Situation Awareness: Angle of Attack Displays

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Introduction

Aircraft accidents categorised as Loss of Control – In Flight (LoC-I) contain the largest number of fatalities across all sectors of aviation. LoC-I contributed to 46% of all commercial jet aircraft fatalities between 2007 and 2016 [1]. The commercial jet fleet is not the whole picture. For commercial air transport including turboprop aircraft LoC-I contributed to 50% of fatalities between 2012 and 2016, with almost twice as many turboprop aircraft accidents than jet aircraft accidents (63% to 37% respectively)[2].

Traditionally, commercial aircraft are fitted with stall warning systems. These may include audible warnings (aural cues), stick-shakers and stick-pushers (haptic cues), however few commercial aircraft are fitted with a visual display of AoA to manage proximity to stall. Following the Air France 447 aviation accident in 2009, the Bureau d'Enquetes et d'Analyses (BEA) recommended that AoA be displayed on the flight deck to help mitigate Loss of Control – In Flight (LoC-I) events and assist in recovery by increasing pilot situation awareness (SA). [3]

In the General Aviation (GA) sector 57.3% of all fatal accidents between 2001 and 2010 were categorised as LoC-I [4]. There has been a recent proliferation of commercially available AoA displays - the growth being attributed to the relaxed restrictions by the Federal Aviation Administration (FAA) with regard to the installation of AOA systems in GA aircraft. This said, there are no published design standards or certification requirements for such displays.

An AoA display is fit for purpose when it has a positive effect on the SA of the pilot. Negative impact on SA would be seen through degradation of task performance or secondary task SA. Two stages of the project are presented: the first stage is a feature categorisation and evaluation of AoA displays throughout the aerospace sector against recognised visual display design principles, and the second stage is a desktop study to evaluate whether examples from the AoA display categories have any impact on pilot performance and SA.

AoA Presentation Evaluation Methodology

Visual AoA presentation solutions from across the aerospace sector (35 total: 8 commercial, 8 military, and 19 GA) were evaluated against the thirteen visual display principles [5] in relation to the aviation context. The AoA display examples were gathered from a number of sources including published research using the displays and current market examples. The 35 displays were evaluated against each display principle considered. Table 1 provides an overview of this process.

The principles of display design relating to perception (Legibility, Absolute Judgement, Top-down Processing, Redundancy Gain, and Discriminability) and Mental Models (Pictorial Realism and Moving Part) were of particular interest at this stage in the project due to the ability to map them to the stages in Endsley's model of SA (Perception, Comprehension, and Projection) [6]: perception principles to the perception stage (awareness of the model) and mental model principles to the comprehension (accuracy of the model) and projection (use of the model) stages.

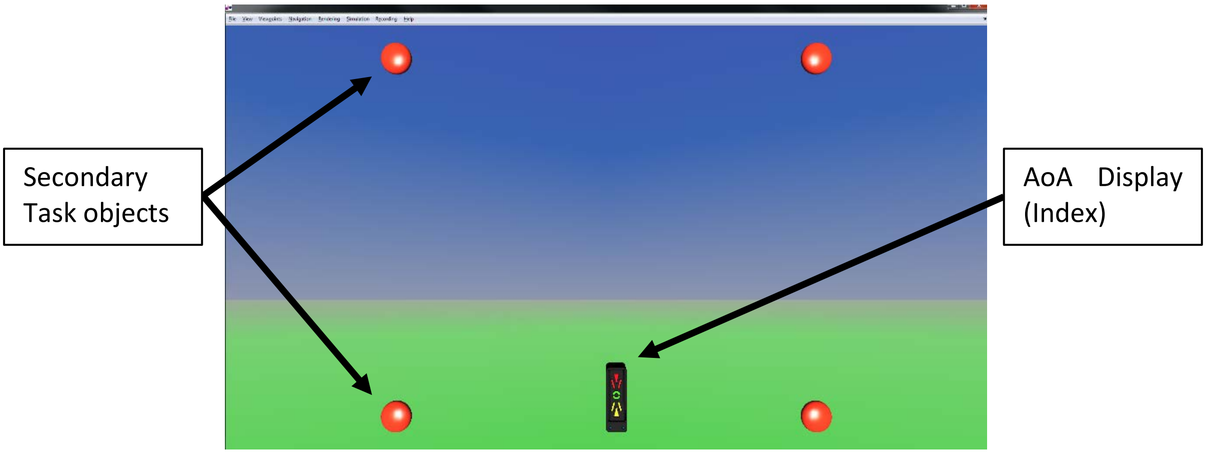
Table 1. Evaluation Process Example

Category	Index	Quantitative	Pictorial
Example	Alpha Systems Eagle The display segments illuminate with respect to AoA. High above; approach centre. 	Teledyne Avionics Dial format, needle sweeps counter clockwise with respect to percentage total AoA. 	ICON A5 The aerofoil shaped needle sweeps with respect to AoA. High above; approach horizontal. 
Redundancy Gain	The display utilises both colour and position for redundancy gain (similar to traffic lights).	Colour is used as a redundancy check for the needle position and numerical values. Less salient than an index display.	The display utilises colour to enhance, or check, understanding of the needle position. Less salient than an index display.
Pictorial Realism	Limited pictorial realism. The shape (and therefore direction) of the chevrons help to identify appropriate action.	No pictorial realism. The pilot has to decode the numerical and positional information to generate a mental picture of the situation.	Good pictorial realism achieved by shaping the needle. However, approach position is where one would expect cruise (wings level) flight to be.
Knowledge in the World	Limited use of knowledge in the world (shape and colour). Some conflicting use of colour consistency with respect to other displays.	Good use of knowledge in the world features such as bugs on the scale to remind the pilot of important regions such as approach.	Use of additional presentation features to denote approach region. Display is still free from clutter.

AoA Situation Awareness Assessment Study

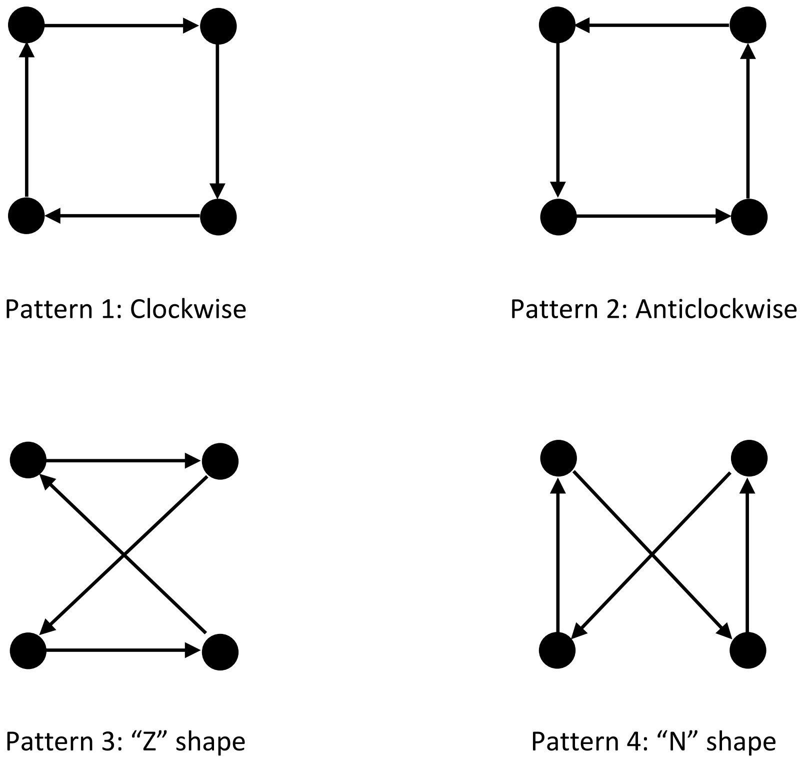
Simulink was used to deploy a pilot-in-the-loop pitch control system with joystick input and 3D scene (Figure 1). Participants completed a series of pitch control scenarios with a secondary task to react to a red object that would appear periodically on the screen. Their SA was assessed using questions in the style of the Situation Awareness Global Assessment Technique (SAGAT). Participant performance (Simulation data) and subjective workload (NASA TLX) were also captured. The displays used were one of each major type (index, quantitative, and pictorial) and based on the examples in Table 1. Also, included in the experiment was a control scenario with no AoA display visible. All display objects were created in Catia and exported into VRealm Builder where either colours (in the case of the index display) or textures (for the quantitative and pictorial displays) were applied.

Figure 1. Scene with all display objects visible prior to scenario commencement.



The secondary task involved pulling the trigger of the joystick controller when a red object appeared on the screen. The behaviour of the red objects was limited: their positions were static; they had a maximum dwell time of six seconds, and they would disappear for the remaining dwell time upon the trigger being actuated. Only one object would appear at a time and the others would remain transparent. The red objects had four sequences available which always began in the top right corner at the start of the scenario (Figure 2). The object was coloured red to differentiate it from the background of the scene (Figure 1). Since the screen dimensions were widescreen, the secondary task objects were not placed in the corners of the screen but were brought closer to the centre of the scene to make them easier for participants to spot.

Figure 2. Secondary task object sequences.



The simulation was a one degree of freedom model based on the stability derivatives of a Cirrus SR20 for pitch and AoA responses to elevator deflection. Ahead of the view point was the AoA display (when required) and the secondary task objects. These objects were linked to the view point so that they would move with the rotation of the observer. Figure 1 shows an example of the scene prior to initiating the scenario with the index display and all secondary task objects visible.

Subjective SA capture followed the SAGAT style, however SAGAT was not employed precisely because of the length of scenarios. Since the scenarios were short it would be too impactful and would not give enough time to build SA if stopped part way through. The scenario length was not increased to avoid detachment in the participants, and to limit their exposure to the secondary task sequences. The questions, outlined in Table 2, were administered at the end of each scenario via an online questionnaire on the same screen. The simulation was closed prior to participants answering the questions so they could not refer to the scene.

Table 2. SAGAT Style Questions

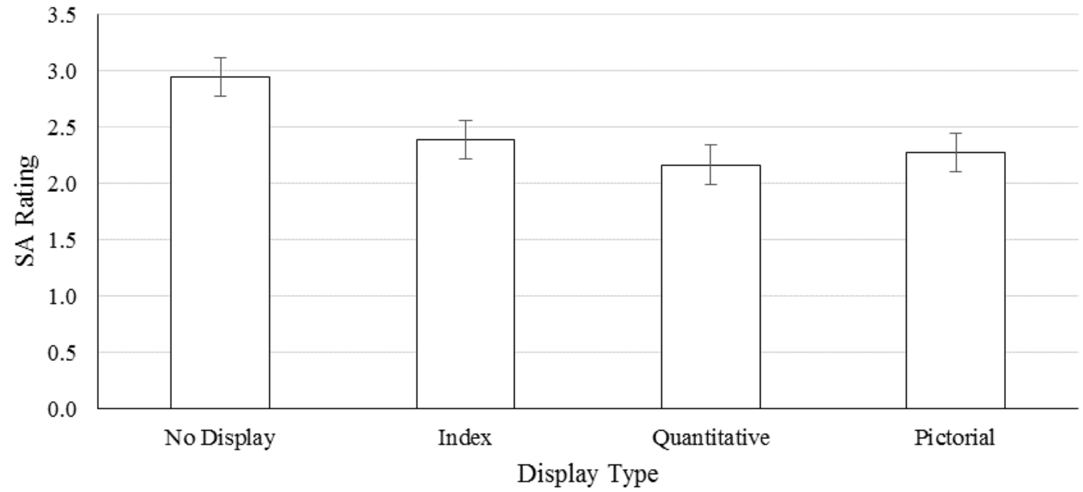
	Questions	**Possible responses**
1	How does your planned attitude compare with your final attitude?	Far above, above, on target, below, far below, don't know.
2	How often did you use the display?	All the time, very often, often, sometimes, seldom, never, not applicable
3	What was the final location of the red object?	Top left, top right, bottom left, bottom right
4	What would be the next location of the red object?	Top left, top right, bottom left, bottom right
5	Did you notice a pattern in the movement of the red object?	Yes, no
6	If yes, what was the pattern?	Free text field
7	In seconds, how long were you flying for?	Less than 45 seconds, between 45 and 55 seconds, between 55 and 65 seconds, between 65 and 75 seconds, more than 75 seconds.

Results

The subjective responses from questions 3, 4, 5, 6, and 7 have definite answers; the responses were coded into ones and zeros for correct and incorrect answers respectively. The questions were designed to gain an appreciation of the SA of the participant with respect to the subtask. Question 3 assessed the perception of the participant (level 1 SA), questions 5 and 6 target the comprehension of the participant (level 2 SA), and question 4 assessed the projection of the participant (level 3 SA). Thus a rating system for subjective SA was generated by summing the responses across the four questions.

The SA rating provides an indication to the split of cognitive resources between the tasks: the no display scenario provides a baseline performance indicator against which the other displays can be assess for their cognitive impact. The first case for each participant was excluded from the analysis set because every case after the first the participants knew what questions to expect. Figure 3 shows the mean SA rating for each display type with error bars based on standard error.

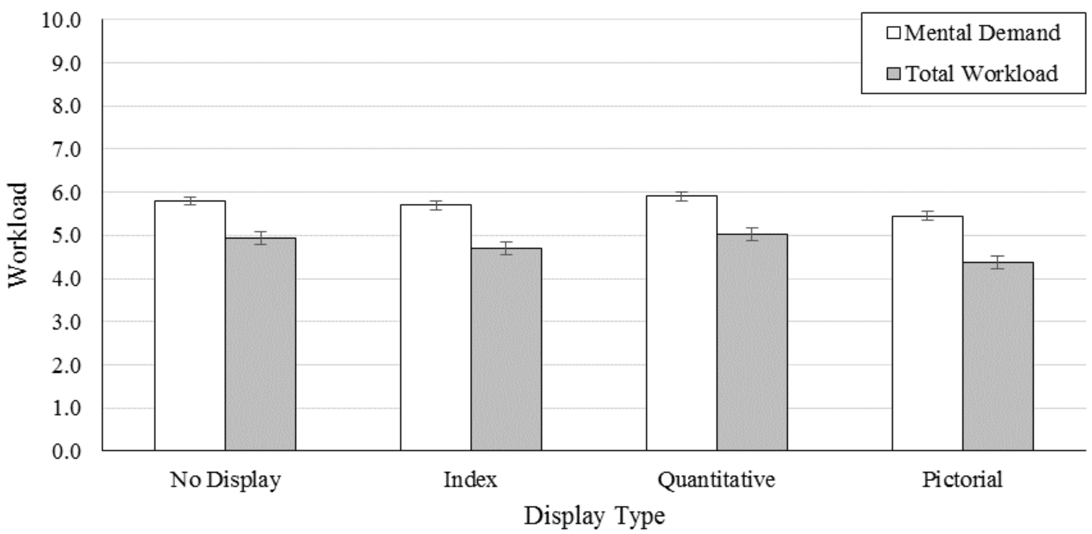
Figure 3. Mean SA rating for each display type.



A judgement was made on the free text answers of Question 6 in order to code the responses. A correct answer required two features: a description or explanation of the sequence and the direction of the sequence. For example, many participants chose to list the corners in which the red object appeared. This was acceptable as an explanation of the sequence and the order in which the corners were listed provided a direction.

SA Rating is ordinal data therefore Kruskal-Wallis and Mann-Whitney tests were used, with the grouping factors Display Type and Piloting Experience, to test the null hypothesis that the samples originate from the same distribution. A k-independent samples Kruskal-Wallis test was used for the Display Type group. The results were not significant ($p = 0.076$). A two independent samples Mann-Whitney test was used for Piloting Experience. The results were also not significant ($p = 0.217$). The results suggest that the independent variables did not have any effect on the secondary task SA performance of the participants.

Figure 4. Mean total workload and mental demand for each display type.



The mean of all factors in the NASA TLX (Mental Demand, Physical Demand, Temporal Demand, Overall Performance, Frustration Level, and Effort) was taken to generate a Total Workload factor. It is clear that there is little variation between the mean mental demand and total workload due to the display type in the scenario (Figure 4). A multiway ANOVA was performed on the total workload on the participant data for each scenario. The groups for the ANOVA were maintained as Display Type and Piloting Experience as with previous analyses. Display type and piloting experience were not significant at $p = 0.301$ and $p = 0.230$ respectively. There was no significance in between-group interactions.

Discussion

In all scenarios with displays, the participants on average exhibited some reduction in subjective secondary task SA, however there was no significant effect on the SA due to the AoA presentation method or pilot experience. A similar outcome was observed from the workload data: no display causes a significant rise or reduction in subjective workload, even compared against not having a display. Based on the evidence available so far, it appears that AoA displays can provide assistance to the pilot while not negatively impacting their secondary task SA.

The piloting experience of the participant pool was not a significant factor in any of the subjective measures. This suggests it was safe to open the participant pool to those without piloting experience due to the design of the experiment being sufficiently detached from aviation, and that members of the study without piloting experience have not unduly skewed the data.

Conclusions

A desktop study to evaluate whether examples from the AoA display categories had any effect on pilot performance and SA was completed with 18 participants, half of which had flying experience. The inclusion of participants without flying experience showed no significant variation in the results. The study included a primary pitch control task and a secondary object tracking task. A questionnaire was administered post scenario to gather subjective SA data. A NASA TLX without pairwise comparisons was used to gather subjective workload data. Objective performance data, taken directly from the Simulink environment, have yet to be analysed.

On average, the participants demonstrated a reduction in subjective secondary task SA for all scenarios with displays compared to the scenario without a display. However, there was no significant difference in these results. The measured independent grouping variables (display type and pilot experience) showed no significant effect on the SA of the secondary task. A similar outcome was observed from the workload data: the grouping variables display type and pilot experience had no significant effect on the subjective workload of the participants. Based on the evidence available so far, it appears that AoA displays can be fit for purpose by providing assistance to the pilot while not negatively impacting their secondary task SA. The next stage is to analyse the performance data from the simulation and to cross reference the results against the subjective measures.

References

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