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A machine built on a scientist's dream

When the machine shop gets a special order from one of the 150 scientists at the National Research Council, it's not everyday stuff they're asking for. Tom Spears takes a look at the latest custom-made scientific instrument.

Tom Spears
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Albert Stolow's lab in downtown Ottawa needed a new machine, one that will shoot individual bits of DNA in a straight line through a vacuum, hit them sideways with tiny bursts of precise laser light, chip off one electron at a time, send that electron straight upward, guide it through the vacuum with magnets to a detector that will sense how it is "feeling," and send the rest of the DNA molecule in the opposite direction to a different detector.

CREDIT: Wayne Cuddington, The Ottawa Citizen

Niklas Gador is one of the 'post-docs' in Albert Stolow's lab. He used to build small remote-controlled airplanes in his native Sweden. 'Just a little hobby. They crash every now and then and you rebuild and try to improve. ... The more I crashed it, the more it turned into custom-made.' Years of building model airplanes are helping him now, as he assembles components from the machine shop for the National Research Council's Photoelectron Photoion Coincidence Spectrometer.

Oddly, there wasn't such a machine in stores anywhere.

So they went and made one.

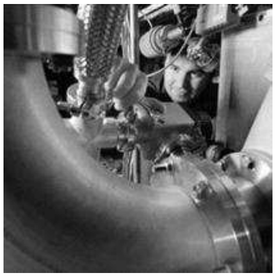
They tossed math and physics ideas around a coffee table, then made sketches, then computer simulations, better drawings, a custom-made circuit board, custom-machined blocks of stainless steel, pumps, tubes, wiring and all.

"Nothing exists if you're doing something really new. You have to build it yourself," says Mr. Stolow, 47, whose specialty is the physics of very small things and very short time periods.

Galileo had to build his own telescopes to see the moons of Jupiter; van Leeuwenhoek had to invent the microscope before he could experiment with bacteria. And like scientists all over the world, the NRC team has had to design its own instruments to explore the innards of a molecule in a way no one has done before.

All this has taken five years.

Today the two-metre-tall Photoelectron Photoion Coincidence Spectrometer is finally being assembled in the basement of the National Research Council's building at 100 Sussex Dr.



CREDIT: Wayne Cuddington, The Ottawa Citizen

It took a year just to get the first parts of the Photoelectron Photoion Coincidence Spectrometer designed get all the parts made -- maybe 200 parts in all. Cylinders of steel or aluminum -- some thicker than an arm, some like pencils -- are sliced like bread to make flat discs that will eventually become gear wheels, or big flanges that clamp the end of a heavy tube in place. Each part is filled with a weird, generally unique, set of holes -- round ones, square ones, and odd-shaped holes where one part of an instrument will fit inside another.

You can buy vacuum chambers, but not many like this: The pressure inside has to be one-millionth of a millionth of Earth's air pressure -- very close to what you'd find halfway between here and the moon.

The materials are special, too. In some parts of the instrument, they can't be porous or liable to melt (so no plastics). Some parts have to conduct electricity while others can't (leading to a mix of steel, gold, copper wire and ceramic.) Some materials have to be magnetic; others not. Some are made of metallic mesh that's finer than a silk stocking.

Where do you turn for custom work like this?

The answer lies just down the road at the NRC's Mechanical Components Lab, better known among NRC scientists as the Montreal Road machine shop.

"We've been working with them for decades. They're not just machinists; they're instrument builders. They're not Speedy Muffler," Mr. Stolow says.

"They can machine things, and weld them, to exacting specifications: That laser sits in a block of solid steel (with the interior carved out) and it has to point exactly the right direction."

He really does means "exactly." The laser has to fire its light beam accurately enough to hit individual molecules as they fly past.

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'Albert decided he wanted

a machine built'

MACHINE

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"They perform these miracles. These pieces of paper with drawings come back as crafted metal."

"Scientists are a real pain to work with," NRC scientist Albert Stolow adds. "They're demanding.

"Aluminum is really easy to machine, but we often want special materials that are hard to machine."

The point of it all is to investigate how DNA works. DNA is, after all, just one giant molecule. It's a chain-shaped molecule with four different types of link in the chain, known as A, C, G and T molecules. And rather than study a piece of DNA millions of links long, the Stolow lab will look at one link at a time -- an A, a T, or an A and T bonded together.

The spectrometer will spit a steady stream of these A and T bits and pieces across the vacuum chamber, a shiny steel box in the form of a cube about 25 centimetres wide.

"We like to use electrons to tell us what a molecule is doing," he says, "or how it is 'feeling.'"

Niklas Gador is one of the "post-docs" in the Stolow lab. This means he has a PhD, but is still working for a more senior researcher. He's from Stockholm and has been here two years.

"Albert decided he wanted a machine built," he says matter-of-factly, as if Albert had decided he wanted a pencil.

Mr. Gador used to build small remote-controlled airplanes in Sweden. "Just a little hobby. They crash every now and then and you rebuild and try to improve. Originally it came as a designer model, but the more I crashed it, the more it turned into custom-made."

Years of building model airplanes are helping him now, as he assembles components from the machine shop.

He's nervous working with some of the little pieces. "You don't want to do it when you're tired. A big part of the assembly's success is to have good hand skills -- being steady with your fingers.

"It looks like it will go faster than I thought," he says as he checks the clean room where everything is assembled. "Say one or two weeks and the spectrometer should be inserted into the vacuum chamber. And a few weeks after that, we should start getting data."

The parts look intriguing, all new and shining in different metallic colours, most of them weird shapes. Many are designed to create either an electrical field or a magnetic one.

The electrical waves will suck ions down into one detector. The magnetic field will force electrons to go in the other direction, toward their own detector. This works like the Earth's own magnetic field, which deflects high-energy particles rushing toward us from the sun, and focuses them in the Arctic and Antarctic -- the Northern Lights and their southern counterpart.

Sections of cylinder are milled from aluminum, but coated in gold. "Gold is an excellent conductor," Mr. Gador says. It also doesn't rust.

"I'd like to have everything done in gold. Then I could take it all home and sell it."

There's a fine metal screen, like window screen except made of copper, coated with more gold. This helps distribute the electrical field evenly around the outside of the cylinder through which ions will fly.

There are even tinier grids -- a copper mesh, gold-coated, that looks like silk. It has eight wires to every millimetres, and even with all those wires, the area is still 90-per-cent air and just 10-per-cent wire.

It took a year just to get the first parts designed and made in the workshop. It took another year to get all the parts made -- maybe 200 parts in all, he thinks.

Here's just one example: To make a tube that acts like a magnetic field, they designed an aluminum cylinder and wound insulated copper wire around it. Electricity flows through the wire, around and around the tube, and makes a magnetic field inside it. But the machinist had to carve it: not just a neat aluminum cylinder with tight fittings on the ends, but also a spiral groove on its outside to hold the copper wire in several dozen turns around the cylinder. And the groove must be smooth all the way, or a jagged edge might puncture the wire's insulation.

Sometimes the scientist and the machinist have to negotiate the details. "Mostly it was about tolerances. In the beginning I was not that strict in my tolerances on my drawings," Mr. Gador says. If two parts each push the edge of their tolerance, they may not fit. Luckily, there was no problems with major parts.

In the machine shop, Todd Pappas spent 150 to 200 hours making Albert Stolow's prized steel vacuum chamber, much of that time thinking.

As with all special orders from about 150 NRC scientists, "you've got to give it a lot of thought. It's not everyday stuff that they're coming in and asking for," he says.

He also built many other parts of the spectrometer. "In most cases we get to do the project from start to finish, which is one of the nice things about working here. We get to do it all."

"It's much easier when you have blueprints," adds his boss, Allan Horner, the shop's fabrication supervisor. "You give them to two, four or five different guys. But when you're working from a sketch or an idea, you've almost got to have one guy take it from the letter A to the letter Z," in order to make sure all the parts fit and match.

Some ideas come in drafted by a pro technician. Others are pencil sketches drawn in a hurry, with little margin notes like: "** Important!"

Either way there are always questions: How deep does this hole have to be drilled? What's the exact dimension of the screw? And so on.

"They know what they want but a lot of times it's hard to communicate on paper what result they need," Mr. Horner says.

"I'm in my 23rd year and I love coming to work every day," he says. "It's different every day and you don't know what you're getting into. And 99 per cent of the scientists walk out of here, they have a great big smile. You're making 'one-ofs'. You're not sitting at a machine and making 50 or 100 the same.

"Anything that you could buy, we don't manufacture," he adds.

Cylinders of steel or aluminum -- some thicker than your arm, some like pencils -- can be sliced like bread to make flat discs that will eventually become gear wheels, or big flanges that clamp the end of a heavy tube in place, or pins and posts to support smaller bits of machines.

Each part is filled with a weird, generally unique, set of holes -- round ones, square ones, and odd-shaped holes where one part of an instrument will fit inside another.

It's all about exacting tolerances -- the amount of "give-or-take" that can be allowed in a measurement. Usually, there isn't much.

The optics shop in the same building, where skilled workers grind and polish different types of glass, quartz and other materials into lenses, prisms and mirrors, may need to make a surface that is within a small fraction of a light wavelength perfectly flat. (A wave of visible light is a few hundred nanometres, or millionths of a millimetre.)

They do much of it by pressing a chunk of glass on a rotating wheel that looks like a potter's wheel and is covered with watered-down rare earth that looks like muddy water. It seems low-tech, but the results are phenomenal.

"This is a unique thing that NRC has," says Albert Stolow. "I'm not aware of any other national lab I've ever been to that has its own optics shop. Certainly, no university would have one.

"It's kind of a small NRC success story that's not very well known.

"A lot of people read about a new discovery and think it's just this one white, middle-aged male who is taking credit for all the work, when in fact it's a whole team of people that spend their days achieving this."

Back in the Stolow lab, Mr. Gador has been second-guessing the project, just a little.

"A couple of times I ask myself if it might be easier to blow up everything by a factor of two (i.e. twice as large). But I haven't found any better way to do this," he says.

"It's always amazing to see what you get back. You always get back a part that you would think would be really hard to machine. Simple to draw a drawing, but making it in real life -- it's amazing to see what they can do."

"We just had the Judgment Day in the clean room," he reports later. "Both my bosses ... spent almost two hours in there, inspecting every detail, twisting, turning things; and I just wanted to say: Be gentle!!!

"But I guess they know if something breaks in the clean room, it would break someday in the chamber."

The bosses like what they saw. Mr. Gador is immensely relieved. This work represents the past two years of his life. What if it had all gone wrong?

But it didn't.

When it's all done, he adds, "we'll open up some bottles of champagne, that's for sure."

CLOSE WINDOW