Angle of attack displays in the cockpit – are they fit for purpose?

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Traditionally, commercial aircraft are fitted with stall warning systems and 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 Angle of Attack (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. In contrast, in the General Aviation (GA) sector, where LoC-I accidents also dominate fatal accident statistics, 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. This study, part of a larger project in Human Centred Design (HCD) of AoA presentation in relation to LoC-I, reviewed multiple presentation methods and designs in their aviation context using human factor principles to try and answer the question: are they fit for purpose?

I. 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]. For General Aviation (GA), 57.3% of all fatal accidents between 2001 and 2010 were categorised as LoC-I [3].

The Bureau d'Enquetes et d'Analyses (BEA), after the loss of 228 passengers aboard flight Air France 447 in 2009 due to a Loss of Control – In Flight, recommended that angle of attack (AoA) be display on the flight deck to help mitigate LoC-I events and assist in recovery by increasing pilot situation awareness (SA) [4]. In the same vein, the Federal Aviation Administration (FAA) recently granted the freedom to install supplemental AoA systems in GA aircraft [5]. Without certification requirements or standards, manufacturers are free to use any presentation style without justification as to its effectiveness.

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. This paper consists of the methodology and initial results of two stages of study, which are part of larger project on Human Centred Design (HCD) of AoA Presentation. 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.

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II.AoA Presentation Evaluation Methodology

Data or information is either represented second-hand (e.g. a picture) or encoded into presentation features (e.g. a sign). Whether or not the data or information is updated will determine whether the presentation method is static or dynamic. The displays of interest to the project can be described as coded dynamic displays: the data is constantly updated and presented as coded features (be it numerals, shapes, or colours) on the display face.

Visual displays can be categorised in a number of ways. Methods include by the role they play or how the data is to be used [6]. However, this is not useful in this case as the AoA displays perform the same role and they display the same data. As an AoA display is not in the standard scanning pattern it would typically fall into a role of a check reading display. In emergency procedures, the display could also be used in a direct monitoring capacity in order for the pilot to manage AoA. The focus of this study was on the human response to how the data was presented and therefore the AoA displays were categorised based on their physical aspects.

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 [6], in relation to the aviation context and how they might affect the pilot. 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. Table 1 provides an overview of this process.

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.

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) [7]: 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.

The memory related principles (Knowledge in the world, Predictive Aiding, and Consistency) have also been taken into consideration across all stages of SA. The attention related principles (Information Access Cost, Proximity Compatibility, and Multiple Resources) have not been considered at this stage in the evaluation due to the flexibility of installation location of the GA AoA displays, which account for most of the designs being evaluated.

Some of the displays were not standalone: they came as part of a set of displays of different types. For example, a common configuration was to have an index display near the pilot's eye sight and a quantitative display in the Head-down display cluster. The displays within these systems were treated separately to evaluate each by their own merits.

III.SA Assessment Desktop Study Methodology

Simulink was used to deploy a pilot-in-the-loop pitch control system with joystick input and 3D scene. 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 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. The scene was set with the view point ahead of the centre of rotation at the same proportion the pilot's eye would be in front of the centre of gravity. 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. An example of the scene prior to initiating the scenario with the index display and all secondary task objects visible is shown in Fig. 1.

A. Participants

Eighteen members of Coventry University participated in the study (Mean Age: 21 years). Half of the participants had piloting experience (number: 9, Mean Hours in Command: 140 hours, Median Hours in Command: 20 Hours). The mean pilot in command flying hours was skewed by two participants with over 250 hours whereas the rest in the group had less than 65 hours. Four of the nine held a Private Pilots Licence (PPL). The other nine participants had zero flying experience.

Each participant was shown an introduction slide showcasing the displays to be evaluated. They were informed that the major task was a pitch control task and they were asked to maintain the current attitude, which was roughly 10 degrees pitch up. All participants also had the scene described as a "two-thirds sky to one-third ground split", though this was mainly to aid those without piloting experience.

For the subtask, the participants were told to pull the trigger on the joystick controller whenever they saw a red object. It was mentioned that a red object would appear around the screen but the fact they followed a pattern was not mentioned. They were then informed that there would be multiple scenarios and that they would be asked to complete two questionnaires after each scenario. Participants spent between 30 to 45 minutes performing the experiment.

B. Study Features

The experiment had three variable elements: the AoA display used, the intensity of turbulence, and the sequence of the subtask. 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.

The hypothesis was that the participants would perform better at the primary task when assisted by an AoA display compared to no display. However, the increase in performance in the primary task may come at the cost of a reduction in the performance and SA of the secondary task, as cognitive resources are split between the tasks.

The AoA displays were controlled by the AoA signal. The quantitative and pictorial displays had a scaled rotation applied to the needle of the display whereas the index display had the signal pass through logic to increase the brightness and intensity of colour of the segment to be illuminated.

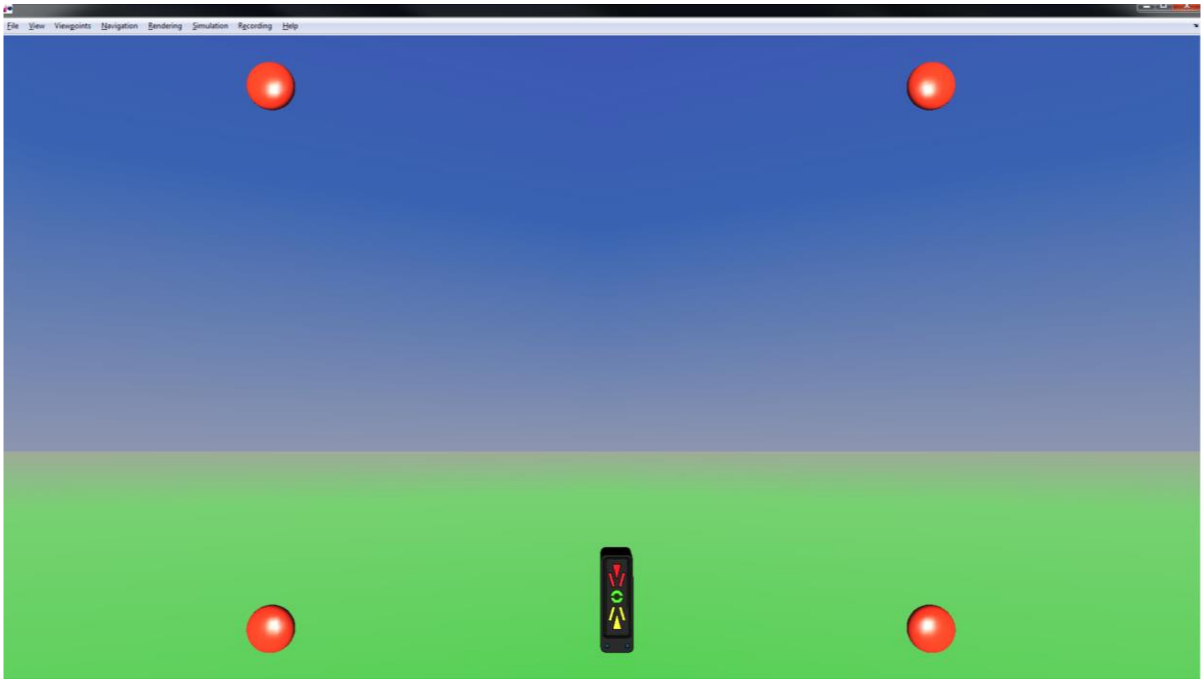


Fig. 1 Scene example with all display objects visible.

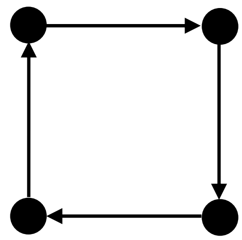
The turbulence intensity could take two levels: high or low. The turbulence was generated using a Simulink in-built block for a Dryden Wind Turbulence Model set at an altitude and velocity consistent with the determination of the stability derivatives. The turbulence intensity was applied as a multiplier to the output of the block. Although the model could only be controlled in pitch, turbulence was added to the roll rotation to create a scenario that was harder to understand and to provide baseline frustration. Any participant that directly asked if there was roll control was informed that there was none as there was no intention to purposefully mislead participants. Movement in yaw was not noticeable because the horizon and outside scene were featureless.

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; the sequences are described in Table 2 and Fig. 2. The object was coloured red to differentiate it from the background of the scene (Fig. 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.

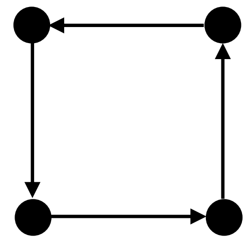
Every scenario was 60 seconds long and the secondary task cycle is 24 seconds: the red object appeared 10 times during the scenario. The red object was present at the start of the scenario at zero seconds therefore the final position of the red object was always the third position in the sequence.

Table 2 Secondary task patterns.

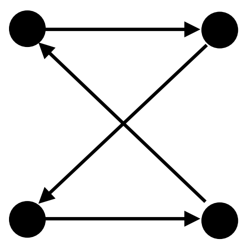
	Description	Sequence
1	Clockwise	Top Right, Bottom Right, Bottom Left, Top Left …
2	Anticlockwise	Top Right, Top Left, Bottom Left, Bottom Right …
3	“Z” shape	Top Right, Bottom Left, Bottom Right, Top Left …
4	“N” shape	Top Right, Bottom Left, Top Left, Bottom Right …



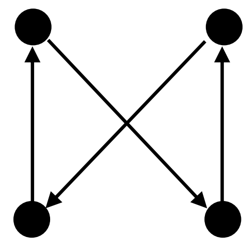
Pattern 1: Clockwise



Pattern 2: Anticlockwise



Pattern 3: “Z” shape



Pattern 4: “N” shape

Fig. 2 Secondary task object locations

C. Study Permutations

Each display option was paired with both turbulence options to give eight scenarios. These scenarios were randomised for each participant to minimise learning effects between them. The order of the secondary task sequence was randomised once, such that each sequence would appear twice, and applied to scenario sequence for each participant. The secondary task was not randomised for each participant so as to ensure a more equal distribution of secondary task sequence and scenario pairs. If both were randomised for each participant there would be no guarantee that each scenario would see each secondary task sequence.

As the luxury of having every permutation of scenario and secondary task sequence was not possible it was felt that this compromise was not particularly impactful. The secondary task is just a tool to assess SA, and it was always expected that there would be an increase in performance during the experiment regardless of order due to the simplistic nature of the sequences. If the secondary task was made more complex it would only become more difficult to assess participant SA.

D. Data Capture

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 boredom and detachment in the participants, and to limit their exposure to the secondary task sequences. The questions, outlined in Table 3, 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.

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.

Table 3 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.

A NASA TLX, without pairwise comparison, was administered via online questionnaire on the same monitor after the participants were finished with the SAGAT style questions. Of particular interest at this stage in the project is the mental demand on the participant and a total workload score. Performance data was recorded to the MATLAB workspace directly, and then saved separately for each scenario. Performance data includes joystick inputs, aircraft response, turbulence, and secondary task reaction times.

IV. Results

A. AoA Presentation Evaluation Outcomes

The major categories of coded dynamic AoA displays, that all examples in this study belonged to, were exposed and described as Index, Quantitative, or Pictorial. An index display presents the current state of a limited number of states, i.e. a traffic light system. Typical index display designs have multiple coloured segments that illuminate in turn and/or in pairs to indicate the current AoA from an ordinal list.

There are three types of quantitative displays: fixed point with a moving index (e.g. Heading Indicator), fixed index with a moving point (e.g. Speedometer), and digital counter (e.g. Home Utilities Meter). Fixed point, moving index and fixed index, moving point display types can be in either dial or tape format. Each of these formats have their own benefits and drawbacks well described in literature. [8]

A pictorial display provides a representation of the object or system to be informed about, or a visualisation of current or future states. Pictorial displays will typically attempt to match the user’s mental model of the system they are portraying. As with an index display, a pictorial display can only provide qualitative information on the data it is presenting.

There were 20 index, 12 quantitative, and three pictorial displays. Of the 20 index displays: two included digital counters, two were in a dial format, two were horizontal, and the remaining 14 were a vertical configuration.

Of the 12 quantitative displays: eight used normalised units, three used degrees, and one used arbitrary units. Nine were a dial format, with eight having counter-clockwise needle movement, two used a digital counter, and one was a fixed pointer moving scale tape. Of the three pictorial displays: two were from the heads-up display (HUD) of military aircraft, and one was from general aviation.

No quantitative displays were found in the GA sector; most of the GA displays are some variation of an index. Similarly, the only standalone pictorial display in the whole set was the ICON A5 display. None of the displays evaluated explicitly presented rate of change of AoA or had a predictive element. Many of the displays, particularly those in the GA sector, do not update to reflect configuration changes.

B. SA Assessment Study Results

1. SA Results

The SA rating was generated by summing the correct responses to the four SA questions as described in Section III D. Level three SA was taken to be a score of 4 on the rating scale. 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. The mean SA rating for each display type is shown in Fig. 3, with error bars based on standard error.

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. An example of an incorrect response for sequence 3 would be “hourglass” as this provides no indication as to the direction of the movement. A direction was required to differentiate between identifying shape and sequence.

SA Rating is ordinal data therefore Kruskal-Wallis and Mann-Whitney tests were used, with the grouping factors display type, turbulence level, 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 both Turbulence Level and Piloting Experience as both groups have two independent samples. Neither result was significant at $p = 0.891$ and $p = 0.217$ respectively. The results suggest that none of the independent variables had any effect on the secondary task SA performance of the participants.

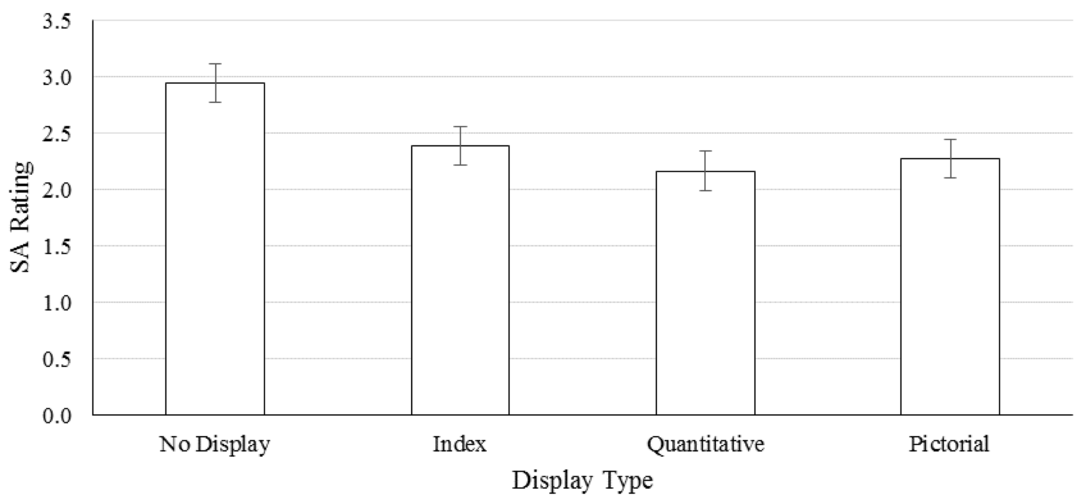


Fig. 3 SA Ratings for each display type.

2. Workload Results

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. The mean mental demand and total workload for each display type is shown in Fig. 4. It is clear that there is little variation between the mean mental demand and total workload due to the display type in the scenario. 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, turbulence level, and piloting experience as with previous analyses. Only turbulence level had a significant impact at $p = 0.019$; 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.

The impact of the groups on Mental Demand of the participants was assessed using the same method as for SA rating. A k-independent samples Kruskal-Wallis test was used for the Display Type group ($p = 0.631$). A two-independent samples Mann-Whitney test was used for the groups turbulence level ($p = 0.114$) and piloting experience ($p = 0.395$). No significance was found for any grouping factor.

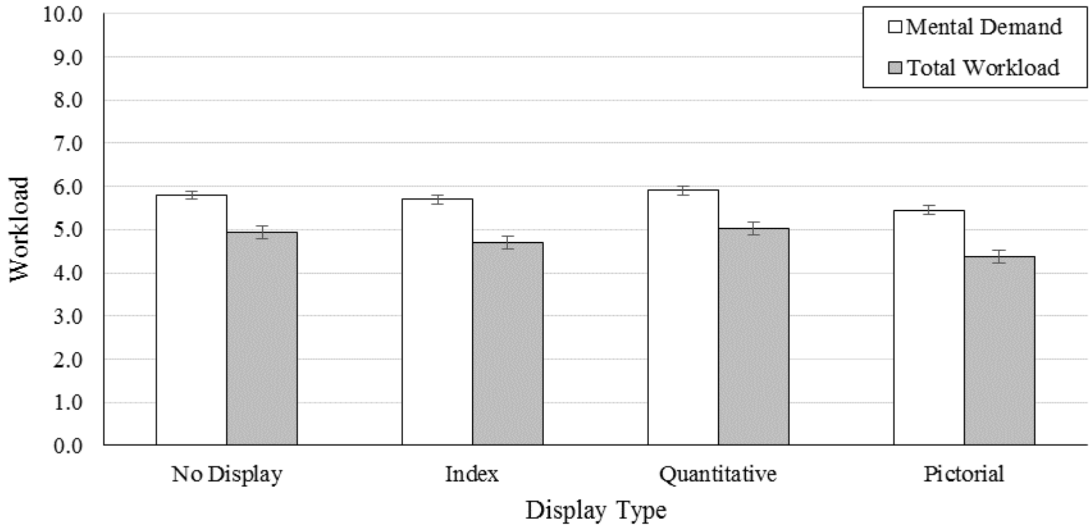


Fig. 4 Mental demand and total workload for each display type.

3. Subjective Display Use

Subjective display use was taken from Question 2 of the SAGAT questionnaire. The possible responses were all subjective terms. The intended percentage time spent looking at the display was 100% for "All the time" dropping by 20% for each subsequent rating ending at 0% for "Never". It was intended that "Not applicable" would only be selected for the scenarios with no display. "Not applicable" responses to any other scenario was taken to be equivalent to "Never". Participants reported that they used the pictorial display type less than the others (Fig. 5).

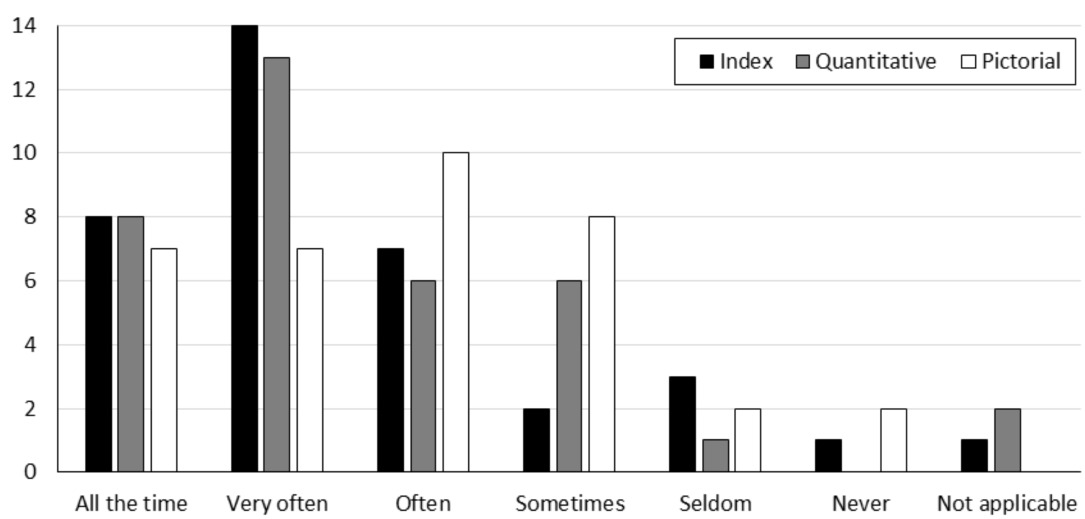


Fig. 5 Subjective display use.

4. Participant Preference Responses

After completing all of their scenarios each participant was asked which of the displays they preferred and why. Two (11%) participants said they preferred to have no display, eight (44%) preferred the index display, three (17%) said they preferred the quantitative display, four (22%) said they preferred the pictorial display, and one (6%) said they preferred both the index and pictorial displays equally. No participants declined to pick a preferred display.

V.Discussion

A. Display Set Evaluation

All of the displays evaluated fell into one of the three categories, albeit with a need for subcategories due to some displays containing features of more than one major category. For example, any index display containing a digital counter was categorised as an index display as this was the major feature and the digital counter was considered an additional element.

No examples explicitly show rate of change of AoA or have a predictive element. Rate and predictive elements are important for actively seeking level three SA. The only displays which have any rate or predictive information are the quantitative displays or the index displays with high segment density. Then the rate of change of AoA can be inferred from the movement of the needle or the speed of illumination of segments. Scale linearity will impact the effectiveness of rate inference. For scales which vary in a non-linear fashion (i.e. the pictorial display used in the desktop study), the same rate of motion in two different regions of the scale must be interpreted differently and may lead to confusion or mistrust.

There are a limited number of pictorial display examples. The only pictorial displays in the set are the ICON A5 or military HUD augmentation. The military HUD AoA consisted of a bounding bracket with a dynamic indicator and should be described as an augmentation to the flight path vector rather than a standalone display. Pictorial displays that accurately represent the system in accordance to the mental model of the user would be more intuitive to the user than a quantitative display as it skips a cognitive task to decode and understand the numerals. However, pictorial displays would not be able to provide the same level of precision that some quantitative displays can provide. Pictorial displays make heavy use of a number of principles, such as: redundancy gain, knowledge in the world, pictorial realism, and principle of the moving part.

There are no quantitative displays in the GA market sector. This is likely to be due to the GA display market: GA AoA displays are typically intended for installation in a range of aircraft and to be simple to calibrate. Including numerals with a unit on a display face gives meaning which may not be appropriate for a wide range of aircraft. However, most of the quantitative displays in the set had normalised units, where the critical AoA would be equivalent to 1 or 1.1 depending on the design.

There is little consistency within the GA market. Although there is consistency in the type (mainly index) there is no consistency in the shape or the colour use of the features across different manufacturers. Most of the GA AoA displays in the set were aftermarket extras from companies separate to the aircraft manufacturer therefore the choice to include an AoA is a personal decision to a pilot. They will pick a design they feel is appropriate and difference in designs will not impact them. However, differences in designs may become confusing to a pilot that rents aircraft for their flying experience.

B. SA Assessment Study 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, turbulence level, 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. The levels of turbulence had the desired effect of increasing the workload, however there was still no significant different between the display types during the levels of raised workload. Based on the evidence available so far, it appears that AoA displays can provide assistance to the pilot without 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.

Subjective responses were also taken into consideration to help build an overall picture from the results of this study. Participants reported that they used the pictorial display type less than the others. This suggests that there was more time available to be used in tracking the secondary task or flying the model using the horizon.

The reasoning for display type preference had commonalities across participants. For the index display, participants noted how easy it was to understand, perhaps due to the display following the principles of redundancy gain (location, colour, and shape of segments) and consistency (use of red as a danger colour). It was noted that a few participants praised the use of colour and shape to inform them of the correct response, rather than only the motion of the aircraft. Other praise reported that the display was quick to read and that participants had trust in its response. Two participants said they have previous experience using such a display which would have improved their trust and acceptance of the display. Some participants found the display distracting to the point of interfering with the secondary task: they would pull the trigger of the joystick controller when the central “on target” segments illuminated.

Of those that preferred the quantitative display two participants said they found it easy to understand: having a display face with numerals gave appreciable and relatable targets to the participants (i.e. enhancing level 2 SA: comprehension). However, many participants did not prefer the quantitative display because they found the response was hard to predict and they lost trust in it. Of those that preferred the pictorial display, there was strong praise for the horizontal alignment of the needle (principle of the moving part and pictorial realism) and the horizontal leader line with which to align the needle (principle: knowledge in the world). Two participants thought that having the ability to see the motion of the needle was beneficial so that they could predict the motion of the model in the near future (i.e. enhancing level 3 SA: projection). No participants raised concerns about the non-linearity of the display scale, suggesting that either the effect was not noticed or was not of concern to the participants.

There were common negative factors reported for all displays. All displays were described as distracting more than once and all displays lost the confidence of some participants. The limitations of the simulation may partly explain the why some participants lost confidence in the displays, as the motion of the AoA display was not what they were expecting from the motion of the horizon. No specific reasoning was given to preferring not to have a display, only that each of the displays came with negatives.

C. SA Assessment Study Limitations

The transfer functions used to model the response of the aircraft in pitch and the AoA had elevator deflection as the input. If there was no elevator deflection then the only movement would be due to the turbulence. Since the model only had one degree of freedom there was no threat of crashing, therefore it is possible that the participants could perform adequately with little input. Turbulence effects were included in the AoA signal to simulate how a gust would locally modify the direction of the oncoming airflow and to encourage active participation.

The state from which the stability derivatives were taken was one of surplus energy: high altitude and high velocity. This meant that a climb, such as the primary task, could easily be accomplished while maintaining low AoA, and due to the reduced freedom of the model there is no atmospheric ceiling to inhibit the climb performance. As a result of the surplus energy, the AoA was slow to change unless there was a large control input. This may have negatively impacted the experience of the participants who were expecting larger and more frequent changes in AoA.

VI.Conclusions

An evaluation of 35 visual AoA displays from across the aerospace sector was completed. A categorisation procedure based on the physical features of the displays produced three major categories: index, quantitative, and pictorial. The index display category had largest number of members at 20 displays. The shape of index displays did not vary much among those evaluated. Likewise, many of the dial format quantitative displays showed little design variation.

Additionally, 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 not yet been 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, turbulence level, 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. There was a significant different in the subjective workload reported based on the turbulence level, as desired from the study design.

Based on the evidence available so far, it appears that AoA displays can be fit for purpose by providing assistance to the pilot without 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 described herein.

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