Symbols for Cockpit Displays of Traffic Information

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13. ABSTRACT (Maximum 200 words)

A web-based study assessed pilots' ability to learn and remember traffic symbols that may be shown on a Cockpit Display 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. Three aspects of using the traffic symbols were evaluated: 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 State, Alert Level, Selection State, and Pairing State of nearby aircraft.

A total of 623 pilots with a broad range of experience participated. 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. Results of the study were considered by a Federal Advisory Committee that develops standards for these traffic displays (RTCA Special Committee 186).

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PREFACE

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The views expressed herein are those of the authors and do not necessarily reflect the views of the Volpe National Transportation Systems Center, the Research and Innovative Technology Administration, or the United States Department of Transportation.

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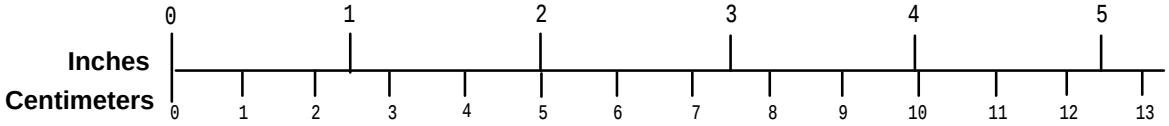
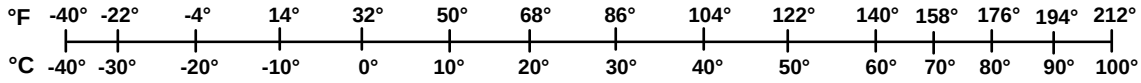
METRIC/ENGLISH CONVERSION FACTORS

ENGLISH TO METRIC	METRIC TO ENGLISH
LENGTH (APPROXIMATE)	**LENGTH (APPROXIMATE)**
1 inch (in) = 2.5 centimeters (cm)	1 millimeter (mm) = 0.04 inch (in)
1 foot (ft) = 30 centimeters (cm)	1 centimeter (cm) = 0.4 inch (in)
1 yard (yd) = 0.9 meter (m)	1 meter (m) = 3.3 feet (ft)
1 mile (mi) = 1.6 kilometers (km)	1 meter (m) = 1.1 yards (yd)
	1 kilometer (km) = 0.6 mile (mi)
AREA (APPROXIMATE)	**AREA (APPROXIMATE)**
1 square inch (sq in, in^2) = 6.5 square centimeters (cm^2)	1 square centimeter (cm^2) = 0.16 square inch (sq in, in^2)
1 square foot (sq ft, ft^2) = 0.09 square meter (m^2)	1 square meter (m^2) = 1.2 square yards (sq yd, yd^2)
1 square yard (sq yd, yd^2) = 0.8 square meter (m^2)	1 square kilometer (km^2) = 0.4 square mile (sq mi, mi^2)
1 square mile (sq mi, mi^2) = 2.6 square kilometers (km^2)	10,000 square meters (m^2) = 1 hectare (ha] = 2.5 acres
1 acre = 0.4 hectare (he) = 4,000 square meters (m^2)	
MASS - WEIGHT (APPROXIMATE)	**MASS - WEIGHT (APPROXIMATE)**
1 ounce (oz) = 28 grams (gm)	1 gram (gm) = 0.036 ounce (oz)
1 pound (lb) = 0.45 kilogram (kg)	1 kilogram (kg) = 2.2 pounds (lb)
1 short ton = 2,000 pounds (lb) = 0.9 tonne (t)	1 tonne (t) = 1,000 kilograms (kg) = 1.1 short tons
VOLUME (APPROXIMATE)	**VOLUME (APPROXIMATE)**
1 teaspoon (tsp) = 5 milliliters (ml)	1 milliliter (ml) = 0.03 fluid ounce (fl oz)
1 tablespoon (tbsp) = 15 milliliters (ml)	1 liter (l) = 2.1 pints (pt)
1 fluid ounce (fl oz) = 30 milliliters (ml)	1 liter (l) = 1.06 quarts (qt)
1 cup (c) = 0.24 liter (l)	1 liter (l) = 0.26 gallon (gal)
1 pint (pt) = 0.47 liter (l)	
1 quart (qt) = 0.96 liter (l)	
1 gallon (gal) = 3.8 liters (l)	
1 cubic foot (cu ft, ft^3) = 0.03 cubic meter (m^3)	1 cubic meter (m^3) = 36 cubic feet (cu ft, ft^3)
1 cubic yard (cu yd, yd^3) = 0.76 cubic meter (m^3)	1 cubic meter (m^3) = 1.3 cubic yards (cu yd, yd^3)
TEMPERATURE (EXACT)	**TEMPERATURE (EXACT)**
((x-32)(5/9)) °F = y °C	((9/5) y + 32) °C = x °F

QUICK INCH - CENTIMETER LENGTH CONVERSION



QUICK FAHRENHEIT - CELSIUS TEMPERATURE CONVERSION



For more exact and or other conversion factors, see NIST Miscellaneous Publication 286, Units of Weights and Measures. Price [2.50 SD Catalog No. C13 10286 **Updated 6/17/98**

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Executive Summary

Introduction

Information on Cockpit Displays of Traffic Information (CDTI) will come from Automatic Dependent Surveillance-Broadcast (ADS-B) and related Aircraft Surveillance Applications System (ASAS) technologies, as well as other surveillance data sources. Such CDTI displays will be capable of providing much more information about nearby aircraft than those relying on Traffic Alerting and Collision Avoidance System (TCAS) alone. In fact, so much information could potentially be provided through the traffic symbol shape, color, and other features that the pilot may have difficulty learning, remembering, and interpreting the symbol, which could lead to operational errors.

Relatively little past research has specifically evaluated different visual features for simple two-dimensional symbols that can easily be drawn on typical flight deck displays. The purpose of this study was to gather data about pilots' ability to intuit, learn, and remember traffic symbols that are based on ADS-B data. The purpose of the study was to uncover general design principles that should be followed, not to develop a single optimal set of symbols for traffic display or evaluate or compare potential sets. Determining such general principles will allow manufacturers flexibility in designing the symbols while providing some level of consistency for users.

Results of this study were considered by an industry committee that is developing standards for these traffic displays (RTCA Special Committee-186). Some of the findings affected standards for future traffic displays.

Method

The study measured three aspects of traffic symbol use in this study: intuitiveness, ease of learning, and ease of remembering the symbols. These three aspects are related, of course; intuitive symbols are likely to be easy to learn and symbols that are easy to learn are likely to be easy to remember.

Participants

The 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). When the data collection closed, 623 pilots had completed at least the first part of the study covering symbol intuitiveness.

Symbols

Four symbol sets were tested in the study, arbitrarily identified as Sets 1 through 4 (see Table 3, page 5). Most of the symbols tested in the study were developed by a subcommittee of RTCA SC-186, whose members included manufacturer and government representatives. The symbols tested in the study encoded information about six symbol parameters, each with two or three possible states. The parameters were:

- Directionality (Directional, with ground track angle shown, or not)
- Data Quality (Full or Limited)
- Air/Ground State (Airborne or On-ground)
- Alert Level (No Alert, Caution, or Warning)
- Selection State (Selected or not)

- Pairing State (“Paired” for a procedure or not)

Procedure

Each pilot only saw one of the four symbol sets. The pilot first read about the above parameters, then completed three tasks. The first task assessed symbol intuitiveness. The second task, the Learning task, addressed ease of learning. The third task, an optional Memory task completed one to two weeks later, addressed ease of remembering the symbols.

In the Intuitiveness task, pilots saw each symbol in a random order before they received any training on the symbol. The pilots simply guessed at what they thought that symbol represented based on any prior knowledge they had. The intuitiveness of a parameter state was measured by the percent of pilots that could correctly guess the state.

In the Learning task, pilots saw a table that listed the correct meaning of each symbol they saw in the Intuitiveness task. After studying this table at their own pace, they again saw each symbol one at a time and tried to indicate what information was represented, as they did during the Intuitiveness task. This time, however, the pilots got feedback on whether their answers were correct or not, giving them a chance to learn the correct symbol meanings. Pilots had to interpret the symbol correctly two times in a row in order to have it regarded as successfully learned. If they answered incorrectly, they saw the symbol again up to a maximum of five times. The ease of learning of a parameter was measured by the average number of trials the pilot selected an incorrect state for the parameter, where fewer incorrect trials indicated greater ease of learning.

The Memory task was done one to two weeks after participants completed the Learning task. There was no review of the correct symbol meanings. The pilots were just asked to interpret the symbols one at a time, the same way they did during the Intuitiveness task. The ease of remembering a parameter was measured as the percent of correct response. Results for the Memory task reported here only included pilots who had learned all the symbols successfully during Learning task in order to measure ease of remembering rather than ability to learn the symbols in the first place.

Findings

Analyses were done by parameter in order to uncover general design principles for representing each parameter state. Key findings were the following:

- The chevron (arrowhead) shape for directional traffic appears to make *non-directional* traffic symbols in the set more intuitive.
- A single visual feature, such as a “LMTD” data tag, works well for indicating Data Quality.
- Color appears to be important for distinguishing airborne from on-ground traffic.
- Yellow and red are well associated with cautions and warnings, respectively.
- Distinguishing the Selection state from the Pairing state with different kinds of borders leads to confusion.

Directionality

For the Intuitiveness task, Symbol Sets 1 and 2 generally had better performance on Non-directional symbols than Sets 3 and 4, despite the fact that there were few differences in Non-directional symbols across the sets. The sets *did* differ in their *Directional* symbols. Sets 1 and 2 used a chevron shape to indicate Directionality, while Set 3 and 4 used a barb. The better performance of Sets 1 and 2 suggests that the use of a barb for Directional symbols may be

making it harder to recognize Non-directional symbols. Perhaps in a quick glance, the vertical direction arrow present in all symbols was sometimes confused with a barb, causing some pilots to mistake a Non-directional symbol for Sets 3 and 4 with a Directional symbol.

Data Quality

On all three tasks, Set 2 had worse performance than the other sets for Data Quality. 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 attribute associated with Data Quality (either an "X" in the symbol or a "LMTD" tag), Set 2 indicated Limited data quality by either a "bullet" shape or a non-directional shape. It may be mentally 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 attribute (a non-directional shape) may indicate states for two different parameters (Directionality and Data Quality). Set 2 had both of these drawbacks.

Air/Ground

In the experiment, one symbol in Set 2 was accidentally rendered as all green when the designer intended that it be tan with a green border. As a result, the only indication that the symbol represented On-ground was the lack of an altitude data tag. All other Ground symbols were distinguished from Airborne symbols by their color. The Ground state for this symbol in Set 2 had particularly poor performance in the Learning and the Memory task. This suggests that color is especially important for indicating an On-ground condition. It may also suggest that absence of an altitude tag may by itself be too weak of a cue that traffic is on the ground.

Alert Level

Color coding with yellow for Caution and red for Warning was apparently very compelling. All Caution and Warning symbols performed very well on all tasks. However, the colors used for No-alert symbols should be chosen with consideration of the strong association of yellow and red with Cautions and Warnings. Three sets used tan to indicate an On-ground No-alert traffic, but the shade of tan was apparently hard to distinguish from the color amber on certain computer monitors used by the pilots, leading them to erroneously identify their alert state as Caution.

Selection and Pairing

All symbols sets used at least two kinds of border, usually to distinguish Selected from Paired states, but also sometimes to indicate an Alert Level as an adjunct to color coding. This appeared to cause confusion in all tasks with pilots attempting to distinguish different kinds of border, and associate each kind with different states. It appears that only one kind of border should be used for a symbol set to mean one state, and using two different kinds of borders to distinguished Selected from Paired should be avoided.

General Findings

Overall, the study findings implied the following guidelines for general symbol design:

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

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1 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 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 Special Committee (SC)-186. The standards have since been published by RTCA (2009) as DO-317, *Minimum Operational Performance Standards (MOPS) for Aircraft Surveillance Applications System (ASAS)*. Partial results from this study were also published and presented earlier at a conference (Chandra, Zuschlag, Helleberg, and Estes, 2009).

2 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 Harte and Wempe (1979), which gathered airline pilot opinions on traffic symbology including content and format. Of particular interest, no significant difference was found in pilot preference between indicating directionality (i.e., the direction in which the target aircraft is moving) 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.

In a more recent unpublished study (Zuschlag, Krebs, and Kaliardos, 2004), 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 data about the target aircraft in the study.

Another relevant study on traffic symbology used 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 (Chandra, Yeh, and Zuschlag 2007). 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 state 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 that does not appear to be intuitive 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.

3 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 control the 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). Word of the study also apparently made its way by an unknown channel to the web-base aviation newspaper AvWeb, which posted a paragraph about the study, including the online address for the experiment.

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.

3.1 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.

A total of 411 participants completed the entire study, which included a follow-up about one week later, and 623 pilots had completed at least the part of the study that covered symbol intuitiveness and ease of learning. Full details of participant attrition are in the Results section below. A breakdown of participant flight 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	91%
Corporate	82	5371	76%
Military	18	3186	28%
Private Only	371	1190	22%
Total	623		46%

Of these 623 pilots, 69% reported at least some experience with a traffic display of some kind (e.g., TCAS I, TCAS II, ADS-B). Of those who had experience with a traffic display, 67% reported having flown over 100 hours with a traffic display and 36% reported having flown over 1000 hours with a traffic display.

3.2 Symbols

The symbols tested in the study encoded information about six symbol parameters, listed below, and described in Table 2:

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

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). The definitions in Table 2 were developed with feedback from a symbology subgroup of RTCA SC-186.

Four symbol sets were tested in the study. The individual symbols and their corresponding definitions are shown in Table 3 below. To limit the length of the study, only a subset of the possible combinations of parameter values were tested.

3.3 Procedure

All participants began the study with a common set of introductory and background training material. After these sections were completed, each subject went on to the symbol-specific portions of the study. Screens shots from the study are provided in Appendix A.

3.3.1 Introduction and Training

Figure 1 illustrates the beginning of the study from the participant's perspective. Participants first saw a screen of introductory material that 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.

Table 2. 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**

[1] Called "coupled" in RTCA DO-317 (2009)

Table 3. Correct meanings 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.

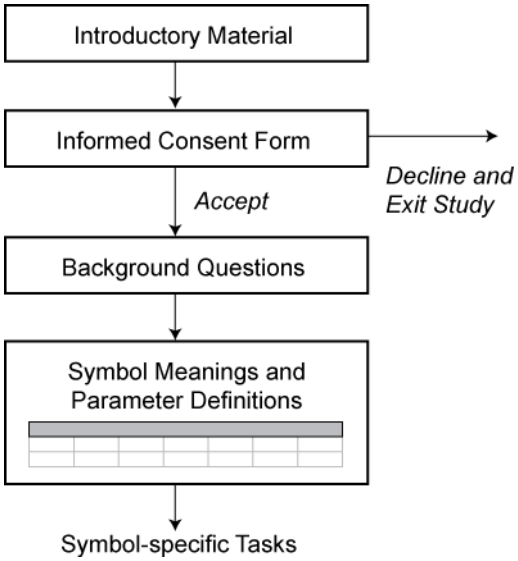

Figure 1. Beginning of study

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.

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.*

In addition to this text, participants were asked to study a parameter definition table (see Table 2), 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, which participants could view for as long as they wanted.

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.

3.3.2 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).

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.

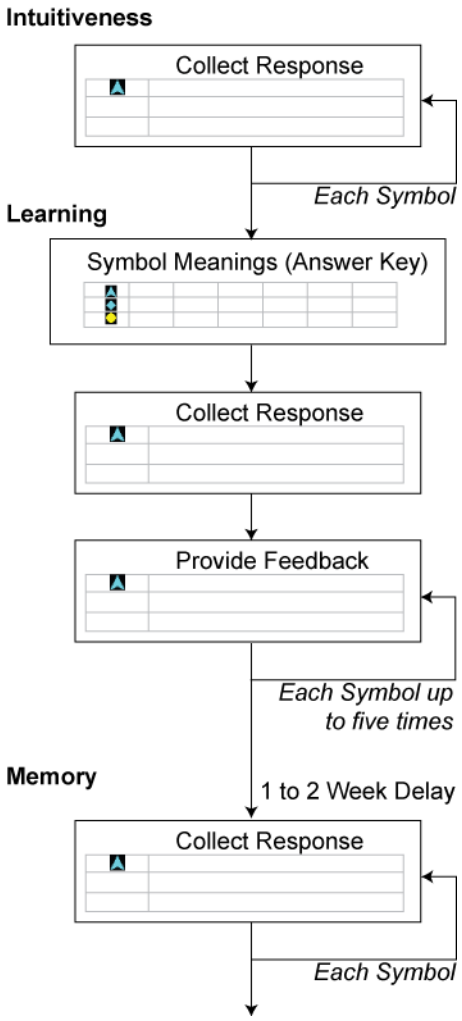

Figure 2. Symbol-specific tasks in the study

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 similar to Table 3 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.

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 states.

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

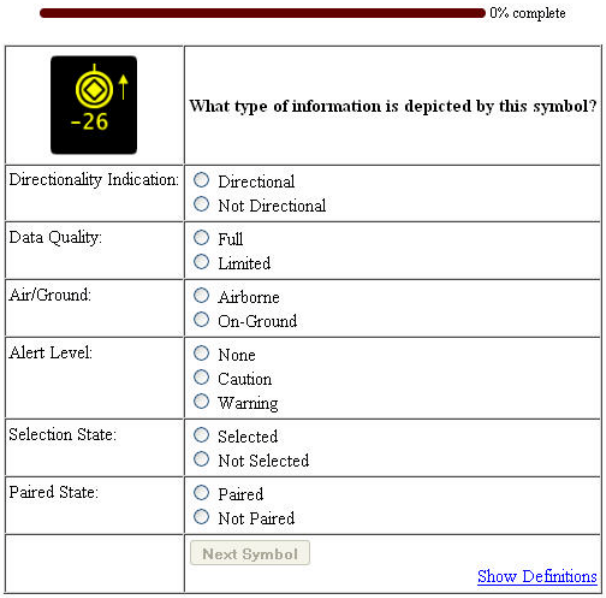

Figure 3. Intuitiveness task sample response page

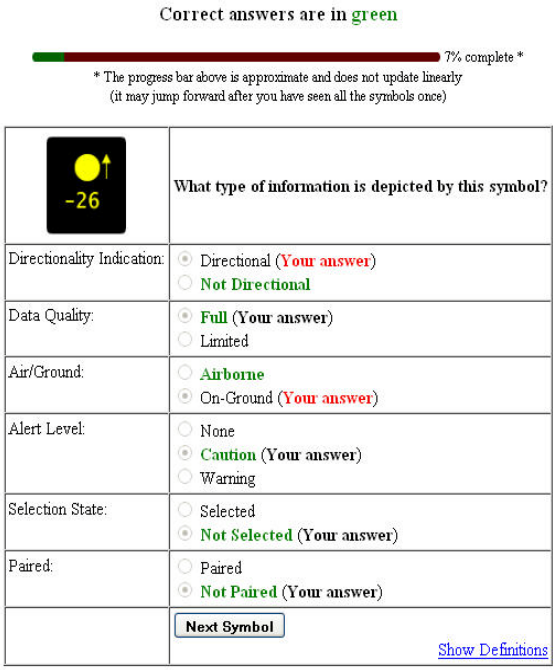

Figure 4. Sample feedback from Learning Task page

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 after five presentations, it was

considered that he/she did not succeed in learning its state within the allotted number of trials and the symbol was not presented again.

After finishing the learning trials by either learning all symbols or completing five presentations, each participant was provided with a page that included a text box where the participant could optionally enter "general comments about this research." Pilots could also indicate if they were interested in receiving a reminder to participate in the follow-up Memory task.

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 (see Figure 3).

4 Analysis

4.1 Strategy

The intent of the study was to identify the relation of individual symbol features to their intuitiveness, learnability, and memorability, rather than to evaluate the overall relative performance of each symbol set. Generally each symbol set used consistent visual features for each parameter state (e.g., a barb for directionality or red for warning). To provide a high-level view of the performance of the visual features therefore, analyses first focused on the performance for each parameter state, aggregating the data across symbols with the same state (e.g., all directional symbols).

If the analysis by parameter state indicated effects on pilot performance, a detailed analysis comparing individual symbols across sets was performed to illuminate the specific relationship between visual features and pilot responses.

With four symbol sets and over twenty symbols in each set, analysis by symbol implies a large number of comparisons between symbols within and across sets, increasing the probability of family-wise Type I error (i.e., reporting a result that is actually due to random sampling, also known as a *false positive*) . However, attempting to control family-wise Type I error by employing corrective techniques increases Type II error rates (i.e., failing to report an actual result, also known as a *false negative*), which is an equal concern.

For this reason, alpha[2] remains at the 0.05 level for each by-symbol analysis. This is justified by a general effect being first established by the prior analysis by parameter state, and the analysis by symbol merely provides details to understand the effects found in the analysis by parameter state. However, specific results reported from analyses by symbol must nonetheless be considered tentative. With over twenty symbols and an alpha of 0.05, one should *expect one of the significant results to be a Type I error (false positive)*. In general the results from the by-symbol analyses should be regarded as exploratory, focusing on the overall pattern of results rather than a single significant result of a single symbol.

4.2 Dependent Variables

Dependent variables representing the performance of the symbols were derived for each parameter state within a symbol set and for each symbol within a set. For the Intuitiveness and

[2] Alpha represents the threshold probability for "statistical significance"; that is, it is the maximum calculated probability *p* that will trigger rejection of an assumption that a statistical deviation is due to random sampling.

Memory tasks, the performance of an individual symbol for a single participant was indicated by whether the participant selected the correct parameter state or not (i.e., accuracy). Each symbol thus had six binary accuracy scores (correct or incorrect), one for each parameter.

To provide a measure of performance on a particular parameter state for the entire symbol set, the *percent correct* was calculated for each participant across all symbols representing a single parameter state. For example, the performance for Directional for Symbol Set 1 was represented by the percent of correct responses for Symbols A, D through H, and N through V, while the performance for Non-directional was the percent of correct responses for Symbols B, and I through M (see Table 3).

For the Learning task, the performance of an individual symbol on a parameter for a single participant was indicated by the number of trials the participant selected the incorrect parameter state for the symbol (i.e., how many trials to learn the symbol). A zero represents the participant getting the symbol correct on the first trial. The maximum score a participant could receive was five since the Learning task terminated after five trials whether the participant correctly learned all the symbols or not.

The learning performance on a particular parameter state was represented by the average number of trials a participant selected the incorrect parameter state for all symbols with that state. That is,

$$\text{Average Trials Incorrect} = w / m,$$

where

w = the number of incorrect trials,

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

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

Comments provided by the pilots after completing the Learning task were categorized by the parameter. One of the authors identified common themes among the comments for each parameter. Themes shared by at least three pilots were considered sufficiently common to report.

4.3 Analysis Design

4.3.1 Analysis by State

Because of a substantial attrition of participants from one task to the next resulted in differences in sample size (see Table 4, page 13) each task was analyzed separately. For each task, the performance of all parameters except for Alert Level were analyzed together in a multivariate analyses of variance (MANOVAs[3]) using the design as depicted in Figure 5.

[3] A MANOVA evaluates the relation of multiple categorical "independent" variables with multiple numeric "dependent" variables. Each significance test (e.g., via Wilk's lambda) determines the statistical significance of the relation between all the dependent variables combined and one independent variable or one combination of independent variables (a.k.a., an "interaction"). A significant result for an independent

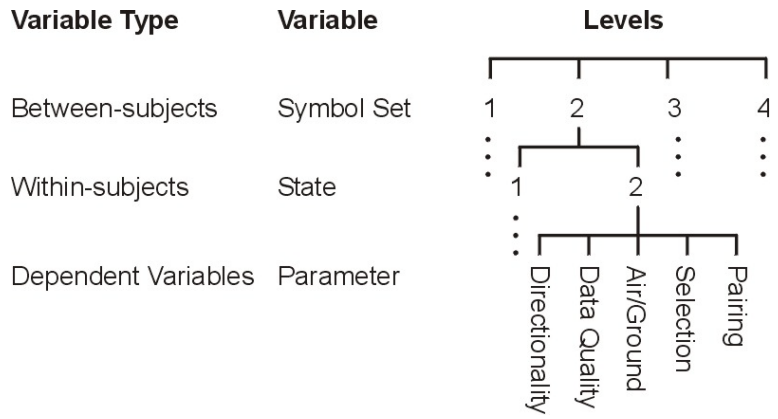

Figure 5. Design for analysis by parameter state, all except Alert Level.

Symbol Set was a between-subjects independent variable (four levels) and the parameter state (e.g., directional or non-directional) was a within-subject independent variable. All the parameters included in the MANOVA had two states, arbitrarily coded as 1 and 2 (e.g., 1 = Directional and 2 = Non-directional). The performance of each parameter (e.g., Directionality) was regarded as a separate dependent measure. With this design, a significant main effect of State for a parameter indicates the visual attributes for one of the parameter's states is more intuitive, learnable, or memorable than the other for all symbol sets. A significant main effect of Symbol Set for a parameter indicates a difference in intuitiveness, learnability, or memorability among the symbols sets for both parameter states. An interaction between Symbol Set and State indicates a difference in relative performance among the symbols sets for a particular state, and thus among the particular visual features used to represent that state.

Because Alert Level had three possible states (Normal, Caution, and Warning), while the other parameters had two possible states, Alert Level could not be included in the MANOVA where State has two levels. Thus, the performance for Alert Level was analyzed separately in an analysis of variance (ANOVA), using the design shown in Figure 6.

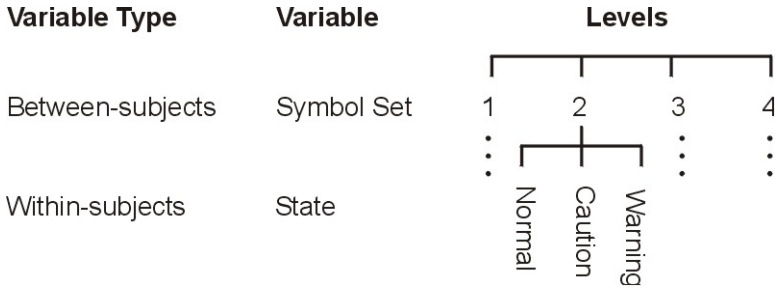

Figure 6. Design for analysis for the Alert Level parameter.

The analyses were also done with TCAS experience (yes or no) as a second between-subjects independent variable. However, there were no significant main effects or interactions of TCAS experience for the Learning and Memory tasks. There were a few significant interactions for the Intuitiveness task, in which pilots both with and without TCAS experience showed the same general trends but the magnitude of the trend varied with TCAS experience. These differences in magnitude are discussed in the Results section below.

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variable (or combination of independent variables) generally implies a significant relation between at least one of dependent variables and the independent variable (or combination). Univariate analyses (e.g., ANOVAs) can then determine which dependent variables are significantly related to the independent variable (or combination).

For the Intuitiveness and Memory tasks, the dependent variables were each pilot's average percent of correct responses for the parameter state. For the Learning task the dependent variables were each pilot's average trials incorrect for the parameter state.

In all ANOVAs, Greenhouse-Geisser corrections were used when a significant Mauchly's *W* indicated a violation of the assumption of sphericity. In these analyses by state, post-hoc comparisons of the means of the symbol sets used Tukey's HSD to control for family-wise error rates.

4.3.2 Analysis by Symbol

Analyses varied by task for performance of individual symbols on a parameter. For data from the Intuitiveness task, Chi-square goodness of fit tests compared the number of correct guesses for a symbol on a parameter with chance performance assuming a rectangular distribution of guessing (i.e., 50% chance of being correct for all parameters except Alert level, which assumed a 33.3% chance of being correct). Significantly better performance than chance indicated an intuitive symbol, while significantly worse performance than chance indicated a *counterintuitive* symbol, where pilots on average expected the symbol to mean something other than intended.

For the Learning task, an ANOVA was performed on the number of trials the participant selected an incorrect parameter state with Symbol Set as a between-subjects independent variable and Symbol as a within-subject independent variable, as shown in Figure 7.

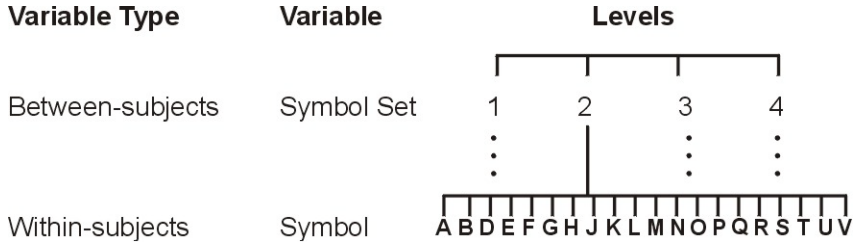


Figure 7. Design for analysis of the learnabiltity of each symbol.

Note that Symbols C and I are not included in such analyses since they are not present in all sets. A significant Symbol Set by Symbol interaction indicates that the learning difficulty of the symbols varies across the symbols sets.

For data from the Memory task, Chi-square tests of independence compared corresponding symbols across the four sets. A significant result indicated different levels of memorability among the sets for the same symbol.

5 Results

General results that apply across all parameters are described in Sections 5.1. Because the purpose of the study was to identify the relation of symbol features with pilot performance on the parameters, detailed results are broken down by parameter. These are in Sections 5.2 through 5.6.

5.1 General Results

Participants tended to drop out of the study as they progressed through the tasks, as shown in Table 4. The proportion of voluntary drop-outs did not vary significantly between sets. However, there were substantial differences across the symbol sets in the number that successfully learned their symbols; overall, a substantial portion (31%) of pilots who participated in the memory tasks had not learned all their respective symbols.

The Memory task was only intended to measure symbol memorability. If all pilots were included in the analyses for the Memory task, low performance for a symbol could be attributed to either poor symbol learnability or memorability. To avoid this ambiguity, 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. This reduced the sample size from the 413 who participated in the Memory task to 283 who learned all symbols *and* participated in the Memory task.

Because only those who had learned their symbols sets were included in the analysis of the Memory Task data, there were significant differences in the sample sizes, as shown in the last row of Table 4.

Table 4. Number of participants by Symbol Set and chi-square goodness of fit test for proportions equal to those from the assignment of Symbol Set[4].

	Set						
Progress	**1**	**2**	**3**	**4**	**Total**	**χ-square**	***p***
Submitted Background Information	253	251	252	252	1008		
Started Intuitiveness Task	216	219	215	213	863	0.12	0.9896
Finished Intuitiveness Task	193	198	202	196	789	0.26	0.9670
Finished Learning Task	153	139	164	167	623	3.00	0.3917
Started Memory Task	91	98	115	107	411	3.25	0.3542
Learned Set and Started Memory Task	68	44	90	81	283	16.79	0.0008

The correlation of the task means of each symbol of each set are shown in Table 5 for each parameter. Overall, the performance of the symbols on the three tasks was somewhat correlated, but sufficiently unrelated to warrant separate analyses for each task. The low correlations between memorability and the other two tasks for Air/Ground and Alert Level can be attributed to restriction of range from a ceiling effect of memorability for these parameters. On average, 98% of pilots correctly remembered the Air/Ground states and 99% correctly remembered the Alert Level states.

Table 5. Correlation of means for each parameter between each pair of tasks.

Tasks Pairs	**Intuitiveness Learning Difficulty**	**Intuitiveness Memorability**	**Learning Difficulty Memorability**
Directionality	–0.650‡	0.015	–0.232*
Data Quality	–0.488‡	0.071	–0.695‡
Air/Ground	–0.596‡	0.319†	–0.124
Alert Level	–0.749‡	–0.066	0.038
Selection	–0.787‡	0.310†	–0.208
Pairing	–0.754‡	0.318†	–0.325‡

*$p < 0.05$, **$p < 0.01$, †$p < 0.005$, ‡$p < 0.001$

The results of the Symbol Set by State MANOVAs are shown in Table 6, indicating the combined effects related to Directionality, Data Quality, Air/ground, Selection, and Pairing parameters.

[4] That is, this statistical procedure determines if the distribution of participants among the sets for a given stage of the study is statistically significantly different than the initial distribution of participants assigned each symbol set.

For all tasks, there were significant differences among the symbols sets and the states, and a significant interaction of Symbol Set and State. The latter indicates that the performance of a state varied with the symbols sets. This implies that, for at least one of the five parameters, the visual features used by some symbol sets were superior to (or worse than) other sets for representing the parameter states.

Univariate details of these results, along with the results for the Alert Level ANOVA are presented separately below for each of the six symbol parameters by task.

Table 6. MANOVA results for each task.

Effect	Statistic	Intuitiveness	Learning	Memory
Symbol Set	Wilk's λ	0.621	0.710	0.694
	F	29.624‡	14.971‡	7.155‡
State	Wilk's λ	0.359	0.799	0.764
	F	305.037‡	30.897‡	17.025‡
Symbol Set	Wilk's λ	0.802	0.807	0.780
× State	F	13.121‡	9.166‡	4.778‡

‡$p < 0.001$

Of the 623 pilots who completed the Learning task, 223 provided comments. Of these 223, 126 pilots provided 157 comments concerning the visual coding of the symbols. These comments generally expressed speculations, confusions, perceived deficiencies, and suggested improvements for the visual codes. Table 7 shows the number of comments submitted, by symbol set and parameter.

Table 7. Number of comments submitted by symbol set and parameter.

	Set				
Parameter	**1**	**2**	**3**	**4**	**Total**
Directionality	3	0	0	3	6
Data Quality	2	12	0	2	16
Air/Ground	6	7	3	4	20
Alert Level, not mentioning Selection or Pairing	6	7	5	8	26
Alert with Selection and/or Pairing	8	6	0	6	20
Selection and/or Pairing	5	19	19	26	69
Total	**30**	**51**	**27**	**49**	**157**

Most comments (73%) concerned some combination of the Alert Level, Selection, and Pairing parameters, with more than half (57%) concerned Selection and Pairing, with or without also including Alert Level. Common themes in the pilots' comments are discussed separately below for each of the parameters.

5.2 Directionality

F-ratios for the univariate analyses for Directionality are summarized in Table 8 and discussed in more detail in Sections 5.2.1 through 5.2.3. Pilot comments about Directionality are addressed in Section 5.2.4.

Table 8. *F*-ratios for effects on Directionality performance for each task

Effect	Intuitiveness	Learning	Memory
Symbol Set	0.667	3.705 *	1.104
State	94.508 ‡	25.646 ‡	48.693 ‡
Symbol Set × State	4.946 †	1.070	2.214

*$p < 0.05$, **$p < 0.01$, †$p < 0.005$, ‡$p < 0.001$

Only the Learning task had a significant effect of Symbol Sets. All tasks had a significant main effect of State. Only the Intuitiveness task had a significant Symbol Set by State interaction.

5.2.1 Intuitiveness

The average percent correct for each Directionality state are shown in Figure 8.

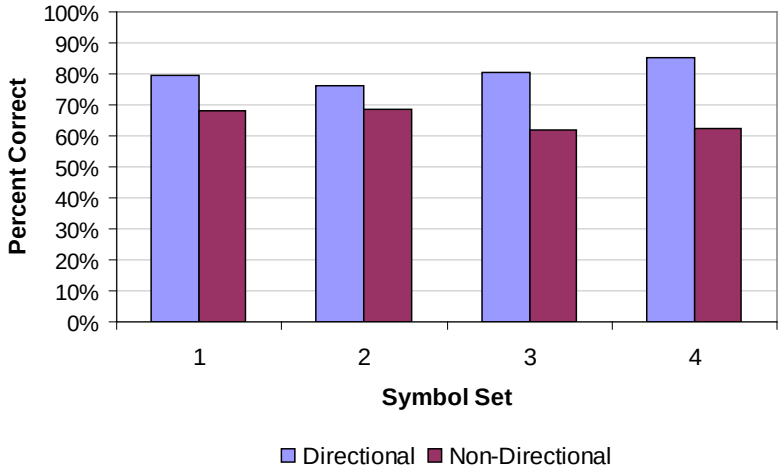


Figure 8. Percent correct on Directionality for Intuitiveness task.

Directional symbols were significantly more intuitive than Non-directional symbols for all sets except Set 2 (interaction $F[3,859] = 4.946$, $p = 0.002$; paired comparison of Set 2 $t[225] = 1.86$, $p = 0.0639$). Pilots with TCAS experience found the Non-directional symbols to be more intuitive than pilots without TCAS experience (interaction $F[1,855] = 11.037$, $p = 0.001$), but TCAS-experienced pilots still found the Directional symbols to be more intuitive than the Non-directional symbols. Symbol Sets 3 and 4 had the largest difference between Directional and Non-directional symbols.

The performance for each symbol of each set for the Directionality is shown in Table 9, where each percent is compared to chance performance. The table highlights the difficulties participants had with certain Non-directional symbols in Sets 3 and 4. For example, while the average percent correct for Sets 3 and 4 for Symbols B, I, K, L, and M (see Table 10) 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.

Table 9. Percent of participants correctly identifying Directionality in the Intuitiveness task.

	Set			
Symbol	**1**	**2**	**3**	**4**
A	83.6%	88.0%	89.9%	91.9%
B	60.1%	58.4%	**52.1%**	**55.7%**
C		68.5%	90.6%	94.3%
D	62.1%	64.8%	**52.6%**	66.2%
E	82.9%	89.2%	88.2%	91.9%
F	86.7%	90.6%	88.9%	91.9%
G	86.1%	87.3%	92.6%	91.6%
H	84.8%	84.0%	88.1%	91.8%
I	59.2%		**53.7%**	**56.1%**
J	95.3%	98.1%	98.6%	96.6%
K	59.0%	59.9%	**55.5%**	**53.4%**
L	61.8%	64.9%	**50.9%**	**53.7%**
M	59.4%	62.6%	**55.7%**	**54.3%**
N	95.8%	**33.6%**	**54.3%**	61.1%
O	60.9%	66.8%	89.0%	93.4%
P	59.1%	70.9%	91.9%	93.4%
Q	62.3%	64.8%	87.0%	89.7%
R	58.1%	66.4%	**51.9%**	63.8%
S	68.6%	78.0%	**50.0%**	66.2%
T	84.3%	89.5%	91.2%	91.5%
U	84.8%	87.7%	90.7%	91.8%
V	87.1%	88.1%	90.1%	91.4%

Note: Yellow (light-shaded) cells represent performance no better than chance based on a Chi-square goodness of fit test and red (dark-shaded) cells represent performance that was significantly worse than chance (i.e., symbols that were counterintuitive).

Table 10. Non-directional symbols B, I, K, L, and M for Sets 1 through 4.

Symbols	Set 1	Set 2	Set 3	Set 4
B				
I				
K				
L				
M				

5.2.2 Learning

Non-directional symbols were harder to learn, with the average trials incorrect being 0.11 versus 0.03 for the Directional symbols (F[1,619] = 25.646, $p < 0.001$). In Tukey HSD post-hoc comparisons, the two directionality states combined were more difficult to learn for Set 2 (M = 0.135) than the other Sets 1, 3, and 4 (Ms = 0.055, 0.064, and 0.056, respectively), which did not differ significantly from each other.

While there was no significant Symbol Set by State interaction (F[3,619] = 1.070, p = 0.361), certain symbols in Set 2 appeared to be more difficult to learn than others, relative to the other sets. An ANOVA of Symbol Set and Symbol on the number of trials to learn the directionality of each symbol produced a significant Symbol Set by Symbol interaction (F[17.6, 3628.8] = 4.147 $p < 0.001$, see Figure 9).

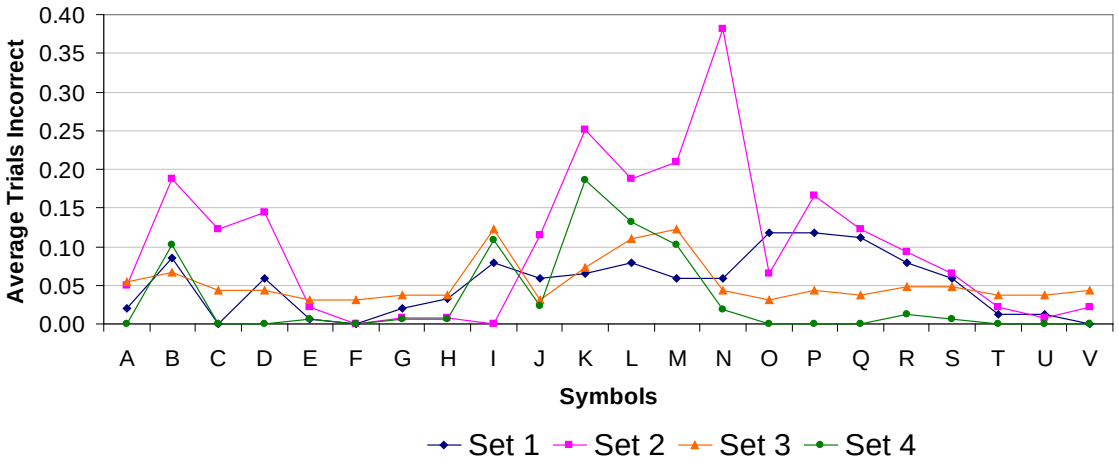
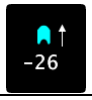


Figure 9. Average trials incorrect for Directionality of individual symbols in each set.

The directionality of Symbols A through D and J through N in Set 2 appear to have been particularly difficult to learn compared to the same symbols in other sets. With the exception of Symbol K, all these symbols lack borders (see Table 11), while the remaining symbols (E through

I, O through V) all had borders in Set 2. However, it is not clear why the absence of a border should result in difficult learning for both Directional and Non-directional symbols. Set 2 was also the only set to have two shapes for Directional traffic contingent on the data quality level. Learning that two shapes may mean one state may be relatively challenging (for example, see 5.3.2), although this also does not explain why the symbols in Table 11 would be particularly hard to learn for Set 2.

Table 11. Symbols A through D and J through N for Sets 1 through 4.

		Set			
Symbols	**Directionality**	**1**	**2**	**3**	**4**
A	Directional				
B	Non-directional				
C	Directional				
D	Directional				
J	Non-directional				
K	Non-directional				
L	Non-directional				
M	Non-directional				
N	Directional, except for Set 1				

5.2.3 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 ($F[3,279] = 2.214$, $p = 0.087$).

5.2.4 Pilot Comments

The six comments concerning directionality did not appear to have any common themes.

5.3 Data Quality

F-ratios for the univariate analyses for Data Quality are summarized in Table 12 and discussed in more detail in Sections 5.3.1 through 5.3.3. Pilot comments about Data Quality are addressed in Section 5.3.4.

Table 12. *F*-ratios for effects on Data Quality performance for each task

Effect	Intuitiveness	Learning	Memory
Symbol Set	50.050 ‡	50.050 ‡	25.868 ‡
State	154.504 ‡	16.341 ‡	28.781 ‡
Symbol Set × State	20.127 ‡	6.040 ‡	14.355 ‡

*$p < 0.05$, **$p < 0.01$, †$p < 0.005$, ‡$p < 0.001$

All effects were significant in all tasks.

5.3.1 Intuitiveness

The average percent correct for each Data Quality state are shown in Figure 10.

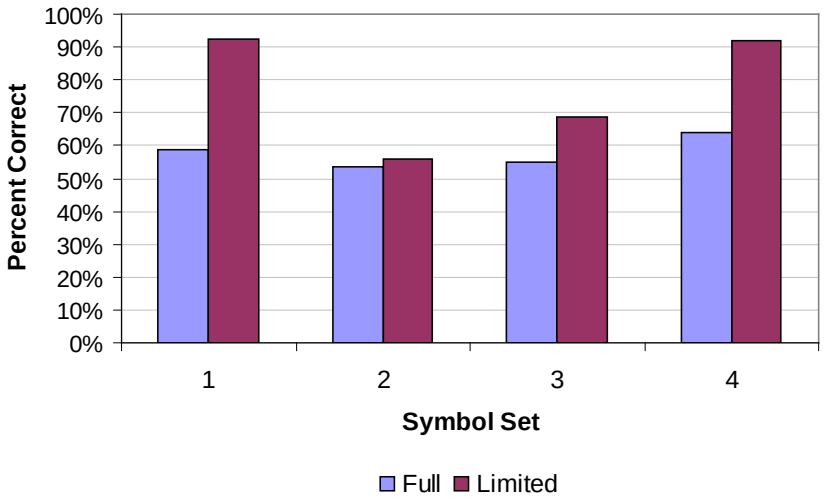


Figure 10. Percent correct on Data Quality for Intuitiveness task.

In general, the representation of Data Quality for Full symbols ($M = 58\%$) was less intuitive than Limited symbols across all symbol sets ($M = 77\%$, $F[1,869] = 154.504$, $p < 0.001$). In paired comparisons, this was significant for all symbols sets, except Set 2 ($t[228] = -1.01$, $p = 0.3112$). Detailed analyses for each symbol revealed that participants tended to regard symbols with blank or dashed data tags (e.g., Symbols D, J, R, and S) to be traffic with Limited data quality (see Table 13 and Table 14). Overall, pilots associated symbols without altitude data to be Limited Data Quality 74.4% of the time.

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. This appears to have resulted in participants selecting the correct data quality for these symbols significantly less often than predicted by chance (see Table 13).

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.

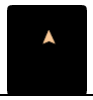
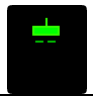
Traditional TCAS symbols (Symbols B, L, and M of Set 1, 2, and 4) did not have an intuitive association with either Full or Limited quality. Across all sets, pilot responses for these symbols were not significantly different from random guessing.

Table 13. Percent of participants correctly identifying each symbol's Data Quality in the Intuitiveness task.

	Set			
Symbol	**1**	**2**	**3**	**4**
A	65.7%	60.1%	63.6%	72.4%
B	**54.9%**	**50.9%**	**54.4%**	68.1%
C		**45.4%**	63.4%	89.5%
D	**29.4%**	**3.8%**	**27.9%**	**31.4%**
E	72.7%	66.5%	65.1%	79.5%
F	73.4%	74.6%	66.4%	78.0%
G	72.2%	68.9%	67.4%	76.6%
H	71.6%	69.8%	67.9%	71.2%
I	92.4%		71.5%	94.1%
J	**22.3%**	98.1%	**23.3%**	**27.5%**
K	64.6%	**46.2%**	59.7%	70.9%
L	**50.5%**	**54.5%**	57.4%	64.0%
M	**56.6%**	**54.0%**	**54.2%**	64.4%
N	99.1%	94.4%	93.8%	98.1%
O	92.3%	**44.9%**	**56.4%**	87.7%
P	91.8%	**37.1%**	64.1%	90.0%
Q	87.3%	**32.9%**	59.5%	87.2%
R	**34.3%**	**5.1%**	**28.0%**	**38.0%**
S	**36.7%**	**19.3%**	**34.6%**	**38.6%**
T	75.7%	71.4%	70.8%	81.1%
U	75.7%	74.1%	68.2%	81.7%
V	78.0%	74.8%	72.2%	79.5%

Note: Yellow (light-shaded) cells represent performance no better than chance based on a Chi-square goodness of fit test and red (dark-shaded) cells represent performance that was significantly worse than chance (i.e., symbols that were counterintuitive).

Table 14. On-ground symbols D, J, R, and S for Sets 1 through 4.

Symbols	Data Quality	Set 1	Set 2	Set 3	Set 4
D	Full				
J	Full, except for Set 2				
R	Full				
S	Full				

5.3.2 Learning

The average trials incorrect for each Data Quality state are shown in Figure 11.

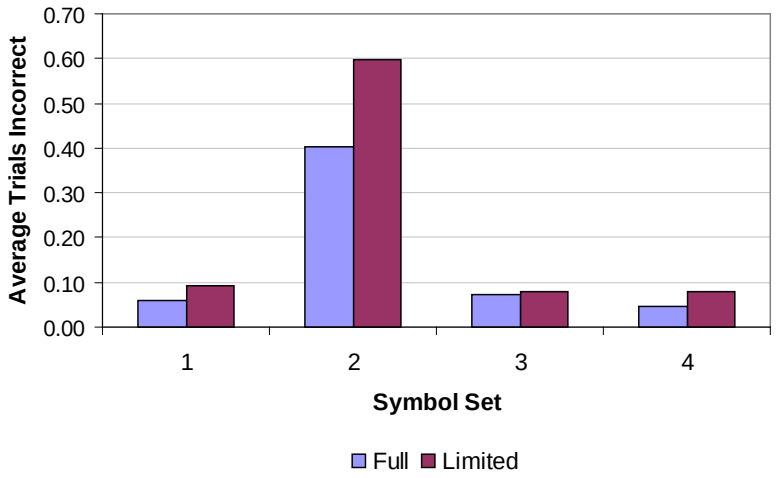


Figure 11. Average trials incorrect for Data Quality for Learning task.

In post hoc comparisons of the sets, the Data Quality parameters for both Limited and Full quality symbols of Set 2 were significantly harder to learn than any of the other sets (Overall effect of Set $F[3,619] = 50.050$, $p < 0.001$), while the other sets did not differ significantly from each other. The average trials incorrect for symbols in Set 2 was 0.50, while the average trials incorrect for the symbols in the other sets was 0.07. In paired comparisons, both Full and Limited Data Quality symbols in Set 2 were significantly harder to learn than the corresponding symbols in any other set.

Paired comparisons indicated that Limited Data Quality symbols were significantly harder to learn than Full Data Quality symbols for all sets except Set 3, (interaction $F[3,619] = 6.040$, $p < 0.001$); Set 3 paired comparison $t[162] = –0.75$, $p = 0.4524$). Set 2 had the largest learning difference between Limited and Full Data Quality.

An ANOVA of Symbol Set and Symbol on the number of trials to learn the data quality of each symbol produced a significant Symbol Set by Symbol interaction (F[3.0, 16.0] = 6.040, p < 0.001, see Figure 12), revealing more detail on the difficulties associated with Symbol Set 2.

Participants had particular difficulty learning the Data Quality for Symbols D, K, and O through S in Set 2 (see Figure 12 and Table 15). Of these, D, R, and S were Full Quality On-ground symbols that lacked a data tag, which the Intuitiveness results suggest is intuitively associated with Limited quality.

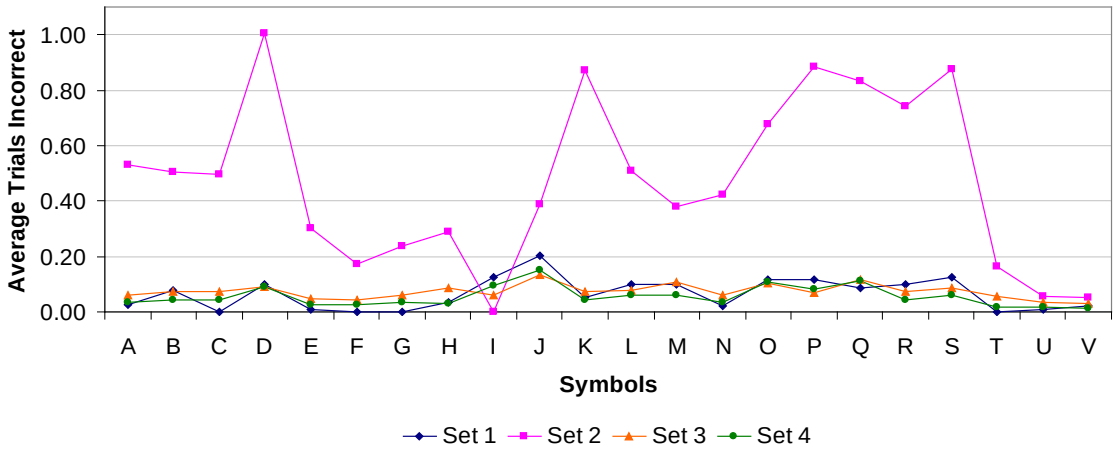
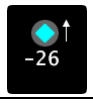
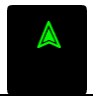


Figure 12. Average trials incorrect for Data Quality of individual symbols in each set.

Table 15. Symbols D, K, and O through S for Sets 1 through 4.

		Set			
Symbols	**Data Quality**	**1**	**2**	**3**	**4**
D	Full				
K	Full, except Limited for Set 2				
O	Limited				
P	Limited				
Q	Limited				
R	Full				
S	Full				

Pilots appeared to learn the Data Quality of Limited Quality On-ground symbols J and N faster, but this may be the result of pilots erroneously attending to the lack of a data tag rather than

symbol shape which actually represented data quality. The remaining difficult-to-learn symbols (O, P, and Q) were the only "bullet" shaped directional symbols surrounded by a border. Pilots did not appear to have the same level of difficulty learning that bullets without borders (C and N) represented Limited Data Quality.

5.3.3 Memory

The average percent correct for each Data Quality state are shown in Figure 13.

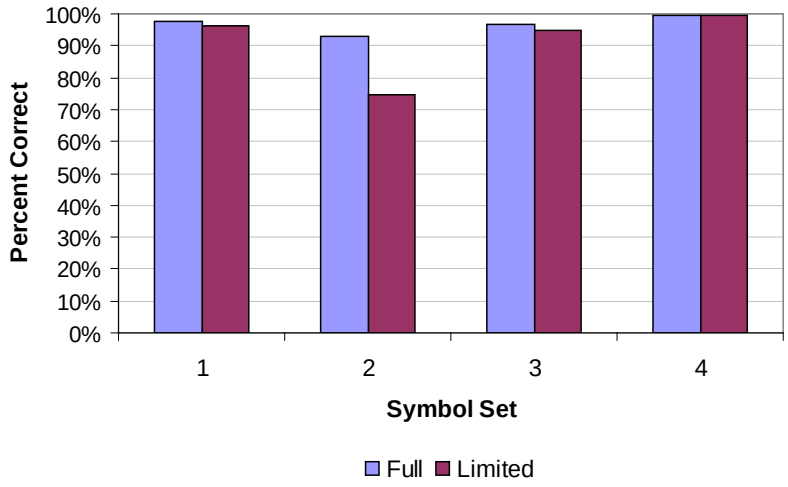


Figure 13. Percent correct on Data Quality for Memory task.

The Data Quality parameter 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 Data Quality for the other three sets was correctly remembered 98% of the time, the Data Quality for Set 2 was correctly remembered only 84% of the time. In particular, Set 2 symbols representing Limited Data Quality were significantly harder to learn than Limited or Full quality symbols of any other set (all ps < 0.001). Set 2 symbols representing Full Data Quality were significantly harder to learn than Full Data Quality symbols in Set 1 ($t[110] = 2.18$, $p = 0.0312$) and Set 4 ($t[123] = 3.27$, $p = 0.0014$), but not Set 3 ($t[132] = 1.85$, $p = 0.0669$). While memory for Limited and Full symbols was not significantly different for Sets 1, 3, and 4, for Set 2, participants had significantly 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 (interaction $F[3,279] = 14.355$, $p < 0.001$; paired comparison $t[41] = 4.25$, $p < 0.0003$).

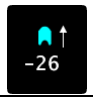
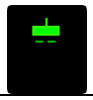
The memorability of each symbol within each symbol set is shown in Table 16, where an asterisk in a row indicates significant differences among the percentages of the sets for a symbol. Symbols B through E and K through S (see Table 17) were less memorable for Set 2 than the other sets. These symbols include the Full-quality ground symbols that lacked data tags (D, R, and S), implying that the meaning of "no data tag" was harder to remember in the context of Set 2 than other sets. The low-memorability symbols also include nearly all airborne non-chevron-shaped symbols. All these symbols represented Limited Data Quality by their shape, whether it be a directional "bullet" or a symmetrical TCAS-style shape. All other sets represented Limited Data Quality by either text in the data tag or a single specific mark added to the shape (an "×").

Table 16. Percent of participants correctly remembering each symbol's Data Quality in the Memory task.

	Set				
Symbol	**1**	**2**	**3**	**4**	
A	98.5%	98.5%	98.9%	97.5%	
B	97.1%	72.7%	97.8%	100.0%	*
C		70.5%	95.6%	100.0%	*
D	92.6%	75.0%	91.1%	98.8%	*
E	100.0%	95.5%	100.0%	100.0%	*
F	100.0%	100.0%	100.0%	100.0%	
G	100.0%	97.7%	98.9%	98.8%	
H	98.5%	97.7%	98.9%	100.0%	
I	97.0%		94.4%	100.0%	
J	89.7%	88.6%	86.7%	95.1%	
K	98.5%	68.2%	98.9%	100.0%	*
L	98.5%	72.7%	97.8%	100.0%	*
M	98.5%	79.5%	97.8%	98.8%	*
N	100.0%	88.6%	100.0%	98.8%	*
O	97.0%	65.9%	91.1%	98.8%	*
P	92.5%	70.5%	95.6%	100.0%	*
Q	94.1%	70.5%	93.3%	98.8%	*
R	94.1%	72.7%	88.9%	100.0%	*
S	95.6%	88.6%	92.3%	100.0%	*
T	100.0%	97.7%	100.0%	100.0%	
U	100.0%	100.0%	100.0%	100.0%	
V	98.5%	100.0%	100.0%	100.0%	

*Significant differences among the sets in a Chi-square test of independence.

Table 17. Symbols B through E, and K through S for Sets 1 through 4.

Symbols	Air/Ground	Set 1	Set 2	Set 3	Set 4
B	Airborne				
C	Airborne				
D	Ground				
E	Airborne				
K	Airborne				
L	Airborne				
M	Airborne				
N	Ground				
O	Airborne				
P	Airborne				
Q	Airborne				
R	Ground				
S	Ground				

5.3.4 Pilot Comments

Of the 16 comments about Data Quality, 12 were from pilots who had Set 2. Of these 12 comments, five expressed an inability to figure out the visual code for Data Quality, such as these two pilots:

> *Symbology for indicating quality of data was very vague; I never did determine the "code."*

Even having completed the training I have no idea how to work out if the data is full or limited.

Four of the twelve specifically expressed confusion on whether Non-directional symbols were necessarily Limited Data Quality or not, such as these pilots:

There is an implicit relationship between limited directionality and limited data which isn't immediately obvious from the symbols. Limited data should perhaps be more prominent in some way.

Does a non-directional indication definitely mean low quality? From the answers it seems so, but what about an aircraft on the ground which is not moving? Quality could be high, but it would be non-directional.

5.4 Air/Ground

F-ratios for the univariate analyses for Air/Ground are summarized in Table 18 and discussed in more detail in Sections 5.4.1 through 5.4.3. Pilot comments are addressed in Section 5.4.4.

Table 18. *F*-ratios for effects on Air/Ground performance for each task

Effect	Intuitiveness	Learning	Memory
Symbol Set	32.861 ‡	25.556 ‡	1.129
State	511.592 ‡	65.771 ‡	15.837 ‡
Symbol Set × State	26.341 ‡	28.242 ‡	2.287

*$p < 0.05$, **$p < 0.01$, †$p < 0.005$, ‡$p < 0.001$

All effects were significant for the Intuitiveness and Learning tasks, while only the main effect of State was significant for the Memory task.

5.4.1 Intuitiveness

The average percent correct for each Air/Ground state are shown in Figure 14

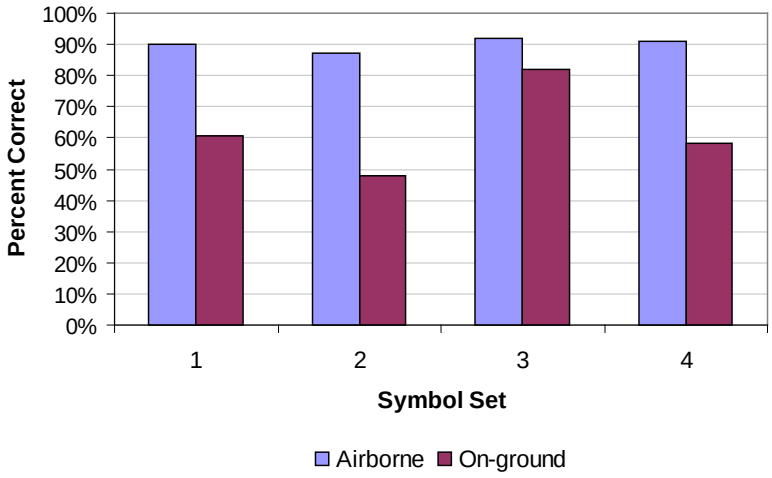


Figure 14. Percent correct on Air/Ground for Intuitiveness task.

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, while significantly less intuitive than Set 3 Airborne symbols ($t[225] = 4.04$, $p < 0.0001$), appear to be less problematic than those of Sets 1, 2, and 4 (interaction $F[3,859] = 26.341$, $p < 0.001$). Specifically, as shown in Table 19,

participants usually correctly identified Set 3's Symbols D, J, N, R, and S as On-ground (see Table 20). For the other three sets, the ground symbols were sometimes not intuitive or even counterintuitive, with participants on average correctly guessing 55.5% of the time that Symbols D, J, N, R, and S were On-ground.

Set 3 was the one set to use green and a unique shape to indicate On-ground traffic. All other sets used tan to indicate On-ground, with Sets 1 and 2 also modifying the symbol shape while retaining the same shape silhouette.

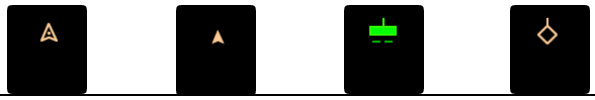
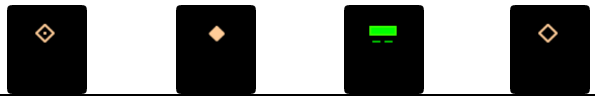
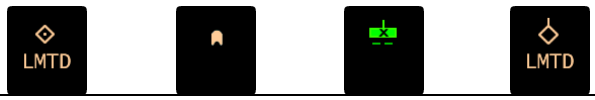
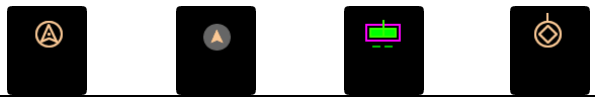
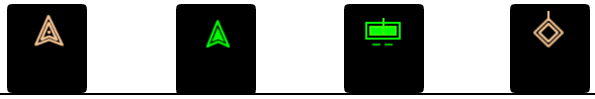
Symbol S of Set 2 was particularly counterintuitive. In this study, that symbol represented its On-ground state strictly by the absence of its data tag, which, as discussed on Page 19, pilots tended to intuitively associate with Limited Data Quality, not On-ground. In all other respects, Symbol S was nearly identical to airborne Symbol F in Set 2 (see Figure 15). This was not the intent of the symbol set designer: the designer intended that the symbol be tan with a green border, but a miscommunication resulted in an all-green symbol in the experiment.

Table 19. Percent of participants correctly identifying each symbol's Air/Ground in the Intuitiveness task.

	Set			
Symbol	**1**	**2**	**3**	**4**
A	95.2%	97.1%	91.7%	91.0%
B	85.0%	85.0%	94.4%	91.0%
C		75.0%	85.9%	91.4%
D	**54.7%**	**42.7%**	81.4%	**54.6%**
E	93.1%	93.9%	92.0%	94.8%
F	95.1%	97.2%	93.1%	90.9%
G	96.2%	96.2%	96.3%	89.3%
H	96.6%	97.2%	89.0%	85.6%
I	86.7%		84.6%	93.2%
J	71.2%	57.9%	86.0%	67.6%
K	84.0%	80.7%	91.9%	91.7%
L	86.8%	85.8%	95.4%	87.4%
M	79.2%	85.3%	92.0%	86.5%
N	68.1%	66.4%	85.1%	**55.3%**
O	85.0%	72.4%	87.2%	93.9%
P	88.5%	74.6%	88.5%	90.5%
Q	84.0%	71.4%	88.4%	88.2%
R	**53.8%**	**48.6%**	80.4%	57.3%
S	**50.0%**	**25.7%**	79.0%	58.6%
T	93.8%	96.2%	95.8%	93.4%
U	96.2%	94.8%	93.5%	92.3%
V	97.6%	98.6%	92.0%	90.0%

Note: Yellow (light-shaded) cells represent performance no better than chance based on a Chi-square goodness of fit test and red (dark-shaded) cells represent performance that was significantly worse than chance (i.e., symbols that were counterintuitive).

Table 20. On-ground symbols D, J, N, R, and S for Sets 1 through 4.

	Set			
Symbols	**1**	**2**	**3**	**4**
D				
J				
N				
R				
S				

Symbol F
Airborne Paired

Symbol S
On-ground Paired

Figure 15. Symbols F and S of Set 2.

5.4.2 Learning

The average trials incorrect for each Air/Ground state are shown in Figure 16. While Airborne symbols for all sets were relatively easy to learn ($M = 0.02$), the On-ground were significantly harder to learn than Airborne for all sets except Set 3 (interaction $F[3,619] = 28.242$, $p < 0.001$; paired comparison for Set 3 $t[161] = –0.75$, $p = 0.4524$). 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 (all $p < 0.0001$ in paired comparisons), while there was no significant difference in learnability among the On-ground symbols of the remaining sets (minimum $p = 0.0770$).

The analysis by symbol found a significant Symbol by Symbol Set Interaction ($F[12.4, 2563.6] = 29.434$, $p < 0.001$, see Figure 17). Symbol S in Set 2 was particularly difficult to learn, perhaps owing to its mistaken similarity to airborne Symbol F (see Figure 15). Excluding Symbol S of Set 2, the significant Symbol by Symbol Set interaction remained ($F[9.5, 2292.1] = 2.056$, $p = 0.026$), with most Set 3 On-ground symbols (e.g., D, J, R, and S) being generally easier to learn than other sets (see Figure 17 and Table 20).

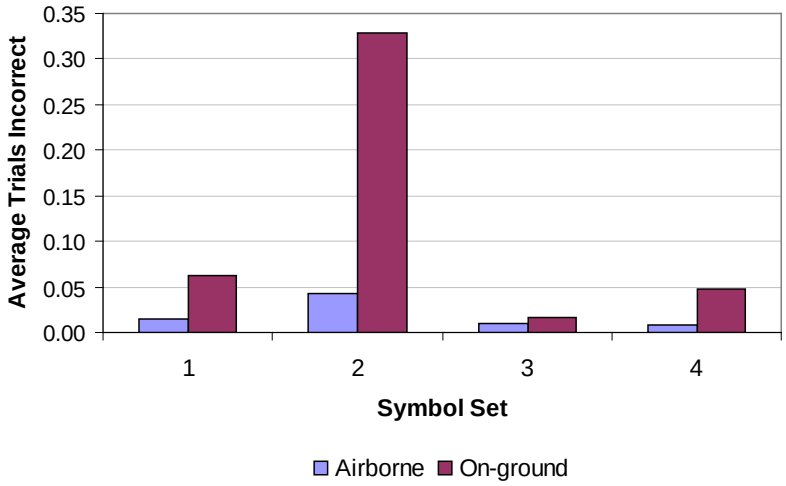


Figure 16. Average trials incorrect for Air/ground for Learning task.

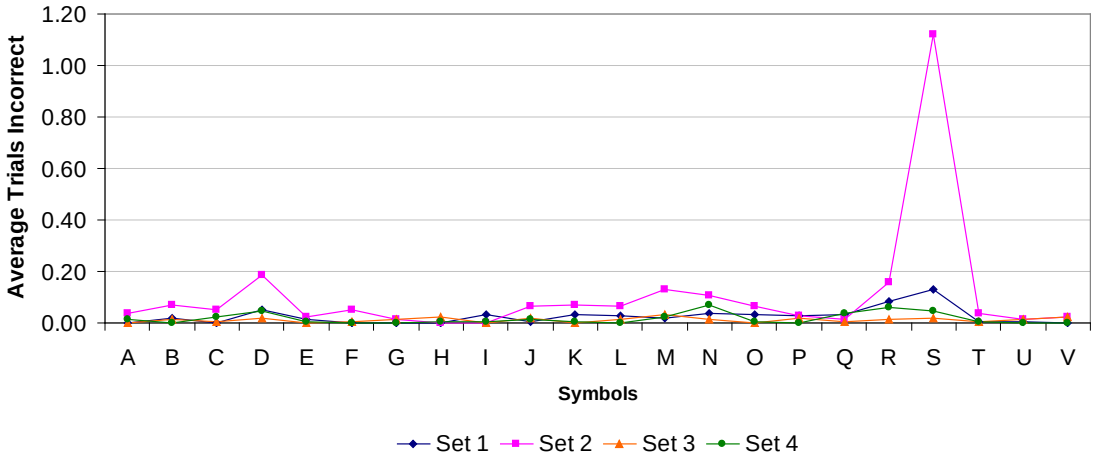


Figure 17. Average trials incorrect for Air/Ground of individual symbols in each set.

5.4.3 Memory

The On-ground state (M = 95.1%) was harder to remember than Airborne (M = 98.7%, F[1,279] = 15.837, $p < 0.001$).

5.4.4 Pilot Comments

Of the 20 comments concerning the visual coding for Air/Ground, seven concerned Set 2, and five of these concerned the use of the same color of Airborne as On-ground, as was erroneously the case for Symbols F and S. Here are comments from two pilots:

> *I found the tan color for ground symbols very straight forward, but was confused when a green symbol w/ no data block was used to represent a target on the ground.*
>
> *I think that one color or one type symbol should be used for targets on the ground.*

There were six comments from pilots who had Set 1, three of these saying that the marking used to distinguished On-ground traffic was too hard to see:

> *The dot in the middle indicating on the ground is kind of small. Perhaps an underbar instead?*

Of the four pilots that commented on Air/Ground for Set 4, three said On-ground needed a shape difference in addition to color and the data tag to distinguish it from Airborne:

> *The use of the diamond for a ground target, although cream, is misleading. I suggest a different standard symbol for ground targets.*

5.5 Alert Level

F-ratios for the univariate analyses for Alert Level are summarized in Table 21 and discussed in more detail in Sections 5.5.1 through 5.5.3. Pilot comments about Alert Level are addressed in Section 5.5.4.

Table 21. *F*-ratios for effects on Alert Level performance for each task

Effect	Intuitiveness	Learning	Memory
Symbol Set	1.068	1.212	0.492
State	45.825 ‡	10.043 ‡	2.022
Symbol Set × State	5.014 ‡	2.403 *	0.586

*$p < 0.05$, **$p < 0.01$, †$p < 0.005$, ‡$p < 0.001$

There were significant effects of State and the Symbol Set by State interaction for the Intuitiveness and Learning tasks, while no such significant effects exist for the Memory task. No tasks had a significant main effect of Symbol Set.

5.5.1 Intuitiveness

The average percent correct for each Alert Level state are shown in Figure 18.

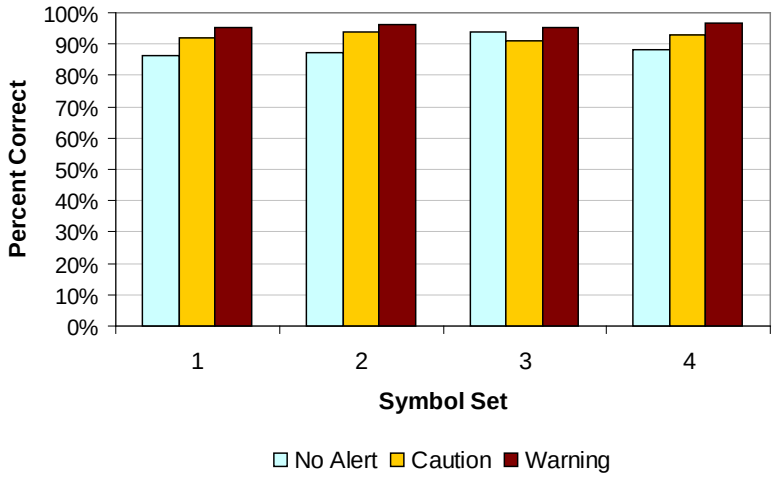


Figure 18. Percent correct on Alert Level for Intuitiveness task.

Pilots found the symbols highly intuitive for indicating Alert Levels, guessing the correct Alert Level 91.0% of the time. However, Caution symbols were significantly less intuitive than Warning symbols for all sets except Set 1 ($t[221] = -1.94$, $p = 0.0533$). This difficulty with Caution symbols was particularly strong for pilots without TCAS experience (interaction $F2,1728] = 3.523$, $p = 0.030$). Furthermore, No Alert symbols were significantly less intuitive than either Caution or Warning symbols for all symbol sets except Set 3 (interaction $F[5.8,1683.4] = 5.014$, $p < 0.001$).

Set 3 was the only set to use green rather than tan to indicate On-ground (see Table 20 in Air/Ground above). As shown in Table 22, the Alert Level for tan-colored No-Alert On-ground symbols (D, J, N, R, and S of Sets 1, 2, and 4, see Table 20 above) tended to be incorrectly identified more often than No-Alert Airborne symbols, which were cyan or green (A, B, C, E, F, I, K, and O of all sets, see Table 23. The tan symbols averaged 78% while the cyan or green symbols averaged 94%. Symbols that included magenta borders (Set 3, Symbols E, K, and O, see Table 24) also tended to be misidentified more often (85%).

Pilots with TCAS experience found Sets 1 and 3 to be more intuitive than pilots without TCAS experience. TCAS experience was not related to difference in pilot performance on the Intuitiveness task for Sets 2 and 4 (interaction $F[3,864] = 4.106$, $p = 0.007$).

Table 22. Percent of participants correctly identifying each symbol's Alert Level in the Intuitiveness task.

	Set			
Symbol	**1**	**2**	**3**	**4**
A	93.2%	97.1%	93.5%	94.3%
B	92.0%	95.3%	94.0%	94.8%
C		93.5%	94.4%	93.8%
D	78.0%	69.0%	99.1%	82.6%
E	91.7%	94.8%	85.8%	94.3%
F	92.6%	96.2%	94.0%	93.3%
G	93.3%	91.5%	91.2%	90.7%
H	97.5%	94.8%	93.6%	95.7%
I	93.4%		94.9%	93.2%
J	80.9%	71.3%	99.5%	81.2%
K	91.5%	93.9%	86.7%	92.7%
L	93.4%	93.4%	90.7%	89.7%
M	93.4%	96.7%	94.3%	96.6%
N	81.2%	71.5%	98.1%	77.9%
O	92.3%	95.8%	81.7%	91.0%
P	95.2%	90.6%	93.3%	94.3%
Q	95.3%	95.7%	95.8%	99.0%
R	80.0%	65.9%	91.6%	75.6%
S	76.7%	97.7%	97.2%	79.5%
T	94.8%	97.1%	88.4%	93.9%
U	91.9%	93.9%	92.5%	94.7%
V	97.1%	97.1%	96.7%	95.7%

Note: All cells represent guessing performance that was significantly better than chance.

Table 23. Airborne No Alert Symbols A, B, C, E, F, I, and K for Sets 1 through 4.

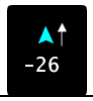
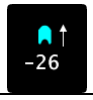
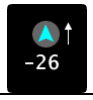
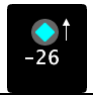
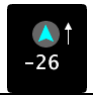
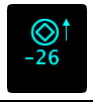
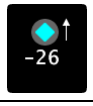
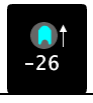
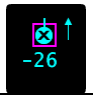
Symbols	Set 1	2	3	4
A				
B				
C				
E				
F				
I				
K				

Table 24. Selected symbols E, K, O, with Set 3 including magenta borders.

Symbols	Set 1	2	3	4
E				
K				
O				

5.5.2 Learning

The average trials incorrect for each Alert Level state are shown in Figure 19.

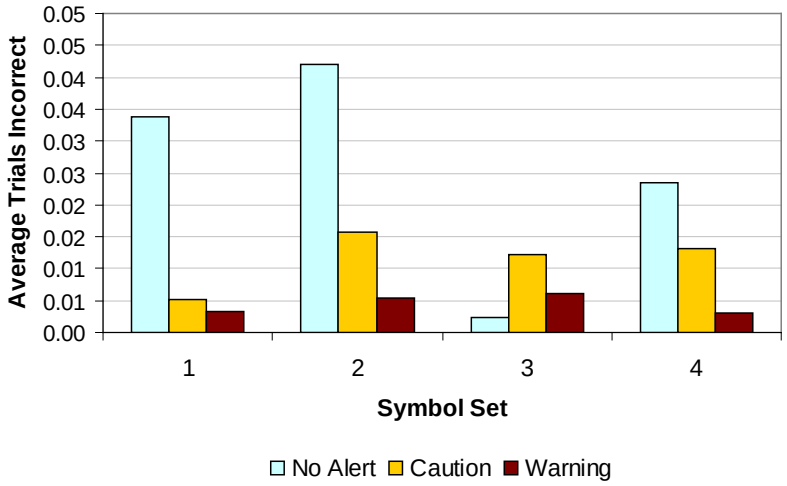


Figure 19. Average trials incorrect for Alert Level for Learning task.

In Sets 1 and 2, No Alert symbols were significantly harder to learn than Caution and Warning symbols, while there was no significant difference for Sets 3 and 4. Learning difficulty was not significantly different for Caution and Warnings symbols in any set.

The analysis by symbol did not find a significant Symbol by Symbol Set interaction (F[14.3, 2959.7] = 1.572, p = 0.077) when Greenhouse-Geisser corrections for sphericity are applied (Mauchly's W = 0.00, $\chi^2(189)$ = 13488.1, $p < 0.001$). However, the pattern of means is consistent with findings from the Intuitiveness task (see Figure 20), where ground symbols (symbols D, J, N, R, and S, see Table 20 above) were harder to learn when tan (Set 1, 2, and 4) than when green Set 3.

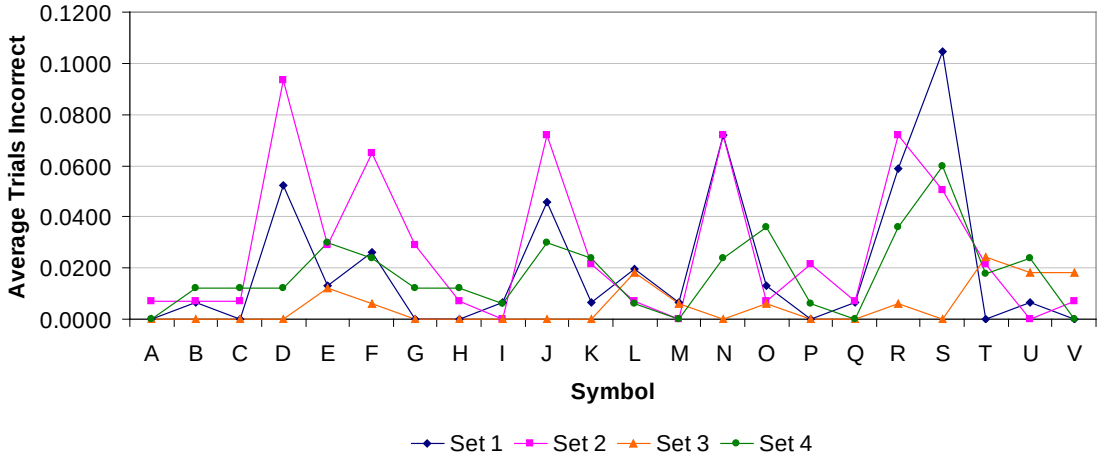


Figure 20. Average trials incorrect for Alert Level of individual symbols in each set.

5.5.3 Memory

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

5.5.4 Pilot Comments

Of the 26 comments concerning Alert Level, 20 involved confusion or concern over the use of the circular and square visual features to provide redundant non-color cues and to remain consistent with standard TCAS symbology. Here, for example, are three pilots:

> Set 1: *Meaning of solid square and solid circle not clear*
>
> Set 2: *I think that threat levels should use color only. I was confused by the addition of the circle and box along with the color change. Simplicity and consistency are very important, particularly when considering the use by non-professional pilots who may fly infrequently.*
>
> Set 4: *I would like to see the shape stay the same for the different alert levels. It takes me a fraction of a second longer to validate the shape instead of just looking for the color.*

This confusion and concern appears to be related comments about to the use of multiple borders as discussed with Selection and Pairing below.

Of the remaining six comments regarding Alert Level, three concerned the association of Caution with tan color used for On-ground in Sets 1, 2, and 4:

> Set 2: *The ground symbol coloring is easily confused for a caution. Why not use green if there is no caution associated?*

5.6 Selection and Pairing

The results for the Selection and Pairing parameters appeared to be closely related, so they are discussed together.

F-ratios for the univariate analyses for Selection and Paring are summarized in Table 25 and discussed in more detail in Sections 5.6.1 through 5.6.3. Pilot comments about Selection and Pairing are addressed in Section 5.6.4.

Table 25. *F*-ratios for effects on Selection and Pairing performance for each task

Parameter	Effect	Intuitiveness	Learning	Memory
Selection	Symbol Set	28.111 ‡	5.076 †	1.988
	State	94.346 ‡	13.119 ‡	0.321
	Symbol Set × State	6.312 ‡	0.970	2.438
Pairing	Symbol Set	3.262 *	3.949 **	1.067
	State	787.983 ‡	59.187 ‡	5.206 *
	Symbol Set × State	0.465	5.809 †	4.134 **

*$p < 0.05$, **$p < 0.01$, †$p < 0.005$, ‡$p < 0.001$

For the Intuitiveness task, all effects were significant except for the Symbol Set by State interaction for Pairing. For the Learning task, all effects were significant except for the Symbol Set by State interaction for Selection. In the Memory task, only the State main effect and Symbol Set by State interaction for Pairing were significant.

5.6.1 Intuitiveness

The average percent correct for each Selection and Pairing state are shown in Figure 21 and Figure 22 respectively.

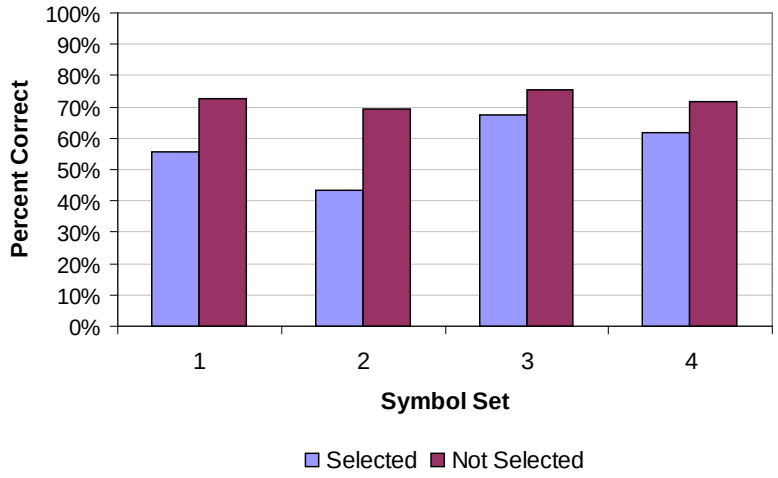


Figure 21. Percent correct on Selection for Intuitiveness task.

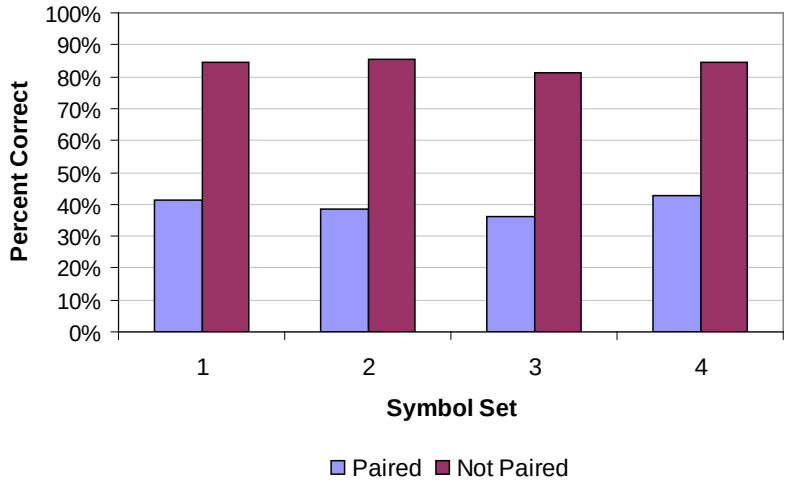


Figure 22. Percent correct on Pairing for Intuitiveness task (interaction not significant).

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 gap in intuitiveness between Selected and Non-selected symbols was larger for pilots with TCAS experience than pilots without (F[1,855] = 6.603, $p = 0.010$). The Selected symbols for Set 2 were particularly non-intuitive, with the percent correct being significantly lower than all other sets in paired comparisons (M = 44%, interaction F[3,859] = 6.312, $p < 0.001$, all paired comparisons ps < 0.001). Selected symbols in Set 1 were significantly less intuitive than Set 3 (t[429] = 3.39, $p = 0.0008$), but not significantly less intuitive than Set 4 (t[427] = 1.80, $p = 0.0720$). For the main effect of Symbol Set on Selection, all post hoc comparisons were significant except for Set 1 versus Set 4 ($p = 0.358$). For Pairing, only Set 3 was significantly different (lower) than Set 4 in post hoc comparisons ($p = 0.021$).

Detailed results by symbol are shown in Table 26.

Table 26. Percent of participants correctly identifying each symbol's Selection and Pairing in the Intuitiveness task.

	Selection				Paired			
	Set				Set			
Symbol	1	2	3	4	1	2	3	4
A	84.1%	89.4%	88.5%	82.9%	89.9%	92.8%	88.0%	90.0%
B	85.9%	89.3%	90.2%	83.3%	91.1%	90.7%	91.2%	91.9%
C		88.0%	74.6%	80.5%		87.0%	80.3%	90.0%
D	85.0%	96.7%	93.5%	92.3%	90.2%	96.7%	93.0%	96.6%
E	49.1%	43.9%	65.6%	62.4%	77.3%	78.8%	65.1%	69.0%
F	62.6%	56.8%	43.8%	47.8%	42.4%	36.2%	36.9%	40.7%
G	55.5%	44.3%	85.1%	69.6%	82.8%	79.2%	89.8%	81.3%
H	55.9%	43.9%	82.6%	73.6%	82.8%	75.5%	85.3%	84.1%
I	87.7%		79.0%	83.4%	93.4%		83.6%	90.7%
J	89.3%	96.7%	96.3%	97.6%	91.6%	98.1%	93.0%	97.6%
K	55.7%	41.0%	64.9%	59.2%	71.2%	81.6%	68.2%	73.8%
L	78.3%	89.6%	89.8%	78.5%	90.6%	95.3%	93.5%	86.0%
M	82.1%	90.0%	88.2%	78.4%	86.8%	91.5%	90.6%	88.9%
N	85.9%	95.3%	84.1%	88.9%	90.1%	96.7%	89.9%	96.6%
O	57.5%	43.0%	72.0%	63.2%	77.8%	79.4%	55.5%	73.6%
P	79.3%	44.6%	78.0%	71.1%	89.9%	73.2%	81.3%	85.8%
Q	75.5%	42.4%	77.2%	73.4%	87.3%	72.9%	79.1%	89.7%
R	44.3%	31.3%	63.6%	45.5%	79.0%	87.9%	68.2%	85.4%
S	69.0%	72.0%	52.3%	64.3%	29.5%	25.2%	30.8%	23.3%
T	67.6%	60.5%	70.8%	76.4%	62.4%	67.6%	63.4%	42.9%
U	37.1%	35.8%	46.7%	25.5%	51.0%	50.0%	32.7%	55.8%
V	46.4%	29.5%	36.3%	31.0%	41.1%	45.2%	42.5%	51.4%

Note: Yellow (light-shaded) cells represent performance no better than chance based on a Chi-square goodness of fit test and red (dark-shaded) cells represent performance that was significantly worse than chance (i.e., symbols that were counterintuitive).

All symbol sets used at least two kinds of borders, usually to distinguish Selected (E, K, O, R, T, see Table 27) from Paired states (e.g., Symbols F, S, U, V, see Table 28, but also sometimes to indicate an Alert Level (G and H for Sets 1 and 2, P and Q for Set 2, see Table 29).

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 counterintuitive (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.

Table 27. Selected symbols for Sets 1 through 4.

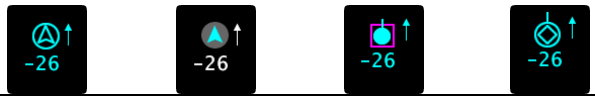
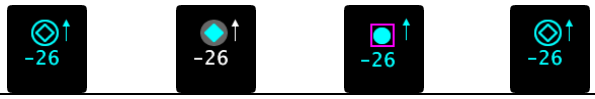
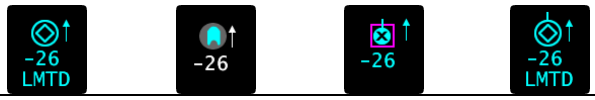
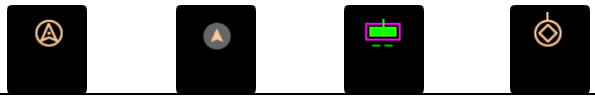
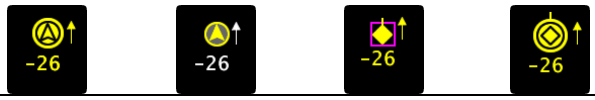
	Set			
Symbols	**1**	**2**	**3**	**4**
E				
K				
O				
R				
T				

Table 28. Paired symbols for Sets 1 through 4.

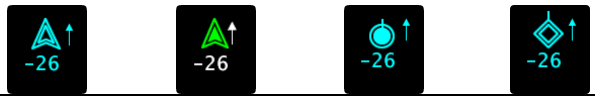
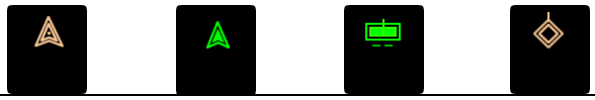
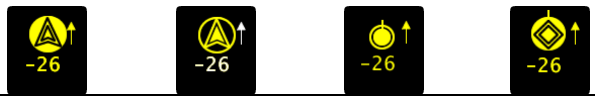
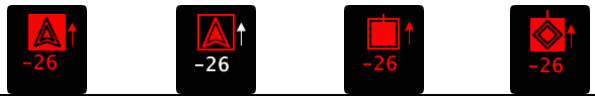
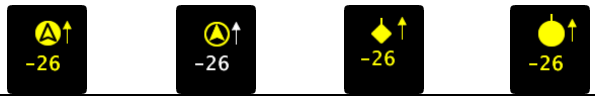
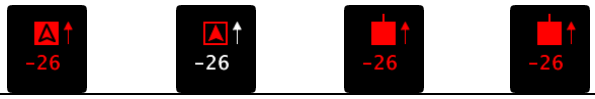
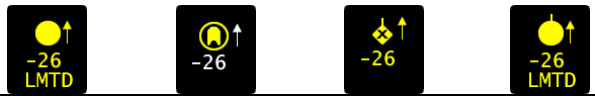
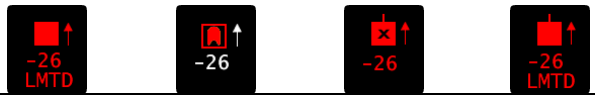
	Set			
Symbols	**1**	**2**	**3**	**4**
F				
S				
U				
V				

Table 29. Directional Alert symbols, with borders used for Sets 1 and 2.

Symbols	Set 1	2	3	4
G				
H				
P*				
Q*				

* P and Q for Set 1 are non-directional, while being directional for other sets.

5.6.2 Learning

The average trials incorrect for each Selection and Pairing state are shown in Figure 23 and Figure 24 respectively. Participants found it hard to learn the difference between Selected and Paired symbols (overall $M = 0.20$). Learning of Non-selected symbols ($M = 0.22$) was harder than learning Selected symbols ($M = 0.15$, $F[1,619] = 13.119$, $p < 0.001$). 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 ($M = 0.45$, interaction $F[3,619] = 5.809$, $p = 0.001$), which was significantly harder than Set 1 and 4 ($t[315] = 3.55$, $p = 0.0004$ and $t[329] = 2.38$, $p = 0.0177$, respectively), but not Set 2 ($t[301] = 0.93$, $p = 0.3540$). Paired symbols for Set 2 were significantly harder to learn than Set 1 ($t[290] = 2.64$, $p = 0.0087$), but not Set 4 ($t[304] = 1.42$, $p = 0.1574$). On average, learning which bordered symbols were Selected and which were Paired had on average 0.27 incorrect trials. In contrast, the learning non-bordered symbols had on average 0.08 incorrect trials.

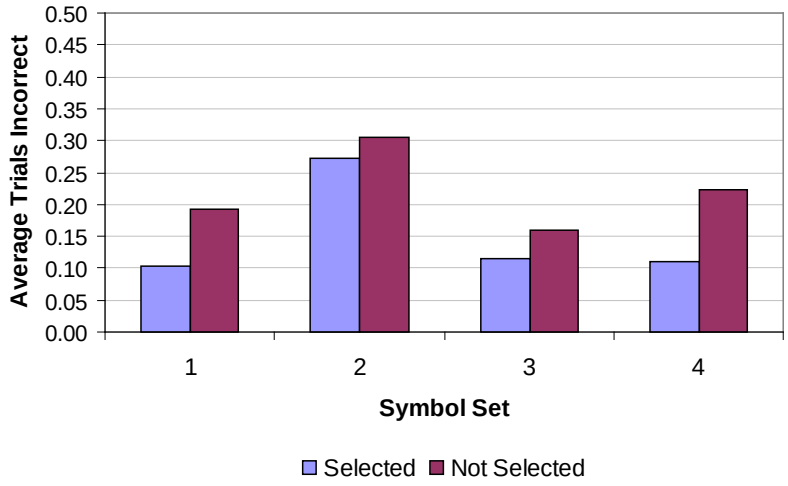


Figure 23. Average trials incorrect for Selection in the Learning task (interaction not significant).

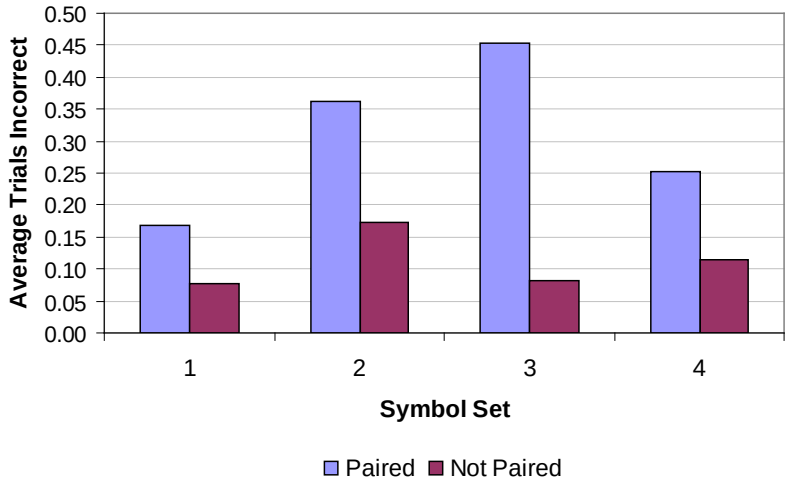


Figure 24. Average trials incorrect for Pairing in the Learning task.

For Selected and Not Selected symbols combined, Set 2 (M = 0.29) was significantly harder to learn than other sets (M = 0.15, main effect F[3,619] = 5.076, p = 0.002; all post hoc p < 0.05), while the other sets did not differ significantly from each other (minimum p = 0.890). For Paired and Not Paired symbols combined, Set 1 (M = 0.122; main effect F[3,619] = 3.949, p = 0.008) was significantly easier to learn than Set 2 (M = 0.268. p = 0.026) and Set 3 (M = 0.268. p = 0.018). All other post hoc tests were not significant.

The analysis by symbol found significant Symbol by Symbol Set interactions for both Selection and Pairing (F[18.3, 3775.0] = 7.174, p < 0.001, F[20.4, 4207.3] = 7.436, p < 0.001, respectively; see Figure 25 and Figure 26).

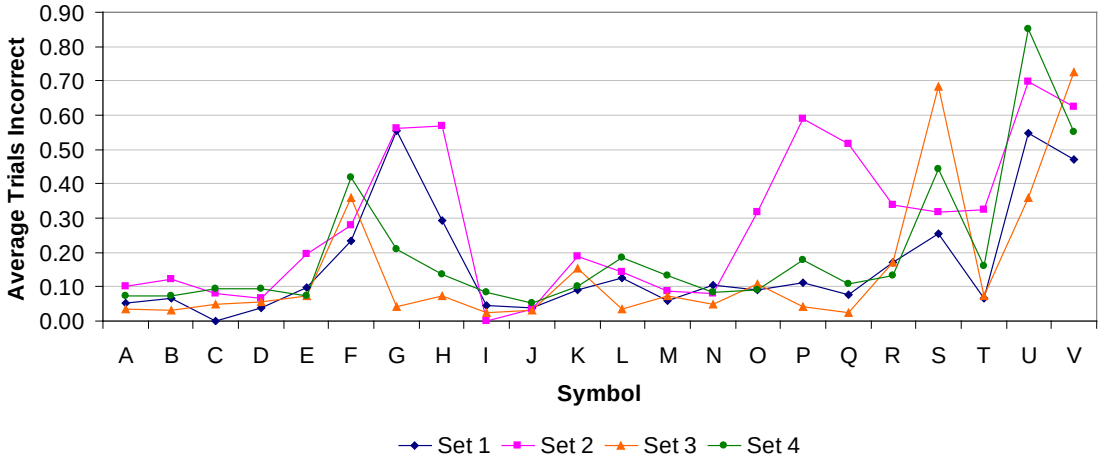


Figure 25. Average trials incorrect for Selection of individual symbols in each set.

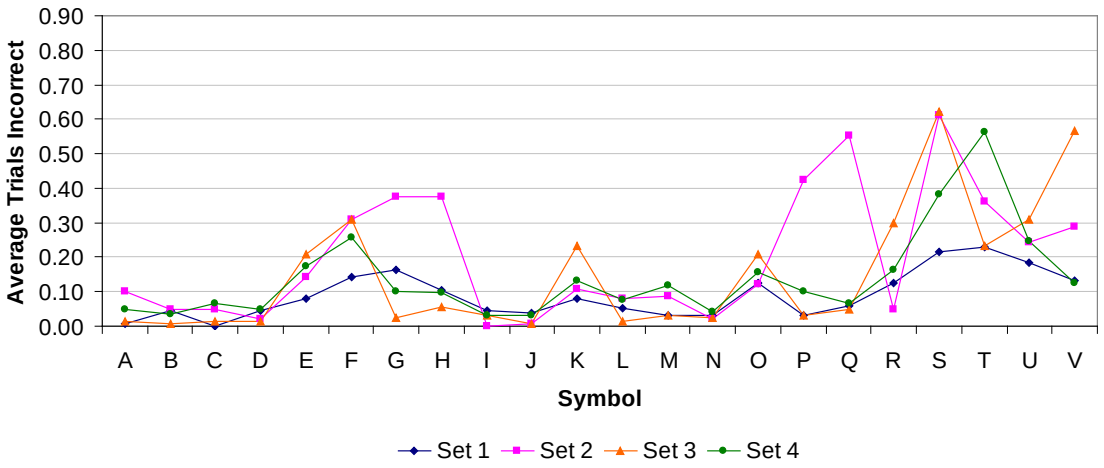


Figure 26. Average trials incorrect for Pairing of individual symbols in each set.

With both Selected and Paired states represented by borders in all sets, participants appeared to have difficulty discriminating the difference between Selected and Paired. Participants frequently indicated that Non-selected but Paired symbols (Symbols F, S, U, and V in Figure 25; see Table 28) were Selected. The difficulty with Set 3 appears to be related to Paired Symbols F, S, U, and V, which differed from Selected symbols sometimes only by the color of the border (compare Table 27). The difficulty with Set 2 appears to be related to its use of borders to indicate Alert Level in addition to Selection and Pairing. 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 (see Table 29). However, this appeared to interfere with learning that these symbols were not Selected or Paired. Learning that the square and circle border did *not* mean Paired took 0.43 incorrect trials on average, and learning that other "conformal" outlines (e.g., symbols F and S, Table 28) *do* mean Paired took 0.46 incorrect trials on average.

5.6.3 Memory

The average percent correct for each Selection and Pairing state are shown in Figure 27 and Figure 28, respectively.

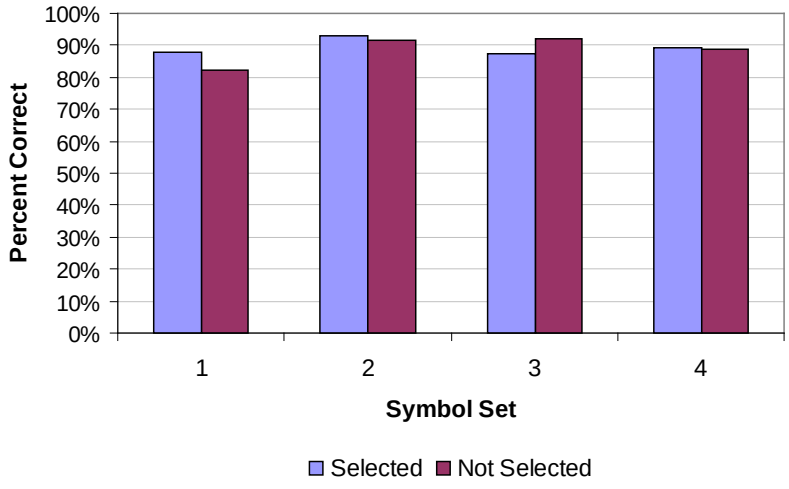


Figure 27. Percent correct on Selection for Memory task (no significant effects).

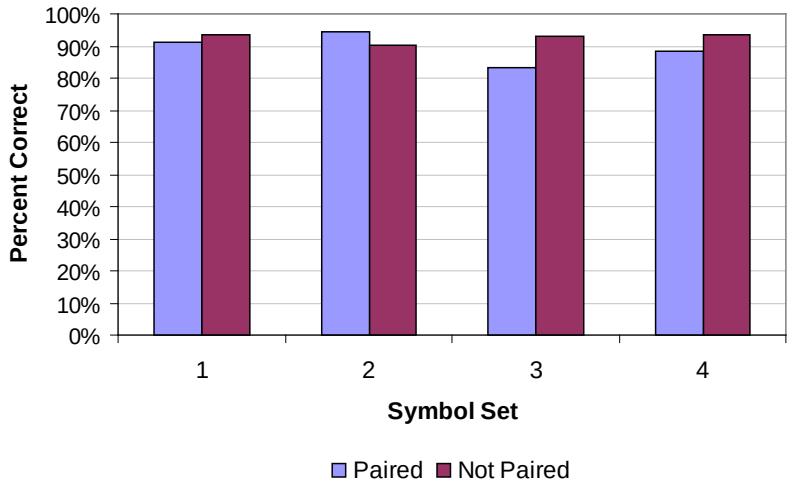


Figure 28. Percent correct on Pairing for Memory task.

The use of borders to indicate Paired was not especially memorable for Set 3 and 4 (interaction $F[1,279] = 5.206$, $p = 0.023$) with participants remembering the Not Paired symbols (M =, 92.9% and 93.6%, respectively) more than the Paired symbols (Set 3 $M = 83.3$ %, $t[88] = -2.38$, $p = 0.0021$; Set 4 $M = 88.6$%, $t[79] = -2.38$, $p = 0.0197$).

The memorability of each symbol within each symbol set is shown in Table 30. For Sets 3 and 4, participants had difficulty remembering the Pairing of Symbols R and S (see Figure 29), which differed from each other by border color only (Set 3) or border shape only (Set 4). In addition for Set 2, Not Paired symbols ($M = 90$%) were forgotten more often than Paired symbols ($M = 94$%), apparently due to confusion with the borders used for Not Paired Caution and Warning symbols (Symbols G, H, P, and Q, see Table 29), which depressed the memorability performance for Not Paired symbols to below that of Paired symbols.

Table 30. Percent of participants correctly remembering each symbol's Selection and Pairing in the Memory task.

	Selection					Paired				
	Set					Set				
Symbol	1	2	3	4		1	2	3	4	
A	94.0%	100.0%	100.0%	97.5%		97.0%	100.0%	96.7%	100.0%	
B	94.1%	100.0%	98.9%	96.3%		97.1%	100.0%	97.8%	98.8%	
C	0.0%	100.0%	96.7%	97.5%		0.0%	100.0%	97.8%	97.5%	
D	92.6%	100.0%	100.0%	100.0%	*	95.6%	100.0%	97.8%	98.8%	
E	86.6%	93.2%	88.9%	93.8%		92.5%	90.9%	83.3%	90.1%	
F	82.4%	88.6%	75.6%	81.5%		88.2%	90.9%	86.7%	87.7%	
G	57.4%	79.5%	100.0%	85.2%	*	98.5%	65.9%	97.8%	97.5%	*
H	77.9%	81.8%	97.8%	90.1%	*	97.1%	81.8%	96.7%	93.8%	
I	97.0%	0.0%	92.2%	98.8%		95.5%	0.0%	96.7%	100.0%	
J	89.7%	100.0%	97.8%	98.8%	*	89.7%	100.0%	100.0%	100.0%	*
K	83.6%	90.9%	86.7%	87.7%		88.1%	93.2%	80.0%	84.0%	
L	85.1%	100.0%	98.9%	88.9%	*	98.5%	100.0%	97.8%	98.8%	
M	86.6%	100.0%	96.7%	93.8%	*	100.0%	100.0%	95.6%	97.5%	
N	92.6%	100.0%	93.3%	100.0%	*	92.6%	100.0%	98.9%	100.0%	*
O	86.6%	90.9%	92.2%	87.7%		88.1%	95.5%	84.4%	82.7%	
P	82.1%	88.6%	96.7%	86.4%	*	98.5%	65.9%	96.7%	98.8%	*
Q	85.3%	86.4%	94.4%	87.7%		100.0%	65.9%	94.4%	95.1%	*
R	89.7%	93.2%	81.1%	85.2%		89.7%	95.5%	76.7%	87.7%	*
S	82.4%	90.9%	73.6%	80.2%		94.1%	90.9%	76.9%	86.4%	*
T	92.6%	97.7%	88.9%	92.6%		70.6%	77.3%	83.3%	63.0%	*
U	57.4%	72.7%	80.0%	55.6%	*	92.6%	95.5%	86.7%	90.1%	
V	64.7%	75.0%	74.4%	67.9%		89.7%	100.0%	82.2%	90.1%	*

*Significant differences among the sets in a Chi-square test of independence.

Figure 29. Symbols R and S of Sets 3 and 4.

5.6.4 Pilot Comments

More than half of all comments about the visual coding of the symbols concerned the Selection or Pairing parameters, sometimes in combination with Alert Level. Forty-seven comments, or 30% of all comments, concerned the confusability of Paired with Selected:

> Set 1: *It took me a little while to figure out the difference between selected (a border around the whole color shape) or paired (a double-line around the interior icon[5]) but it pretty much makes sense now that I've gone through the exercise.*
>
> Set 1: *I kept making the same mistakes with "paired" and "selected" as you can tell..;)*
>
> Set 2: *There is initially a confusion in my mind between "paired" and "selected" which took a while to comprehend.*
>
> Set 2: *Paired vs selected symbology should be more different, not just color[6].*
>
> Set 3: *Need to differentiate selected and paired better. Whenever I saw a border around an object, my mind assumed I had selected it.*
>
> Set 3: *When the outline of the symbol matched the symbol shape (rectangle/rectangle) SOMETIMES it meant the two aircraft were PAIRED, and SOMETIMES it meant they were SELECTED. This was WAY TOO CONFUSING!!!*
>
> Set 4: *I found the Paired and Selected symbols to be easy to confuse. Maybe one or the other should have an alphabetic tag or be blinking.*
>
> Set 4: *I am still not clear on "Selected" and "Paired". It seems sometimes triple boxes meant paired, but sometimes double boxes meant paired?[7]*

An additional 20 comments, of which 14 were for Sets 1 and 2, extended the confusion of Selected or Paired to Caution and Warning Alert Levels:

> Set 2: *I found that while the associated colors made perfect sense, I confused the circle and square for selection or cursor symbols in the first part of the test. I understand the need for shapes to augment colors for certain situations and/or pilots, but I think that something less ambiguous than the square and circle might be found, especially when a new user is told that there are "selected" and "paired" symbols in the mix.*
>
> Set 2: *I think it is confusing that drawing a box around the symbol doesn't indicate that it is selected.*
>
> Set 3: *Seems bad to me to have multiple uses of "circle" whether hollow or not - yellow circle meaning alert and empty circle with diamond meaning "selected" seems prone to misinterpretation.*

In particular, the use of circular visual borders to represent both Caution and Selected in Sets 1 and 2 lead to ambiguity:

> Set 1: *While I understand that only the "circle" around the target symbol means "selected" and can adapt, my mind wants to see the yellow disc indicating "caution" as "caution and selected" because of the circular shape.*
>
> Set 1: *Solid circle for "caution" may be easily confused with "selected".*
>
> Set 2: *Everything makes sense except the SELECTED/NOT SELECTED state. I thought a circle should indicate but the symbology seems inconsistent to me.*

There were also seven pilots who were felt the gray "halo" border used for Selected in Set 2 was to hard to see:

---

[5] For Set 1, Paired was actually represented by a *single* border "around the interior symbol."

[6] For Set 2, Selected and Paired were also distinguished by a circular versus conformal border respectively, but this participant apparently did not notice that convention.

[7] For Set 4, Selected and Paired were distinguished by a circular versus conformal border respectively, not by the number of borders.

Set 2: *There may be too much subtlety in the difference between a caution symbol (yellow w/circle) and a caution symbol which is in the selected state (yellow w/circle w/shaded circle). I almost missed that symbol but gave it a second look and changed my answer before submission.*

Set 2: *The shading for "selected" should be stronger - it is hard to see, and would demand more eyes-down time to discern.*

5.7 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. A shape difference may also help.
- The colors yellow and red are well associated with Cautions and Warnings, respectively.
- Caution should be exercised when using tan-like colors to mean On-ground because it may be associated with an alert level.
- Distinguishing the Selection parameter from the Pairing parameter with different kinds of borders leads to confusion.

6 Discussion

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

6.1 Directionality

Pilot learning and memory performance on the Directionality parameter was consistent with pilot preferences found in Harte and Wempe (1979), with no differences across the symbol sets, except for Set 2 being somewhat more difficult to learn. Given that the method of coding directionality in Set 2 is very similar to the method in Set 1, this performance decrement may be attributed to confusion created by other parameters that were particularly difficult in Set 2.

There was, however, evidence that 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. This possibility is supported by the finding that TCAS-experienced pilots, who were presumably familiar with the vertical speed arrow, were less likely to be confused by the Non-directional symbols. It is also supported by the greater intuitiveness found for Set 1 and Set 2 on Non-directional symbols, suggesting that the arrowhead-shaped Directional symbols may make it easier to guess the Non-directional symbols (see Table 31). 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.

Table 31. Example symbols for Sets 1 through 4 illustrating differences in Directionality.

	Set			
Directionality	**1**	**2**	**3**	**4**
Directional				
Non-Directional				

6.2 Data Quality

In the intuitiveness task, pilots tended guess that symbols without data tags had Limited Data Quality, when in fact this indicated On-ground traffic. 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 relatively high confusion observed for Set 2 in all three tasks 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 "×" in the symbol or the text “LMTD”), Set 2 indicated Limited Data Quality by either a bullet shape or a non-directional shape (see Table 32).

Table 32. Example Limited Data Quality symbols for Sets 1 through 4.

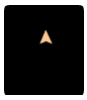
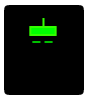
	Set			
States	**1**	**2**	**3**	**4**
Directional and Limited Data Quality				
Non-Directional and Limited Data Quality				

Participant comments suggest that pilots found this confusing. 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.

6.3 Air/Ground

The On-ground state of Symbol S of Set 2 had relatively low intuitiveness and low learnability. This difficulty may have been similar to the difficulty observed with Data Quality for Set 2, where the parameter was not consistently mapped to a single visual feature. In the case of Set 2, an On-ground state 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 (see Table 33).

Table 33. Example symbols for Sets 1 through 4, including erroneously rendered Symbol S for Set 2.

			Set			
Symbol	**Air/Ground**	**Pairing**	**1**	**2**	**3**	**4**
D	On-ground	Not Paired				
S	On-ground	Paired				
F	Airborne	Paired				

Several pilots who had Set 2 commented on the difficulty of two different colors representing an On-ground state. 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, see Table 33), 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 (2007), 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). Supporting this, several pilots who had Set 4, where On-ground symbols had the same shape as Airborne symbols (see Table 33), suggested in their comments that shape also be used to indicate Air/Ground states. It is also possible that the flat rectangle in particular suggested something non-aerodynamic or stable on the ground, and therefore not airborne (as intended by the symbol set designer). Further research is needed to explore these possibilities.

6.4 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, although several pilots commented that it was confusing. Changes in additional visual aspects may be necessary to provide cues to pilots with color vision deficiencies.

No Alert symbols were less intuitive and harder to learn than Caution and Warning symbols, particularly for symbols that used tan to indicate On-ground (see Table 33). This implies that the 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. Several participants reported in their comments that they confused the On-ground color with a Caution indication. Among pilots, amber is associated with a Caution state (FAA, 2009a, b, c, d). This inclination may be so strong that pilots without TCAS experience found yellow to be less intuitive for indicating caution than pilots with TCAS experience (who therefore expected to see yellow rather than amber to represent Caution traffic). The similarity of magenta to red on certain participants' monitors may also account for the tendency for pilots to mis-identify the alert level symbols with magenta borders (Set 3) in the Intuitiveness task (see Table 24 above). 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.

6.5 Selection and Pairing

In contrast to the results of Chandra, Yeh, and Zuschlag (2007), 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. Compared to symbols without borders, all symbols with borders performed more poorly on the parameters of Selection and Paired on all tasks.

Using different borders to distinguish Selection and Pairing states appeared to confuse pilots, as indicated by the pilot comments. The comments also indicated that this confusion extended to the use of outline squares and especially circles for Warning and Caution states for Sets 1 and 2 when circular borders are also used for Selected states (see Table 34).

Table 34. Example symbols for Sets 1 through 4 illustrating use of borders for both Selected, Paired, and Alert states (the latter for Sets 1 and 2 only).

	Set			
State	**1**	**2**	**3**	**4**
Selected				
Paired				
Caution				

The implication is that only one kind of outline should be used for a symbol set to represent a state of a parameter, and using two different kinds of outlines to distinguish Selection from Pairing states 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 a Pairing state even among pilots familiar with ASAS, and perhaps a different visual aspect should be used. Further research on this is necessary.

7 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 states 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 states).

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.

8 References

Chandra DC, Yeh M, and Zuschlag M (2007). Presentation to RTCA SC-186 WG-1. Traffic Symbology Test.

Chandra, D., Zuschlag, M., Helleberg, J. and S. Estes. (2009). Symbols for cockpit displays of traffic information. In *Proceedings of the 28th Digital Avionics Systems Conference.* 25-29 October 2009, Orlando, FL.

Federal Aviation Administration (2009a). Airworthiness standards: Normal, utility, acrobatic, and commuter category airplanes, Warning, caution, and advisory lights, *Federal Aviation Regulations*, 14 CFR § 23.1322.

Federal Aviation Administration (2009b). Airworthiness standards: Transport category airplanes, Warning, caution, and advisory lights, *Federal Aviation Regulations*, 14 CFR § 25.1322.

Federal Aviation Administration (2009c). Airworthiness standards: Normal category rotorcraft, Warning, caution, and advisory lights, *Federal Aviation Regulations*, 14 CFR § 27.1322.

Federal Aviation Administration (2009d). Airworthiness Standards: Transport category rotorcraft, Warning, caution, and advisory lights, *Federal Aviation Regulations*, 14 CFR § 29.1322.

Hart SG & Wempe TE. (1979). Cockpit Display of Traffic Information: Airline Pilots' Opinions about Content, Symbology, and Format. NASA technical report A-7884, NASA-TM-78601.

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

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

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Appendix A: Experiment Screen Captures

Informed Consent Page

Symbols for Cockpit Display of Traffic Information (CDTI) Research Study
US Department of Transportation (DOT) Volpe Center
MITRE Center for Advanced Aviation System Development (CAASD)

I understand that this study, titled "Symbols for Cockpit Display of Traffic Information" is being conducted jointly by the John A. Volpe National Transportation Systems Center, United States Department of Transportation (USDOT), and the MITRE Center for Advanced Aviation System Development, and is being directed by Dr. Divya Chandra and John Helleberg. The USDOT Volpe Center is funded by the Federal Aviation Administration, Human Factors Research and Engineering Group. The MITRE Center for Advanced Aviation System Development is a Federally Funded Research and Development Center (FFRDC) non-profit organization that conducts research in the public interest for the FAA.

Purpose of Study. Recent technological advances (e.g., ADS-B) provide a means to display traffic in the cockpit. There are currently no standards or recommendations for what the traffic symbols should look like. The purpose of this study is to evaluate proposed symbols for traffic to assess how intuitive they are and how easy they are to learn. Several symbols will be tested to determine whether any are especially difficult to learn and use.

Procedure. There are two main sections in the study plus an optional third section. In the first section you will see each traffic symbol one at a time and make a guess about what that symbol means. After seeing every symbol in the set, you will be shown their intended meanings. In the second section of the study, you again will see each symbol one at a time and indicate what it is supposed to mean, but this time you will check your answers after making a response. You will be asked about the different symbols until you are able to recognize them all, or until time runs out for the study. The study is estimated to take 45 minutes to complete. The optional third part of the study will occur one to two weeks later. In this follow up task, you will be asked to indicate the symbol meanings again, just once per symbol. The follow up task is expected to take just 10 minutes.

Discomfort and Risks. There are no known physical risks in this study other than what a participant might experience working on his/her home or office computer for 45 minutes.

Benefits to You. Participation provides you an opportunity to aid in the development of recommendations for the design of cockpit displays of traffic information. These systems will be available more widely over the next few years, and they may be easier to use because of your input.

Assurances and Rights of the Participant. Your participation in this study is completely voluntary. Your participation is strictly confidential, and no individual names or identities will be recorded with any data or released in any reports. Only arbitrary numbers are used to identify pilots who provide data. You may terminate your participation in the study at any time.

If you have any questions, please let us know. For further information about this study, please feel free to contact:

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Statement of Consent

I, <please type your name here>, have read this consent document. I understand its contents, and I freely consent to participate in this study under the conditions described.

Submit and Proceed to Research Study | Print Consent Form | Decline/Exit

Demographics Page

Pilot Background

Please answer the following questions to provide us with some information about your piloting background.

Are you licensed and "current" by FAA standards and definitions? ○ Yes ○ No

Are you currently a student pilot? ○ Yes ○ No

Additional background information (optional) [ ]

Total Flight Hours (approximate) [ ]

Flight Experience: Please describe the type of flight experience that you have.

☐ Air Transport ☐ Corporate ☐ Private ☐ Military

Cockpit Traffic Display Experience

Please note whether you have experience with the following systems.

☐ TCAS I or TAS (no Resolution Advisories)
☐ TCAS II (with Resolution Advisories)
☐ Mode S TIS
☐ ADS-B/TIS-B
☐ Other Traffic Display (specify): [ ]

If you have experience with ADS-B, please describe:

☐ UPS CDTI using ADS-B
☐ Test ADS-B system in Alaska (Capstone)
☐ Other (please describe): [ ]

Rate approximately how much time you have flown with any kind of cockpit traffic display.

○ ○ ○ ○ ○ ○ ○ ○

Never | Under 10 hrs | Over 100 hrs | Over 1000 hrs

How did you hear about this study?

☐ ALPA
☐ NBAA
☐ AOPA
☐ From a pilot colleague
☐ Other (specify): [ ]

Continue to Pilot Expectations Task >>

Intuitiveness Task, Initial Page with Instructions

Pilot Expectations (start)

In this task, you will see each traffic symbol one at a time. There are 22 symbols in the study.

For each symbol, please indicate what information you think it represents by clicking in the button next to your choice for each piece of symbol information. Please make a guess, even if you do not have any strong opinions. If you would like, you can call up the traffic symbol information and definitions by clicking in the "Show Definitions" link.

After completing this task, you will go on to the Pilot Training task.

Continue to Pilot Expectations task >>

Parameter States Page

Information	Possible States	
Directionality Indicated	**Directional** The track of the traffic aircraft is displayed.	**Not Directional** The 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.	
Selected State	**Selected** The traffic aircraft is chosen by the pilot to display general information (e.g., Flight ID).	**Not Selected** The traffic aircraft is **not** chosen by the pilot to display general information.
Paired State	**Paired** The traffic aircraft is chosen by the pilot to use its information for a specific procedure (e.g., guidance for following an aircraft on approach). The system allows pairing only if the traffic has full data quality.	**Not paired** The traffic aircraft is **not** chosen by the pilot to use its information for any specific procedure.

Close this Window

Intuitiveness Task (Sample Page)

Pilot Expectations

9% complete

	**What type of information is depicted by this symbol?**
Directionality Indication:	○ Directional ○ Not Directional
Data Quality:	○ Full ○ Limited
Air/Ground:	○ Airborne ○ On-Ground
Alert Level:	○ None ○ Caution ○ Warning
Selection State:	○ Selected ○ Not Selected
Paired State:	○ Paired ○ Not Paired
	Next Symbol Show Definitions

Intuitiveness Task Completion Page and Learning Task Preview

Pilot Expectations Task (end)

You have now seen all the symbols in the set. This is a good opportunity for a short break if you need it. Next you will see a table in which the intended meanings of all the symbols are described. You can study the table briefly, but do not spend more time on it than you would under normal circumstances (e.g., as if you had just installed a CDTI in your aircraft).

When you are ready to begin the next task, click on Continue.

Continue to Symbol Meanings >>

Symbol Meanings Training

Symbol	Directionality Indication	Data Quality	Air/Ground	Alert Level	Selection State	Paired
	Directional	Full	Airborne	None	Not Selected	Not Paired
	Not Directional	Full	Airborne	None	Not Selected	Not Paired
	Directional	Limited	Airborne	None	Not Selected	Not Paired
	Directional	Full	On-Ground	None	Not Selected	Not Paired
	Directional	Full	Airborne	None	Selected	Not Paired
	Directional	Full	Airborne	None	Not Selected	Paired
	Directional	Full	Airborne	Caution	Not Selected	Not Paired
	Directional	Full	Airborne	Warning	Not Selected	Not Paired
	Not Directional	Limited	Airborne	None	Not Selected	Not Paired
	Not Directional	Full	On-Ground	None	Not Selected	Not Paired
	Not Directional	Full	Airborne	None	Selected	Not Paired

	Not Directional	Full	Airborne	Caution	Not Selected	Not Paired
	Not Directional	Full	Airborne	Warning	Not Selected	Not Paired
	Directional	Limited	On-Ground	None	Not Selected	Not Paired
	Directional	Limited	Airborne	None	Selected	Not Paired
	Directional	Limited	Airborne	Caution	Not Selected	Not Paired
	Directional	Limited	Airborne	Warning	Not Selected	Not Paired
	Directional	Full	On-Ground	None	Selected	Not Paired
	Directional	Full	On-Ground	None	Not Selected	Paired
	Directional	Full	Airborne	Caution	Selected	Not Paired
	Directional	Full	Airborne	Caution	Not Selected	Paired
	Directional	Full	Airborne	Warning	Not Selected	Paired

Continue to Pilot Training Task Instructions >>

Learning Task, Instruction Page

Pilot Training Task

You will see each symbol one at a time and be asked to indicate what it means. You can check your answers after you enter your response for each symbol. You will see all of the symbols at least two times, even if you accurately describe their meanings. If you would like, you can call up the traffic symbol information and definitions by clicking in the "Show Definitions" link. The study is complete when you correctly identify the meaning of all symbols.

Continue to Pilot Training Task >>

Learning Task (Sample Page)

Correct answers are in green

7% complete *

* The progress bar above is approximate and does not update linearly
(it may jump forward after you have seen all the symbols once)

	**What type of information is depicted by this symbol?**
Directionality Indication:	Directional (**Your answer**) **Not Directional**
Data Quality:	**Full** (**Your answer**) Limited
Air/Ground:	**Airborne** On-Ground (**Your answer**)
Alert Level:	None **Caution** (**Your answer**) Warning
Selection State:	Selected **Not Selected** (**Your answer**)
Paired:	Paired **Not Paired** (**Your answer**)
	Next Symbol Show Definitions

Comment and Follow-up Request Page

Thanks for your time and input! You have successfully completed this study on CDTI symbols. Your help makes it possible to develop a set of symbols that will facilitate safer cockpit displays of traffic information for the future.

If you have any other general comments about this research, please enter them below.

Preliminary results of the study will be presented to the RTCA SC-186 industry group and the Federal Aviation Administration in early 2009. If you would like to receive a copy of the preliminary results, please send a note to Divya Chandra (divya.chandra@dot.gov) or John Helleberg (jhelleberg@mitre.org). If and when a formal report is prepared on the study, it will be posted online the USDOT Volpe Center website (www.volpe.dot.gov/hf/pubs.html).

Registration for Optional Follow-up Study

Will you help us further with testing these symbols? We would like you to return to this study in a week to see how easy the symbols are to remember after not using them for some time. This follow-up task takes about 10 minutes.

If you would like to help us with this test, please enter an email address for us to send you a reminder note in one week.

Email address:

One week from today, we will send you the link for this follow-up study. We will not use the email for any other purpose, nor will we give it to anyone else.

Submit comments and/or registration for follow-up study

Exit without submitting comments

Memory Task Initial Page

CDTI Symbol Follow Up

About a week ago, you participated in an online survey to evaluate a proposed symbol set for a Cockpit Display of Traffic Information (CDTI). We would now like to see how easy it is to remember the traffic symbol set after not using it for some time.

In order for us to know which symbol set you saw last week, please enter the email address you sent to us for the follow-up task, so that we can match it to your previous input.

Similar to last week's task, you will be presented with each symbol one at a time and asked to indicate what it is supposed mean. After you have done so for the entire symbol set, you may check your answers against the intended meanings. Note that you will not be able to review the symbol meanings before you enter your responses.

Email address: johndoe@abc.com BEGIN >>

Memorability Task (Sample Page)

5% complete

	**What type of information is depicted by this symbol?**
Directionality Indication:	◉ Directional ○ Not Directional
Data Quality:	○ Full ◉ Limited
Air/Ground:	◉ Airborne ○ On-Ground
Alert Level:	◉ None ○ Caution ○ Warning
Selection State:	◉ Selected ○ Not Selected
Paired State:	○ Paired ◉ Not Paired
	Next Symbol

Final Page

End of CDTI Symbol Follow Up

You have completed the follow-up test on CDTI symbols. Thank you for participating!

Review Symbol Meanings (optional)