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Instrument-Approach-Plate Design Considerations for Displaying Radio Frequencies

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This experiment examined the effectiveness of four different layouts for displaying radio frequencies on instrument approach plates. Three of the four layouts were similar to those found in existing charts published by the National Oceanic and Atmospheric Administration (NOAA), Jeppesen Sanderson, Inc., and the Canadian Department of Energy, Mines, and Resources. The fourth layout was a two-column format not currently found on existing charts. Subjects' performance with the two-column and boxed layouts was found to be superior to that of subjects' performance with the one-column layouts representative of NOAA and Jeppesen charts.

The instrument approach procedure is a high-workload situation that requires the pilot to perform a multitude of tasks. The pilot's attention is divided among many activities, including monitoring the cockpit instruments, communicating with air traffic control (ATC), and looking out the cockpit window for traffic. Therefore, it is essential that information needed from the instrument approach plate (IAP) be retrieved as quickly as possible. However, due to an increase in workload during the approach, the cognitive limitations on the amount of information that can be processed in a given period of time conflict with the increasing demand for information. Traditionally, chart designers have been concerned with cramming as much information onto charts as possible (Taylor, 1976). Charts have become so

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cluttered that finding the necessary information quickly and accurately is increasingly difficult. In the only recent large-scale survey of problems associated with IAPs (Cox & Conner, 1987), respondents complained that too much time was required to find information on their chart. A key issue for chart designers, therefore, is how to facilitate the visual search to minimize the time it takes to find and identify a particular item.

For IAPs, spatial layout is important to readability. The spacing of information serves as a cue for perceptual grouping of information (Hartley, 1981; Wright, 1977). The grouping of information is affected by the space that separates an object from its surroundings. Space helps to define the boundaries of an object as well as separate multiple objects from one another.

In the case of text, there are several spacing attributes that influence readability, including spacing between letters, between words, and between lines. For example, in reading a word, the interletter spacing is an important factor in determining the clarity of a word. If the letters are spaced too closely, the individual letters are difficult to discriminate and the word may not be legible. If the letters are spaced too far apart, the letters are not perceived as belonging together and are not interpreted as a single word.

The structure of the space separating text also plays a role in clarity. Letters or numbers separated by a structured space enable the reader to develop spatial expectancies that may not develop when spacing is unstructured (Tullis, 1981). For example, one method for structuring the space between text is through justification, in which the left or right edge of the text column is aligned vertically. This alignment creates a boundary separating the text from the background and has the same effect as drawing a vertical line to delineate text.

One IAP aspect that has not been studied but that may benefit from effective spatial layout (and the possible result of ease of use) is the presentation of radio communication frequencies. During the course of flight, the pilot communicates with a variety of ATC facilities. Although the radio frequency to be selected next is usually transmitted to the pilot by ATC, the IAP serves as an additional source for this information. The high-workload conditions present during the approach require the pilot to be able to find the radio frequency for contacting ATC as quickly as possible. The speed with which a particular frequency can be located partially depends on the layout of that information. Layout includes factors such as font type and size, spatial layout, and amount of information. The interactions among these factors, rather than any one factor, determine how effectively radio frequencies can be found. The presentation of radio frequencies on IAPs has been implemented in different ways by the chart publishers, but the comparative effectiveness of those layouts has never been tested. Although charts display the same information, the spatial layout of that information differs in several ways. The purpose of the present study was to evaluate the effectiveness of different layouts for displaying radio frequencies.

Two U.S. chart publishers—Jeppesen Sanderson, Inc. and the National Oceanic and Atmospheric Administration (NOAA)—each take a different approach to the layout of radio frequencies. Figures 1 and 2 show how the two publishers portray

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this information. Jeppesen left-justifies the facility name with the frequency to its right separated by one space. NOAA also left-justifies the facility name but places the frequency in one of two locations: left-justified and below the facility name, or one space to the right of the name (mostly the former case). In contrast to the close proximity of the radio frequencies to each other in the Jeppesen and NOAA charts, the Canadian Department of Energy, Mines, and Resources takes a very different approach (Figure 3). Each radio frequency is enclosed in its own box and is laid out horizontally along the top of the plan view. The facility name and frequency are centered inside each box, with the frequency located below the name.

All three chart types also differ in the use of formatting variables unrelated to spatial layout—such as font size and style and the order in which the frequencies are laid out. In an effort to better understand the effects of layout on the presentation of radio frequencies, four unique layouts were designed for this experiment, with font characteristics held constant. Three of these designs are similar to the layouts used in the three chart types just described. The four layouts are shown (not drawn to scale) in Figure 4. In Layout 1, the frequency was located directly below the text, similar to the NOAA format. In Layout 2, the frequency was located directly to the right of the text, as in the Jeppesen charts. In Layout 3, the facility names and frequencies were placed in two left-justified columns separated horizontally by .15 in. (.38 cm) of space, with each name located to the left of its frequency. Last, in Layout 4, each facility name and frequency pair were enclosed in a box across the top of the plan view, as in the Canadian chart format.

This experiment evaluated the relative speed and accuracy with which pilots could find radio frequencies using the four layouts. A comparison of the four layouts addressed several questions.

First, is it better to display the frequency to the right of the name or below the name? Given that it is normal to read prose from left to right and that this is a highly practiced habit in most readers, it was hypothesized that frequencies to the right of the name would be read faster than frequencies below the name. Later comparison of Layouts 1 and 2 addresses this question.

Second, is reading speed affected by the spatial separation of facility names and frequencies into two separate groups? If it is not affected, would it be better to maintain close proximity so that the two data items are perceived as belonging in the same column? Wright's (1977) review of the literature indicates that readers locate information faster when multiple items are separated than when they are in the same column. The second hypothesis tested in this study proposes that it is easier to find radio frequencies in tabular columns in which the names are spatially separated from the frequencies. This hypothesis is evaluated by comparing a one-column format (Layout 2) to a two-column format (Layout 3).

Last, how does the Canadian approach, in which each text pair (facility name and frequency) is separated by boxes, compare to the approaches taken by U.S. publishers? In addition to boxing the frequencies, the Canadian charts include more space between text frequencies than do the U.S. publishers' charts. One possible advantage of the Canadian layout as compared to the NOAA layout is that it may mitigate the proximity effects of nearby text. The NOAA charts and (to a lesser

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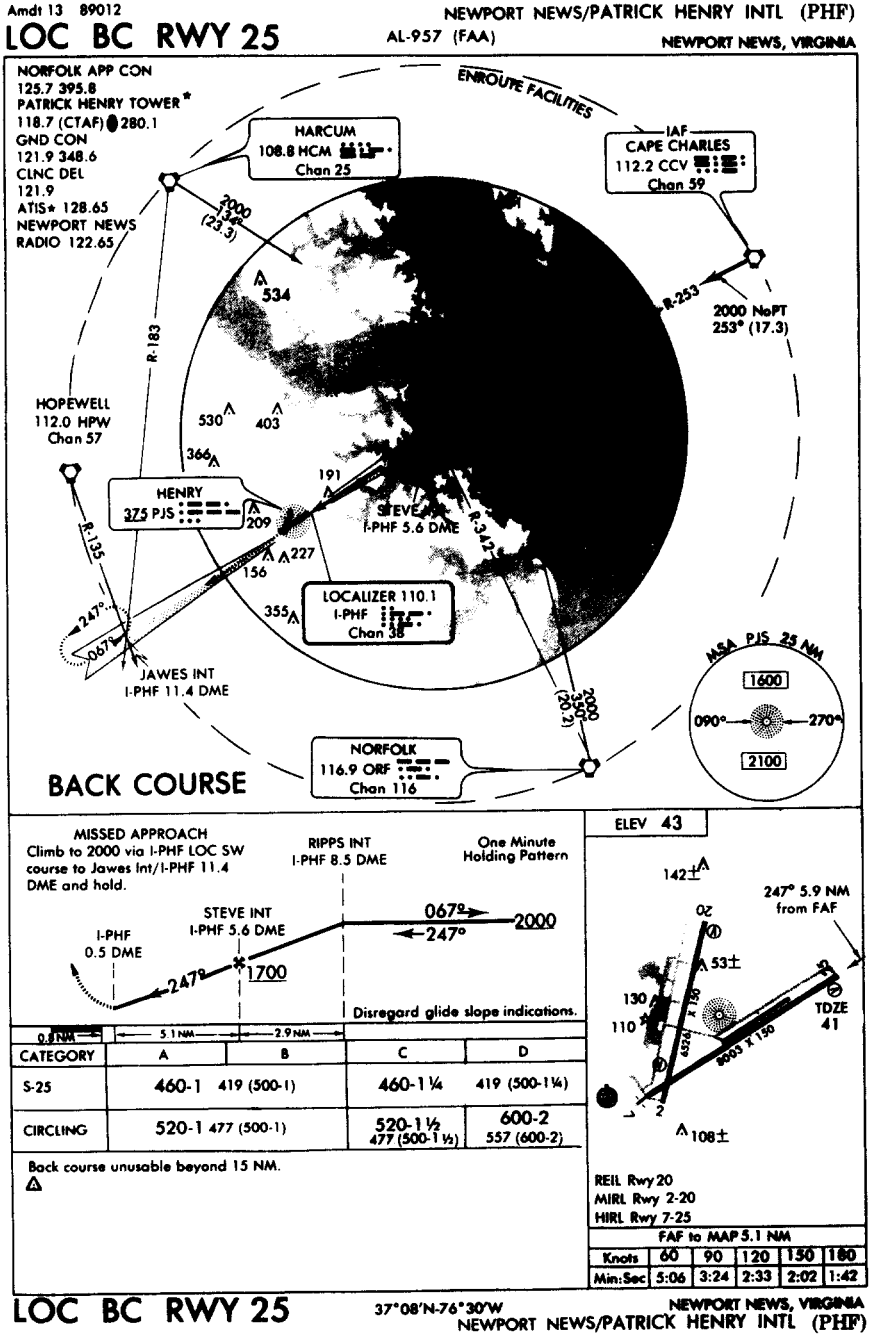

CATEGORY	A	B	C	D
S-25	460-1 419 (500-1)		460-1¼	419 (500-1¼)
CIRCLING	520-1 477 (500-1)		520-1½ 477 (500-1½)	600-2 557 (600-2)

Knots	60	90	120	150	180
Min:Sec	5:06	3:24	2:33	2:02	1:42

FIGURE 1 NOAA IAP. Not for navigation.

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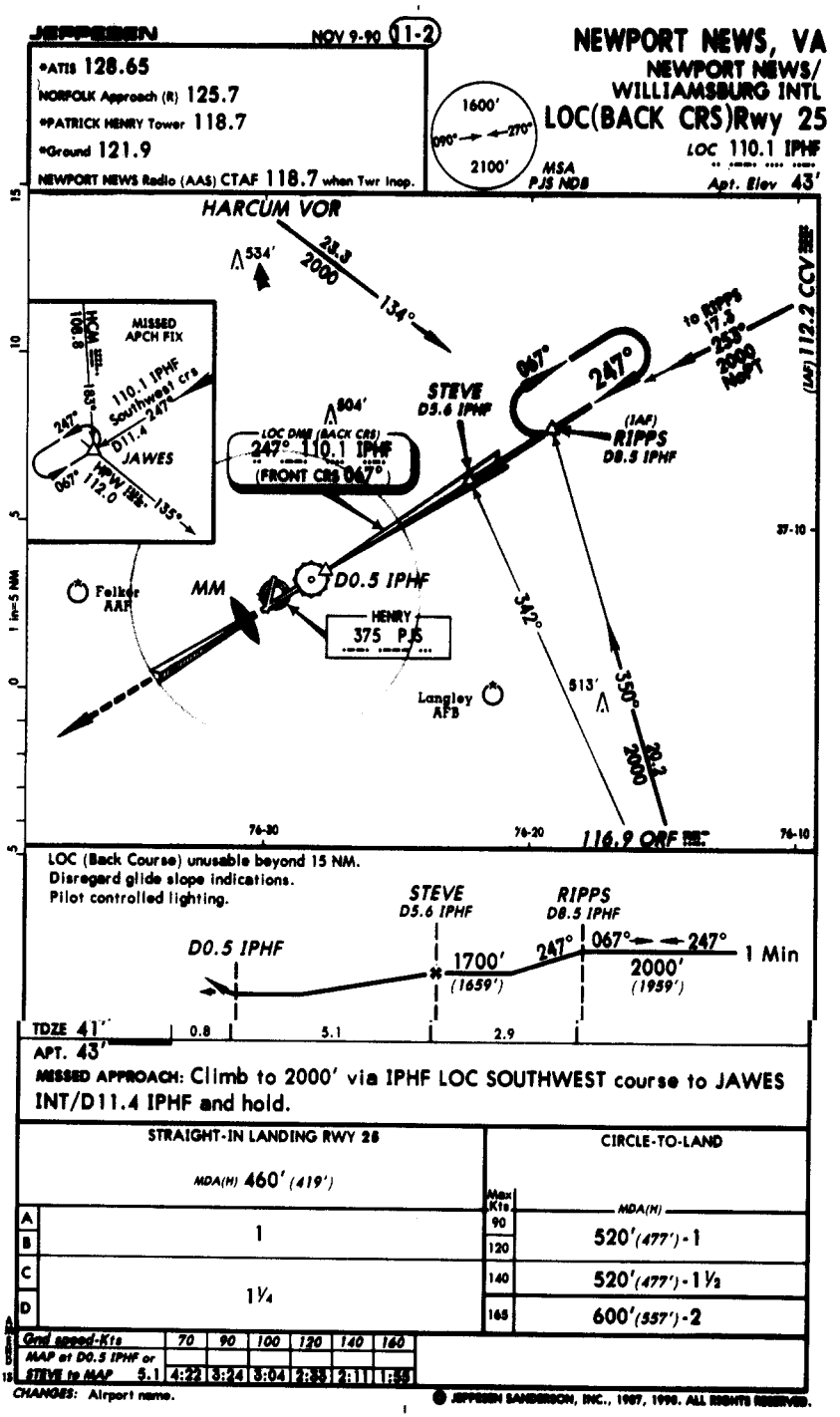

FIGURE 2 Jeppesen IAP. Copyright © 1991 Jeppesen Sanderson, Inc. Reproduced with permission. Reduced for illustrative purposes. Not for navigation.

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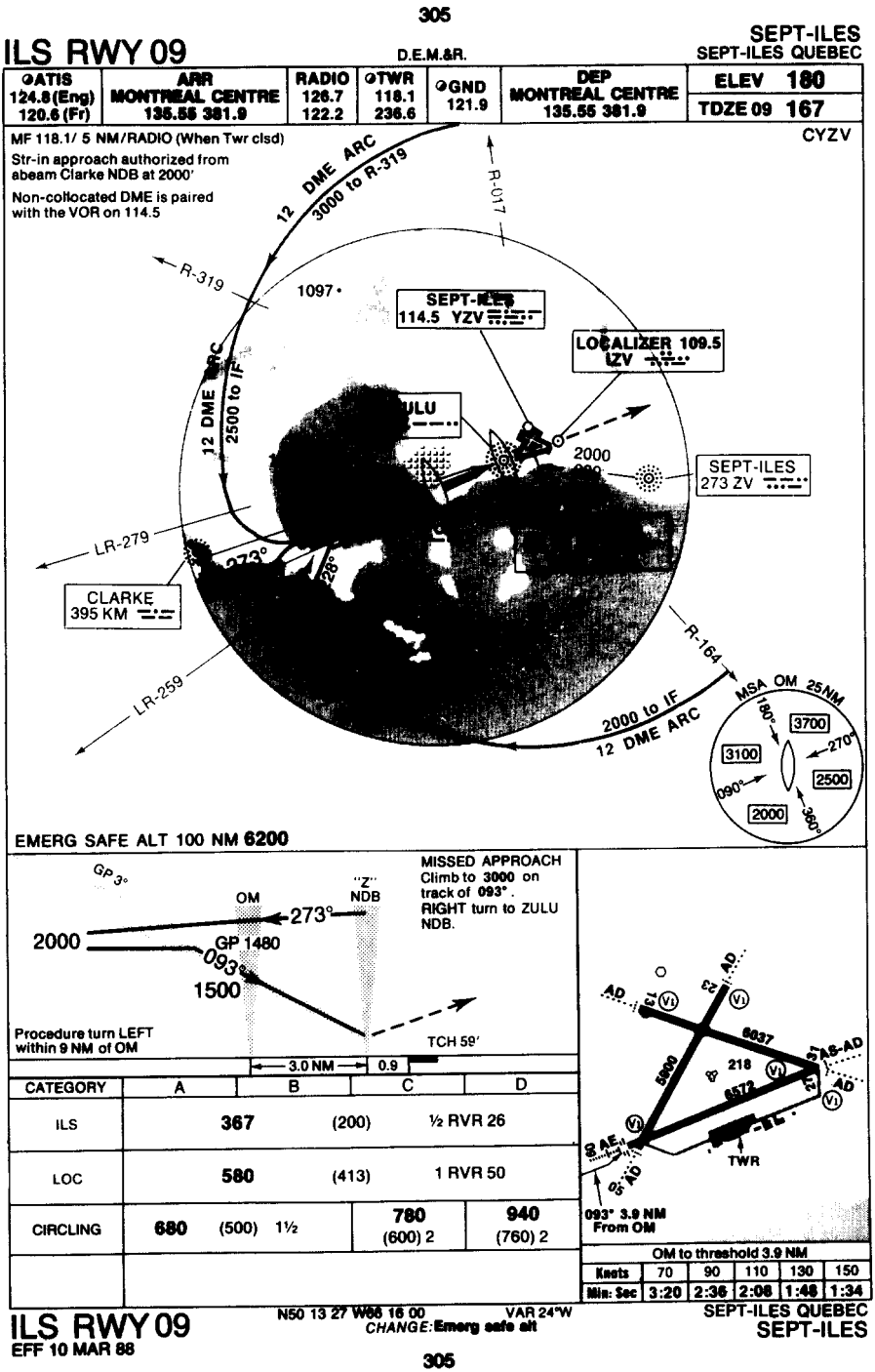

FIGURE 3 Canadian IAP. From the Canada Centre for Mapping, Department of Energy, Mines, and Resources, Canada. Used with permission for illustrative purposes only. Not for navigation.

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Four Layouts

1	2	3		4	
Frequency under name	**Frequency to right of name**	**Frequency to right of name & left justified**		**Frequency under name, boxed and centered**	
App Con	App Con 121.7 247.0	App Con	121.7 247.0	App Con	Tower
121.7 247.0	Tower 122.3	Tower	122.3	121.7	122.3
Tower				247.0	
122.3					

FIGURE 4 Four experimental layouts of frequency information.

degree) the Jeppesen charts place all the facility names and frequencies in close proximity. Noyes (1980) reported that distractors in the proximity of a word being fixated increase the search time required for that word. The close proximity of the frequencies increases the likelihood that an unrelated, nearby frequency may distract the reader during the search process and increase the chances of making an erroneous identification. The Canadian charts, with their greater separation between items, may be read more quickly, as there are fewer distractors in close proximity. Later comparison between the boxed format (Layout 4) and the one-column formats (Layouts 1 and 2) addresses this question. It was hypothesized that Layout 4, with a larger amount of space separating the radio frequencies, would exhibit faster response times (RTs) than Layouts 1 and 2.

METHOD

Subjects

Subjects were recruited through the Air Line Pilots Association and through notices posted at the Volpe National Transportation Systems Center (VNTSC) and the Massachusetts Institute of Technology (MIT). VNTSC employees were given an account number to which they charged the time they spent in the study. All other subjects were paid $50.

Twenty pilots participated in this study. Nine of the pilots were rated for instrument flight rules (IFR), and 11 were rated for visual flight rules (VFR). The pilots ranged in age from 19 to 61 years, with a median age of 31. Flight experience for the VFR-rated pilots ranged from 60 to 220 hr, with a median of 120 hr, whereas

flight experience for the IFR-rated pilots ranged from 275 to 15,000 hr, with a median of 600 hr. Of the 9 IFR pilots, 2 used NOAA charts, 4 used Jeppesen charts, and 3 used charts from both publishers.

Apparatus

Subjects sat 20 in. (50.8 cm) from a rear-projection screen mounted on a desk directly in front of them. A floor-mounted chin rest was used to maintain a constant viewing distance from the screen; the height of the chin rest and chair was adjusted to fit each subject. Stimuli were projected onto the screen using a Gerbrands Model 1178 3-Field Projection Tachistoscope (T-scope; Cambridge, MA), located behind the rear-projection screen. The T-scope, mounted on a Formica base and seated on a cart 38 in. (96.5 cm) from the floor, consisted of three KODAK EKTAGRAPHIC™ (Rochester, NY) Model IIIB slide projectors with internally mounted Gerbrands shutters and a shutter drive control console. Three mirrors direct each of the projector beams to the same area on the rear-projection screen. The three slide projectors displayed different stimulus materials; one projector displayed the fixation point, a second displayed sample stimuli, and the third displayed the experimental stimuli. A button box, located on the desk in front of the projection screen, was used by the subject to indicate that the stimulus was identified. An IBM-compatible 286 computer controlled the timing of the T-scope and recorded the signals from the button box.

Design

A mixed, two-factor design with one between-subjects factor (Pilot Rating) and one within-subject factor (Layout) was used. There were two levels of pilot rating (IFR and VFR) and four types of layout: frequency below name, frequency to the right of name, two columns, and boxed. Layout 1 displayed the frequency below the facility name. Layout 2 displayed the frequency one space to the right of the name. Layout 3 displayed the frequency and name in two left-justified columns separated by .15 in (.38 cm). Layout 4 displayed each frequency and name in its own box; the boxes for the names were placed across the top of the chart plan view. Figure 5 illustrates the four layouts.

The experiment was conducted in four blocks. A block consisted of 20 trials using stimuli of the same layout type throughout that block. A Latin square was used to balance the presentation of the four blocks. Within a block, trials were randomized. The subject was asked to report one of two civil frequencies: approach control or tower. Searching for the frequency was counterbalanced by (a) asking half the subjects to search for the approach control frequency for the first two blocks and for the tower frequency for the last two blocks and (b) asking the other half to do the opposite.

Stimulus Construction

The experimental stimuli were modeled after the NOAA IAPs. The experimental and sample charts were created from scratch on an Apple Macintosh® (Cupertino, CA) computer using the Canvas™ graphics program by Deneba Systems (Miami,

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FL). Figure 5 shows stimuli representing the four layouts. The charts were photographed and mounted in pin-registered slide mounts.

Twenty-one charts were created from six original chart templates. The stimuli were created by changing the airport names and radio frequencies and by rearranging obstructions in the plan view. Fictitious frequencies in the VHF bandwidth were randomly assigned to the charts.

On each of the 21 chart templates, the layout of the radio frequencies was modified four times, creating a total of 84 stimuli. Only the format of the radio frequencies was modified; all other information on the chart remained constant.

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Procedure

Subjects were run one at a time. Each subject was told that he would see a series of IAPs and was instructed to search for the target VHF frequency as quickly and as accurately as possible. The experimenter briefly described each layout type and presented examples of the four layouts.

The subject completed four blocks of 20 trials each. At the start of each new block, the subject viewed a sample chart for 5 sec to become familiar with the chart format to follow. After each block was a brief (2- to 4-min) rest period.

For each trial the subject was presented a fixation point and an experimental stimulus. The subject focused on the fixation point, located in the center of the plan view, for 1.5 sec. Immediately following the termination of the fixation point, an experimental chart was presented, and the subject searched for the target. The subject was instructed to press the button box and to state a response aloud upon identifying the target. Pressing the button ended the presentation of the experimental stimulus and marked the end of the trial. There was a 1.5-sec intertrial interval. Following the experiment, the subject completed a questionnaire ranking preferences for the different conditions.

RESULTS AND DISCUSSION

RT and number of errors were the two primary performance measures. RT was measured by the computer from the point when the stimulus was presented on the screen to the point when the subject pressed the button box. Number of errors was measured by recording the verbal identification of the target stimulus and by tabulating the number of correct and incorrect responses.

Pilot Rating

An analysis of variance (ANOVA) was performed to determine whether there were differences in RT as a function of flight experience and to learn whether experience affected performance differentially. The ANOVA was not statistically significant, $F(1, 18) = 0.05, p > .82$, indicating that experience did not reliably affect how the two groups performed. In addition, no differences in the number of errors were

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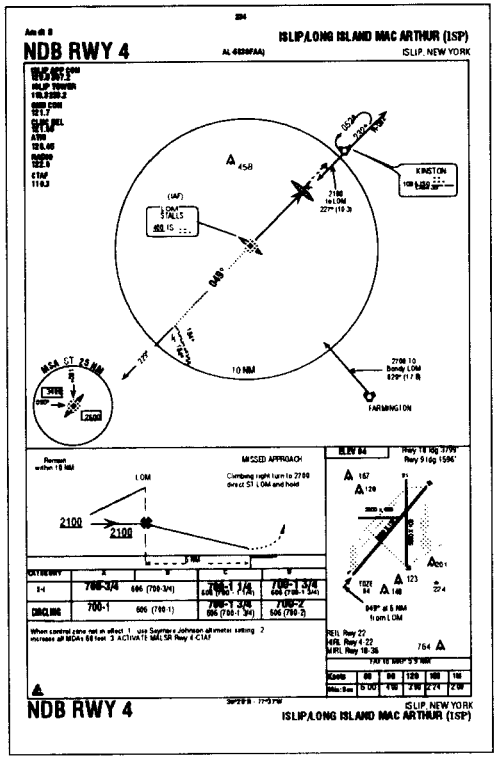
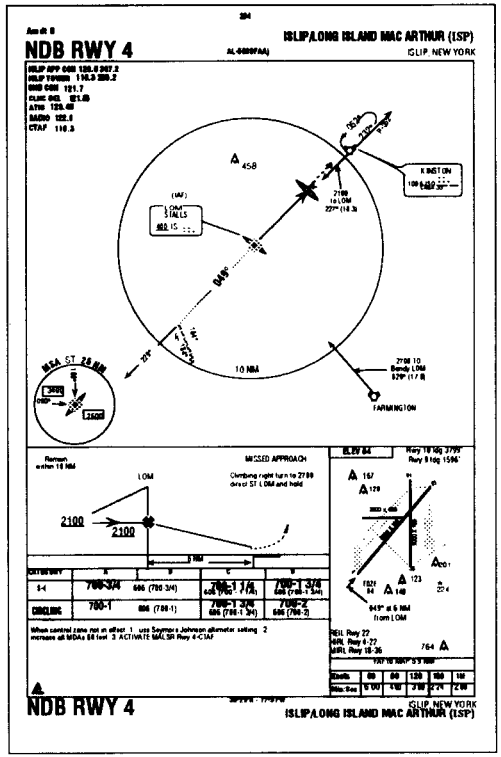
Layout 1:
Frequency below name



Layout 2:
Frequency to the right of name



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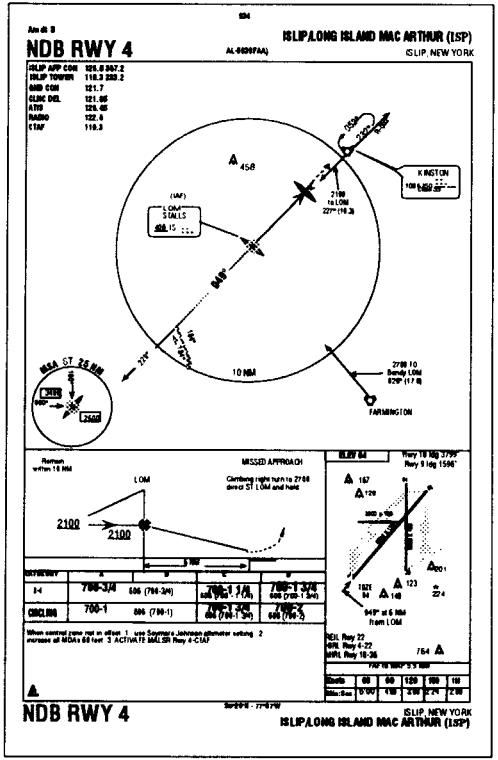
Layout 3:
Two column



Layout 4:
Boxed

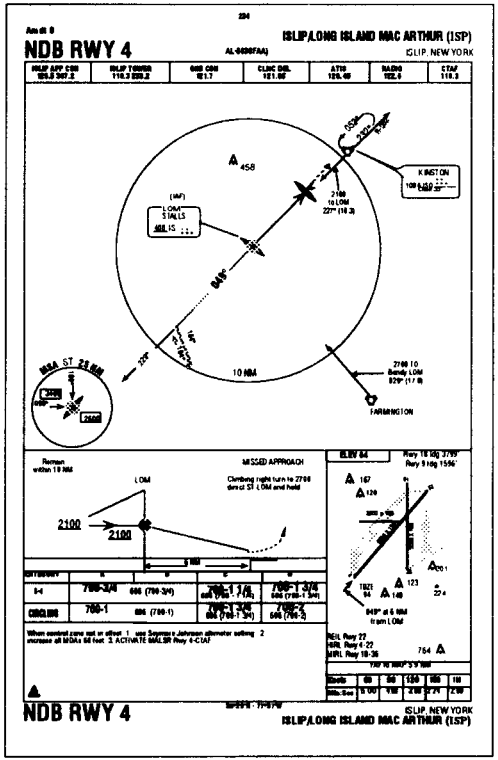


FIGURE 5 Experimental stimuli showing four layouts.

found as a function of pilot ratings. The remaining analyses were performed on data collapsed across pilot rating.

Layout Effects

An ANOVA revealed a significant effect of layout for mean RT, $F(3, 57) = 10.89$, $p < .0001$. Table 1 illustrates the relation between the type of layout and mean RT. Mean RT was almost identical for the layouts with the frequency below the name (Layout 1) and to the right of the name (Layout 2), corresponding to the NOAA and Jeppesen formats, respectively. The two layouts differed by 0.003 sec. and exhibited the longest mean RTs. The two-column layout (Layout 3) and the boxed layout (Layout 4) exhibited faster mean RTs. Although subjects performed faster in the boxed layout than in the two-column layout, the difference (0.121 sec) was not statistically significant. However, a Student–Newman–Keuls test of pairwise comparisons indicated that the two-column and boxed layouts were significantly different from the other two layouts, $CR_{n-k}(3, 57) = .1846$, $p < .05$. This relation accounts for the statistically significant effects of layout type found in the ANOVA. It should be noted that, although these differences were statistically significant, these average reading-time differences were obtained below ideal viewing conditions and do not indicate the magnitude of the differences that would be found in the cockpit.

The results of an analysis of the errors that were made identifying the frequency found an error rate of 5.31% (85 of 1,600). A Friedman two-way ANOVA by rank found no statistically significant relation between error rate and layout type.

Subject preferences for the four layouts were consistent with the mean RT measures. Subjects were asked to rank their preferences on a scale ranging from *most preferred* (1) to *least preferred* (4). Table 2 shows the rank totals, where each score represents the number of ranks assigned to that score multiplied by the score (i.e., 1 to 4). The lower the rank total, the more that layout was preferred. The boxed and two-column layouts were both preferred over the other two layouts. A Friedman two-way ANOVA by rank found these differences to be statistically significant, $\chi^2_r(3) = 8.16$, $p < .05$.

The data from this experiment did not support the hypothesis that placing the frequency to the right of the facility name would improve performance as compared to placing the frequency below the name. Performance in these two layouts (1 and 2) was virtually identical. The expectation that performance would be faster with the frequency to the right of the name (due to the well-practiced habit of reading

TABLE 1
Effect of Layout on Mean RT

Layout Type	*Mean RT (sec)*
Frequency below name	2.260
Frequency to right of name	2.257
Two columns	2.058
Boxed	1.927

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TABLE 2
Subject Preference for Four Layouts

Layout Type	*Rank Total*
Frequency below name	58
Frequency to right of name	61
Two columns	42
Boxed	38

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from left to right) may be mitigated by the small amount of text to be read and/or by the close proximity of text elements.

The comparison between the two-column layout (3) and the layout with the text close together in one column (2) supports the notion that spatially separating names and frequencies into separate columns improves performance. Performance was faster in the two-column layout than in the one-column layout. Similarly, the effects of spatial separation were also observed in the comparison between the boxed layout (4) and the one-column layouts. Performance in the boxed layout was superior to that in the one-column layouts.

In the case of the two-column layout, the horizontal spacing between the name and frequency may aid the reader because it conforms to well-established reading habits. The reader can search the left column for the appropriate name, then read the frequency from the corresponding right column by moving his eyes from left to right. Similarly, in the boxed layout condition, the reader can move his eyes from left to right until the appropriate name is found and then read the corresponding frequency below. The space between the two-columns may also act as the black lines surrounding the text pairs in the boxed layout do—forming a frame that separates words. Both the space and the lines guide the reading process.

Additionally, the greater space between the two-columns and between the text pairs in the boxed layout may reduce the likelihood that surrounding text will act as a potential distractor. This finding is consistent with Noyes's (1980) recommendation that words in a map display be kept clear of surrounding materials to aid processing speed. In Noyes's experiments, the distractors were within one space of the target word. For both one-column layouts, the facility name and frequency were separated by a single space. To facilitate reading the radio frequencies, the layouts could benefit from more than one space between items. However, as the effectiveness of both the two-column and the boxed layouts demonstrates, there are multiple methods for achieving this goal.

CONCLUSIONS

This experiment evaluated the effectiveness of four layouts for displaying radio frequencies. The purpose was to evaluate the use of spatial layout on the readability of IAPs. The data indicate that spatial layout affects the speed with which radio frequencies can be read.

The two layouts representative of the NOAA and Jeppesen formats resulted in similar performance. Neither layout was more effective than the other. These layouts presented facility names and frequencies in one column—with the frequency either to the right of or below the associated name. The data from this experiment should not be used to suggest that the presentation of radio frequencies on NOAA and Jeppesen charts is equally effective; this experiment did not address that question. The presentation of radio frequencies by the two publishers differs by more than just their spatial layouts (e.g., use of fonts and boldface and location of frequencies on the chart).

Performance in the two-column layout and in the boxed layout representative of the format developed by the Canadian Department of Energy, Mines, and Resources was superior to that in both of the one-column layouts. The two-column and boxed layouts use space to actively organize the placement of text. The two-column layout uses white space to separate the names and frequencies into two columns, and the boxed layout uses white space to separate the name-and-frequency text pairs horizontally along the top of the plan view. Further, more space was used than in the one-column layouts. These data suggest that the readability of radio frequencies in IAPs can be increased by placing each frequency in a separate box, with each box organized in a row across the top of the plan view. Alternatively, displaying radio frequencies in a two-column format with facility names in one left-justified column and frequencies in another will also improve readability by reducing the time needed to locate a particular frequency.

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