SYMBOLS FOR COCKPIT DISPLAYS OF TRAFFIC INFORMATION

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Abstract

A web-based study assessed pilots' ability to learn and remember traffic symbols that may be shown on Cockpit Displays of Traffic Information (CDTI). These displays convey data obtained from Automatic Dependent Surveillance-Broadcast (ADS-B) and related Aircraft Surveillance Applications System (ASAS) technologies, as well as other surveillance data sources.

We evaluated three aspects of using the traffic symbols when presented in isolation on a static display: intuitiveness, ease of learning, and ease of remembering the symbols. Four symbol sets were tested, each with approximately 22 symbols. Each participant saw only one of the four symbol sets. The sets used different visual features of the traffic symbol to represent the Directionality, Data Quality, Air/Ground Status, Alert Level, Selection Status, and Pairing Status of nearby aircraft.

A total of 623 pilots with a broad range of experience participated in the main portion of the study. Results showed that while some conventions are well understood, such as the use of red and yellow for warnings and cautions (respectively), other conventions may be confusing and should be avoided. Two examples of confusing conventions are (a) using more than one visual feature (e.g., two different shapes) to represent the same traffic information, and (b) using similar visual features (e.g., two different outlines) to represent different traffic information.

Results of the study were considered by a Federal Advisory Committee that develops standards for these traffic displays (RTCA Special Committee (SC) 186).

Introduction

Many pilots are familiar with traffic displays such as those provided with the Traffic Alert and Collision Avoidance System (TCAS). Cockpit Display of Traffic Information (CDTI) is a new traffic display based on Automatic Dependent Surveillance-Broadcast (ADS-B) and related Aircraft Surveillance Applications System (ASAS) technologies. These technologies are capable of providing much more data about nearby aircraft than TCAS or other current surveillance systems. In fact, so much data might be provided through the traffic symbol's shape, color, and other visual features, that the pilot may have difficulty interpreting all of it. A particular concern is in regards to learning and remembering how to interpret the traffic symbols, because incorrect interpretations could lead to operational errors.

This study was conducted to assess pilots' ability to learn and remember traffic symbols based on ASAS data. We focused on the visual features of the symbols that could be interpreted on a static display. However, we recognize that symbols shown on a dynamic and interactive display may be easier to interpret than static symbols, because pilots may be able to derive information from the motion of the symbol or from direct interaction with the symbol. The impact of these dynamic aspects of the CDTI could be evaluated in future research. While the current study by itself cannot answer all the questions related to design of traffic symbology, it addresses a very important aspect related to overall symbol set usability.

Our goal in testing the traffic symbols was to determine whether there are some general design principles that should be followed. This will allow manufacturers flexibility in designing the symbols while providing some level of consistency across

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platforms for pilots. Our intention was not to develop a single optimal set of symbols for traffic display.

Results of this study were considered by a Federal Advisory committee that develops standards for these traffic displays (RTCA SC-186). The standards have since been published by RTCA as DO-317 [1].

Previous Research

A literature review conducted in regards to traffic symbols found relatively little past research that specifically evaluated different visual features for simple two-dimensional symbols that can easily be drawn on typical flight deck displays. One of the few studies of symbols was by Harte and Wempe [2] from 1979, in which they gathered air line pilot opinions on traffic symbology including content and format. They found no difference in pilot preference between indicating Directionality with a barb attached to the traffic symbol versus a triangular shape for the traffic symbol. However, they did not measure human performance with the two alternatives.

A more recent unpublished study was conducted by Zuschlag, Krebs, and Kaliardos [3]. In this study, symbols were shown to participants on a laptop computer for a short time and the participant's task was to identify the symbol. The results found that encoding information by outlining a traffic symbol may interfere with distinguishing between outlined and filled symbols. Symbol fill was used to encode other information in the study.

A study on traffic symbology was also conducted by Chandra, Yeh, and Zuschlag in 2007. Results of this study were presented to RTCA as a briefing [4]. This study was based on a short paper-and-pencil task in which pilots tried to interpret ten example traffic symbols without any prior training, in order to evaluate what pilots would find intuitive in a traffic symbol set. The test was completed by 112 pilots, of which 72 were Air Transport pilots and 90 had TCAS II experience. The results showed that:

- Selection state is associated with a symbol border of some type.
- Air/Ground state is associated with symbol shape.
- Conflict alert status is associated with red and yellow color coding.
- Information quality (high vs. low) is not strongly associated with a single feature.

These results suggest what pilots would find intuitive in a traffic symbol set, at least for a relatively small number of symbol possibilities. However, the intuitiveness of the symbols is not the only indication of symbol set ease of use. Symbol set ease of use is more directly tied to how easily pilots can learn the symbol set and how well they remember the symbol set after a period of nonuse. While an intuitive symbol set should be easy to learn and remember, it is possible that an alternative well-designed set may be as easy or easier once pilots are exposed to it and understand its internal logic.

The current study assesses four symbol sets for their intuitiveness (as discussed above), ease of learning, and ease of remembering. The intent was to identify the relation of individual symbol features to pilot's intuition, learning, and remembering of the symbols. For the purpose of providing guidance for developing minimum operational performance standards, the emphasis was on identifying any *major* performance impacts associated with certain symbol features. The intent of the study was not to establish a single best symbol set from the four nor was the intent to evaluate the symbols on all dimensions relevant to human performance.

Method

The current study was conducted online in order to reach a large number of pilots within a short time frame and in order to allow a dynamic presentation of symbols according to the participant's performance. Participants were recruited through postings in electronic newsletters of the Aircraft Owners and Pilots Association (AOPA), the Air Line Pilots Association (ALPA), and the National Business Aviation Association (NBAA).

The participants accessed the online study from a link provided in the electronic postings. Each time the study was accessed, one of the four symbol sets was sequentially selected, and only the symbols in that set were shown. The study was expected to take approximately 45 minutes to complete. Participants were not compensated for their time.

Participants

All participants were required to answer a question regarding whether they were licensed and current pilots or were student pilots. Participants who indicated that they were licensed and current (and not student pilots) were allowed to complete the study, although there was no way to independently verify whether each participant was actually a pilot. Data were aggregated for each participant for the analysis.

When the data collection closed (two weeks after the study opened), 623 pilots had completed at least the part of the study that covered symbol intuitiveness and ease of learning. A total of 411 participants completed the entire study, which included a follow-up about one week later. A breakdown of pilot experience is shown below in Table 1.

Table 1. Participant flight experience breakdown

Type of Operation	# Pilots	Average Flight Hours	# of Pilots with TCAS Experience
Air Transport	152	8841	139
Corporate	82	5371	62
Military	18	3186	5
Private Only	371	1190	83
Total	623		289

Symbols

The four symbol sets used in the study and their corresponding definitions are shown in Table 2 below. Each symbol is described in terms of six parameters:

- Directionality
- Data Quality
- Air/Ground Status
- Alert Level
- Selection Status
- Pairing Status

A description of each of these parameters is provided in Table 3. All parameters had two possible states (e.g., Airborne, On-ground) except for the Alert Level parameter which has three possible states (No Alert, Caution, or Warning).

Procedure

Figure 1 illustrates the beginning of the study from the participant's perspective. In the first screen they saw introductory material. This material explained the requirements for participants (e.g., licensed and current pilots only), the different tasks, a few ground rules for participation (e.g., each participant should only submit data once), and background on how the results of the study would be used.

Next, participants saw an Informed Consent form. To proceed, the pilots had to select a link to indicate that they freely agreed to participate; otherwise they could choose to decline and exit the study.

After agreeing to participate, pilots answered background questions about their flight experience. The questions asked about total flight time, the types of flight operations they flew, experience with other traffic displays (e.g. TCAS), and how they heard about the study.

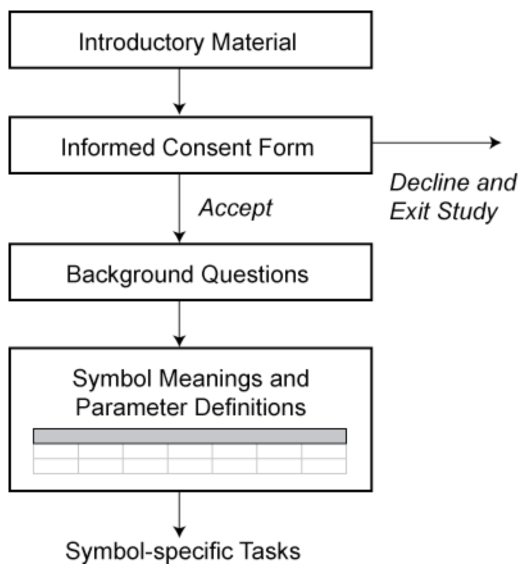

Figure 1. Beginning of the study

Prior to seeing any test symbols, the pilots received basic instructions on the information that the symbols could indicate. The instructions read:

> *The symbol conveys information about the traffic through its color and/or shape. Other characteristics that may encode information include the symbol border, symbol size, and presence/absence of a data tag. The data tag indicates the relative altitude difference between ownship and the traffic aircraft includes a climb/descent trend arrow, and possibly other information as well.*

Table 2. Correct interpretations of tested symbols.

Label	Set 1	Set 2	Set 3	Set 4	Direc-tional	Limited Data Quality	Ground (vs. Airborne)	Alert Level[1]	Selected	Paired
A					✓					
B						✓ 3				
C	--				✓	✓				
D					✓		✓			
E					✓				✓	
F					✓					✓
G					✓			Caution		
H					✓			Warning		
I		--				✓				
J						✓ 3	✓			
K						✓ 3			✓	
L						✓ 3		Caution		
M						✓ 3		Warning		
N					✓ 2	✓	✓			
O					✓ 2	✓			✓	
P					✓ 2	✓		Caution		
Q					✓ 2	✓		Warning		
R					✓		✓		✓	
S					✓		✓			✓
T					✓			Caution	✓	
U					✓			Caution		✓
V					✓			Warning		✓

[1] Blank represents no alert
[2] Non-directional only for Set 1. Directional for Sets 2, 3, and 4.
[3] Limited Data Quality only for Set 2. Full Data Quality for Sets 1, 3, and 4.

Table 3. Data available in each traffic symbol

Information Category	Possible States	
Directionality Indicated	**Directional** The ground track of the traffic aircraft is displayed.	**Not Directional** The ground track of the traffic aircraft is not known.
Data Quality	**Full** The position of the traffic aircraft is of high accuracy and can be used for all operational procedures.	**Limited** The position of the traffic aircraft is of reduced accuracy and can only be used for limited operational procedures. The position is of sufficient quality to assist in visually locating the aircraft out the window.
Air/Ground	**Airborne** The traffic aircraft is in the air.	**On-Ground** The traffic aircraft is on the ground.
Alert Level (Three States)	**No Alert** The traffic is not a threat of any kind	
	Caution A caution is given for a traffic aircraft that may soon become a threat. The condition requires immediate pilot awareness, and possible subsequent pilot response. For example, the TCAS traffic advisory (TA) symbol represents a caution state.	
	Warning A warning is given for a traffic aircraft that is a threat. The condition requires immediate pilot awareness and immediate pilot response. For example, the TCAS resolution advisory (RA) symbol represents a warning state.	
Selection	**Selected** Traffic aircraft is "selected" by the pilot for further information and/or action.	**Not Selected** Traffic aircraft is not "selected" by the pilot.
Pairing	**Paired**[1] Traffic aircraft information is being used by an aircraft system to provide data and/or guidance (e.g., for following an aircraft on approach).	**Not Paired**

In addition to this text, participants were asked to study a parameter definition table (see Table 3), which listed and described each of the six parameters indicated by the symbol. Participants could review the parameter definition table at any time during the first two tasks. A "Show Definitions" link on each page provided access to a pop-up window containing for review.

After these initial steps outlined above, pilots completed the first two tasks with the test symbols, described below in the Tasks section. Once the tasks were completed, the participant saw a conclusion page, which gave him/her the option to submit an email address to register for the follow-up task. Pilots who registered were sent a reminder email in one to two weeks with a different link to get to this third task.

Symbol-Specific Tasks

Figure 2 illustrates the order and details of the symbol-specific tasks. The first task assessed symbol intuitiveness. The second task addressed ease of learning. The third task, an optional follow-up one to two weeks later, addressed ease of remembering the symbols. For a given pilot, all three tasks used the same symbol set (Set 1, 2, 3, or 4).

[1] Called "coupled" in RTCA DO-317 [1].

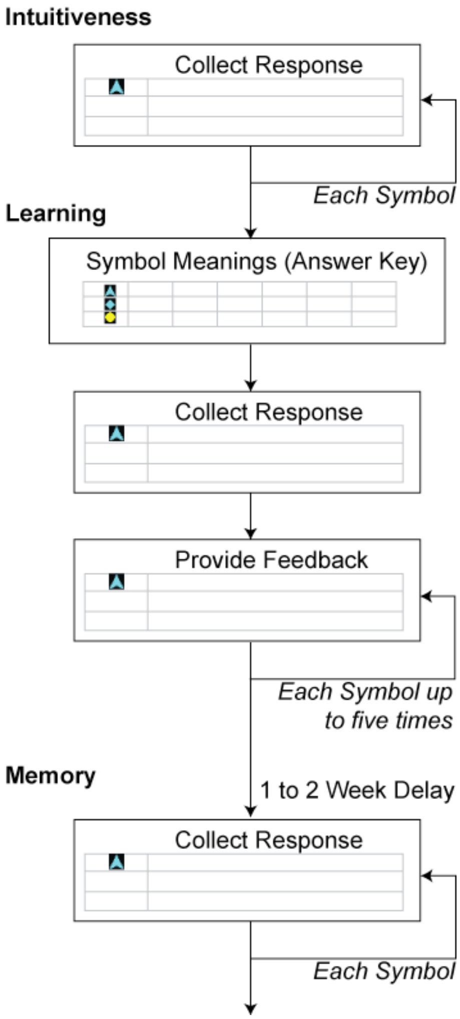

Figure 2. Symbol-specific tasks in the study

In the Intuitiveness task, pilots saw each symbol in a random order before they received any training on the symbol meanings. The pilots simply guessed at what they thought the symbols represented based on any prior knowledge and any assumptions based on that knowledge.

Figure 3 shows a screenshot of a response page from the Intuitiveness task. Pilots indicated their response by clicking on the corresponding radio buttons (circles) on the screen. A progress bar appeared across the top of the screen to help the pilot estimate the time remaining on the task. On the bottom right, pilots were given a link to the parameter definitions ("Show Definitions"), in case they wanted to review any of the items

During the Learning task, pilots first saw a table that listed the meaning of each symbol in the set. This table essentially provided an answer key that was specific to the symbol set that the participant was shown. Participants were not limited in the amount of time to study the table, but once they moved past the table, they could not return to it.

Figure 3. Intuitiveness task sample response page

After viewing the table of symbol meanings, the participant was again presented with each symbol one at a time in random order and asked to indicate what information was represented, using the same response entry method as during the Intuitiveness task. However, this time, the pilots received feedback after each symbol presentation on whether their answers were correct or not, to aid them in learning the correct symbol meanings.

A sample feedback page is shown in Figure 4. The correct response is shown in green, and the pilot's response is indicated with "Your answer" printed next to it; in red if the pilot's response was incorrect, in black otherwise.

If a pilot's response to a symbol was correct two times in a row, then the symbol was considered to be "learned" and it was not presented again to the pilot. If a pilot answered incorrectly on any one of the six parameters, the symbol was shown again, up to a maximum of five presentations. If the pilot did not respond to the symbol correctly two times in a row even after five presentations, it was considered that he/she did not succeed in learning its meaning within the allotted number of trials and the symbol was not presented again.

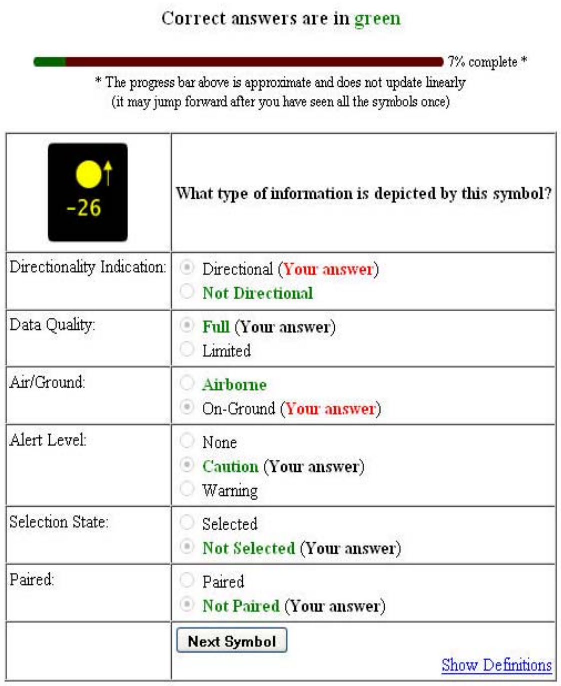

Figure 4. Sample feedback from Learning Task page

The follow-up Memory task was completed one to two weeks after participants completed the Learning task. This Memory task assessed pilots' retention of the symbol meanings after a period of nonuse. Pilots were presented the same symbol set as in the previous tasks without a review of the correct symbol meanings or parameter definitions. The participants were asked to interpret the symbols one at a time, the same way as in the Intuitiveness task.

Analysis

Each task and each parameter was analyzed separately. In all cases, Symbol Set was a between-subjects independent variable with four possible values and the symbol parameter (e.g., Directionality) was a within-subjects independent variable with two possible values for all parameters except Alert Level, which had three possible values.

For the Intuitiveness and Memory tasks, the dependent variables were each pilot's average *percent of correct responses* (i.e., accuracy) for indicating the parameter meaning. For the Learning task the dependent variable was a *Learning Difficulty Score* which was calculated for each parameter meaning (e.g., On-ground symbols had a different score than Airborne symbols). The Learning Difficulty Score represents the frequency of getting a meaning wrong, normalized by exposure to that meaning. The learning difficulty for meaning is calculated according to the following formula,

Learning Difficulty Score = w / m,

where

w = the number of incorrect trials

m = the number of symbols with that meaning (e.g., $m = 5$ for On-ground for all symbol sets).

In other words, the Learning Difficulty Score was each participant's *number of trials to learn the parameter meaning divided by the number of symbols in the pilot's set with that meaning.* Thus, a zero represents the participant getting the meaning correct for all trials in which the symbols with that meaning were presented. A 1.0 is equivalent to the participant getting every symbol with that meaning wrong once. A score of 1.0 is also equivalent to a participant getting half of the symbols with that meaning wrong twice. Random guessing for a binary meaning (any parameter other than Alert Level) has Learning Difficulty Score of about 2.5, indicating a participant was presented each symbol with a meaning five times, and got the meaning wrong half of the time [$w = m * 5 * 0.5$, Learning Difficulty Score = $(m * 5 * 0.5) / m$].

T-tests and Chi-square tests were also performed on individual symbols to explore the details of the results of the above analyses. The analyses of the Memory task included only pilots who successfully learned the symbols in order to measure *retention* of the meanings that had been learned before.

Results

Results are presented separately below for each of the six symbol parameters by task. Averages across participants are denoted as *M*. Sometimes these are average percent correct responses, other times these represent average Learning Difficulty Scores. The results from analyses of variance (ANOVAs) are presented with their respective *F* test statistics and their associated Null Hypothesis probability levels, *p*, indicating the strength of the findings; lower *p* values indicate higher levels of statistical significance.

Directionality

Intuitiveness

Directional symbols (*M* = 80%) tended to be more intuitive than non-directional symbols [*M* = 65%, $F(1,859) = 94.508$, $p < 0.001$]. This appeared to be especially true for Symbol Sets 3 and 4 [$F(3,859) = 4.946$, $p = 0.002$]. For example, while the average percent correct for Sets 3 and 4 for Symbols B, I, K, L, and M was near chance (54.1%), the average percent correct for Sets 1 and 2 on the same symbols was higher (60.6%), even though the non-directional symbols for Set 1 and 2 were similar (in some cases identical) to Sets 3 and 4.

Learning

Non-directional symbols were harder to learn, having a Learning Difficulty Score of 0.11 versus 0.03 for the directional symbols [$F(1,619) = 25.646$, $p < 0.001$]. However, in contrast to the intuitiveness results, the sets showed no significant differences in the learnability of the Non-directional versus Directional symbols [$F(3,619) = 1.070$, $p = 0.361$)].

Memory

Non-directional symbols were harder to remember than Directional symbols after they had been learned [$F(1,279) = 48.693$, $p < 0.001$], with participants remembering Non-directional symbols correctly 88% of the time and remembering Directional symbols correctly 98% of the time. The sets showed no significant differences in the memorability of the Non-directional versus Directional symbols [$F(3,279) = 2.214$, $p = 0.087$].

Data Quality

Intuitiveness

The Data Quality of Full symbols (*M* = 58%) was less intuitive than Limited symbols [*M* = 77% $F(1,869) = 154.504$, $p < 0.001$]. Participants tended to associate the lack of altitude data with Limited Data Quality; 74.4% of the time symbols with blank or dashed altitude tags were regarded as Limited. Pilots may have assumed that if altitude is "unknown," the Data Quality for the traffic must be Limited. In fact, all four symbol sets were designed such that the altitude tag was suppressed for ground traffic. In other words, lack of an altitude tag indicated an on-ground target, but had no bearing on the Data Quality.

The Limited symbols for Sets 2 and 3 tended to be less intuitive than Set 1 and 4 [$F(3,859) = 20.127$, $p < 0.001$], the latter of which used the text "LMTD" in the data tag. Participants marked Symbols C, K, P, Q, R, S of Sets 1 and 4 as Limited 91.7% of the time. The "bullet" shape in Set 2 in particular (a round head with two tails) was not associated with Limited quality, with participants marking Symbols C, P, Q, R, of Set 2 as Limited 50.9% of the time.

Traditional TCAS symbols (Symbols B, L, and M of Set 1, 2, and 4) did not have an intuitive association with either Full or Limited quality. Pilot responses for these symbols were not significantly different from random guessing.

Learning

The Data Quality parameters for both Limited and Full quality symbols of Set 2 were substantially harder to learn than the other sets [$F(3,619) = 50.050$, $p < 0.001$], with each symbol in Set 2 having a Learning Difficulty Score of 0.50 while symbols in the other sets had 0.07. While Limited and Full symbols were about equally hard to learn in Set 2, the Limited symbols for the other sets were harder to learn than the Full symbols [$F(3,619) = 6.040$, $p < 0.001$].

Memory

The Data Quality for the symbols in Set 2 was not as easy to remember as Data Quality for the symbols in other symbols sets [$F(1,279) = 28.781$, $p < 0.001$)]. While the Data Quality for other three sets was correctly remembered 98% of the time, the Data Quality for Set 2 was correctly remembered only 84% of the time. While Limited and Full symbols were remembered about equally well for Sets 1, 3, and 4, for Set 2, participants had more difficulty correctly remembering the Limited symbols (the bullet and non-directional symbols), than the Full symbols (the arrowhead shapes), averaging 75% and 93% respectively [$F(3,279) = 14.355$, $p < 0.001$].

Air/Ground

Intuitiveness

Airborne symbols (*M* = 90%) were more intuitive than On-ground symbols [*M* = 62%, $F(1,869) = 33.070$, $p < 0.001$]. However, Set 3 On-ground symbols, the one set to use green to indicate On-ground, appear to be less problematic than those of Set 1, 2, and 4 [$F(3,859) = 26.341$, $p < 0.001$], with participants correctly guessing 82.4% of the time that

Symbols D, J, N, R, and S were On-ground. For the other three sets, the ground symbols were not intuitive, with participants correctly guessing 55.5% of the time that Symbols D, J, N, R, and S were On-ground.

Learning

While Airborne symbols for all sets were relatively easy to learn (*M* = 0.02), the On-ground symbols for Set 2 (*M* = 0.33) were on average more difficult to learn than the On-ground symbols of the other sets [*M* = 0.04, $F(3,619) = 28.242$, $p < 0.001$]. However, detailed inspection revealed that only Symbol S in Set 2 was particularly difficult to learn. In the experiment, this symbol was mistakenly rendered as all green when the designer intended that it be tan with a green border. As a result, its only difference from Symbol F in Set 2 (an Airborne symbol) was the absence of the altitude tag. All other On-ground symbols for Set 2 consistently included tan coloring.

Excluding Symbol S of Set 2, the On-ground symbols of all sets were relatively easy to learn, having a Learning Difficulty Score of 0.04. Set 3 On-ground symbols were somewhat easier to learn than the other sets, with a Learning Difficulty Score of 0.02 [$F(9.5,2292.1) = 2.056$, $p = 0.027$)].

Memory

The only finding for ease of remembering was difficulty remembering the erroneously rendered Symbol S of Set 2, which was also hard to learn. Otherwise, pilots did not perform significantly differently among the remaining symbols.

Alert Level

Intuitiveness

Pilots found the symbols highly intuitive for indicating Alert Levels, guessing the correct Alert Level 91.0% of the time. Warnings (*M* = 96%) were guessed correctly more often than Cautions (*M* = 92%), which were guessed correctly more often than No Alerts [*M* = 89%, $F(1.9,1683.4) = 45.825$, $p < 0.001$], except, however, for Set 3 [$F(5.8,1683.4) = 5.014$, $p < 0.001$], where No Alert (*M* = 94%) was about as intuitive as Caution.

Set 3 was the only set to use green rather than tan to indicate On-ground (see Air/Ground above). The Alert Level for tan-colored symbols (used to mean On-ground) tended to be incorrectly identified more often than purely cyan symbols (78% versus 94%). Symbols that included magenta borders (Set 3, Symbols E, K, and O) also tended to be misidentified more often (85%).

Learning

Overall, the Alert Levels were learned easily on all sets, with each symbol having a Learning Difficulty Score of 0.018 on average. Warning (*M* = 0.004) and Caution (*M* = 0.011) symbols were learned faster than No Alert symbols [*M* = 0.025 $F(1.3, 831.5) = 10.043$, $p < 0.001$], except for Set 3 [$F(4.0, 831.5) = 2.403$, $p = 0.048$] where No Alert was as easy to learn as the other symbols (*M* = 0.002).

Memory

The Alert Levels were highly memorable, with symbols being correctly identified 99.2% of the time. There were no significant differences among the sets or Alert Levels.

Selection and Pairing

Intuitiveness

In general, pilots found the symbols were not very intuitive for the Selection and Pairing parameters, with pilots guessing correctly 63% of the time on average. Selected (*M* = 57%) and Paired (*M* = 40%) symbols were less intuitive than Non-selected (*M* = 72%) and Non-paired symbols for all sets [*M* = 84%, $F(1,869) = 94.346$, $p < 0.001$ and $F(1,869) = 787.983$, $p < 0.001$, respectively]. The Selected symbols for Set 2 were particularly non-intuitive [*M* = 44%, $F(3,859) = 6.312$, $p < 0.001$].

All symbol sets used at least two kinds of borders, usually to distinguish Selected from Paired states (e.g., Symbols E, F, K, O, R, S, T, U, V), but also sometimes to indicate an Alert Level (G and H for Sets 1 and 2, P and Q for Set 2). No particular kind of border was intuitively associated with Selected; symbols with borders were regarded as Selected 54.6% of the time overall (which is statistically consistent with random guessing). However, the gray "halo" border used for Set 2 (Symbols E, O, and R) was generally *counter-intuitive* (being guessed correctly significantly less than chance) for indicating a Selected state, averaging 39.7%.

A border tended to be counterintuitive for the Paired information state, with all bordered symbols being regarded as Paired 31.9% of the time. It appears that none of the visual features in any of the symbols were associated with Paired. On average each symbol was marked as Paired 20.7% of the time.

Learning

Participants found it hard to learn the difference between Selected and Paired symbols (M = 0.20). Learning of Non-selected symbols (M = 0.22) was harder than learning Selected symbols [M = 0.15 $F(1,619) = 13.119$, $p < 0.001$], with pilots frequently indicating that Non-selected but Paired symbols (Symbols F, S, U, and V in Table 2) were Selected. Learning which bordered symbols were Selected and which were Paired had a Learning Difficulty Score of 0.27 on average. In contrast, the Learning Difficulty Score for non-bordered symbols was 0.08 on average.

Paired symbols (M = 0.31) were harder to learn than Non-paired symbols [M = 0.11, $F(1,619)$ = 59.187, $p < 0.001$], especially for Set 3 [M = 0.45, $F(3,619) = 5.809$, $p = 0.001$], where the difference between Paired and Selected symbols was in some cases only the color of the border.

Set 2 (M = 0.29) was harder to learn than other sets [M = 0.15, $F(3,619) = 5.076$, $p = 0.002$] for Selected and Not Selected symbols. In Set 2, Symbols G and H used circular borders to indicate Caution Alert Levels, and Symbols P and Q used square borders to indicate Warning Alert Levels in an effort to be consistent with TCAS symbols. However, this made it difficult for participants to learn that these symbols were not Selected or Paired. Learning that the square and circle outlines did *not* mean Paired had a Learning Difficulty Score of 0.43 on average , and learning that other “conformal” outlines (symbols F and S) *do* mean Paired had a Learning Difficulty Score of 0.46.

Memory

The use of borders to indicate Paired was not especially memorable, with participants forgetting the Paired symbols (M = 88% remembered) more than Non-paired symbols [M = 93%, $F(1,279)$ = 5.206, $p = 0.023$]. Across all sets, symbols with borders were correctly remembered 86% of the time regardless if they were Paired or not. In contrast, participants correctly remembered that un-bordered symbols were Not Paired 98% of the time. The tendency to forget Paired symbols was especially true for Set 3 [M = 83%, $F(3,279) = 4.134$, $p = 0.007$]. However, for Set 2, Non-paired symbols (M = 90%) were forgotten more often than Paired symbols (M = 94%), apparently due to confusion with the borders used for Non-paired Caution and Warning symbols.

Summary of Results

To summarize the results:

- The arrowhead shape for Directional traffic appears to be intuitive for distinguishing between Directional and Non-directional traffic within the symbol set.
- A single visual feature, like a “LMTD” data tag, appears to be effective for identifying Data Quality that is Limited (as opposed to Full).
- Color appears to be effective for distinguishing Airborne from On-ground traffic.
- The colors yellow and red are well associated with Cautions and Warnings, respectively.
- Distinguishing the Selection parameter from the Pairing parameter with different kinds of borders leads to confusion.

Discussion

Results are discussed separately below for each of the six symbol parameters.

Directionality

Pilot learning and remembering performance on the Directionality parameter was consistent with pilot preferences found by Harte and Wempe [2], with no differences across the symbol sets. However, the arrow that depicts vertical speed, which was not present in Harte and Wempe’s symbology, may have been confused with the depiction of lateral directionality (heading or track) for untrained pilots. The greater intuitiveness of Sets 1 and 2 on *Non-directional* symbols suggests that the arrowhead-shaped *Directional* symbols may make it easier to guess the *Non-directional* symbols. Perhaps the arrowheads cue pilots that the vertical direction arrow is not a lateral directionality indication (i.e., that one should look for “shape-silhouette difference” not “line absence” for a Non-directional state).

Note that this experiment always had the traffic symbol and the vertical direction arrow in the same orientation (pointing up) which could have exaggerated this effect. In a dynamic display, it is unlikely that the traffic symbol and vertical direction arrow would be pointed in precisely the same direction for very long. However, the results suggest it may be better to place the vertical direction arrow beside the altitude tag rather than next to the traffic symbol to increase the visual association of the vertical direction arrow with vertical position.

Data Quality

It may be logical to remove the altitude tag for traffic on the ground, but designers should recognize that untrained pilots may assume that the absence of a data tag represents Limited Data Quality. A separate strong visual indication of Data Quality may be necessary to overcome this tendency. The confusion of the altitude tag with Data Quality illustrates an issue that emerges when a single symbol encodes multiple parameters. The more parameters to encode in a symbol, the greater the likelihood that one form of encoding may be intuitively associated with more than one parameter. If Data Quality were not represented in these symbols, and thus pilots were not looking for its encoding, they may have been more likely to intuitively recognized that a lack of an altitude tag indicated On-ground traffic.

The confusion in Set 2 seems to be fostered by the lack of a single visual indication of Data Quality. While Set 1, 3, and 4 had a unique visual feature associated with Data Quality (either an "X" in the symbol or the text "LMTD"), Set 2 indicated Limited Data Quality by either a bullet shape or a non-directional shape. It may be difficult to learn that a single state (Limited) can be represented by two different visual aspects (bullet or non-directional shapes). It also may be hard to learn that a single visual feature (a non-directional shape) may indicate states for two different parameters (Directionality and Data Quality). Set 2 had both of these within its symbol set which likely increased the difficulty of learning the set

Air/Ground

The confusion pilots had with On-ground for Symbol S of Set 2 may have been similar to the difficulty they had with Data Quality for Set 2, where the parameter was not consistently mapped to a single visual feature. In the case of Set 2, On-ground status was denoted by a tan color, except for Symbol S, which was mistakenly rendered as all green when the designer intended that it be tan with a green border. The difficulty may also suggest that absence of an altitude tag may by itself be too weak of a cue that traffic is on the ground. As we have seen, pilots are more likely to associate the absence of the data tag with Limited Data Quality.

A higher level of performance for Set 3 for On-ground could be attributed to a several possibilities. Possibly "ground" was more associated with green (used by Set 3) than tan (used by the other three sets), or that the color values used for tan in this study did not appear particularly tan on some participants' computer monitors (see Alert Level below). Alternatively, consistent with Chandra, Yeh, and Zuschlag [4], perhaps pilots expected ground (versus airborne) traffic to have a unique shape silhouette rather than a shape modification that keeps the same silhouette (like a dot or size used by Sets 1 and 2). It is also possible that the rectangle in particular suggested something non-aerodynamic, and therefore not airborne (as intended by the symbol set designer). Further research is needed to explore these possibilities.

Alert Level

Using yellow for Caution and red for Warning was well understood by pilots. All symbol sets tested included other symbol changes (e.g., shape) in addition to color to indicate Alert Level (e.g., circles and squares for Caution and Warning respectively in Sets 1, 2, and 4). However, we did not assess the effect of the shape changes as a separate factor in this experiment. Changes in additional visual aspects may be necessary to provide cues to pilots with color vision deficiencies.

Colors used in non-alert symbols should also be considered in the context of the yellow and red symbols used for indicating Cautions and Warnings. One possible difficulty with tan may be because it was hard to distinguish from the color amber on certain computer monitors used by our participants. In 14 CFR §§ 23.1322, 25.1322, 27.1322, 29.1322, amber is associated with a Caution state. This suggests a need for careful evaluation of color rendering performance on an airborne display if the intention is to show non-alert symbols in colors close to red, amber, or yellow.

Selection and Pairing

In contrast to the results of Chandra, Yeh, and Zuschlag [4], borders did not appear to have a strong intuitive association with Selected. However, unlike the symbols use by Chandra, Yeh, and Zuschlag, each symbol set in this study had more than one kind of border which may have created some ambiguity. Using different borders to distinguish Selection and Pairing status appeared to confuse pilots. This confusion extended to the use of outline squares and circles for Warning and Caution states for Set 2. The implication is that only one kind of outline should be used for a symbol set to mean information parameter, and using two different kinds of outlines to distinguish Selection from Pairing status should be avoided. If more than one kind of border is used (e.g., one to indicate a Selected state and one to make Caution and Warning symbols consistent with TCAS, as in Set 1), the border types should be as different as possible, such as by using a "reverse" border circle and square border for Caution and Warning, as seen for Symbols G and H in Set 1, and a conformal outline for Selected or Paired, as seen for Symbol F in Set 2.

For the symbols tested, there does not appear to be any visual feature that is particularly intuitive for indicating a Paired state. This may be due to the Pairing concept being unique to ASAS operations and unfamiliar to most pilots. If pilots were more familiar with ASAS, perhaps the symbols would have been more intuitive. Or, perhaps if a border were reserved consistently for *either* the Selected or Paired state, pilots would learn the meaning of the border regardless of any previous associations. Alternatively, perhaps borders of any kind are not intuitively evocative of Pairing status even among pilots familiar with ASAS, and perhaps a different visual aspect should be used. Further research on this is necessary.

Summary and Conclusions

In this study, pilot performance was assessed for intuitiveness, ease of learning, and ease of remembering on four sets of symbols. Each symbol encoded six traffic parameters. While the current study addressed important aspects of traffic symbol usability, it did not address other human performance considerations, such as clutter, workload, symbol discriminability, and effects on other flight-related tasks. The main goal of this study was to identify symbol design options that could have significant problems in terms of intuitiveness, ease of learning, or ease of remembering. The results of this study cannot (and were not intended to) determine an optimal symbol set.

With the above limitations in mind, the results of this study support the following conclusions about traffic symbol design:

- Directionality is most intuitively associated with a pointed symbol shape rather than a barb.
- Data Quality is easily learned and remembered if it is indicated by the presence/absence of data tag text or another single specific feature.
- Color is effective for distinguishing between Airborne and On-ground symbols. Shape may also be an effective cue.
- Yellow is strongly associated with Caution and red is strongly associated with Warning. Using colors close to yellow and red for other meanings can cause confusion.
- Confusion during learning is minimized if only one kind of border is used in the symbol set. In this study, which used borders for both Selected and Paired symbols, intuitiveness was maximized if the border was not used for Paired symbols.

The results also have implications for general symbol design:

- A symbol set should avoid using more than one visual feature to represent one information parameter (e.g., using both a bullet and diamond shape to indicate Limited Data Quality).
- Two or more similar-looking visual features (such as two forms of outlining) should not be used to represent different information parameters (e.g., Selection and Pairing status).

Future work should address other human performance considerations for traffic symbology, such as the number and types of information parameters that should be graphically represented within the traffic symbol, versus whether those information parameters should be shown in a data tag or block. Also, research should investigate real world effects on symbol usability, such as traffic motion cues, integration with surface maps, and pilot workload.

References

[1] RTCA (2009). Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications System (ASAS). DO-317.

[2] Hart, S.G. and T.E. Wempe, TE. (1979) Cockpit Display of Traffic Information: Airline Pilots' Opinions about Content, Symbology, and Format. NASA technical report A-7884, NASA-TM-78601.

[3] Zuschlag M; Krebs W; Kaliardos W (2004) Assessment of Proposed Traffic Symbol Set. Unpublished poster for FAA AAR-100 2004 Program Review.

[4] Chandra, D.C., Yeh, M., and Zuschlag, M. (2007) Presentation to RTCA SC-186 WG-1. Traffic Symbology Test.

[5] Warning, caution, and advisory lights, 14 CFR § 23.1322 (2005).

[6] Warning, caution, and advisory lights, 14 CFR § 25.1322 (2005).

[7] Warning, caution, and advisory lights, 14 CFR § 27.1322 (2005).

[8] Warning, caution, and advisory lights, 14 CFR § 29.1322 (2005).

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