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Honeywell NextGen Aviation Human Factors
Research & Development

**Task 8: EFB [*and portable electronic devices*] Components in the Flight Deck:
Analysis & Recommendations**

Chart Legibility on Portable Electronic Devices

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Acronyms & Abbreviations

AC	Advisory Circular
AEG	Aircraft Evaluation Group
CFR	Code of Federal Regulations
COTS	Commercial off the shelf
EFB	Electronic flight bag
FAA	Federal Aviation Administration
IAP	Instrument Approach Procedure
in	inch
LCD	Liquid Crystal Display
Min	Minimum
MP	Mega Pixel
PC	Personal Computer
PED	Portable electronic device
pixel	Picture element
PPI	Pixels per inch
S/W	Software
TFT	Thin Film Transistor

Executive Summary

The objective of this research is to develop a tool that could be used for assessing the legibility of electronic charts. The tool is intended to provide an objective means for demonstrating that the display of the electronic chart on a Portable Electronic Device (PED) has equivalent legibility to paper charts.

FAA Advisory Circular (AC) 120-76, *Guidelines for the Certification, Airworthiness, and Operational Use of Electronic Flight Bags*, states that:

“The screen must display an instrument approach procedure (IAP) chart in an acceptable aeronautical chart format similar to a published paper chart. The screen must be large enough to show the entire standard format one-page IAP chart all at once, with a degree of legibility and clarity equivalent to that of a paper chart. This requirement is not meant to preclude panning and zooming features, but is intended to prevent a workload increase during the approach phase of flight. Alternate representations of IAP charts will need to be evaluated for operational suitability by the AEG for functionality and human factors.” (AC 120-76C, Section 13.d(1)(b)).

The legibility of electronic IAP charts is affected by the text size used on the chart and one’s viewing distance to a chart (which in combination equate to visual angle), as well as the pixel (picture element) density and contrast of the PED on which the chart is displayed. After examining the interaction of these factors, Honeywell developed a legibility assessment tool comprised of two lookup tables. The *visual angle lookup table* shows whether information on an electronic chart will be legible to a person with 20/40 vision (corresponding to the FAA’s pilot near vision requirement) as a function of the smallest text size on the electronic chart and the viewing distance to the PED. The *pixel density lookup table* shows whether the PED pixel density is sufficient to display the smallest text clearly. Because determining the smallest text size on an electronic chart is not straightforward, three methods for measuring the smallest text size on an electronic chart are provided to complement the legibility assessment tool. A summary of the smallest text size measurement methods are shown in the table below.

Method	Description
Ratios	This measurement is based on a pre-calculated ratio of the smallest text size on a chart provider’s <i>paper chart</i> to the height of the paper chart border. This ratio can then be used to calculate the smallest text size on the electronic chart.
Pixel counting	This measurement is based on counting the number of pixels that make up the smallest text on the electronic chart.
Photo measurement	This method uses a photo measurement application to determine the height of the smallest text relative to a reference object with a known size.

1 Introduction

Portable electronic devices (PEDs)/Electronic flight bags (EFB) are an important flight deck enabling technology for achieving NextGen operational improvements and capabilities. One common EFB application is electronic charts, which can vary in presentation quality due to PED screen size and resolution. The size of the electronic chart may be further limited by the design and layout of the electronic charting software. The FAA specifies guidance for the display of electronic charts in the current version of Advisory Circular (AC) 120-76, *Guidelines for the Certification, Airworthiness, and Operational Use of Electronic Flight Bags*. Specifically:

“The screen must display an instrument approach procedure (IAP) chart in an acceptable aeronautical chart format similar to a published paper chart. The screen must be large enough to show the entire standard format one-page IAP chart all at once, with a degree of legibility and clarity equivalent to that of a paper chart. This requirement is not meant to preclude panning and zooming features, but is intended to prevent a workload increase during the approach phase of flight. Alternate representations of IAP charts will need to be evaluated for operational suitability by the AEG for functionality and human factors.” (AC 120-76C, Section 13.d(1)(b)).

The purpose of this research is to develop a tool that could be used for objectively assessing the legibility of electronic charts. While a considerable amount of research has been conducted on factors that contribute to the legibility of text printed on paper (e.g., see Legge and Bigelow, 2011, for a recent review), there are additional factors that contribute to legibility of information on electronic devices, such as the amount of compression of text and symbols on small displays, the number of pixels per inch (resolution), and display contrast.

In order to develop an electronic chart legibility assessment tool, Honeywell conducted a brief literature review on the legibility and clarity of electronic IAP charts, reviewed pilot vision requirements to identify proven criteria for legibility, and performed analyses to identify and measure key electronic chart legibility factors that the tool needed to incorporate. The tool and short descriptions of legibility factors and tool usage are provided in this report.

2 Analysis of Factors Underlying Electronic Chart Legibility

A literature review was conducted to determine what factors impact the legibility of IAP charts on PEDs. The results suggested that there are three main factors: visual angle, pixel density and contrast. Each factor is briefly discussed below.

2.1 Visual Angle

The angle at which an object subtends at the eye is referred to as *visual angle*. As shown in Figure 1, the visual angle for a particular object is determined by the size of the object being viewed and the distance from which the object is viewed. A small object viewed up close (the leftmost “A” in Figure 1) could have a similar visual angle to a large object that is far away (the rightmost “A” in Figure 1).

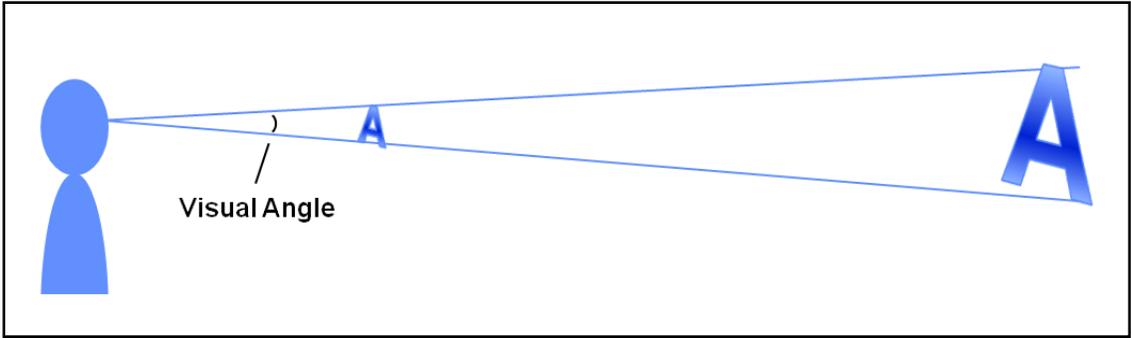


Figure 1. Example of different sized text with the same visual angle at different distances

In general, as text gets smaller (when viewed from the same distance), it become more difficult to see. The smallest visual angle that a person can see is expressed in terms of visual acuity (e.g., 20/40 vision). The FAA’s near vision requirement for all pilot medical classes is 20/40 or better in each eye, with or without correction, when measured at 16 inches (see Figure 2). Using this vision requirement, the smallest text that will be legible at 16 inches must subtend 0.1667° of visual angle on the viewer’s retina. Note that when making a comparison between paper charts and electronic charts, visual angle must be used rather than text size alone because visual angle also takes viewing distance into consideration.

Figure 2. FAA Medical Certification Requirements for Vision (14 CFR Part 67)

VISION REQUIREMENTS for FAA Medical Certification			
Medical Class	First-Class	Second-Class	Third-Class
Pilot Type	Airline Transport Pilot	Commercial Pilot	Private Pilot
DISTANT VISION	20/20 or better in each eye separately, with or without correction.		20/40 or better in each eye separately, with or without correction.
NEAR VISION	20/40 or better in each eye separately (Snellen equivalent), with or without correction, as measured at 16 inches.		
INTERMEDIATE VISION	20/40 or better in each eye separately (Snellen equivalent), with or without correction at age 50 and over, as measured at 32 inches.		No requirement.
COLOR VISION	Ability to perceive those colors necessary for safe performance of airmen duties.		

Legibility is usually concerned with how far away an object can be seen, that is, the *maximum* viewing distance. However, *minimum* viewing distance should also be considered because even a relatively young pilot with 20/20 vision could not be expected to be able to focus on text that is presented on a paper chart or PED closer than about 6 inches¹. The analyses performed

¹ Near-to-eye displays are able to overcome this limitation by adjusting the focal distance of the display, effectively presenting the perceived image further away than it really is.

here do not account for minimum viewing distances, but one should not assume that legibility of charts on small displays can be achieved by moving them closer and closer to the user's eyes.

A large portion of this report is focused on the effect of visual angle (i.e., the combination of viewing distance and text size) on legibility. While viewing distance is simple to measure in the field, text size is not, especially the smallest text size on an electronic chart. In fact, the smallest text on an electronic chart may be so small that it cannot be measured with traditional methods such as a ruler. Moreover, the smallest text size varies as a function of the PED screen size, the electronic charting software used, and the chart provider. Therefore, alternative methods for determining the smallest text size were developed and are presented in Section 3.1.

2.2 Pixel Density

When viewing a PED at close distances (e.g., less than 16 inches), legibility is limited by the device pixel density (Wright, 2002), that is, the number of picture elements in a device's screen per linear inch (PPI). If a device does not have sufficient pixel density, text may not be legible or clear enough to be read. A minimum of 5 pixels high is required to render a letter, and 6 pixels are needed for text to be considered "fully recognizable" (Wright, 2002). Based on the findings that the height of a character of text must be made up of at least 6 pixels, Honeywell created a lookup table for identifying the pixel size needed to legibly display the smallest text (see Table 2) by identifying the smallest text size on the electronic chart and dividing this value by 6 (based on the 6 pixel guideline). Because PPI is the most common way that manufacturers refer to pixel density of their screens, we then converted our estimates of pixel size to pixel density (in pixels per inch, or PPI) using the formula: $1/(\text{Pixel Size})$.

2.3 Contrast

Contrast ratio, as it pertains to legibility, is the difference in luminance (how light or dark something is) between the text and the background. Contrast ratio is an important component supporting legibility of both electronic and paper media (Lin, 2003). The FAA Human Factors Design Standard, states that a contrast ratio of at least 3:1 is needed but 7:1 is preferred in bright ambient light (Ahlstrom & Longo, 2003). The contrast ratio on a PED is affected by the hardware (e.g., screen brightness and materials), software (e.g., colors used) and environmental factors, such as ambient light or direct sunlight. Note that while contrast ratio is an important component of legibility, contrast ratio cannot be measured without very specialized lab equipment. Therefore, information about how to measure contrast ratio is not included in this report. However, we performed contrast ratio measurements in the laboratory on some common PED devices and found that under both high and low ambient light, the PED contrast ratios for black text on white background on the devices we examined were always greater than 7:1. Contrast ratios for high resolution PEDs for text presented in color in high ambient light on the devices we examined were lower than the preferred 7:1 ratio (e.g., dark brown on a white background had a contrast ratio of 5:1), but were higher than the contrast ratios for paper charts for the same color combinations and lighting conditions.

3 Tool for Evaluating the Legibility of EFBs

Based on the analysis provided above, an electronic chart legibility assessment tool was developed consisting of two tables. The tables are intended to provide an objective means to determine whether an electronic chart displayed on a PED has the equivalent legibility to a paper chart. The tables are based on the assumption that in order for a chart to be considered legible, the smallest text on the chart must be legible. The first table, the visual angle lookup table, is intended to show the minimum text size that will be legible to a pilot meeting the FAA's near vision requirements (20/40) at various viewing distances. Note that 6 inches is the shortest viewing distance provided in the table; this is because it is the shortest distance that a young adult can focus. Note that this shortest focal distance increases with age, and even with correction older adults may not be able to read the smallest text on electronic charts at 6 -12 inches.

To use the visual angle lookup table, one must know the smallest text size and proposed viewing distance. If the smallest text size is not known, methods for determining the smallest text size are described in Section 3.1. Note that in most cases, the smallest text on an electronic chart cannot be determined accurately with a ruler.

Legibility and clarity cannot be solely determined using the visual angle lookup table, however. In some cases, the size of the smallest text on an electronic chart may be sufficient for the viewing distance, but the PED pixel density is not sufficient to display it clearly. Therefore, a second table that shows the minimum pixel density needed to view different sizes of text is also provided. More information on using the lookup table is provided in the Lookup Tables Quick Reference Guide, following the tables.

Determining Legibility: Visual Angle Lookup Table

Table 1. Minimum legible text size for a given viewing distance for a pilot with 20/40 vision

Minimum Legible Text Size for a Given Viewing Distance			
Viewing Distance (in)	Min Text Size (in)	Viewing Distance (in)	Min Text Size (in)
6	0.0200	23	0.0670
7	0.0205	24	0.0700
8	0.0235	25	0.0730
9	0.0265	26	0.0760
10	0.0295	27	0.0785
11	0.0320	28	0.0815
12	0.0350	29	0.0845
13	0.0380	30	0.0875
14	0.0410	31	0.0905
15	0.0440	32	0.0930
16	0.0465	33	0.0960
17	0.0495	34	0.0990
18	0.0525	35	0.1020
19	0.0555	36	0.1050
20	0.0585	37	0.1080
21	0.0615	38	0.1105
22	0.0640	39	0.1135

Determining Legibility: Pixel Density Lookup Table

Table 2. Minimum pixel density needed to legibly display text of a given size

Recommended Pixel Density					
Smallest Text Size (in)	Min PPI Needed	Smallest Text Size (in)	Min PPI Needed	Smallest Text Size (in)	Min PPI Needed
0.02	300	0.038	158	0.056	107
0.021	286	0.039	154	0.057	105
0.022	273	0.04	150	0.058	103
0.023	261	0.041	146	0.059	102
0.024	250	0.042	143	0.06	100
0.025	240	0.043	140	0.061	98
0.026	231	0.044	136	0.062	97
0.027	222	0.045	133	0.063	95
0.028	214	0.046	130	0.064	94
0.029	207	0.047	128	0.065	92
0.03	200	0.048	125	0.066	91
0.031	194	0.049	122	0.067	90
0.032	188	0.05	120	0.068	88
0.033	182	0.051	118	0.069	87
0.034	176	0.052	115	0.07	86
0.035	171	0.053	113	0.071	85
0.036	167	0.054	111	0.072	83
0.037	162	0.055	109	0.073	82

Quick Reference Guide: Lookup Tables

Visual Angle Lookup Table

1. Determine the smallest text size. Three methods are provided: ratio method, pixel counting method, and the photo measurement method. Find the value that most closely matches the smallest text size in the leftmost column.
2. Determine the PED viewing distance, the distance between the PED screen and the pilot's eyes on the flightdeck (measured to the nearest inch). Find the intersection of the smallest text size and the PED viewing distance to determine whether the smallest font is legible at the proposed viewing distance.

Pixel Density Lookup Table

1. Get the pixel density (in pixels per inch, PPI) for the PED from the manufacturer or calculate PPI by dividing the largest number of the screen resolution by the longest screen dimension (in inches).
2. Find the smallest text size in the table. The corresponding value in the "PPI Requirements" column is the smallest PED pixel density that could still legibly display the smallest text size.

3.1 Smallest Test Size Measurement

Smallest text size is difficult to measure in the field. While text size can be measured in a laboratory environment in a traditional fashion using calipers and some type of magnification to ensure accuracy, PEDs have a thin glass layer which does not allow the calipers to come in direct contact with the object being measured. If one does use this traditional measurement method, care should be taken to maintain visual perpendicularity on electronic displays to minimize the effects of parallax due to the thickness of the display glass. Also, because the text on charts is so small, a small measurement error can lead to very different visual angles.

Further, anti-aliasing, a method for “smoothing” text so that text does not appear pixilated, can also lead to manual text size measurement errors. For example, light grey pixels at the top and bottom of anti-aliased characters are often only visible when the text is viewed at magnification, so these pixels should not be included in text height determinations. The pixels created due to anti-aliasing are indicated in the figure embedded in the [Quick Reference Guide for the Pixel Counting Method](#).

It can also be difficult to identify the smallest text size on a chart. We found that the smallest text was typically in the runway slope labeling on the runway diagram, but the size of this text can vary based on runway configuration. For example, the text for runway slope tends to be about 20% smaller at a large airport with closely spaced parallel runways compared to airports with crossing runways or parallel runways that are spaced further apart. We recommend a conservative approach (such as using the runway slope labeling for airports with closely spaced parallel runways) in identifying the smallest text on the IAP charts.

Because of all these factors, it is very difficult to take accurate manual measurements of small text size. Consequently, Honeywell has developed three more practical methods for calculating or measuring the smallest text size. The methods are described below, followed by step-by-step instructions in a quick reference guide, and advantages and limitations of each method.

Ratio Method

One method for determining the smallest text size uses the ratio of the outline box (or “box”) on a paper or electronic chart to the smallest text size on the paper or electronic chart. The box height can be determined by measuring the left side of the box (see the orange line on the AeroNav Products chart in the Quick Reference Guide below for an example). The smallest text size can then be calculated as a function of the box height and the ratios provided in the Quick Reference Guide.

Before using the ratio method, it is important to understand how the ratios were developed as well as potential limitations of the ratio method. Honeywell calculated the ratios by measuring the smallest text size on the chart for each provider. These ratios are specific to each chart provider and are current as of March 2014. The ratios are applicable only when the software being evaluated is a direct representation of the printed chart format (like PDF) before the ratio

method is applied. Unfortunately, there is no way to assure this will always be the case. The ratios may change if the chart provider changes the design or layout of their charts.

Pixel Counting Method

The second method developed for determining the smallest text size involves counting pixels. The operating systems of almost all PEDs are capable of taking a screenshot, an image that captures everything that is visible on the device's display at that moment in time. Moreover, every PED capable of taking a screenshot does so at its native resolution. This means that if a screenshot is captured and the image is transferred to a personal computer (PC), individual pixels can be seen exactly how they were displayed on the PED. The height of the smallest text can then be determined by zooming into the image and counting the number of pixels used to draw the smallest text. The number of pixels per inch (PPI), which have already being determined for pixel density requirements, can then be used in combination with how many pixels tall a character of text is to determine the text height (in inches). When using this method, the user must account for anti-aliasing, a technique that smoothes pixilated text and images to make them more aesthetically pleasing. A method for accounting for anti-aliasing is suggested in the quick reference guide. Note that the pixel counting method is based on horizontally or vertically oriented text. Consequently, the pixel density requirements provided in Section 2 may underestimate the pixel density required to legibly display text that is drawn diagonally. Also, the end user should consider the advantages and limitations discussed in Section 3.2 when using the pixel counting method for determining the smallest text size.

Photo Measurement Method

The final technique developed for determining the smallest text size uses photo measurement. There are several commercial off the shelf (COTS) photo measurement applications that are available as Smartphone applications, or "apps." The apps generally require the user to place a reference object on top of the PED that is showing an electronic chart. The user then is required to open the photo measurement app within a second smart phone or tablet and take a picture of the PED and reference object within the app. Because the size of the reference object is known, the size of any other object in the picture can be estimated accurately.

Note that the level of accuracy may vary by application creator. Before using this method to measure smallest text size, it is recommend that the user practice taking measurements of a small object with a known measurement (see Quick Reference Guide). Finally, before using the photo measurement method for determining smallest text size, the end user should consider the advantages and limitations discussed in Section 3.2.

Quick Reference Guide: Ratio Method

1. Determine if there have been any formatting changes by the chart producer since March 2014. If the chart layouts have changed, the ratios provided are no longer valid.
2. Open a chart on the PED. Make sure that the entire chart is shown on the screen.
3. Measure the height of the chart box outline using a ruler. For more precision, measure to the nearest 1/16th of an inch. An example is indicated by the orange line on the electronic chart figure below. Be sure to place the ruler directly on the PED screen, and view the ruler from as much of a perpendicular position as possible to avoid issues with parallax. [Note: the AeroNav Products chart shown in the figure is presented as an example only.]
4. Multiply the measured distance by the ratio below for the appropriate chart provider. The ratio is the smallest text size for each chart source relative to the length of the chart box outline for a paper chart. The result is the smallest text size in inches for the combination of device, S/W application, and chart type.

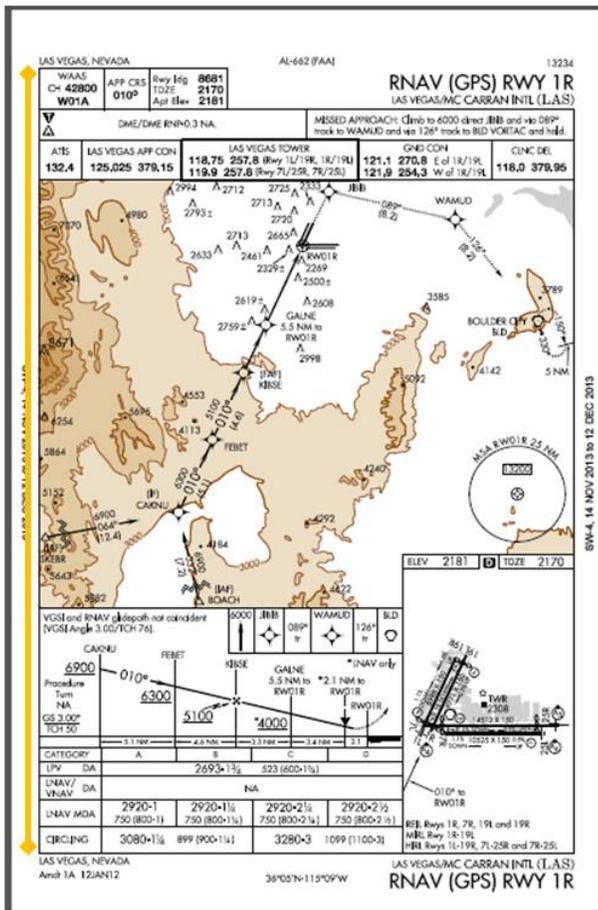
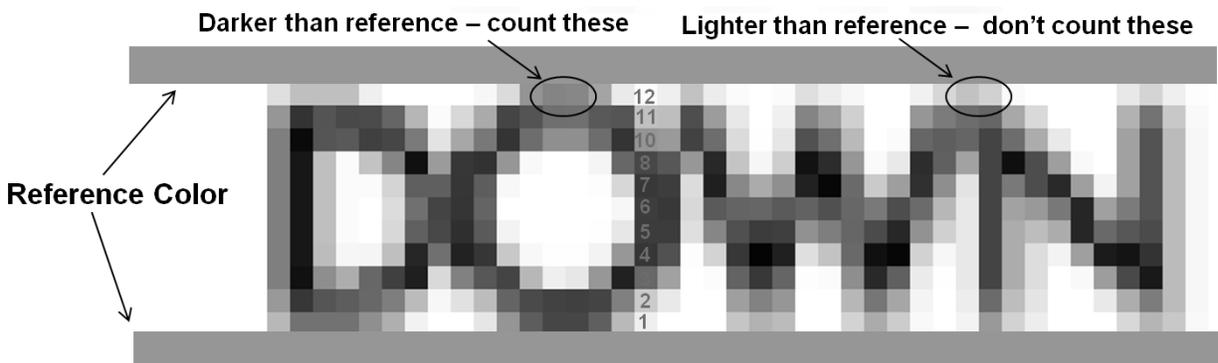


Chart Type	Ratio*	Smallest Text (in)	Outline box length (in)
AeroNav Products	.00601	0.0430	7.151
Jeppesen	.00713	0.0560	7.859
Lido	.00842	0.0595	7.063

*Current as of March 2014

Quick Reference Guide: Pixel Counting Method

1. Open a chart on the PED and make sure that the entire chart is shown on the screen.
 - a. If text is displayed diagonally, this method will not work.
 - b. If the charting software uses AeroNav Products charts, pick an airport with closely spaced parallel runways (such as KLAS).
2. Take a screenshot of the electronic chart.
3. Copy the screenshot to a computer and open it in a photo viewer application. Zoom the image in as much as possible. Make sure that the text to be measured is centered on the computer screen.
4. Copy the reference color (below), and then electronically paste it into the document containing the screenshot. This color is used to determine which pixels should be counted and which should be ignored
 - a. Note that the reference color is not intended to provide an error free method for accounting for anti-aliasing. Instead, it was created to give users an idea of what pixels should likely be counted, and which pixels should not be counted.
 - b. Note that the reference color may change slightly if this document is repeatedly converted between different formats, therefore it is suggested that this document should be accessed from the original source whenever possible.
5. Count the number of pixels (squares) that comprise the height of a capital letter. Be sure to only measure capital letters. Some tips to improve precision are:
 - a. Account for anti-aliasing by only counting the pixels that are darker than the reference color (see below).
 - b. Measure capital letters that have a relatively large top and bottom, such as "O" "D" "B" "C".
 - c. Avoid measuring letters with angles or that have a smaller top or bottom, such as "V" "X" "W" "M" "J".



6. Get the pixel density (in pixels per inch, PPI) for the PED from the manufacturer or calculate PPI by dividing the largest number of the screen resolution by the longest screen dimension (in inches).
7. Multiply the number of pixels counted by (1/PPI) to obtain the smallest text size in inches.
8. We recommend repeating the above steps 5-7 with a different word to make sure the smallest text size on the chart has been captured.

Quick Reference Guide: Photo Measurement Method

1. It is recommended that the user first practice measuring a US dime (10¢).
 - a. It is recommended that the camera on the Smartphone or tablet running the photo measurement application has at least 1.5 MP.
 - b. The photo measurement method should determine that the diameter of the dime is about .705 inches.
 - c. If the photo measurement app does not measure the dime to an accuracy within two one-thousandths of an inch (.703 - .707), this will begin to impact the accuracy of the legibility recommendations.
 - d. If unable to measure to the desired level accuracy using the photo measurement method, it is suggested that the user try a different photo measurement application or a different method for determining smallest text size.
2. Open a chart on the PED and make sure that the entire chart is shown on the screen.
 - a. If the charting software uses AeroNav Products charts, pick an airport with closely spaced parallel runways (such as KLAS).
3. Place a reference object specified by the app on top of the PED, next to the smallest text on the IAP chart. It is recommended that the user use the smallest reference object that the application allows (an object less than about two inches is recommended) to help reduce measurement error.
4. Open the photo measurement application (on a smart phone or tablet other than the device to be evaluated) and use it to take a photo of the reference object lying on the PED. Make sure that camera is as level as possible and positioned directly over the reference object when taking the photo. The goal is to make the reference object as large as possible in the photo while still being able to measure the length or width of the reference object in its entirety and the smallest text height.
5. Within the photo measurement application, align one set of markers with the reference object and the other second set of markers with a capital letter of the smallest text size. The photo measurement application will use the known length of the reference object to calculate the smallest text height and provide you with the calculated text height. Some tips to improve the precision are as follows:
 - a. Be sure to only measure capital letters.
 - b. If possible, measure capital letters that have a relatively large top and bottom, such as "O" "D" "B" and "C".
 - c. Avoid measuring letters with angles or that have a similar top or bottom, such as "V" "W" "M" and "J".
6. We recommend repeating the measurement with a different word to make sure the smallest text size on the chart has been captured.

3.2 Advantages and Limitations for each Text Size Measurement Method

Method	Advantages	Disadvantages
Ratios	<ul style="list-style-type: none"> • Only 1 measurement required • Accurate within about 5%-10% of actual text size 	<ul style="list-style-type: none"> • Ratios are no longer valid if chart providers change the format of their charts • Ratios are specific to a chart provider
Pixel Counting	<ul style="list-style-type: none"> • Independent of chart type • No physical measurements required • Can be accurate to within about 1%-2% of actual text size 	<ul style="list-style-type: none"> • Takes more steps and time than the ratio method • Method to account for anti aliasing is not perfect <ul style="list-style-type: none"> ○ This method cannot be used with colored or diagonal text ○ Further research is required to refine the reference color
Photo Measurement	<ul style="list-style-type: none"> • Independent of chart type • No physical measurements required • Can be accurate within about 1%-2% of actual text size 	<ul style="list-style-type: none"> • Takes more steps and time than the ratio method • Has both hardware and software requirements <ul style="list-style-type: none"> ○ Requires a smartphone or tablet with a camera of at least 1.5MP ○ Requires the use of a 3rd party application • Photo must be captured carefully

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