be retrieved from the flight crew operating manual by the pilot monitoring (BEA, 2012). The time period in which pilots retrieve this information – before being able to stabilize and secure the aircraft – is particularly stressful and associated with an important workload. Displaying the thrust and pitch data directly into the PFD via the Sycopaero interface facilitated the retrieval of the relevant flight parameters, eliminating the division of attentional resources, and enabling almost immediately the PF to stabilize and secure the aircraft (Fitts et al., 1949). Participants were also found to spend proportionally more time monitoring the N1d and less time monitoring the ECAM with than without the Sycopaero interface. Moreover, the analysis of the transition rate matrices between the merged AOI revealed that the transition rates between the ATT/HDG area (i.e., attitude and heading indicators) and the N1d in the PFD tended to increase (+12%). These results suggest that the participants most often monitored the thrust on the N1d and at least partially abandoned the usual N1 indicator located in the ECAM. The interface appears to have limited the scattering of the participants' attentional resources over different and distant flight instruments, facilitating the monitoring during this specific type of UAE (Wickens et al., 2017). These results are also bolstered by the pilots' comments during the postexperimental debriefing. Except for one pilot who declared that he had some difficulty adapting to the N1d, the remaining 21 pilots reported that duplicating the N1 in the PFD made the monitoring easier and lessened their workload. Moreover, they positively valued the decision not to delete the N1 indicator in the ECAM, indicating that they found it reassuring. More generally, no difference in dwell time percentages and transition rates was found for the remaining AOIs between the two scenarios. This result demonstrates that the introduction of the Sycopaero interface did not affect the monitoring of the remaining flight instruments (i.e., the areas aside from the ECAM and the SYC areas). Taken together, these results suggest that the Sycopaero interface, by locating the critical indicators directly in the PFD, facilitated the retrieval of the thrust and pitch information, increased the time spent monitoring the AOIs (i.e., main flight instruments) and did not distort the way PFs allocated their attentional resources to the main fight instruments. The present study suggests that this new and easy-to-implement human–machine interface may be a suitable solution for supporting the PF when reliable airspeed information is no longer available and may help prevent disastrous accidents in the future.

Further investigation is, nevertheless, needed before this interface can be implemented in commercial aircraft. The present experiment aimed at investigating how the Sycopaero interface impacts the mental workload and the performance of PFs when an unreliable speed event occurs and is immediately identified. While we did not investigate its impact on the pilots monitoring, it is very likely that the interface will also benefit them, as the simplification of the aircraft stabilization procedure may (1) lower both their stress and workload and (2) enable them to almost directly focus on the correction of the airspeed failure. Nevertheless, this assumption should be confirmed experimentally. In the present study, we chose to use a scenario in which the UAE was immediately detected and understood, and we were only able to investigate its impact on the mental workload associated with the aircraft operation. The present study does not allow us to conclude on whether the Sycopaero interface would facilitate the detection and/or understanding of UAEs. Therefore, this interface should be tested on both the PFs and the pilots monitoring using different scenarios where the UAE is hard to detect and/or understand, as it happened in the AF447 accident for instance. Further research is also needed on the way the Sycopaero interface should be displayed and reversed in the event of, respectively, an airspeed failure and its resolution. We think that the automatic display of the Sycopaero interface when the system detects airspeed inconsistencies (as it was implemented in the present study) would make these failures – which can sometimes be difficult to detect – more explicit for the pilots and strongly facilitate the detection of the system change of state (Silva & Hansman, 2015). It may also be helpful to allow pilots to manually activate the interface in the case of doubt and/or to decide whether they want to cross out the airspeed indicator or not. Most UAEs resolve in some minutes (BEA, 2012), raising the question of whether and how the Sycopaero interface should be reversed. We think that it might be a better option to let the pilots decide whether they want to continue operating the aircraft with the Sycopaero interface or not. These assumptions should now be confirmed experimentally. Finally, UAEs are an important problem in both general and military aviation. It would be interesting to investigate whether the Sycopaero is a suitable solution to this problem in other aviation fields. In closing, the present study advocates for a more widespread use of the eye-tracking method for the evaluation of human–machine interfaces before they are implemented in cockpits.

Electronic Supplementary Material

The electronic supplementary material is available with the online version of the article at https://doi.org/10.1027/2192-0923/a000221

ESM 1. Both the way the Sycopaero interface was designed and the fictional interfaces are described in details in the ESM 1 Material & Method section. The details of the Tukey posthoc analyses performed on the dwell time percentages for both the main effect of AOI and the AOI × Scenario interaction are summarized in Table E1 and Table E2 of the ESM 1 Results section.

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Publication Ethics

All participants were informed of their rights and gave written informed consent for participation in the study according to the Helsinki Declaration. The experimental protocol was reviewed and approved by a regional ethics committee (CERNI no. 2018-108).

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