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DIGITAL COLOR LABORATORY

Final Report

HP DeskJet 1220C Comparative Study:

vs. Epson Stylus Color 1160 *and* Epson Stylus Photo 1200

SpencerLab Digital Color Laboratory, a division of Spencer & Associates Publishing, Ltd., has conducted independent comparative test and evaluation study of the Hewlett-Packard DeskJet 1220C, the Epson Stylus Color 1160, and the Epson Stylus Photo 1200[1] color inkjet printers. Analysis and testing covered two of the most significant user concerns:

- THROUGHPUT SPEED PERFORMANCE, and
- COST-PER-PAGE

In order to provide meaningful comparisons, Throughput Speed Performance must be tested at comparable Print Quality; therefore, *SpencerLab* initially performed a Print Quality analysis to ascertain the modes a user would choose to print each of the six test documents. Cost-per-Page was tested at the default driver settings. Both Throughput Speed and Cost-per-Page were evaluated using documents selected from the *SpencerLab* Printer Test Suite[2]. Representative office-type and graphic documents were selected to simulate typical end-user experiences.

Although this evaluation was sponsored by Hewlett-Packard, *SpencerLab* is an independent test laboratory with a well-earned reputation for the integrity of its testing and analyses.

Summary

In these competitive tests, the HP DeskJet 1220C maintained the wide-format leadership demonstrated in our previous testing of the HP DeskJet 1120C. Although the new Epson Stylus Color 1160 is faster and less costly to operate than earlier Epson wide-format printers,

- The HP DeskJet 1220C throughput speed performance outperformed both Epson printers overall; it provided *an advantage in every office-type document* and in two of the three graphic documents.
- The HP DeskJet 1220C had the *lowest cost-per-page* in all tests; it also had the *lowest frequency of required interventions* in all tests.

The results of this study lead us to conclude that the HP DeskJet 1220C provides the most cost-effective combination of print quality and throughput speed among these tested printers. Users requiring quick turn-around, cost-effective office documents on plain paper and those needing high-quality photographic output would be served well by the range of modes available on the HP DeskJet 1220C – and the resultant print quality, speed, and ink cost.

Throughput Speed Performance

The HP DeskJet 1220C demonstrated a faster print speed than either the Epson Stylus Color 1160 or the Epson Stylus Photo 1200 in every office-type document and in two of the three graphics documents. The HP DeskJet 1220C printed the *One-Page Letter* on plain paper in BEST mode in *less than one-third the time* required by either Epson printer in their comparable QUALITY modes. When printing the RGB photograph on photo paper, the Epson Stylus Color 1160 took two minutes (42%) longer than the HP DeskJet 1220C; the Epson Stylus Photo 1200 took more than twice as long. The Epson Stylus Color 1160 was fastest in one test, the *Newsletter,* where it took first place by four seconds (out of almost 4 minutes) over the HP DeskJet 1220C. Comparisons were performed at comparable print quality for the intended use of each test document, as detailed below.

Methodology

Many factors contribute to the overall Throughput Speed Performance of a print system. The maximum rate at which the marking engine can image a page necessarily restricts performance testing, but this simple model neither accurately nor completely represents real-world throughput speed. Most commonly, a host workstation sends print jobs to a printer through a print driver that may require significant processing overhead, causing a delay in printing prior to and/or during the operation of the marking engine; this delay prolongs the print duration increasingly as jobs become more complex. Although throughput speed for a print device can be based solely on marking engine speed, our testing measures speed within a realistic workflow.

The interval between the user-initiated print request and the release of the printed document ("Last Page Out") is a more accurate representation of the user experience with the system. This is sometimes referred to as "click-to-clunk" time. Other time intervals, also measured from the user-initiated print request, are of interest. "Application Release" measures the time elapsed for an application to send information to the Windows spooler. "Workstation Release" measures the time until the workstation is released from the print task and can be used at full processing power for productive work. Our testing also measures "Engine Start", the time at which the print engine physically begins printing, an indicator of print job bottlenecks and an important user interaction point that can affect perception of the print duration.

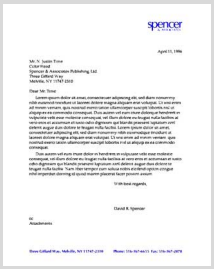
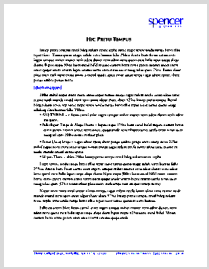
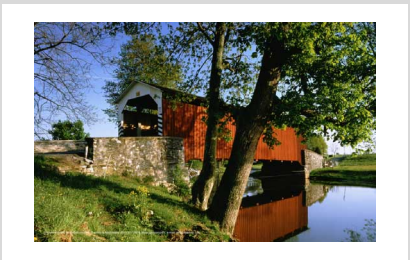
All throughput speed testing was performed with standard application programs running on a Dell Dimension XPS T500 under Windows 98SE (version 4.10.2222 A) without background processes wherever possible. The XPS T500 workstation uses a 500 MHz Pentium III with 128 MB of RAM and a 7 GB hard drive. A Universal Serial Bus (USB) connection provided communication from the workstation. A clean system was reinstalled before testing

each printer. Only the current driver for the printer under test was installed. Driver versions tested were: version 1.0 for the HP DeskJet 1220C; version 5.0CE for the Epson Stylus Color 1160; and version 4.5CE for the Epson Stylus Photo 1200.

The samples from our throughput suite comprised 15 pages. All samples contain some color. Throughput time measurements were repeated a minimum of three times until the variance was less than one percent or one second.

Test Documents

Throughput Speed Performance comparisons were based on the analysis of six representative documents selected from the *SpencerLab* Printer Test Suite:

Office Documents			
	Word: ***One-Page Letter***	**Word:** ***Ten-Page Report***	**Excel:** ***Spreadsheet & Charts***
Graphic Documents			
	QuarkXPress: ***Newsletter***	**Illustrator:** **CMYK *"Dragon"***	**Photoshop:** **sRGB *"Covered Bridge"***

Office Documents

One-Page Letter (Microsoft Word 97) – black text with color logo
Ten-Page Report (Microsoft Word 97) – limited spot color
Spreadsheet & Charts (Microsoft Excel 97) – tabloid-size color

Graphic Documents

Newsletter (QuarkXPress 3.3) – mixed text, color graphics and photograph
Illustration (Adobe Illustrator 8) – computer-generated CMYK "*Dragon*"
Photograph (Adobe Photoshop 5.0) – tabloid-size sRGB "*Covered Bridge*"

Print Quality Analysis

The analysis of Throughput Speed Performance in the context of comparative Print Quality is detailed below. Therefore, *SpencerLab* performed a print quality analysis to ascertain the modes a user would choose to print each of the six test documents.

Modes were compared based on their applicability to similar user scenarios and corresponding documents. Mode selection was considered based on the content of each document, spanning office word processing and a combination of image and graphics in a professional page layout. Quality comparisons went well beyond the obvious output resolution specification; a simple measure of device addressability, to include evaluations of each type of document element, including text, graphics, photographic image, and color issues. To complete each scenario, representative media was chosen for each document according to estimated user preference or vendor recommendation.

Each tested printer provides an array of modes to match the tradeoff between throughput speed and image quality with the user's objective for each print job. Although all the units include an ECONOMY mode, the Epson printers do not allow a casual user access to this mode, possibly due to the mode's clearly sub-standard print quality (appearing to be low contrast 180 dpi). Only the HP DeskJet 1220C allows direct access to its lowest print resolution that, at 300 dpi, provides acceptable output in many basic situations. In each product, a highest-quality mode reverses this tradeoff: quality is boosted while speed is sacrificed. Between these diverse modes each vendor has adopted a slightly different ladder: The Epson Stylus Color 1160 offers up to three modes and the Epson Stylus Photo 1200 two modes depending upon media type, with identically named modes producing different results at different speeds on different media; the HP DeskJet 1220C provides up to three modes that also vary with media selection. Each printer allows several media types besides the generic "Plain Paper" mode, with print parameters tuned to take advantage of the specific media's special attributes.

The special inkjet media available for the HP and Epson inkjet printers permits the three tested printers to perform more competitively. Overall, available modes on the HP DeskJet 1220C, the Epson Stylus Color 1160, and the Epson Stylus Photo 1200 provided a similar range of print quality.

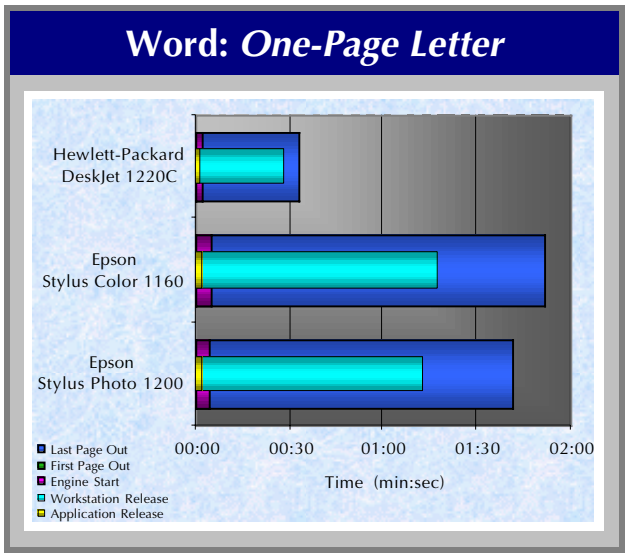
Throughput – Office Documents

For most desktop printer users, common office applications create the majority of print jobs. These documents traditionally contain information in the form of black text; color is used to improve communication and to render the document more visually appealing.

Word Processing

Perhaps the simplest but most frequent of all printing jobs, the *One-Page Letter* contains standard black text with a colored logo and footer. Users will generate this type of document in situations ranging from simple personal notes to professional letterhead for high-level correspondence. Since the printers under study are intended for business use, we established the testing scenario as external business correspondence. Plain Paper media was selected, as this is most frequently the media available to office personnel.

Under these guidelines, we found the most comparable quality provided by modes on each printer to be near 600 dpi: BEST on the HP DeskJet 1220C and QUALITY on the Epson printers.

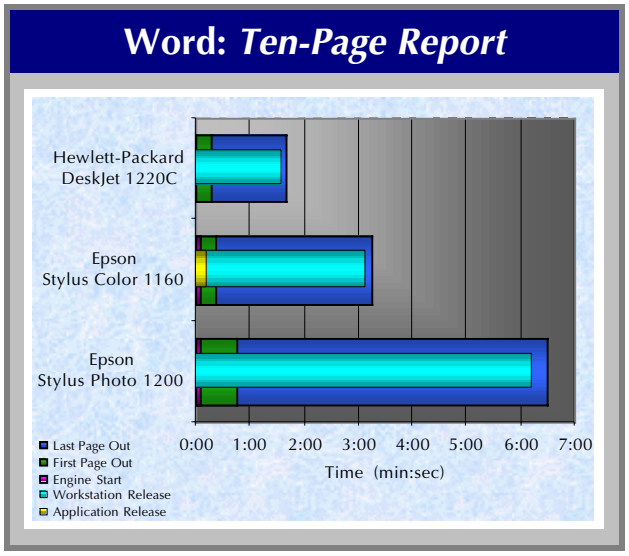


For the *One-Page Letter* document, throughput speed of the HP DeskJet 1220C was significantly faster than either of the tested Epson printers. The HP DeskJet 1220C completed printing of the *One-Page Letter* on plain paper in BEST mode in *less than one-third the time* required by either Epson printer in their comparable QUALITY modes. The HP DeskJet 1220C completed Last Page Out in 33 seconds. The corresponding time of the Epson Stylus Photo 1200 (1:42) was slightly faster than the Epson Stylus Color 1160 (1:52).

We carefully considered selecting the mid-range mode between QUALITY and SPEED on the Epson Stylus Color 1160; however, black text was somewhat thick and small characters in the logo had ragged right edges. Printing the *One-Page Letter* in that mode took over 50 seconds, still significantly longer than the performance of HP's BEST mode.

Although all printers achieved Application Release in approximately two seconds, the HP DeskJet 1220C achieved Workstation Release in only 28 seconds, compared to 1:18 and 1:12 for the Epson Stylus Color 1160 and Stylus Photo 1200 respectively. The HP DeskJet 1220C achieved Engine Start in only 2 seconds, compared to 5 and 4 seconds for the respective Epson printers.

The second word processing document included in this study was the *Ten-Page Report*, comprised primarily of black text with some highlight color, graphical tables, and color logos. The chosen scenario is internal distribution on plain paper. Because of its length, this document would benefit significantly by the use of the fastest print mode that provides adequate legibility. While an ECONOMY mode was available on both the Epson Stylus Color 1160 and the Epson Stylus Photo 1200, the resultant quality is such that it was deemed unusable in most office environments. On the HP DeskJet 1220C in FAST mode, although there is color shift in the logo reproduction and the text edge sharpness is limited, the resultant quality remains adequate for this scenario in most office environments. Therefore, SPEED was the fastest acceptable mode on the Epson printers, while FAST was the acceptable choice on the HP DeskJet 1220C.



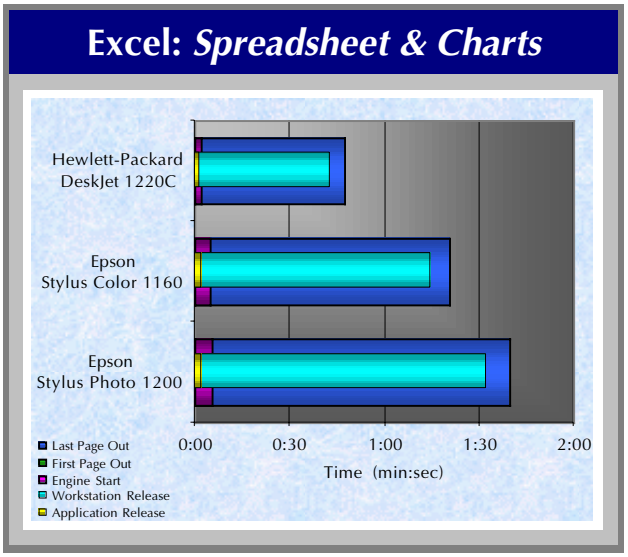
With its adequate FAST mode quality, the HP DeskJet 1220C completed Last Page Out for the *Ten-Page Report* in 1:39, almost twice as fast as the Epson Stylus Color 1160 (3:15). The Epson Stylus Photo 1200 (6:30) took a surprisingly 94% longer than the Epson Stylus Color 1160, in its comparable SPEED mode. The ECONOMY mode of the Epson printers, while not selected for this document due to its inadequate print quality, showed approximate times of 2:05 and 2:40 respectively, still slower than the HP DeskJet 1220C.

The HP DeskJet 1220C achieved Application Release in 2 seconds, the Epson Stylus Photo 1200 in 3 seconds, and the Epson Stylus Color 1160 took 12 seconds. It achieved Workstation Release in only 1:34, compared to 3:08 and 6:12 for the Epson Stylus Color 1160 and Epson Stylus Photo 1200 respectively. Engine Start was in approximately one second, compared to 6 and 5 seconds for the respective Epson printers. The HP DeskJet 1220C achieved First Page Out in 18 seconds, compared to 20 and 44 seconds for the respective Epson printers.

Spreadsheet

The third office test document is a spreadsheet with charts created in Microsoft Excel. Unlike word processing documents that may take advantage of color to highlight text or incorporate it in a logo, modern spreadsheets often incorporate color as a significant aid to differentiating data in both tabular and graphical forms.

The *Spreadsheet & Charts* test document includes large bands of background color, used to facilitate reading of long lines of data, as well as 3-D bar and pie charts. These elements are arranged on a tabloid-size page to compare performance across the inkjets that particularly feature this larger page size. A scenario of an internal working document on plain paper was chosen because as a standalone spreadsheet, it is most often used as such. Again, as with the text documents, users are inclined to use plain paper.



In its FAST mode the HP DeskJet 1220C has some font rendition issues; and in their SPEED modes, both Epson printers show screening artifacts. All three printers showed horizontal lines in the brown area of the graphs in these modes. Although these defects disappear when the modes were changed to NORMAL on the HP DeskJet 1220C and QUALITY on the Epson Stylus Color 1160 and the Epson Stylus Photo 1200 printers, print quality was still deemed adequate for internal distribution.

For the *Spreadsheet & Charts* test document, throughput speed performance of the HP DeskJet 1220C was significantly faster than either of the tested Epson printers. The HP DeskJet 1220C completed printing of the *Spreadsheet & Charts* on plain paper in FAST mode in 47 seconds, while the Epson Stylus Color 1160 took 70% longer (1:20), and the Epson Stylus Photo 1200 took more than twice as long (1:40), both in SPEED mode.

The HP DeskJet 1220C achieved Application Release in approximately one second, a second faster than either Epson printer. Similarly, Engine Start occurred in two seconds, three seconds faster than either Epson. The HP DeskJet 1220C achieved Workstation Release in only 43 seconds, compared to 1:15 and 1:32 for the Epson Stylus Color 1160 and Epson Stylus Photo 1200 respectively.

Throughput – Graphic Documents

Graphic documents often contain more color and require higher levels of font and color fidelity, including smooth blends, high quality image halftones and color balance. These more stringent needs, in addition, will push graphics users towards premium media that are costlier but designed specifically to perform better on each particular inkjet printer.

It is in this area that the difference between resolution specifications and print quality becomes most apparent. On the *"Covered Bridge"*, little difference was seen between the Epson Stylus Color 1160 1440×720 mode and its 720×720 dpi mode, despite a doubling of data fed to the print engine. Similarly, although the HP DeskJet 1220C is actually capable of 2400×1200, at a resolution of 600 dpi with PhotoREt III its sharpness, halftoning, and color depth allow it to provide results comparable to those of the nominally higher resolution Epson printers.

Computer-based graphics generally fall into two categories, vector and raster. Various applications are used to create graphical elements, each catering to one of these particular types (though some hybrid applications have evolved). The methods by which these types of graphics are stored and reproduced are significantly different, leading to both print quality and throughput speed implications.

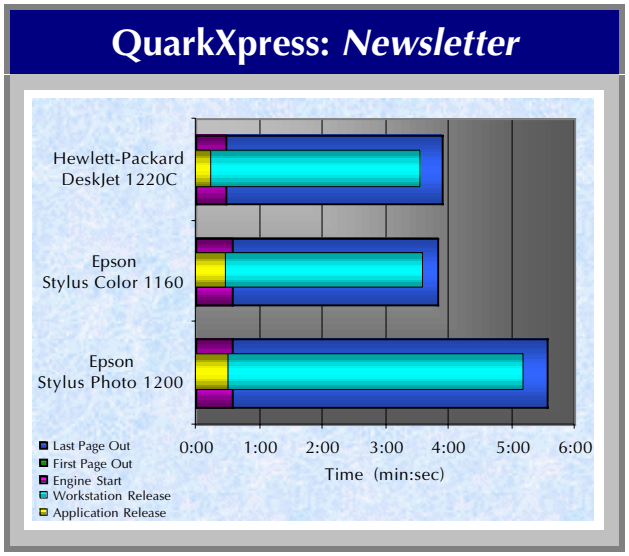
Vector artwork is based on a description of discrete elements that make up the piece in a manner that also describes their interaction. Each time the piece is reproduced, be it on a monitor or printer, the elements are recreated one-by-one until the entire artwork is complete. This procedure can be very computationally taxing, and error-prone, leading to the aforementioned throughput speed and quality pitfalls.

As an example of vector graphics we have selected the CMYK Illustration "*Dragon*", computer generated in Adobe Illustrator. As an example of raster graphics, we have selected the tabloid size sRGB Photograph *"Covered Bridge*". We have also included a compound document that includes text, vector and raster graphics, the *Newsletter* created in QuarkXPress, which will be discussed first.

Page Layout

Since they combine text, graphics, and image elements in the same document, page layouts are quite taxing on a print system; they represent a complex combination of elements. Furthermore, since the page layout is the final document in the production chain, it will be the version printed for external distribution. Therefore, this scenario requires printing on special matte-finish inkjet paper.

As such, our testing pushed the printers to moderately high output quality levels. Premium InkJet Paper was selected for the HP DeskJet 1220C. With this media, BEST mode was judged to provide the appropriate print quality for this scenario, showing superior line graphics with better image color fidelity and image detail, especially in shadows and highlights. Photo Quality InkJet Paper is specifically mentioned for newsletters in the Epson Stylus Color 1160 "Printer Basics" manual. With that media, the user has only the QUALITY or SPEED modes as options; SPEED print quality was not acceptable, therefore we chose the QUALITY mode for the page layout. The print quality analysis determined the appropriate corresponding modes: for the HP DeskJet 1220C, BEST on Premium InkJet Paper; and for both Epson printers, QUALITY on Photo Quality InkJet Paper.

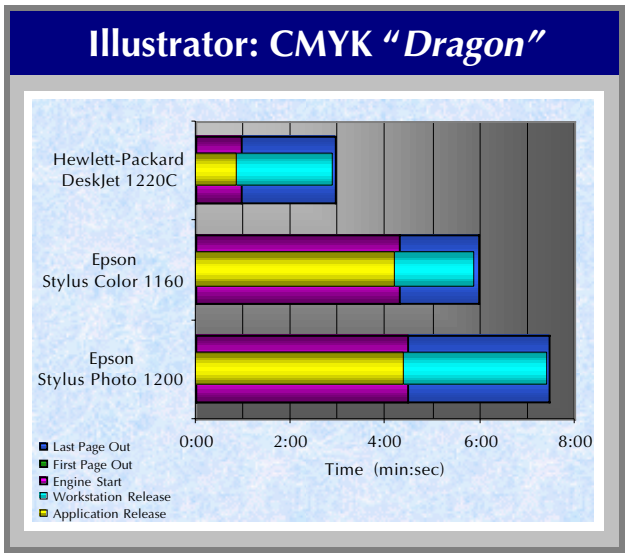


In the test results for the *Newsletter*, the Epson Stylus Color 1160 produced the fastest printing time at 3:50. The HP DeskJet 1220C was 4 seconds slower (1.7%) at 3:54. The Epson Stylus Photo 1200 took substantially longer (31%) at 5:33. The HP DeskJet 1220C was fastest in Application Release at 15 seconds, versus 29 and 31 seconds respectively; in Workstation Release at 3:34 versus 3:36 and 5:11; and in Engine Start at 29 seconds versus 34 and 35 seconds respectively.

Vector Artwork

As an example of vector graphics we have selected the CMYK Illustration "*Dragon*", computer generated in Adobe Illustrator. The graphic is quite complex and contains a difficult blend between the complementary colors of blue and yellow, as well as sharp details and a wide gamut.

In the test scenario, the "*Dragon*" print is being used by the artist as a proof of their design before it is incorporated into a more complex document, where text and other elements may be added. We therefore chose heavyweight matte inkjet media: for the HP DeskJet 1220C, Premium Plus Photo Paper – Matte was selected, and for both Epson printers, Matte Paper – Heavyweight was selected.



The quality baseline for this scenario seeks to balance print quality on premium inkjet paper with throughput speed, so as to match the artistic intent and color while allowing a designer who may be producing many hardcopies of the artwork to have output most quickly. The Epson Stylus Color 1160 displays significant high frequency stitching errors (about 17 per inch) in the desaturated mid-tones, such as blue-yellow blends. On the HP DeskJet 1220C, print quality of the reverse text is not clear white, there is some low frequency banding (about 3 per inch), and the rendering of stroked lines is piecewise – linear instead of smooth curves. All three printers showed visible stepping in the blue-yellow blend. However, on all three printers output is quite impressive with strong, saturated colors and sharp edges. It was determined that HP's NORMAL mode and Epson's SPEED modes when used with these media would provide adequate, comparable quality.

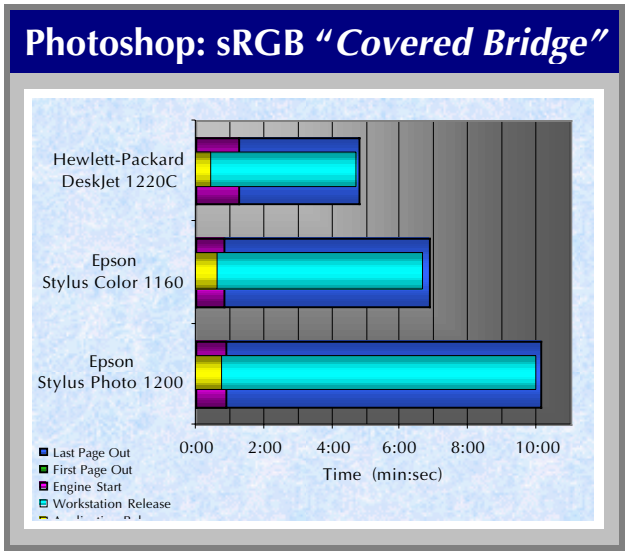
In the test results for the *"Dragon"*, the HP DeskJet 1220C took less than half the time of the fastest Epson competitor, having completed printing in 2:56. The Epson Stylus Color 1160 took more than twice as long (5:57) to print the *"Dragon"*, and the slower Epson Stylus Photo 1200 did not complete

printing until 7:28 (more than $2^1/_2$ times as long). The HP DeskJet 1220C's 51 second Application Release was more than four times faster than the Epson Stylus Color 1160's 4:13 or the Epson Stylus Photo 1200's 4:24. Engine Start was similar at 58 seconds versus 4:18 and 4:29, respectively. In all cases, Workstation Release took nearly as long as printing completion at 2:52, 5:52, and 7:24, respectively.

Photographic Image

The sixth and last throughput speed test document is an example of raster graphics, the tabloid size sRGB Photograph *"Covered Bridge"*. Unlike the vector artwork, this graphic is comprised of a grid of halftone data representing the appropriate photograph. Sharp details must still be retained, however, as must specific memory colors that match those found in nature. Color balance is also significant, requiring that each printer's conversion from RGB not favor any color that would appear as a cast over the entire photograph.

To provide maximum data density and thus the finest detail for throughput speed comparison, the scenario for this sample was a tabloid-size reproduction on glossy media. Printers were tested in comparable quality modes, enabling the closest comparison to an actual photograph.



Print quality analysis began with a comparison of the HP DeskJet 1220C in BEST mode with PhotoREt III OFF, to achieve 2400×1200 dpi, and the Epson Stylus Color 1160 in Custom 1440×720 dpi mode. Upon examination it was determined that the print quality of the Epson Stylus Color 1160 was below that of the HP DeskJet 1220C, but above that of it's own QUALITY mode. Through detailed analysis of modes and quality, it was determined that the HP DeskJet 1220C's NORMAL mode and the QUALITY mode on both Epson printers were most comparable and provided adequate quality and substantially faster throughput. In general, the Epson prints had higher contrast, leading to more apparent detail in the midrange at the expense of blown-out

highlights and loss of shadow detail. All tested printers demonstrated impressive photorealism with excellent detail retention and realistic highlights and shadows.

Here again the HP DeskJet 1220C throughput speed is much faster than either of the Epson printers, completing the sRGB Photograph"Covered Bridge" in 4:48. The Epson Stylus Color 1160 took more than two minutes longer at 6:49 (42% longer), but was still more than three minutes faster than the Epson Stylus Photo 1200 at 10:08 (more than twice as long). The HP DeskJet 1220C had the fastest Application Release at 25 seconds, versus 38 and 46 seconds, respectively, but exhibited the slowest Engine Start at 1:15, versus 50 and 51 seconds, respectively. The HP DeskJet 1220C exhibited the fastest Workstation Release at 4:42, while the Epson Stylus Color 1160 took 6:41, and the Epson Stylus Photo 1200 did not release the workstation until 9:59.

Throughput Speed Performance Chart

The chart below details results of all of the Throughput Speed Performance time measurements in this study.

Throughput Speed Performance

Document	Media	Mode	Application Release	Workstation Release	Engine Start	First Page Out	Last Page Out
Word: *One-Page Letter*							
Hewlett-Packard DeskJet 1220C	Plain Paper	Best	00:02	00:28	00:02		00:33
Epson Stylus Color 1160	Plain Paper	Quality	00:02	01:18	00:05		01:52
Epson Stylus Photo 1200	Plain Paper	Quality	00:02	01:12	00:04		01:42
Word: *Ten-Page Report*							
Hewlett-Packard DeskJet 1220C	Plain Paper	Fast	00:02	01:34	00:01	00:18	01:39
Epson Stylus Color 1160	Plain Paper	Speed	00:12	03:08	00:06	00:20	03:15
Epson Stylus Photo 1200	Plain Paper	Speed	00:03	06:12	00:05	00:44	06:30
Excel: *Spreadsheet & Charts* (Tabloid)							
Hewlett-Packard DeskJet 1220C	Plain Paper	Fast	00:01	00:43	00:02		00:47
Epson Stylus Color 1160	Plain Paper	Speed	00:02	01:15	00:05		01:20
Epson Stylus Photo 1200	Plain Paper	Speed	00:02	01:32	00:05		01:40
QuarkXPress: *Newsletter*							
Hewlett-Packard DeskJet 1220C	Premium InkJet Paper	Best	00:15	03:34	00:29		03:54
Epson Stylus Color 1160	Photo Quality Ink Jet Paper	Quality	00:29	03:36	00:34		03:50
Epson Stylus Photo 1200	Photo Quality Ink Jet Paper	Quality	00:31	05:11	00:35		05:33
Illustrator: CMYK "*Dragon*"							
Hewlett-Packard DeskJet 1220C	Premium Plus Photo Paper - Matte	Normal	00:51	02:52	00:58		02:56
Epson Stylus Color 1160	Matte Paper - Heavyweight	Speed	04:13	05:52	04:18		05:57
Epson Stylus Photo 1200	Matte Paper - Heavyweight*	Speed	04:24	07:24	04:29		07:28
Photoshop: sRGB "*Covered Bridge*" (Tabloid)							
Hewlett-Packard DeskJet 1220C	Premium Photo Paper	Normal	00:25	04:42	01:15		04:48
Epson Stylus Color 1160	Photo Paper	Quality	00:38	06:41	00:50		06:49
Epson Stylus Photo 1200	Photo Paper	Quality	00:46	09:59	00:51		10:08

*Media package says use PQIJ setting

Cost-per-Page Analysis

The Ink Cost-per-Page of the Hewlett-Packard DeskJet 1220C was analyzed in comparison with the Epson Stylus Color 1160 and the Epson Stylus Photo 1200. Testing compared the amount of ink used to print five documents that were selected as above from the *SpencerLab* Printer Test Suite to represent a range of potential uses for this class of color inkjet printer. In this comparison:

- The HP DeskJet 1220C *had the lowest cost-per-page* in all tests.
- The HP DeskJet 1220C also *had the lowest frequency of required interventions* in all tests.

The ink cost-per-page advantage of the HP DeskJet 1220C was significant. The Epson Stylus Color 1160 ranged from 13% to 35% more expensive, and the Epson Stylus Photo 1200 ranged from 18% to 59% more.

Aided by its larger cartridges, the HP DeskJet 1220C had substantially fewer interventions for cartridge changes, another important element of Total Cost of Ownership. The Epson Stylus Color 1160 required 46% to 172% more interventions, while the Epson Stylus Photo 1200 required 19% to 170% more.

Methodology

The primary method of determining Cost-per-Page for inkjet printers is based upon determining the number of copies of a test document that can be printed by the black and color cartridges. This testing is repeated over multiple cartridges to assure consistency. Cartridge cost is obtained, in this case from ARS, an independent third party that surveys cartridge street prices. Once an average number of Pages-per-Cartridge is established for black and color, the cost of each cartridge is divided by this result to calculate the black and color component costs-per-page. The black and color ink component costs for each test document are then added to obtain the total Cost-per-Page. This process is repeated for each test document.

In order to determine when it is appropriate to replace a cartridge, the print quality was monitored with every page printed. The cartridge was judged to be exhausted when the test page showed visible defects based on ink supply.[3] For color cartridges, which contain cyan, magenta, and yellow, the cartridge was deemed empty when the first color ran out – consistent with the use environment.[4,5] When a document consumed one cartridge much more frequently than the other, that particular cartridge was replaced until sufficient, consistent data was acquired. From that point, printing continued with only one cartridge to avoid waste and superfluous data.

Cost-per-Page testing was conducted with each of the three printers in their plain paper default modes, according to the following chart:

Cost-per-Page – Print Modes		
Hewlett-Packard DeskJet 1220C	**Epson Stylus Color 1160**	**Epson Stylus Photo 1200**
Mode: Normal Media Type: Plain	**Print Mode: Speed Media Type: Plain**	**Print Mode: Speed Media Type: Plain**

All cost-per-page testing was performed with the appropriate application programs running on Intel-standard PCs under Windows 98SE without background processes wherever possible. A clean system was reinstalled before testing. Driver versions tested were: Release Candidate 3 for the HP DeskJet 1220C; version 5.0CE for the Epson Stylus Color 1160; and version 4.5CE for the Epson Stylus Photo 1200. Since cost-per-page testing of the Epson Stylus Photo 1200 occurred earlier, the configuration of the PC used for testing differed slightly; however, each workstation was configured with identical drivers, applications, and test documents to provide identical printed results.

Test Documents

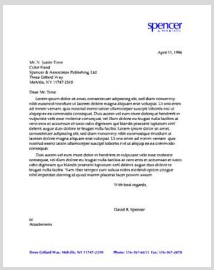
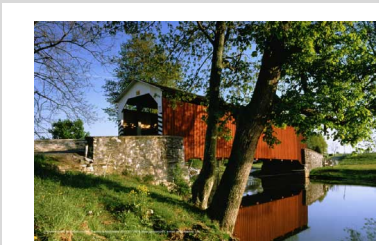
Cost-per-Page comparisons were based on the analysis of five representative documents selected from the *SpencerLab* Printer Test Suite[6]. Test documents range from a simple one-page business letter to a tabloid-size illustration and photograph. All samples contain some color:

Office Documents

One-Page Letter (Microsoft Word 97) – black text with color logo
Spreadsheet & Charts (Microsoft Excel 97) – tabloid-size color

Graphic Documents

Composite (*SpencerLab* PostScript Level 2) – "*Associates*" CMYK graphics and text, RGB photograph
Illustration (Adobe Illustrator 7) – tabloid-size, computer-generated CMYK "*Dragon*"
Photograph (Adobe Photoshop 5) – tabloid-size sRGB "*Covered Bridge*"

Office Documents			
	Word: ***One-Page Letter***	**Excel:** ***Spreadsheet & Charts***	
Graphic Documents			
	SpencerLab: ***"Associates"***	**Illustrator:** **CMYK *"Dragon"***	**Photoshop:** **sRGB *"Covered Bridge"***

Pages-per-Cartridge and Pages-between-Interventions

The basic Cost-per-Page testing results are the number of pages of each test document that can be printed with a black and a color cartridge, or Pages-per-Cartridge. Another calculation is Pages-between-Interventions. Every time a cartridge is used up, an operator Intervention is required to change it. The Pages-per-Cartridge data may be used to estimate a bound on the number of Pages-between-Interventions. That is, there may be additional Interventions for other reasons (such as a paper jam), but at minimum, these Interventions consisted of ink cartridge replacements. The greater the number of Pages-between-Interventions, the less a user must interact with the printer.

The Pages-per-Cartridge data for the black and color may be combined to calculate the minimum bound on Interventions using the equation:

$$\#\text{ Pages-between-Interventions} \geq \left(\text{Pages-per-Cartridge}[\text{Black}]^{-1}+\text{Pages-per-Cartridge}[\text{Color}]^{-1}\right)^{-1}$$

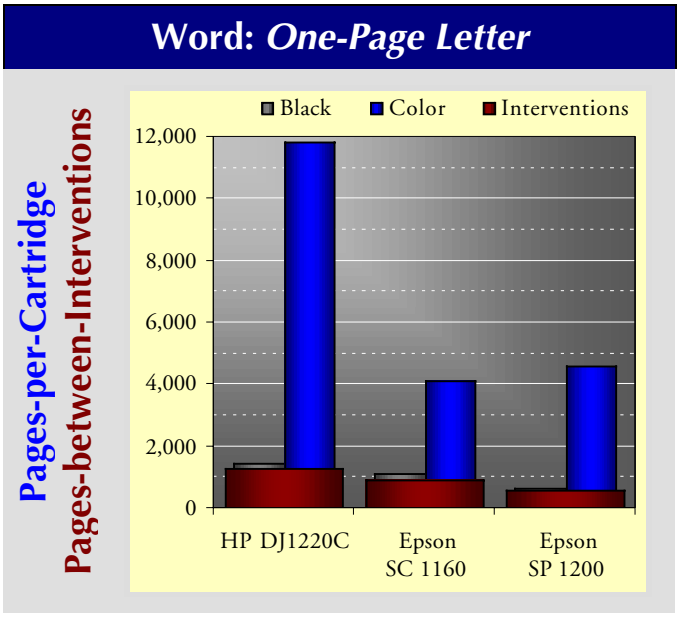
The results of *SpencerLab's* testing are summarized in the following table:

	Word: *One-Page Letter* (A)			Excel: *Spreadsheet&Charts* (B)		
	Pages-between-Interventions	Pages-per-Cartridge		Pages-between-Interventions	Pages-per-Cartridge	
		Color	Black		Color	Black
HP 1220C	1,303	11,849	1,465	129	174	498
Epson SC 1160	896	4,106	1,146	59	75	285
Epson SP 1200	577	4,590	661	108	152	377

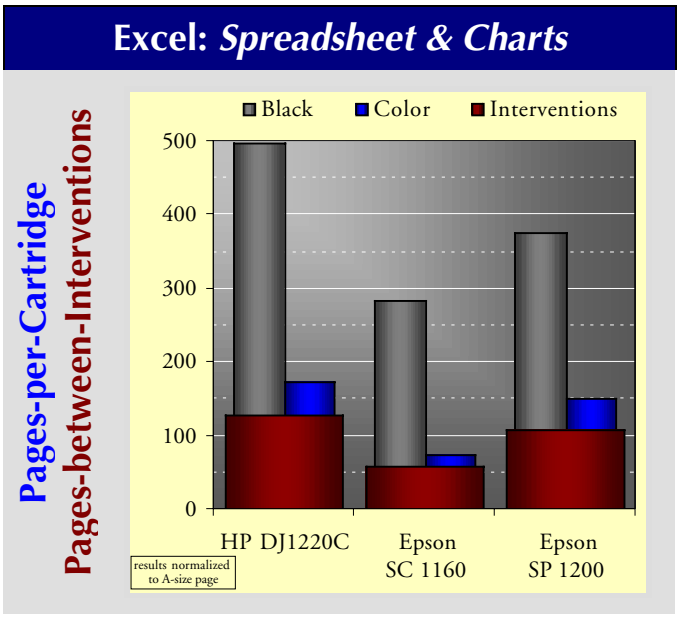
	SpencerLab: *"Associates"* (A)			Illustrator: CMYK *"Dragon"* (B)			Photoshop: sRGB *"Covered Bridge"* (B)		
	Pages-between-Interventions	Pages-per-Cartridge		Pages-between-Interventions	Pages-per-Cartridge		Pages-between-Interventions	Pages-per-Cartridge	
		Color	Black		Color	Black		Color	Black
HP 1220C	255	377	788	52	65	281	33	45	135
Epson SC 1160	111	140	536	19	22	155	15	18	84
Epson SP 1200	94	128	365	34	44	144	28	38	105

This data for Pages-per-Cartridge and the resultant bound on the number of Pages-between-Interventions are shown graphically for each test document:

Office Documents

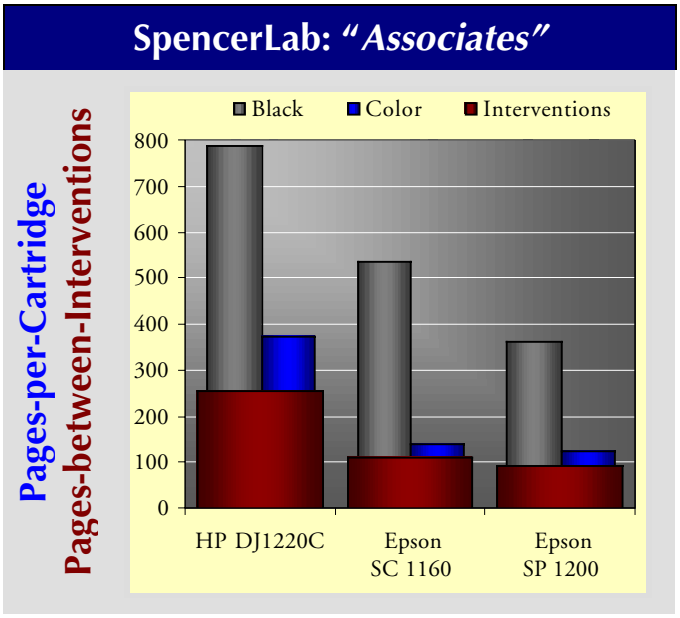


At an estimated bound of over 1300 Pages-between-Interventions when printing documents such as the *One-Page Letter*, the HP DeskJet 1220C requires Intervention to change a print cartridge some 30% less often than the Epson Stylus Color 1160 and less than half as often as the Epson Stylus Photo 1200.

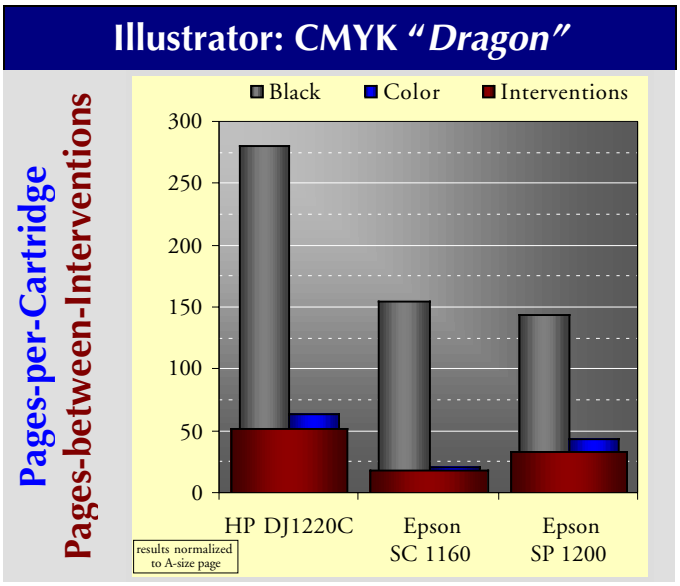


At an estimated bound of 129 Pages-between-Interventions when printing documents such as the *Spreadsheet & Charts*, the HP DeskJet 1220C requires Intervention to change a print cartridge less than half as often as the Epson Stylus Color 1160. The Epson Stylus Photo 1200 is better than the Epson Stylus Color 1160 in this regard when printing this type of document.

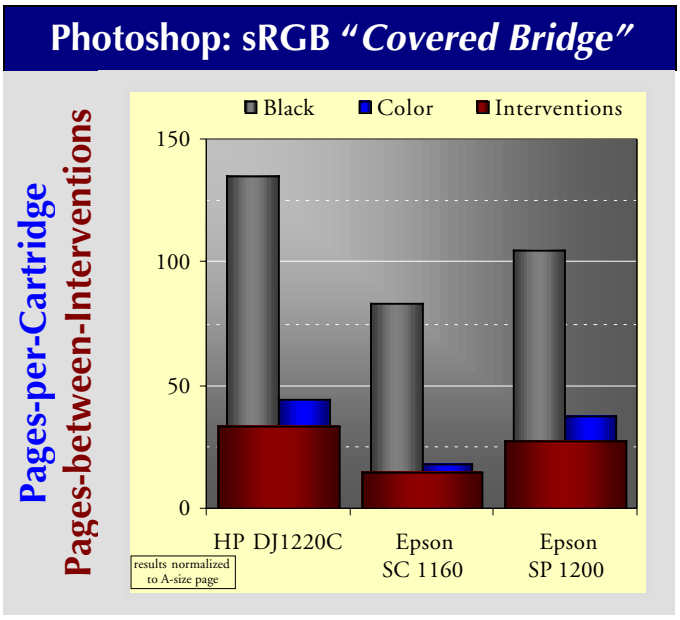
Graphic Documents



At an estimated bound of over 250 Pages-between-Interventions when printing documents such as the "*Associates*" mixed text and graphics, the HP DeskJet 1220C requires Intervention to change a print cartridge less than half as often as either the Epson Stylus Color 1160 or the Epson Stylus Photo 1200.



At an estimated bound over 50 Pages-between-Interventions when printing documents such as the CMYK *"Dragon"*, the HP DeskJet 1220C requires Intervention to change a print cartridge less than half as often as the Epson Stylus Color 1160. The Epson Stylus Photo 1200 is somewhat better than the Epson Stylus Color 1160 in this regard when printing this type of document, but still well behind the HP DeskJet 1220C.



At an estimated bound 33 Pages-between-Interventions when printing documents such as the *"Covered Bridge"* photograph, the HP DeskJet 1220C once again requires Intervention to change a print cartridge less than half as often as the Epson Stylus Color 1160. The Epson Stylus Photo 1200 is somewhat better than the Epson Stylus Color 1160 in this regard when printing this type of document, but still well behind the HP DeskJet 1220C.

Cartridge Cost

The following table lists estimated street prices of cartridges as reported by ARS in the Non-Retail Consumables Price/Margin Model for Inkjet Supplies Average Street Price Trend Analysis January 31, 2000.

Cartridge Cost	Hewlett-Packard DeskJet 1220C	Epson Stylus Color 1160	Epson Stylus Photo 1200
Color	#C6578A $61.98	#S020191 $28.00	#T001011 $27.78
Black	#51645A $31.51	#S020189 $27.85	#S020187 $24.42

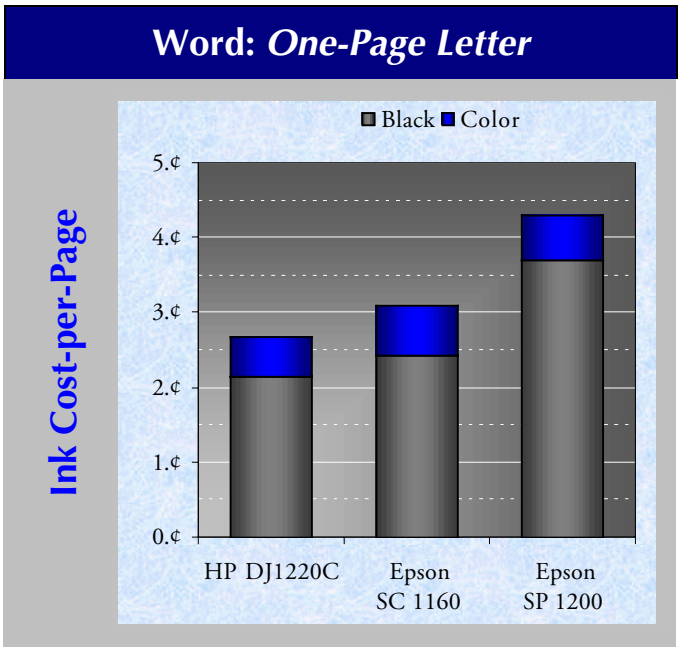
Cost-per-Page

The overall results of *SpencerLab's* Cost-per-Page analysis are summarized in the following table. Results were compiled by adding the costs for black and color inks. All costs for tabloid pages are normalized to letter-size to facilitate comparisons between test documents. In all cases, the cost of media is not included.

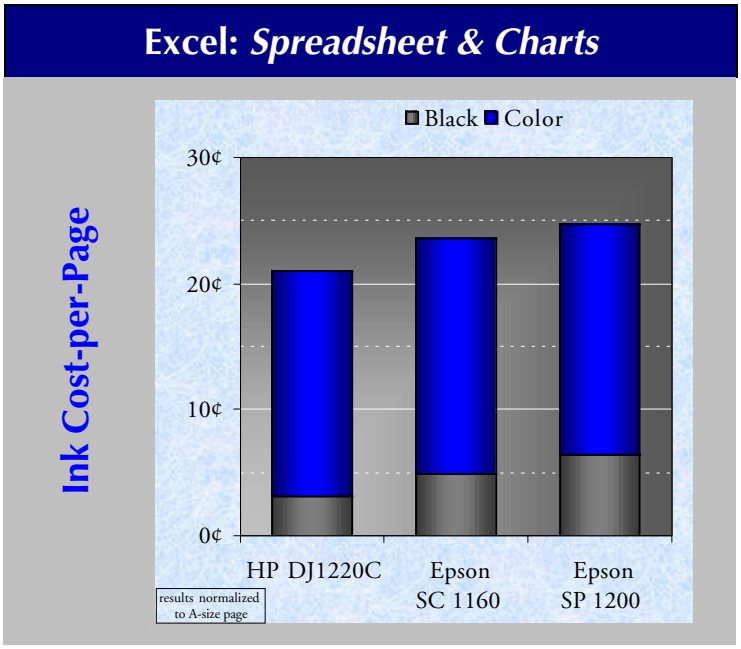
Cost-per-Page	Page Size	Hewlett-Packard DeskJet 1220C	Epson Stylus Color 1160	Epson Stylus Photo 1200
Letter	Letter	**2.7¢**	**3.1¢**	**4.3¢**
Spreadsheet & Charts	Tabloid	**21.0¢**	**23.7¢**	**24.8¢**
"Associates"	Letter	**20.5¢**	**25.2¢**	**28.5¢**
"Dragon"	Tabloid	**53.7¢**	**72.6¢**	**79.5¢**
"Covered Bridge"	Tabloid	**81.3¢**	**94.5¢**	**96.4¢**

Cost-per-Page – Office Documents

Cost-per-Page results are summarized individually by test sample in the following graphs.



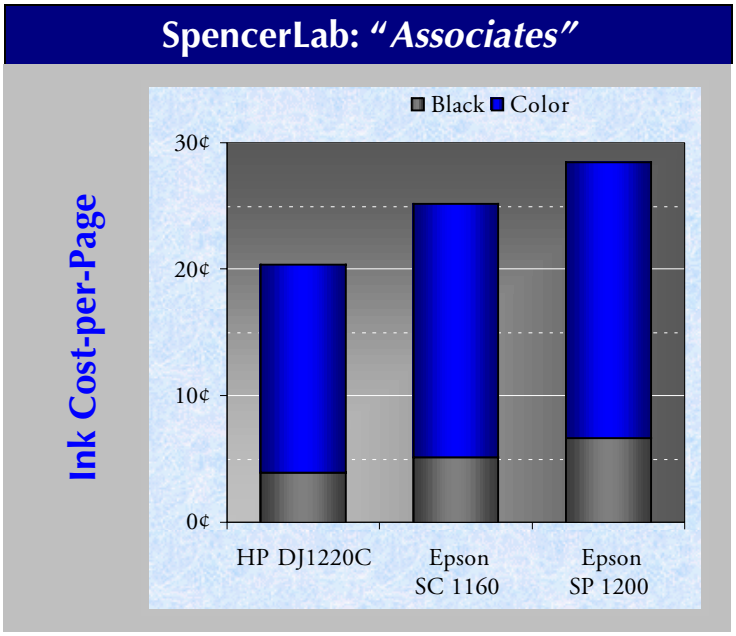
With each of the office documents, the HP DeskJet 1220C surpassed the other inkjets. For example, printing the *One-Page Letter* on the Epson Stylus Color 1160 is 15% more expensive than the HP DeskJet 1220C. The Epson Stylus Photo 1200 is 59% more expensive.



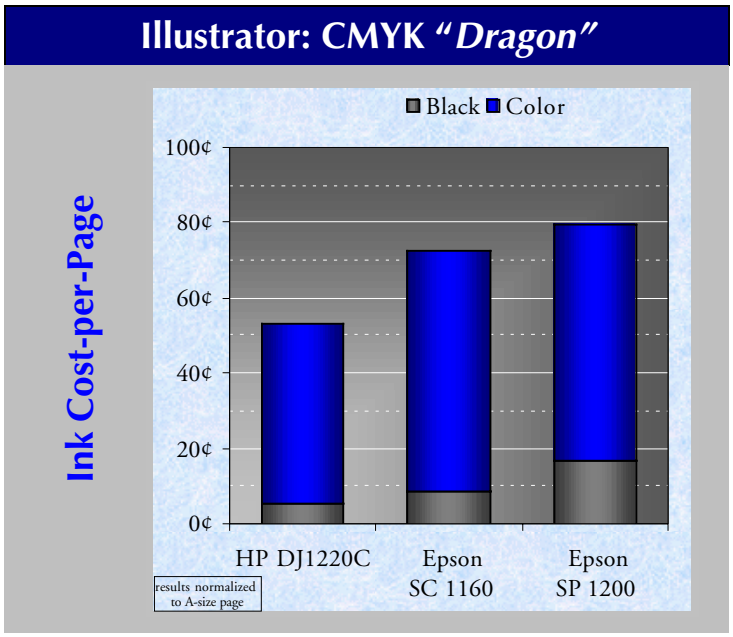
Printing the *Spreadsheet & Charts* on the Epson Stylus Color 1160 is 13% more expensive than the HP DeskJet 1220C. The Epson Stylus Photo 1200 is 18% more expensive. For each of the applications tested, the Cost-per-Page of

the Epson Stylus Photo 1200 is less economical than either the HP DeskJet 1220C or the Epson Stylus Color 1160.

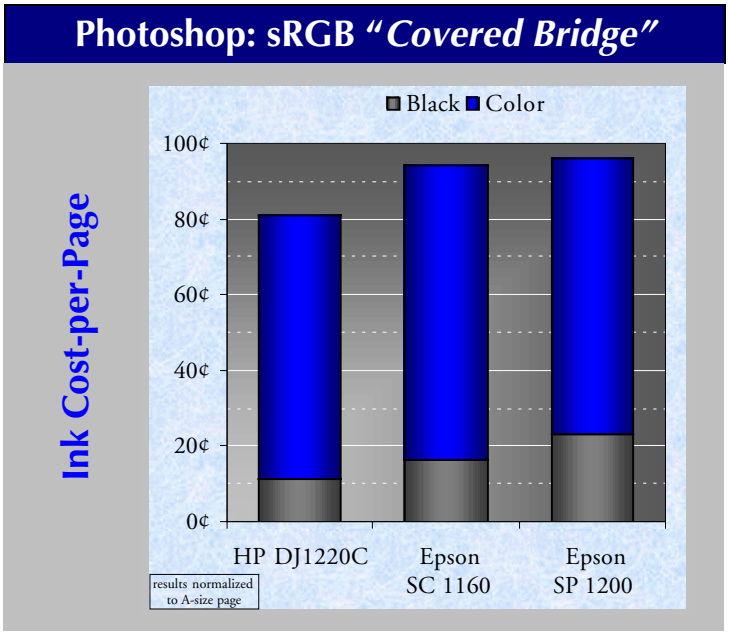
Cost-per-Page – Graphic Documents



The HP DeskJet 1220C is more cost effective than either the Epson Stylus Color 1160, or the Epson Stylus Photo 1200 for graphic arts documents as well. Results for the *SpencerLab* "*Associates*" test document again shows the HP DeskJet 1220C as being more cost effective totaling 20.5¢. These results indicate that the Epson Stylus Color 1160 (25.2¢) is 23% more expensive than the HP DeskJet 1220C (20.5¢) and the Epson Stylus Photo 1200 (28.5¢) is 39% more expensive ink cost-per-page.



For the *"Dragon"* test document, the Epson Stylus Color 1160 (72.6¢) is 35% more expensive than the HP DeskJet 1220C (53.7¢). The Epson Stylus Photo 1200 (79.5¢) is 48% more expensive.



For the "*Covered Bridge",* the total Cost-per-Page of the HP DeskJet 1220C (81.3¢) is 14% (13.2¢) cheaper per page than the Epson Stylus Color 1160 (94.5¢). The HP DeskJet 1220C was 16% (15.1¢) cheaper than the Epson Stylus Photo 1200, at 96.4¢.

February 24, 2000

[1] To accommodate the pre-release status of the Epson Stylus Photo 1200 at the time of cost-per-page testing, the Japanese version, the PM-3000, was used.
[2] The *SpencerLab* Printer Test Suite, now in Beta, is an extension of Spencer & Associates' *Color Hardcopy Quality Factors* test suite, a de facto industry standard.
[3] When replacing cartridges, the HP DeskJet 1220C performs an automatic alignment procedure; the number of alignment pages for each file tested are… Word: *One-Page Letter*=6; Excel: *Spreadsheet & Charts*=5; *SpencerLab*: "*Associates"*=5; Illustrator: CMYK "*Dragon"*=8; and Photoshop: sRGB "*Covered Bridge"*=5.
[4] The HP DeskJet 1220C continues to print even when the ink in the print cartridge is low or empty. There is a warning light on the front of the machine; however, if the user misses the warning or sends another print job, the light is reset and will not appear until the end of that job. If not monitored, the print quality will deteriorate. However, the user can receive a warning through the HP Toolbox, which links to an e-commerce site for ease of replacement cartridge ordering.
[5] For the Epson printers, although this issue was mitigated by the printers' own detection of ink depletion, which is more convenient for the user in that the user will never print pages when the ink has begun to run out, this invariably wastes some ink due to limited accuracy of the printer's use detection method.
[6] Application versions used for Cost-per-Page testing were chosen to be consistent with previous testing on the Epson Stylus Photo 1200.

Appendix A: Cost-per-Page Test Document Descriptions

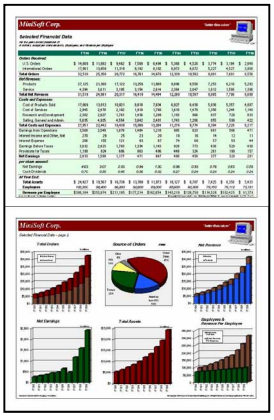
The content of the five Test Documents – the Word *One-Page Letter,* the Excel *Spreadsheet & Charts,* the *SpencerLab* "*Associates*", and the Illustrator *"Dragon"*, and the Photoshop s*RGB "Covered Bridge"* – are described in detail in the following paragraphs. These documents are part of a pre-release version of the *SpencerLab* Printer Test File Suite.

Word: *One-Page Letter*

The *One-Page Letter* was created in Microsoft Word 97, a component of Office 97. The document represents a typical single-page office letter. It is comprised of two paragraphs of monochrome text, a header with the blue Spencer & Associates logo, and a blue footer with the company address, phone and fax numbers.

We estimate that this document coverage at about 3% black, and less than 1% each of cyan and magenta, and negligible yellow. Note that these percentages are determined in detail by the individual printer driver as it converts RGB data (through Microsoft Windows 98SE) into device-dependent CMYK data for printing. (More detailed information about test document ink coverage is provided at the end of this section on cost-per-page analysis.)

Excel: *Spreadsheet & Charts*



The Excel *"Spreadsheet & Charts"* was designed in Microsoft Excel 97, a component of Office 97. It serves as an example of a tabloid-size office spreadsheet with various corporate data formatted in six graphs and charts. The thumbnail of the sample on the right shows that the B-size page is comprised of two $8^1/_2 \times 11$" pages with landscape orientation. In fact, Excel allows this data to be printed as shown, or as two A-sized landscape pages.

The tints in the numeric data area add to the overall color content of this test document, resulting in overall coverage somewhat higher than that of the *"Associates"* test document.

SpencerLab "Associates"

The *SpencerLab "Associates"* Test File combines many elements that appear in composite documents, especially those created in page layout programs. The test file is programmed directly in the PostScript page description language to maximize device-independence – including color depth and resolution-independence. The program will preserve device defaults, including screening.

This document contains an image of approximately 12 in^2 and approximately 17 in^2 graphic blends, representing about 31% of the total content of the $8^1/_2 \times 11$" page. The image and graphics include a mixture of black and color. The balance of the page is more sparsely covered, primarily with color test and line work.

Illustrator: CMYK *"Dragon"*

The *"Dragon"* is Adobe Illustrator (version 7.0) EPS file created by Donna Helliwell and is representative of a wide range of high-coverage graphics arts samples.

At a coverage well over 100%, the sample provides examples of blends and fine detail, including patterned regions. In its B-size version, as was used in this test, it measures approximately $9^1/_2 \times 11^1/_2$". Deterioration in screening or rendering accuracy is readily apparent as the smooth blends and sharp detail in vibrant colors puts heavy demands on print quality.

Photoshop: RGB *"Covered Bridge"*

The s*RGB "Covered Bridge"* is a 38.6MB calibrated color image, saved in Adobe PhotoShop (version 5.0) EPS/JPEG compressed format. The file is 7.46MB; the 5.17:1 JPEG compression ratio retains extremely high image quality. The file does not specify halftoning or transfer functions. RGB calibration is to a gamma of 1.8, a white -point of 6500°K, and Trinitron phosphors. Its printed dimensions are 10 × 15" (3000 by 4500 pixels) with a resolution of 300 dpi.

The image has a fairly large gamut of colors, including significant memory colors. The image covers approximately 80% of the B-size page. The predominantly primary is yellow, although all primaries are well represented. The amount of black is strongly dependent upon the Gray Component Replacement and/or UnderColor Removal (GCR/UCR) utilized by the individual printer drivers in their conversion from RGB to CMYK.

About *SpencerLab*

SpencerLab Digital Color Laboratory is an independent printer evaluation laboratory that provides services to vendors and corporations for whom color printing is mission-critical. The Laboratory follows strict guidelines in the integrity of both methodology and reporting; vendor-sponsored studies do not guarantee favorable results. *SpencerLab* has developed industry-standard test software, and performs print quality, throughput speed, cost-per-page, and ease-of-use analyses for color printers in all technology classes, from inkjet and laser printers to digital color presses.

SpencerLab is operated by Spencer & Associates Publishing, Ltd., a premier information technology consulting boutique specializing in the application of Digital Color Technology to all aspects of color imaging. For over eleven years Spencer & Associates has been providing strategic support to manufacturers in product planning, development, and launch. Color printing workflow analysis, print system selection, and usage optimization services are provided to corporate users.

For more information, please contact Spencer & Associates at 631-367-6655, by fax at 631-367-2878, by email at info@spencer.com, or visit us on the web at www.spencer.com and www.spencerlab.com.

Appendix B: Test Document Coverage Estimates

Calculation of ink coverage requires knowledge of the driver algorithm for conversion to CMYK. Lacking this information, some estimates for the five cost-per-page test documents are summarized in the following table:

	Source	"1 Minus" CMYK w/o GCR	"SWOP" CMYK w/o GCR	"SWOP" CMYK w/full GCR
Word: *One-Page Letter*	0.00% R	0.30% C	0.23% C	-
	0.00% G	0.30% M	0.23% M	-
	0.30% @ 83.13% B	0.05% Y	0.23% M	-
	2.95% @ 100.00% K	2.95% K	3.01% K	-
	Total Ink:	3.6%	3.5%	-
Excel: *Spread-sheet & Charts*	33.60% @ 70.50% R	9.91% C	14.84% C	6.52% C
	33.60% @ 70.06% G	10.05% M	13.96% M	11.26% M
	33.60% @ 61.70% B	12.86% Y	16.88% Y	10.85% Y
	15.60% @ 35.52% K	5.54% K	0.00% K	5.04% K
	Total Ink:	38.4%	45.6%	33.7%
SpencerLab **"*Associ-ates*"**	12.74% @ 55.87% R			
	12.74% @ 35.20% G			
	12.74% @ 31.78% B			
	8.57% C	14.19% C	13.05% C	8.76% C
	8.70% M	16.95% M	15.83% M	13.19% M
	8.86% Y	17.55% Y	15.00% Y	12.11% Y
	3.77% K	3.77% K	3.77% K	8.21% K
	Total Ink:	52.5%	47.7%	42.3%
Photo-shop: sRGB "*Covered Bridge*"	80.21% @ 70.05% R	27.47% C	51.88% C	16.75% C
	80.21% @ 73.21%	28.71% M	45.94% M	8.16% M
	80.21% @ 57.88% B	22.70% Y	55.47% Y	28.91% Y
	-	0.00% K	0.00% K	41.82% K
	Total Ink:	78.9%	153.3%	95.6%
Illustrator: CMYK "Dragon"	34.51% C	34.51% C	34.51% C	34.51% C
	38.43% M	38.43% M	38.43% M	38.43% M
	14.90% Y	14.90% Y	14.90% Y	14.90% Y
	10.59% K	10.59% K	10.59% K	10.59% K
	Total Ink:	98.43%	98.43%	98.43%

Word: *One-Page Letter*

A Microsoft Word file under Window 98SE, the *One-Page Letter* is an RGB document. Black text is 2.95%, and color test (header and footer) is 0.30%. According to Photoshop, all color text is 83.13% blue.

If simplistic "one minus" equations were used (without GCR), the inks to make blue would be 100% cyan, 100% magenta, and 16.87% yellow, resulting in 0.30%, 0.30%, and 0.05% coverage, respectively. The total coverage in a "one-minus" scenario would be 2.95% black plus 0.30% cyan, 0.30% magenta, and 0.05% yellow – or 3.6%.

In an alternate scenario, we estimated conversion to SWOP with 25% dot gain from a 9300°, 1.8 gamma monitor. The resulting coverage in this scenario without GCR is 3.01% black plus 0.23% cyan, 0.23% magenta, and 0% yellow – or 3.47%; GCR is not possible due to the lack of yellow in the SWOP conversion.

Excel: *Spreadsheet & Charts*

A Microsoft Excel file under Windows 98SE, *"Spreadsheet & Charts"* is an RGB document. Black and gray cover 15.60% of the 11" x 17" page; color covers 33.60%, and the remaining 50.80% of the page is uncovered. The black and gray is at an average Lightness of 64.48%. The Color consists of 70.50% red, 70.06% green, and 61.70% blue.

Using the simplistic "one minus" equations as above, the total coverage would be 5.54% black plus 9.91% cyan, 10.05% magenta, and 12.86% yellow – or 38.4%.

In the alternate scenario, we estimated conversion to SWOP. The resulting coverage in this scenario without GCR is 0% black plus 14.84% cyan, 13.96% magenta, and 16.88% yellow – or 45.6%; with 100% GCR it is 5.04% black plus 6.52% cyan, 11.26% magenta, and 10.85% yellow – or 33.7%.

SpencerLab "Associates"

A hand coded PostScript test program, the "*Associates"* file contains both RGB and CMYK data. Most of the elements in the document are defined in CMYK, with the exception of a Photoshop image which is defined in RGB. The RGB image covers 12.74% of the 8.5" x 11" page. The Color consists of 55.87% red, 35.20% green, and 31.78% blue.

The larger portion of the document is defined in CMYK. It has a total coverage of 8.57% cyan, 8.7% magenta, 8.86% yellow and 3.77% black or 29.9% total ink coverage.

Using the simplistic "one minus" equations with GCR for the 12.74%-of-page RGB image would contribute coverage of 0% black plus 5.62% cyan, 8.25% magenta, and 8.69% yellow – or 22.6%. Adding in the remainder of the page, the total coverage would be 3.77% black plus 14.19% cyan, 16.95% magenta, and 17.55% yellow – or 52.5%.

In an alternate scenario, we estimated conversion of the RGB image to SWOP with 25% dot gain from a 6500º 1.4 gamma monitor. The resulting coverage without GCR is 0% black plus 4.47% cyan, 7.11% magenta and 6.14% yellow – or 17.72%; with 100% GCR it is 4.44% black plus 0.19% cyan, 4.48% magenta, and 3.25% yellow – or 12.36%. Combining this with the CMYK coverage from the rest of the document yields a total estimated coverage without GCR of 3.77% black plus 1113.05% cyan, 15.83% magenta, and 15.00% yellow – or 47.7% with 100% GCR it is 8.21% black plus 8.76% cyan, 13.19% magenta, and 12.11% yellow – or 42.3%.

Photoshop: sRGB *"Covered Bridge"*

An Adobe Photoshop file under Windows 98SE, the *Covered Bridge* is an sRGB image that covers 80.21% of the 11"x 17" page. The color consists of 70.05% red, 73.21% green, and 57.88% blue.

Using the simplistic "one minus" equations without GCR as above, the total coverage would be 0% black plus 27.47% cyan, 28.71% magenta, and 22.70% yellow – or 78.9%

In the alternated scenario, we estimated conversion to SWOP. The resulting coverage in this scenario without GCR is 0% black plus 51.88% cyan, 45.94% magenta, and 55.47% yellow – or 153.3%; with 100% GCR it is 41.82% black plus 16.75% cyan, 8.16% magenta, and 28.91% yellow – or 95.6%.

Note that the printer driver optional implementation of GCR can very significantly influence the trade-off between black and color usage. Heavy GCR increases black to replace color. Since three color primaries are replaced by one black, total ink coverage is reduced. However, fewer screen dots are available to render smooth highlights. The decision is generally different for each printer manufacturer and each product.

Illustrator: CMYK *"Dragon"*

An Adobe Illustrator file under Windows 98SE, the "*Dragon"* is specified in CMYK and covers 2/3 of the 11"x 17" page. The covered region requests 51.84% cyan, 57.59% magenta, 22.30% yellow, and 15.80% black.

Since the file is specified directly in CMYK, there is no conversion between source specification and CMYK specification. Clearly, internal transfer functions will convert the colors to RGB for communication purposes and then back to CMYK, but coverage estimates are based only on the CMYK request, as this patently represents the intended correct conversion.