

Pilot Stereotypes for Navigation Symbols on Electronic Displays

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ABSTRACT

There is currently no common symbology standard for the electronic display of navigation information. The wide range of display technologies and the different functions these displays support make it difficult to design symbols that are easily recognized across platforms. This paper presents the findings of an experiment that addressed the issue of *symbol stereotypes*, i.e., whether symbols have key features that are necessary for recognition. Pilots were shown symbols for navigation aids collected from five aviation display manufacturers and published documents. They were asked to indicate whether they considered the symbol shapes to be representative of a specific symbol type. The results showed that pilots do have stereotypes regarding what symbol shapes are representative of a symbol type. Stereotypical shapes for navigation symbols were identified despite variations in the size, color, and fill with which the test symbol shapes were presented. The results suggest that symbol stereotypes exist and should be considered in the design of electronic symbols to maintain safety. While the scope of this work addresses electronic navigation symbology, the techniques used here are applicable to addressing other types of symbology.

Keywords

Aeronautical charts, symbology, electronic symbols, map displays, navigation displays

INTRODUCTION

An increasing number of electronic displays show navigation information, i.e., information from aeronautical charts that assists the pilot in determining the aircraft's position. The display may be an in-flight moving map display driven by a Flight Management System (FMS), an electronic chart on an Electronic Flight Bag (EFB), a surface moving map displays on an installed unit, or a panel-mounted moving map displays on a Global Positioning System (GPS) unit. The design of symbology for navigation displays is complex due to this wide range of display technology and functionality. Some level of commonality is important so that pilots are able to extract and integrate information conveyed by symbols from electronic sources and paper charts for flight planning, situation awareness, and navigation.

The Volpe National Transportation Systems Center worked with the Federal Aviation Administration (FAA), specifically the Office of Aircraft Certification (AIR), the National Aeronautical Charting Office (NACO), and the Human Factors Research and Engineering Group (AJP-61) to prioritize research issues in order to support efforts for developing symbol standards. One concern was the variety of symbols shapes currently in use. There is currently no standard symbology for the electronic display of navigation

information. Although multiple documents provide recommendations and guidelines for symbology for moving map displays (e.g., [1, 3]), use of these symbol sets has not been achieved on a voluntary basis. The goal of this effort is to assist in the development of recommendations for electronic aeronautical chart symbology that *will* be adopted by industry, by providing data on how symbols are perceived and used by pilots. These data will also be considered by the FAA and by the International Civil Aviation Organization (ICAO) for inclusion in their guidance material.

We focused on eight navigation symbols that represent the majority of the navigation symbol types used in the United States of America (USA): DME, intersection/fix, NDB, TACAN, VOR, VOR/DME, VORTAC, and waypoint. We contacted five aviation display manufacturers and asked them to send us their navigation symbol sets. Additionally, we collected symbols used on USA government charts produced by NACO [2], symbols recommended in ICAO *Annex 4, Aeronautical Charts* [1], and symbols in the Society of Automotive Engineers (SAE) Aviation Recommended Practice (ARP) 5289 [4]. We compared these eight symbol sets and noted the use of non-standard symbols, varying levels of detail in the symbols depending on the manufacturer, and differences between symbols shown on electronic displays and those used on paper charts. An example, comparing the representation of the VORTAC symbol, is shown in Table 1.




	USA Symbol (NACO)	Jeppesen Symbol	SAE ARP 5289
VORTAC			

Table 1. Variations in the VORTAC symbol.

Note: Jeppesen symbology, Copyright 2004 Jeppesen Sanderson, Inc.

The USA symbol is used by the FAA NACO on paper charts, the Jeppesen symbol is a prototype for use on electronic charts, and the SAE symbol is recommended for use on electronic moving map displays. The USA symbol and Jeppesen symbol are different but both share some features with the symbol recommended in SAE ARP 5289. The symbols are different enough that pilots may not realize that they all represent a VORTAC. Thus, the potential for confusing and misleading symbology exists.

It was therefore of interest to determine whether there are key features that pilots considered representative of a symbol type, regardless of display format. These *representative* key features are the basis for pilots'

stereotypes for a symbol type. In this paper, the terms *representative* and *stereotype* are used interchangeably.

The goal of the current experiment was to determine the acceptable variations in a symbol's design. The focus was on the symbol shapes used to represent the eight navigation symbols: DME, fix, NDB, TACAN, VOR, VORDME, VORTAC, and waypoint. A full report on this study and a related study on the use of symbol-feature rules is provided in [6]. A plan for the study was presented in 2004 [5].

Method

Participants

Seventy-three active instrument-rated pilots from local flying clubs, the FAA, and the Air Line Pilots Association (ALPA) participated in the experiment. Forty-one were air transport pilots, 14 were military pilots, 12 were General Aviation (GA) pilots, and six were pilots working at the FAA who had a mix of air transport and/or military flying experience. Because the symbols pilots are familiar with will vary depending on the charts they use, participants were asked to indicate the primary chart provider for the charts they used most often. Twenty-seven pilots considered themselves USA NACO chart users, and 46 considered themselves Jeppesen chart users. However, pilots sometimes use charts from other providers. Nine of the USA NACO chart users indicated that they had experience with Jeppesen charts, and 14 of the Jeppesen chart users had experience with the USA NACO charts. Many of these pilots indicated that their use of these "secondary" charts was infrequent.

Symbols

The experiment addressed the eight navigation symbol types: DME, fix, NDB, TACAN, VOR, VORDME, VORTAC, and waypoint.¹ The symbol shapes were collected from five aviation display manufacturers and published documents (ICAO *Annex 4* [1], FAA NACO *Aeronautical Chart User's Guide* [2], and SAE ARP 5289 [4]). Because most moving map and navigation displays today use a black background, most of the symbols collected for the experiment were already drawn on a black background, and were presented in the color provided by the manufacturer in the experiment. A few symbols, however, were drawn in black on a white background. For consistency, these symbols were modified and presented as white symbols on a black background. No other modifications to colors of symbols were made.

Foils, i.e., "fake" symbols that are not currently in use, were also presented. Three foils that were shown for each symbol type are presented in Figure 1 au-dessous.



Figure 1. Foils.

Responses to the foils were used as an indicator as to whether or not participants discriminated between shapes. For example, some pilots may not associate a definitive

¹ Note that while fixes and waypoints are both types of intersections, a *fix* is defined by the intersection of pathways referenced to ground-based navigation aids whereas a waypoint is defined by latitude and longitude coordinates.

shape for a symbol type, but rather expect and accept variation in the presentation of symbols. If this were the case, then pilots would judge the foils to be acceptable.

Tasks

The experiment consisted of eight blocks, with each block addressing one of the symbol types. For each block, participants were shown a series of test symbol shapes and instructed to indicate whether the test symbol was representative of the symbol type. Pilots completed two tasks: *symbol recognition* and *symbol recall*.

In the *symbol recognition task*, participants were shown test symbol shapes and asked to indicate whether they would consider it to be representative of the symbol type. Two versions of this task were developed: an electronic version and a paper version. In the electronic version of the task, participants were shown the test symbol shapes one at a time *without context* on a laptop computer. Participants were asked the following question: *Based on your knowledge of charts and navigation displays, decide whether the symbol would represent a <symbol type> or not if you saw it on a chart or navigation display*, where **<symbol type>** was replaced with the name of the symbol of interest.

A trial was the presentation of a test symbol shape. Test symbol shapes were shown in isolation on a black background. Each trial began by showing a black screen with a white crosshair (+) in the center for approximately 250 ms. Next, the crosshair was removed and the test symbol shape was shown centered on the display. Participants gave a yes/no response to the test symbol using the arrow keys on the keyboard. The arrow keys were labeled "yes" or "no" to prevent confusion. Participants then provided a rating of confidence in their response. Confidence was measured on a 7-point scale from 1 (Not confident) to 7 (Very confident). Participants entered their confidence rating using the number keys on the keyboard.

For each symbol type, participants were shown 24 different test symbol shapes. Because the size at which the symbol is shown on a navigation or moving map display may vary, the symbol shapes shown in the electronic version of the symbol recognition task were presented in two sizes: small (0.125 in or 0.318 mm), and large (0.25 in or 0.635 mm). There were a total of 48 experimental trials.

In the paper version of the symbol recognition task, participants were asked to answer the same question posed in the electronic version. Participants were asked to cross out the test symbol shapes that they did not consider to be representative of the symbol type. The paper questionnaire showed 24 test symbol shapes for each symbol type. The test symbol shapes were identical to those presented in the electronic version of the task. However, symbol size was not manipulated. The symbol size shown in the paper questionnaire was representative of the actual size with which the symbol would be displayed.

In the *symbol recall* task, participants were asked to draw the symbol shape(s) that they considered to be most representative of the symbol type and state the rule they used in classifying the symbols in the electronic and/or paper symbol recognition task. The symbol recall task was presented on paper only.

Procedure

The electronic version of the experiment took approximately one hour to complete. The electronic version of the symbol recognition task was available on a laptop and administered by an experimenter. Participants completed all tasks for one symbol type before moving on to the next symbol type. The order in which the symbol types were presented was counterbalanced between subjects.

Because the electronic version of the symbol recognition task could not be self-administered, participation in the electronic version of the task was limited to pilots based in or flying through the local area. Additionally, there was one data collection trip to the FAA in Washington D.C. In total, 28 pilots completed both the electronic and paper versions of the symbol recognition task and the symbol recall task. Participants who completed both tasks were given a \$30 gift certificate to thank them for their time and participation.

Initial analyses showed no difference between participants' responses to the electronic and paper symbol recognition tasks. In order to increase the number of pilots participating in the study, a paper questionnaire, consisting of the paper version of the symbol recognition task and symbol recall task, was distributed by mail to 200 additional pilots. Completing the paper version only took approximately 20 minutes. Of the 200 questionnaires distributed, 45 were returned (a 22.5% response rate).

Analysis

Data from the *symbol recognition* task were used to calculate the frequency with which a test symbol was considered representative of a symbol type. The frequency data were analyzed with a chi-square test to determine whether the frequency of "yes" responses was significantly higher than what would be expected from a random split.

Separate chi-square tests were conducted on the data for the electronic task and paper task, but because there was virtually no difference in the classification of the responses, the data were combined.

The test symbols were categorized into three groups:

- *Representative symbols*: test symbols considered by pilots to be representative of the symbol type ("yes")
- *Mixed results*: mix of "yes"/ "no". That is, the test symbols did not receive enough "yes" responses to be considered to be representative of the symbol type but also did not receive enough "no" responses to be considered not representative of the symbol type.
- *Not representative*: test symbols that were *not* considered to be representative of the symbol type ("no")

Note that no comparison was conducted to determine a "single most stereotypical" symbol.

Shapes drawn by pilots in the *symbol recall* task were categorized by shape and counted. Since pilots sometimes drew more than one "representative" symbol, the total number of symbol shapes drawn may be greater than the number of pilots participating in the study. Pilots were also asked to write the rule(s) they used to classify the test symbol shapes for the symbol recognition task. These rules are best described by the shapes that pilots drew in the symbol recall task and will not be presented in detail here.

Results

The results of the study identified symbol shapes that were considered to be representative of the symbol type. Table 2 presents the results of the symbol classification task for the eight navigation symbols. *All the test symbol shapes shown are real symbols that are currently in use, unless marked as a foil.* Drawings from the symbol recall task for each symbol type and the number of times each shape was drawn are shown in Table 3.


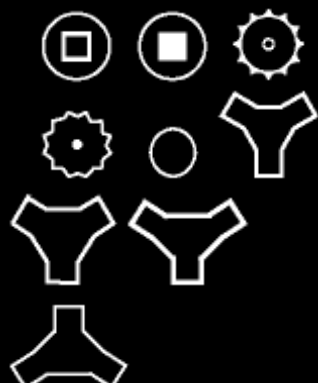



Symbol Type	Symbol Color	Representative	Mixed	Not Representative
DME	White			
	Cyan			
	Green			

Table 2. Symbol Recognition.

Note: Jeppesen symbology, Copyright 2004 Jeppesen Sanderson, Inc. Some symbols are reduced or use different colors for illustrative purposes. Specifically with reference to color, the symbols provided by Jeppesen were inverted from being black symbols on a white background to white symbols on a black background. No other changes to the color of the symbols were made.

Symbol Type	Symbol Color	Representative	Mixed	Not Representative
Fix	White			
	Cyan			
	Magenta			
NDB	White			
	Cyan			
TACAN	White			
	Cyan			
	Green			
VOR	White			
	Cyan			
	Green			

Table 2. Symbol Recognition (continued).

Symbol Type	Symbol Color	Representative	Mixed	Not Representative
VORDME	White			
	Cyan			
	Green			
VORTAC	White			
	Cyan			
	Green			
Waypoint	White			
	Cyan			
	Magenta			
	Orange			

Table 2. Symbol Recognition (continued).









































DME	Fix	NDB	TACAN	VOR	VORDME	VORTAC	Waypoint
 33	 83	 70	 55	 53	 32	 64	 77
 16	 13	 7	 13	 22	 20	 9	 5
 16	 7	 5	 7	 3	 15	 3	 1
 5	 1	 1		 1	 7	 1	
 3	 1			 1	 5	 1	
 1					 3		
 1					 1		
 1							

Table 3. Hand-drawings of Symbols. Frequencies are shown next to each symbol.

DME

Table 2 shows that no representative shape for the DME symbol was identified in the aggregate results of the symbol classification task. Pilots commented that they typically see a DME in combination with another symbol; consequently, they were not familiar with the shape of a stand-alone DME.

Pilots' drawings of shapes in the symbol recall task, shown in the first column of Table 3, confirm the results of the symbol recognition task shown in Table 2. The frequency with which each shape was drawn and the variety of shapes suggest that pilots do not have a clear stereotypical shape for a DME. The square shape, which was classified in the "Mixed" category in Table 2, was the most frequently drawn shape in the *symbol recall* task.

Pilots' drawings and written rules indicate that pilots considered the DME to be a *square* (the first symbol in the first column of Table 3), a *starburst symbol* (the second symbol), or a *TACAN* symbol (the third symbol). These three shapes are in use by various manufacturers and chart providers for representing a DME. The three symbols drawn by only one pilot each either do not exist or are not used to represent a DME.

Fix

The results of both the symbol recognition and symbol recall tasks show that pilots considered the stereotypical shape for a fix to be a triangle. As shown in Table 2, pilots classified the test symbol shapes despite variations in the size, fill, or color of the symbol shape. Also shown in Table 2 is the fact that some manufactures and chart providers do not distinguish between symbols for fixes (usually represented as a triangle) and waypoints (usually represented as a four-pointed star). In fact, the first three symbols drawn, shown in the second column of Table 3, are

all in use to represent a fix. The last two symbols drawn for the fix either do not exist or are not used to represent a fix.

NDB

As shown in both Tables 2 and 3 and by their written rules, pilots considered the "representative" NDB shape to be an *array of small dots* with a circle in the center. The "representative" NDB shape did not differ based on the size of the circle in the center, whether the circle in the center was filled or unfilled, or whether the symbol was surrounded by a circle or not. As the array of dots became less distinctive (e.g., see the top symbol in the Mixed category column), however, pilots were not sure if the symbol was an NDB or not. Test symbol shapes shown in Table 2 that were considered to be *not* representative of an NDB were probably because the array of dots was not present.

TACAN

The TACAN symbol is used primarily by the military, but a representative shape was identified even though many non-military pilots noted that they did not use the symbol. Table 2 shows how the test symbol shapes representing the TACAN were classified in the symbol recognition task. The fourth column of Table 3 shows pilots' drawings of shapes they considered to be representative of a TACAN in the symbol recall task.

Pilots' rules for the TACAN described the "representative" shape as a *Y-shaped symbol* or a *three pronged object with flattened points to prongs and curved webbing between prong points*. This shape is shown in the "Representative" column in Table 2; pilots identified the shape as being representative despite variations in the size, color, and fill of the test symbol shapes. A *Y-shaped symbol* was also drawn most frequently in the symbol recall task, shown au-dessus in Table 3.

VOR

The results of the symbol recognition task (in Table 2) and the symbol recall task (in the fifth column of Table 3) show that the stereotypical shape of a VOR was considered to be a hexagon, regardless of variations in the size, color, and fill of the test symbol shapes. Note in Table 2, one foil consisting of two concentric hexagons, received a mix of “yes” and “no” responses. While that test symbol is not a real symbol, it is likely that some pilots considered it to be a VOR because its overall shape was a hexagon, hence matching the representative shape.

VORDME

Pilots’ rules described the representative shape for a VORDME as a *hexagon surrounded by a square*. As Table 2 shows, pilots identified a representative shape despite variations in the size and color of the shape. The fill of the center and the presence of a circle surrounding the symbol did introduce some uncertainty in the classification, however. This is shown by the first two symbols in the “Mixed” column; pilots were not sure if these filled symbols were VORDMEs.

The representative shape identified in the symbol recognition task was drawn most frequently in the symbol recall task, shown in Table 3. It is interesting to note that in the task, the eight pilots drew individual components of the VORDME; five pilots drew the symbol shape for a stand-alone VOR only and three drew the shape for a stand-alone DME.

VORTAC

Pilots’ rules indicated that the stereotypical shape for a VORTAC was a *hexagonal shape with three of the tips blocked*. The rule is depicted in the results of the symbol recognition task in Table 2 and symbol recall task in Table 3. Table 2 also shows that pilots identified a representative shape regardless of the variations in the size, fill, color, and orientation with which the test symbol shapes were presented. In fact, one foil, which had the same overall shape as a representative VORTAC symbol but was rotated 180°, was categorized as being representative of a real VORTAC symbol (shown in the bottom row of Table 2). A second foil received a mix of “yes” and “no” responses. This foil, shown in the bottom row of the “Mixed” column in Table 2, is triangular with rounded, filled endpoints, but the overall shape and fill pattern is similar enough to that of the representative symbols that the foil was considered to be representative of a VORTAC symbol 47% of the time.

Waypoint

The classification of symbols (shown in Table 2), drawings (shown in the last column of Table 3), and written rules all indicate that pilots’ consider the representative shape for a waypoint to be a four-pointed star. As Table 2 shows, the representative shape was identified despite variations in the size, fill, color, or presence of a circle surrounding the symbol.

Summary of Results

Table 4 shows the representative shape identified for each symbol type.








Symbol Type	“Representative Shape”
DME	None Identified
Fix	
NDB	
TACAN	
VOR	
VORDME	
VORTAC	
Waypoint	

Table 4. Representative shapes.

Note: Jeppesen symbology, Copyright 2004 Jeppesen Sanderson, Inc. Some symbols are reduced or use different colors for illustrative purposes.

A representative symbol shape was identified for seven of the eight symbols. No representative shape was identified for the DME in the aggregate results. Pilots’ comments indicated that DMEs are typically drawn in conjunction with another symbol, so they were less familiar with the shape of a stand-alone DME.

Symbol shape was the key factor for classifying symbols in the *symbol recognition* task. The representative shapes identified from the electronic version of the symbol recognition task, the paper version of the symbol recognition task, and the symbol recall task were identical – a finding that strongly supports the idea that pilots have stereotypes for symbols and that those stereotypes were identified by the current study. The results indicated that the size, color, and orientation were not critical factors in determining what the symbol was. Representative shapes were identified despite the variations in size, color, and orientation with which the test symbol shapes were presented. Symbol fill generally did not influence pilots’ ratings as to whether a symbol shape was representative of the symbol type, but circles surrounding symbols created some uncertainty. The presence of a circle surrounding a symbol is a convention used by some chart providers to distinguish a fly-over symbol from a fly-by symbol. However, this convention is not yet in widespread use². Consequently, pilots may not have known whether the circle was a feature of the symbol or created a different symbol entirely. Therefore, while the results show that symbols surrounded by a circle tended to fall in the “mixed” category, the results should not be interpreted to speak to the usability of the circle rule.

The test symbol shapes presented in this study consisted of symbols used on paper charts, electronic charts, and electronic navigation displays. It is interesting to note that the representative symbols shown in Table 4 are commonly used on FMS and moving map displays (with the exception of the NDB symbol). These shapes are also used on NACO

² Sixteen of the pilots who participated in the study were previously exposed to the circle feature-rule, but this did not appear to influence the results.

paper charts. The representative shapes identified are most likely due to pilots' familiarity with the symbols shown on electronic displays, regardless of their chart provider.

Surprisingly, pilot experience and chart usage did not influence which symbols were easiest to recognize and use. The representative shape identified did not differ as a function of experience (e.g., air transport, general aviation, or military) or chart provider (e.g., Jeppesen, NACO).

Conclusion

The results of this study highlight the importance of consistency in symbol design not only across chart providers but also across display mediums. This issue of consistency will become more important as electronic charts replace existing paper charts in the future. These findings contribute towards the development of recommendations to FAA, industry, and ICAO regarding electronic symbology for navigation information. The results of the studies will be used in industry efforts to develop best practices for electronic symbols that will be adopted voluntarily (i.e., an update to [4]). The FAA expects to reference these industry recommendations in their guidance, and ICAO is examining the recommendations carefully as well, for possible updates to their symbology guidance. The studies described here provide data on what navigation symbol shapes are easily recognized and how those symbols may be modified while remaining recognizable. The next steps will be to study an expanded set of proposed symbols to address their recognizability, and to evaluate other symbology issues that may arise as SAE ARP 5289 is updated. While the scope of this work addresses navigation symbology, the techniques used here are applicable for addressing other types of symbology as well.

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