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## *Ultimate Guide to*

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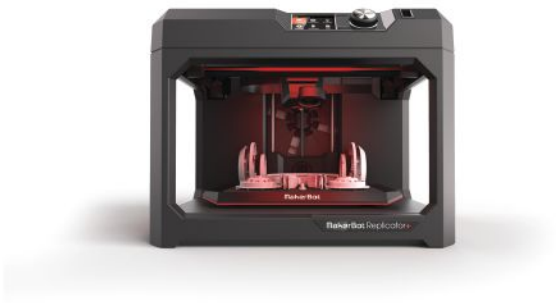
Vol. 54 December 2016/January 2017

# TACKLE YOUR BEST IDEAS HEAD-ON.

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December 2016/January 2017


SPECIAL SECTION

# Desktop Fabrication Guide 2017

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## FEATURES



**ON THE COVER:**
With the highest ever score in our rigorous testing, the Prusa i3 MK2 is the year's best new 3D printer.
Photo by Hep Svadja.



Christopher Garrison

## SKILL BUILDER



## PROJECTS



## TOOLBOX



## SHOW & TELL



Hep Svadja, Christopher Garrison





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Publisher, Todd Sotkiewicz, Maker Media, Inc., 1160 Battery St., Suite 125, San Francisco, CA 94111, Editor, Mike Senese, Maker Media, Inc., 1160 Battery St., Suite 125, San Francisco, CA 94111, Managing Editor, N/A, Maker Media, Inc., 1160 Battery St., Suite 125, San Francisco, CA 94111. 10. Owner: Maker Media, Inc.; 1160 Battery St., Suite 125, San Francisco, CA 94111. 11. Known bondholders, mortgages, and other security holders owning or holding 1 percent of more of total amount of bonds, mortgages or other securities: None. 12. Tax status: Has Not Changed During Preceding 12 Months. 13. Publisher title: MAKE Magazine. 14. Issue date for circulation data below: Oct/Nov 2016. 15. The extent and nature of circulation: A. Total number of copies printed (Net press run). Average number of copies each issue during preceding 12 months: 133,407. Actual number of copies of single issue published nearest to filing date: 127,399. B. Paid circulation. 1. 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# Make:®

"Here's a thing about 3D printing: it is exciting; then very, very boring; then it is exciting again."
*— Cory Doctorow, from "The Man Who Sold the Moon"*


EXECUTIVE CHAIRMAN & CEO
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dale@makermedia.com

CFO & PUBLISHER
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todd@makermedia.com

VICE PRESIDENT
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**Sonia Wong**
sonia@makermedia.com

## EDITORIAL

EXECUTIVE EDITOR
**Mike Senese**
mike@makermedia.com

PROJECTS EDITOR
**Keith Hammond**
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SENIOR EDITOR
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## CONTRIBUTORS

*What's something you wish you could make on your desktop or workbench, but can't (yet)?*

**Amanda Cole**
*Saylorsburg, PA (Irresistible Resistors)*
Since I tend to misplace things, it would be nice to print hardware and tools right on my desk to avoid having to scour boxes and bins.

**Christopher Garrison**
*Providence, RI (Photographer, digifab shootout)*
I'm excited to see where 3D printers are headed in the medical fields. If I could, I would print a new set of kidneys for my mother.

**Steph Grimes**
*Baltimore, MD (Robox review)*
I love the intricate and delicate nature of prints you can achieve with SLS printing and would love to see that technology brought to the desktop format.

**Ryan Priore**
*Wexford, PA (Prusa i3 MK2 review)*
Since I like to play with light, I wish that I could fabricate high-quality optical components such as lenses, fiber optics, and diffraction gratings on my desktop.

**James Austin**
*Oakland, CA (Make Your Own Mead)*
To download and print 3D tutorials of the tools and technical stages for complex blacksmithing projects. I'm currently developing a way to migrate this type of knowledge to the internet.

# Food Trucks, 3D Redemption, and Detecting Monsters


## THERE BE NO MONSTERS HERE

Readers Jonathan Lackman and Christian Puryear showed us their excellent modified "Monster Detectors" (Volume 52, page 62). It was the first Arduino project for both of them. Great job, guys!

## WINNING A 3D PRINTER

3D printing has changed my life. In 2012, I was recovering from cancer treatment and was physically unable to return to my previous job as a warehouse grunt for FedEx Ground. During that transitional time back into the workforce I saw a YouTube video on 3D printing.

There was no way I was going to be able to afford to buy one, so I set up a Google notification for "win a 3D printer." Most of what I was able to find were contests on Instructables, which had so many people entering, I had no chance. That's when "Project Remake" from *Make:* and Schick razors started. I didn't care about the [grand prize] trip to New York. I only cared about making it to the top 5 [the prize was a MakerBot Replicator]. Well, I did.

That MakerBot Replicator carried me from a warehouse grunt to an engineer in three years. It has provided me with a means to support my family. My children are growing up in a house where 3D printing is very much a part of our lives. I love 3D printing and I believe that I owe it to this technology to help it grow in the world. Thank you.

*—Clayton McIntyre, San Diego, California*

***Executive Editor Mike Senese responds:***
Congratulations, Clayton! We're pleased we've been able to help you boost your making skills to benefit your career and family. And we appreciate the brilliant tip for finding and winning contests. Keep up the great work.

## MAKE AMENDS

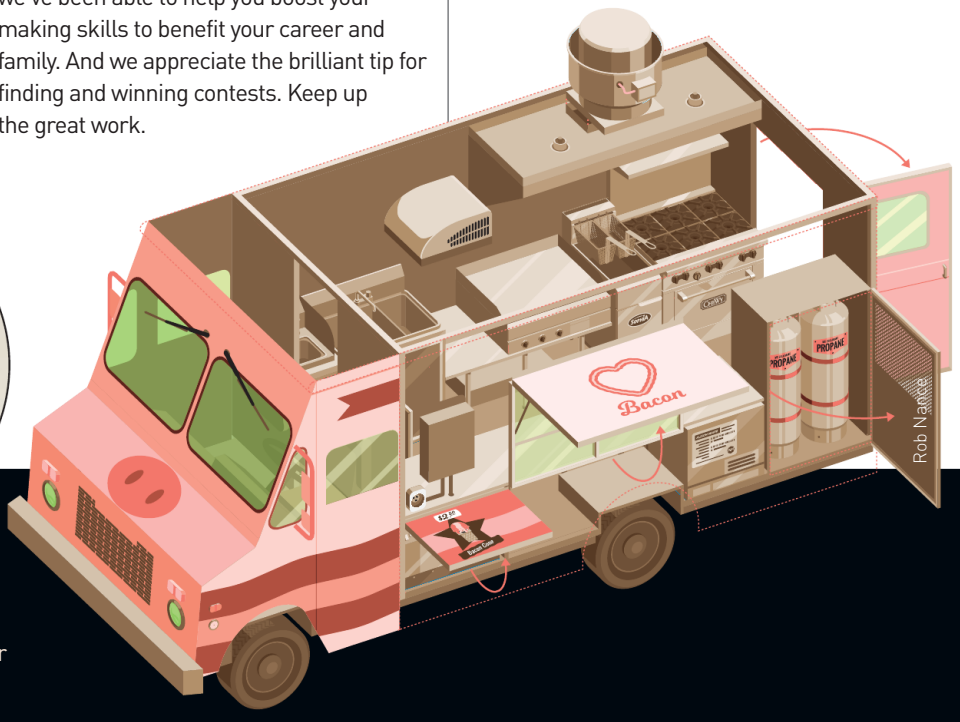
In "Maker to Market" (Volume 53, page 43) we mistakenly said that Dale Dougherty's book *Free to Make* would be available late 2017. It's actually available right now!

## BIGGER IS BETTER

As a food truck owner (Volume 53, page 28, "Meals on Wheels"), I would like to stress how important it is to get it right the first time! I also recommend going with more of everything, from generator size, propane tank size, water capacity size, cooler size, etc. The last thing you want is to realize down the road that you need more than you have.

*—Brandon Sarkis, Austin, Texas*

Sweet, souped-up Monster Detectors built by Jonathan Lackman (left) and Christian Puryear (right) help the little ones sleep at night.




Mike Senese, Jonathan Lackman, Christian Puryear

Rob Nance

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Handibot's Brian Owen is a stargazer. He wanted to use his camera in tandem with his telescope to take photos of what he was seeing, but the adaptor that came with his telescope didn't give him the kind of view he needed. Enter the Handibot® Smart Power Tool *Adventure Edition.*

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# Open Source Pushes On

**BY MIKE SENESE,** executive editor of *Make:* magazine

**DESKTOP 3D PRINTING'S STORY STARTS WITH A 2005 ENDEAVOR** by Adrian Bowyer to design a machine that could produce parts to replicate itself, suitably named the RepRap project. Through its open source mandate, others quickly joined in, iterating on the original concepts to design hardware and software that largely became the basis for most 3D printers we see nowadays.

Some of the core RepRap developers have become familiar names, including Josef Prusa, whose latest machine features prominently in our reviews this year, and Erik De Bruijn, who founded the highly respected printer company Ultimaker. But the most famous from this era is the MakerBot team: Bre Pettis, Adam Mayer, and RepRap pioneer Zach Smith. These three worked with RepRap's concepts and community to develop the first viable kit-built 3D printer, the Cupcake, which they launched in April 2009 and we put on the cover of *Make:* in 2010. They quickly became the face of the 3D printing movement.

As the hype of 3D printing grew, larger industrial additive fabrication companies — namely 3D Systems and Stratasys — made moves to get involved with the desktop market. 3DS introduced the Cube, a refined, consumer-friendly machine that looked good for education. Stratasys, meanwhile, purchased MakerBot, which had just controversially shed two founders and gone closed source with its Replicator 2, for $403 million in 2013. An arms war was underway, each side vying for the lion's share of a market that the media was fully hyping.

Fast forward through bizarre celebrity hires and unproven product releases and in just a few years the consumer division of both companies had fallen flat. 3DS abandoned its small Cube printer line, and Stratasys had to lay off a number of MakerBot employees while it reset internal expectations on the brand. And with that, the media flipped from hype to failure, focusing on floundering MakerBot as the representative of 3D printing.

As *Make:* founder Dale Dougherty notes in his new book *Free to Make*, however, "there were lots of tortoises" in the 3D printing arena. An industry of printer companies was quietly flourishing, many of them remaining largely committed to the open source ideals that the community established at its beginning. Again, Prusa and Ultimaker, but also LulzBot, SeeMeCNC, Printrbot, and others have made being open a viable business approach, all while creating reliable machines that get better results than ever, and selling more units every year.

Wall Street will always cycle through hype, but we at *Make:* see that 3D printing perseveres and will remain a solid pillar of our community. We're happy that the movement that helped launch desktop 3D printing is continuing its march, and bringing the rest of us along with it.

Hep Svadja

# MADE ON EARTH

## Backyard builds from around the globe

Know a project that would be perfect for Made on Earth? Let us know: *makezine.com/contribute*

# Exquisitely Twisted

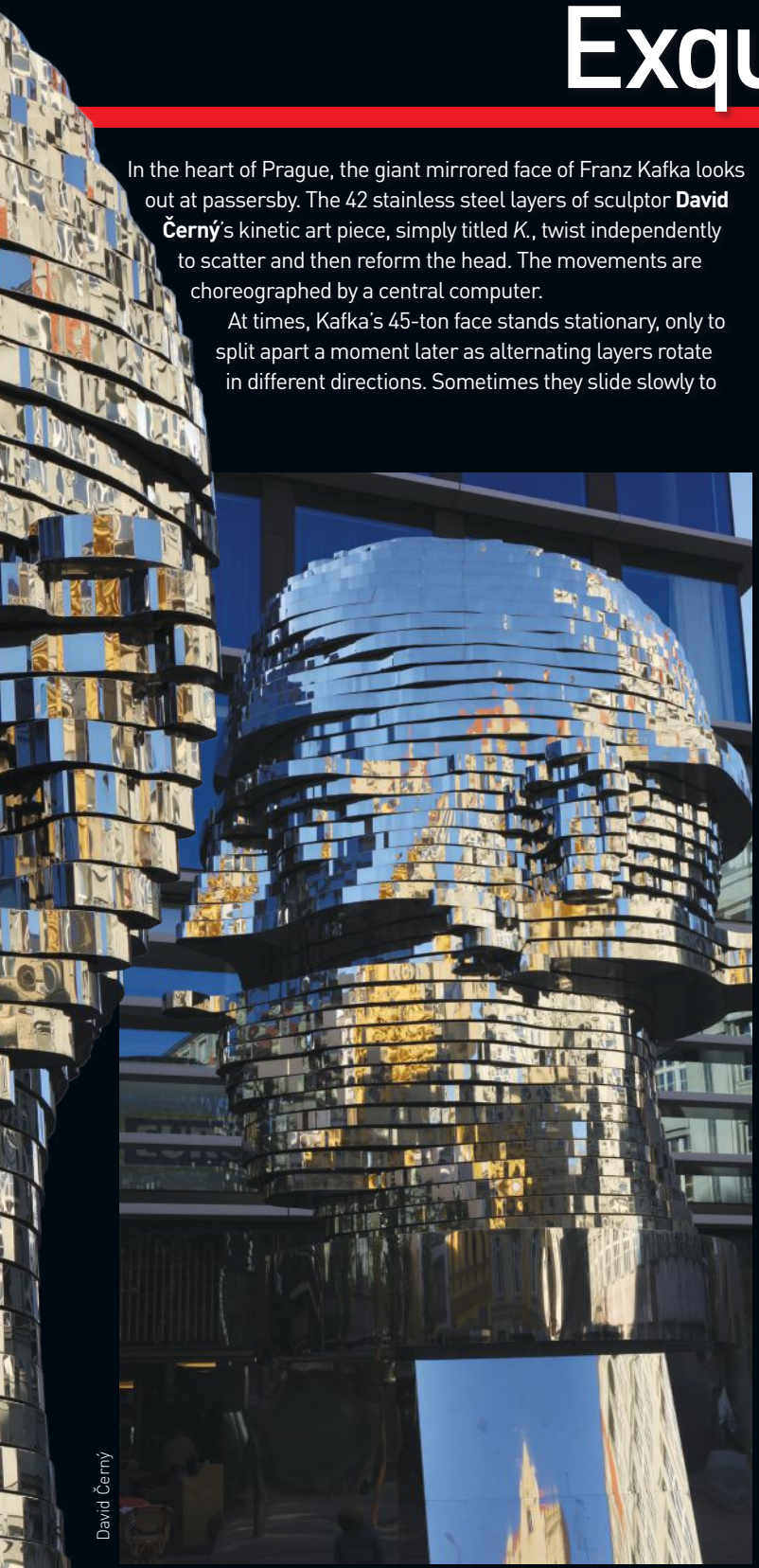
**WWW.DAVIDCERNY.CZ**

In the heart of Prague, the giant mirrored face of Franz Kafka looks out at passersby. The 42 stainless steel layers of sculptor **David Černý**'s kinetic art piece, simply titled *K.*, twist independently to scatter and then reform the head. The movements are choreographed by a central computer.

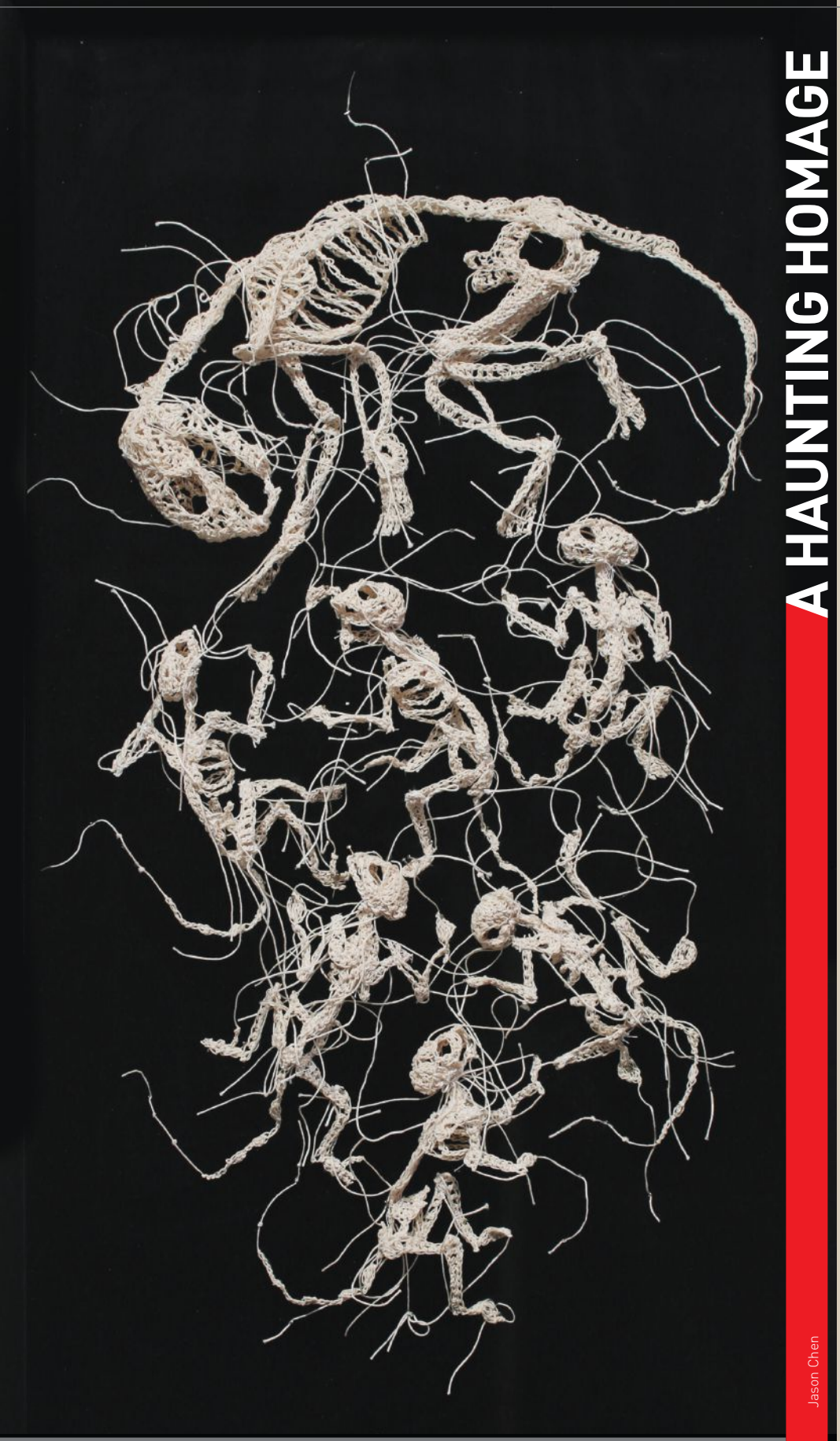
At times, Kafka's 45-ton face stands stationary, only to split apart a moment later as alternating layers rotate in different directions. Sometimes they slide slowly to one side, a single layer at a time, making a long curving smear of the author's nose. It's a fitting depiction for an author best known for genre-bending fiction and characters that undergo fantastic transformations.

"It's my destiny to create," says Černý, who has designed many other iconic and thought-provoking sculptures located across his native Czech Republic and throughout the world.

*—Lisa Martin*



David Černý



# A HAUNTING HOMAGE

CAITLINTMCCORMACK.COM

While this eerie sculpture may seem simply macabre, there's more to South Philadelphia-based artist **Caitlin McCormack's** crocheted figurines than what's present. Yes, McCormack sculpts animal skeletons with string and glue — but there are also memories, there are empty spaces, there is a family legacy of craftsmanship, and all the ways that these things change and reconstruct themselves over time.

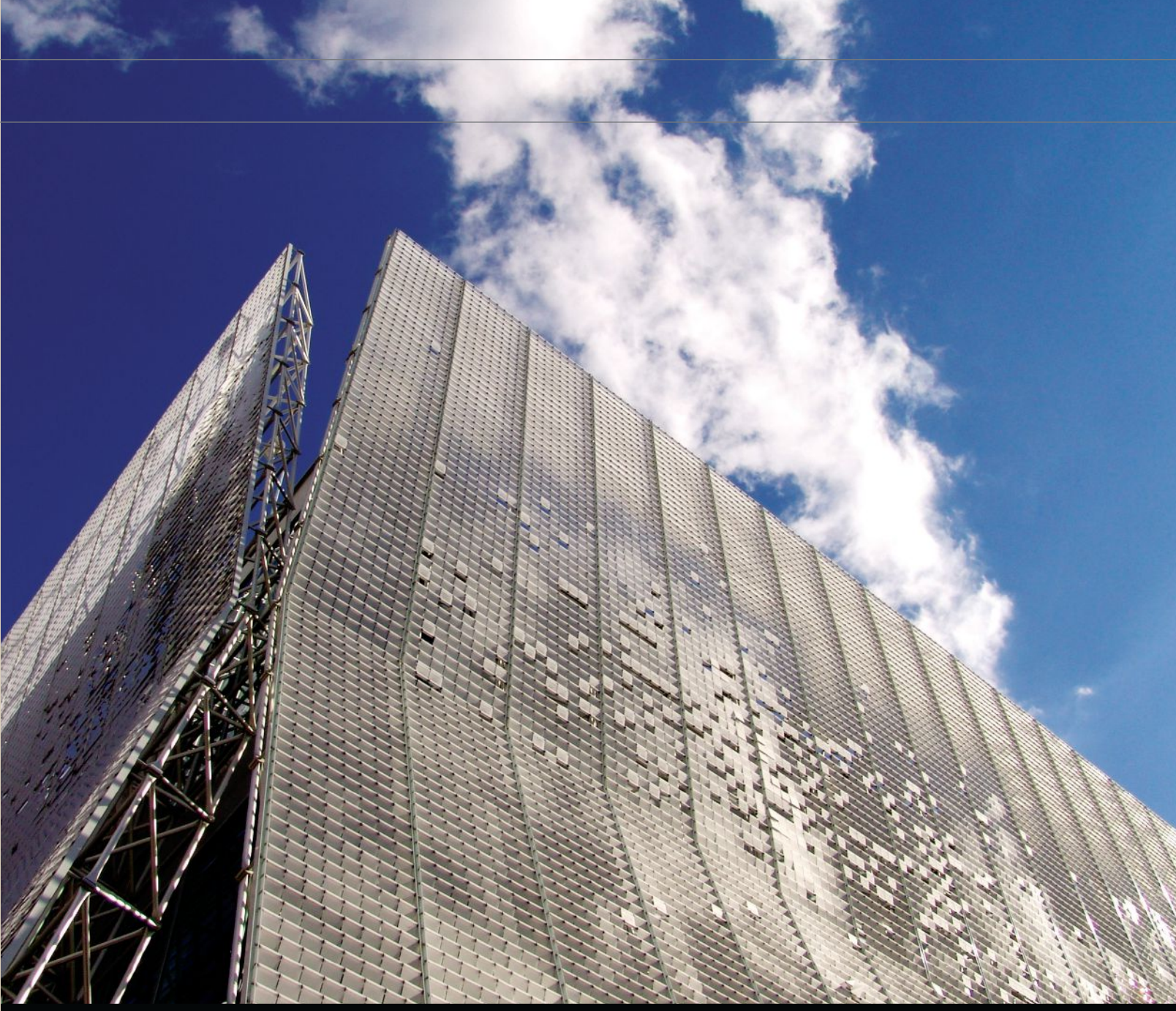
Since 2010, McCormack has been crocheting animal skeletons with cotton string, using a slurry of glues to stiffen them. "The animal forms that I construct all correlate with specific memories," she says. After her grandparents passed away — a talented crocheter and bird carver, respectively — McCormack decided that "it would be fitting to create a synthesis of their two crafts, by using my grandmother's ancient, worn, and stained cotton string to construct what could be viewed as the fibrous innards of a carved, wooden bird."

She crochets each individual bone with a tiny hook, dredges it in the slurry, and repeats. Then she sews the bones together, often positioning and pinning them to black velvet like a specimen. Although she studies references, McCormack prefers to form her pieces purely from her own biased, imperfect memory. In this way, she reinforces "the ways in which matter can simultaneously consist of both substance and nothingness. The way our memories change over time, and the manner in which all things inevitably crumble and eventually reconstitute themselves in numerous, and sometimes unforeseen ways. [Those] might be the things that inspire me most of all."

*—Lisa Martin*

Read the full interview online at makezine.com/go/macabre-crochet.

Jason Chen



Courtesy of Ned Kahn

# ELEMENTAL ACTUATOR

NEDKAHN.COM

At first glance, many of environmental artist **Ned Kahn's** large-scale, wind-inspired installations appear to be gigantic digital displays programmed to show perfectly flowing abstract designs, ever-changing in subtle and unpredictable ways. Upon close inspection, these "displays" are anything but digital, comprised of a multitude of perfectly geometrical and identical pieces of metal or plastic meticulously mounted to a grid with enough wiggle room to respond to the gorgeous whimsy of one of Kahn's favorite collaborators: the wind.

Take, for example, one of his smaller pieces, the 25'×110' *Chain of Ether*, installed on a building façade in San Diego. Precisely 3,960 squares of 9"×9" flowing aluminum "fabric" hang neatly on rods, actuating the invisible patterns of the wind.

As if recognizing that the wind demands larger and larger canvases, Kahn's *Articulated Cloud* (pictured above) encases the entire building at the Pittsburgh Children's Museum in translucent plastic squares hung on an aluminum frame. Depending on the weather, the building appears to be engulfed in a digital cloud.

Though his works are globally acclaimed, he's always credited his invisible collaborators: "Most sculptures are a celebration of the skill of the artist. You look at any art magazine, and the table of contents is all names. You look in a science magazine, and the table of contents is all phenomena. In the art world, it's all about the artist's cleverness or their mastery of certain media. In the things that I make, even though I've created the physical structure, it's really not me that's doing the sculpting. It's something other than me, something beyond me, something larger than me."

*— Goli Mohammadi*

# ITTY-BITTY BEEST

JEREMYCOOKCONSULTING.COM

After seeing Theo Jansen's walking Strandbeest creatures a few years ago, I decided to build my own. Jansen had already done all the hard work of figuring out the linkages that power his PVC contraption, so all I had to do was scale it and assemble it with wood instead of PVC and attach a motor ... Or so I thought.

Three years and four 'beest iterations later, I came up with something quite a bit smaller than Jansen's. Not only can it walk via remote control and two motors, but it can also observe its environment via a turret-mounted GoPro camera. Because of this, I can drive it in first-person view. Joachim Haas, whose similar walker was featured in the January 2016 issue of the German edition of *Make:*, designed a gear train concept that was extremely helpful to building a reliable version.

I call this little one-foot-tall contraption the FPV StrandMaus, or "beach mouse," as a small-stature homage to Jansen's "beach beast."

The first two 'beests that I built were closer to the size of a golf cart, but due to various issues with weight, friction, and unsuitable motors, they never walked. The third 'beest (and the first that I would call a 'maus) was even smaller than what's pictured here, but didn't feature bearings or the same gear train setup. Though it walked for a limited time, I soon scaled it up to the successful FPV StrandMaus, which I CNCed out of ¼" MDF.

*—Jeremy Cook*

Jeremy Cook

# UNDER SUSPICION

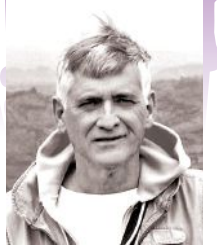
## Makers beware: Most airport and TSA personnel don't know how to evaluate homemade electronics

*Written by Forrest M. Mims III*

Star Simpson was an electrical engineering student at MIT in 2007 when she visited the baggage section of Boston's Logan International Airport to meet a friend. Instead, she was arrested at gunpoint, placed in handcuffs, and put in a jail cell. Her offense? Star's sweater featured a DIY light-up star made from 11 green LEDs and a 9-volt battery cemented to a solderless breadboard. A plastic rose she made for her friend was suspected of being an explosive.

Airport security is supposed to protect us from authentic terrorists, and Star's LEDs and plastic rose certainly didn't earn her such harsh treatment. Even though the police quickly determined her LED star was harmless, Boston's judicial system took a year to drop a "hoax device" charge against Star, a violation that requires an intention to alarm others that never even entered her mind. She was sentenced to a year of probation for "disorderly conduct" and required to write a public apology and do 50 hours of community service.

I've not (yet) been arrested in airport security. But Star and I are kindred spirits, for I've also experienced rough treatment at airports when my carry-on bag is crammed with electronics (Figure A). Other makers can learn a valuable lesson from our experiences.



**FORREST M. MIMS III** (forrestmims.org) an amateur scientist and Rolex Award winner, was named by *Discover* magazine as one of the "50 Best Brains in Science." His books have sold more than 7 million copies

## CHOKED BY AN AIRLINE CAPTAIN

While checking in for a flight several years before 9/11, I made the mistake of telling a check-in agent that I was planning to measure the water vapor outside the aircraft with a homemade near-infrared hygrometer. This alarmed the agent, who quickly called her supervisor. After the supervisor grilled me, she called her supervisor, who told me that the captain would have to approve my presence on his aircraft. She then escorted me through the checkpoint without even inspecting my carry-on bag.

When we reached the end of a very busy corridor, the security boss firmly ordered, "Wait here while I find the captain." After waiting a few minutes someone suddenly came up behind me, placed me in a chokehold, dragged me toward a wall and shouted "You're going to do what on MY AIRPLANE!?"

It's difficult to speak while being choked, but I managed to gurgle: "If—you—let—go—of—my—neck—I'll—tell—you." The assailant slowly released me, and I turned around. The man was shorter than me, built like a football player and wearing the uniform of an American Airlines captain.

"I'm going to measure the water vapor outside the airplane," I said. The captain cocked his head slightly and sounded genuinely curious when he asked, "How are you going to do that?"

I retrieved the water vapor instrument (Figure B) from my bag and handed the captain the palm-sized device and explained how it worked.

Fascinated, the captain said, "Wait here; I want my co-pilot to see this." When the co-pilot arrived, the captain enthusiastically repeated my description of the instrument. He then asked, "How can we help you during the flight?"

## THE SWISS STYLE OF PRACTICAL SECURITY

During a flight from Switzerland to New York, a flight attendant became worried about the water vapor measurements I was making through a window and demanded that I give her my instruments. I did, along with a brochure for the Rolex Award I had received in Geneva a few days before for my ozone research.

After visiting the cockpit, she returned with a smile and said the captain had invited me to the cockpit. I spent 20 minutes in the jump seat talking with the captain about the plane, the ozone layer, and a Concorde that flashed by on its way to Europe.

## "BULLETS" IN BRAZIL

While waiting to board a plane in Brazil, armed security guards called my name. Then they drove one of my checked bags and me to the remote bomb disposal section of the Sao Paulo airport and told me to unlock the bag.

Their x-ray equipment had detected a homemade photometer fitted with light sensors installed in gas couplers that resembled bullets. After I showed them how the device worked, the relieved guards drove me straight to the plane.

## POST-9/11 AIRPORT SECURITY

After police were called when I was going through security at San Antonio International Airport and after major problems going through security in Kona, Hawaii, I finally realized the obvious: Most people have no idea how to evaluate homemade equipment. Some are terrified by exposed wires and circuit boards, maybe because of bomb scenes in movies.

So I gave up. Now my carry-on bag is only half stuffed with electronics; the rest is shipped ahead via FedEx.

As for the airport security officers who have hassled me over the years, they are charged with protecting us from terrorism. They have a responsibility to carefully inspect anything unusual passengers might be carrying, and you and I have a duty to cooperate with them. So far they haven't arrested me, and they don't arrest children wearing shoes with flashing LEDs. But they went too far when they arrested Star Simpson after they determined that the LEDs on her sweater were harmless.

## GOING FURTHER

You can learn much more about Star Simpson's misadventure with airport security from her story in *Make:* (makezine.com/2008/11/11/star-bust) and her interview in Boing Boing (makezine.com/go/star-simpson-interview).


My carry-on bag loaded with instruments.


Near-infrared hygrometer used on the Chicago flight whose captain choked me.

Forrest M. Mims III

# The Factory Finders

*Matthew Burnett and Tanya Menendez's Maker's Row connects entrepreneurs to American manufacturers*

*Matthew Burnett and Tanya Menendez are the co-founders of Maker's Row, an online platform that connects entrepreneurs to American manufacturers. Matthew began his career designing watches for fashion brands like Marc Jacobs. Tanya worked as an analyst with Goldman Sachs. After launching a leather goods line together, and experiencing the difficulty of finding the right manufacturers, they started Maker's Row. Introduced in 2013, with a focus on apparel and accessories, the site has recently added furniture and home decor.*

**Q. As factory experts, what's your advice to makers with a project that needs to be manufactured?**

**Matthew:** Understand that the product never sells itself. Don't get so enthralled with your product that you neglect other important stuff. How are you going to bring your product to market? Are you going to go direct to consumer or go wholesale?

**Tanya:** Test the product. Put the product in the hands of your harshest critic, not only the friends who will just congratulate you. Don't be afraid to share the idea before you sell it, don't be so nervous that it might be knocked off. Be open.

**Matthew:** Don't rush the process. If the product is not ready, do not take it to market. It will be dead on arrival.

**Q. It's often said that 75% to 85% of first-time entrepreneurs fail before their first prototype. What's your advice on how to beat the odds?**

**Matthew:** The more you understand the complexity and art of production, the better off you are. Learn as much as you can about the ups and downs of production.

**Tanya:** Before you produce the prototype, find the right manufacturer. It used to be so difficult to find a manufacturer to produce your product that some people just wanted to find a good manufacturer and start their company with whatever that manufacturer produced. That's so backward. We're trying to reverse that cycle. Whatever you ultimately want to create, start with that.

**Q. What can Maker Pros learn from the fashion industry?**

**Tanya:** Apparel is shifting from mass market to community driven. Independent fashion designers have gained more traction working through their own distribution channels, and I think hardware also has that opportunity.

## The 6 Steps to Production (of anything!)

To help fledgling designers work with manufacturers, Tanya and Matthew broke the process down into six steps.

- **IDEATION:** "You need to gather up your sketches, reference images, and anything else that shows the factory what your product will look like."
- **PATTERN MAKING/ TEMPLATING:** "If ideation helps you define your idea, then pattern-making hammers down how you're going to make it. Pattern-making is essentially creating the template for assembling your product. Sometimes it is made of paper, other times paperboard or cardboard."
- **MATERIALS:** "Factories with materials capabilities can help you source the raw materials you need for your product, from fabrics to labels to hardware."
- **SAMPLE MAKING/ PROTOTYPING:** "This is the first working model of your product, so it should be perfect. This is the reference point for every other unit of the product that you make. Think of it as a contract between you and your factory."
- **TOOLING:** "Tooling consists of creating the tools or adjusting existing ones to make your production run as smoothly as possible. Common categories of machine tooling include fixtures, dies, gauges, molds, cutting equipment, and patterns."
- **PRODUCTION:** "Finally, your products are actually being produced."

Maker's Row

**DC DENISON** is the editor of the *Maker Pro Newsletter*, which covers the intersection of makers and business. He is the former technology editor of *The Boston Globe*.

For more Maker Pro news and interviews, visit makezine.com/go/maker-pro.

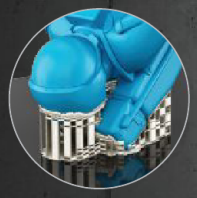
# ATOM 2.5 EX

Our most advanced 3D printer

*"The best 50 micron layer print I've ever produced on any printer."*

- Thomas Sanladerer's YouTube Review of Atom 2.0

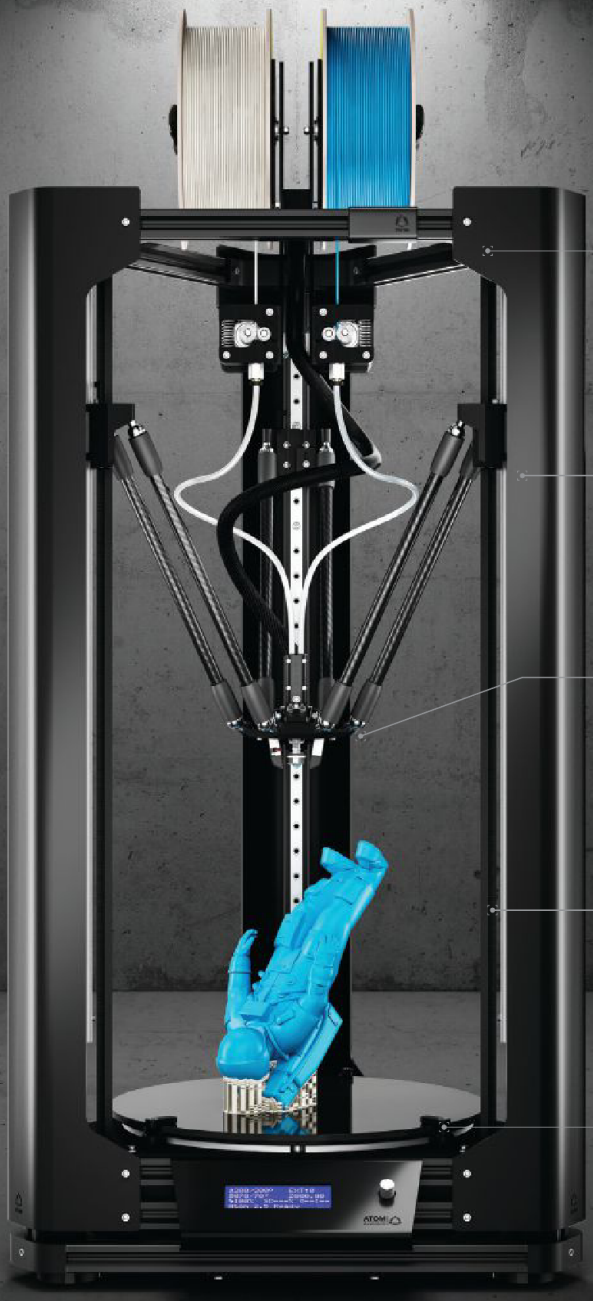
All-new, versatile 2-in-1 dual extrusion hot end



Achieve unsurpassed precision and surface quality with water soluble supports

Print mechanical parts and prototypes with complex features easily and cleanly

Experiment with multiple materials



Omron® optical endstops (3 axes + autolevel)

Super rigid, all-metal frame with precision CNC milled components

Modular, adaptable delta effector

Highest quality Japanese drive train (THK, Minebea, Unita)

Quick-release heated glass build plate

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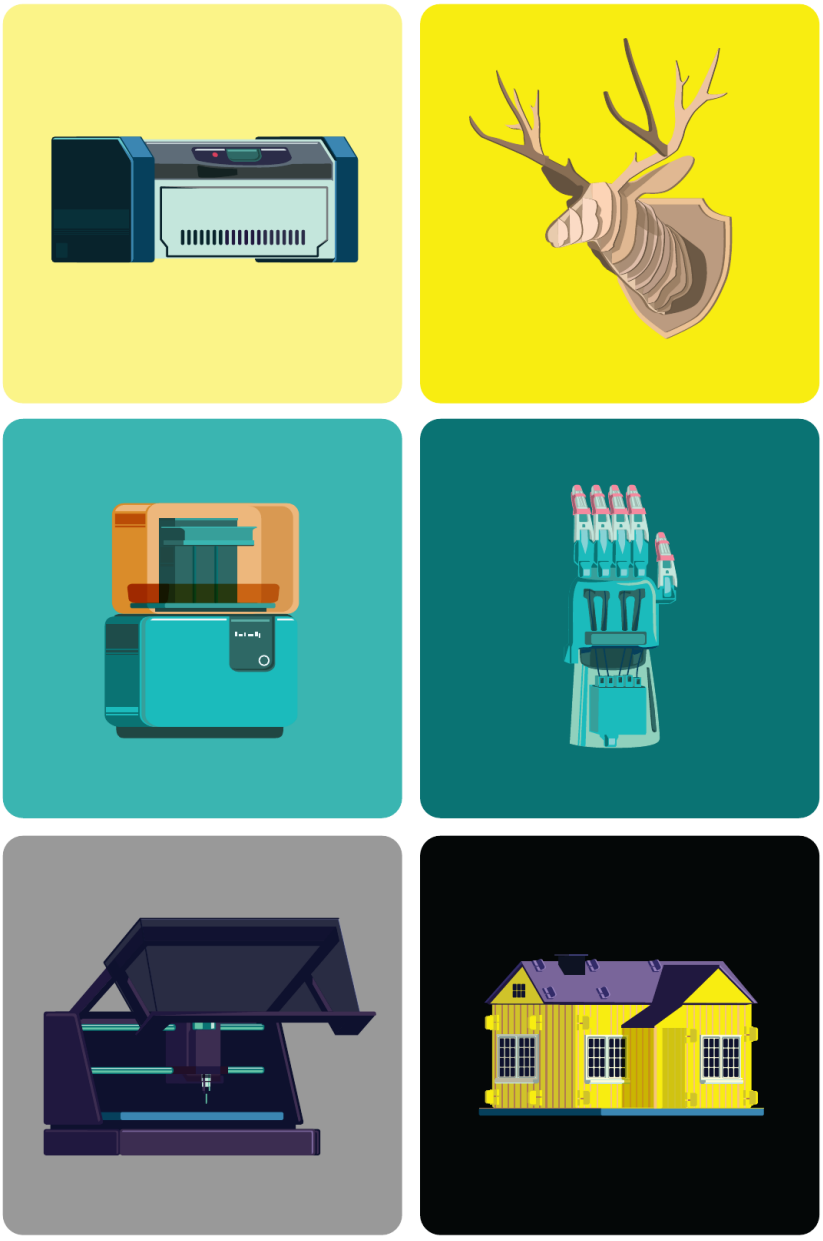
makezine.com/go/fab-guide-2017

# 5

Written by Matt Stultz

# FAB(ulous) YEARS

Desktop fabrication has shifted quite a bit since we started our printer shootouts. Here's what's new this year.



James Burke

In 2012, the *Make:* testing team began reviewing 3D printers to help our readers know which of the dozen or so that were then available best fit their needs. Over the next two years we continued this focus as the number of printers on the market exploded, while more and more makers found 3D printing as a solution to some of their creative endeavors. In 2015, to match the growing appeal and accessibility of CNC machines, laser cutters, and vinyl cutters, we began including these fabrication processes in our annual testing.

We return this year with a new selection of these types of digital fabrication tools. In them, we continue to see new features that make the hardware easier and more reliable, and new software interfaces that are more intuitive. This year we also introduce a new class of machines we call Hybrids. These machines have swappable tool heads that allow the user to not only 3D print, but also change over to milling, laser etching, and other functions, all within the same machine. This is substantial for someone who may not have the space for multiple machines but wants to work with as many processes as possible.

In 3D printing we continue to see the dominance of open source with the new i3 MK2 from early RepRap pioneer Josef Prusa taking our top spot and showing numerous breakthroughs in printing technology. Overall, 3D printers are becoming further self-calibrating, and are offering bells and whistles that get them closer to becoming standard household devices.

This year's mills showed that tools capable of doing real work are becoming more accessible. The Tormach PCNC 440 puts the power of a machine shop in your garage or workspace, bringing "benchtop" metal manufacturing home. While the software still needs work, these machines are more user-friendly than those we saw last year, a direction we like to see things moving.

We hope you enjoy this foray into home manufacturing and that this guide helps you find the tool that's right for you.

# HOW WE TESTED

Written by Matt Stultz

The location's changed, but the procedure remains the same

**OUR ANNUAL DIGIFAB SHOOTOUT IS AN EVENT THAT EACH MEMBER OF THE TESTING TEAM LOOKS FORWARD TO.** This year, we brought the event to my home hackerspace, Ocean State Maker Mill (OSMM), in Pawtucket, Rhode Island. OSMM gave us the space we needed for an even wider variety of products, and our loading dock made it easy for us to test some larger machines that were logistically difficult in the past.

Hosting it at OSMM also meant we could tap two east coast testers, Shawn Grimes and Chris Yohe, to involve more members of their spaces. While in previous years, our team was made up of experts from around the country (and even around the world), this year our team came from three groups: Digital Harbor Foundation in Baltimore, Maryland, HackPittsburgh in Pittsburgh, Pennsylvania, and Ocean State Maker Mill. Our team comprised professional designers, engineers, fabricators, and educators, all with a diverse background in digital fabrication.

Over the years we've refined our 3D printer testing process and for the first time, we used the same models and procedures from last year to allow for direct comparisons against the previous round of machines, as well as those that we looked at individually throughout this past year. For fused filament printers, we print nine specific designs, called test probes, and one overnight print on each machine. The probes target individual aspects of a printer's performance, such as surface quality or ability to print overhangs. The overnight print shows us what to expect out of the machine with a design that takes eight hours to produce, or as close as the machine will allow us to get to that.

Most importantly in our tests, we maintain blind judging. As each print is created, an ID number is affixed to it and a data entry is made. When our judge scores each print, they do so only knowing the type of probe it is and that ID number, but not which printer the print came from. This ensures that in the end, there is no bias in our judging. While the opinions expressed in our reviews reflect the experiences of our testers, the scores were produced in an isolated capacity.

Find out more about our testing process at makezine.com/go/how-we-test.

## MEET THE TESTERS

**ADAM BOUHMAD** is a network engineer for Terbium Labs, a Cyber Security startup in Baltimore. Formerly, he was the senior technology specialist at the Digital Harbor Foundation.

**DARIUS MCCOY** is a 3D printer specialist at the Digital Harbor Foundation where he founded 3D Assistance, a 3D printer repair service for educators throughout Baltimore.

**JEAN CARLOS CEDRE** is a web developer and a maker. As a computer geek and wannabe artist, he is constantly trying to make things look pretty but functional.

**RYAN PRIORE** is an analytical chemist, an entrepreneur in the photonics industry, an active member of HackPittsburgh, and the cofounder of 3DPPGH.

**MATT DAURAY** is a mechanical engineer. Finish carpenter by day, leatherworker by night, he spends his spare time at the Ocean State Maker Mill.

**JENNIFER SCHACHTER** has a degree in fine arts, but despite that, finds herself building and tinkering more often than painting and drawing.

**KELLY EGAN** is an artist in Providence, RI and a founding member of Baltimore Node and Ocean State Maker Mill.

**MANDY L. STULTZ** is a founding member of Ocean State Maker Mill. She favors fiber arts, but explores digifab tools to help in these ventures.

**SHAWN GRIMES** is the executive director at the Digital Harbor Foundation, an incubator of creativity and productivity in youth and educators.

**MATT STULTZ** is the digital fabrication editor for *Make:* and the founder of Ocean State Maker Mill, HackPittsburgh, and 3DPPVD.

**STEPH GRIMES** is the director of Education at the Digital Harbor Foundation. She's taught 3D printing workshops over the last three years for groups around the country.

**CHRIS YOHE** is a professional software developer and cheap digifab freak. He co-founded 3DPPGH and is a member at HackPittsburgh. His next project involves an ark.

**KURT HAMEL** is a mechanical engineer working in the shipbuilding industry. He brings the innovative spirit of makers to an otherwise conservative field.

**SPENCER ZAWASKY** works for an embedded systems company outside Boston. Often you'll find him 3D printing at the Ocean State Maker Mill.

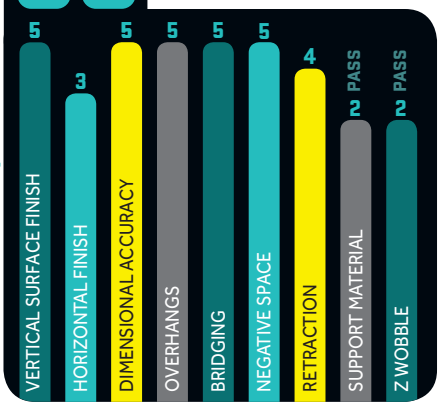
**JASON LOIK** is a sculptor, toysmith and educator. He teaches at Massachusetts College of Art and Design and distributes joy with his toy creations.

Christopher Garrison

36 Fused Filament Printers

MACHINE RATING

prusa3d.com




# PRUSA i3 MK2

## This open source beast is breaking barriers, but not your wallet

Written by Ryan Priore

**AFTER THE INITIAL SMOOTH-AS-SILK HOMING SEQUENCE, I KNEW THAT I SHOULD BUCKLE MY SEAT BELT FOR ONE INCREDIBLE JOYRIDE.** Prusa Research has raised the bar for consumer 3D printing platforms while not breaking the bank. And with its total score of 36 points — more than any machine we've ever tested — the Prusa i3 MK2 became the machine all the testers wanted, and more than one of us went home and immediately placed an order.

The MK2 boasts an E3D all-metal hot end, a next-generation heated bed with PEI print surface, bed-leveling compensation, and a 31% larger print volume over the previous i3. Available as a kit, assembled printer, or upgrade option for the original i3 model, the MK2 offers beautiful prints across a multitude of plastic filament options.

### BED UPGRADES

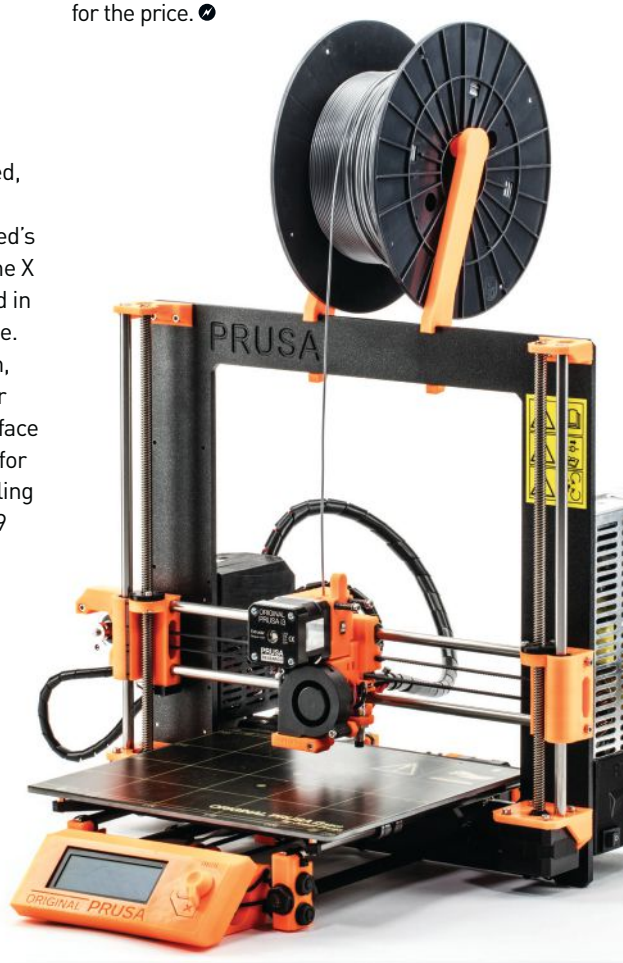
I was drawn to the new MK42 heated bed, which compensates for cold corners by using three power zones to warm the bed's corners slightly more than its center. The X and Y dimension markers on the bed aid in visualization of available printing surface. And the icing on this cake is the PEI film, which effectively eliminates the need for glue, ABS juice, or painter's tape as surface adhesion enhancements. It also allows for nearly edge-to-edge printing. Auto leveling is performed using a specialized set of 9 calibration points on the bed.

### EXOTIC FILAMENTS

Inside of the deceptively simple X carriage, both an E3D v6 hot end and an inductance probe sit behind the cooling fan. The direct drive extruder and all-metal hot end allows the MK2 to use high-temperature and exotic filaments, including polycarbonate, nylon, and flexibles. The test probes looked fantastic, and the overall printing time was faster than average as compared to the rest of the printers reviewed.

### EVOLUTIONARY SUCCESS

It was surprising to see the abundance of improvements that the MK2 brought to the table since the original i3 was already a respectable open source offering. While some users may not like the RepRap aesthetics, others will applaud the advanced capabilities offered along with the support of the open source community behind it. The MK2 is aimed at a broad spectrum of end users, from RepRap enthusiasts to the average home user. The MK2 is a performance leader and a tremendous value for the price.




## PRO TIPS

Use the onboard printer self-test feature to ensure it is ready for operation.

Clean the PEI bed surface periodically with isopropyl alcohol.

## WHY TO BUY

One of the best bangs for the buck for such a large print volume and plastic filament options.

The extensive community, detailed documentation, and pre-configured software/firmware will keep your printer in top performance.

**THE ONBOARD SELF-TEST WAS HELPFUL AS A DAILY CHECK TO ENSURE THAT THE PRINTER WAS READY FOR ACTION**

- **MANUFACTURER** Prusa Research
- **PRICE AS TESTED** $899
- **BUILD VOLUME** 250×210×200mm
- **BED STYLE** Heated bed with PEI surface
- **FILAMENT SIZE** 1.75mm
- **OPEN FILAMENT?** Yes
- **TEMPERATURE CONTROL?** Yes, tool head (300°C max); bed (120°C max)
- **PRINT UNTETHERED?** Yes (SD card)
- **ONBOARD CONTROLS?** Yes (display screen and control wheel)
- **HOST/SLICER SOFTWARE** Prusa3D, Slic3r, MK2
- **OS** Windows, Mac, Linux
- **FIRMWARE** Open, Marlin
- **OPEN SOFTWARE?** Yes, Prusa3D Slic3r MK2 is derived from Open Source Slic3r
- **OPEN HARDWARE?** Yes, GNU GPLv3
- **MAXIMUM DECIBELS** 67.5

THE PRINT

Christopher Garrison

# N2 PLUS

Written by Matt Stultz

## This big, easy-to-use machine is packed with features


**THERE IS A LOT TO LOVE ABOUT THE N2 PLUS,** starting with its print size: at 12"×12"×24" it is one of the tallest commercially available machines. The entire printer even sits on casters for floor placement. The dual high-temperature extruders allow for a variety of materials (including support material).

### NO BED CALIBRATION

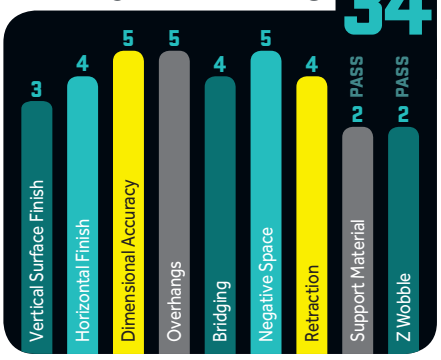
Prints were clean and smooth in our tests, scoring a very impressive 34 points. The built-in touchscreen tablet lets you choose files from USB, SD card, or internal storage connected through Wi-Fi or Ethernet.

A fixed bed is meant to eliminate the need for calibration, and although it worked fine for small prints in the center of the bed, it wasn't quite level when I printed a full plate. You can tweak this yourself, but it's not as simple as with fully adjustable beds.

### A VETERAN'S MACHINE

While the price tag and footprint might scare off new users, this machine is a veteran's dream. If you're ready for your second, third, or nth machine, the N2 Plus is what you need.

MACHINE RATING **34**




raise3d.com

- **MANUFACTURER** Raise3D
- **PRICE AS TESTED** $3,499
- **BUILD VOLUME** 305×305×610mm
- **BED STYLE** Heated glass with BuildTak
- **FILAMENT SIZE** 1.75mm
- **OPEN FILAMENT?** Yes
- **TEMPERATURE CONTROL?** Yes, tool head (300°C max); bed (120°C max)
- **PRINT UNTETHERED?** Yes (Wi-Fi, SD, internal storage, or USB stick)
- **ONBOARD CONTROLS?** Yes (large built-in touchscreen)
- **HOST/SLICER SOFTWARE** Proprietary IdeaMaker or Simplify3D
- **OS** Windows, Mac, Linux
- **FIRMWARE** Custom
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No
- **MAXIMUM DECIBELS** 53.5

### PRO TIPS

Since the touchscreen interface is capacitive, ground yourself to the machine by touching a metal component and the display will register your actions every time.

# ULTIMAKER 2 EXTENDED+

## Top-notch prints and a sizable, active community make this upgraded machine one of our favorites

Written by Jason Loik

**WITH HIGH-QUALITY, RELIABLE PRINTS** and a large build volume, the Ultimaker 2 Extended+ is a hard machine to beat. Add in a huge, helpful community and you have a solid choice.


### 2ND+ TIME'S A CHARM

The Extended+ is not a new printer, but an upgraded version of the Ultimaker 2. It sports a new Bowden extruder and hot end to reduce skipping and clogging, and with nozzles ranging from .25mm up to .8mm, users can change extrusion width to suit their needs. These help push the machine from 30 points last year to 34 points in this year's tests.

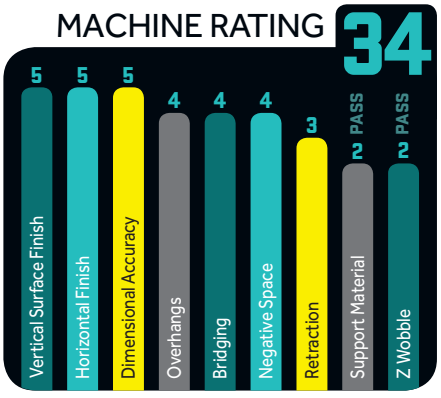
Only complaints: I found drooping in the overhangs and bridging to be a bit disappointing. Also, the scroll wheel interface feels a bit dated compared to other machines this year.

### A SERIOUS CONTENDER

The Extended+ is a sturdy machine with reliable, quality results that Ultimaker has become known for. If you already have an original Ultimaker 2, an upgrade kit will get you all the +'s goodies.

**JUST ANNOUNCED:** The Ultimaker 3 brings dual extrusion, Wi-Fi, and active bed leveling to Ultimaker's game. Look for our review soon.

MACHINE RATING **34**




ultimaker.com

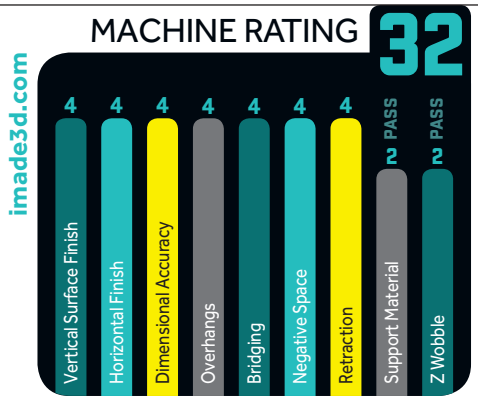
- **MANUFACTURER** Ultimaker
- **PRICE AS TESTED** $2,999
- **BUILD VOLUME** 223×223×304mm
- **BED STYLE** Heated glass plate
- **FILAMENT SIZE** 3mm
- **OPEN FILAMENT?** Yes
- **TEMPERATURE CONTROL?** Yes, extruder (230°C max); bed (120°C max)
- **PRINT UNTETHERED?** Yes (SD card)
- **ONBOARD CONTROLS?** Yes (scroll wheel with LCD)
- **HOST/SLICER SOFTWARE** Cura
- **OS** Windows, Mac, Linux
- **FIRMWARE** Marlin
- **OPEN SOFTWARE?** Yes, GPL
- **OPEN HARDWARE?** Yes, CC-BY-NC
- **MAXIMUM DECIBELS** 75.6

### PRO TIPS

Wait until the platform has cooled to pull your print off. It's faster than reprinting a broken part. PVA-based glue sticks help with bed adhesion, but clean periodically.

Christopher Garrison

imade3d.com




# JELLYBOX

Written by Shawn Grimes

## Don't be fooled by its appearance, this printer is no joke

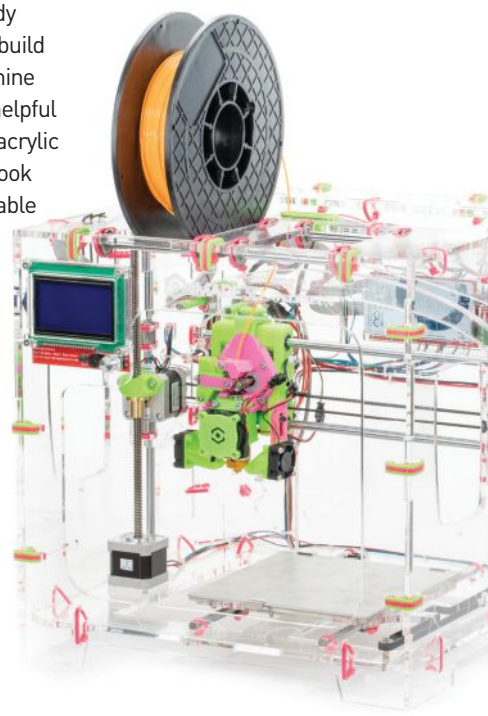
**DESPITE SOME EARLY SKEPTICISM** about its cobbled-together appearance, the Jellybox impressed me with its ease of use and fast printing. The prints (tallying 32 points) were not perfect, but they were consistent, quick, and never failed during our testing. The speed and reliability should attract any educator or family looking for a DIY 3D printer.

### A PRINTER FOR EDUCATORS

Held together by colorful zip ties, it's easy to imagine it as a class project getting built and rebuilt at the start of each semester. The unit we received was already assembled, and while build directions for the machine are decent (including helpful notes etched onto the acrylic pieces), you'll have to look elsewhere for comparable software guidance.

### THE KIT EXPERIENCE

Jellybox isn't the best starting place for a total novice, but it's a great machine for learning more about the engineering behind how 3D printers work.

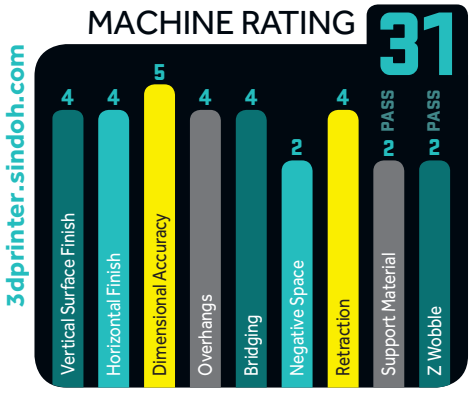


### PRO TIPS

The Jellybox enclosure provides two ways to carry the printer: a reinforced archway at the top of the printer, and two handles on the sides.

- **MANUFACTURER** IMade3D
- **PRICE AS TESTED** $949
- **BUILD VOLUME** 170×160×150mm
- **BED STYLE** Non-heated aluminum (heated upgrade optional)
- **FILAMENT SIZE** 1.75mm
- **OPEN FILAMENT?** Yes
- **TEMPERATURE CONTROL?** Yes, tool head (245°C max)
- **PRINT UNTETHERED?** Yes, (SD card)
- **ONBOARD CONTROLS?** Yes
- **HOST/SLICER SOFTWARE** Cura JB Edition
- **OS** Windows, Mac, Linux
- **FIRMWARE** Marlin
- **OPEN SOFTWARE?** Yes (Cura profiles available)
- **OPEN HARDWARE?** No
- **MAXIMUM DECIBELS** 71.1

3dprinter.sindoh.com




# DP200 3DWOX

Written by Ryan Priore

## This sleek workhorse feels like the printer of tomorrow

**THE 3DWOX IS A FEATURE-RICH, TURNKEY PRINTER** that aims for the multiuser office environment, but is also a great introduction to 3D printing for new users. The assisted bed leveling, removable bed, and ability to load prints via flash drive ensures an easy printing experience, and the touchscreen interface is second to none.

### PRINTING IS ALMOST TOO SIMPLE

One of the coolest features is the print preview that shows an image of the file being printed as well as additional progress monitoring information on the 5" touchscreen. And though I'm no fan of closed-source, chipped filament, the 3DWOX offers some reasonable benefits like usage monitoring and the ability to intervene if, for example, an ABS print profile is coupled with PLA filament.

### CONVENIENT

As a RepRap enthusiast, I was blown away by the convenience and execution of the 3DWOX. It simply just worked right out of the box with respectable print performance at a faster average speed than other printers tested.


### PRO TIPS

Check on your prints from your mobile device or computer using the onboard camera, and take advantage of the print queuing feature to speed up multiple print jobs.

- **MANUFACTURER** Sindoh
- **PRICE AS TESTED** $1,299
- **BUILD VOLUME** 210×200×195mm
- **BED STYLE** Heated bed with PEI surface
- **FILAMENT SIZE** 1.75mm
- **OPEN FILAMENT?** No (chipped)
- **TEMPERATURE CONTROL?** Yes (tool head (260°C max); bed (100°C max)
- **PRINT UNTETHERED?** Yes (USB drive; wired LAN; wireless LAN)
- **ONBOARD CONTROLS?** Yes (5" color touchscreen)
- **HOST/SLICER SOFTWARE** 3DWOX Desktop
- **OS** Windows, Mac
- **FIRMWARE** Closed; 20160505_1
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No
- **MAXIMUM DECIBELS** 79.9

Christopher Garrison

# ATOM 2.0

Written by Darius McCoy

## Trust this Atom: it makes everything, but bigger!

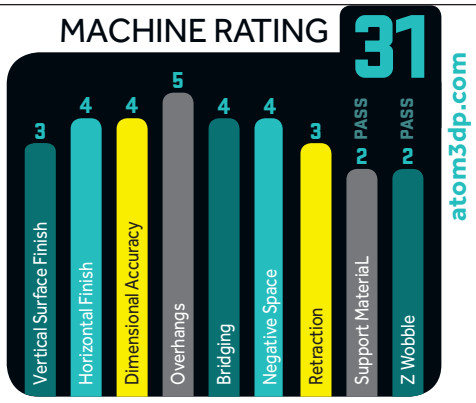
**LIKE ALL DELTA PRINTERS, THE ATOM 2.0 IS BUILT FOR SPEED,** but not all deltas have quality prints to back up the quickness. Luckily, it succeeds in both categories.

### TOP-RATE TOUCHES

The printer features high-torque and precision stepper motors, carbon fiber rods that gracefully carry the hot end attached by magnetic effectors, and a hot end that heats up to 200°C within a minute. The magnetic effectors make it quick and easy to detach the hot end to repair it — or replace it with one of Atom's laser engravers, which was not available for testing. A dual hot end is also still in development by the company.

### WORTH YOUR WALLET

The ease of setup and the quality of prints are things that any user would appreciate. The documentation, additional online support (a community slack channel), and quality of the components make the Atom 2.0 a great printer for a beginner. The price may scare away some newcomers, but as their knowledge of 3D printing increases, spending the extra bucks for this printer will be money well spent.




- **MANUFACTURER** Atom
- **PRICE AS TESTED** $1,699
- **BUILD VOLUME** 220×220×320mm
- **BED STYLE** Unheated glass, but upgradable
- **FILAMENT SIZE** 1.75mm
- **OPEN FILAMENT?** Yes
- **TEMPERATURE CONTROL?** Yes, tool head (240°C max); bed (100°C max)
- **PRINT UNTETHERED?** Yes (SD card)
- **ONBOARD CONTROLS?** Yes (LCD with a control knob)
- **HOST/SLICER SOFTWARE** KISSlicer, Cura
- **OS** Windows, Mac
- **FIRMWARE** Open, Marlin
- **OPEN SOFTWARE?** Open Source, Atom 2.0 has slicing profiles used in Cura
- **OPEN HARDWARE?** No
- **MAXIMUM DECIBELS** 68.5

### PRO TIPS

Coat the glass bed with a glue stick before printing, but wipe off the dried glue with isopropyl alcohol between prints, and apply again to maintain good adhesion.

# CEL ROBOX

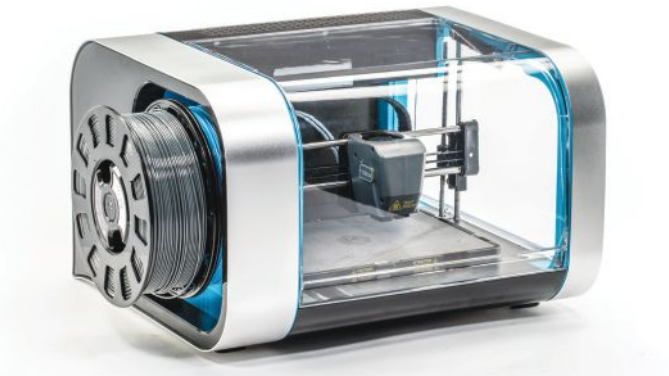
Written by Steph Grimes

## Truly plug and play, and so much more

**THE ROBOX IS A GREAT PRINTER FOR ANYONE** just starting out or looking for reliability and ease in their 3D printing experience.

### NOVEL FEATURES THAT WORK

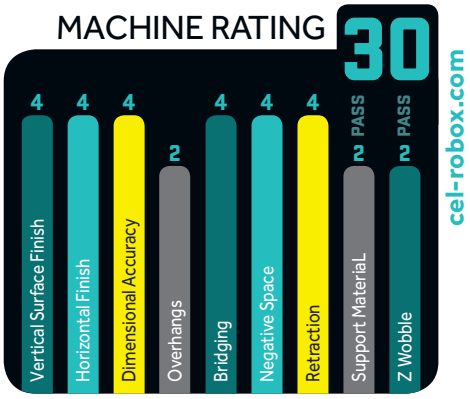
The machine has quite a few appealing and unique components, including a printer head with dual nozzles (one for speed, one for detail), a two-material upgrade option, and "smart" spools that store data like material type, color, temperature settings, and how much filament is remaining. Users, fortunately, are not locked into using proprietary filament.



### SOLID RESULTS

The machine produced consistent prints — on the default settings with no tweaks needed — which adhered well to the bed, but usually did not require a tool for removal.

The only problem I encountered was the auto-locking enclosure not opening after some prints. Robox guided me to an advanced option to disable this function in their well-designed software.

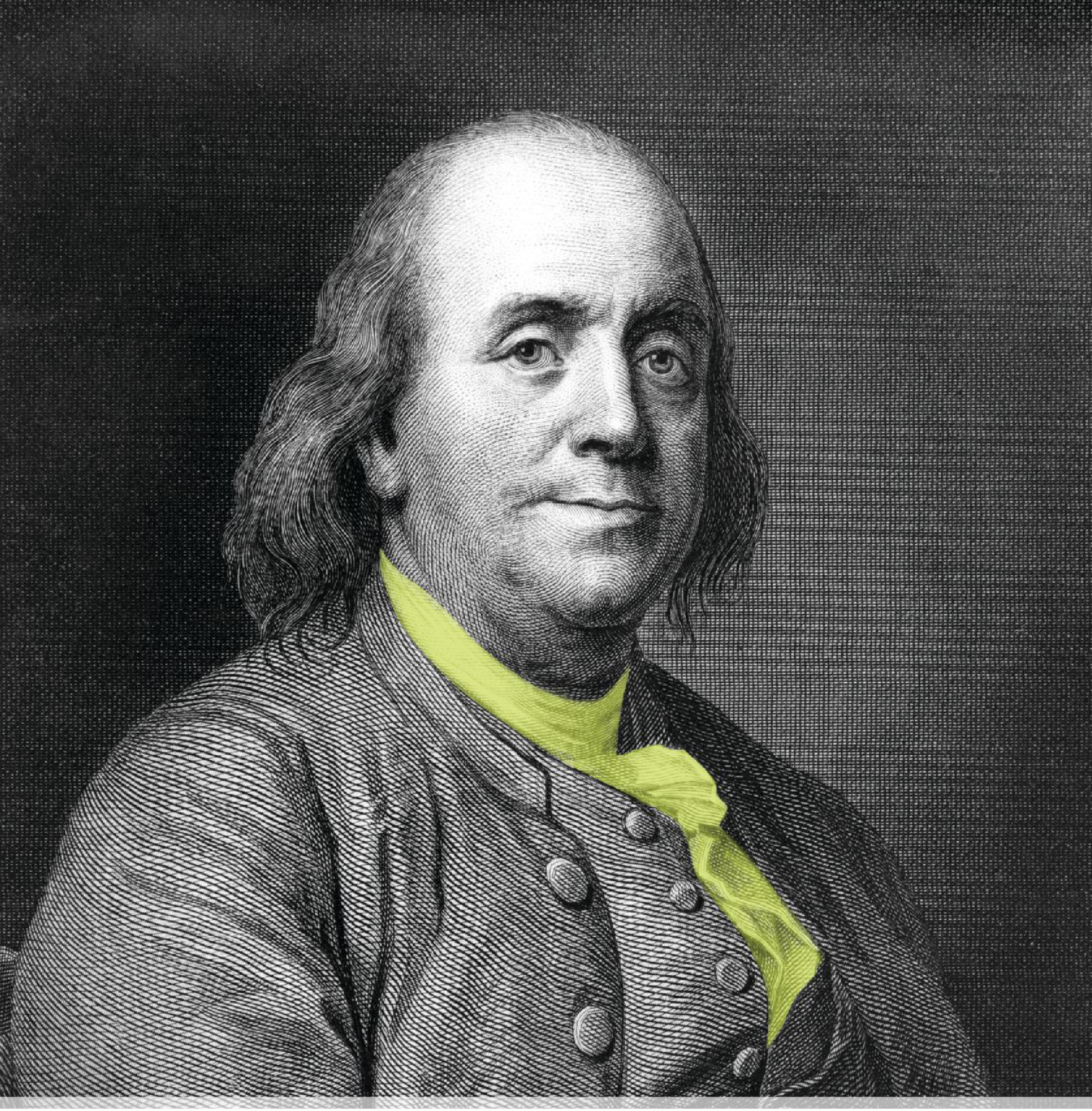



- **MANUFACTURER** Cel
- **PRICE AS TESTED** $1,326
- **BUILD VOLUME** 210×150×100mm
- **BED STYLE** Heated bed with PEI surface
- **FILAMENT SIZE** 1.75mm
- **OPEN FILAMENT?** Open or chipped filament
- **TEMPERATURE CONTROL?** Yes, bed (150°C max); nozzle (300°C max)
- **PRINT UNTETHERED?** Yes (unplug USB after starting print)
- **ONBOARD CONTROLS?** No (power switch only)
- **HOST/SLICER SOFTWARE** Cel AutoMaker Software (proprietary)
- **OS** Windows, Mac, Ubuntu Linux
- **FIRMWARE** Proprietary
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No
- **MAXIMUM DECIBELS** 70.3

### PRO TIPS

For experienced users or environments where there are no concerns about accessing the heated elements or disturbing a print, turn off SafeLock for easy access to the enclosure.

Christopher Garrison



*As we enjoy great advantages from the inventions of others, we should be glad of an opportunity to serve others by any invention of ours; and this we should do freely and generously.*

- Benjamin Franklin

LULZBOT

# Free Thinking in the 18th Century

Benjamin Franklin was one of the most prolific inventors of his day, yet he held no patents. He shared his ideas to contribute the progress of society. As a result, Franklin's inventions and legacy of sharing endure today.

We continue this tradition with LulzBot 3D printers. From CAD files and Free Software, to Bills of Materials and the factory floor layout, we freely share it all and hope our work can benefit your next project. Join us as we build a more free and knowledgeable 3D printing community, together.


# Leading Libre Innovation Today

From Fortune 500 corporations and Ivy League Schools, to makers and hackers, people around the world rely on award-winning LulzBot 3D printers to get the job done. We are proud to be the #1 fastest-growing privately held computer hardware company in the United States, and rank #122 on Inc. Magazine's 2016 Inc. 500 list. Rock-solid reliability, Free Software, a huge selection of print materials, and acclaimed technical support are just the beginning.

Learn more about LulzBot 3D printers and our commitment to freedom at **LulzBot.com/freedom**

Inc. 500 · EDITOR'S CHOICE tom's guide · 3D HUBS BEST OF PLUG 'N' PLAY 2016 · 3D HUBS BEST OF ENTHUSIAST 2016 · TOM Approves · open source hardware · RESPECTS YOUR FREEDOM fsf.org/ryf

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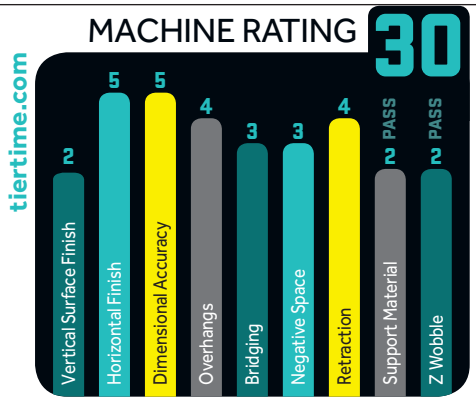



# UP BOX+

Written by Ryan Priore

## This prosumer printer yields beautiful prints via Wi-Fi

**GORGEOUS PRINTS COMBINED WITH A PROFESSIONAL-LOOKING MACHINE** are a one-two combo for anyone looking to upgrade to a reliable, turnkey printer.

### A BIT QUIRKY ...

Manually level the bed for best results. This model introduces a "Flex Board" atop the perforated board. It was challenging to remove prints while avoiding the nozzle height detector at the rear. Be sure to allow enough cooling time!

### ... BUT SMOOTH AS SILK

The top, flat surfaces of the test prints looked fantastic, but it was a rare print that didn't have at least one discolored blemish, which I attribute to burnt plastic dislodging from the hot end. The automatic print resume after power failure feature works like a charm, and the included HEPA filter will keep printing fumes at bay.

### NEW AND IMPROVED

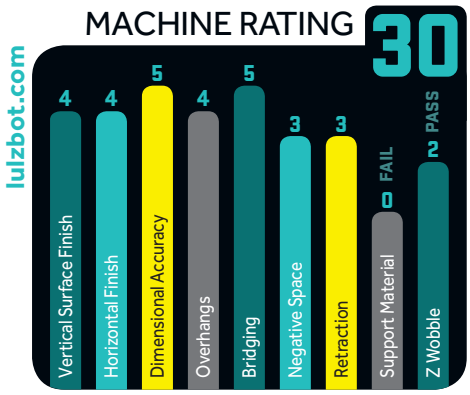
It's hard to argue with results: this machine is a worthy upgrade to the traditional Up Box line of printers, and steps up to 30 points from last year's 27. It excels at top surface finishes and accuracy, is noticeably quiet, and will look great in any workspace.


### PRO TIPS

The multifunction side buttons are very useful — just mount a cheat sheet alongside them before you accidentally press the wrong one.

- **MANUFACTURER** Tiertime
- **PRICE AS TESTED** $1,899
- **BUILD VOLUME** 255×205×205mm
- **BED STYLE** Heated with Up Flex Print Board
- **FILAMENT SIZE** 1.75mm
- **OPEN FILAMENT?** No
- **TEMPERATURE CONTROL?** Yes, tool head (260°C max); bed (100°C max)
- **PRINT UNTETHERED?** Yes (unplug USB after starting; wireless)
- **ONBOARD CONTROLS?** Yes (3 multifunction buttons)
- **HOST/SLICER SOFTWARE** Up Studio
- **OS** Windows, Mac
- **FIRMWARE** Closed
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No
- **MAXIMUM DECIBELS** 67.5

lulzbot.com




# TAZ 6

Written by Matt Stultz

## This open source, user-friendly machine remains a team fave

**A FANTASTIC SIZE AND ACCESSIBLE TO NOVICE OWNERS AND EXPERTS ALIKE**, the open source LulzBot Taz 6 is one of this year's must-have printers.

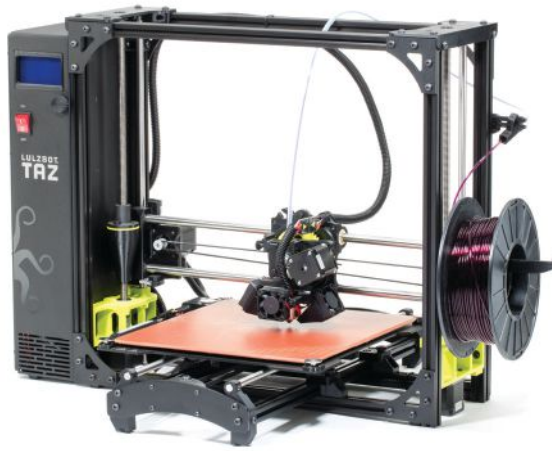
### FUSING PROVEN FEATURES

The Taz 6 is a natural progression from last year's excellent Taz 5. It blends the best of the LulzBot Taz and Mini platforms: new Z- and X-axis components, an integrated power supply, an upgraded auto print-leveling system, and the fantastic PEI bed surface, which keeps prints adhered when warm and releases them when cool.

### MINOR ADJUSTMENTS YIELD MAJOR RESULTS

The print quality on the machine is good, but it didn't stand out from the pack like last year's model. However, tweaking the settings and swapping PLA brands made big improvements.

LulzBot printers show an incredible amount of engineering, and their community continues to make their machines even better. For those who are serious about open source, this line of printers is a top choice.




Christopher Garrison

### PRO TIPS

The Taz 6 retracts the bed to let prints cool, then moves the bed forward when they're ready to remove. Grab a print too quickly and you could damage the bed.

- **MANUFACTURER** LulzBot
- **PRICE AS TESTED** $2,500
- **BUILD VOLUME** 280×280×250mm
- **BED STYLE** Heated bed with PEI-coated build surface
- **FILAMENT SIZE** 3mm
- **OPEN FILAMENT?** Yes
- **TEMPERATURE CONTROL?** Yes, tool head (300°C max); bed (120°C max)
- **PRINT UNTETHERED?** Yes (SD card)
- **ONBOARD CONTROLS?** Yes (scroll knob and LCD)
- **HOST/SLICER SOFTWARE** LulzBot Cura
- **OS** Windows, Mac, Linux
- **FIRMWARE** Marlin
- **OPEN SOFTWARE?** Yes, CC BY-SA 4.0 International
- **OPEN HARDWARE?** Yes, CC BY-SA 4.0 International
- **MAXIMUM DECIBELS** 65.2

# BEST OF THE REST

Here's a quick look at some of the other noteworthy fused filament machines we tested

Written by Matt Stultz

With so many machines on the market, it's hard to test them all and even harder to fit them into the pages of a magazine. While we wish we could include every one, here's a quick overview of the other FFF machines we looked at in this year's shootout. Go online for full reviews of all of the printers we've tested over the past couple years at makezine.com/comparison/3dprinters.

## SIGMA

**bcn3dtechnologies.com**


The major issues with dual-extrusion 3D printers are that unused nozzles can ooze material slowly into your print, and improperly adjusted nozzles can knock your print off the bed completely. The Sigma from BCN3D fixes these issues by using two separate X carriages, one for each extruder. When an extruder is not in use, its carriage parks to the side and then runs across a wiper to remove ooze before going back to work. We had a few build quality issues during testing, but are excited to see what a second revision could bring.

- **MANUFACTURER** BCN3D
- **PRICE** $2,695
- **BUILD VOLUME** 210×297×210mm
- **EXTRUDER** Dual high temp
- **HEATED BED** Yes
- **PRINT UNTETHERED** Yes

MACHINE RATING

**31**

## DREMEL 3D40

**3dprinter.dremel.com**


The 3D40 is Dremel's second foray into 3D printing. It features an enclosed build space and an easy-to-use touchscreen interface. Gone is the need to transfer files with loose, potentially breakable SD cards, which are now replaced by USB sticks and 4GB of internal storage. Dremel has also worked with Autodesk to make Print Studio the default slicing application for the 3D40.

- **MANUFACTURER** Dremel
- **PRICE** $1,299
- **BUILD VOLUME** 255×155×170mm
- **EXTRUDER** Single standard temp
- **HEATED BED** No
- **PRINT UNTETHERED** Yes

MACHINE RATING

**30**

Christopher Garrison

## DA VINCI PRO us.xyzprinting.com

- **MANUFACTURER** XYZprinting
- **PRICE** $699
- **BUILD VOLUME** 200×200×190mm
- **EXTRUDER** Single standard temp
- **HEATED BED** Yes
- **PRINT UNTETHERED** Yes

MACHINE RATING **30**

One of the biggest complaints about the da Vinci line of printers was the mandatory use of their chipped filament. However, da Vinci Pro gives you the freedom to use any filament you want. Plus, an added laser etching head makes this an interesting machine to check out.

## CETUS tiertime.com

- **MANUFACTURER** Tiertime
- **PRICE** $299
- **BUILD VOLUME** 180×180×180mm
- **EXTRUDER** Single standard temp
- **HEATED BED** No
- **PRINT UNTETHERED** Yes

MACHINE RATING **29**

The super minimal design of the Cetus hides solid features under the hood, like printing over Wi-Fi. The Up software has always felt limiting, and you won't see a change with the Cetus. While the unit we tested was just a prototype, we have high hopes for this little guy.

## ERIS seemecnc.com


- **MANUFACTURER** SeeMeCNC
- **PRICE** $549
- **BUILD VOLUME** 124mm diameter× 165mm
- **EXTRUDER** Single standard temp
- **HEATED BED** No
- **PRINT UNTETHERED** No

MACHINE RATING **26**

The Eris features a new calibration sensor unique to SeeMeCNC. The hot end includes an accelerometer and taps multiple points on the bed to calibrate the machine. This system allows a new user to pull the Eris out of a box, run a script, and start printing in minutes.

## UP MINI 2 tiertime.com

- **MANUFACTURER** Tiertime
- **PRICE** $500
- **BUILD VOLUME** 120×120×120mm
- **EXTRUDER** Single standard temp
- **HEATED BED** Yes
- **PRINT UNTETHERED** Yes

MACHINE RATING **23**

With features like power resume, Wi-Fi printing, a filament caddy to store materials, and HEPA filtering, the $500 UP Mini 2 is an extremely good value for any family or educator looking to get a start in the 3D printing world.

## DELTA GO deltaprintr.com


- **MANUFACTURER** Deltaprintr
- **PRICE** $499
- **BUILD VOLUME** 115mm diameter× 127mm
- **EXTRUDER** Single standard temp
- **HEATED BED** No
- **PRINT UNTETHERED** Yes

MACHINE RATING **21**

The Delta Go is a compact little printer with an elegant look, but has a few kinks when operating. It also lacks some of the features found in other recently released printers such as wireless printing and better onboard user interfaces.

## R1 +PLUS robo3d.com


- **MANUFACTURER** Robo 3D
- **PRICE** $800
- **BUILD VOLUME** 254×228×203mm
- **EXTRUDER** Single high temp
- **HEATED BED** Yes
- **PRINT UNTETHERED** Optional

MACHINE RATING **20**

The R1 +Plus looks like it stepped out of an outer space fantasy movie. It features an all-metal hot end and heated glass bed. While the R1 has a loyal following, its performance didn't leave us thrilled.

# mUVe 3D DLP PRO+

## This DLP-based resin machine creates beautiful results affordably

Written by Matt Stultz


**LOOKING AT THE MUVE 3D DLP PRO+'S ALUMINUM EXTRUSION LEGS,** projector, visible electronics, and partial coroplast case, it's easy to think this might not be a high-quality machine, but you'd be wrong. The Pro+'s exposed interior leaves the machine open to fix, expand, or change as desired. Beautifully shaped acrylic cases may look nice, but have fun replacing them when you break something.

### IT JUST WORKS

The mUVe 3D performed well right out of the box, with the first print coming off without a hitch. Our test prints on the Pro+ were clean and crisp, and the high-resolution projector made the layer lines hard to spot. The lettering detail on top of our rook test looked like it had been chiseled in place with edges so sharp you could feel them. The Pro+ also won't restrict you to a proprietary resin, which means you can use a wide range of colors and properties that won't break the bank.

### A STANDALONE MACHINE

The Raspberry Pi-based nanoDLP software does all the heavy lifting. Once you plug the system into your network, you can control the printer via your web browser with nanoDLP's built-in web server. There's no software to install on your local computer since the files are sliced onboard the machine in nanoDLP. This makes it easy to share the Pro+ in a collaborative environment like a lab or hackerspace. All the settings and software live on the machine, no need to ensure every team member has the correct software.

### A FEW QUIRKS

One of my few complaints with the machine is how the resin vat and build plate are hard to remove. Both are screwed in place, which makes it difficult to switch between resins without cross contamination and to remove finished parts from the top-heavy printer.

- **MANUFACTURER** mUVe 3D
- **PRICE AS TESTED** $1,899
- **BUILD VOLUME** 175×98.5×250mm
- **OPEN RESIN?** Yes
- **PRINT UNTETHERED?** Yes (Raspberry Pi included for wireless printing via nanoDLP)
- **ONBOARD CONTROLS?** No
- **HOST/SLICER SOFTWARE** nanoDLP
- **OS** Any (web interface through nanoDLP/Pi)
- **FIRMWARE** Marlin and nanoDLP
- **OPEN SOFTWARE?** Partially, Marlin is open source but nanoDLP is not
- **OPEN HARDWARE?** Yes, CC-BY-NC 4.0

### PRO TIPS

Consider your size-to-quality scale when you order to have the team pre-configure your machine to your needs. You can adjust it yourself, but it's always better factory-ready.

### WHY TO BUY

This printer gets beautiful results from resin that won't break the bank. If you care more about how a machine performs than how it looks, there are few better options.

muve3d.net

THE PRINT

### REMARKABLE RESULTS

For the highest print quality and detail you can get on a desktop machine, resin printers are the way to go. I couldn't be happier with the performance of the mUVe 3D DLP Pro+. There is no doubt that this printer has moved to the top of my recommendation list for resin printers.

Christopher Garrison

# DROPLIT V2

## This upgraded, inexpensive resin machine produces crisp, clean results

Written by Chris Yohe

seemecnc.com

### PRO TIPS

Open style means that the user can upgrade and tweak to their heart's content.

### WHY TO BUY

An inexpensive way to get access to resin printing, the DropLit v2 provides an increased build size from the previous version, and an updated user experience to those willing to put in a little work.

- **MANUFACTURER** SeeMeCNC
- **PRICE AS TESTED** $749 (plus projector)
- **BUILD VOLUME** 115×70×115mm
- **OPEN RESIN?** Yes
- **PRINT UNTETHERED?** Yes (Raspberry Pi included for wireless printing via nanoDLP)
- **ONBOARD CONTROLS?** No
- **HOST/SLICER SOFTWARE** NanoDLP (recommended)
- **OS** Any (web interface through nanoDLP/Pi)
- **FIRMWARE** Vendor supplied (fork of Repetier GNU GPL V3)
- **OPEN SOFTWARE?** Yes, GNU GPL V3
- **OPEN HARDWARE?** Yes, Open Source Mini-Rambo

THE PRINT

Christopher Garrison

**A LOW-COST ENTRY TO THE WORLD OF CRISP, HIGH-RESOLUTION 3D PRINTING**

**AS WITH ITS PREDECESSOR, SEEMECNC'S DROPLIT V2 IS A BRING-YOUR-OWN-PROJECTOR RESIN PRINTER** kit that requires a healthy dose of patience and elbow grease. However, the reward is a low-cost entry to the world of crisp, high-resolution 3D printing.

### SOME WELCOME ADDITIONS

The white melamine and blue acrylic printer ships in the familiar SeeMeCNC flat pack-style. A few new additions are inside, including a Mini-Rambo board for the controller and a Raspberry Pi to run the printing software. The addition of a flex vat, with its FET drumhead-style bottom, brings a larger print area and an easier vat renewal process for when you wear out the surface. Assembly is fairly easy for anyone who has put together the laser-cut-wood printer kits of years past, and can be done in less than a day for new builders.

After the mechanical and electrical install comes the tough part, the software install and configuration. SeeMeCNC recommends nanoDLP, a Pi-based host and control software that can be accessed from a web browser — it's like the Repetier-Host of resin printing. It's a newer software package, especially for use with the DropLit, so the documentation is in flux. SeeMeCNC provided great support and had us up and printing fairly easily, but configurations are highly dependent on your hardware and resin choices.

### CALIBRATE, CALIBRATE, CALIBRATE

For those new to resin printing, plan to spend time calibrating and dialing in the settings. Even with a recommended projector, not every resin is equal, and it takes time to adjust for new ones. We tested using a few projectors (both 720p and 1080p) and got crisp print results using common resins.

### RELIABLE AND AFFORDABLE

The DropLit v2 lived up to expectations, and the larger flex vat, electronics, and software advancements were welcome improvements. The boxy, clean exterior is good looking, but the mess and safety concerns of resin printing will likely keep this machine firmly in a workshop area. Even with the added cost of a DLP projector, the DropLit v2 is an incredible value.

# ZMORPH 2.0 SX

## This all-in-one machine is packed with potential

Written by Chris Yohe

**WITH A STAGGERING FIVE SWAPPABLE TOOL HEADS, THE ALL-IN-ONE ZMORPH 2.0 SX** "Full Set" packs quite a punch card of possibilities. This CNC mill, laser engraver, and versatile 3D printer is surprisingly capable for those willing to dive in and get their hands dirty.

### POWERFUL PRINTER

The beds, as well as some tool head accessories, are held in place magnetically, which worked quite well even against a few jams. Our prints turned out great and we were pleased with the ease of tool head swapping and the variety of capabilities. Even if this were only a 3D printer, it would be a welcome one in our collection, but we were just getting started.

### DOING IT ALL

Leveling the laser engraving head was a tad confusing, but the tool head itself was easy to use and we were quickly engraving and cutting to our heart's content. The milling head was more challenging, but we were able to get it carving through wood, even without the tutorials to help us. Well-built and rugged, the paste extruder was mechanically up to task. Paste extrusion is a lot of experimentation, followed by the occasional success, and the 2.0 SX will allow you to get a few of those.

Using Voxelizer software for all of the tools is confusing at first, but after awhile the workflow starts to make sense, and the ability to easily switch between tools and use cases without having to switch software is a definite plus. Unfortunately moving away from 3D printing is where the documentation gap really starts to appear, but some tools were straightforward, and ZMorph seems to be constantly updating their tutorials.

### ONE-STOP MACHINE SHOP

The sheer variety of tool heads the ZMorph 2.0 SX provides is stunning, and the results lived up to expectations. As the documentation and software catches up over time this machine will only become even easier to use. While these hybrid machines all require a bit of sweat equity at these early stages to get them running, we found the 2.0 SX to be a solid offering — with more good things to come. If you are looking for a single machine to do it all, look no further.

**EVEN IF THIS WERE ONLY A 3D PRINTER, IT WOULD BE A WELCOME ONE IN OUR COLLECTION**

- **MANUFACTURER** ZMorph
- **PRICE AS TESTED** $3,890
- **BUILD VOLUME** 250×235×165mm with covers, 300×235×165mm open
- **BED STYLE** Heated glass bed for printing, comes with BuildTak, wooden and metal beds for machining
- **FILAMENT SIZE** 1.75mm as tested (3mm capable)
- **TOOL HEADS** 3D printing extruder, dual extruder, paste extruder, milling head, laser module
- **OPEN FILAMENT?** Yes
- **TEMPERATURE CONTROL?** Yes, bed (120°C max), extruder (225°C max)
- **PRINT UNTETHERED?** Yes (SD card, internal drive — unplug after USB, LAN port also available, and Wi-Fi when connected to router)
- **ONBOARD CONTROLS?** Yes (LCD touchscreen)
- **HOST/SLICER SOFTWARE** Voxelizer recommended; Cura
- **OS** Mac Windows Linux (older version for Linux)
- **FIRMWARE** Open source Smoothieware, GNU GPL
- **OPEN SOFTWARE?** Voxelizer is closed source but open source Cura is optional
- **OPEN HARDWARE?** No (open source firmware but not all hardware is open source)
- **MAXIMUM DECIBELS** 50.8

### PRO TIPS

**CHECK THE WIKI** — an ever-growing list of information and tutorials will help get you on your way.

**TAKE YOUR TIME** — don't rush the setup and calibration.

**DON'T RISK IT!** Laser glasses for everyone in the room, or else!

### WHY TO BUY

A multi-use machine in sleek futuristic packaging netted us surprising results. While some details are still being worked out, we found a tool that did many jobs acceptably, and some great.

zmorph3d.com

Christopher Garrison

# BoXZY

## A new kid on the block that's taking everyone's lunch money

Written by Jean Carlos Cedré

**THE BOXZY IS A 3-IN-1 MACHINE THAT FUNCTIONS AS A CNC MILL**, laser engraver, and 3D printer. This desktop hybrid sports a solid aluminum frame, which encloses its industrial-level ball screws and magnetically coupled build plate. With the quality of these components the BoXZY definitely feels up to making anything you can throw at it.

### PROFICIENT PRINTER

Compared to other big name brands the BoXZY's 3D printing capabilities hold up well for a machine that does more than just 3D printing. It comes equipped with a 0.4mm nozzle and can handle PLA easily. The BoXZY community even has guides up on how to add a heated bed element for those of you who want to print in ABS or some exotic filament.

### CAPABLE CNC AND LASER

The BoXZY's CNC milling capabilities are also on par with some other desktop CNC's out there. The kit comes with a 1¼-horsepower Makita router with spindle speeds from 10,000rpm to 30,000rpm. Prepping for milling is a breeze with a provided sacrificial board and metal grips, but don't get too excited: The kit only comes with a ¼ milling bit which doesn't work well for any intricate or small milling projects. Different milling bits and even adapters for very fine milling are available for purchase.

The laser etching capability can come in handy when you want to add some finishing touches to a project. While the 2W laser is on the weaker side, it still provides enough of a punch to etch onto wood, leather, acrylic, and many other materials. The BoXZY software allows you to use bitmap images, and even an Inkscape plugin to export a custom design as a G-code file.

### VERSATILE WORKHORSE

Having a jack-of-all-trades in your shop may come in handy when you need it, and if you already have the resources to get a 3D printer in the same price range then why not get a machine that will give you more bang for your buck? The BoXZY still has a lot of room for improvements, but with what I have seen so far I am sure this will be an exciting machine to watch.

boxzy.com

### PRO TIPS

Don't remove the rapid swap head collets, this can interfere with machine homing.

**3D PRINTING** — A glue stick will help your first print layer stick to the bed.

**LASER** — Include the G-code command to turn off the laser once it's done engraving or it can stay on and continue burning your part.

**CNC** — Watch where you attach the provided clamps, they can catch on the machine when the Z-axis moves up.

### WHY TO BUY

Printing, etching, and milling — this machine provides an almost unparalleled flexibility.

- **MANUFACTURER** BoXZY
- **PRICE AS TESTED** $3,599
- **BUILD VOLUME** 165×165×165mm
- **BED STYLE** Non-heated (but you can add a heated bed to it)
- **FILAMENT SIZE** 1.75mm
- **TOOL HEADS** 3D printing extruder, laser module, CNC milling router
- **OPEN FILAMENT?** Yes (supports PLA, ABS, and PVA)
- **TEMPERATURE CONTROL?** Yes, tool head (230°C max)
- **PRINT UNTETHERED?** No
- **ONBOARD CONTROLS?** No (power switch only with an e-stop on power supply)
- **HOST/SLICER SOFTWARE** Repetier, BoXZY interface
- **OS** Mac, Windows
- **FIRMWARE** Vendor recommended firmware which they offer on their how-to website
- **OPEN SOFTWARE?** Yes (uses GNU General Public License inherited from the Repetier-Firmware)
- **OPEN HARDWARE?** No
- **MAXIMUM DECIBELS** 71.3


Christopher Garrison

**AS A JACK-OF-ALL-TRADES THE BOXZY CAN DO MULTIPLE THINGS — AND CAN DO THEM WELL.**

# PRO4824

## A modular, expandable system keeps this capable machine competitively priced

Written by Matt Stultz

**NUMEROUS TIMES OVER THE PAST FEW YEARS I HAVE PULLED UP THE CNC ROUTER PARTS WEBSITE** and started configuring a router I would like to build. When they contacted me about being included in this year's round of testing, I finally got to try one out, and I could not be happier with this machine.

### CUSTOM COMBINATIONS

At CNC Router Parts everything is modular and expandable. The base price is not for a working machine, but simply a frame. You can add on motor and electronics packs, spindles and mounting options, various sensors, and just keep going from there. Of course, all of these quickly add up — but there is still a lot of cost savings to be had compared to their competitors.

This modular system does mean that there is a lot of assembly work, but most large machines require at least some kind of setup. The 48"×24" cutting space is plenty to get started with furniture and other objects, but you'll need to cut down plywood sheets. The more industrious will find that they can pass through sheets to cut larger pieces at one time. If and when you decide it's time to upgrade to a 4'×4' or the coveted 4'×8' (full sheets of plywood), there are kits available that make it easy to do.

Our testing included cutting an AtFab chair, and the process was smooth and painless. While many CAM solutions will work for CNC Router Parts machines, they recommend VCarve Pro from Vectric and it's the perfect solution, making laying out your designs and then planning the machining operations a fairly easy process.

CNC Router Parts uses the industry standard Mach3 software for controlling their machines. While extremely powerful, it's not the most intuitive. Keeping Mach3 for the veterans while offering a second, more streamlined solution would be a big help for new users.

### GREATER POSSIBILITIES

A large flat bed CNC router is a tool that opens up new levels of projects for makers. The PRO4824 is excellent for anyone who wants to get started with a larger router but doesn't have the space for a full 4'×8'.

cncrouterparts.com

- **MANUFACTURER** CNC Router Parts
- **BASE PRICE** $3,500
- **PRICE AS TESTED** $7,637
- **ACCESSORIES INCLUDED AT BASE PRICE** None, the base price is for a frame only — no electronics
- **ADDITIONAL ACCESSORIES PROVIDED FOR TESTING** Electronics, spindle, leg kit, Mach3 software, proximity sensors, Z touch plate
- **BUILD VOLUME** 1,219×609×203mm
- **MATERIALS HANDLED** Wood, plastics, foam, light metals
- **WORK UNTETHERED?** No
- **ONBOARD CONTROLS?** E-stop and power switches only
- **DESIGN SOFTWARE** Compatible with many but works best with VCarve Pro from Vectric
- **CUTTING SOFTWARE** Mach3
- **OS** Windows
- **FIRMWARE** Proprietary
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No

### PRO TIPS

Buying additional parts rounds this machine out to a very capable workhorse while still coming in well under the cost of some of its competitors.

### WHY TO BUY

First, it's rock solid. Second, it's modular — want to expand to a full 8' machine in the future? You're covered.


Christopher Garrison

# PCNC 440

## This machine packs the power of industrial-grade metalworking into a workshop-sized package

Written by Matt Stultz

**MOST OF THE CNC MACHINES THAT WE TEST ARE TARGETED TOWARDS CUTTING WOOD, PLASTIC, AND OTHER SHEET MATERIAL,** with the possibility of light metalworking. The Tormach PCNC 440, on the other hand, is purpose-built for cutting metals — and lots of it. Of course, metal is hard and so is working with it; in trained hands the 440 is production ready, but getting your skills up to speed can come with a few bumps in the road.

### MONEY WELL SPENT

The deluxe packages may double the cost of this machine, but the included specialty tools (measurement gauges, an auto coolant system, an enclosure, a selection of end mills, collets, and tool holders, etc.) are well worth it.

The most important accessory included in the deluxe package is the control system. A custom PC comes with Tormach's Path Pilot software pre-installed. On first boot, you will choose which machine you are connecting to and it will load up all the configurations to run it. One thing to keep in mind if you decide not to order a deluxe package: The PCNC 440 connects to your computer with a DB25 cable, which has been long phased out from your average PC. The frame and table of the PCNC 440 are cast iron and you need an engine hoist to lift and move the machine, so you should definitely consider purchasing the stand.

### METAL TESTS YOUR METTLE

In our tests, cutting wood was smooth and easy — it felt as if you could just crank up the speed and it would still cut like it was passing through tissue paper (although I wouldn't suggest doing so). Moving to aluminum, however, was a pretty steep learning curve. Tormach has a few very good instructional videos on their site and a great community independently generating content. I would love to see Tormach create example aluminum projects that are set up to use their included bits and tools.

Spending time on the PCNC 440, I know I have a lot to learn, but the machine has a lot to reward anyone interested in putting forth the effort.


Christopher Garrison

### PRO TIPS

Measure your movements before attempting your first cut. There is a known issue: Some machines are shipped with incorrect step settings, as was the case with the unit we received.

### WHY TO BUY

The PCNC 440 puts the power of industrial-grade CNC metalworking in a package that can fit in almost anyone's garage or workshop.

- **MANUFACTURER** Tormach
- **BASE PRICE** $4,950
- **PRICE AS TESTED** $9,895
- **ACCESSORIES INCLUDED AT BASE PRICE** None
- **ADDITIONAL ACCESSORIES PROVIDED FOR TESTING** Deluxe package: control system, mills, vice, and numerous tools
- **BUILD VOLUME** 254×158×254mm
- **MATERIALS HANDLED** This machine will work with just about anything you throw at it — wood, metal, plastics, wax, foam, etc.
- **WORK UNTETHERED?** No
- **ONBOARD CONTROLS?** E-stop and activation button only
- **DESIGN SOFTWARE** The PCNC 440 comes with a yearlong license for Fusion 360, which can be used for design but is also the primary CAM package for the 440
- **CUTTING SOFTWARE** Path Pilot from Tormach
- **OS** Path Pilot comes installed on its own control machine
- **FIRMWARE** Proprietary
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No

tormach.com

# X-CARVE

Written by Jennifer Schachter

## Inventables' new machine is the gateway drug to subtractive manufacturing

**THIS EDITION OF THE X-CARVE IS A MAJOR IMPROVEMENT TO THE POPULAR DESKTOP CNC.** The beefed-up gantry takes it beyond its predecessor in terms of production quality. The new clamp system is nothing short of genius. Changing bits can be a little awkward (not uncommon for a router). Its shortcoming is the lack of dust collection, but you can build a simple vacuum rig for it.

### THE EASE OF EASEL

Easel, Inventables' web-based CAD/CAM software, isn't perfect, but it's the first truly entry-level interface for CNC operation — even the most rookie user will be making functional objects on their first day. The advanced menus let you customize feed, speed, step over, and the like for fine-tuning.

### AN OBVIOUS CHOICE

The insanely easy interface, fully integrated toolchain, and supportive community make the X-Carve a no-brainer. Experienced users will appreciate its versatility and the fully open source hardware. From 500-1000mm, there's a size for every shop.


- **MANUFACTURER** Inventables
- **BASE PRICE** $1,329
- **PRICE AS TESTED** $1,493
- **ACCESSORIES INCLUDED AT BASE PRICE** 110V DeWalt 611 spindle and mount, 750mm wasteboard kit, 750mm side board kit, X-Controller kit, NEMA 23 750mm motor kit, 750mm drag chain kit, 750mm homing switch kit, Z-Probe, toolkit, clamp set, digital calipers, end mill starter set, bit set for wood and plastic, bit set for fine detail engraving, wood + MDF material bundle
- **ADDITIONAL ACCESSORIES PROVIDED FOR TESTING** We tested the medium-sized 750mm version rather than the base 500mm version
- **BUILD VOLUME** 750×750×67mm
- **MATERIALS HANDLED** Wood, plastic, PCBs, metal
- **WORK UNTETHERED?** No
- **ONBOARD CONTROLS?** E-stop and basic play, pause, stop controls
- **DESIGN SOFTWARE** Easel allows for basic designs, but any vector creation software will work
- **CUTTING SOFTWARE** Easel
- **OS** Windows 7 or newer, OS X 10.10 (Yosemite) or newer
- **FIRMWARE** Grbl
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** Yes

**PRO TIPS**

So simple and user-friendly, you can start carving in the first 2 minutes. However, if you're a new user, read the tutorials and check the forums.

inventables.com

# NOMAD 883 PRO

Written by Chris Yohe

## Make less mess with this highly capable carver

**THE NOMAD'S SLEEK DESIGN HOUSES A POWERFUL DESKTOP CNC MILL** with a great software suite that can handle amazing projects.


### A CLEAN MACHINE

The highly capable Nomad 883 Pro keeps tidy enough to not get banished to the garage. We milled through foam, wax, wood, plastics, and even a little metal by the end of our testing and consistently were left with great results and a surprisingly clean work area. Its bed size is on the smaller side, and a self-zeroing Z-probe would be a nice addition on top of its tool-length sensing.

### SOFTWARE FOR ALL SKILL LEVELS

The Nomad comes with a suite of software including the beginner-oriented Carbide Create and the more advanced MeshCAM, each with useful features for designing files, streamlining toolpath generation, and dialing in settings. More documentation is always welcome, but Carbide 3D is using email newsletters to provide must-read mini-courses and tutorials.

- **MANUFACTURER** Carbide 3D
- **BASE PRICE** $2,699
- **PRICE AS TESTED** $3,100+
- **ACCESSORIES INCLUDED AT BASE PRICE** MeshCAM 3D CAM software, Carbide Create 2D CAD/CAM software, MDF wasteboard, ⅛" ER-11 collet and wrenches, ⅛" ball mill, ⅛" end mill
- **ADDITIONAL ACCESSORIES PROVIDED FOR TESTING** Flip jig, threaded work surface, low profile vise, various .125 bits (ball and straight), various materials
- **BUILD VOLUME** 203×203×76mm
- **MATERIALS HANDLED** Wood, plastic (ABS, acrylic, Delrin, HDPE), PCBs, soft metals up to ¼ (aluminum, brass, etc.)
- **WORK UNTETHERED?** No
- **ONBOARD CONTROLS?** Power switch/stop
- **DESIGN SOFTWARE** Carbide Create for beginners/easy design; MeshCAM for advanced design/3D capabilities
- **CUTTING SOFTWARE** Carbide Motion
- **OS** Mac OS X, Windows
- **FIRMWARE** GRBL board, GRBL is open, customized version for them
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** Yes

**PRO TIPS**

Always remember to set your zero! All that jogging with no pay-off makes us sad.

You can do a lot with SVG! Thinking in layers can make complex projects much easier.

*Getting Started with CNC* — one of *Make:*'s latest books — is an essential read, and these guys wrote it!

carbide3d.com

# SHOPBOT DESKTOP MAX

Written by Kurt Hamel

## This powerful machine takes workbench performance to the limit

shopbottools.com

### PRO TIPS

The waste-board that comes with the machine can shift during shipping. Make sure it's centered on the bed before running the surfacing and rabbet scripts prescribed by the user manual.

- **MANUFACTURER** ShopBot
- **BASE PRICE** $9,090
- **PRICE AS TESTED** $9,285 (including the $195 Mini Enclosure)
- **ACCESSORIES INCLUDED AT BASE PRICE** ¼" and ½" collets, collet wrenches, wasteboard, and Z-zero assembly
- **ADDITIONAL ACCESSORIES PROVIDED FOR TESTING** Mini Enclosure
- **BUILD VOLUME** 965×635×140mm
- **MATERIALS HANDLED** Wood, plastic (ABS, acrylic, Delrin, HDPE), foam, possibly soft sheet metals such as aluminum
- **WORK UNTETHERED?** No
- **ONBOARD CONTROLS?** E-stop and spindle speed control
- **DESIGN SOFTWARE** VCarve Pro from Vectric can be used for some designing and generating the needed G-code. Compatible with numerous other pieces of design software.
- **CUTTING SOFTWARE** ShopBot Control Software
- **OS** Windows
- **FIRMWARE** Proprietary
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No

**BETTER CONSTRUCTION, A STIFF FRAME, AND BETTER SOFTWARE** give the ShopBot Desktop Max professional capabilities and precision worthy of its price tag. It doubles the cutting area of its cousin, the Desktop. Although you can fit a ¼ sheet of plywood (48"×24") on the bed, the Max only cuts into the first 36" of the workpiece. However, a clever layout of parts allows you to flip the sheet end-to-end and use the whole piece in two steps.

### POWERFUL SOFTWARE

Like ShopBot's other mills, the Max uses the industry's best software, VCarve Pro, to generate toolpaths — normally an expensive additional purchase. VCarve is easy enough for beginners and powerful enough for most CNC tasks. The Max's control software is ShopBot 3 (free to download), which ran perfectly on our 10-year-old netbook computer.

### A GOOD VALUE

If you can afford it, the ShopBot Desktop Max is a worthwhile upgrade from the smaller Desktop and Buddy 32 models without breaking into five figures.


# MONOFAB SRM-20

Written by Kurt Hamel

## Seamless workflow and clear documentation make for a great user experience

rolanddg.com

### PRO TIPS

If you wake up your computer by hitting the space bar, you could inadvertently cancel your job. Minimize the VPanel control software if you plan to walk away from the machine.

- **MANUFACTURER** Roland
- **BASE PRICE** $4,495
- **PRICE AS TESTED** $4,495
- **ACCESSORIES INCLUDED AT BASE PRICE** Cutting tool, collet, set screw, spanners (7,10mm / 0.28, 0.39 inches), hexagonal wrench (size 2,3 mm / 0.059, 0.12 inches), positioning pins, double-sided tape
- **ADDITIONAL ACCESSORIES PROVIDED FOR TESTING** None
- **BUILD VOLUME** 203×152.4×60.5mm
- **MATERIALS HANDLED** Modeling wax, wood, foam, acrylic, polyacetate, ABS, PCBs
- **WORK UNTETHERED?** No. Unit must be connected by USB to a computer running VPanel for SRM-20 during cutting.
- **ONBOARD CONTROLS?** Power switch only
- **DESIGN SOFTWARE** Click Mill (V1.32) for simple cutting, iModela Creator (V1.2) for 2D, MODELA Player 4 (V2.12) for 3D
- **CUTTING SOFTWARE** VPanel
- **OS** Windows 7, 8, 10 (32 and 64 bit)
- **FIRMWARE** Proprietary
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No

**ROLAND IS A TRUSTED NAME IN VINYL CUTTERS** and makes the legendary Modela MDX40 PCB Mill. Their desktop CNC, the monoFab SRM-20, boasts accuracy comparable to other manufacturers. However, the user experience is where the monoFab really excels.

### LESSONS FROM 3D PRINTERS

There are no fancy lights or features, but the thorough documentation means using the machine is very clear. The monoFab uses different software for 3D parts, 2D parts, and on-the-fly 2D operations, but they all share a user-friendly approach. Once tool paths are defined, clicking "cut" starts the job, just like clicking "print" in popular 3D printing software. You can tweak the parameters, but often the default settings are acceptable.

### A STRAIGHTFORWARD MACHINE

If you want a small CNC mill from a trusted brand that can ace small jobs with the user-friendly workflow of a 3D printer, the monoFab SRM-20 is for you.


Christopher Garrison

# CARVEY 2016

Written by Matt Dauray

## This sexy machine is the strong, silent type

**THE NEW CARVEY'S AIM IS TO BRING CNC MACHINING TO THE MASSES** via an easy-to-use, cloud-based interface that couples with an uncomplicated physical machine.

### SIMPLIFIED SYSTEM

The machine comes fully assembled, and powering it up is as easy as plugging in the power cord and USB, then hitting the rocker switch on the back. It's self-zeroing; when starting a cut, the bit taps a button to determine material thickness, then gets right to business. Carvey is designed to work with Inventables' entry-level, browser-based Easel software, but seasoned machinists will be able to get the most out it by designing with more powerful programs, and using Easel as merely a translator.


### EFFICIENT AND QUIET

The Carvey is a sleek, sexy, streamlined machine that pretty much does exactly what it is advertised to do. It works beautifully and makes so little noise you almost forget it's running. If you're in the market for a user-friendly desktop machine, the Carvey is a great choice.

- **MANUFACTURER** Inventables
- **BASE PRICE** $1,999
- **PRICE AS TESTED** $1,999
- **ACCESSORIES INCLUDED AT BASE PRICE** Smart corner clamp with auto Z-zero, innovative side clamp system (which works on material up to ¾" thick) with three lengths of clamps (5 each) and two heights of clamp bases (5 each), two wrenches, a 1/16" solid carbide bit, a set of calipers
- **ADDITIONAL ACCESSORIES PROVIDED FOR TESTING** None
- **BUILD VOLUME** 290×400×70mm
- **MATERIALS HANDLED** Aluminum, copper, MDF, plastics, acrylics, woods, PCBs
- **WORK UNTETHERED?** No
- **ONBOARD CONTROLS?** Front facing "pause" switch
- **DESIGN SOFTWARE** Easel
- **CUTTING SOFTWARE** Easel imports SVG and G-code
- **OS** Mac, Windows
- **FIRMWARE** Custom
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No

**PRO TIPS**

If you're new to CAD/CAM and looking to produce your own 3D carvings, brush up on Fusion 360, or MeshCAM etc. Cam experience beforehand greatly increases the machine's functionality right out the box.

**inventables.com**

# SHAPEOKO XXL

Written by Ryan Priore

## This benchtop powerhouse illustrates why you go big or go home

**THE OPEN SOURCE XXL OFFERS FOUR TIMES THE CUTTING AREA OF THE SHAPEOKO 3.** Available exclusively as a kit, it ships with everything you need to begin carving away except for your favorite stock material.

### POWER AND CONTROL

Our testing unit was supplied with a DeWalt DWP611 compact router, however Carbide 3D offers kits that let you bring your own to the party. The 1-¼ horsepower DeWalt combined with four NEMA 23 stepper motors glided the ¼-inch end mill through stock material like a hot knife through butter. The XXL shipped with Carbide Create, which simplified the workflow for translating vector imagery into G-code for hand off to the Carbide Motion software, which ultimately controls the tool head for carving up your project.

### BANG FOR YOUR BUCK

The XXL is simply a tremendous value for the capability and usable cutting area, just make sure that you have a large horizontal surface in your shop ready for its nearly 12½-square-foot footprint.


- **MANUFACTURER** Carbide 3D
- **BASE PRICE** $1,730
- **PRICE AS TESTED** $1,730
- **ACCESSORIES INCLUDED AT BASE PRICE** One ¼" carbide end mill
- **ADDITIONAL ACCESSORIES PROVIDED FOR TESTING** None
- **BUILD VOLUME** 838×838×76mm
- **MATERIALS HANDLED** Wood, plastic (ABS, acrylic, Delrin, HDPE), PCBs, soft metals up to ¼" (aluminum, brass, etc)
- **WORK UNTETHERED?** No
- **ONBOARD CONTROLS?** Power switch only
- **DESIGN SOFTWARE** Carbide Create for beginners/easy design, MeshCAM for advanced design/3D capabilities (both written in house)
- **CUTTING SOFTWARE** Carbide Motion
- **OS** Mac OS X, Windows
- **FIRMWARE** Grbl board, Grbl is open, customized version for them
- **OPEN SOFTWARE?** No, desktop software developed in house. Grbl itself is open and proceeds fund Grbl development.
- **OPEN HARDWARE?** Yes

**PRO TIPS**

Take advantage of your keyboard's arrow keys for the subtle jogging movements required when aligning the tool to the cutting origin. Have that shop vacuum ready with an extension attachment to keep your hands out of harm's way.

**carbide3d.com**

Christopher Garrison

# CAMM-1 GS-24

Written by Mandy L. Stultz

## This hardworking vinyl cutter handles a wide variety of materials

rolanddga.com

### PRO TIPS

While the hardware for this machine is outstanding and proved very capable for multiple materials, the software poses limitations. There's no support for Mac OS or beyond Windows 8.1, so a non-upgraded Windows machine is required.

### WHY TO BUY

The Roland GS-24 is capable of cutting many additional materials: heat transfer, fabrics, auto film, and more. The wide cutting area works well for larger designs as well as smaller graphic multiples.

- **MANUFACTURER** Roland
- **PRICE AS TESTED** $1,995
- **CUTTING SIZE** 584×25000mm
- **CUT UNTETHERED?** No
- **ONBOARD CONTROLS?** Yes (buttons and lever to adjust cut head home, material positioning, cut head pressure, and test cut)
- **CONTROL SOFTWARE** Roland OnSupport and Roland CutStudio. Must be downloaded. Plug-ins are also available for Adobe Illustrator and CorelDRAW.
- **OS** Windows 7/8/8.1 (32/64-bit), Windows Vista Home Premium (32-bit)/ Business (32/64-bit)
- **OPEN SOFTWARE?** No

**REGARDLESS OF SIZE — FROM A SERIES OF SMALL STICKERS TO LARGER DESIGNS FOR SIGNAGE —** the Roland CAMM-1 GS-24 vinyl cutter performed with flying colors. Whether cutting out vinyl decals, heat transfer designs, paper, laminates, or more, this machine held strong.

### DIFFICULT SOFTWARE

While the machine itself is one of the best we've had our hands on, the two programs required, Roland OnSupport and Roland CutStudio, had several limitations. As of press time, neither supports the latest version of Windows or Mac OS. CutStudio was handy for simple designs, but not user-friendly for anything complex. Plug-ins are available for Adobe Illustrator and CorelDRAW, but if you don't already have those programs, add them to your costs.

### PUT A SIGN ON IT

This machine is ideal for small and large businesses to handle signs, decals, and more. Plus it's a solid cutting machine for hackerspaces and group organizations to produce promotional materials. If you have the budget, the GS-24 is a great choice.


# VOCCELL DLS

Written by Matt Dauray

## This quality laser cutter is equally suited for business or hobby

voccell.com

### PRO TIPS

Vlaser's "preview" feature offers a visual preview, estimated processing time, and even a simulation of your job. On the laser itself, the "run extents" command will run the extent box of your job with the laser off, so you can make sure it's in the position you want it.

### WHY TO BUY

Engraving is this machine's bread and butter, as its 40-watt tube will only cut material up to 0.313" (about 8mm) thick. Sign makers and engravers could run this machine all day for a relatively low initial investment.

- **MANUFACTURER** Voccell
- **PRICE AS TESTED** $4,999
- **BUILD VOLUME** 546×349.25×114mm
- **TUBE** 40 watt $CO_2$ laser tube. Class 4
- **CUT UNTETHERED?** Yes (machine carries onboard memory)
- **ONBOARD CONTROLS?** Yes (directional pad and menu buttons, separate interior light switch, e-stop switch)
- **HOST SOFTWARE** Vlaser
- **OS** Windows XP, 7, 8 (32 and 64 bit), OSX 10.7
- **FIRMWARE** Proprietary
- **OPEN SOFTWARE?** No
- **OPEN HARDWARE?** No

**THE REAL POWER OF VOCCELL'S FLAGSHIP DLS IS ITS 100% DUTY CYCLE** at 90°F. The company is marketing it as an industrial moneymaker, rather than a hobbyist's tool — but for what's included in the price, I could see it being used in both settings.

### ARE YOU EXPERIENCED?

The DLS ships with almost everything you need to get started, including a whole stack of pre-cut material so you can really explore the machine's capabilities. Seasoned laser users should read ALL the setup instructions and tutorials, because some pieces of the workflow are a bit quirky. One major difference is that engraving and cutting operations cannot be completed in the same job, because the laser is focused differently for its respective operation.

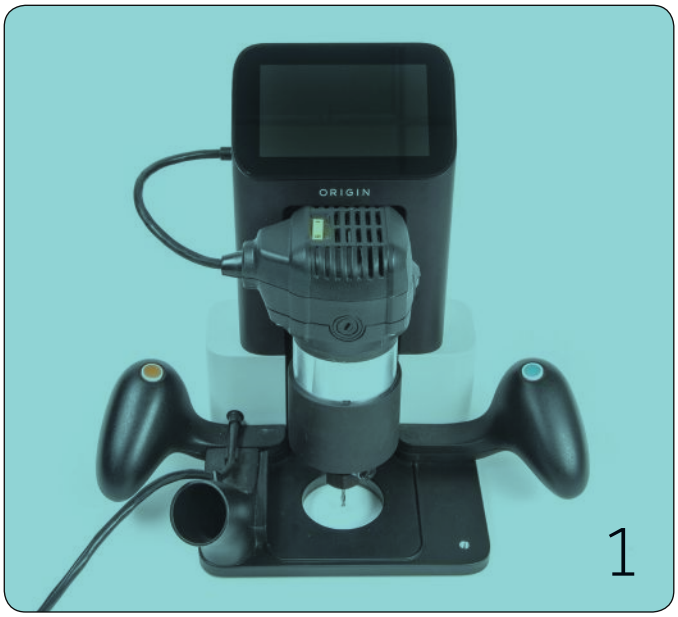
### CUTS TO THE CHASE

Our test cuts and engraving were very crisp. If you are in the market, the DLS may not have all the bells and whistles some upcoming competitors are showing off, but then again, it is a functioning laser you can have today!

Christopher Garrison

# ONES TO WATCH

## These machines promise to become the new tools of innovation



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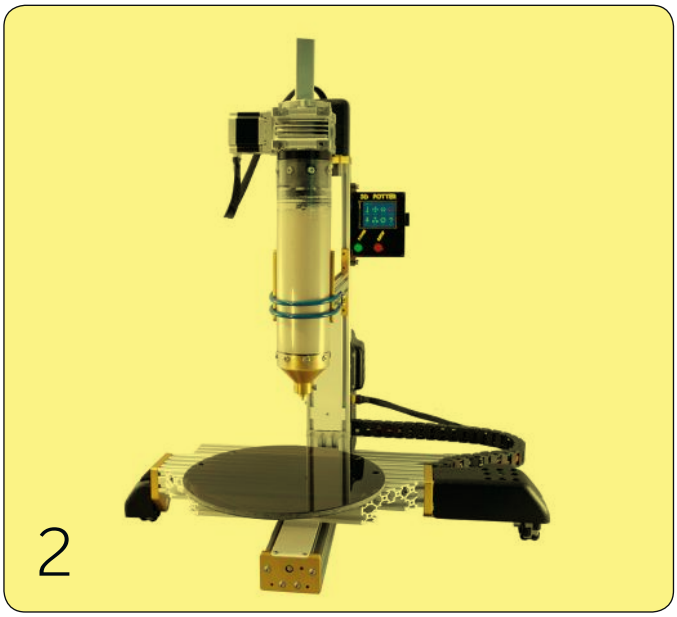
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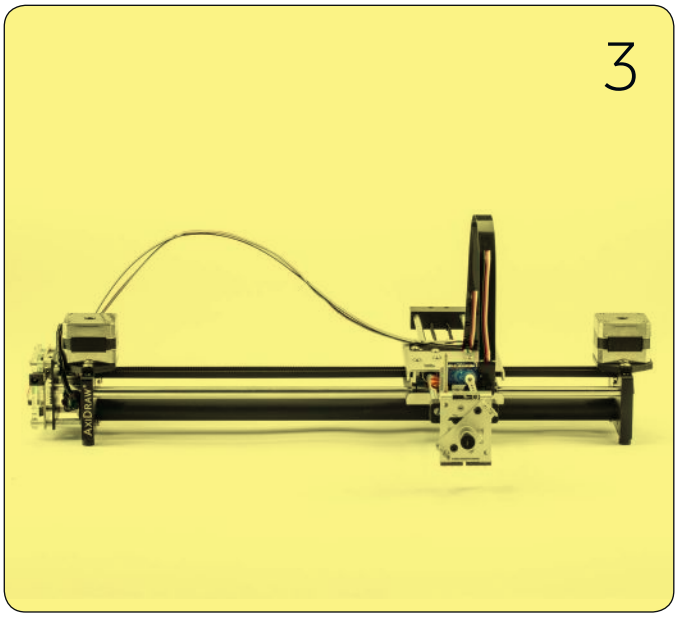

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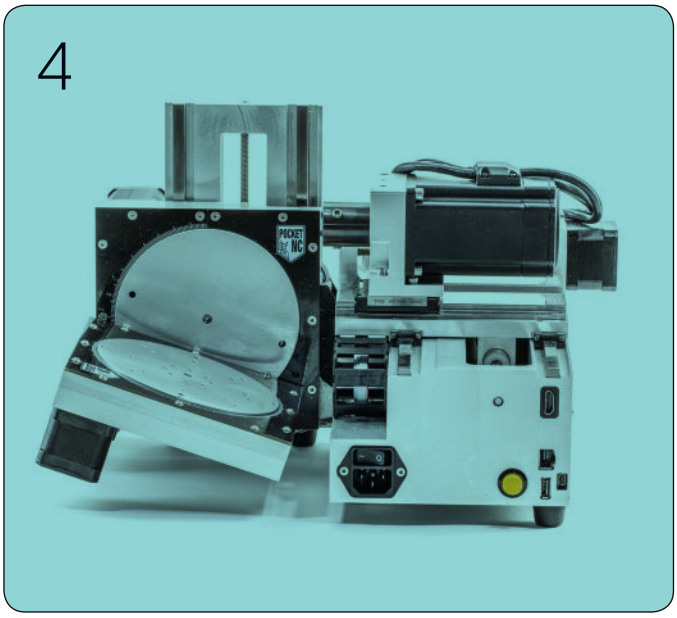

4

Hep Svadja, 3D Potter, Christopher Garrison

### WAZER

- **MACHINE TYPE** Desktop Waterjet
- **BASE PRICE** $6,000
- **WEBSITE** wazer.com


No longer just the domain of large industrial machines, Wazer offers hobbyists and small shops the ability to cut almost any material using pressurized water and abrasive aggregate. Its Kickstarter campaign ended early November, with machines promised to ship mid-2017. The prototype shows smooth functionality on glass, plastic, titanium and more; maximum thickness varies by material with ¼" aluminum and polycarbonate being on the upper limit. It's slower than an industrial machine and might be less cost effective than sending your design to a local shop, but for immediate convenience, this will be a game changer.

*— Mike Senese*

Wazer

# 1

## SHAPER ORIGIN

- **MACHINE TYPE** Handheld Assisted Mill
- **BASE PRICE** $2,099
- **WEBSITE** shapertools.com

The Shaper Origin is a router that has about two inches of computer numerically controlled motion in the X, Y, and Z directions. The tool pairs this mechanical configuration with a camera and a touchscreen display that lets you see your design superimposed on your workpiece. You move the router along the digital path with your clumsy hands and the Origin uses those two inches of motion in each direction to keep the cutting bit exactly on that line — stray too far from the line and the device lifts the cutting tool to prevent you from damaging the piece.

One of the best features of the Origin is its on-the-fly functionality for adding elements like finger joints. This is important and useful, but is probably overshadowed by the Origin's more obvious technical achievements.

There's one hang-up, however. I decided to make some furniture from a 4'×8' sheet of ¾" thick plywood, but in my excitement, I forgot about the unique deal the Origin makes with its user; it provides the brain and they provide the brawn. After a few hours of cutting, I moved on to other projects without a piece of furniture to show.

*— Kurt Hammel*

# 2

## POTTERBOT

- **MACHINE TYPE** Paste Extrusion Printer
- **BASE PRICE** $5,990
- **WEBSITE** deltabots.com

Printing in moist clay is much more forgiving than other materials. PotterBot's "vase mode" makes it incredibly easy to produce quality vessels. No hot end means you can manually shape and safely apply custom clay support structures on the fly. It is fast enough that its creations come out quite soft and can still be smoothed by hand afterwards. The PotterBot provides excellent compression and after a glaze firing the results can be as durable as traditionally made wares. High-resolution pottery designs present some material challenges, however.

PotterBot uses two omnidirectional wheels to achieve smooth, consistent movement on the X- and Y-axes. It has a sturdy aluminum slide gantry supporting the clay barrel and, despite the weight of the clay and motors, it incurs little or no sagging. The DC servomotors are fantastic, silent, speedy, and accurate.

*— Tom Burtonwood and Bowie Croisant*

# 3

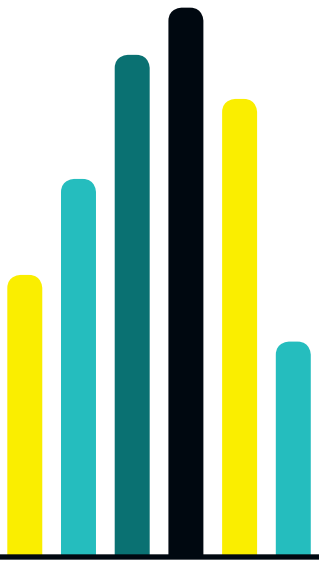
## AXIDRAW

- **MACHINE TYPE** Drawbot
- **BASE PRICE** $450
- **WEBSITE** evilmadscientist.com

The AxiDraw takes the pen plotter of yesteryear and brings it into the modern age, without feeling like you are lugging around a boat anchor. With the AxiDraw all of your vector artwork can be transferred to the physical page with incredible accuracy and detail.

To see the AxiDraw at work is to fall in love with it. I have to admit that when I first saw the device online, the price tag threw me off, and I wondered why it needed to be crafted out of milled aluminum. Once I tried it, I got it. The construction means that the AxiDraw is stable and won't shift as it glides through its motions quickly scribing your art to the page. And with its functionality, it is even capable of replicating signatures and calligraphy.

*— Matt Stultz*



# 4

## POCKET NC

- **MACHINE TYPE:** Five-Axis CNC
- **BASE PRICE** $4,000
- **WEBSITE** pocketnc.com

In addition to the standard CNC's forward/backward, left/right, and up/down movements, the Pocket NC is also able to tilt and rotate the workpiece, giving the cutting bit almost unlimited access to the material to produce hyper-complex shapes.

A five-axis desktop mill is no small feat, a fact that is proven by Pocket NC's lack of competition; most good ideas nowadays quickly have copycats nipping at their heels. Controlling the machine is tricky, but the Pocket NC team has been working with Autodesk to provide Fusion 360 CAM support for the complicated machining process that the two extra axes create.

The included end mill is capable of cutting wood, plastic, and wax, which are probably the best choices of materials for this machine. While Pocket NC has shown demos of parts cut from aluminum, the lack of a coolant system probably means milling metals should be avoided.

The construction is rock solid — you will be surprised by its weight. To ensure that it's rigid enough to function in five axes, the entire thing is milled from 6061 aluminum. Pre-loaded lead screws help minimize backlash to keep the machine as accurate as possible.

*— Matt Stultz*

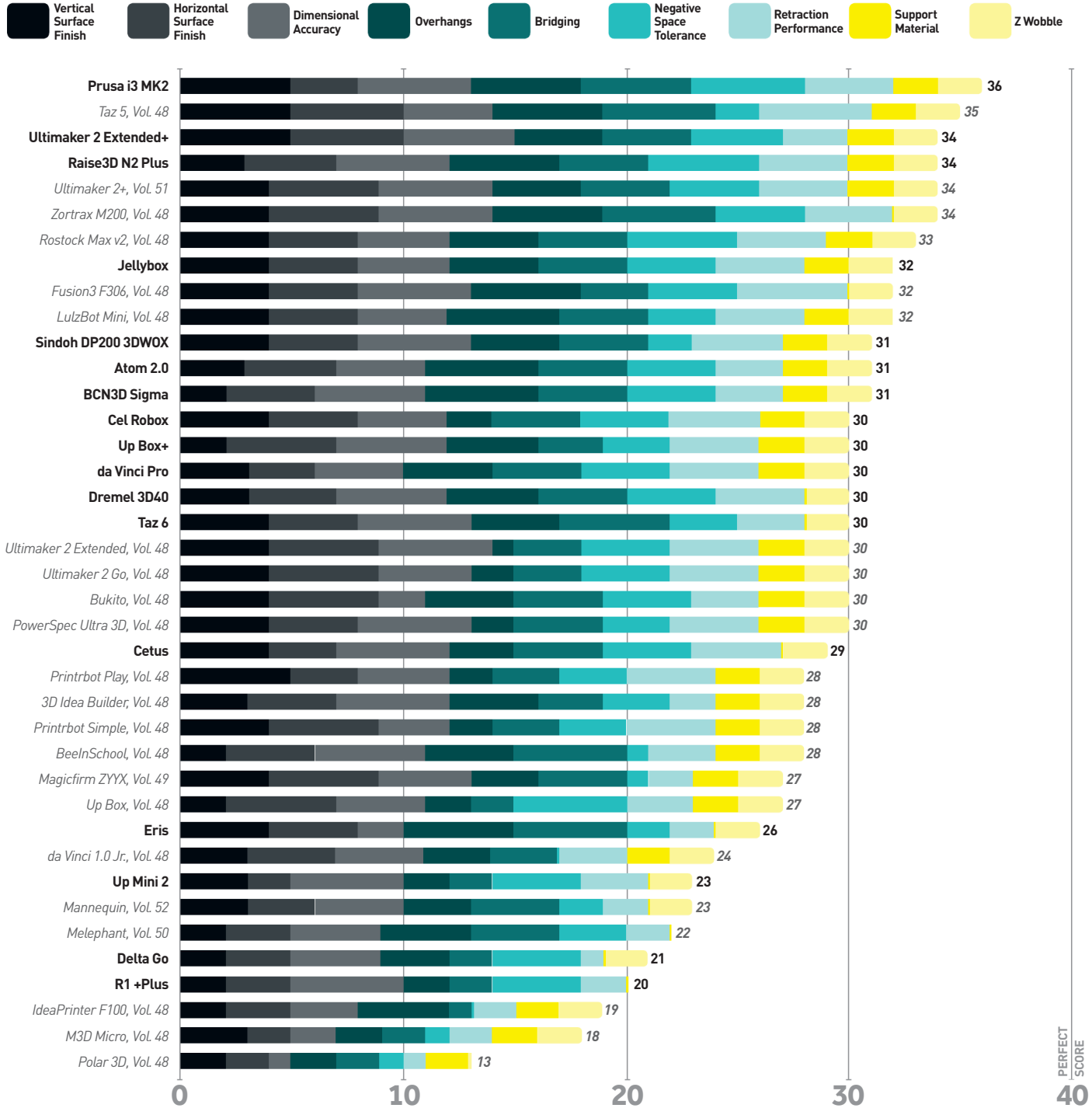
# BY THE NUMBERS

## Test scores and machine specs

There's no one machine that can do everything for everyone; use these charts to help find the right digital desktop fabricator for your needs. Find out more about our testing process at makezine.com/comparison/3dprinters/how-we-test/shootout.

### FFF PRINTER TEST SCORES

(includes machines reviewed in past volumes of *Make:*)

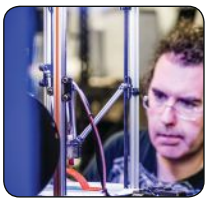


## FFF COMPARISON

(see all reviews: makezine.com/comparison/3dprinters)

| Machine | Manufacturer | Cost | Build Volume | Open Filament | Bed Style | Print Untethered | Open Source | Total Score | Review |
|---|---|---|---|---|---|---|---|---|---|
| Atom 2.0 | Atom | $1,699 | 220×220×320mm | Yes | Non-heated, glass | Yes (SD card) | No | 31 | Page 26 |
| BCN3D Sigma | BCN3D | $2,695 | 210×297×210mm | Yes | Heated, glass | Yes (SD card) | No | 31 | Online |
| Cel Robox | Cel | $1,326 | 210×150×100mm | Yes | Heated, PEI | Yes (unplug USB after starting print) | No | 30 | Page 26 |
| Cetus | Tiertime | $299 | 180×180×180mm | Yes | Non-heated, aluminum | Yes (Wi-Fi) | No | 29 | Online |
| da Vinci Pro | XYZprinting | $699 | 200×200×190mm | Yes | Heated, aluminum | Yes (Wi-Fi) | No | 30 | Online |
| Delta Go | Deltaprintr | $499 | 115mm diameter×127mm | Yes | Non-heated, aluminum | Yes (microSD card) | No | 21 | Online |
| DP200 3DWOX | Sindoh | $1,299 | 210×200×195mm | No | Heated, PEI | Yes (USB drive, wired LAN, wireless LAN) | No | 31 | Page 25 |
| Dremel 3D40 | Dremel | $1,299 | 255×155×170mm | No | Non-heated, plastic | Yes (USB drive) | No | 30 | Online |
| Eris | SeeMeCNC | $549 | 124mm diameter×165mm | Yes | Non-heated, BuildTak | No | Yes | 26 | Online |
| Jellybox | IMade3D | $949 | 170×160×150mm | Yes | Non-heated, aluminum | Yes, (SD card) | No | 32 | Page 25 |
| N2 Plus | Raise3D | $3,499 | 305×305×610mm | Yes | Heated, glass/BuildTak | Yes (Wi-Fi, SD, internal storage, or USB stick) | No | 34 | Page 24 |
| Prusa i3 MK2 | Prusa Research | $899 | 250×210×200mm | Yes | Heated, PEI | Yes (SD card) | Yes | 36 | Page 23 |
| R1 +Plus | Robo 3D | $800 | 254×228×203mm | Yes | Heated, glass | Default no (optional LCD and tablet) | Partial | 20 | Online |
| Taz 6 | LulzBot | $2,500 | 280×280×250mm | Yes | Heated, PEI | Yes (SD card) | Yes | 30 | Page 29 |
| Ultimaker 2 Extended+ | Ultimaker | $2,999 | 223×223×304mm | Yes | Heated, glass | Yes (SD card) | Yes | 34 | Page 24 |
| Up Box+ | Tiertime | $1,899 | 255×205×205mm | No | Heated, Up Flex Board | Yes (unplug USB after starting; wireless) | No | 30 | Page 29 |
| Up Mini 2 | Tiertime | $500 | 120×120×120mm | Yes | Heated, Up Flex Board | Yes (unplug USB after starting; wireless) | No | 23 | Online |



## CNC COMPARISON

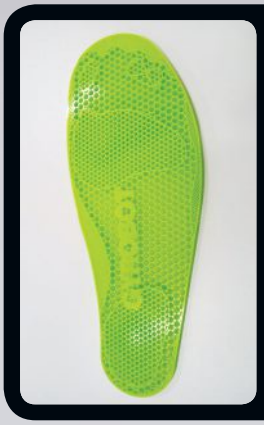
| Machine | Manufacturer | Cost | Build Volume | CAM Software | Materials Handled | Review |
|---|---|---|---|---|---|---|
| Carvey 2016 | Inventables | $1,999 | 290×400×70mm | Easel | Wood, light metal, plastic, PCB | 40 |
| MonoFab SRM-20 | Roland | $4,495 | 203×152.4×60.5mm | Click Mill, iModela Creator, MODELA Player 4 | Wood, plastic, wax, foam, PCB | 39 |
| Nomad 883 Pro | Carbide 3D | $2,699 | 203×203×76mm | Carbide Create or MeshCAM | Wood, light metal, plastic, PCB | 38 |
| PCNC 440 | Tormach | $4,950 | 254×158×254mm | Fusion 360 | Wood, metal, plastic, wax, foam, and more | 37 |
| PRO4824 | CNC Router Parts | $3,500 (base price is for frame only, no electronics) | 1219×609×203mm | VCarve Pro | Wood, light metals, plastics, foam | 36 |
| Shapeoko XXL | Carbide 3D | $1,730 | 838×838×76mm | Carbide Create or MeshCAM | Wood, light metals, plastic, PCB | 40 |
| ShopBot Desktop Max | ShopBot | $9,090 | 965×635×140mm | VCarve Pro | Wood, light metal, plastic, foam | 39 |
| X-Carve | Inventables | $1,329 | 750×750×67mm | Easel | Wood, metal, plastic, PCB | 38 |

# FABULOUS FABRICATION

## 9 Clever Creations You Can Make Too

Written by Eric Chu

**HERE ARE SOME OF OUR FAVORITE DIGITALLY FABRICATED PROJECTS** from makers, designers, and artists — and most are freely shared with plans so you can create your own, or iterate further.



### GENSOLE CUSTOM INSOLES

BY GYROBOT

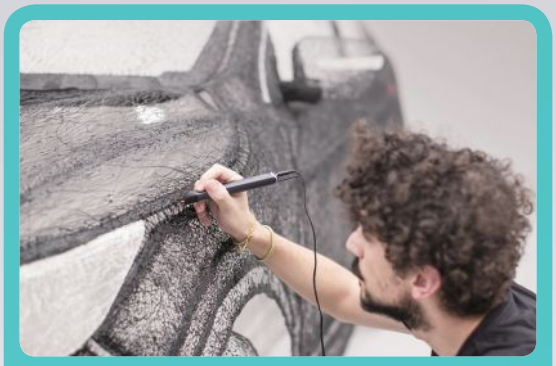
gensole.com

Everyone's feet are different and finding the perfect-fitting shoe insole can be difficult. The Gensole web app uses 3D foot scans to generate custom 3D-printable insoles for sweet support.

### DEER RACK

makezine.com/go/deer-rack

CNC this faux taxidermy trophy from ½" (12mm) ply; use as a hanger for your hat, charms, or even your two-wheeled steed.



### WORLD'S LARGEST 3D PEN SCULPTURE BY NISSAN

makezine.com/go/3d-drawn-car

This full-size Nissan Qashqai crossover was created using the 3Doodler pen and took 800 hours to complete. How? Parts of the car were pre-assembled, then fused together. Try making your own version (though probably a little smaller).

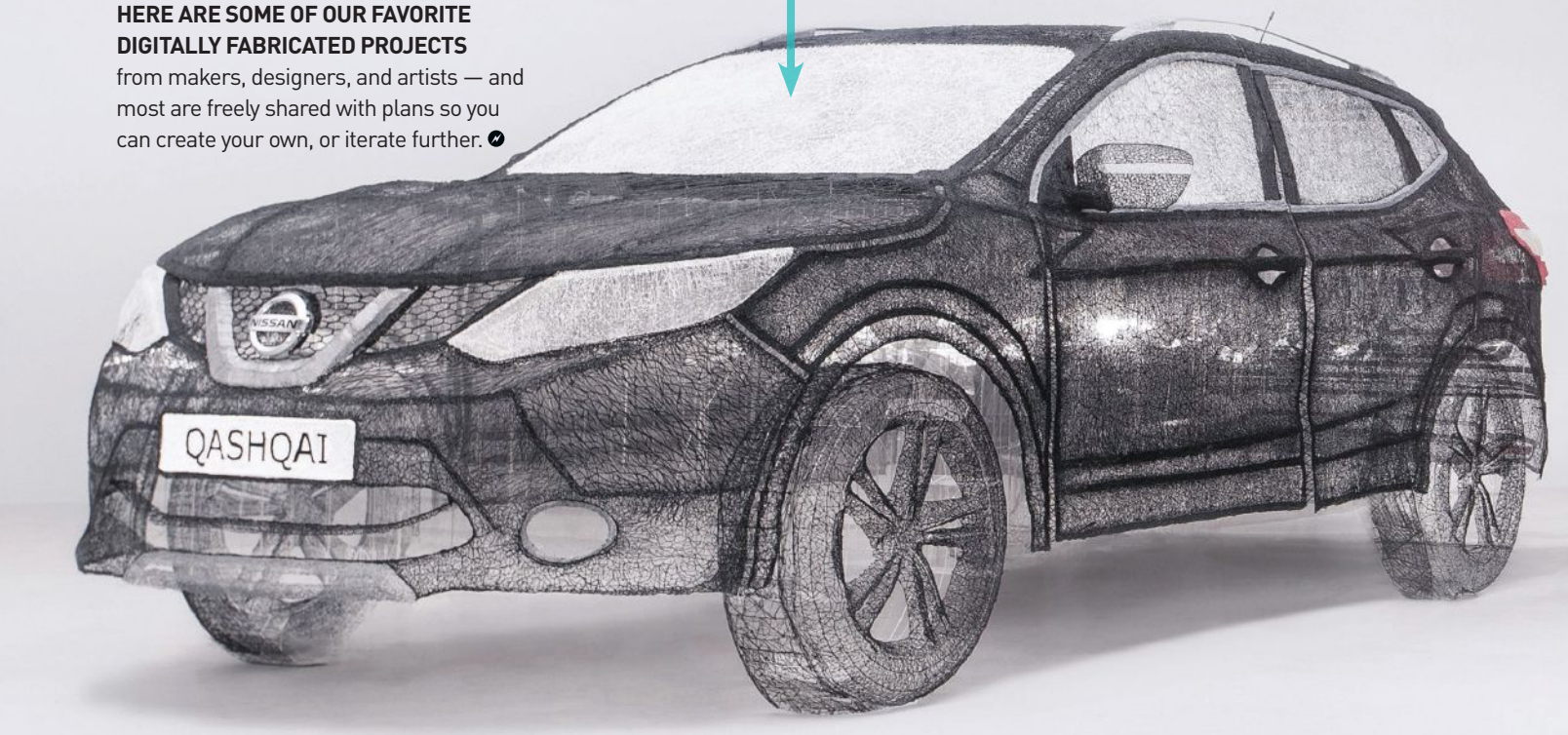

### PIP BOXES

BY ANDREW ASKEDALL

thingiverse.com/thing:1766512

Organize small parts and tools with these stackable, print-in-place drawers that are also self-capturing so they'll never fall out and spill their contents.

Steve Wood, Hep Svadja, Nissan, Andrew Askedall



## CAMPBELL PLANTER

BY AGUSTIN FLOWALISTIK

thingiverse.com/thing:1625573

Grow new plants and reuse old soup or soda cans, with this fully 3D-printed self-watering planter that fits snugly over the rim of standard-sized cans.

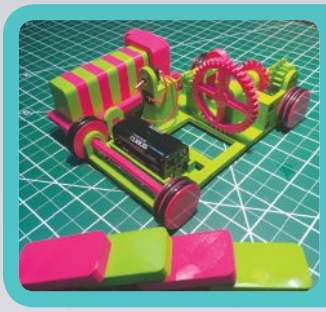
**ERIC CHU** is a lifestyle-centric industrial designer who enjoys finding creative and delightful solutions to everyday problems. Discovering new foods and ways to cook is his mission in life.

## SLO 3D-PRINTED CAMERA

BY AMOS DUDLEY

pinshape.com/items/25871

We've seen 3DP pinhole cameras but now comes the world's first fully 3D-printed, interchangeable optical lens camera, produced entirely on Formlabs' Form 2 SLA resin printer. Yes, that lens required a lot of polishing, but still — awesome.



## THE PINK AND GREEN DOMINO MACHINE

BY GREG ZUMWALT

thingiverse.com/thing:1660937

As a kid or an adult, setting up domino blocks is scary business: One wrong move and the whole trail is knocked down. This amazing little machine sets them up automatically without the worry.

## Z-PURSE

BY DRAGON MOUNTAIN DESIGN

dragonmountaindesign.com/z-purse

This flexible handbag uses NinjaTek SemiFlex filament and is held together without glue or fasteners; instead, its edges lock together with T's and slots. Travel in style and show off your 3D printing love.

## LASER-CUT PHENAKISTOSCOPES

BY DREW TETZ

makezine.com/go/laser-phenakistoscopes

Etched on a laser cutter, then spun on a record turntable, these cousins of the zoetrope create mesmerizing animations when viewed with a strobe, smartphone, or videocam.

Agustin Flowalistik, Formlabs, Greg Zumwalt, James Drachenberg, Drew Tetz


Nissan

# PRINT-À-PORTER

Written by Sahrye Cohen and Hal Rodriguez

## 3D print directly on fabrics with these new techniques



**SAHRYE COHEN** is a costumer and designer from San Francisco who makes tech couture using electronic components and responsive materials. Her work has walked the runways of Calgary, Canada, the San Francisco Bay Area, and Xiamen, China.



**HAL RODRIGUEZ** studied design but got sidetracked into programming. Now he enjoys exploring how fashion and technology blend.

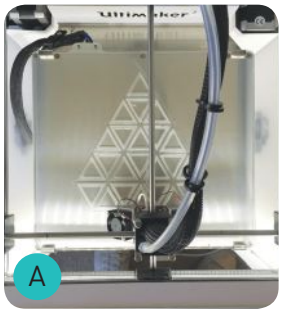
Want to put a 3D-printed design on your next dress? Or maybe add some interesting accents to your shirt or jacket lapel? You can 3D print directly onto many fabrics with your home printer using standard PLA, ABS, or other regular filament. These techniques retain the flexible properties of the fabrics, don't require exotic filament, and permanently incorporate the 3D elements into your garment.

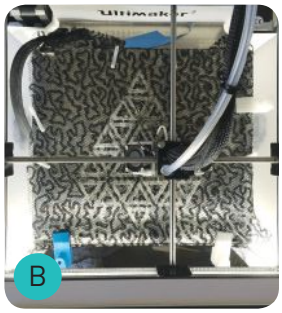
### 3D-PRINT ON TULLE, LACE, AND MESH FABRICS

This method works for net, tulle, lace, or other similar fabrics with holes. You can use fabric yardage or a constructed garment with tulle, lace, or net areas. The critical step in this method is to pause the print after printing a couple layers, so the filament forms a sandwich with the fabric.

**1.** Select your model. Small designs, lettering, and arrays of geometric shapes are good choices. Large designs with no spaces between the elements will not be flexible.

Farzana Khimani





**2.** Slice your model and convert to G-code. We've found that 15%–30% infill is adequate for most models. If you use Cura for slicing, there's a plugin that allows you to put a pause in the G-code. Insert the pause after 2 or 3 layers of the design have printed.

**3.** Print the first 2–3 layers of your design (Figure A), then pause the printer (use your printer's manual control if necessary).

**4.** Carefully lay the fabric down over your first layers (Figure B). An advantage of this method is that you can precisely place the fabric since you know exactly where the design is printing. This is great if you're trying to match up designs on the same piece of fabric, or you're enhancing a garment that already has a 2D design with some 3D-printed elements.

Smooth the fabric on the build plate and use small plastic clips or clothespins to hold it taut. Check to be sure that your fabric won't get caught in any moving parts of the printer, and the extruder won't hit the clips while it's moving around to print.

**WARNING**
The paused extruder nozzle is hot! Don't touch it! You might want to wear work gloves during this step.

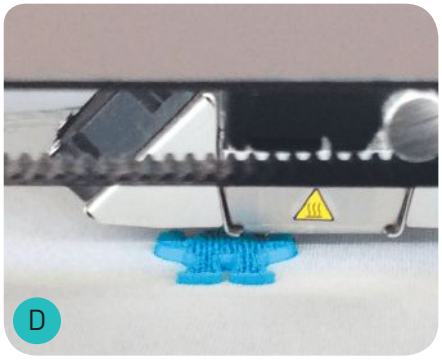
**5.** Resume printing (Figure C). Carefully watch the next couple of layers to be sure the extruder head isn't pulling the fabric too much. A couple of small wrinkles generally aren't a problem, but dragging the prints off-center is.

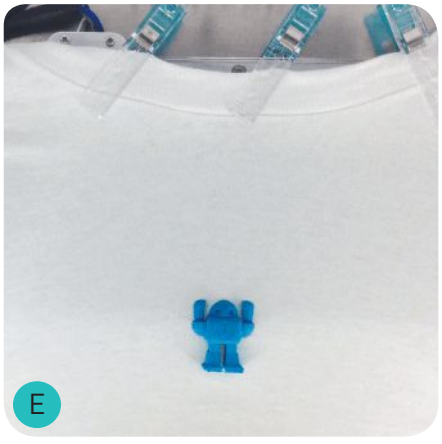
When the print is done, wait for the build plate and nozzle to cool and carefully remove your fabric sandwich. Now you're ready to wear your awesome garment or use your 3D fabric to make something fantastic. See the whole process at makezine.com/projects/how-to-3d-print-on-tulle-net-or-lace-fabrics.

## 3D PRINT ON KNITS AND WOVENS

Print a 3D logo right on your T-shirt! You can print directly onto knits (like T-shirts) and wovens (like dress shirts) using ordinary filament. Follow the procedure described above, but skip the sandwich technique and just print your design right onto the front (or back) of the shirt (Figures D and E).

Then, to be sure your print sticks, reinforce it with fabric glue. On the inside of your shirt, cover the backside of the print with enough glue to permeate the fabric and stick to the print on the front. On the outside, you can also use a fine tip to spread a thin layer of glue along the edges of the print where it meets the fabric. Learn more at makezine.com/projects/how-to-3d-print-directly-onto-t-shirts.




Sahrye Cohen (A–E), Hep Svadja, Kristin Neidlinger

## 3D PRINT ANIMATED STRUCTURES ON MESH

I love 3D printing. It's so versatile, but I want it to be more wearable, flexible, and fun! I create biometric fashions and I'm always experimenting with materials. I've found Power Mesh lycra fabric and PLA filament to be amazing cohorts. Power Mesh is durable (mostly nylon) and it's porous, so you can print into the fabric. And it seems to melt a little bit, so the filament fuses with the fabric. Works great! I print the 3 bottom layers first, lay the fabric on, and then print the top layers.

Now I'm printing structures that open and close with the motion of your body. The hexagon construction of my Goosebump Fractals garment is a digital representation of skin cells, inspired by Buckminster Fuller's geodesic domes and by polygonal structures from architectural 3D modeling. Originally, this design was made to cover a silicone inflatable that expands when your body's "goose bumps" sensation is detected by biosensors. The inflation opens each hexagon into 6 triangles to animate the "hair follicles." After printing the design, I realized it's almost better to have the fabric articulate right on the joints of the body — it's more dynamic.

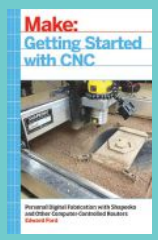
See more at makezine.com/go/sensoree-3dp-goosebumps.

*—Kristin Neidlinger*

# G-CODE: SPEAKING CNC

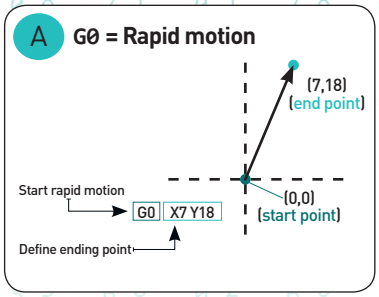
Written by
Edward Ford

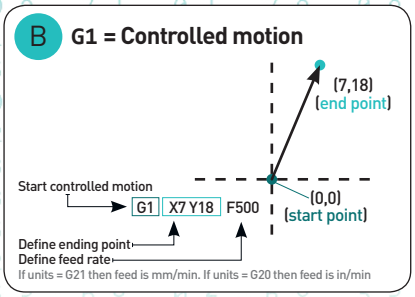
Understanding the commands lets you read a file and figure out what's going on




## WANT MORE?

This tutorial is excerpted from *Make: Getting Started with CNC*, which provides a basic overview of how to use affordable, hobbyist-level computer-controlled routers. Available at Maker Shed (makershed.com) and fine bookstores.




*G-code* is the generic name for a plain-text language that CNC machines can understand.

Using a modern-day desktop CNC machine and software, you'll never have to enter G-code manually, *unless you want to*. The CAD/CAM software and the machine controller will take care of all of this for you. However, some people (especially makers!) like to know what's under the hood and how things really work.

A G-code file is plain text; it's not exactly human readable, but it's pretty easy to look through the file and figure out what's going on. G-codes tell the controller what sort of motion is desired. Here are the most common commands and how they work.

### G0/G1 (RAPID/CONTROLLED MOTION)

The G0 command moves the machine at maximum travel speed to whatever coordinates follow G0 (Figure A). The machine will move in a coordinated fashion, and both axes complete their travel at the same time. G0 is *not* used for cutting. Instead, it's used to move the machine quickly to begin a job or move to another operation within the same job. Here's an example of a rapid (G0) command:

```
G0 X7 Y18
```

A G1 command (Figure B) is similar but tells the machine to move at a specified rate called the *feed rate* (F):

```
G1 X7 Y18 F500
```

### G2 (CLOCKWISE MOTION)

Setting the mode to G2 and specifying the offset from center (Figures C and D) creates clockwise motion between the starting point and the specified ending points.

```
G21 G90 G17
G0 X0 Y12
G2 X12 Y0 I0 J-12
```

The G2 starting point is where the machine is located prior to issuing the G2 command. It's easiest if you move your machine to the starting point *before* trying to issue the G2 command.

### G3 (COUNTERCLOCKWISE MOTION)

Just like G2, the G3 command creates an arc between two points. Whereas G2 specifies clockwise motion, G3 specifies counterclockwise motion between the points (Figure E). A valid set of commands to produce G3 motion is shown here:

```
G21 G90 G17
G0 X-5 Y25
G3 X-25 Y5 I0 J-20
```

### G17/G18/G19 (WORKING PLANES)

These modes set the plane to be machined. Typically G17 is used and is the default for most hobby machines, but two other planes can be used in a three-axis machine:

- G17 = x/y plane
- G18 = z/x plane
- G19 = y/z plane

### G20/21 (INCHES OR MILLIMETERS)

The G21 and G20 commands determine the G-code units, either inches or millimeters:

- G21 = millimeters
- G20 = inches

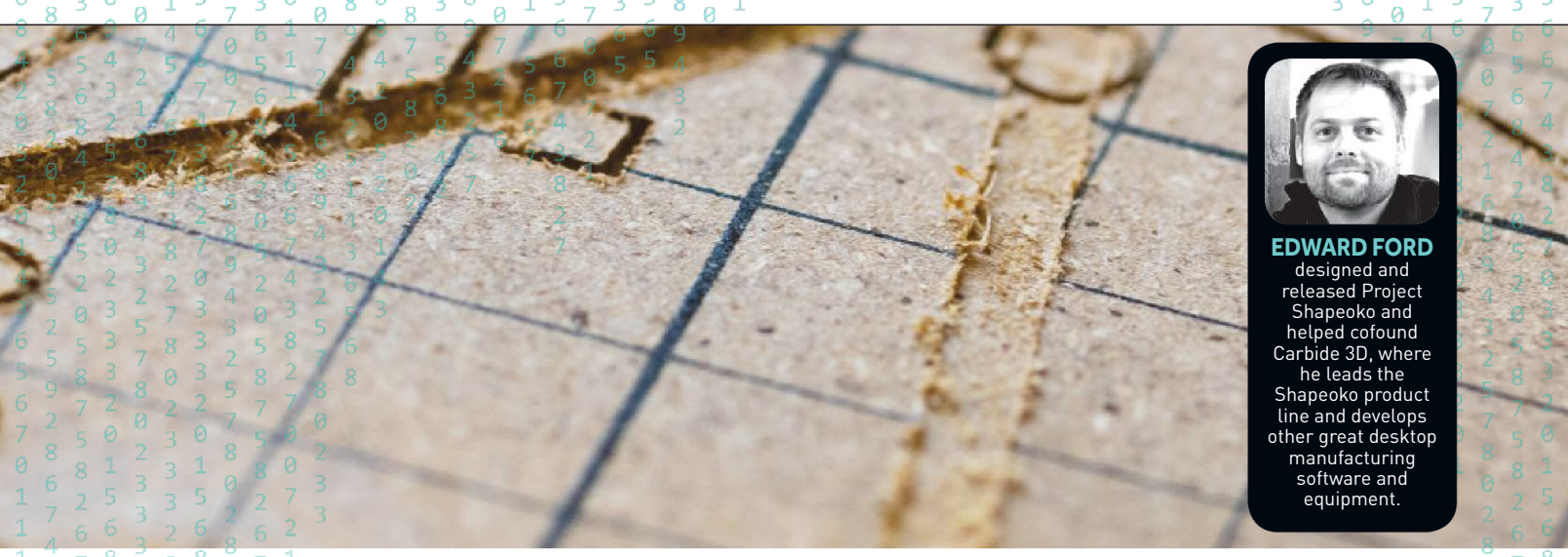
Here's an example that's set to millimeters:

```
G21 G17 G90
```

### G28 (REFERENCING HOME)

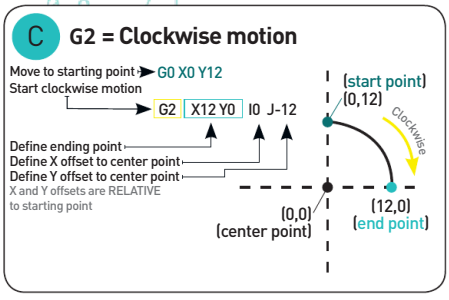
A simple G28 command sends the machine to its *home position*. Adding coordinates will define an intermediate point to go to, before homing (to avoid collisions), like this:

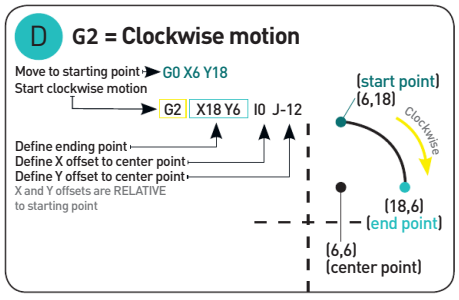
Christopher Garrison

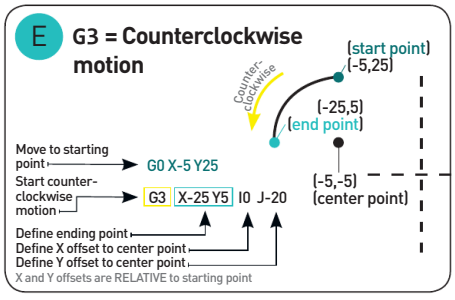




**EDWARD FORD** designed and released Project Shapeoko and helped cofound Carbide 3D, where he leads the Shapeoko product line and develops other great desktop manufacturing software and equipment.




```
G28 Z0
```

Some machines require a `G28.1` command to define the home position coordinates:

```
G28.1 X0 Y0 Z0
```

## G90 (ABSOLUTE MODE)

`G90` causes units to be interpreted as *absolute coordinates*. This is the most common mode for hobby-grade CNC machines; it's the "default" mode.

Absolute coordinates will be interpreted as exactly that — absolute. `G0 X10` will send the machine to $x = 10$. It will not send the x-axis to "10 more" units from where it's currently located.

## G91 (INCREMENTAL MODE)

The opposite mode of `G90`. Setting *incremental mode* means that every command issued will move your machine the specified number of units *from its current point*.

For example, in incremental mode, `G1 X1` will advance the machine 1 unit in the $x$ direction, regardless of its current location.

## G-CODE RULES

Just like a math equation, G-code has its own rules about the order of operations.

Here are the most common, in order of precedence (that is, comments will be interpreted first and the change tool will be interpreted last):

- **Comments**
- **Feed rate**
- **Spindle speed**
- **Select tool**
- **Change tool**

When you issue a `G` command, you are putting the machine into that *mode*. If you issue a `G1` command, such as `G1 X5 Y13`, then the machine moves to `X5 Y13`.

If you issue another set of coordinates, you do not need to issue another `G1` command. Why? Because the machine is in `G1` mode until you change it to something else like `G0` or `G2` or `G3`.

## FEEDS, SPEEDS, AND TOOLS

Simple G-code commands are used for setting the speed, feed, and tool parameters.

### "F" IS FOR "FEED"

The `F` command sets the feed rate; the machine operates at the set feed rate when `G1` is used, and subsequent `G1` commands will execute at the set `F` value.

If the feed rate (`F`) is not set once before the first `G1` call, either an error will occur or the machine will operate at its "default" feed rate. An example of a valid `F` command:

```
G1 F1500 X100 Y100
```

### "S" IS FOR "SPINDLE SPEED"

The `S` command sets the spindle speed, typically in revolutions per minute (RPM). An example of a valid `S` command:

```
S10000
```

### "T" IS FOR "TOOL"

The `T` command is used in conjunction with `M6` (M-codes are machine *action codes*) to specify the tool number to be used for cutting the current file:

```
M6 T1
```

On industrial machines, an `M6 T` command usually produces a tool change with an automatic tool changer. On hobby machines with no tool changer available, issuing a new `M6 T` command will generally cause the machine to issue itself a feed-hold command, wait for the operator to change the tool, and then continue the job after the "resume" button is pressed.

# UNITED STATES OF WOOD

Cut a giant topographical relief map of your state — or all of them! Written by Noah Lorang

**MATERIALS**
- **Wood, 2"–3" thick** about 60 board feet total

**TOOLS**
- **CNC router**
- **Computer and CAM software**

**TIME REQUIRED**
- **3–4 Hours (Per State)**

**COST**
- **$200–$1,000**

**NOAH LORANG** is a engineer-turned-data-analyst by day, and maker by night and weekend. He makes furniture and other wood things by hand and with his homemade CNC router.

Last year I got the idea to make a giant topographic map of the United States out of wood to hang on my wall, using a CNC router, various pieces of free software (USGS data, QGIS, MeshLab), and Autodesk Fusion 360.

The end result is an impressive 7 feet wide by 4 feet tall, and sticks out from the wall about 3½ inches. It uses 15 species of wood: oak (red and white), birch, ash, poplar, walnut, maple, butternut, cherry, cedar, mahogany (African and Honduran), pine, and two mystery woods. It was all cut on my homemade CNC router using leftover wood from other projects, so I only spent about $200 on router bits and other consumables. It took about 200 hours total — generating 3D models, CAM programming, prepping stock, cutting, fitting, and finishing.

You can download my 3D files from thingiverse.com/thing:1524543 and cut your own state or the entire Union. Here's how I did it; you can get complete details online at makezine.com/go/cnc-usa-topo-map.

## TURNING ELEVATION DATA INTO 3D FILES

From the **U.S. Geological Survey's EarthExplorer** website (earthexplorer.usgs.gov), I selected the GTOPO30 data set and

Noah Lorang

downloaded the GeoTIFF files, which use grayscale values to represent elevation.

Using **QGIS** (qgis.org), I added state borders (Figure A), transformed each state into the desired coordinate system (I finally settled on Lambert Conformal Conic projection), and exported it in a GIS file format called ASC (ArcInfo ASCII Grid).

Next, I used **AccuTrans 3D** (micromouse.ca) to convert each ASC to a 3D mesh (an STL file). To exaggerate the topography, I scaled the elevation about 4 times "too tall" relative to latitude and longitude (Figure B), to a maximum height of 3½". In hindsight, this really is too tall — I had trouble finding stock to make mountains that tall, had a hard time cutting them, and they look overly pointy. If I did it again, I'd constrain my max height to about 2".

Using **MeshLab** (meshlab.sourceforge.net) I "decimated" each 3D mesh to less than 10,000 faces so that CAM software could handle it.

Finally, using **Autodesk Fusion 360**, I converted the mesh to a "body," aligned the flat bottom with the Z-plane, then intersected the body with the Z-plane. This gives you a sketch that perfectly outlines the state. Usually this sketch has a closed outline, and you're done — but occasionally there are a couple of open segments to close, or islands to delete.

## CAM SETUP

In Fusion 360 (or your CAM of choice), set up your preferred coordinate system and stock size. I always use the bottom left corner of the stock as my X-Y zero, and set my Z zero to the table.

For most states, I used 3 tools to run 5 machining operations:

1. A *3D adaptive clearing* operation using a ½" router bit at ¼" levels (Figure C). This gets rid of most of the material within the border of the state, quickly and safely.

2. A *2D contour* operation using the same ½" router bit gets as close to the state border as it can, given its size. This operation removes everything outside the state's silhouette; this is where the intersected sketch made before comes in handy (selecting the contour to cut out).

3. A *parallel pass* (roughing) with a ¼" ball nose end mill, ⅛" stepover, leaving 0.100" of stock. This gets closer than the adaptive clearing operation and reduces stress on the smaller bit that'll be used for the upcoming finish pass.

4. A parallel pass (finishing) with a very long ⅛" ball nose end mill, 0.010" stepover.

5. A final 2D contour pass with a ⅛" bit around the border cleans up what the ½" couldn't get to.

You'll have to figure out what works best for your machine, available tooling, and tolerance for pain. In hindsight, I wish I'd spent more time adjusting the state borders so they could be cut easily with a ⅛" bit. I had to do a lot of cleanup of sharp corners so that the whole map fit together decently.

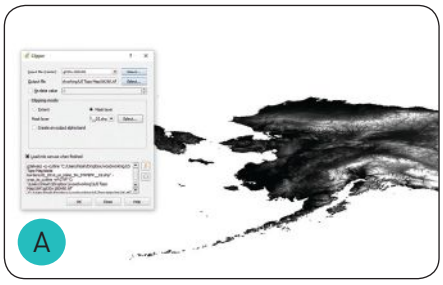
## CUTTING ON THE CNC

My homemade CNC router, loosely inspired by CNCRouterParts, has roughly 4'×4' of travel, but you can cut a map like this on a much smaller machine like a Shapeoko or X-Carve.

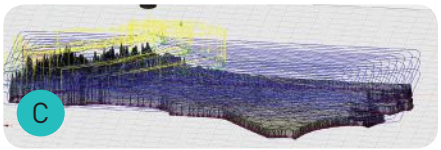
I tried a lot of different fixturing and hold-down methods and after ruining several parts (and end mills) with hold-down screws, I finally settled on hot glue. High-quality hot glue, liberally applied, held every state rock solid through heavy machining, and it pops right off with a putty knife and a hammer. It tears up the tabletop a little, but that's sacrificial anyway.

In Figure D, Idaho has been through the adaptive clearing and the first contour operation with the ½" bit . At this tool change, I remove all the uncut stock to avoid accidentally running into it with a shorter tool later on. Figure E shows the same state after the roughing pass with the ¼" ball nose — it looks more like the right topography, but still lacks a lot of detail. Figure F is most of the way through the finishing pass with the ⅛" ball nose end mill, and looking sharp.

Once it's finished cutting, fit it to the neighboring states, spray with some shellac, and you're done. Now, just repeat 49 more times!


A


B


C


D


E


F

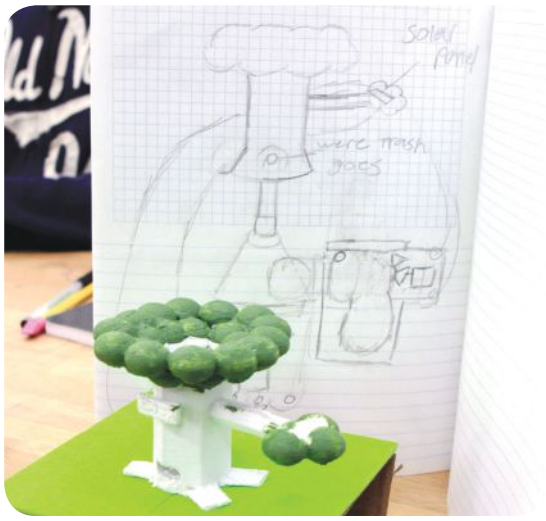
See the step-by-step instructions and share your CNC maps at makezine.com/go/cnc-usa-topo-map.

# PICKING A CLASSROOM PRINTER

Written by Shawn Grimes

Want to offer rapid fabrication to your students? These guidelines will help ease the way.

**SHAWN GRIMES** is the executive director at the Digital Harbor Foundation, a youth- and educator-focused makerspace that uses technology and maker skills to develop creativity and productivity.



A number of national initiatives are underway to support getting students access to maker skills and tools, including 3D printers. As schools and educators are seeking advice on what to get, it is important for them to recognize that the needs of students in a classroom are different than those of hobbyists or professional makers. Here are a few important criteria for educators to consider when evaluating 3D printers for their class:

## 1. RELIABILITY

3D printers will break, and spending more money on a printer does not necessarily mean that it will break less. Educators and school IT support staff are already stretched pretty thin; having to fix 3D printers is going to be an unwelcome burden. Get recommendations from *Make:*, sites like 3dhubs.com, or from your local universities, and join an #edtechchat on twitter to ask educators how often they are doing repairs on their machines.

## 2. SPEED

3D printing is a form of "rapid prototyping" but you should know that this is a relative term. Even small prints can take 45 minutes or more, roughly the same length of time as a typical class. All 3D printers print relatively slowly, just make sure you don't select one that is exceptionally slow. Stay above a print speed of 50mm/sec and you should be good.

## 3. PRINT QUALITY

Resolution is not as important as you might think when it comes to 3D printing with youth. Kids are amazed by the simple fact that their digital creations are becoming physical realities. They don't care about the difference between 200 microns and 300 microns.

## 4. COST

The price of 3D printers has come down dramatically, and price does not necessarily reflect quality with these machines, so you will find a lot of options to fit almost any budget. Make sure you take into account any proprietary filament costs, which are usually higher than standard filament.

## 5. SIZE

The urge is to get the biggest printer you can afford, but fight that feeling for your classroom. The larger the print bed, the bigger your youth are going to want to print, which means the longer it is going to take. Spend some time using a smaller 3D printer, then feel free to get a larger printer to reward youth who have exceptional interest and prototypes.

## 6. QUANTITY

The more 3D printers you have, the more students can use them and the more spares you will have when something breaks down. My biggest recommendation is to favor quantity over quality when using 3D printers with youth. Staying with the same model will also ensure that you can have spare parts and that you don't need to learn multiple workflows.

Digital Harbor Foundation

# 3D PRINTER HACKS AND MODS

Written by Spencer Zawasky

Make that great printer of yours even better



**SPENCER ZAWASKY**
When he's not working for an embedded systems company outside Boston, Spencer is 3D printing at Ocean State Maker Mill in Pawtucket, Rhode Island.

**You're probably the sort of person who likes to tinker with your gear. And why should your 3D printer be any different? Go ahead, get hands-on with it!**

## EASY

### BUILD A THERMAL ENCLOSURE

Having trouble with large prints warping? Grab some fanfold insulation, a utility knife, and some packing tape and whip together an enclosure to keep them warm. This can be as simple as a box, or more elaborate with form-fitting lines, ports for viewing, and vents to keep electronics from overheating.

### ENHANCE YOUR PRINT SURFACES

One of the simplest printer upgrades is a nice new print bed surface.

- **PEI:** Polyethylenimine (PEI) polymer holds a print firmly while it's hot, and then releases it gently at room temperature. And it's tough — gouges or scratches won't require replacement.
- **BuildTak:** Similar to PEI, this proprietary plastic comes in printer-specific sizes and shapes, including circles. Just order, peel, and stick to your bed for a quick performance upgrade.

## INTERMEDIATE

### ADD A NEW EXTRUDER

Sure, all-metal hot ends are all the rage. But get a grip! Let's not neglect the other end of your tool head.

- **E3D Titan:** E3D, makers of the oft-imitated v6 hot end, now offers this extruder boasting the unusual ability to change between 1.75mm and 3mm filaments without swapping any parts.
- **Bondtech QR:** This extruder features machined gears on both sides of the filament, promising an unparalleled grip. Left- and right-handed configurations offer dual-extrusion goodness.
- **Diabase Flexion:** Do soft filaments keep worming out of your extruder every which way except through the nozzle? The Flexion extruder, from the people who invented NinjaFlex filament, uses a short, constrained filament path to help tame those wayward noodles.

## ADVANCED

### CONTROLLER BOARD SWAP

Powerful ARM boards are ushering in new capabilities over Arduino-based electronics.

- **Smoothieboard:** An ARM Cortex-M3 adds full Ethernet support, 1/16 microstepping, and 2 amps per stepper.
- **Duet Wifi:** Get all the power of an ARM Cortex-M4 processor and an independent Wi-Fi chip. This board can handle up to 7 extruders, a touchscreen, and 1/256 microstepping.
- **Pronterface/Printrun:** Printrun software and a Linux board can turn a tether-needy printer into a network-enabled, remote-controlled workhorse. The included Pronsole app gives you full control of your printer from any machine with an SSH client.

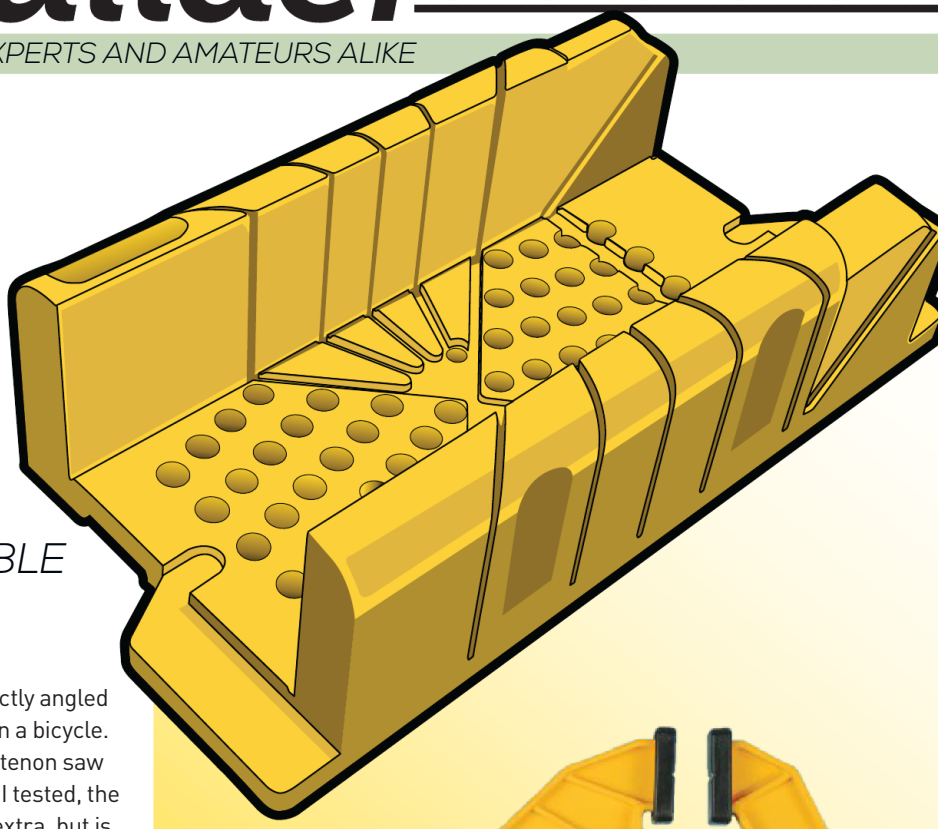
INSANE **Powder Printer Conversion:** Willing to rework your printer's tool head? Then consider Aad van der Geest's **ColorPod**. It adds a commercial-grade powder and binder process to consumer 3D printers, so you can create full-color prints like the pros.

Christopher Garrison

# SAW PRECISE ANGLES

## WITH A SIMPLE, AFFORDABLE MITER BOX

WRITTEN BY CHARLES PLATT



**A MITER BOX HELPS YOU TO MAKE STRAIGHT,** correctly angled cuts. You can think of it as being like training wheels on a bicycle.

In your local retailer, you may see a miter box and a tenon saw sold in one package. However, in the combination that I tested, the saw was of poor quality. Buying one separately costs extra, but is worthwhile. Look for a tenon saw, back saw, or miter saw with *hardened teeth*, greatly reducing cutting effort. Stanley FatMax 17-202 is ideal.

### CLAMPING YOUR WORK

Many people will tell you that you can saw wood by placing it on a sawhorse and holding it there with your foot. I've worked this way myself, but accuracy is difficult to achieve when you are standing on one leg, anchoring the wood with your other leg, and working at arm's length.

For the projects in my new book *Make: Tools*, you will need to make precise cuts. The best way to achieve this is to clamp your work to a solid bench or table.

A trigger clamp is the easiest to use, as shown in Figure 1. It is also known as a bar clamp. The small metal lever is the trigger, which releases the jaw of the clamp, allowing it to slide up or down the bar. Let go of the trigger, and the large black plastic lever closes the jaws of the clamp when you squeeze it repeatedly.

If you are using a miter box, Figure 2 shows how to clamp it to stop it from jumping around. Anytime you are not using a miter box, you can apply a clamp directly to the wood that you're working on.

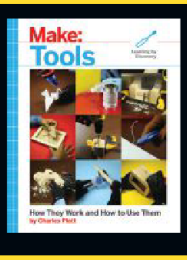
### CUTTING A USABLE LENGTH

Long pieces of wood are difficult to control precisely. If your piece of wood is longer than 36", reduce it to about 36" or slightly less.

Place the wood in the miter box — I used a square dowel in Figure 3.

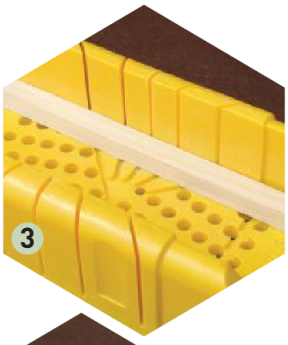
1 A trigger clamp is essential to stabilize your work.

**CHARLES PLATT**
is the author of *Make: Electronics*, an introductory guide for all ages, and its sequel *Make: More Electronics*. *Make: Tools* is his latest book. makershed.com/platt.

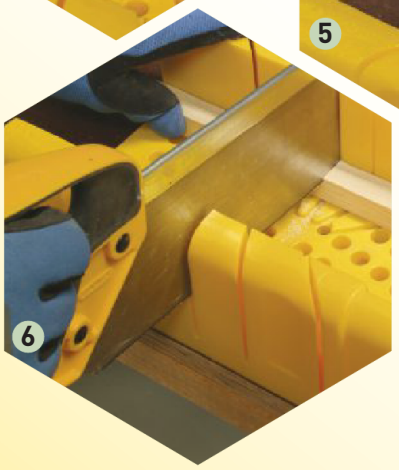



This tutorial is excerpted from *Make: Tools*, which begins with the basics and continues to sophisticated techniques through 20 projects. Available at the Maker Shed (makershed.com) and fine bookstores.

James Burke




The miter box that I have is equipped with a couple of pegs, described as "cams." You insert a peg in a hole close to the wood and turn it to lock the wood in place, as shown in Figure 4.

If your miter box doesn't have this feature, you can hold the wood in the miter box with your left hand, as shown in Figure 5. (If you are left-handed, hold it with your right hand.) Be careful not to put your hand too close to the saw. I do recommend that you wear work gloves while using a saw.

Beginning a cut can be difficult, because the saw tends to dig in. Draw the saw toward you a few times, to create a shallow groove in the wood. Now when you push the saw, it should cut more easily. If you still have trouble, drag the saw toward you a few more times. Keep your free hand at least 4" away from the saw blade, as shown in Figure 6.

Don't press too hard when you are cutting the wood. You shouldn't be fighting a battle. The saw should do most of the work for you.

Charles Platt

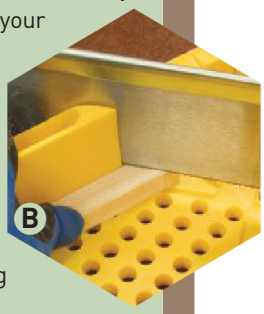
## YOUR FIRST MITERING EXPERIENCE

The best way to learn is by practicing, so I suggest you use some square dowel to make a small frame measuring 6"×5" along the outside edges.

First, draw two vertical lines 6" apart on your dowel (Figure A). (Picture frames are usually sized by their inside dimensions, so that you know if your picture will fit, but for this project it's easier to start with the outside.)

In Figure B, the dowel is in the miter box, and the saw is

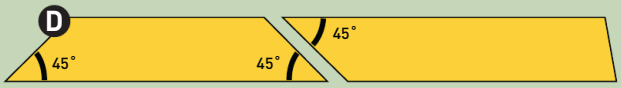

in the slots angled at 45°. A cam could be used to hold the wood in place, but I assume you may not have one, as many boxes are supplied without them. You can use your thumb to hold the wood, but keep your fingers away from the saw blade. Cut carefully down the outside of the vertical pencil mark, while pressing with your thumb as hard as you can, as the saw will tend to push the wood around.



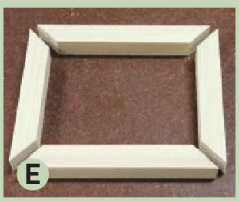

Check the length of your work, as in Figure C. You may be tempted to smooth the fuzzy sawn edges with some sandpaper, but sanding will tend to spoil the accuracy of the cut.

Now the good news: cutting your first piece at 45° automatically creates a 45° angle on the remainder of the


dowel, so that it can be used for the next section of the frame. This is shown in Figure D. Just make a new measurement, and cut that section, turn it around to fit the first, and continue until you have a total of 4 (Figure E).




Check that the angles fit correctly. To secure the corners, use carpenter's glue and wrap a ratchet strap around the frame, or use heavy nylon rope with a slip knot. Tighten well, wipe away glue that squeezes out, and let dry.




No plasma cutting until I figure this out!

# UNDERSTANDING 240V AC FOR HEAVY-DUTY POWER TOOLS

*Learn a thing or two about electricity to stay safe, save your tools, and build your own adapters*

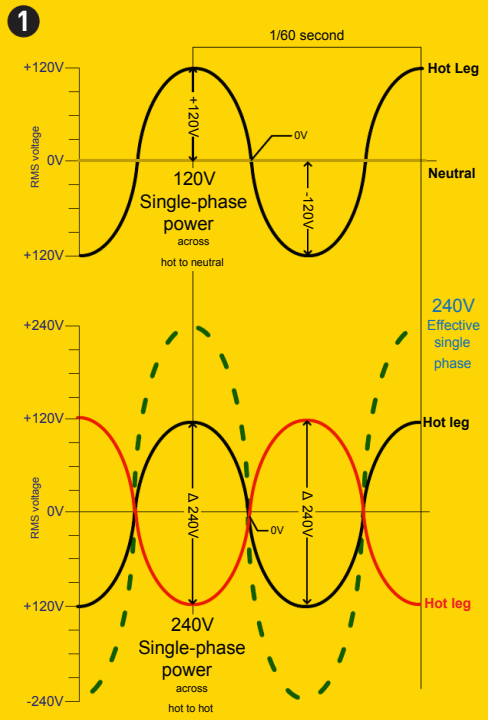


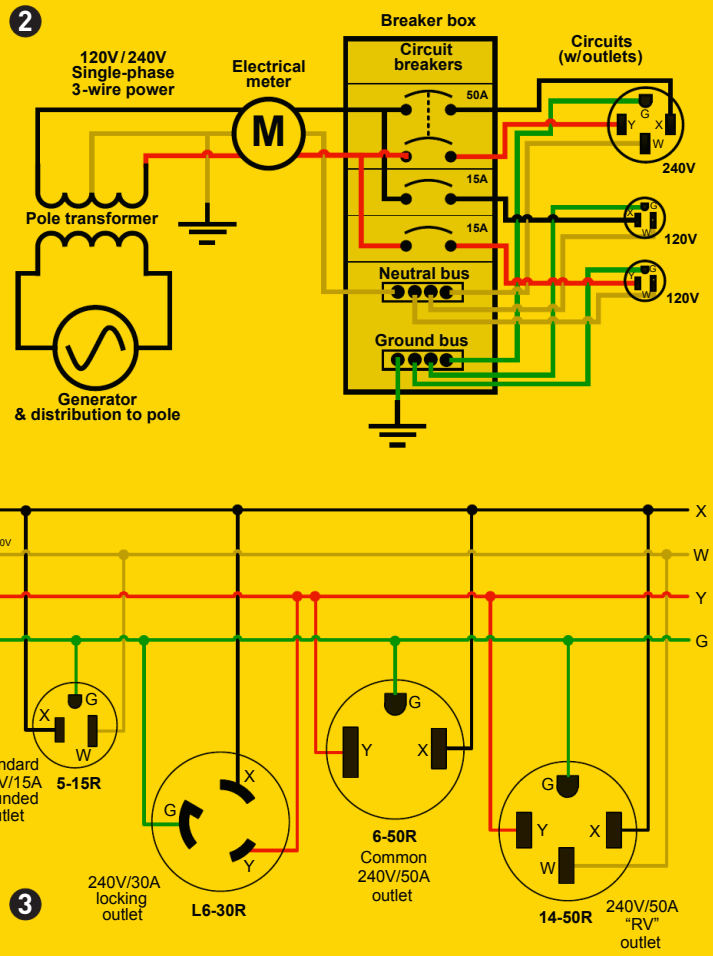
**TIM DEAGAN** (@TimDeagan) casts, prints, screens, welds, brazes, bends, screws, glues, nails, and dreams in his Austin, Texas shop. A career troubleshooter, he designs, writes, and debugs code to pay the bills. He has written for *Make:* magazine and *Nuts & Volts*, *Lotus Notes Advisor* and *Database Advisor*.

WRITTEN BY TIM DEAGAN

**IF YOU'RE ABOUT TO BUY A 240V PLASMA CUTTER, OR A MIG OR TIG WELDER, YOU'RE LIKELY TO EXPERIENCE A VERY COMMON PROBLEM.** The plug won't fit your outlet. You can solve this with a simple adapter, but your first step should be learning enough about 240V power to be safe.

**ALTERNATING CURRENT (AC)** was Nikola Tesla's solution to transporting electricity long distances. Instead of having fixed polarity like direct current (DC), the polarity oscillates between positive and negative in a sinusoidal wave. In the United States, it performs this oscillation 60 times a second (60Hz). The **voltage** is the amplitude of the wave. Like DC power, AC requires a potential difference to do work. For 120V plugs with two wires, the difference is between a **hot wire** (connected to the electrical source), and a **neutral wire** (connected to the electrical source and to the earth). For 240V circuits, the potential difference




1 120V and 240V AC power waveforms

2 AC power distribution

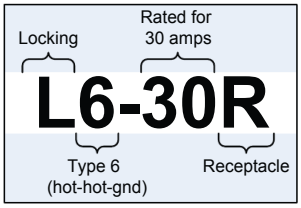
3 240V receptacles use combinations of the same wires

is between two hot wires that are 180° out of phase (see Figure 1). Because we only measure across two wires, both 120V and 240V are referred to as **single-phase power**. (It's rare to find three-phase AC power in residential situations).

Neutral and ground are related but serve different roles. The neutral wire is the current return path for 120V circuits. It's connected to earth (grounded) at multiple points along its path from generator to outlet (see Figure 2.) The oscillating current in the hot legs creates magnetic fields that induce undesirable currents in the neutral wire. Connecting the neutral to earth stabilizes the signal. Many electrical outlets are also "grounded outlets," meaning they have a ground wire. Under normal operation, the ground wire never carries current. If the hot wire shorts to ground (or the grounded case,) the ground wire path has less resistance and more current flows through the circuit breaker than it is rated for, causing it to trip, cutting off power. The ground wire is "bonded" to the neutral wire at the box to assure it has a viable connection to earth.

There's a lot of confusion about voltage values. You'll see references to 220V appliances, 230V, 240V, and NEMA (the National Electrical Manufacturer's Association) connectors are even rated at 250V. Despite all these different numbers, everyone is pretty much referring to the same thing: the U.S. 240V standard. (Actually, the U.S. has five standard voltages for different purposes — 120V, 208V, 240V, 277V, and 480V — but we'll stick to 240V.)

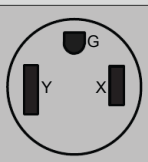
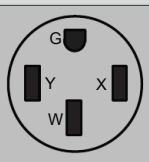
Residential 240V outlets usually have three or four connectors, which provide two hot 120V wires and either a ground wire, a neutral wire,



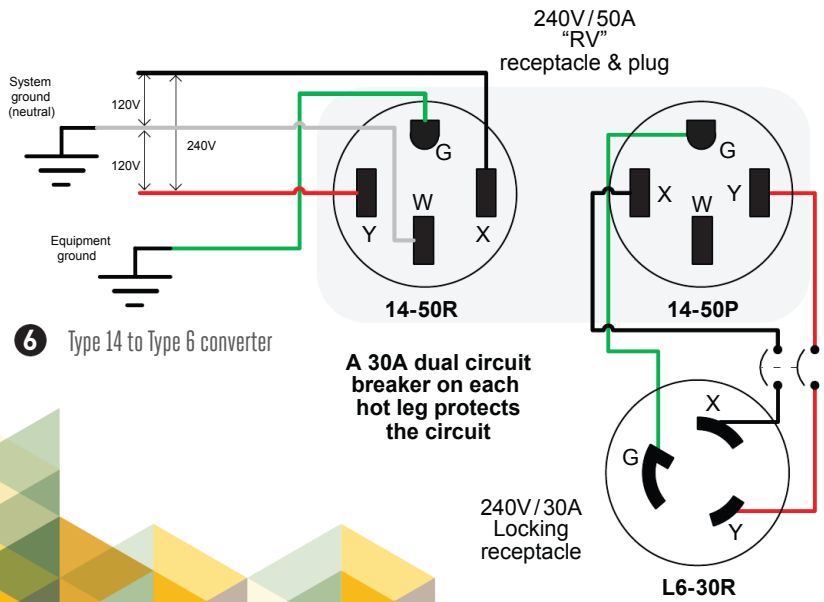

4 NEMA connector naming standard

**CAUTION:** This information doesn't even scratch the surface of what a licensed electrician knows. Electricity has no mercy, and permit inspectors rarely have much more. Always get professional help installing permanent circuits, wiring, or outlets in your home or shop.

Tim Deagan

| | TYPE 6 2-pole, 3-wire, grounding (hot/hot/ground) | | TYPE 14 3-pole, 4-wire grounding (hot/hot/neutral/ground) | |
|---|---|---|---|---|
| | STRAIGHT BLADE | LOCKING | STRAIGHT BLADE | LOCKING |
| 15 AMP |  6-15R |  L6-15R |  14-15R | |
| 20 AMP |  6-20R |  L6-20R |  14-20R |  L14-20R |
| 30 AMP |  6-30R |  L6-30R |  14-30R |  L14-30R |
| 50 AMP |  6-50R | |  14-50R | |

5 Common NEMA 240V receptacles




6 Type 14 to Type 6 converter

or both (see Figure 3, previous page). The neutral wire provides a way for the appliance to use just one of the hot wires for 120V appliances like a clock or fan. As long as your outlet has the wires your plug needs, wiring an adapter is straightforward. The first thing to do is to identify the outlet type and understand what it provides.

There are at least 20 types of 3- or 4-wire 240V connectors defined by NEMA. They designate them with a group number and an amperage rating. Locking connectors start with "L," plugs end with "P," and receptacles end with "R." (See Figure 4, previous page)

The most common of these are either Type 6 (2-pole, 3-wire grounding connectors that have two hot wires and a ground) or Type 14 connectors (3-pole, 4-wire connectors that have two hot wires, a neutral and a ground). For most combinations of type and amperage rating, there are straight blade and locking versions (see Figure 5).

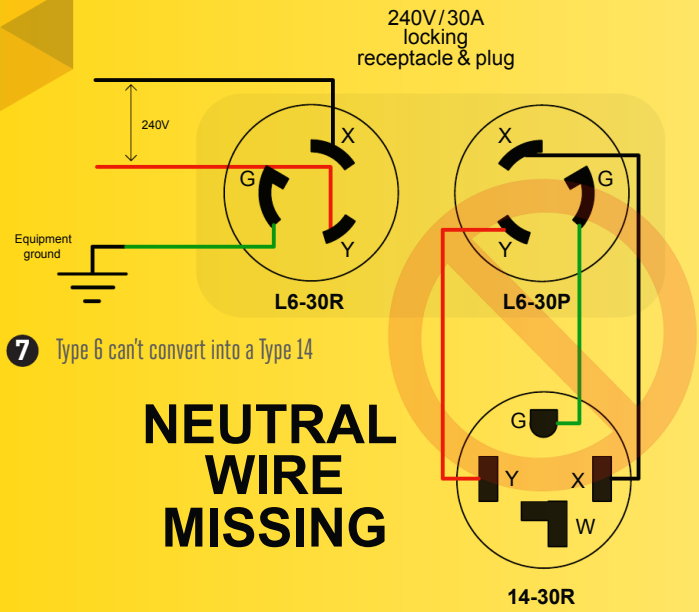
To convert from one type to another we need to answer two questions: "What's the amperage?" and "Do I need a neutral connection?" Let's start with amperage.

Never connect equipment to a circuit rated for less than the device's amperage draw. The delightful word for this is **ampacity**. Keep in mind that this means the ampacity of the wiring as well as the breaker. If you're trying to pull 45A through a circuit that has wire rated for 30A, the wire becomes a heating element. Always use wire rated at, or above, the value of the circuit's breaker. The breaker should trip if you try to draw more current than it's rated for, but you don't want your gear shutting down like that. (And I hate having to trust breakers to keep my house from burning down, so why push them?)

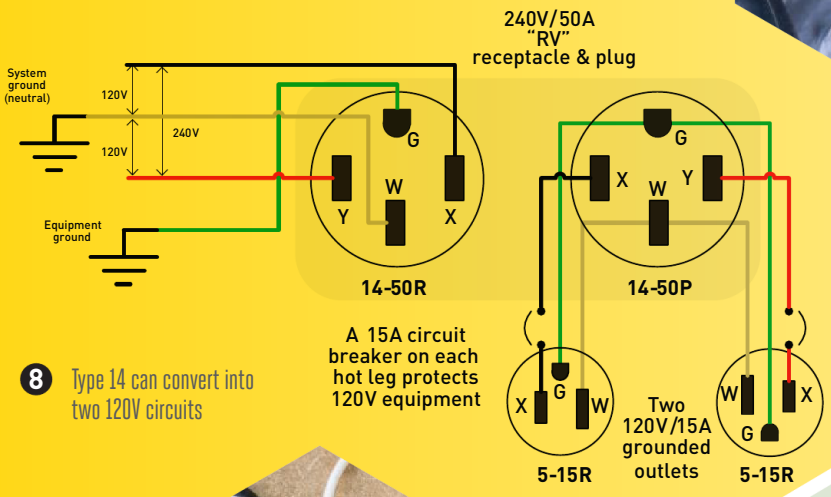
It's generally safer to attach a device to a circuit that draws less current than the circuit's ampacity. The only risk is that the equipment might draw more current than it's rated for before something trips. If you're building an adapter to convert an outlet rated for 50A into an outlet rated for 30A, you should put a 30A breaker in the adapter to protect your gear.

The second question involves the neutral wire. Since it has all four wires, a Type 14 can convert into a Type 6 of the same or lesser amperage (see Figure 6). A Type 6 cannot convert into a Type 14 because it doesn't have the neutral wire that the Type 14 requires (see Figure 7). A Type 14 can convert into two 120V circuits, one from each of

Tim Deagan




7 Type 6 can't convert into a Type 14




8 Type 14 can convert into two 120V circuits

9 My custom-built adapter

the hot legs combined with the neutral (see Figure 8). A Type 6 cannot convert into 120V because it has no neutral to tie one of the hot legs to.

You can purchase adapters to convert between various plugs and receptacles. If you have experience working with AC wiring, you can construct many of these yourself. In a fit of frustration, I built myself an adapter to allow me to use my 14-50R 50A RV outlet with a 6-50P, an L6-30P, a 14-50P, and then I tossed in two 15A 120V circuits (using pre-wired outlet strips) (see Figure 9). You may not need something this involved, but know that as long as you have the service, you can get your new gear up and running!

Follow Tim's instructions to build your own adapter at makezine.com/go/240v-adapter.

Matias Eertola

# 3D Print a High-Power Electric Unicycle

Written by Matias Eertola

Cruise 25 miles at 20mph on a sweet, one-wheeled ride you built yourself!

**Time Required:**
**Print: 1 Week**
**Build: 3–4 Hours**
**Cost:**
**$400–$800**

**MATIAS EERTOLA** lives near Helsinki, Finland. He works in marketing and sales but has always had a great interest in technology and DIY, starting with R/C planes as a kid. He got involved in 3D printing in 2013 and has been riding electric unicycles for a year now.


**LAST YEAR I BOUGHT A GENERIC 350-WATT UNICYCLE AND LOVED IT,** but I soon realized how limited its performance was: about 9mph (15km/h) top speed, maybe 5–6 miles (8–10km) of range, and poor climbing ability. So I thought I would upgrade it with a more powerful motor and make it a real means of transportation, with good speed and enough range to actually go somewhere without having to worry all the time about running out of juice.

Online I bought a 500-watt motor and controller from Shenzhen MicroWorks with impressive specs at a very reasonable cost. But then I realized I needed a completely new enclosure with room for more batteries. Finding nothing suitable, I decided to design my own and 3D print it myself.

It worked great! This project is my updated version: the E14S Electric Unicycle. It's more compact, with better ergonomics, but with the same impressive range and performance as its predecessor. Where my old version used four 16-cell battery packs (16S1P) connected in parallel, this new version uses 2 packs of 32 cells (16S2P), so the battery housings can be smaller with the same total capacity. Also, this version uses a horizontal speed controller board, so the housings on both sides are available for batteries, for excellent weight distribution.

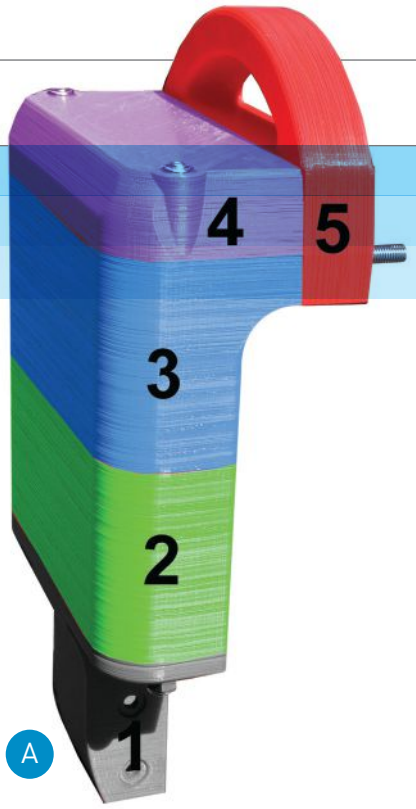
The essential structure is the same: The housing is printed in sections that are then stacked and secured with M8 threaded rods that go through the whole structure from top to bottom. These housings are bolted to each other crosswise through the top handle section, also using M8 rods. The new horizontal mainboard goes in the space underneath the top handle.

I've tried to keep the design as simple, compact, and smooth as possible. I recommend using PLA filament to avoid warping issues. Be aware that these parts are large and will take a long time to print.

With the motor I used, the unicycle's top speed is around 20mph (30km/h), and at full battery capacity your range should be around 25 miles (40km) in actual road conditions. You'd have to spend $1,100 or more for a top-of-the-line unicycle to get similar performance. It is really a joy to ride.

## 1. PREPARE THE PARTS

Use PLA filament to print 1 handle (part 5), 1 of each top cover (parts 4a and 4b), and 2





Matias Eertola

of all other parts. Pedal brackets (part 1) will be exposed to the greatest mechanical stress, so use at least 45% infill. For the remaining parts 25% or more will do (Figure A).

**NOTE:** The 32-cell batteries are a tight fit in their housings (parts 2 and 3), maximum width 43.5mm. Check the exact dimensions of yours, and make sure they fit, or modify the 3D files if necessary. You could use two 16-cell batteries, which are smaller, and some extra padding, but you'll have less range

Test-fit the printed parts and the M8 threaded rods. The 8mm bolt holes on the top covers don't go all the way through to the nut; there's 0.5mm of material left in between which needs to be drilled out (Figure B). This is simply because the parts print better this way.

## 2. MOUNT PEDALS TO MOTOR

Assemble and mount the metal pedals to the motor (it's pretty obvious how they go together). Make sure the wheel nuts are well tightened, and use thread locker here so they stay tight. An old-fashioned spark plug key

## Materials

» **3D-printed housing parts** Download the 3D files at github.com/EGG-electric-unicycle/shell_MattJ/releases/tag/E15S-v1.21.

**PARTS FROM SHENZHEN MICROWORKS:**

» **High-speed brushless motor, 500W, 14" wheel** It's got 48 coils, 44 magnets, and 3 Hall sensors. Shop at microworks.en.alibaba.com or contact Mr. Charles Lee directly at lee@microworks.cn.

» **Tire and inner tube, 14"×2.5"** or buy locally

» **30B4 high-speed controller with Bluetooth module, horizontal style** Be sure to get the "horizontal programming" version.

» **Pedals and assembly parts**

» **Electrical accessories: switch, charging socket, LED indicators, LED PCB, and cables**

» **Battery charger, 67V, generic** Get the 115V version if you're in the USA. You can find these from other vendors too.

**FROM A HARDWARE VENDOR:**

» **Threaded rod, M8 × 1.25mm pitch: 225mm lengths (4) and 60mm lengths (2)** such as McMaster-Carr #99067A115, mcmaster.com

» **Locknuts, M8, nylon insert (8)** McMaster #94645A210

» **Cap nuts, M8 (4)** aka acorn nuts, McMaster #99164A102 or 94000A039

» **Washers, M8 (8)** McMaster #91166A270

» **Machine screws, M5 × 12mm long (12)** pan head or flat head, McMaster #92005A322 or 91420A322

» **Washers, M5 (12)** McMaster #91166A240

» **Thread locker** Loctite or similar

**FROM A HOBBY VENDOR:**

» **Batteries, lithium ion, 60V, 32 cell, 16S2P type (2)** maximum width 43.5mm, with XT60 power connector and Deans charging connector, such as Shenzhen MicroWorks #ARS16S2P (alibaba.com), or Shenzhen Anysun #60V4.4AH or Shenzhen Foxell #60V5.2AH (aliexpress.com). You could use 16-cell (16S1P) batteries, which are cheaper and easier to find, but they'll have only half the capacity — which is still not bad.

» **XT60 parallel battery connector cable** such as AliExpress #506505

» **Deans parallel splitter cable, 1 female to 2 male** to connect both charging leads

» **Piezo buzzer(s), 5V (1 or 2)** Adafruit #160

» **JST-XH connector** for buzzer(s); such as UPC #7113311626180

» **Heat-shrink tubing and zip ties**

» **Anti-slip grip tape (optional)** for pedals

## Tools

» **3D printer (optional)** You'll use about 2 spools (2kg) of filament. Or use a service instead; check out makezine.com/where-to-get-digital-fabrication-tool-access.

» **Hacksaw**

» **Drill and 8mm bit**

» **Socket set, metric**

» **Adjustable wrenches**

» **Soldering iron**

» **Hot glue gun**

» **Voltmeter**

» **Spark plug key (optional)**

» **Android device** for calibration only

» **Strap** for learning to ride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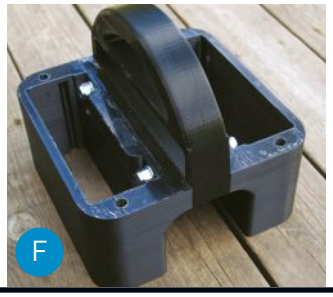
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can be used for this, so you can pull the motor cable through while tightening.

**TIP:** This unicycle is designed for the 14" 500W motor from Shenzhen MicroWorks, but it can be used with others as well.

### 3. MOUNT THE PEDAL BRACKETS

Use M5 screws and washers, with thread locker, to attach each pedal bracket to the pedal assembly (Figure C). Insert the longer M8 rods into the pedal brackets.

### 4. BOLT THE UPPER HOUSINGS

Bolt together both upper sections of the battery housings (part 3) with the handle (part 5) in between, to form a single unit. Use M8×60mm rods, washers, and locking nuts (Figures D, E, and F).

### 5. ATTACH THE LOWER HOUSINGS

Stack the lower sections of the battery housings in place and push the M8×225mm rods through the openings.

### 6. LOAD THE BATTERIES

Stuff the batteries into their housings (Figure G). Make sure the motor leads are pulled through.

### 7. ADD THE UPPER HOUSINGS

Pull the motor leads up into the handle section where the control board will be located.

### 8. MOUNT THE CONTROLLER BOARD

Install the board with its big capacitors (Figure H) pointing to the right when the side of the motor with the cables is facing toward you. This is important — otherwise the controller will react exactly opposite the way it's supposed to.

Attach the board's aluminum backing plate to the bottom of the handle section, using hot glue. Watch that the Bluetooth module doesn't get bent, and make sure you leave enough space on one side for the power switch, charging socket, and LED power indicators.

### 9. INSTALL ELECTRONIC ACCESSORIES

Take the top cover with openings (part 4b) and mount the power switch, LED battery indicators, charging socket, and buzzer. The LED PCB and buzzer are secured with hot glue (Figure I). If you're using two buzzers, connect them in parallel to the same JST connector.

**NOTE:** The buzzer(s) are important for safety, because they'll let you know when you're approaching maximum speed. Otherwise you might accidentally try to go faster than the unicycle is able to, and crash at top speed.

### 10. CONNECT IT ALL

Connect the batteries and electronic components, following manufacturer's instructions (Figure J).

You can learn more about the MicroWorks 30B4 unicycle motor and controller at github.com/EGG-electric-unicycle/documentation/wiki/Motor-MicroWorks-500W-30km-h.

**CAUTION:** It is extremely important that both batteries are charged to exactly the same voltage before connecting them in parallel. Measure the voltage before connecting them, or you might risk overheating and even fire!

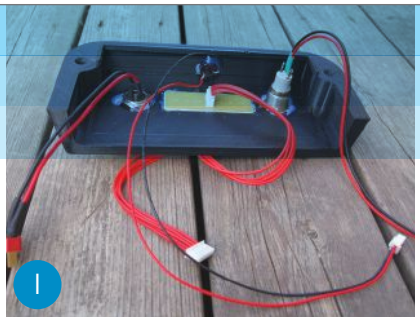
### 11. CLOSE IT UP

Insert the cap nuts into both top covers, and tighten the M8 rods and bottom nuts from below. Your electric unicycle is complete (Figure K).

Matias Eertola


G


H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## YOU PRINT IT, YOU RIDE IT!

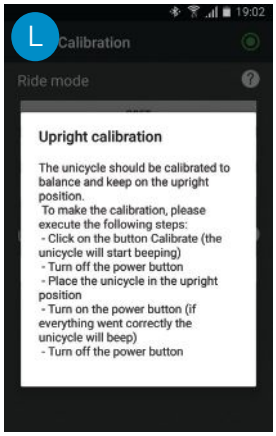
Before you step aboard, you must calibrate the horizontal position of your unicycle according to your board manufacturer's instructions. The MicroWorks board has a Bluetooth app for that — but it's in Chinese and not easy to use. Luckily older versions of the GotWay app (github.com/EGG-electric-unicycle/documentation/tree/master/apps) are compatible with the MicroWorks motor, and there's also a new open source app, EGG Electric Unicycle (github.com/EGG-electric-unicycle/egg_app), which is very good. Both of these are in English and fairly easy to set up and use. First you pair your electric unicycle controller (EUC) board with an Android phone or tablet, via Bluetooth. Then you calibrate your EUC's upright position and you're ready to ride. It only takes a couple of minutes (Figure L).

There are 3 riding modes to choose from. Soft mode is the softest and "Madden" mode the firmest. I recommend you start with Madden mode, or possibly Comfort mode, but Soft mode is so soft that I had trouble keeping my balance when I tested it. The app also has plenty of other useful info like current speed, battery voltage and charge, board temperature, and how many amps the motor is drawing (Figure M).

Charge your unicycle's batteries fully (if you haven't already). If you're a noob, tie a long strap to the handle and hold onto it while you ride — so you can catch the runaway unicycle until you learn to step off gracefully.

Step on and start riding. Use safety gear and be careful — it's fast!


K





Get more tips on sourcing parts, building your own batteries to save money, and riding your unicycle at makezine.com/go/3d-printed-electric-unicycle.

# Make Your Own Mead

Written by James Austin

## It's easy to brew the ancient elixir from honey and yeast

**JAMES AUSTIN** forges custom metalwork and teaches historical blacksmithing in Oakland, California. He's also got a background in chemistry and a general love for fermentation and food making.


Hep Svadja





**MEAD IS AN ANCIENT DRINK OF FERMENTED HONEY THAT WAS PRIZED, NOTABLY, BY THE UPPER CLASSES OF SCANDINAVIA** but was actually quite widespread through Europe, Africa, and Asia. Today it's making a comeback in mixology circles. Here's a simple method of making a delicious semi-sweet mead, which you can carry out in your kitchen!

### 1. PRE-WARM THE HONEY

Put the containers of honey in a warm location, such as near a water heater, or in a water bath so that the honey warms to about 100°F (38°C) and is easy to pour. Make sure it doesn't overheat.

### 2. CLEAN THE EQUIPMENT

It's important to work with spotlessly clean equipment to minimize the risk of spoilage. Starting with the 4gal–5gal stock pot, thoroughly scrub all vessels and equipment that will contact your mead with hot water and unscented detergent or sodium percarbonate (Figure A), then thoroughly rinse and drain (Figure B). Scrub the carboy (your fermenter) with a long carboy brush, and soak it with hot detergent water to remove any residue of dried yeast from a previous fermentation. Carefully inspect all equipment for cleanliness and store it on a clean surface.

### 3. SANITIZE THE FERMENTER

The carboy and any gear used to fill and seal it must also be *sanitized* to eliminate the vast majority of bacteria and wild yeasts that could hijack your fermentation.

To do this, put 1.5gal of warm water in a clean 2gal plastic bucket and stir in 2tsp of Starsan sanitizer — an acidic surfactant combined with food-grade phosphoric acid. This will give you a dilute, sudsy, clear solution that will quickly kill stray bacteria and yeast on contact. Pour 16oz of this solution into the spray bottle (for spot-sanitizations — very useful!) then pour about half of what's left into the carboy using the funnel.

Gently roll the Starsan solution around inside the fermenter to wet the entire surface, then drain it into the bucket for reuse. Rinse a piece of aluminum foil with the Starsan solution and close it over the mouth of the carboy to keep out contamination until you're ready to brew. Drain the carboy once or twice more at 10-minute intervals to get out as much Starsan as possible. If a little dry foam is left, it won't detectably affect the mead and it is not at all harmful. That's part of the beauty of Starsan!

### 4. MIX HONEY, WATER, AND NUTRIENTS

Weigh 15.75lbs of spring water into the stockpot (or measure 1gal + 7pts) then heat it to 120°F (49°C) on a stove (Figure C). Meanwhile weigh 7lbs of pre-warmed honey into a 4qt mixing bowl (Figure D).

Turn the stove off and pour the honey into the

**Time Required:**
**Prep: 3 Hours**
**Ferment: 14 Weeks**
**Cost:**
**Ingredients: $55–$60**
**Brew Gear: $150–$175**

## Materials

- **Honey, light, 7lbs** such as clover or orange blossom honey
- **Yeast, Lalvin D47, 2 packets** Store in the refrigerator until use.
- **Spring water, 2gal** or distilled or filtered water
- **Yeast nutrient, 1oz** from a brewing supply store
- **DAP (diammonium phosphate), 1oz** another yeast nutrient
- **Acid Blend, 1oz** Used by winemakers, it will help protect your mead from spoilage.
- **Campden tablets (potassium metabisulfite)** to sterilize the mead

## Tools

**FROM THE BREWING SUPPLY STORE:**

- **Glass carboys, 3gal (2)**
- **Caps for carboys (2)**
- **Airlock for carboy**
- **Scale, 1/10 gram**
- **Carboy brush**
- **Starsan sanitizer, 4oz**
- **Sodium percarbonate, 8oz** or just use unscented dish detergent
- **Spray bottle, 16oz**
- **Siphon, self-starting**
- **Clip for siphon**
- **Vinyl tubing, 3/8", 6' length**
- **Bottle capper**
- **Bottle caps**
- **Hygrometer (optional)**

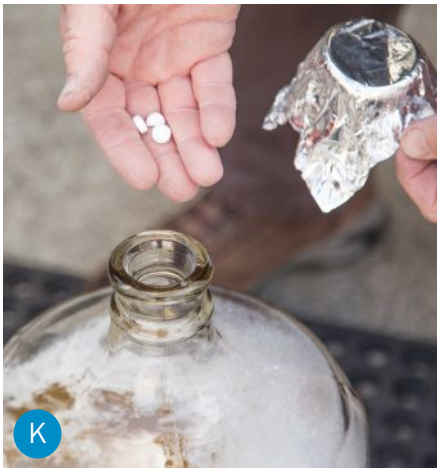
**FROM HOME:**

- **Stockpot, 4gal–5gal**
- **Mixing bowl, 4qt–6qt**
- **Bucket, 2gal** like new and clean
- **Funnel, large** like new and clean
- **Mixing spoon, long-handled**
- **Scoop, 16oz–32oz**
- **Scale 10lb–25lb range**
- **Small plastic cup** for weighing ingredients
- **Kitchen thermometer**
- **Measuring spoons**
- **Paper towels**
- **Aluminum foil**
- **Bowls, 2–3 quart**
- **Beer or champagne bottles** Save and wash.
- **Clipboard (optional)**










**CAUTION:** The filled carboy is heavy, and any moisture or Starsan will make it extremely slippery! Before you move it, dry the carboy and your hands. And never set the carboy on a concrete floor without cushioning it with a carpet or cardboard mat.

stockpot (Figure E), then dip the mixing bowl into the pot to dissolve out all traces of honey (Figure F). Stir until the honey is completely dissolved, using very gentle heat if necessary.

Now weigh out and add 8g of Acid Blend, 7g of yeast nutrient, and 5g of DAP (Figure G). Stir until dissolved (Figure H).

The specific gravity of the batch should now be 1.100 to 1.105, which you can verify with a hygrometer if you wish (Figure I). Recording this value, along with the amounts and descriptions of all the ingredients and temperatures used, will help you make progress as a mead maker.

## 5. FILL THE CARBOY

Set the covered carboy on the floor. Sanitize the funnel and carboy cap in the Starsan solution. Shake off the funnel and use it, along with a sanitized scoop, to pour the honey-water mixture into the carboy (Figure J). Now add 2½ Campden tablets to sanitize the mixture (Figure K).

Shake off the carboy cap and put it on the carboy (Figure L). Dry the carboy with a paper towel and carefully set it in a dark, cool space that maintains a fairly even temperature between 60°F–65°F (15°C–18°C). It must sit there for 24 hours to cool and let the sulfite from the Campden tablets dissipate (too soon and the sulfite might kill your fermenting yeast).

## 6. START FERMENTATION

Take the 2 packets of Lalvin D47 yeast out of the refrigerator and let them warm to room temperature (Figure M). Take off the carboy cap and set it in the Starsan solution. Cut the tops off of the yeast packets and slowly pour the yeast into the carboy where it will dissolve over the next few hours (Figure N).

Replace the carboy cap and set into it a sanitized airlock that's half full of Starsan solution (Figure O). Within 24–48 hours the batch should start bubbling, showing that the fermentation has started (Figure P). This primary fermentation will continue for about 1 month until the yeast action has slowed considerably.

## 7. AGITATE YEAST

Mead fermentation can go slowly and much of the yeast will settle to the bottom.


L

M


N


O


P


Q

This yeast layer won't have good access to sugars and nutrients so it's good to shake it up every day or two. Gripping the dry carboy near the bottom with both hands, swirl it gently for 20 seconds to stir up the yeast.

Carbon dioxide will bubble out of the liquid and come out through the airlock — probably driving out some of the Starsan with it. Dry the carboy, refill the airlock to half-full, and return it to its dark, cool space. This will reinvigorate the fermentation.

**NOTE:** From time to time the airlock will dry out. Top it off with new Starsan.

### 8. RACK FOR SECONDARY FERMENTATION

After 4 weeks, it's good practice to rack (transfer) the mead into another sanitized carboy to separate it from the bulk of the yeast sediment, which could break down and harm the flavor of the mead in the long run. The yeast that's still in suspension will continue to improve the quality and flavor of the mead for another 2 months or so.

Use a sanitized, automatic siphon and about 6' of ⅜" clear vinyl tubing to avoid getting any mouth-borne bacteria into the mead. Place the full carboy on a sturdy table or countertop and siphon it into a sanitized carboy on the floor. Close the new carboy with a sanitized cap and airlock as before, and return it to the cool, dark space for secondary fermentation.

### 9. BOTTLE

When the mead has finished its secondary fermentation and become still, at about week 14, the yeast will settle out leaving it quite clear (in my experience). You may have to help the clarification by adding a clarifying agent (consult your homebrewing shop or *The Compleat Meadmaker* by Ken Schramm) and waiting a few days. Clarity is very important to the delicate flavor of light mead.

Using sanitary equipment and containers, rack the mead back into the first (scrubbed and sanitized) carboy for bottling. Add 2½ Campden tablets to sanitize the batch one last time, wait for them to dissolve, then agitate the mead to mix it thoroughly. Immediately siphon your 2.4gal of mead into sanitized beer bottles or American (cappable) champagne bottles and cap them with sanitized caps (Figure Q).

Now amaze your friends and family with this unique, delicious, and historical drink!

**SPECIAL THANKS:** To the people at Oak Barrel Winecraft in Berkeley, California, for teaching me the mead-making process, and to Trina Lopez, for providing honey from her urban hives in San Francisco.

### GOING FURTHER

**Log everything.** By carefully logging your procedure (ingredients, amounts, temperatures, specific gravities before and after fermentation, airlock activity, pH, qualities of the finished mead, etc.) you can develop your techniques for better and more varied meads. It's worth starting with the first batch!

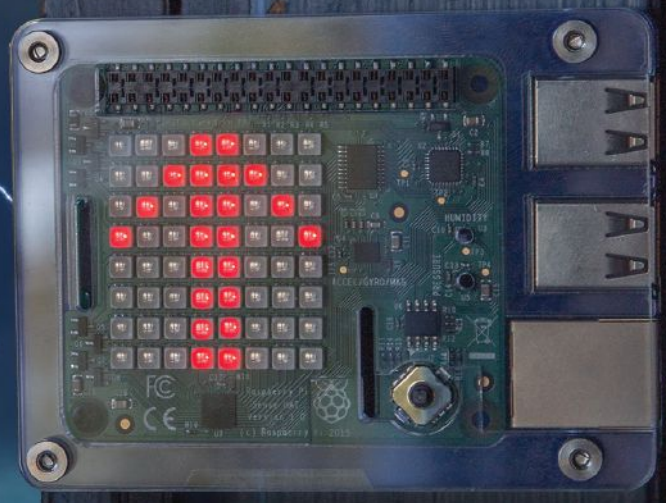
**Mix it up.** Mead variants mixing honey with fruit juices, pressed grapes, and malt — each with their own names — have a long history and offer many possibilities for experimentation. Clear, chilled mead tastes outstanding with a couple of mint leaves in it and a little carbonation. Ginger is good too. That's my little secret.

See more photos and swap mead-making tips and tasting notes at makezine.com/go/brew-your-own-mead.

# Raspberry Pi Weather Station

Stick a multi-sensor board onto a Pi and join the Weather Underground network!

Written by John M. Wargo



**JOHN M. WARGO** is a professional software developer and author. He's a software guy more than a hardware guy, but he loves working with both. He wrote the first book on BlackBerry development and has published four books on Apache Cordova (also known as Adobe PhoneGap). Find him at johnwargo.com and on Twitter at @johnwargo.

Hep Svadja and istockephoto.com

**FOR YEARS I'VE WANTED TO SET UP A WEATHER STATION IN MY BACKYARD**, but I've balked at the cost of those expensive kits. When the folks at Astro Pi (astro-pi.org) released the Sense HAT sensor board for the Raspberry Pi computer, I knew I had an easy way to build my own Pi-based weather station using off-the-shelf parts.

The Sense HAT was designed to be sent into space, and schoolchildren in England were engaged to create (and code, of course) experiments for it that would be executed by an astronaut on the International Space Station. The HAT stacks right on top of the Raspberry Pi computer and has the following hardware capabilities:

- Temperature, humidity, and pressure sensors
- Accelerator, gyroscope, and magnetometer
- 8×8 full-color RGB LED display
- 5-button joystick

For this project, I use the Sense HAT to measure temperature, humidity, and barometric pressure. Once I started collecting the data, I needed to do something with it, so I coded the application to upload the measurements to Weather Underground (wunderground.com), creating my own online weather station. Weather Underground (WU) lets you set up your own station and upload your data for others to use; your data becomes part of the aggregate weather data, and you (and your neighbors) can view your station's data separately as well.

Since the HAT also has an LED display, I decided to use it to display information about the weather data. You could use it to display numbers (1 or 2 digits at a time), but I decided to display a red arrow pointing up when the temperature increased over the last reading, a blue arrow pointing down when the temperature decreased, and blue and red bars (like a strange equal sign) when the temperature stays the same between measurements.

The project's really easy to complete. Just assemble the hardware (which takes about 5 minutes), install some Python libraries, download and configure the project's code, and you're all set. Overall, the whole project should take you no more than an hour. The complete source code is available at github.com/johnwargo/pi_weather_station.

John M. Wargo

You'll also want to mount the project in a container that protects it from the elements while at the same time enabling the HAT's sensors to accurately measure current conditions. I'm going to use mine on my covered back porch, but I also improvised a rain shield for exposed locations.

## WEATHER UNDERGROUND WEATHER STATION SETUP

Weather Underground (WU) is a public weather service, now owned by the Weather Channel, that lets you upload local weather data into the WU database for public consumption. Setting up a WU weather station is free and easy to do. Point your browser of choice to the Weather Underground Personal Weather Station Network (PWSN) home page at wunderground.com/weatherstation/overview.asp and click the Join button in the upper-right corner (Figure A).

On the page that appears, you'll be prompted to enter your email address, a user name, and password to create a new account. Then go back to the PWSN home page and click the My PWS button at the upper right. On the page that appears, populate the form to create your new personal weather station (Figure B).

Once you complete the setup, WU will generate a station ID and an access key you'll need to access the service. Be sure to capture those values, you'll need them to configure the project application later.

## ASSEMBLE THE HARDWARE

Assembly is really easy. Just mount the Sense HAT on top of the Raspberry Pi, put it all in the case, and power it up.

The C4 Labs Zebra Case comes with 2 heat sinks, one for the top of the Pi (shown in Figure C) and one for the bottom. Mount these before assembling the case; they'll help dissipate heat from the processor and should help reduce the effect of the Pi's processor on readings (see "Calculating Ambient Temperature," page 73).

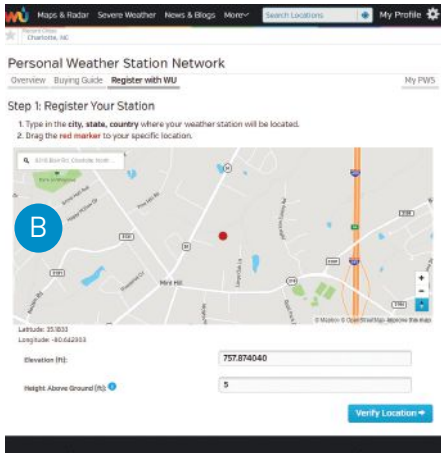
The Zebra Case is built in layers, so you have to stack multiple parts around the Pi to assemble it. Build the case, following the included instructions, but leave the final piece off as shown in Figure C.

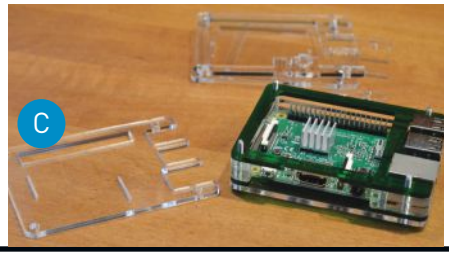
The Sense HAT Upgrade replaces the top layer of the case with several parts,

**Time Required:**
**1 Hour**
**Cost:**
**$100–$110**

## Materials

- **Raspberry Pi single-board computer, version 2 or later** I used the Pi 3 with built-in Wi-Fi.
- **MicroSD memory card, 4GB or higher** to hold Raspbian, the Raspberry Pi OS (free from raspberrypi.org/downloads/raspbian).
- **Raspberry Pi power supply** such as CanaKit #DCAR-RSP-2A5, Amazon #B00MARDJZ4. Or get the Pi, the SD card, the power supply, and more accessories in our Getting Started with Raspberry Pi kit, makershed.com/collections/raspberry-pi.
- **Astro Pi Sense HAT add-on board** for Raspberry Pi, Adafruit #2738, adafruit.com
- **Enclosure** of your choice. The only commercial case I could find that fits the Sense HAT is the C4 Labs Zebra Case (it comes with heat sinks for the Pi 3) with their Sense HAT Upgrade, c4labs.net/collections/raspberry-pi/sense. You can find files online for 3D-printable cases, or design your own enclosure for outdoor use.
- **Temperature/humidity sensor (optional)** DHT22 type, Adafruit #385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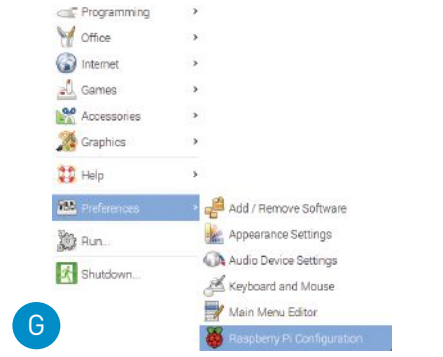

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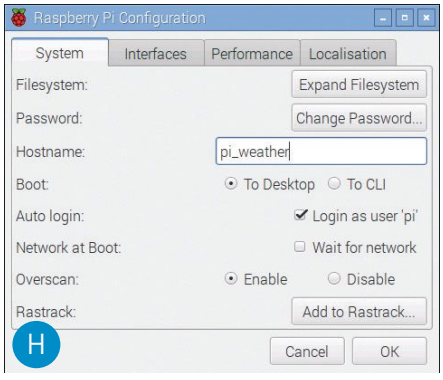

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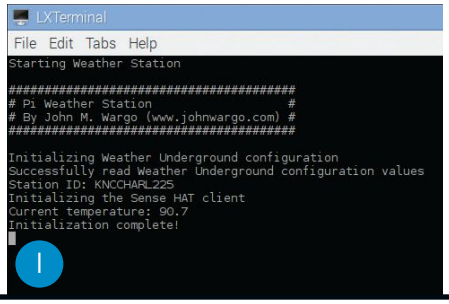

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including a set of longer screws. In Figure C, the original case top is sitting to the left of the Pi, with the extra Upgrade parts behind the device.

Mount the Sense HAT on the Raspberry Pi. The Sense HAT will sit flush against the top of the colored part of the case as shown in Figure D.

**NOTE** The Raspberry Pi Foundation recommends that you install standoffs between the Pi and the HAT for stability, but you can't use these standoffs with the C4Labs Zebra case; the HAT won't fit correctly if you do.

Next comes a clear piece that fits flush around the outline of the Sense HAT as shown in Figure E.

Finally, add the remaining 2 pieces: one covers the Sense HAT around the joystick area, and the top plate covers the rest, while still exposing the Sense HAT's sensors. You can see the assembled case in Figure F.

Before you tighten the case using the longer screws provided with the Sense HAT Upgrade, be sure to look around all sides to make sure everything fits snugly. If you see any big gaps or bent parts, then you may not have the case assembled correctly.

## SET UP THE RASPBERRY PI

The Raspberry PI needs an OS to boot, so grab your microSD card, then follow the instructions at raspberrypi.org/documentation/installation/installing-images/README.md to download and install the OS on the SD card. Once that's completed, insert the SD card into the Pi. Turn on your monitor, then plug the Pi's power supply into a power outlet and the Micro-USB port on the Pi.

Now you'll configure some system-wide settings on the Raspberry Pi. Open the Raspberry menu in the upper left corner of the Pi screen, then select Preferences→Raspberry Pi Configuration (Figure G).

By default, the Raspbian image only utilizes a part of the SD card's storage (3GB); if the card you used for your Raspbian installation is larger than 3GB, you'll need to expand the file system to use the whole disk, to make sure you'll have room for the additional software used in this project.

In the Raspberry Pi Configuration utility shown in Figure H, click the Expand Filesystem button to enable the Pi to use the whole SD card for storage. Making this change will require rebooting your Pi, so don't be surprised.

If you want, use this opportunity to change the host name for the Pi device, so you can easily find it on the network later. You can see I've named mine `pi_weather`. If you're a U.K.-based reader, you're done; click the OK button and let the Pi reboot

If you're outside the U.K., switch to the Localisation tab and make sure the settings are properly configured for your locale, time zone, and keyboard. Click OK and reboot.

Next you'll need to update the Pi's core software. Open a terminal window and execute the command:

```
sudo apt-get update
```

This command updates the Pi's indexes of available software packages. Next, execute:

```
sudo apt-get upgrade
```

This command fetches and installs the latest and greatest versions of the Raspbian OS and other software packages installed on the Pi. It will take quite a while.

## INSTALL PROJECT SOFTWARE

The Sense HAT uses its own Python libraries. To install them, go to the terminal window and execute the command:

```
sudo apt-get install sense-hat
```

Next, create a directory for the project files:

```
cd ~
mkdir pi_weather_station
cd pi_weather_station
```

Then copy the project's Python source code to the new directory with this command:

```
wget https://github.com/
johnwargo/pi_weather_station/
archive/master.zip
```

and extract the files with this command:

```
unzip -j master.zip
```

## CONFIGURE PROJECT SOFTWARE

In order to upload data to the Weather Underground service, our Python app needs access to the station ID and station access key you created earlier in the setup process. Open the project's *config.py* file in your text editor of choice then populate the `STATION_ID` and `STATION_KEY` fields with the appropriate values from your Weather Underground Personal Weather Station:

John M. Wargo

```
class Config:
  # Weather Underground
  STATION_ID = "YOUR_STATION_ID"
  STATION_KEY = "YOUR_STATION_KEY"
```

The project's main Python app, *weather_station.py*, has two configuration settings that control how it works. To change these values, open the file in your text editor and look for these lines near the top:

```
  # specifies how often to upload
  values from the Sense HAT (in
  minutes)
  UPLOAD_INTERVAL = 10  # minutes
```

The app reads the temperature sensor on the Sense HAT every 10 seconds, for use in calculating ambient temperature. But we don't want to upload data to Weather Underground that frequently. So, the `UPLOAD_INTERVAL` variable controls how often the app sends measurements to WU. To change this interval, just change the value to the right of the equal sign.

If you're testing the app and don't want your data uploaded to WU until you're ready, change the value for `WEATHER_UPLOAD` to `False` (in Python, case matters, so it has to be `False`, not `false`):

```
  # Set to False when testing the
  code and/or hardware
  # Set to True to enable upload
  of weather data to Weather
  Underground
  WEATHER_UPLOAD = False
```

### TEST THE PROJECT'S PYTHON APP

To run your weather station Python application, open a terminal window, navigate to the folder where you copied the project files and execute the following:

```
  python ./weather_station.py
```

The terminal window should quickly sprout the following output:

```
################################
# Pi Weather Station
#
# By John M. Wargo (www.johnwargo.
com) #
################################
Initializing Weather Underground
configuration
Successfully read Weather
Underground configuration values
Station ID: YOUR_STATION_ID
Initializing the Sense HAT client
Initialization complete!
```

If you see something like that, you're golden. If not, figure out what any error messages mean, fix things, then try again. At this point, the application will start collecting data every 10 seconds and uploading it to the Weather Underground every 10 minutes (unless you changed the app's configuration to change the upload interval).

### START THE APP AUTOMATICALLY

Finally, you must configure the Raspberry Pi so it executes the Python app on startup. In a terminal window, navigate to the folder where you extracted the project files. Then make the project's Bash script file executable by executing the following command:

```
  chmod +x start-station.sh
```

Next, open the Pi user's session autostart file using the following command:

```
  sudo nano ~/.config/lxsession/
  LXDE-pi/autostart
```

Add the following line to the end (bottom) of the file:

```
  @lxterminal -e /home/pi/pi_
  weather_station/start-station.sh
```

To save your changes, press Ctrl-O then press the Enter key. Next, press Ctrl-X to exit the `nano` application. Reboot the Raspberry Pi. When it restarts, the weather station's Python process should execute in a terminal window (Figure I).

## USE IT

You're now running a personal weather station! You can share your Weather Underground page with friends and neighbors, or just enjoy knowing that you're contributing to one of the world's biggest weather databases powered by citizen science.

### CALCULATING AMBIENT TEMPERATURE

One of the frustrating parts of building this project was that I ran into a problem with faulty temperature readings. It turns out the Sense HAT has a design flaw, in that the humidity and pressure sensors (each of which can be used to measure temperature) are not thermally isolated from the Pi's CPU, and therefore can't measure ambient temperature accurately. Ugh! Anyway, the Pi community has figured out ways to read the CPU temperature, then use that value to guesstimate ambient temperature to within 1°C — pretty good. I implemented one of these solutions in the code so you can grab near-accurate temperature readings. This is especially important if you're using a Raspberry Pi 3, which generates more heat than older Pi boards.

You can also connect a standalone temp/humidity sensor to the Pi's GPIO pins, and edit the code to read that sensor too! I've built a version using an off-the-shelf sensor (Adafruit #385) and the Adafruit libraries at github.com/adafruit/Adafruit_Python_DHT. My revised code for this version lives at github.com/johnwargo/pi_weather_station_simple.

### MOUNTING YOUR WEATHER STATION OUTDOORS

The Zebra case is not waterproof, so you'll want to install it in a sheltered spot like a porch, or make an enclosure that protects it while letting the sensors breathe.

For exposed locations, I improvised a simple rain shield (Figure J) using a plastic food container and a Chinese takeout lid. It's open at the bottom, with vents at the top, so the temperature should equalize easily with the surroundings (Newton's law of cooling applies). I didn't want to drill holes in the sides, as that would let water in, so I mounted the Pi on a piece of ¼" plywood and velcroed it to the inside of the container. To see how I made it, visit the project page online — and I'd love to see your ideas too!

J

See more photos and share your weather station ideas at makezine.com/go/raspberry-pi-weather-station.

Written by Ray T. Lam

# Origami Bike Trailer

## It folds flat so it stows anywhere!

**Time Required:** A Weekend
**Cost:** $40–$120

## Materials

**FOR THE TRAILER:**

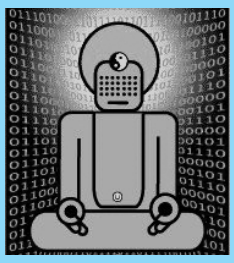
- **Plywood, ½", about 4'×6' total:** Sides 16"×22" (2), bottom panels 9"×22" (2), front/back panels 9"×16" (4), top cover 23"×21" (1)
- **Hinges (18)**
- **Hasps (5)**
- **Wood screws, ½"** enough to attach all your hinges and hasps
- **Carabiners (5) (optional)**
- **Bike wheels, 24" (2)**
- **Bolts, ½"×6" (2)**
- **Nuts, ½" (4)**
- **Fender washers, ½" (4)**
- **Lock washers, ½" (2)**
- **Paint**

**FOR THE TOW BAR:**

- **Steel or aluminum bar, ⅛"×1½"×24" (2)**
- **Pipe, 1" diameter, 6" length**
- **Threaded rod, ¼", 7" length**
- **Cap nuts, ¼" (2)**
- **Bolts, 5⁄16"×1" (4)**
- **Wing nuts, 5⁄16" (4)**
- **Washers, 5⁄16" (4)**

## Tools

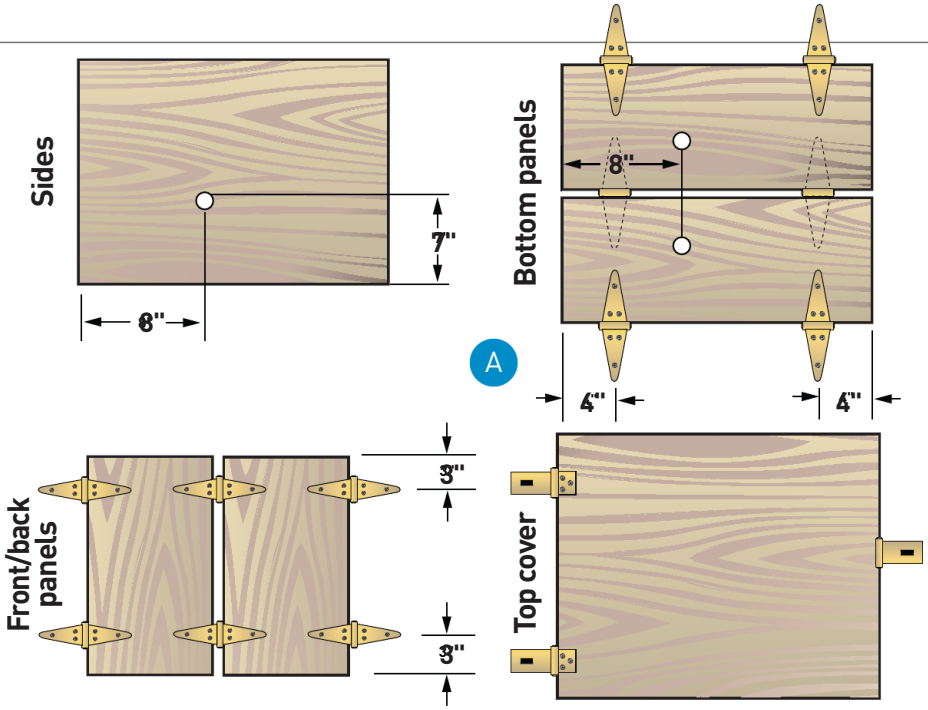
- **Drill and bits: ⅜" twist, ⅝" spade, 1" spade**
- **Screwdriver**

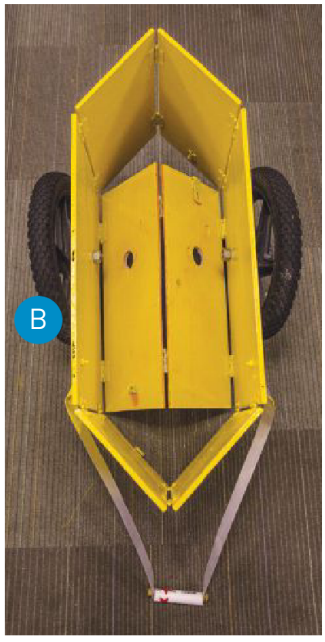


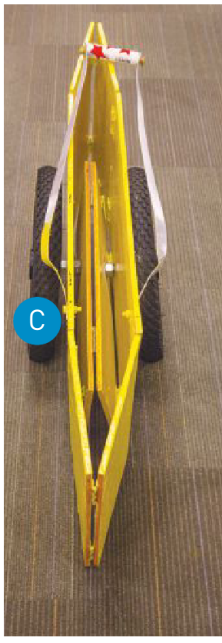
**RAY T. LAM** loves science, art, design, engineering, and philosophy. He blogs his DIY projects at rtlbuiltdiy.blogspot.com.

Get your own limited edition plush Makey at Barnes and Noble this winter.

Hep Svadja




**AFTER LOOKING FOR BIKE TRAILERS, I WASN'T THRILLED WITH THE CHOICES.** Spend $250 for one I sort of like? It was just too much. So I built this folding, origami-ish trailer on the fly with what I had at hand. In New York City space is at a premium, so it had to fold up so that I can store it in my squish-box of an apartment. I decided right away to use ½" plywood; I knew ¾" would be too much weight.

Here are the results of my tinkering. There's lots of room for improvement, but it easily carries 100+ pounds. Plus I can stick my monstrous Chevy Volt battery inside — *really* extending the range of my electric bike!

With the handle I designed, it also works as a simple cart. I drew up some rudimentary plans to help you build one too.

## 1. BUILD THE FOLDING BOX

Follow the assembly diagrams and photos here (Figure A), then test the folding action. I found that the folds worked fairly well. If the box sags, you can keep it nice and square by adding 2 hasps inside, to lock each bottom panel to a front or back panel.

## 2. ADD THE WHEELS

The axles are ½" bolts attached directly to the plywood with large flange washers. I used a ⅝" spade bit for the axle holes.

Test-fold the trailer again and mark where the wheel bolts touch the bottom panels. Then drill 1" clearance holes for the axle nuts to fit into (Figure B), so it's narrower when it's folded (Figure C).

## 3. ADD THE TOP COVER

Since it all has to collapse, the top cover is removable for storage. I used 3 hasps to attach it; the 2 inside hasps I had to bend for a better fit. I locked mine with little carabiners (Figure D) but you could also just use a twist-lock style hasp.

## 4. PAINT

Remove the wheels and paint the trailer. I used Boeing green epoxy primer.

## 5. MAKE THE TOW BAR

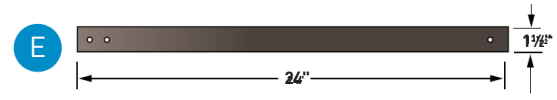
For the tow arms (Figure E), I used ⅛" flat steel bar from Home Depot and bent it to the configuration you see here. For the handle I used 1" aluminum pipe. Threaded rod (¼") holds the pipe between the bars.

## 6. FINAL ASSEMBLY

I used four 5⁄16" bolts with wingnuts to attach the tow bar to the trailer, because I want it to be removable. If you remove only the 2 rear bolts it folds down neatly (Figure F).

I'm using a bungee cord right now to attach it to my rear bike rack. Just haven't gotten around to building a better coupling yet — stay tuned.

There you have it. It still needs lots of minor modifications but it's very usable — and foldable!



See more step-by-step photos and diagrams and share your build at makezine.com/go/origami-folding-bike-trailer.

James Burke, Hep Svadja, Ray T. Lam

# Leaf Blower Wiffle Ball Launcher

## Put the world's most obnoxious yard tool to batter use!

Written by William Gurstelle


Caleb Krafft

**SCIENCE MARCHES FORWARD BUT NOT ALWAYS IN THE DIRECTION WE WANT IT TO GO.** Sometimes things get invented that, really, I wish were not. Choosing the "worst invention of the century" is a pretty subjective exercise no matter how you go about it. Still, some ideas are just terrible no matter how you look at them.

First, take the 20th century's worst idea: the baby nuke.

During the dark days of the Cold War, nuclear war meant one thing — mass devastation on a scale so horrific that the mere thought of it normally stops the conversation right there. But in the middle of the 20th century, U.S. Army war planners hit on the idea of waging small-scale, limited nuclear war. Thus was born the idea for something called "tactical" nuclear weapons.


Worst 20th-century invention: Battlefield nuclear weapons

The first artillery-based nuclear weapon was the M65 cannon. Nicknamed Atomic Annie, this weapons system fired a 15-kiloton shell about 7 miles. Soon after Annie's inception, an even smaller nuclear cannon was developed.

Code-named Davy Crockett, the small weapons system consisted of a recoilless rifle and small, portable nuclear shell (Figure A). In my opinion, Davy was a terrible rendition of a terrible idea on many levels. The nuclear payload would destroy most everything within a half mile of where it landed and release a cloud of deadly radioactivity in the process. Since the rifle had a maximum range of only about 3 miles, the gunners were bound to get a good dose of radiation themselves, especially if the wind was blowing their way.

Worse, it's not hard to imagine that if one side used a small nuke, then the other side would respond in similar fashion. After a few rounds of retaliation and counterretaliation, the big ICBMs would likely start flying, after which cockroaches and tardigrades would emerge as the dominant species on the planet. So that's why I think tactical nukes are the worst idea ever.

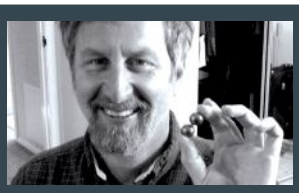
OK, enough with the serious stuff. The second worst invention of the 20th century is the leaf blower (Figure B).

Your local home center has lots of gas- and electric-powered outdoor machines that really can make your life better. While I can't say I love my lawnmower or snow blower, they do serve important purposes. But the leaf blower? Like the Davy Crockett, it's something that should have never been invented. To subjectively paraphrase Shakespeare, a noisy, consumer-grade leaf blower is a device used "by an idiot, full of sound and fury, and that does almost nothing."


Second-worst 20th-century invention: Leaf blowers

My former neighbor Big Pete loved his leaf blower. For him, any time was leaf blower time. Instead of using a rake or broom to clean up his yard, he'd joyfully shoulder up his leaf blower and spend a merry hour or two shattering the neighborhood peace with a 100-decibel roar, doing a job that could have likely been done in half the time with a manual tool.

Not only that, these breathtakingly irrational wasters of energy are highly polluting. The typical leaf blower's tiny and primitive two-stroke gas engine (in which oil is dumped directly into the fuel tank and from there, spewed into the atmosphere) puts out more pollutants per minute than a 3-ton Ford pickup truck, and has a carbon footprint 30 times greater. It's true that electric leaf blowers are less polluting than gas-powered ones, but they're still noisy and, in my opinion, they work poorly when compared to a regular garden rake.



**WILLIAM GURSTELLE** is a contributing editor of *Make:*. Find his new book on DIY artillery at readythecannons.com.

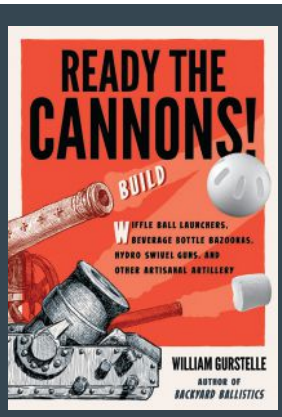
**Time Required:**
**1-2 Hours**
**Cost:**
**$25 plus leaf blower**

## Materials

- **PVC pipe, 3" diameter, 11½' total length** Cut to 10' and 18" lengths.
- **PVC pipe, 2" diameter, 4" length**
- **PVC fitting, low heel inlet, 3"×3"×2"**
- **Small screw eyes (2)**
- **Sawhorses (3)** or other sturdy supports
- **Bungee cords (2)**
- **Leaf blower** A leaf blower's power is described by the number of cubic feet per minute (CFM) of air it discharges. More powerful blowers with higher CFM ratings deliver greater distance and accuracy, so choose accordingly.
- **Duct tape**
- **Wiffle balls**

## Tools

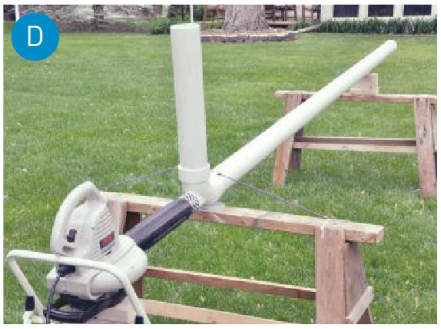
- **Electric drill**
- **Twist drill bits**
- **Safety glasses**
- **Batter's helmet**






U.S. Dept. of Defense, William Gurstelle

Low heel inlet detail



Completed Wiffle Ball Launcher, ready for batting practice

So is there any reason on Earth for a leaf blower to exist? Surprisingly, yes. It makes a terrific Wiffle Ball Launcher.

The Wiffle Ball Launcher will accurately (by Wiffle ball standards) pitch ball after ball for games or practice. Made from $25 of plumbing supplies, some scrap wood, and your leaf blower, this project shows off your DIY chops to their best advantage. A key component is an easy-to-find PVC plastic fitting called a "low heel inlet elbow."

By a miraculous quirk of fate, the 3"×3"×2" low heel inlet elbow couldn't be better for turning your leaf blower into a Wiffle ball pitching machine. First, it accepts a 3" diameter PVC pipe, which is the optimum-diameter barrel for a regulation Wiffle ball. Second, the 2" inlet matches up exactly with most round leaf blower nozzles.

But here's the magical part: because of the fitting's geometry and a fluid mechanics principle called Bernoulli's Law (see my Remaking History column "Giovanni Venturi and the Venturi Effect" in *Make:* Volume 49, makezine.com/projects/giovanni-venturi-venturi-effect), an object like a Wiffle ball inserted in the top of the fitting will be sucked in and shot out the barrel.

## BUILD YOUR WIFFLE BALL LAUNCHER

**1.** Drill two ⅛"-diameter holes and insert the small screw eyes into the thick part of the low heel inlet, as shown in Figure C.

**2.** Refer to the Wiffle Ball Launcher Assembly diagram below during the remaining steps. Attach the 10-foot-long, 3"-diameter PVC pipe to the 3" horizontal opening on the low heel inlet. Don't reduce the length of the barrel because a short barrel won't provide as much range or velocity.

**3.** Attach the 18"-long, 3"-diameter loading tube to the 3" vertical opening on the low heel inlet.

**4.** Place the barrel, loading tube, and low heel inlet assembly on the sawhorses. Center the assembly and rotate it so the loading tube is vertical. Attach bungee cords from the sawhorses to the screw eyes to hold the loading tube vertical.

**5.** Some leaf blower nozzles fit well into the 2" opening on the low-heel inlet. If yours fits, skip ahead to Step 6. If not, insert the 4"-long, 2"-diameter pipe into the 2" hole on the low heel inlet and use reducing fittings as necessary to make it fit.

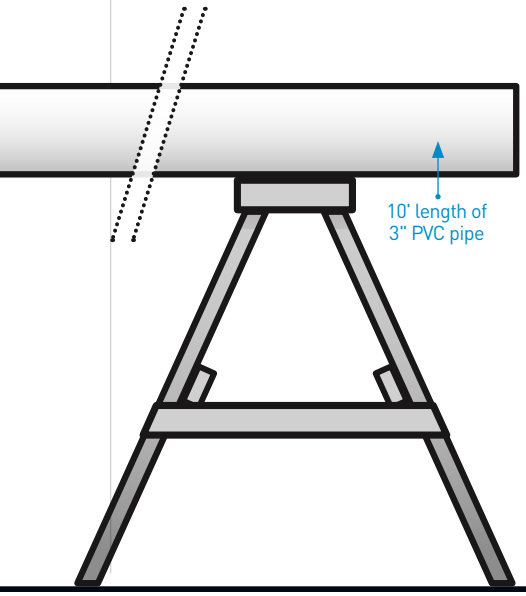
**6.** Align the nozzle of your leaf blower with the 2"-diameter pipe on the low heel inlet. Use duct tape to securely seal the connection (Figure D). You're ready to go.

## BATTER UP!

Turn on the leaf blower, insert the Wiffle balls in the loading tube, and watch them shoot out. My shooting chronograph shows a muzzle velocity of about 50mph using my moderately powerful leaf blower. You can elevate the barrel with wood blocks to adjust the trajectory of the ball into the strike zone. Because of the Wiffle ball's holes, each pitch will flutter and curve, making the batting challenge extra fun.

Most leaf blowers don't produce enough power to propel a Wiffle ball with a high enough velocity to be really dangerous. Still, Wiffle ball trajectories are erratic by design, so be aware you'll frequently get hit by a pitch. Wear a batter's helmet and eye protection.

Share your Wiffle Ball Launcher build and batting tips at makezine.com/go/leaf-blower-wiffle-ball-launcher.




William Gurstelle, Damien Scogin courtesy of Chicago Review Press

# VICTORY THROUGH AIR POWER

**TWO DIFFERENT AIR RIFLES** by Isaiah Lukens (top) and Bartholomäus Girandoni (bottom), believed to have been carried by Capt. Meriwether Lewis on the Corps of Discovery's expedition of 1804–1806.

**AIR GUNS, IN ONE FORM OR ANOTHER, HAVE BEEN AROUND FOR THOUSANDS OF YEARS** — much longer than gunpowder weapons. If you think about it, blowguns are a type of air gun that has been used for hunting since prehistoric times.

The use of mechanically powered air guns goes a long way back as well. The first were simply blowguns powered by a bellows attached to the breech. Instead of huffing into the pipe, some clever large-game hunter came up with the notion of putting a squeezable bag on the end. When the bag was squeezed, the compressed air shot a dart or pellet out of the gun. And if the bag was squeezed using the mechanical advantage derived from a system of levers (imagine a fireplace bellows), then the gun could be made to shoot much more powerfully than could be accomplished through lung power alone.

The oldest existing mechanical air gun is thought to be a specimen in the collection of the Livrustkammaren museum in Stockholm, Sweden. Inside this old gun, which the museum dates to about 1580, a spring mechanism operated an air bellows located in the stock of the gun. When the shooter pulled the trigger, the spring caused the bellows to force a powerful air gush that shot a specially shaped bolt, or dart, toward the target.

By roughly 1600, air-powered darts were being shot for sport across Europe, in a variety of ways. According to the people who study such arcana, spring-powered air guns activated by a moving piston (which was a big improvement upon the earlier bellows-reservoir technology) quickly appeared. An early, exceptionally detailed description of such an air gun is found in the *Elemens d'Artillerie* by David Rivaut, who was preceptor to Louis XIII of France. He ascribes the invention to a man identified only as "Marin, a burgher of Lisieux," who presented the first air gun to England's Henry IV. By the turn of the 19th century, air guns had developed to the point where they were likely more accurate and more powerful than black powder weapons of similar size.

Circa 1800, air guns of any size and quality were frightfully expensive to make. It took months of time, arcane knowledge, and excellent tools to make a device of this type because the components — valves, locks, cylinders, and reservoirs — had to be very carefully machined. Consequently, an air gun cost far more than a simple black powder rifle and was beyond what most people of the time could spend on a sporting piece.

But for those who could afford them, air guns offered a lot of advantages. By comparison with a smoothbore, muzzle-loading musket, air guns were a hunter's dream. For one thing, they could be fired several times a minute, far more readily than the muskets of those days, which required a load-tamp-fire procedure.

Second, they didn't emit any smoke. This made it easier to aim the next shot if it was needed; line of vision wasn't obscured by powder smoke. Third, a shooter didn't need to be concerned about keeping his powder dry; it worked as well in damp weather as in dry.

Probably the most famous air gun in American history was a rifle carried by Meriwether Lewis during the Lewis and Clark expedition of 1803–1806. The actual gun may reside (there is controversy surrounding its pedigree) in the Virginia Military Institute's museum of historical weapons. The VMI museum claims that the .31" caliber, flintlock-style pneumatic rifle in its collection is the one built by expert clockmaker Isaiah Lukens in Philadelphia and hauled to the Columbia River Valley and back by the Corps of Discovery. But recent scholarship suggests Lewis carried a Girandoni air rifle, an Austrian repeater that could empty its 20-ball magazine in 1 minute. In either case, Lewis' air rifle demonstrations astonished the Native American tribes they met along their epic journey.


# Irresistible Resistors

Written by Amanda Cole

## Crochet these adorable *amigurumi* components — and memorize the common ohm values

**Time Required:**
**1-2 Hours**
**Cost:**
**$5-$10**

### Materials

- **Yarn, medium weight, in 6 colors**
  - **Color 1:** Resistor body, usually tan
  - **Color 2:** First digit resistor color band
  - **Color 3:** Second digit resistor color band
  - **Color 4:** Resistor multiplier color band
  - **Color 5:** Resistor tolerance color band
  - **Gray** to make a chain
- **Polyester stuffing or similar** About 2 large handfuls per resistor

### Tools

- **Crochet hook, 4mm/6/G**
- **Yarn needle**
- **Safety pin or crochet stitch marker**

### ABBREVIATIONS USED IN THE PATTERN

- **st** — stitch
- **sl st** — slip stitch
- **ch** — chain
- **sc** — single crochet
- **inc** — increase — 2 sc in one st
- **dec** — decrease — (insert hook into next st, pull up a loop) twice, pull through all 3 loops on hook

**I'VE FOUND A WAY TO MERGE MY PASSION FOR ELECTRICAL ENGINEERING WITH THE WONDERFUL ART OF CROCHET:** I've rendered the form of the resistor into a purely aesthetic plushie made from yarn and polyester stuffing, and I've written up a crochet pattern for all the world to use.

The Japanese-derived term *amigurumi* refers to stuffed animals, creatures, or inanimate objects rendered in knitting or crochet. After discovering these, I decided it would be neat to make amigurumi versions of common electronic components. Choosing to design a resistor first was an obvious choice. The simple shape makes it easy to crochet, and the color bands make it instantly recognizable by the maker/electronics community.

I started by designing the general shape, and then took a trip to the craft store to pick the perfect colors. I find that changing yarn colors frequently, as done while making this resistor, keeps crocheting fun and fresh. As an added bonus, making these has helped me memorize the common ohm values of resistors!

The crochet pattern itself is relatively simple and can be done by a confident beginning crocheter. It takes less than an hour to make a single resistor once you understand the pattern.

### PATTERN NOTES AND STITCHES

The resistor is worked in rounds in a spiral. Use the stitch marker to note the first stitch of each round. There is no slip-stitch joining or turning at any point. As you finish crocheting each color band, tie the colored yarn tails together and cut them short. The resistor is stuffed before the last few rounds.

Hep Svadja



**AMANDA COLE** enjoys martial arts, crochet, and making pointless inventions. She's studying electrical engineering at Penn State, and she blogs at Electrothoughts (electrothoughts.wordpress.com).

**FINISHED MEASUREMENTS:** 6"×2"×2"

## THE PATTERN

- **Round 1:** With Color 1, ch 4, sl st into first ch to form ring. Ch 1 (counts as first sc), 11 sc in ring. Do not join. [12 sc]
- **Round 2:** Inc around. [24 sc]
- **Rounds 3–6:** Sc around. [24 sc]
- **Rounds 7–8:** Do not cut off Color 1, as it will be carried up in round 9. With Color 2, sc around. [24 sc]
- **Round 9:** Picking up Color 1 from 2 rounds below, (dec, sc 1) 8 times around. [16 sc]
- **Round 10:** Sc around. [16 sc]
- **Rounds 11–12:** Again, do not cut off Color 1, as it will be carried up. With Color 3, sc around. [16 sc]
- **Rounds 13–14:** Picking up Color 1, sc around. [16 sc]
- **Rounds 15–16:** With Color 4, sc around. [16 sc]
- **Round 17:** With Color 1, sc around. [16 sc]
- **Round 18:** (Inc, 1 sc) 8 times around. [24 sc]
- **Rounds 19–20:** With Color 5, sc around. [24 sc]
- **Rounds 21–24:** With Color 1, sc around. [24 sc]
- **Round 25:** Dec around. [12 sc] Stuff the resistor evenly before moving on.
- **Round 26:** Dec around. [6 sc] Sl st, sl st, then fasten off, using the Color 1 tail and a needle to stitch closed the end of the resistor. Weave in tail end.

To make the chain, with gray yarn ch 20 and bind off. Thread chain onto yarn needle, and thread through the top of the resistor. Tie together tails and trim yarn ends.

This amigurumi resistor could be used as a Christmas ornament, a neat workshop decoration, a way to show off your favorite resistor value — or a gift for that special nerdy someone.

Share your amigurumi creations at makezine.com/projects/crochet-your-own-adorable-amigurumi-resistor.

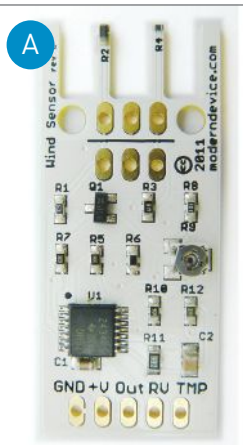
# A Bright Idea

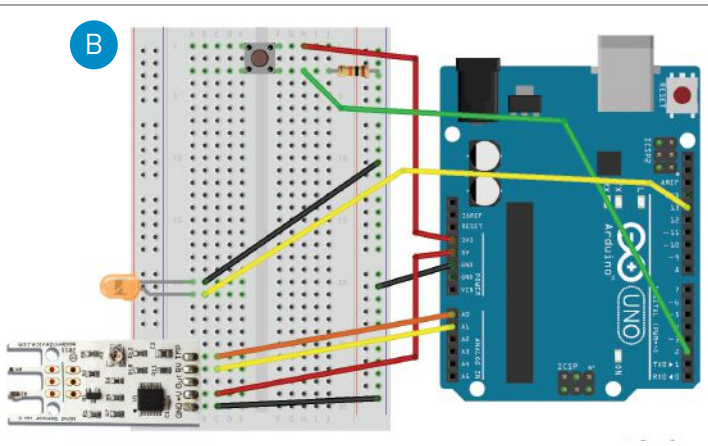
Written by John Keefe

## Arduino-powered electric candle you can actually blow out

**JOHN KEEFE** is senior editor on the Data News Team at public radio station WNYC in New York. He also leads workshops on sensors and journalism, teaches at NYC colleges and universities, and founded an invention collaborative called Really Good Smarts LLC.

Hep Svadja




**"HOW MIGHT WE MAKE AN LED CANDLE THAT YOU CAN ACTUALLY BLOW OUT?"**

That was a question my daughter and I had one evening, so we got online and started exploring different ways to sense wind. Along the way, we discovered a pretty nifty sensor that does exactly what we needed. That sensor is the center of this project.

## CONCEPTS: SENSING AIR MOVEMENT AND WIND

Weather stations use a set of spinning cups, called an anemometer, to measure wind. Another way to detect air movement might be to hang two strips of tinfoil next to each other and detect when they touch, completing an electrical circuit — though that might also detect a curious cat.

There's another method, which works on the same principle you use when your pizza slice is too hot to eat and you blow on it to cool it down. In the same way, a wire warmed up by a little electricity will cool when air blows across it — and it's possible to measure that temperature change to sense the wind! These are called "hot-wire" wind detectors, and there's one from Modern Device (Figure A) that plays nicely with an Arduino.

## 1. ASSEMBLE THE WIND SENSOR

You need to solder the row of header pins to the sensor so you can then stick them into the breadboard.

*Wait, soldering? Scary!*

Not at all! Soldering is not difficult, but you do need a soldering iron, some solder, and a little lesson. Learning to solder is empowering, awesome, and easy. I like the tutorial at SparkFun (keefe.cc/soldering), and you can find soldering Skill Builders at *Make:* too (makezine.com/skill-set-soldering). This project is a great time to learn, because you need to solder just 5 spots: the 5 pins that make the "header" to stick into the breadboard. (These header pins come with the sensor board.)

The hardest part of soldering is holding everything together while you actually apply the solder to the pins. But in this case, your breadboard can be your assistant. Just push the long ends of the header pins into the breadboard and place the 5 holes at the end of the wind sensor onto the short ends. To keep the board level, place a coin between the breadboard and the other end of the sensor board.

Then solder away, making sure none of the solder from one pin touches solder from another pin. Once you have the header attached, you're good to go.

## 2. WIRE UP THE PARTS

Here's the wiring diagram for this project (Figure B). It's all plug-and-play from here, no more soldering required!

- Insert the pushbutton at the top of the breadboard so it straddles the center canal of the breadboard and 2 of its legs are in row 1.
- Grab the resistor, and put one of its legs into the breadboard's column J at row 3.

**NOTE** This resistor leg should be in the same row as a leg of the button. But some buttons are different sizes, and if yours has a leg in a different row, put this resistor leg in that row instead.

- Put the other leg of the resistor in any hole along the blue negative (–) rail.
- Grab the LED and insert its shorter leg into the column A at row 20.
- Insert the LED's longer leg one hole below, at column A, row 21.
- Where the LED legs meet the breadboard, carefully bend the LED at a right angle so it's basically "lying down" on the breadboard.

**Time Required:**
**1–2 Hours**
**Cost:**
**$50 – $60**

## Materials

- **Modern Device Wind Sensor** $17 from moderndevice.com/product/wind-sensor

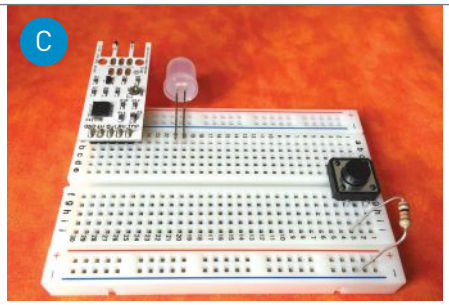
**You can buy the remaining items separately, or get them all in the Make: Getting Started with Arduino Kit,** from makershed.com or Barnes and Noble stores nationwide.

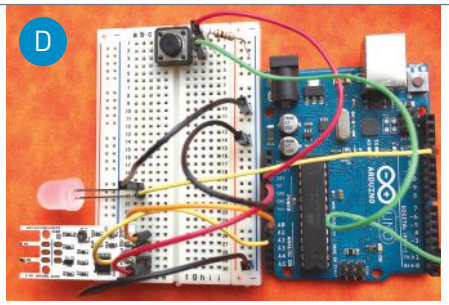
- **Arduino Uno microcontroller board** To miniaturize this project, you could substitute an Arduino Nano or similar tiny Arduino-compatible board.
- **USB cable** for Arduino
- **Solderless breadboard, 10×30 size** or larger
- **Switch, momentary pushbutton** with 0.1" pin spacing, for plugging into a breadboard
- **Resistor, 10kΩ** This one has a brown-black-orange stripe pattern.
- **LED, generic** You can upgrade to a really nice flickering LED available from Evil Mad Scientist, item #408 at shop.evilmadscientist.com.
- **Jumper wires (10)**
- **9V battery pack with switch (optional)** or Arduino power supply

## Tools

- **Soldering iron and solder**
- **Computer with Arduino IDE software** free download from arduino.cc/downloads
- **Project code** free download from keefe.cc/electric-candle


This article is excerpted from *Family Projects for Smart Objects*, which contains ***11 fun Arduino builds perfect for young makers***. Find it at the Maker Shed (makershed.com) and fine bookstores.





```
electric_candle

#define analogPinForRV    1   // change to pins you the analog pins are using
#define analogPinForTMP   0

const float zeroWindAdjustment =  .2;
int TMP_Therm_ADunits;
float RV_Wind_ADunits;
float RV_Wind_Volts;
unsigned long lastMillis;
int TempCtimes100;
float zeroWind_ADunits;
float zeroWind_volts;
float WindSpeed_MPH;

int led = 13;                // candle LED
const int buttonPin = 2;     // the pushbutton pin
int buttonState = 0;         // variable for reading the pushbutton status

void setup() {

  // initialize the digital pin as an output.
  pinMode(led, OUTPUT);

  // initialize the pushbutton pin as an input:
  pinMode(buttonPin, INPUT);

  // turn LED on
  digitalWrite(led, HIGH);
```

## WHERE'S THE RESISTOR?

You may have noticed that in most projects, we pair the sensors with a resistor. In this project, we do that again for the button (which is really a kind of sensor), but not with the wind sensor.

The reason? We've graduated to more sophisticated sensor boards that include not just the sensor itself but also some additional electronics — those little parts on the wind sensor board — that manage the power and send back to the Arduino just the information we need. To the extent resistors are needed, they're already onboard. (Literally!)

- Insert the 5 pins of the wind sensor into the bottom 5 rows of the column A, so they're in rows 26 through 30. The rest of the wind sensor should extend off the left side of the board, and the sensor's GND pin should be in column A, row 30. Things should now look like Figure C.

Time for the jumper wires! Each step below is for one jumper wire, with the connections for both ends. The colors really don't matter, but I'll mention them as they match the wiring diagram in Figure B.

- Insert one end of a (red) jumper wire into the Arduino's 3.3V pin, and the other end into the breadboard at column H, row 1.
- Insert one end of a (green) jumper wire into pin 2 on the Arduino's Digital row, and the other end into the breadboard at column H, row 3. Note that this end should share a row with one of the button legs and one of the resistor legs. Again, if your button leg is in a different row, use that row instead.
- Insert one end of a (black) jumper wire into one of the Arduino's GND pins, and the other end into any hole along the breadboard's blue negative rail on the right — the same rail as one leg of the resistor. This will be our "ground rail," which will provide ground to all of the components on the breadboard.
- Insert one end of (another black) jumper wire into the same blue negative rail on the breadboard, and the other end into column B, row 20. This is the same row as the short leg of the LED, providing ground, or the negative (–) side of the circuit, to the LED.
- Insert one end of a (yellow) jumper wire into the Arduino's pin 13, and the other end in the breadboard's column B, row 21 — the same row as the longer leg of the LED.
- Insert one end of a (red) jumper wire into the Arduino's 5V pin, and the other end into the breadboard's column C, row 29. Notice that that's the same row as the sensor's +V pin. This wire provides the power to the sensor.
- Insert one end of an (orange) jumper wire into the Arduino's analog pin A0, and the other end in the breadboard's column C, row 26. This is the same row as the sensor's TMP (temperature) pin.
- Insert one end of a (yellow) jumper wire

John Keefe [C-F], Hep Svadja

into the Arduino's analog pin A1 and the other end into the breadboard's column C, row 27. This shares a row with the sensor's RV (raw loop voltage) pin.

» Finally, insert one end of a (black) jumper wire into column C, row 30, and the other end into any hole in the blue negative rail on the right side — our ground rail.

The build is complete (Figure D).

Well done!

## 3. LOAD THE CODE

If you're new to the Arduino, follow the instructions at arduino.cc/en/Guide/ArduinoUno to connect it to your computer.

To get the project code, just visit keefe.cc/electric-candle and click the "Copy Code to Clipboard" button.

Open your Arduino software and start a new Arduino sketch using File→New from the menu. You'll get a mostly-blank sketch window. Delete the little code that's there. Click anywhere inside the blank window, then paste the code you copied from the website using Edit→Paste (Figure E). Save your work using File→Save .

Now upload this code to the Arduino over the USB cable. You can do this from the menu, by choosing Sketch→Upload, but an even easier way is to click on the upload arrow at the top of the blue Arduino software window. You should see the "Done Uploading" message in the lower part of your Arduino window and your LED should be lit. Congratulations! You've just programmed your Arduino.

## 4. MAKE IT GO, AND BLOW!

Now whenever you power up the Arduino it will run the candle program. With the LED flickering, give a good puff across the top of the sensor (Figure F). The light should go out! Press the button on the breadboard to relight it.

To free your candle from the computer's tether, you can plug an optional power adapter into your Arduino. You could also power the project with a 9V battery. There are some battery holders that have an Arduino adapter and a little switch. That's important because even when the candle is out, your Arduino is still running. So remember to power it down completely with the switch (or by unplugging the battery) or you'll run out of juice.

## FIXES

The code should work to detect a good puff. If you want to make it more or less sensitive, adjust the wind speed that triggers the dousing by changing the number value in the following line from **6** to something else:

```
if (WindSpeed_MPH > 6) {
```

## WHAT'S GOING ON?

As air moves across the sensor's "hot wire" (it's not that hot), the wire cools and its conductivity changes. The other electronics on the board detect this change and turn it into values the Arduino can read.

When these values hit our threshold, the code douses the light ... and then waits for someone to push the button to relight it.

## CODE CORNER

### You're a Star

There's some serious math in the code for this project. You don't need to know all of what's going on, of course, but I thought it would be a good time to point out some basic math symbols.

You can probably gather that **+** is used for addition and **–** is used for subtraction.

But what about the star ***** ? That's multiplication. So **2 * 3** equals 6. And **/** is for division. Which means **6 / 3** is 2.

In this code, there's even a **pow**. That's not comic-book slang for a punch; it's "power," as in "10 to the power of 2." You might know that as $10^2$. In Arduino, that's written **pow(10, 2)**. Either way, it's 100!

### Fun Functions

If you take a peek at the code for this project, you'll see our old friends **void setup()** and **void loop()** which occur in every Arduino program.

But scroll down a bit and you'll see they're joined by a couple of new sections: **void douseCandle()** and **void lightCandle()**. What's going on there? These are two *functions* I've created to perform a specific task in the code. Basically, I've added two commands to the existing Arduino vocabulary, joining existing commands such as **analogRead()** and **digitalWrite()**.

Up in the **void loop()** section, I "call" these functions in a couple of different spots. One of them looks like this:

```
if (WindSpeed_MPH > 6) {
douseCandle();
}
```

When the program sees **douseCandle()**, it goes and looks for the function I've made, which is written like this:

```
void douseCandle() {
// turn LED off
digitalWrite(led, LOW);
}
```

When the function is called, the program runs the code between the function's brackets **{ }** — which sets the LED pin to **LOW**.

Functions are super useful. For one, they let you run the same block of code in many different spots. You can create a function for that code, and then just call the function whenever you need it. That way, you don't repeat yourself — which is something coders try to abide by. They even have a name for it: DRY code (for Don't Repeat Yourself).

## TAKING IT FURTHER

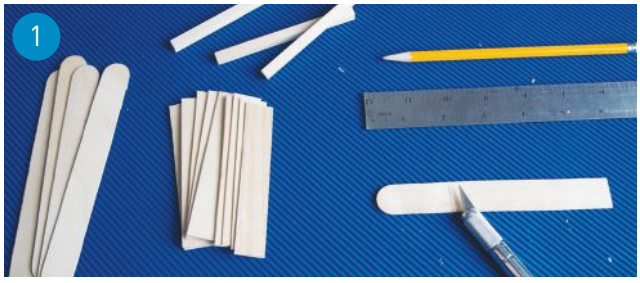
In this project we're simply interested in whether or not there's *any* significant air movement across the sensor. But this little device can actually provide good data on *how fast* that air is moving — an actual wind speed detector. To be accurate, though, the sensor needs its own source of power, separate from the Arduino. That's because the power running through the Arduino can fluctuate slightly, and that will affect the precise measurements of the sensor. For more information on how to wire up a separate power supply, check out the technical notes at moderndevice.com/product/wind-sensor.

You can also miniaturize this project to fit it into a candle-shaped enclosure. Just substitute an Arduino Nano (or other mini Arduino-compatible microcontroller), skip the breadboard, and solder the connections using hookup wire. *Make:* engineering intern Sydney Palmer created this cool candle (Figure G) using a cardboard tube, hot glue for the "wax" drips, and paint!

See more photos and share your Electric Candle build at makezine.com/go/blow-out-electric-candle.

# 1+2+3 Mini Pallet Coasters

Written by Brittani Ginoza






**YOU MAY HAVE SPOTTED MINI PALLET COASTERS FLOATING AROUND THE INTERNET LATELY;** I spied them while searching for easy and affordable gifts to make for the holidays. When I saw the design, I knew it wouldn't be too difficult to work out a comparable pattern. Well, it took me the better part of a day to lock in the exact dimensions of these little babies, but I finally got it!

## 1. CUT

For one pallet, you'll need:

» 10 "deck boards" made from the thinner (1/16") wood, measuring 9/32"×3 3/4"

» 3 "stringers" made from the thicker (1/4") wood, measuring 1/4"×3 7/8".

## 2. STAIN

Mix some black paint with water and do a test on some scrap wood. I found that black paint works better than brown. You can apply it to the wood using your hands or a paintbrush. When you're happy with your test wood, repeat the process for all of your pallet pieces.

**NOTE:** Make sure you vary the darkness of the pieces so that they don't all look the same.

Let them dry (you can use a hair dryer to speed up the process). You might want to make a few extra deck boards in case they warp from painting.

## 3. GLUE

Glue 5 deck boards across 3 stringers, then flip it over and attach the remaining 5 deck boards to match the first side.

If some of your boards are longer than others, you can sand the ends to make them more even.

See more photos and share your build at makezine.com/go/pallet-coasters.

**Time Required:** 30–45 Minutes

**Cost:** $5–$10

## Materials

» **Craft sticks, jumbo (6") size, 10 per coaster** Or use craft basswood sheet, 1/16" thick.

» **Wood strip, 1/4"×1/4", 12" total length per coaster**

» **Wood glue or hot glue**

» **Black paint, or coffee/tea** for the stain

## Tools

» **Box cutter or X-Acto knife**

» **Small bowl or paper plate** for mixing paint

» **Paintbrush (optional)**

» **Sandpaper**

**BRITTANI GINOZA** is an avid crafter and cosplayer who spends most of her time creating cool costumes and home decor. She is almost completely self-taught in crafting, sewing, and prop making.

Hep Svadja

# Toy Inventor's Notebook

## TUMBLE TOWER RACEWAY

Invented and drawn by Bob Knetzger

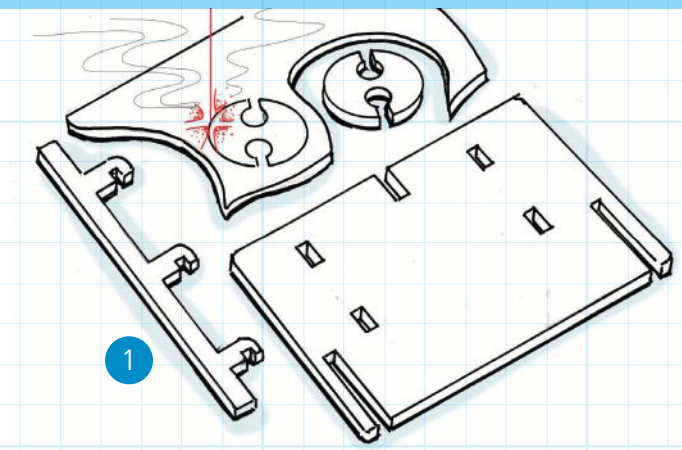
**HERE'S A SIMPLE GRAVITY-POWERED RACE GAME** you can build from almost any sheet material. You could cut out the parts by hand but why not try a laser cutter? No excuses: Your local makerspace can help you out.

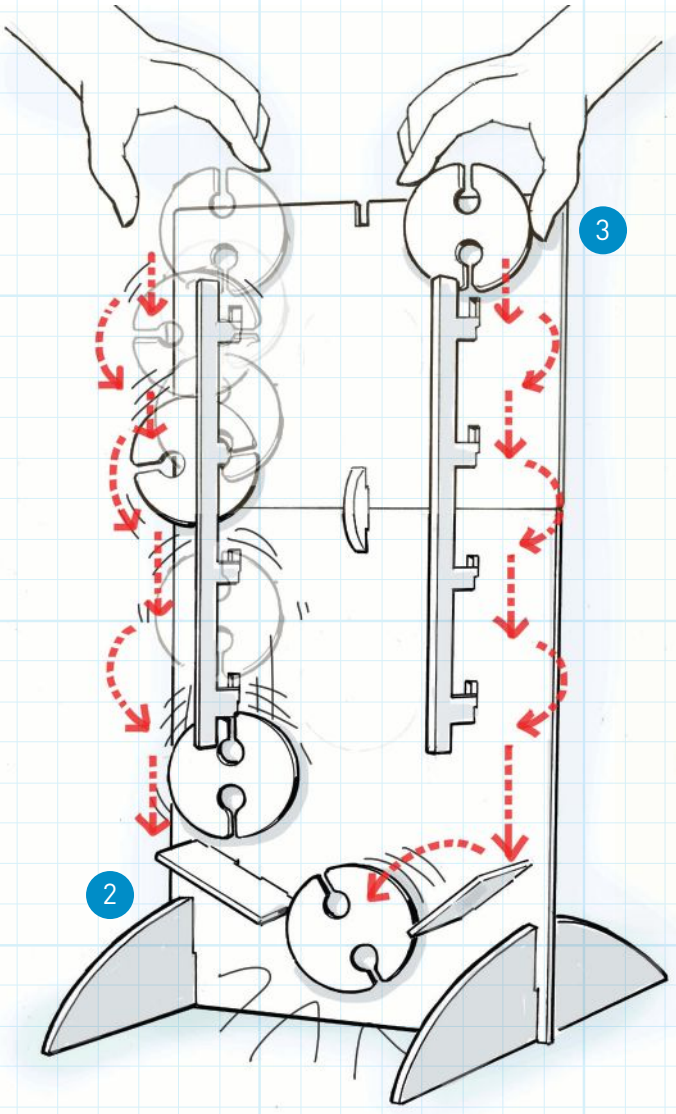
1 **CUT!** Download the vector path pattern for the parts online at makezine.com/go/tumble-tower-raceway. You can edit and position the parts to fit your material. (The layouts were drawn to make snug fits for the tab-and-slot construction for 3mm-thick material, but you can scale the entire drawing up or down slightly to make a different slot size to fit your material exactly.)

2 **BUILD!** Assemble the tower as shown.

3 **RACE!** Each racing disc has holes and slots that fit onto the vertical track of spaced tabs. Drop the disc onto the first tab: the disc stops, swivels around the tab, and when the slot swings back to vertical, the disc falls again onto the next tab, where the cycle repeats. Lots of random action! The first disc to make it to the bottom is the winner.

4 **MOD!** Make modifications to create a faster racing disc. Try different slot widths: Wider slots may fall faster but at the risk of falling off the track. Try different thicknesses and types of material: MDF, plywood, or acrylic. Add some nonfunctional cutout holes: Will a lighter disc go faster? Or just get crafty and add some cool-looking etched designs with the laser cutter. Cut lots of extra track parts and connectors, then join them to build a super tall racetrack tower!



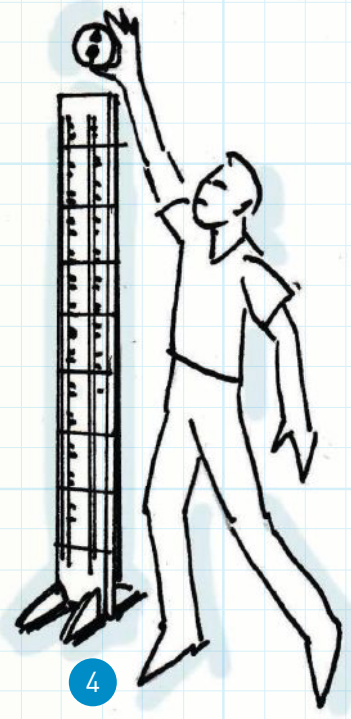

**Time Required:**
**1–2 Hours**
**Cost:**
**$10–$20**

### Materials

» **Plywood, MDF, or acrylic sheet, 3mm thick** or similar stock you can cut on a laser cutter. You can adjust the project for different thicknesses too!

### Tools

» **Laser cutter**




Watch the Tumble Tower in action and share your build at makezine.com/go/tumble-tower-raceway.

# MILWAUKEE 16-GAUGE STRAIGHT FINISH NAILER KIT


**$400** milwaukeetool.com

Nail guns are transformative tools, letting you power through carpentry in a fraction of the time it would take to use a traditional hammer and nail. Until recently they've been pneumatically powered, requiring a suitable compressor, air hose, oil, teflon tape, and more. Their tanks need time to pressurize (noisily) and at their smallest are still only marginally portable. Still, their efficiency have made them desirable.

New high-powered electric nailers alleviate these hassles of dealing with air systems. I've been testing Milwaukee's 16-gauge finish nailer, which couples an 18V battery with a brushless motor to shoot nails with surprising authority. The tool handles nails from ¾" to 2½", and boasts a 2,000-nail-per-charge power capacity, effectively stuffing all the power of a decent pneumatic system into the tool itself. Suddenly, building a picket fence around my house doesn't require stretching a power cord and air hose across the yard — I can nail anywhere with a satisfying "ka-THUNK."

The downside of these new nailers is their price. Four bills for the Milwaukee kit is enough to get a small compressor AND a full assortment of pneumatic tools. In comparison, adding an electric brad nailer to your finish nailer kit will run you an additional $300 without battery. But you get a professional-grade tool that's designed for extreme convenience on daily use.

For me the tradeoff is worthwhile. This tool lets me clear out some space in the garage, but I'll be compromising on the nail type used for my projects — 16-gauge finish nails for everything, for now.

*—Mike Senese*

Hep Svadja

## MILLER WELDING HELMET — BLACK CLASSIC VSI LENS 260938

**$117**
cyberweld.com

I'm constantly switching back and forth between my welder and angle grinders. Because my auto-shade helmet goes dark during grinding, I pull my welding helmet off and put on a full-face shield. Arguably, I could turn down the auto-setting on my welding helmet, but I'm always afraid I'll forget and catch a dose of UV in my eyes. Despite my skepticism that any welding helmet I could afford would make a difference, I recently bought the Miller Black Classic VSi Lens 260938 helmet with an integrated grinding shield.

Instead of pulling my helmet off and putting my grinding shield on over and over, I can just flip up the front of the helmet with the welding auto-shade unit, leaving me with a clear grinding shield while I do a quick touch up with the wire cup on the angle grinder, then I can flip the welding shade down again and get back to welding. This sounds like a small thing, but the ergonomics are tremendously improved. I no longer have to look around constantly — I get the helmet comfortably set and am covered for all my work.

The helmet costs about twice as much as the budget auto-shade helmet at the import tool store. Miller also touts the helmet's X-Mode setting for welding outdoors or at low amperage. I'd honestly thought my budget auto-shade helmet was just fine. Now I can't ever go back.

*—Tim Deagan*

## FLUKE THERMAL IMAGING MULTIMETER


**$1,000** en-us.fluke.com

Many electrical and electromechanical problems manifest thermal irregularities, sometimes even before a failure has occurred. The Fluke 279 FC is a TRMS multimeter with a built-in thermal imaging camera that allows you to visualize the thermal profile of a device or part, and then use the test leads to measure its electrical properties, such as voltage, current, resistance, capacitance, and frequency. The thermal imaging mode displays or graphs a single temperature value, and it even comes with an iFlex current clamp for measuring high AC current (Fluke also offers a more affordable model without the iFlex).

The coolest feature of this model is that, as a "Fluke Connect" tool, it can connect wirelessly to your smartphone or other device. When connected to my Android, the Fluke Connect app shows real-time measurements, and logged measurements graphically. You can record these measurements for your reference.

The thermal imager offers 80x60 resolution, which is enough to see what's going on with macro components like circuit breakers and motors. If you need higher resolution, consider a standalone thermal imager.

This is a tool for commercial users and industrial professionals (reflected both in its capabilities and price), but makers with sophisticated needs will also find it very useful.

*—Stuart Deutsch*

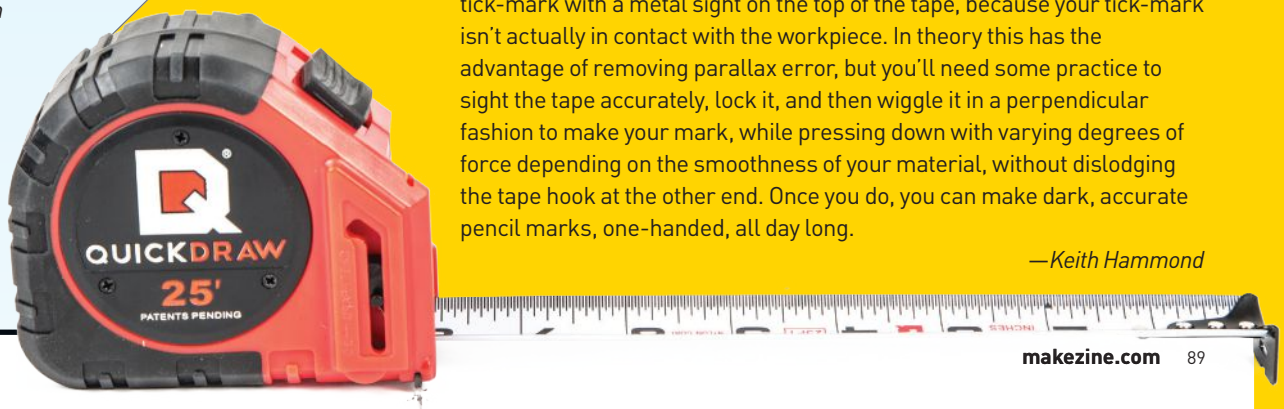
## QUICKDRAW PRO SERIES 25' SELF-MARKING TAPE MEASURE

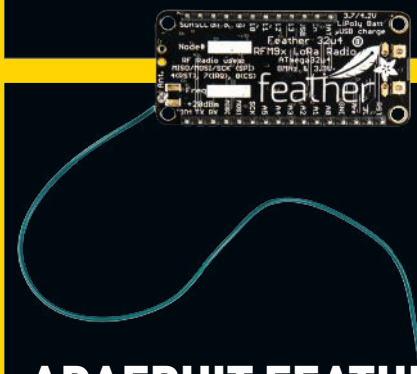
**$20–$43** quickdrawprotape.com

If you've ever cursed like Deadpool after misplacing or dropping your pencil for the umpteenth time, you can appreciate a tape measure that makes its own marks. Once the QuickDraw tape is loaded with a standard 0.9mm graphite lead, its tiny metal marking wheel deposits a fat pencil mark on your workpiece at the distance you've measured. I found it marked well on plywood, laminates, and even aluminum.

But there are a few tricks to it. For one, you've got to align your chosen tick-mark with a metal sight on the top of the tape, because your tick-mark isn't actually in contact with the workpiece. In theory this has the advantage of removing parallax error, but you'll need some practice to sight the tape accurately, lock it, and then wiggle it in a perpendicular fashion to make your mark, while pressing down with varying degrees of force depending on the smoothness of your material, without dislodging the tape hook at the other end. Once you do, you can make dark, accurate pencil marks, one-handed, all day long.

*—Keith Hammond*






## ADAFRUIT FEATHER

**$35** adafruit.com

Adafruit's Feather boards are simple, compact microcontrollers built to showcase advanced features like powerful processors and GPS. The Feather has a built-in radio, tuned for communication over a mile using just a few inches of wire as an antenna. Adafruit has a knack for writing clear, concise documentation that will get a maker up and running quickly, and these boards are no exception. With their combination of excellent hardware and tutorials, Adafruit opens up long-range radio to the maker masses.

*—Sam Brown*

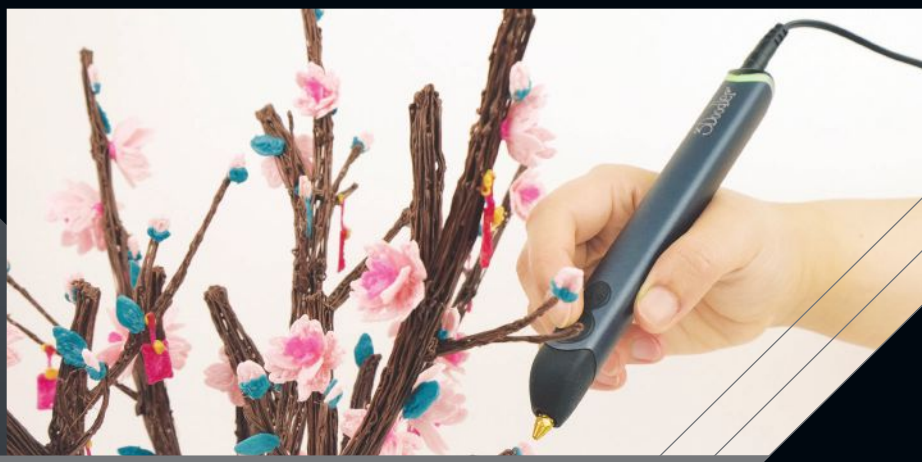
## GOOGLE'S SCIENCE JOURNAL KIT

**$85** makershed.com

Our phones are packed with sensors that act as mega-computing micro-brains. Google and the Exploratorium know this, and have teamed up to unleash your phone's potential, letting you learn about the scientific world around you. Detect light levels, record sounds, sense movement, and graph all the data in pretty, visual ways using your phone.

The kit includes a plethora of craft materials, as well as an Arduino 101. Currently, there is only one project that utilizes the Arduino, but they plan to release more in the near future. So much potential here for bright minds, young and old alike!

*—Caleb Kraft*



## 3DOODLER CREATE

**$99** the3doodler.com

Practically everyone is enchanted by the magical notion of a 3D-printing pen. So, I was delighted when the folks behind the 3Doodler recently released the 3Doodler Create.

In addition to the mind-boggling possibilities of the original 3Doodler, the 3Doodler Create comes with a greater variety of accessories (pen stand, nozzle set) and materials (which come in different finishes like matte, clear, and glossy). The 3Doodler Create has two heat settings for different types of plastics; the settings and packaging are even color-coded so you know which temperature to dial in.

I tried a few different projects — some playful, some practical — and referred to the very helpful video tutorials on the 3Doodler website. It's as simple as heating the pen, inserting your material, and choosing an extrusion speed. I used the slow speed almost the entire time and it always came out quickly enough for me.

While the 3Doodler Create often works like magic, it did require the occasional finagling. The "flexy" material seemed too soft to extrude correctly, so I had to remove one of the pen's panels to push it through. Despite this, the troubleshooting tips provided in the instructions and the tutorial videos helped me to fix whatever problems I encountered, and the pen continued to work properly after each issue was resolved.

The 3Doodler Create could be useful to just about anyone. It takes a little getting used to, but for those who love a challenge and mastering new skills, the 3Doodler is a fun and rewarding instrument!

*—Andrew Salomone*


## MOTOROLA MOTO E (2ND GENERATION)

**$70** motorola.com

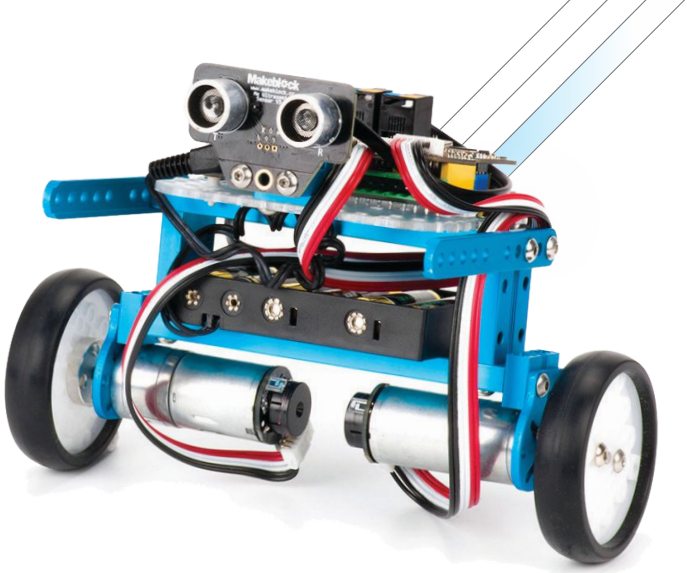
There are a few maker apps that are Android-only, which was a hang-up until we found this affordable handset. While it's not flagship-grade, it works great for most of our app needs, from Google's Science Journal to Walabot. Pop in your SIM card, or just use it on Wi-Fi. And you can find it for less than $50 new online, which almost makes it disposable.

*—MS*

# DON'T MISS THE 2016 MAKE: GIFT GUIDE

Robots and welders and open source printers. Solder and drones and crafts that glitter. These are a few of our favorite things ... Visit our online Gift Guide for great ideas about tools, gadgets, books, and kits for the favorite makers in your life.

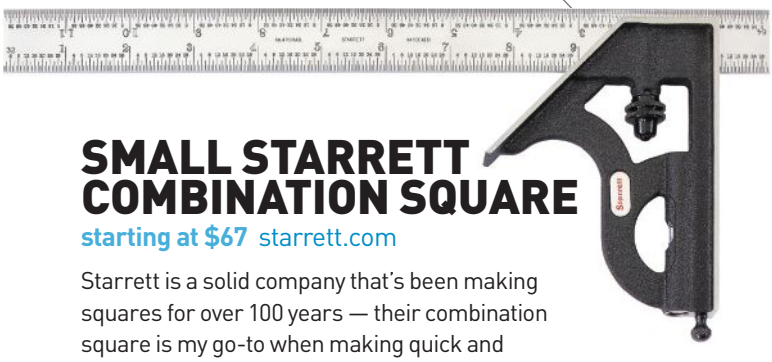
MAKEZINE.COM/GIFTGUIDE




## MAKEBLOCK ULTIMATE 2.0 10-IN-1 ROBOT KIT

**$350** makeblock.com

This beautiful anodized aluminum kit is a fun robotics challenge for kids of all ages looking to take advantage of its programmability and possibility. *—Rafe Needleman*



## SMALL STARRETT COMBINATION SQUARE

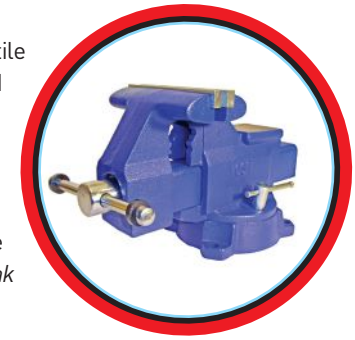
**starting at $67** starrett.com

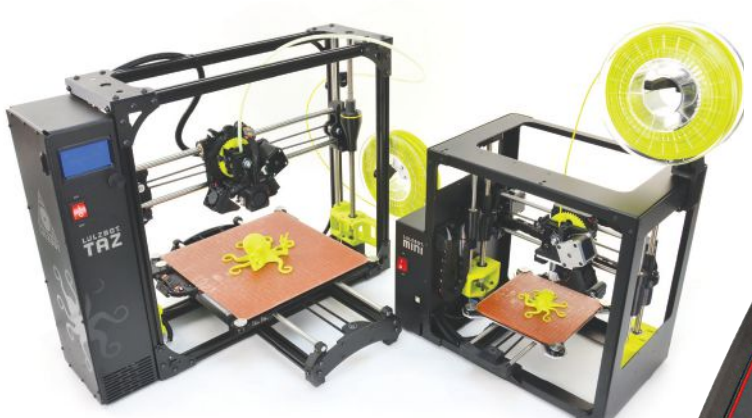
Starrett is a solid company that's been making squares for over 100 years — their combination square is my go-to when making quick and accurate lines on any project. *—Margaux Ryndak*

## YOST APPRENTICE VISE

**$105** yostvices.com

This vise is a super versatile tool that can act as a third hand and anvil plate for smaller ferrous and non-ferrous metal projects. The more securely it's mounted, the better! *—Margaux Ryndak*






*SPONSORED*

## LULZBOT TAZ 6 & LULZBOT MINI

**$2,500 & $1,250** lulzbot.com

The Taz 6 and Mini are incredible workhorses. The auto nozzle cleaning and bed leveling are wonderful and the PEI bed is magically effective. You can tell them to print and walk away without worrying. *—Caleb Kraft*

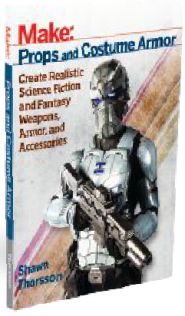

## BESSEY D-BKAH-2B LOCK BACK KNIFE WITH SMOOTH/ SERRATED BLADE & UTILITY BLADE

**$19** besseytools.com

This perfect shop knife can be opened one-handed and comes with two blades — and one of them is replaceable, so you can use this knife for all the jobs you would hesitate to use your expensive knife on. *—Laura Kampf*

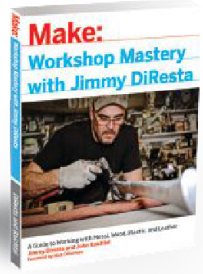
Makeblock, Starrett, Yost, LulzBot, Bessey

# Maker Shed NEW BOOKS




## MAKE: PROPS AND COSTUME ARMOR
**by Shawn Thorsson $30**

Whether you want to emulate your favorite video game hero, comic book star, movie character, or a ninja of your own devising — this book will show you how to use ordinary items to create a great costume, armor, and all the props you need! Humorous, frank, and complete, this book by renowned maker and one-time *Make:* magazine cover subject Shawn Thorsson is an essential text for anyone who has ever fantasized about wowing the crowd at Comic-Con or simply being the best dressed next Halloween.




## MAKE: WORKSHOP MASTERY
**Jimmy DiResta and John Baichtal $25**

Like talking with a good friend, this anecdote-filled book takes you through a full array of tools and a bevy of different builds, remarking on methods used and decisions made along the way. You'll expand your knowledge of woodworking tools, get the basics of CNC routers, learn metal projects, understand the basics of styrene, see how to use leather — and finally, make and mod your own tools just like Jimmy does in his popular YouTube videos and in his own workshop.

## NEW & NOTABLE

**MAKE: TOOLS**
**by Charles Platt $25**

**MAKE: DRONES**
**by David McGriffy $30**

**FAMILY PROJECTS FOR SMART OBJECTS**
**by John Keefe $20**

**GETTING STARTED WITH CNC**
**by Edward Ford $25**

**DESIGN FOR CNC**
**by Gary Rohrbacher and Ann Filson $35**

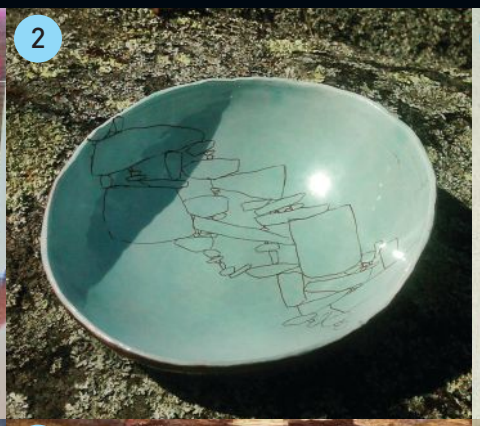
**FORREST MIMS' SCIENCE EXPERIMENTS**
**by Forrest M. Mims III $20**

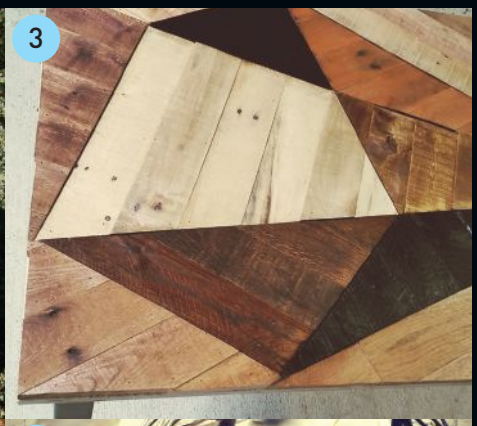
**REMAKING HISTORY, VOLUME 2**
**by William Gurstelle $20**

# SHOW & TELL

## Dazzling projects from inventive makers like you

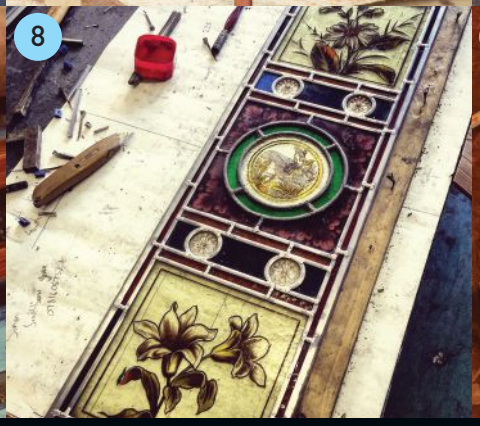
Sharing what you've made is half the joy of making! Check out these makers on Instagram, and show us your photos by tagging @makemagazine.







1. This psychedelic deer by painter **Lindsay Pace** (@lindsay_pace_art) fills up a 32"×32" pallet canvas.
2. This earthly meta vision of a rocky stack on a clay bowl on a rocky background is the work of ceramicist **Rebekah Wostrel** (@rebekahwostrel).
3. **Chris Morris** (@c2creativeconcepts) added a bit of steel and glass to reinvigorate this wood-pallet-turned-coffee-table.
4. **Beau Trifiro** (@beau.trifiro) founded Open Source Skateboards to teach STEAM to high school students via skateboard design and manufacturing. Shown here is a board by participant Ty, who engraved it with copper, bronze, aluminum, brass powder inlay, and painted it by hand at a workshop hosted by MakerPlace.
5. Woodworker **Mark Willett** (@mr_willett) carefully hand carves naturally beautiful wares like this soup ladle.
6. Artist and silversmith **Susan Lenart Kazmer** (@SusanLenartKazmer) uses shimmering druse to warm up her metallic jewelry.
7. **Tony Bellaver** of @alpenglowflyrods hand planed this spey rod for a custom fly-fishing experience.
8. Both soft and sharp, this floral stained glass is the work of glassworker **Ashley Ashton** (@ashjashton).
9. **Melanie Van Houten** of @creativecovestudio steps up to the challenge of symmetrical portraiture (to give Van Gogh his ear back).

*What are you working on? Send us your stories, projects, and more at makezine.com/contribute.*

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