The Daisy Wheel Story

Written by:
Michael Weisberg and George Comstock

November 30, 2016

CHM Reference number: X8123.2017

Part I
George Comstock, Diablo Systems co-founder, summarizes the backstory of Daisy Wheel Printers:

"In 1969, my partner Andrew Gabor and I were seeking VC money for developing a single-platter, cartridge loading disk drive. On a flight returning from another fruitless presentation, I asked Andy whether the unique digital-servo head positioning technology he was planning for the disk drive could position a daisy print wheel with sufficient speed and accuracy for a serial impact printer.

This thought had jumped to my mind based on some studies we had done at Friden in 1966-67 focused on the Fred P. Wilcox daisy wheel-based police car printer. His basic problem had been misunderstanding the true nature of the spoke dynamics as the character is printed, leading to an unacceptable level of wheel failure.

So I was prepared with an answer when Andy asked, "What performance would it need?"

I replied, "At 30 char/sec of Letter Quality Printing, if you could stop a daisy wheel's spin with the type face stationary in its printing position, we will have solved the spoke breaking problem, and our product will have double the IBM Selectric Typewriter's advertised speed. It will take the world by storm."

After half an hour of back-of-the envelope figuring, he said, "YES, I can do it with a safety margin of 30% to 45%!"

When presented to Bill Draper, Sr. Partner at Sutter Hill, he needed only a couple of weeks to line up the $1.5 million required to start the now two-product company.

We opened the doors for Diablo in August 1969 in Hayward, CA.

Was it pure hutzpah to think we could create a line of disk drives and a line of printers in 3 years? IBM had started work after WWII, taking fifteen years and fifteen million dollars to develop just the Selectric golf-ball typewriter!

The first Diablo Disk Drives shipped in Dec 1970. They dominated the OEM market for a decade!

In fall 1970 when the drive design was finished, Andy focused his attention on the Daisy Wheel Printer, starting with an IBM 1130 computer for checking his earlier estimate and settling on the dimensions of the Wheel.

In August 1972, Diablo's profitable prior 12 months sales were $5.4 million, all from the disk drives, and Xerox acquired Diablo for $30 million because of its interest in the Daisy Wheel printer.

Diablo's operations continued in Hayward as an OEM supplier, with Xerox's OPD (Office Products Division) in Dallas adopting our technology for their Word Processors.

Diablo "HyType" printers began shipping in March 1972 at an OEM price on the order of $1,000 each in modest quantities. By the end of 1973 printer revenues were surging ahead of the disk drive revenues. The Diablo Model 630, introduced in 1976 with Mike Weisberg's new very low cost, extremely durable, print wheel, became the market's undisputed favorite, bar none (story follows below)!

Its developing competition is exemplified by:

The DEC LA36, introduced in 1974, was a 5 x 8 dot matrix impact printer with a 132 column print line printing at a rate of 60 poor-quality characters/second.

In 1974, Qume's founder left Diablo and, in 1975 announced their clone of the HyType printer. In 1978, Qume was acquired by ITT for $165 million, making Lee a VP in charge of ITT's new OPD. A few years after that, he had left ITT and was reported to have repurchased the Qume trade mark from ITT for $20 million.

HP introduced the first laser printer for IBM compatible personal computers in May 1984. It was a 300-dpi, 8 page per minute printer that sold for $3,495, reduced to $2,995 in September 1985. They had very high print quality, and electronic type fonts stored in the printer's own memory.

IBM's Selectric brand was retired in 1986 because of the dominance of daisy-wheel printers and Laser Jets.Epson released the MJ-500 inkjet printer in March 1993, in 1994, the first high resolution color inkjet printer (720×720 dpi).

By 1983 Diablo's printer sales were peaking, and their printer supplies annual revenue surpassed that of the then-declining revenue from new OEM printer sales. Supplies sales revenue peaked by1986, and persisted as a profitable business for another 10 years. Diablo's total revenues had reached about $250 million annually at the peak.

I was told later by a Xerox executive that Gabor's two relevant patents, #3,663,880, filed in 1970 and #3,954,163, filed in 1974, were earning more royalty dollars for Xerox than its copier patents!"

Part II

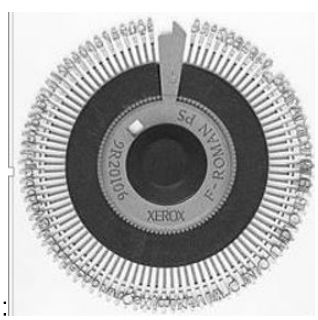
Mike Weisberg reveals how his team perfected the Daisy Print Wheel:

"I had joined Xerox Electro Optical Systems in Pasadena as a manufacturing engineer in 1967, moving up to manufacturing manager in 1968.

In early 1974 I became employee #8 of Xerox's new Office Products Division in Dallas as a materials and process specialist tasked with improving the performance of the company's daisy wheel print elements. Immediately I saw serious problems with the fiberglass filled nylon print wheels coming from sole-source Charactêres, SA, a company based in Neuchatel, Switzerland.

They met all of Xerox/Diablo, Xerox OPD, and Qume daisy print wheel needs. They created font designs and tooling, through to manufacturing the wheels. Charactêres insisted on retaining ownership of all tooling, even charging a royalty on each wheel sold despite our having paid for the tooling in the first place!

The current print wheel was failing under high impact pressures due to its use of a soft Nylon material. I created a unique design using a steel hub and with hard-chrome plating for extra wear resistance shown here:



:

Xerox Metalized Wheel

This new design became the standard print wheel for the Xerox OPD line of word processors. The Swiss firm continued as a subcontractor for OPD, working to our designs and specifications. The new wheel, covered by Xerox's US Patent #4,037,706, filed on May 6, 1976, was almost indestructible, yielding 500 million or more impressions.

In 1975, I moved to Hayward, California, as manager of supplies engineering at Diablo. I championed a "Skunk Works" to be co-located in a building withAndy Gabor's "Skunk Works" where staff were inventing the Quiet Typewriter, a new Xerox product.

I reasoned that keeping outsiders out was going to give us better protection in our impact-printing market niche than relying on the slow process of patenting and defending inventions.

Peter McCullough, the chairman of Xerox, paid a visit to Diablo in Hayward in 1980 when our print wheel manufacturing was rolling. He insisted on a visit to the Skunk Works and was overwhelmed with what we he saw. Immediately he decided Xerox should make a short PR documentary demonstrating their superiority in this field. [Editor's note: This film is available on the CHM YouTube channel: https://www.youtube.com/watch?v=VBTuKa2JwMA]

Our secret was out. But by then we had a sufficient lead to maintain our position until laser jet and color inkjet printers took over.

In the skunk works operation, my strategy was to perfect a long-life print wheel, manufactured in-house, capable of printing six-part forms and having a manufacturing cost far lower than Charactêres' pricing.

I hired staff, including mechanical engineers, graphic artists, machinists, tool and die makers, computer and software engineers, draftsmen, photo techs, test techs and equipment maintenance techs. Total staff, including contractors, reached 50 people. Some significant milestones include:

Teaming up with a computer system integrator who helped us create an integrated CAD/CAM system, probably the first of its kind in private industry.

We equipped a machine shop and labs with advanced equipment doing things far beyond what Charactêres could do.

The diameter of our cutting tool faces were as small as 75 microns, about the diameter of a human hair, with 4 helical cutting edges ground into the bottom and side walls of the cutter head.

The development required many innovations to enable us to engrave 1/16" deep in tool steel: the engraving cutter was driven at 250,000 rpm by an air turbine and was cooled by a special cutting fluid derived from an automotive racing lubricant.

The engraving machine had a 3-axis air-bearing table accurate to plus/minus 1.5 microns, an angle indexer, roll control, and an overlaid spherical concave motion.

In a little over a year we were successful at implementing these advances. With tooling and molding under control, we moved to character details and font design for various languages.

We switched to a conical center gate design and ring venting which eliminated all molding flaws from the wheels, and permitted higher injection pressure for denser, fully-formed, consistent wheels.

We improved print quality, reliability and lifespan, along with providing quick response times for new custom-designed print wheels such as wheels for multiple languages and scientific symbols.The original Diablo fiberglass-filled nylon was replaced by a far stronger, clay-filled composition.

Engraving a new complex shape into our typefaces corrected several problems such as compensating for plastic shrinkage that left large letters sunken in the middle, leading to excessive flexing and short life. The sinking also tended to produce lighter print density in the center of such characters as "M," "W," "&," and "@," so we employed variable buttress angles plus microscopic profile changes on selected characters to strengthen them. Before we started our project, many wheels were lasting less than 500,000 impressions printing Standard English text. Periods and commas, were an order of magnitude worse than that.

With all these improvements we got 20 million impressions and more.

Charactêres' print wheel price to Diablo and Xerox was $5-6 each, while the new wheel's in-house manufacturing cost was about 10 cents each, liberating us from the Swiss!

With improved wheel quality, we saved further by loosening some tolerances in the print mechanism. Meanwhile, after-market suppliers were struggling to sell very poor print quality wheels. Diablo was providing the highest quality print wheels at a fair price.

We worked with the printer engineering department, studying print wheel and machine dynamics with a high-speed camera and strobe-based test stands. Our contributions improved machine speeds, print wheel dynamics, hammer energy tables, and reduced print wheel damaging printing conditions. My team also identified some long term reliability problems that showed up with a large population of aging printers in our life test lab.

I traveled, lecturing at all major US and European customers on how to improve print quality and reduce supplies costs.

The improvements came in all areas, from raw material specifications, to making the print wheel, to customer training. If it had anything to do with the printing process, my group got involved no matter where the issue originated. It was a systems solution not one magic fix.

The Diablo/Xerox Model 630 printer, incorporated all these advances, and preserved its major share of the OEM market.

The customer base was demanding superior world class print quality and the ability to print a six stack carbonless carbon paper set, while others wanted all of the above plus color graphics and pictures, with low noise.

The ink jet printer came to market at a lower price than daisywheel printers but the output came out damp, limp and pixellated, along with what was called “background noise.” This noise would appear as small ink droplets randomly scattered on the page. Additionally, the page was not crisp, bright or clean but could print graphics and photographs with lower noise and cost -- causing many of our customers to add ink jet printers to their offices or phase out the daisywheel printer entirely.

When the inkjet manufacturers changed their business model from selling everything at a profit to selling the printer below cost and making up the difference in higher priced supplies, the unit cost was irresistible to customers.The inkjet inks were aqueous dye-based and lacked bright color saturation, and were not light-fast or of archival quality. These printers were limited in print speed by how fast the page could dry.

Another type of inkjet printer emerged that used pigmented hot-wax ink. This technology was developed by a division of Tektronix, which was later acquired by Xerox. This hot-wax printer produced very bright images that rival color photographic images. Since they used molten wax ink that had to cool, their print speed was higher than aqueous ink printers. These machines never got as inexpensive as aqueous ink printers and are still in use. They are also the basis of the first 3D printers.

The laser printer was developed by Xerox PARC and originally appeared on the market as a $10,000 machine. It was a very fast, high-end printer and not as pixelated as ink jet output. It still had some “background noise” random toner fog on the printed page. The toners were based on Xerox toners and were high quality.

Xerox knew their laser printer was a high cost, complex device and their efforts were focused on cost reducing this big print engine, not ever entering the low-end market.

Canon took on the task of cost reducing the laser printer and was very successful in sweeping the low cost, high volume market. They approached the task from the ground up, only using the Xerox concept. This printer was sold under several brands including Canon and HP.

HP later acquired rights to manufacture Canon’s design. One of the high cost, difficult components was the print drum, which was coated with a rare earth material that was photosensitive. Canon developed a polymer-based photosensitive coating. It was not as durable as Xerox’s, so they made the print drum a component of the replaceable toner cartridge. Totally unheard of in the Xerox world.

Another high cost component was the polygon and motor assembly. Its original Xerox cost was in the $500 range and the current low cost polygon/motor assembly is below $10. This subsystem was used to scan the print laser across the photosensitive print drum.

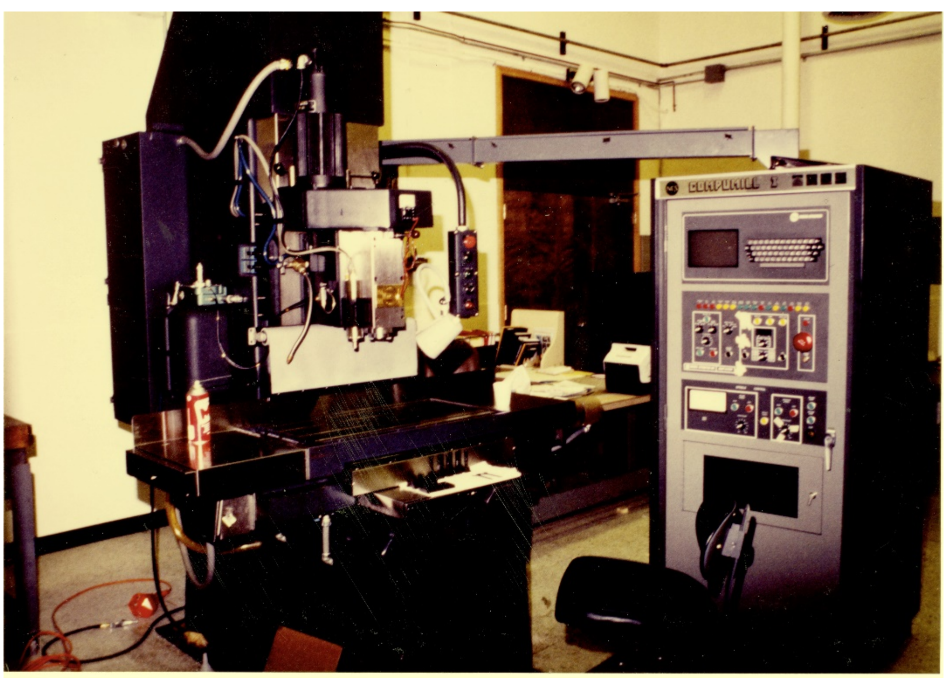
As of 2016, the inkjet printer (both aqueous and hot wax) and laser printer still hold almost the entire office and home market. Using the technology developed in inkjet printing, the 3D printing market has also exploded on to the market.

I left Diablo/Xerox in 1985 with the Daisy Wheel Supplies Business going strong, to start my own consulting business specializing in laser and inkjet technologies along with defense-related work. I later returned to Xerox PARC to do solar energy development along with display and ink jet development for 14 years, retiring in 2011."

M. Weisberg
Nov 30, 2016

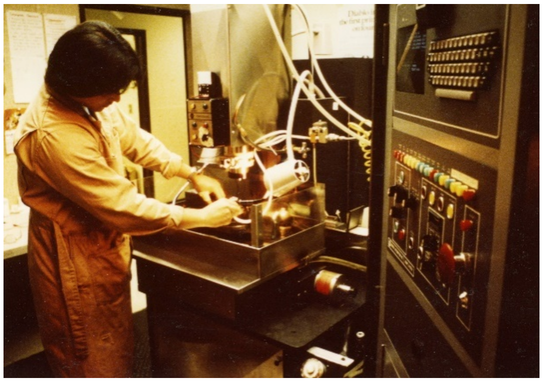
Tools Used at Diablo "Skunk Works"

1) CAD system generating tool path commands:

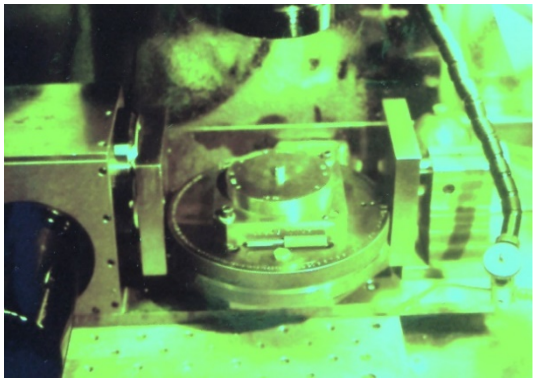


2) Eight cubic foot (2' x 2' x 2') working volume CAM machine.

3) 5-axis engraving machine - with a 6" cubic work volume,
1.5 microns positioning precision. Total time to make a typeface side of the tool is 4 hours vs. 3 months at Charactêres.

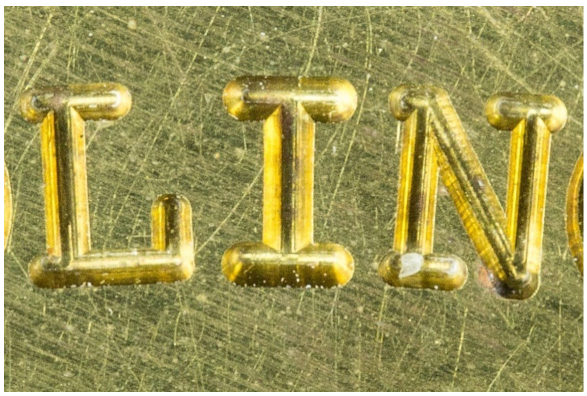


The 6" Setup

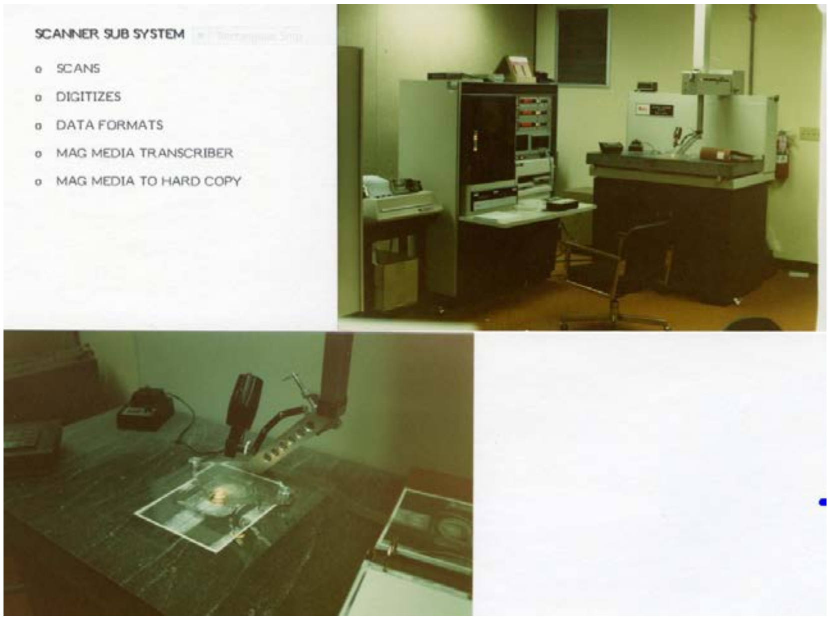


Close-up View

Here are close-ups of two of our engraved forms. The letters may look as though they project, but this is a photographic illusion – they are actually inset!



4) **3D digitizer**.



5) Custom built Swiss cutter grinder makes these four fluted spiral end mill 75 microns in diameter.

Tool used for engraving the sturdy letters. Shank diameter is 0.125”. Rotates at 250,000 RPM. Can you pick out the 30 micron long cutting edge at the very end of the tip?

6) **Photo lab capturing** any type set on any printing element or printed page and producing a set of 10X scale model photos in 2 hours.

7) **Collimated 1KW UV light source** for exposing photo polymer to form 10X engraving masters used to engrave the pad side of the mold. The UV source is a surplus 1KW Israeli tank search light that I built while at Xerox EOS along with 500 more.

8) **We also developed** our own collimated high pressure caustic wash out machine for the photo polymers.

9) **We established and maintained a bank of 50 production printers** that tested print wheels and ribbon 24/7.

10) **High speed camera**, several strobe stands and many high-powered microscopes.

