

Characterization of Thermal and Piezo-Electric Print Heads in a Microgravity Setting.



Rochester Institute of Technology
1 Lomb Memorial Drive
Rochester, NY 14623



Microgravity Printer Experiment
Imaging and Photographic Technology
Building 7B

Team Leader:

Christopher Ubelacker
cwu1318@rit.edu
267-250-9524

Faculty Advisors:

Andrew Davidhazy
andpph@rit.edu
585-475-2592

Scott Williams
sawppr@rit.edu
585-475-7088

James Craven
Flyer
Senior
Imaging and Photographic Technology
jdc6559@rit.edu

Greg Sharp
Flyer
Senior
Imaging and Photographic Technology
gls0786@rit.edu

Christopher Ubelacker
Flyer
Senior
Imaging and Photographic Technology
cwu1318@rit.edu

Jarret Whetstone
Flyer
Senior
Imaging and Photographic Technology
jrw4200@rit.edu

ABSTRACT

Thermal and Piezo-electric ink jet printhead technologies comprise a large majority of the current printer market share. This technology has been designed and used effectively with good results in its normal environment on the Earth's surface. The Rochester Institute of Technology Imaging and Photographic Technology Team participating in the 2008 National Aeronautics and Space Administration Reduced Gravity Student Flight Opportunities Program tested the ability of current inkjet printing technologies to function in a microgravity setting. Testing was done on an Epson R280 Printer which utilized thermal printhead technology and a Kodak EasyShare 5100 Printer that uses piezo-electric printhead technology. This involved both high speed imaging of the ink drops as they were ejected from the printhead along with quality testing of the printer that the printhead belonged to. These tests were performed using specially design printer test-targets that measure density, resolution, fine line detail, and registration, which provides characterization data of the printer functionality. Included in this paper are explanations of the testing design, the results, and the suggestions for printer modifications and further study.

DEFINITIONS

Carriage, The physical mechanism that moves cross-process as the paper moves in-process to deposit ink-droplets over the page. It contains the droplet ejection system and the ink cartridges.

Cross-Process, refers to printing in the direction of the carriage movement.

In-Process, refers to printing in the direction of the paper movement.

INTRODUCTION

Traditionally, inkjet printers are used to print text and images on various materials. However, these devices have the ability to function beyond these conventional uses. Current efforts include the production of circuit board tracings (Cooley; Hayes; Yoshioka), biomedical research (Ilkhanizadeh; Lange), and three-dimensional prototyping (Cho; Cooley; Hayes). This changes the function of an inkjet printer from a visual output device to an accurate and precise construction tool which uses micro-liquids as the base material.

These technologies were created to work on the surface of the Earth under a constant 1G gravitational force. This same technology can be used in space as an assembly device. A system designed specifically for a space environment can be developed and optimized through collaboration and experimentation.

A refitted C-9 aircraft is used to test experiments in a microgravity environment. The C-9 was provided by the NASA Reduced Gravity Flight Opportunities Program. The aircraft flies in a parabolic path creating a simulated weightless environment for 20 to 30 seconds during descent and an increased gravity environment, approximately 1.8 G, during the ascent. The parabolic cycle is repeated 30 times to provide ample opportunity for the personnel to acclimate to the changes in gravity and to provide multiple chances for data collection.

OBJECTIVES

The goal of the experiment was to characterize the functionality of thermal and piezo-electric inkjet-printhead technologies, in the microgravity environment. This was

accomplished by using the printers in their normal functioning state along with high speed imaging of the drops as they were ejected during a period of microgravity.

TEST PROCEDURES

The experiment was conducted in two parts, the properties of the printheads and the quality of the output. The data from this two-part process provided an explanation of printer-quality attributes in comparison to the physical function of the printhead. This was achieved by using high-magnification, high-speed imaging of the drops being ejected from the printhead and by using the same printhead to print specially designed printer test-targets.

A Vision Research Phantom v9.0 digital high speed camera was used to capture the ink drops in flight. The spatial resolution of the captured images was 480 x 480 pixels and the frame rate was 4000 pictures per second at an exposure of 230 μ s. The camera was equipped with a full-frame CCD sensor with a pixel size of 11 μ m. The camera used a 50mm macro lens with 1:1 magnification fixed to 270mm of extension which provided a total of 5.44x optical magnification. The camera provided data from which flight trajectory, velocity, size, shape, and volume were determined for drops that travelled across the imaging plane.

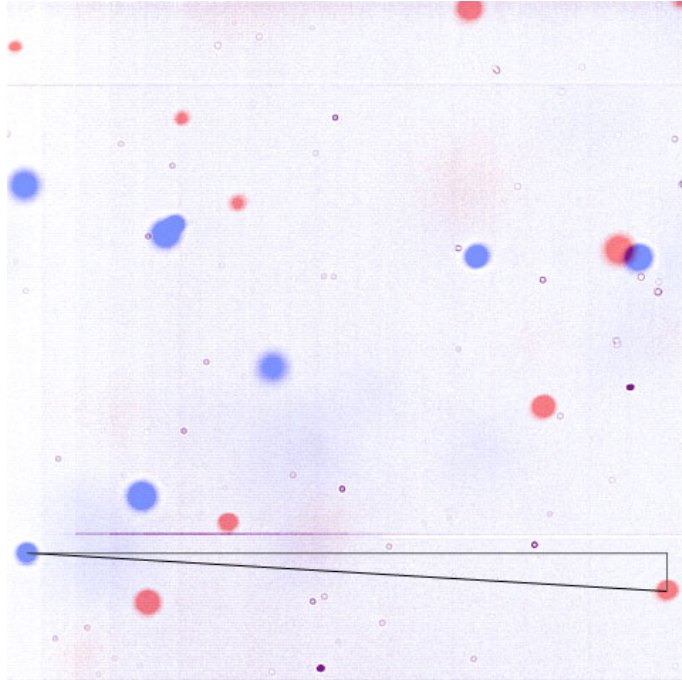


Figure 1. High Magnification High Speed Image of Ink Drops.

Figure 1 shows an example of the high-speed imaging that was used for the experiment. Blue drops represent the first usable data point as it entered the camera frame and the red drops represents the last usable drop data point before it exited the frame. These high-speed captures average seventy frames for the entire drop flight event. Since both time and distance are captured using the camera system velocity can be determined.

The same printers were also used to print test-targets to quantify the density, resolving power, fine line detail and registration. These test-targets were printed on the ground in 1G under normal conditions to act as a control for the experiment. The targets were printed again during the 0G interval of the flight path. This was the sample data for overall effectiveness of the original manufactured printhead technology.

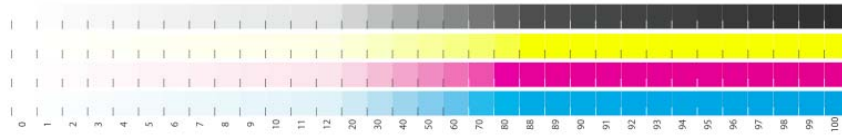


Figure 2. CMYK Step Gradient Test Target. *IQAF CMYK Target Set, Xerox Co.*

The test target shown in Figure 2 was used to quantify the dynamic range of the printer. If ink droplets were not absorbed or dispersed in flight, there would have been noticeably less density and a smaller dynamic range.

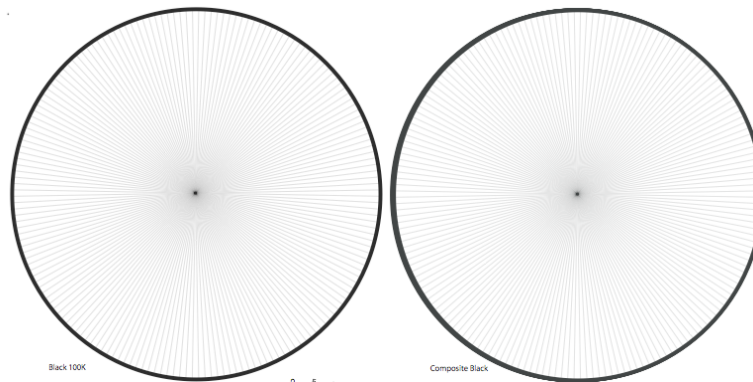


Figure 3. Angular Resolution Test Target. *IQAF CMYK Target Set, Xerox Co.*

The test target in Figure 3 was used to test the angular resolution of printer output. These targets consisted of fine lines at 1° intervals converging at the center of a circle. This provided accurate resolution measurements which caused a noticeable moiré pattern where the resolution exceeded the spatial limits of the printer.

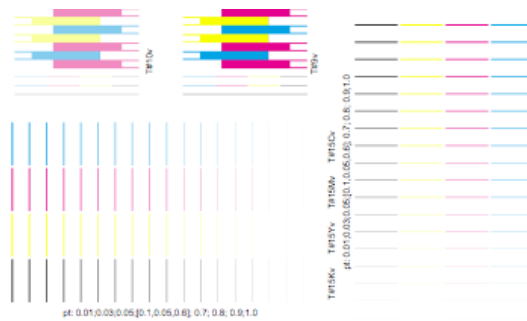


Figure 4. Cross Process and In-Process Fine Line Test Target. *IQAF CMYK Target Set, Xerox Co.*

Figure 4 shows the cross-process and in-process fine-line test-target. These four gradations of primaries decrease in line width. Micro-imaging of the finest line reveals how single-droplets form on the paper. This will determine resolution, fine line detail, and detect scattering effects.



Figure 5. Color to Color Registration Test Target. *IQAF CMYK Target Set, Xerox Co.*

Figure 5 is a color-to-color registration target. Thin lines of the three primary colorants were intended to print in register. If one colorant did not line up with another on the print it indicated a printhead registration error. This information was used to determine if one colorant deviated significantly more than other colorants.

Analyzing these four test-targets along side high-speed imaging provides an understanding of the limits of the printers being tested and the effects of microgravity on image output.

RESULTS

Drop Flight Trajectory

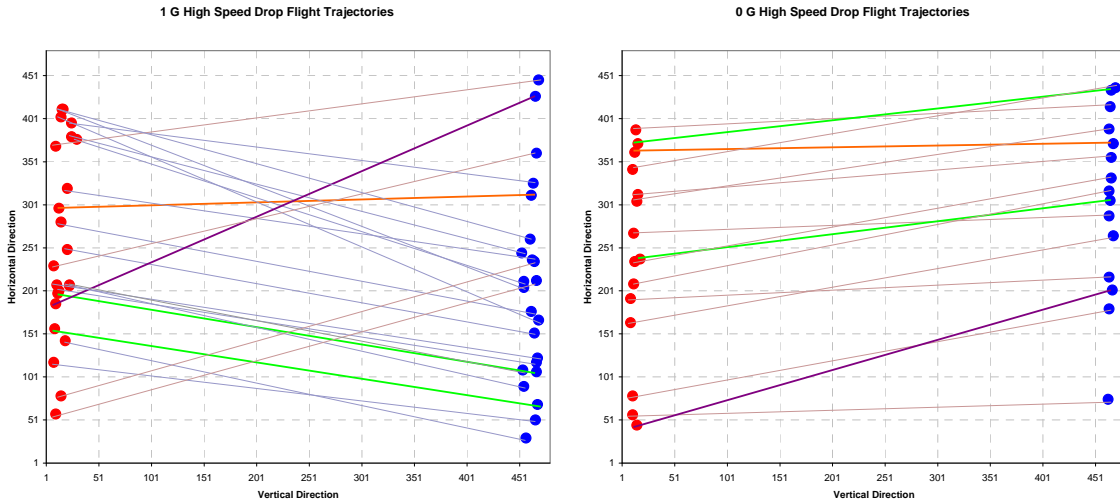


Figure 6. Comparison between the drop trajectories in 1 G (left) and 0 G (right).

In Figure 6, the orange line represents the minimum horizontal displacement from a straight drop trajectory. The purple line represents the maximum horizontal displacement from a straight drop trajectory. The green line represents the average horizontal displacement from a straight drop trajectory. Pale red lines represent a horizontal displacement towards the right side of the image plane and pale blue lines represent a horizontal displacement towards the left side of the image plane.

The comparisons between the drop flight trajectories in Figure 6 show the forces that act upon the ink drops after they are ejected from the printhead. There is a noticeable difference between the data collected in 1G and 0G. In the 1G environment, the drops deviated in both the right and left directions off of a straight line trajectory. There was also a large average horizontal displacement off of the normal in 1G, which shows that there are outside forces beyond the droplet ejection acting upon the ink drops on the Earth's surface.

However, in 0G the horizontal displacement from a straight line trajectory was much more uniform. During microgravity testing there was a lower average horizontal

displacement off of the normal which shows and isolated environment that will allow for more accurate results if all other aspects of the printer functions are optimized.

Drop Shape

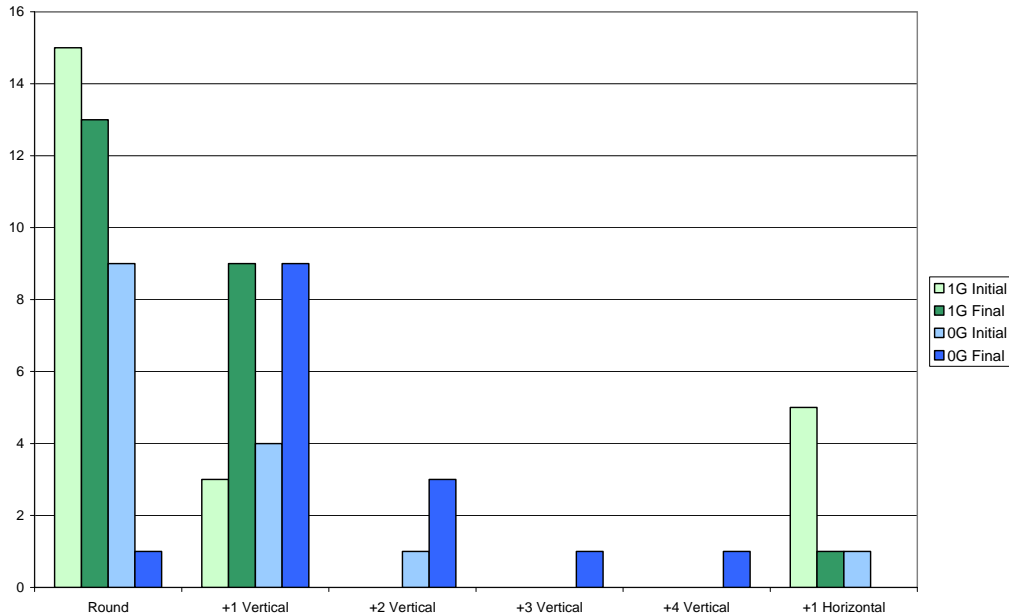


Figure 7. Initial and Final Drop Shapes in 1 G and 0 G.

Figure 7 represents the drop shapes as they entered and exited the camera's field of view. This shows the drops tendency to change shape from a sphere ejected from the printhead into ovular and teardrop shapes as they travel away from the printhead nozzle. The x-axis of the chart is the shape of the drops, showing whether it was round or ovular and in what direction relative to the printhead. In the 1G environment there was a greater tendency to remain in a spherical shape as compared to 0G. The ink drops imaged in 0G had a noticeable tendency to elongate in the vertical direction from the beginning of the frame to the end. This shows that there was some force acting upon the ink drops, potentially gravity. In the 1G environment, which allowed for longer drop flight times, the drops remained in a spherical shape.

Density

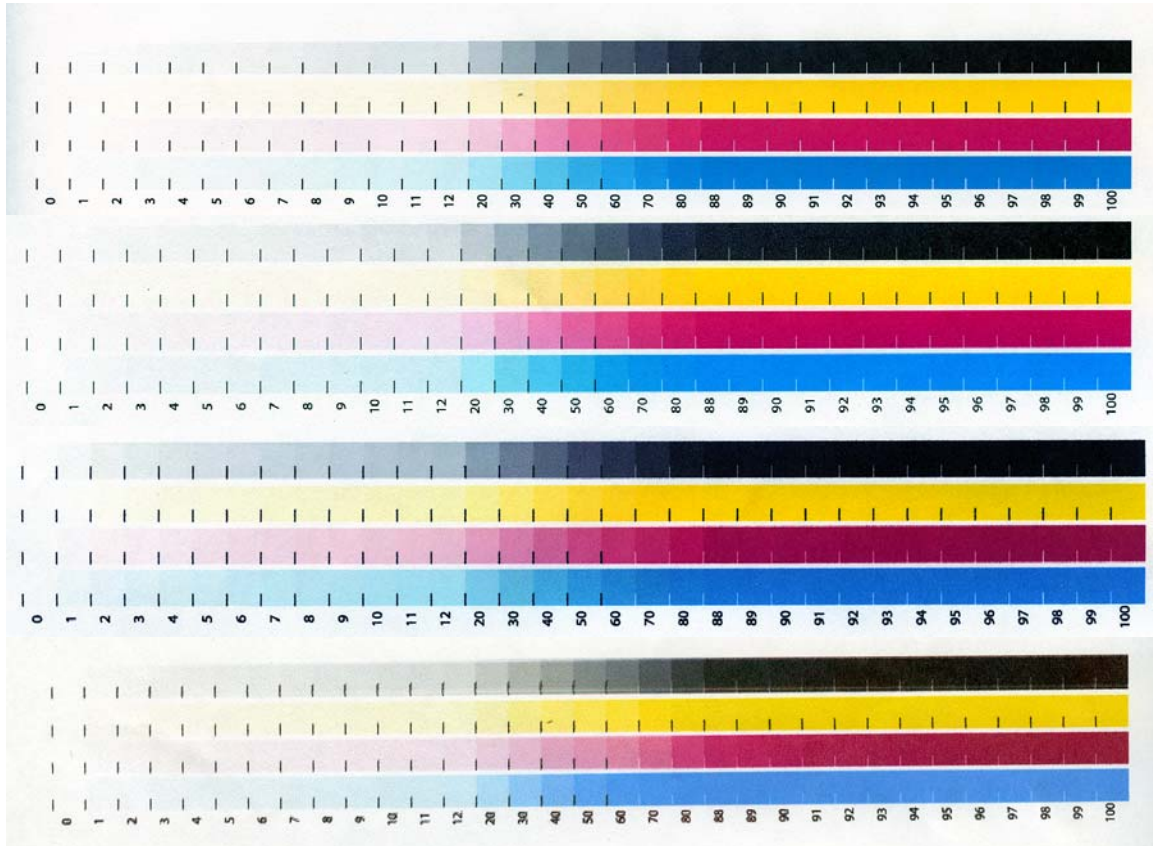


Figure 8. Density Test Target Scans. Top image is from the Kodak Easyshare 5100 printed in 1G the second image is from the same printer in 0G. Third image is from the Epson R280 printer printed in 1G the bottom image is from the same printer in 0G.

Printing the CMYK gradient test target in microgravity resulted in a decrease of print density for both printers. The change in density was approximately uniform across all colors. On average, the Kodak printer had a density of 0.11 less than the density of the control. The Epson averaged a density of 0.10 less than the density of the control. The reduction of patch coverage resulted in a reduction of density, indicating an even reduction in the amount of ink at all densities. A comparison of overall density levels between the two printers can not be made because the print density varies depending on the manufacturer's settings.

Resolution

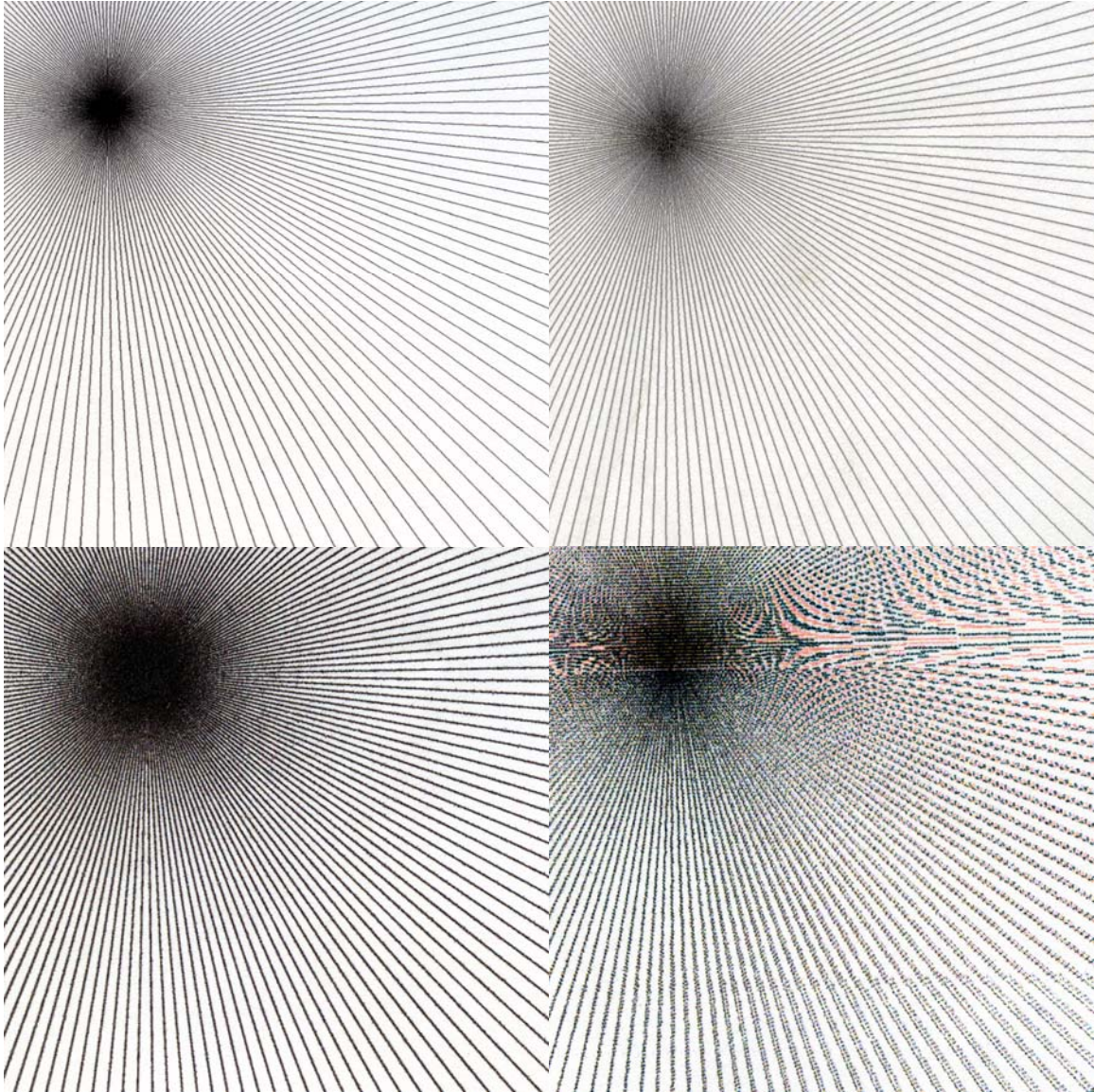


Figure 9. Resolving Power Test Target Scans. Upper left image is from the Kodak Easyshare 5100 printer in 1G and upper right is the same printer in 0G. Bottom left image is from a Epson R280 Printer in 1G and bottom right image is the same printer in 0G.

The Kodak printer displayed insignificant change between normal gravity and microgravity. The circle of good definition remained constant at a 1.2cm radius. The Epson printer produced a circle of good definition radius of 2.0cm in both environments, but suffered a registration error. The shift is noticeable in the Epson R280 in 0G (lower right image) when the magenta colorants are mis-registered horizontally but not

vertically, indicating an in-process skew. This registration error was at most 0.7mm in-process, visually distinct defect.

Fine Line Detail



Figure 10. Fine Line Detail Test Target Scans. Top left image was printed by the Kodak EasyShare 5100 in 1G. The bottom left image is from the Epson R280 printer in 1G and the same printer produced the bottom right image in 0G.

A fine line detail test target could not be produced during the flight for the Kodak printer. The Epson printer showed no horizontal displacement cross-process, resulting in no visible horizontal displacement of droplet path. The in-process line however, displayed registration errors and a directional shift shown previously in the resolving power test.

Registration

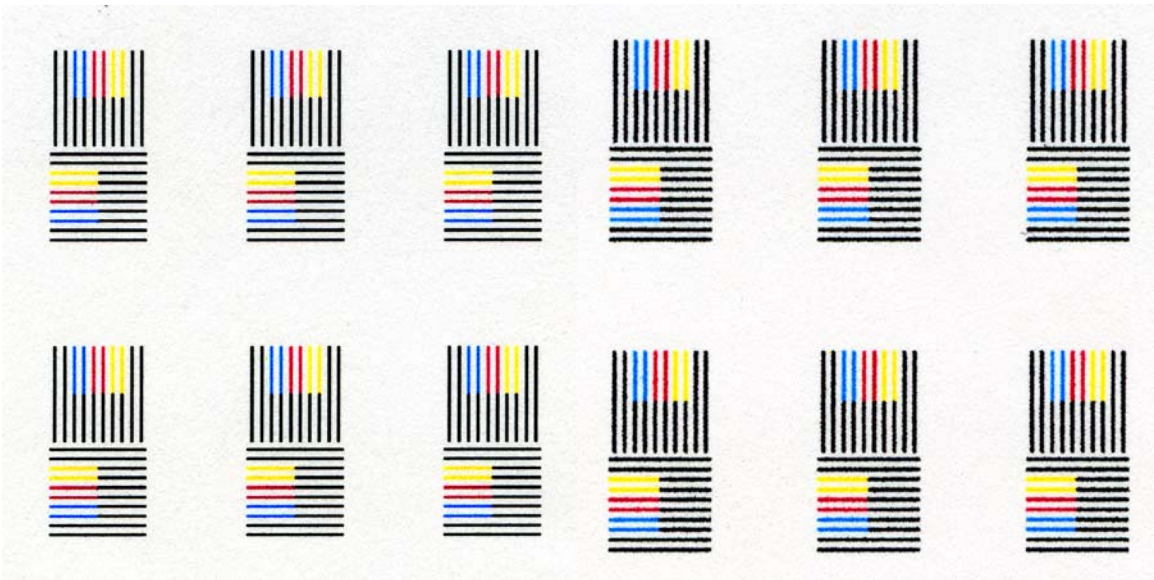


Figure 11. Registration Test Target Scans. Left image was created with the Kodak EasyShare 5100 in 1G and the right image was created with the Epson R280 in 1G.

A color to color registration target could not be produced for either the Epson printer or Kodak printer in microgravity. Under normal gravity conditions no abnormalities are present, as illustrated in Figure 11.

Overall the results are positive in microgravity. Neither ink-delivery systems showed severe degradation of droplet size or density reduction. Neither systems had severe horizontal displacement of the droplets or reduction in resolution.

The only error was apparent during the Epson print tests. The noticeable in-process mis-registration was not caused by the piezo ink delivery system, a lack printhead performance would be more apparent in cross-process fine lines. Instead it is far more likely that during the microgravity timeframe the entire cartridge mechanism lifted or slanted away from the page, causing the drops to fire at an angle and causing the different colorants to travel different distances, therefore reaching the page mis-registered.

CONCLUSION

It is possible to achieve usable functionality of both Thermal and Piezo-electric printhead technology in a microgravity setting. Slight modifications must be made to secure the carriage and prevent unwanted movements. There were no detrimental changes in the ink-delivery system. Therefore it is likely that certain models of inkjet printers with more secure hardware are already able to perform in microgravity without alteration.

FUTURE WORK

Experiment Design Modifications

There are several necessary modifications that must be made to the overall experimental design to further the research started by this experiment. The high speed imaging must be changed so that the actual printhead nozzles can be imaged along with the initial drop trajectories. This will enable a greater understanding of the event that occurs to form and expel the ink drops and the relationship this has to print function and quality. In addition a, specially designed scale should be added to the image to aid in analysis of the high speed imaging. Ideally the ejection from the printhead and adhesion to the paper could both be captured in the same frame, which would provide the most insight into drop characteristics in microgravity.

Another alteration would be to enclose the printhead being tested in a pressure controlled container. This would alleviate any outside forces from altering the drop trajectories. Specifically, the effect of air currents which caused adverse effects and unusable data must be eliminated.

It would also be useful to employ an accelerometer and IRIG time system. This would provide synchronization between the high speed digital camera and printer test-

targets. This would allow for an understanding of exactly what events occurred at what time and what forces would be involved. Doing so would remove the speculation of what images correlate to which section of the test target.

Suggested Printer Design Modifications

The main modifications to the printer revolve around the need to have stability of the printhead carriage as it moves back and forth in the device. Any unwanted movement resulted in improper registration and a lack of accuracy of drop placement. Since the technology is not being utilized as a document creation device but a precise placement tool this is the primary concern for a inkjet technology device designed for microgravity. Two rails should be used for the printhead carriage with either a fixed height or a sturdy vertical adjustment to accomplish this.

The open paper tray and other removable components must be replaced for enclosed equivalents. This ensures that the paper won't float around and that it will load consistently without human interaction. The output from the printer must have an enclosed compartment as well so that the output remains in tack in a secure location.

A partially pressurized ink delivery system should be used in microgravity environments. This can be accomplished with a combination of foam-filled reservoirs and a low-pressure ink cartridge to ensure constant ink-delivery. This is a precaution to ensure ink delivery and prevent unnecessary wear on the printhead components, as there were no adverse effects observed during microgravity on ink delivery. A sealed ink-bag with a low positive pressure below 2 psi would ensure this. A more complex system could include the use of removable ink revisions and a pump to ensure a constant supply of ink.

It would be ideal to increase the velocity of the drop ejection to the absorption threshold of the substrate being printed on to gain better results. If the speed was altered to the point just before the ink splashed the flight time would be decreased, which would decrease the time in which outside forces would act upon the ejected drops. This could potentially result in higher output quality from the printer.

ACKNOWLEDGEMENT

We would like to thank Kodak and T-Slots for their assistance in our efforts. Special thanks also go to Andrew Davidhazy, Dr. William Destler, and Mr. and Mrs. Howard Lyon for their generous donations.

REFERENCES

1. Cho, Hanjin., Parameswaran, M., Yu, Hua-Zhong. "Fabrication of Microsensors Using Unmodified Office Inkjet Printers." ScienceDirect. RIT Wallace Library., Rochester, NY. October, 2007 <<http://www.sciencedirect.com>>.
2. Cooley, Patrick., Wallace, David., Antohe, Bogdan. "Applications of Inkjet Printing Technology to BioMEMS and Microfluidic Systems." Microfluidics and BioMEMS SPIE Vol. 4560 (2001)
3. Hayes, D.J., Wallace, D.B., Chen, T., Cox, W.R. "Ink-jet printing in the manufacturing of electronics, photonics, and displays." Nanoscale Optics and Applications SPIE Vol. 4809 (2002)
4. Ilkhanizadeh, Shirin., Teixeira, Ana I., Hermanson, Ola. "Inkjet Printing of Macromolecules on Hydrogels to Steer Neural Stem Cell Differentiation." ScienceDirect. RIT Wallace Library., Rochester, NY. October, 2007 <<http://www.sciencedirect.com>>.