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WHY PAPER JAMS PERSIST

A trivial problem reveals the limits of technology.

By Joshua Rothman

Building 111 on the Xerox engineering campus, near Rochester, New York, is vast and labyrinthine. On the social-media site Foursquare, one visitor writes that it's "like Hotel California." Conference Room C, near the southwest corner, is small and dingy; it contains a few banged-up whiteboards and a table. On a frigid winter afternoon, a group of engineers gathered there, drawing the shades against the late-day sun. They wanted to see more clearly the screen at the front of the room, on which a computer model of a paper jam was projected.

The jam had occurred in Asia, where the owners of a Xerox-manufactured printing press were trying to print a book. The paper they had fed into the press was unusually thin and light, of the sort found in a phone book or a Bible. This had not gone well. Midway through the printing process, the paper was supposed to cross a gap; flung from the top of a rotating belt, it needed to soar through space until it could be sucked upward by a vacuum pump onto another belt, which was positioned upside down. Unfortunately, the press was in a hot and humid place, and the paper, normally lissome, had become listless. At the apex of its trajectory, at the moment when it was supposed to connect with the conveyor belt, its back corners drooped. They dragged on the platform below, and, like a trapeze flier missing a catch, the paper sank downward. As more sheets rushed into the same space, they created a pile of loops and curlicues—what the jam engineers called a "flower arrangement."

"It's the worst-case scenario," Erwin Ruiz, the leader of the paper-jam team, said. In the study of paper jams, Ruiz has found his Fountain of Youth: he is fifty but looks almost two decades younger. Born in Brooklyn, he grew up in Puerto Rico before going to graduate school in Rochester, where he is now a fixture of the city's wintertime indoor beach-volleyball scene. Wearing designer sneakers, hip-hugging maroon trousers, a trim plaid shirt rolled to the elbows, and elegant stubble, he began to pace in front of a whiteboard.

Bruce Thompson, the computer modeller who sat at the head of the table, had spent days creating a simulation of the jam. "We're dealing with a highly nonlinear entity moving at a very high speed," he said. On the screen, his wireframes showed a sheet of paper in mid-flight. He called up a shadowy slow-motion video made inside the press. "There's a good inch before the vacuum takes effect," he observed.

The team began to consider their options. The most obvious fix would have been to buffet the paper upward from below using a device called an air knife. This was off limits, however, because the bottom side was coated with loose toner. "An air knife will just blow the toner right off," Ruiz said. Another possibility was to place "fingers"—small, projecting pieces of plastic—where they could support the corners as they began to droop. "That might create a higher jam rate on different paper shapes," an engineer said—it could be a "stub point." A mystified silence descended.

A mechanical engineer named Dave Breed pointed toward the upside-down conveyor belt. "The vacuum pump actually works by pulling air through holes in the belts," he said. "So what is the pattern of those holes relative to the corners? Maybe there's no suction there."

On the whiteboard, Ruiz sketched a diagram of the conveyor belt—the V.P.T., or vacuum-paper transport—showing the holes through which the suction operated. "Optimize belt pattern," he wrote.

"If my understanding of air systems is right," Breed went on, "then the force that gets a sheet moving isn't really pressure—it's *flow*."

Thompson nodded, miming the pushing of air away from himself with his hands. "It's flow," he concurred.

"Could we somehow create more acquisition flow?" Breed asked.

By this point, Ruiz appeared to be vibrating. "Here's a stupid idea," he said. "Bernoulli!" Bernoulli's principle, discovered in 1738, entails that fast-moving air exerts less air pressure than slow-moving air. Because the top side of an airplane wing is curved, while the underside is flat, the air above moves faster than the air below, and the wing rises. "If you have jets of air shooting above the corners, the airflow will lower the pressure, and they'll lift," Ruiz said. Using the flat of his hand, he mimed the paper levitating like a wing.

"We could take the output from the vacuum pump and port it around to make it the air source for your Bernoulli," Breed said.

"Stupid idea No. 7!" Ruiz said, grinning triumphantly. The whiteboard now contained an elaborate diagram of rollers, conveyors, vacuum pumps, air knives, air jets, stub points, and fingers. "Jets on corners to lift with Bernoulli," Ruiz wrote. Outside, the wind howled. Lake-effect snow had begun to dust the parking lot. The engineers were aglow: conspirators who'd just planned the perfect crime.

Late in "Oslo," J. T. Rogers's recent play about the negotiation of the Oslo Accords, diplomats are finalizing the document when one of them reports a snag: "It's stuck in the copy machine and I can't get it out!" The employees in Mike Judge's 1999 film "Office Space" grow so frustrated with their jam-prone printer that they destroy it with a baseball bat in a slow-motion montage set to the Geto Boys' "Still." (Office workers around the country routinely reënact this scene, posting the results on YouTube.) According to the *Wall Street Journal*, printers are among the most in-demand objects in "rage rooms," where people pay to smash things with sledgehammers; Battle Sports, a rage-room facility in Toronto, goes through fifteen a week. Meanwhile, in the song “Paper Jam” John Flansburgh, of the band They Might Be Giants, sees the jam as a stark moral test. “Paper jam / paper jam,” he sings. “It would be so easy to walk away.”

Unsurprisingly, the engineers who specialize in paper jams see them differently. Engineers tend to work in narrow subspecialties, but solving a jam requires knowledge of physics, chemistry, mechanical engineering, computer programming, and interface design. “It’s the ultimate challenge,” Ruiz said.

“I wouldn’t characterize it as annoying,” Vicki Warner, who leads a team of printer engineers at Xerox, said of discovering a new kind of paper jam. “I would characterize it as almost exciting.” When she graduated from the Rochester Institute of Technology, in 2006, her friends took jobs in trendy fields, such as automotive design. During her interview at Xerox, however, another engineer showed her the inside of a printing press. All Xerox printers look basically the same: a million-dollar printing press is like an office copier, but twenty-four feet long and eight feet high. Warner watched as the heavy, pale-gray double doors swung open to reveal a steampunk wonderland of gears, wheels, conveyor belts, and circuit boards. As in an office copier, green plastic handles offer access to the “paper path”—the winding route, from “feeder” to “stacker,” along which sheets of paper are shocked and soaked, curled and decurled, vacuumed and superheated. “Printers are essentially paper torture chambers,” Warner said, smiling behind her glasses. “I thought, This is the coolest thing I’ve ever seen.”

There are many loose ends in high-tech life. Like unbreachable blister packs or awkward sticky tape, paper jams suggest that imperfection will persist, despite our best efforts. They’re also a quintessential modern problem—a trivial consequence of an otherwise efficient technology that’s been made monumentally annoying by the scale on which that technology has been adopted. Every year, printers get faster, smarter, and cheaper. All the same, jams endure.

Gutenberg invented his printing press around 1440; the modern paper jam was invented around 1960. During most of the years in between, jamming was impossible, because printing was done one sheet at a time. Traditional presses lowered inked type onto individual sheets of paper; their successor, the rotary drum, was hand-fed. In 1863, an inventor and newspaper editor named William Bullock created the Bullock press, which was fed by a single roll of paper several miles long. Bullock’s press revolutionized the printing industry by vastly increasing printing speeds. Sadly, in 1867 Bullock’s leg was caught in the press; it became gangrenous, and he died. There are jams worse than paper jams.

The Bullock press was one of the first presses with a paper path, but by today’s standards its path was simple. The most complex step, the composition of type, happened off-line; if a printer wanted to change the type, he had to stop the press to reset it. The holy grail of printing—a paper path that incorporated composition, and so could produce different pages, one after another—remained inconceivable. The creation of a miniature press, for use in offices, was an even wilder dream.

The solution was xerography, invented by Chester Carlson, the physicist co-founder of Xerox, in 1938. In xerography, static electricity quickly and precisely manipulates electrostatically sensitive powdered ink—a.k.a. toner. As the term “photocopier” suggests, a xerographic machine is less like a traditional printer and more like a darkroom. Using an early Xerox machine required placing an original under a glass pane, reflecting light off it onto a statically charged photosensitive plate, using the charged plate to draw toner from a tray, transferring the toned image to plain paper, and then melting the toner into the paper in a miniature electric oven.

(Between the charging of the plate and the ding of the oven, or “fuser,” each copy took around three minutes to make.) The Xerox 914, introduced in 1959, automated this process. Caressed by sultry secretaries in advertisements, it resembled an instrument console from the Starship Enterprise and shipped with a fire extinguisher, in case its heating elements set the paper alight; seven plain-paper copies per minute trundled through its paper path. Between 1960 and 1979, the 914 earned Xerox around forty billion dollars—funding, among other things, the construction of the corporate campus in Rochester, and jump-starting the development of the personal computer, at Xerox *PARC*, in California. (Xerox failed to capitalize on the P.C. revolution; recently, Fujifilm announced plans to acquire a majority stake in the company.) Today, not all Xerox printers are xerographic; many are ink-jets, which work by converting an image into a waveform, then using the waveform to control an ink nozzle. Almost all, however, follow the template of the 914 paper path: feeder, printer, fuser, stacker.

Jams emerge from an elemental struggle between the natural and the mechanical. “Paper isn’t manufactured—it’s processed,” Warner said, as we ambled among the copiers in a vast Xerox showroom with Ruiz and a few other engineers. “It comes from living things—trees—which are unique, just like people are unique.” In Spain, paper is made from eucalyptus; in Kentucky, from Southern pine; in the Northwest, from Douglas fir. To transform these trees into copy paper, you must first turn them into wood chips, which are then mashed into pulp. The pulp is bleached, and run through screens and chemical processes that remove biological gunk until only water and wood fibre remain. In building-size paper mills, the fibre is sprayed onto rollers turning thirty-five miles per hour, which press it into fat cylinders of paper forty reams wide. It doesn’t take much to reverse this process. When paper gets too wet, it liquefies; when it gets too dry, it crumbles to dust.

To a sheet of paper, a paper path is like a Tough Mudder—a multistage obstacle course that must be run in hostile conditions. With a hint of swagger, Warner walked me through the paper path of a hulking, truck-size iGen printing press (around a million dollars and a hundred and fifty pages per minute). “We start by sucking a sheet off the stack with vacuum feeders,” she said. “Then it travels along thirty feet of path at one thousand three hundred and fifty millimetres per second, changing speed and direction at accelerations reaching 3g.” In xerographic printers, she continued—she had to shout above the press’s vacuum pumps, which sound like a copier’s, but louder—“the sheets are charged with sixty-five hundred volts. In ink-jets, they’re soaked in liquid. Then we have to keep the image from shaking or wiping off.” Warner pointed to the back of the paper path, where the fuser was situated: a set of black rubber rollers heated to three hundred and eighty-five degrees. “It’s like wringing a shirt through an old washing machine,” she said, miming the motion with her hands. Later, she gave me a flowchart of the printing process; it featured a cartoon of a paper sheet, its mouth agape in terror.

Ruiz gestured down the length of the iGen, which resembled many copiers daisy-chained together. “The straighter the path, the less probability of damaging the paper,” he explained. For this reason, printing-press paper paths tend to sprawl horizontally. Office printers must be smaller, and so their paths must fold back on themselves, making a series of hairpin turns. “Think about being in a car,” Ruiz said. “The more turns you take, the more likely you are to get into an accident.” Contemplating the “tight radiuses” of office printers and their other daunting requirements—they must be quiet, cheap, and low-power, and “people without master’s degrees” must be able to clear their jams—Ruiz shook his head with parental indulgence. “For us, the smaller ones are more challenging than the bigger ones.”

The owners of printing presses have exotic tastes: they print on magnets, tinfoil, windshield decals. Xerox executives push the engineers to accommodate new kinds of stock, which might open new markets. But even plain office paper is full of hidden dangers. In the facility some engineers call the Paper Torture Lab—officially, it's the Media Technology Center—Bruce Katz, a soft-spoken paper technologist, examined some copy paper through a microscope. "The edge of a sheet of paper is really a third dimension," he said. Magnified, the edge resembles a snowy mountain range about four thousandths of an inch thick; the snow is paper dust, ready to drift into a printer's jammable gears. More expensive paper is more cleanly split, and its straighter edges have less dust-generating surface area. (They are also more likely to cause paper cuts.)

"Papers are not created equally," John Viavattine, the head of the Torture Lab, said. Some stocks generate excessive friction; others swell in the humidity. (In general, winter jams are more common than summer jams.) Sheets cut from the same forty-ream roll can vary in quality. At the center of the roll, paper fibres tend to arrange themselves in an orderly matrix; nearer the edges, they become jumbled. ("Think of logs going down a river; the flow is different at the edges of the river from down the middle," Katz said.) When heated, wood fibres contract; neatly arranged fibres contract equally in both dimensions, but badly aligned fibres do so unevenly, creating curl. The team from the Paper Torture Lab travels around the world, helping paper mills improve their product, and raising the quality of printer paper has played a major role in increasing print speeds. Still, even the highest-quality paper can be ruined by poor "paper handling." A half-used package of paper left to sit will grow damp and curly or dry and "tight." Reams of paper that are thrown around or kept in stacks can develop hidden curls that lead to jams.

At a hip Rochester restaurant called Nosh, Viavattine held the menu up to the light to assess its "flocculation" (the degree to which its fibres had clumped infelicitously together). He launched into a fabulous paper-jam war story. "I was asked to go to Chicago to visit the Chicago children's court," he said. "This was the mid-nineties, and a sales rep had put our printers—I think they were 400 Series—all over the court system. What was happening was, lawyers had to deliver certain court documents to the defense attorneys within a certain amount of time. Otherwise, the defendant was let go. And they were losing two out of three cases because of paper jams." He paused. "*Two out of three* defendants were *gone*—walking out the door—because of paper jams!"

Ruiz looked both fascinated and skeptical. "So, just so I understand—the repeated jams were delaying the process so much that—?"

"That two out of three times they would be late, and the defendant would be released!" Viavattine said. "And the problem was that they were using some off-brand, really down-in-the-dumps paper."

Ruiz turned to me with a twinkle in his eye. "Paper jams!" he said. "Now you know why the crime rate in Chicago went down."

Paper jams are a species within a larger genus. Traffic jams, too; so do tape decks, guns, and sewing machines. On humid days, voting machines jam, leading to recounts; over the aeons, tectonic plates jam, resulting in earthquakes. Ice floating down a river makes an ice jam; floating logs join up into logjams. (Before railroads transformed the transportation of lumber, logjams had to be addressed by "jam breakers"—experts who spotted and removed the "key logs" jamming up the river.) Jamming happens whenever something that's supposed to flow through a space fails to do so, perhaps because of overcrowding, or bending, or because its constant movement degrades the space through which it travels.

To some extent, jamming is what engineers call a “scheduling” problem. Picture a warehouse in which thousands of packages are travelling on intersecting conveyor belts. If the distance between the packages isn’t carefully maintained, they will collide and pile up, creating jams. Printer designers solve this problem by making the paper path smart. In a typical office photocopier, a host of small optical sensors monitor the location, angle, and speed of individual sheets of paper; if one gets too close to its neighbor, the rollers slow it down. Similarly, if a sheet is subtly off-angle, rollers on the slow side accelerate to straighten it; if the sheet is duplex—that is, printed on both sides—they adjust on the fly to insure that both sides are aligned. Printer engineers call this “agile registration.”

“The tolerances are very tight,” Ruiz said. “When you’re moving a box from here to there, if you’re off an inch it’s probably fine. But our images cannot be off by more than eighty-five microns”—a third of a thousandth of an inch—“or else they’ll be fuzzy.” Dave Gurak, a software engineer who designs printer control systems (“It’s his brain in there!” Ruiz said) thinks that the biggest jump in print speed happened in the nineteen-nineties, when cheaper microprocessors enabled paper-path designers to control scheduling at a minute level. Today, he said, “twenty-five thousand independent events happen per page.” In some printers, if a sensor in a paper tray detects a curl in a sheet the tray tilts to make up for it.

In the largest sense, jamming is a problem in a field called tribology—the study of friction, lubrication, and wear between interacting surfaces. In the nineteen-sixties, the British government asked an engineer named H. Peter Jost to investigate this subject; the 1966 “Jost Report” found that poorly lubricated surfaces—sticky ball bearings, rusty train rails, and the like—cost Britain 1.4 per cent of its G.D.P. (The term “tribology,” coined by Jost, comes from the Greek verb “to rub.”) The smooth functioning of the world depends on invisible tribological improvements. We rely on axles and gears that don’t grind, artificial joints that don’t stick, and hard drives that spin smoothly. Everything in a printer, likewise, must slide quickly and smoothly over everything else. Paper-path engineers work to accelerate a system that wants to get stuck.

Tim Slattery, a recent graduate of R.I.T., stood in Erwin Ruiz’s paper lab, inspecting a stacker—the final component of a large printing press. The owners of an identical machine hoped to print on thick, laminated plastic labels—the kind that might mark the price of an item in a big-box store. The problem was static electricity. “There’s so much static between the sheets that they levitate in the stacker,” Slattery said. I grabbed one, and had to make a concerted effort to push one sheet across another. “Our fluffers are constantly on, and we’re alternating our vacuum and air knife,” Slattery noted, but it wasn’t working.

“Instead of sliding the sheet, we’re going to corrugate it,” Ruiz said.

“Corrugating is when we put an intentional wave in the sheet, like in a piece of corrugated cardboard,” Vicki Warner explained. “It adds stiffness.” The plan was to corrugate the sheet lengthwise by running it over a line of rollers turning at variable speeds before “flying it” into the stacker. If a physical fix was necessary, a part might be 3-D-printed and installed, on-site, by one of the engineers. (On some occasions, printer-jam fixes are propagated through software updates.)

For a little while, I watched the team at work. Then I asked whether it would ever be possible to build a jamless printer.

“Well, we have printers on submarines, and also in space,” Ruiz said. “For the right amount of money you can build lots of redundant systems. So I think the answer is maybe yes.”

“I think the answer is no,” Warner said. “It’s paper. There will always be something unpredictable about paper that will cause a jam.”

Perfectly made synthetic paper might eliminate jams; it might also create unforeseen problems of its own. They stood, contemplating the problem, while the copiers whirred.

Xerox’s engineering campus can be a spooky place. Over time, the workforce there has dwindled. Warehouses contain pyramids of unused office chairs, and groups of copiers lurk in utility corridors like robots preparing to take over. (If the machines ever do rise up, jams may be what save us.) While we walked through mazes of cubicles, Ruiz thought about his future. He and his team are very good at their jobs—printing speeds keep rising, and jam rates hold steady or decline—and his promotion seems inevitable. But he loves paper jams too much to move on.

“Once, a cell-phone company tried to hire me,” he recalled. “They said, ‘You’re going to be working on the frames of the cell phones.’ I said, ‘What else?’ They said, ‘No, that’s it—the frames of the cell phones.’ That’s so boring! I don’t think they sell this job well enough. It’s, like, ‘Printers—I used to have one, it used to break.’ But, if you really want to learn more about everything, this is what you should do.” He grinned. “I like solving problems. Once you go to Toner Tower”—Xerox’s coal-black skyscraper in downtown Rochester—“life starts passing you by.” In the hallway, we walked past another engineer, who gave Ruiz a discreet fist pump. Ruiz turned to me: “Volleyball buddies!”

In one of the company’s climate-controlled testing chambers, the team working on the Asian dog-ear problem had gathered around a printing-press component identical to the one the customer owned. Earlier, conditions within the chamber had been set to eighty degrees and eighty-per-cent humidity, to match those at the customer’s facility; now the room was cooler and crowded with engineers. There was an atmosphere of convivial fascination. Everyone took a turn bending down to squint at the area that Bruce Thompson had represented so clearly in wireframe, on the computer.

“Can you see it?” Ruiz asked, sinking, with athletic fluidity, into a deep squat. He pointed to the small upside-down conveyor belt. “It’s tiny! Actually, maybe just one finger would do it.”

“Can you see the stripper fingers going?” Gurak asked. “Or is it just the air knife? We used to have the stripper fingers down there.”

“Yeah,” Ruiz said. “In theory, we could have stripper fingers pick up the lead edge, but then they might touch the belt, and that would be super bad.”

Someone turned the machine on, and paper began flowing through the path. The engineers drew closer, looking for the flower arrangement. ♦

An earlier version of this article incorrectly described the shape of airplane wings.