A CUT ABOVE

Machinist Dana Spence adjusts a Devlieg Micropoint precision tool grinder in the tool and cutter room where a suite of legacy and new technology is used to craft parts with exact geometry for customers and other machines within the complex.

LAWRENCE Livermore National Laboratory is focused on providing greater responsiveness to meet evolving national security threats. Priority efforts include the W87-1 Modernization Program and the W80-4 Life Extension Program, as well as expanded research conducted by a rapidly growing scientific staff in support of the mission. More than 200 people in the Laboratory's Manufacturing Engineering Section enable this support by providing agile, responsive manufacturing services that produce necessary parts for testing, experimentation, and end use spanning the breadth of Livermore's research efforts. Occupying approximately 9,200 square meters of space spread across the Laboratory, the manufacturing complex is evolving to meet Livermore's mission by replacing legacy equipment, adding modern capabilities and upgrading workspaces. A new facility to expand capacity and capability in a centralized location is also under construction. Furthermore, the manufacturing complex is recruiting new skilled machinists and technicians to support the W87-1 and W80-4 programs and future Livermore and nuclear security enterprise efforts.

Established in 1959, the manufacturing complex has supported Livermore and other national laboratory partners with the skill and expertise to provide customized equipment and parts for experiments and to repair or upgrade the facilities where

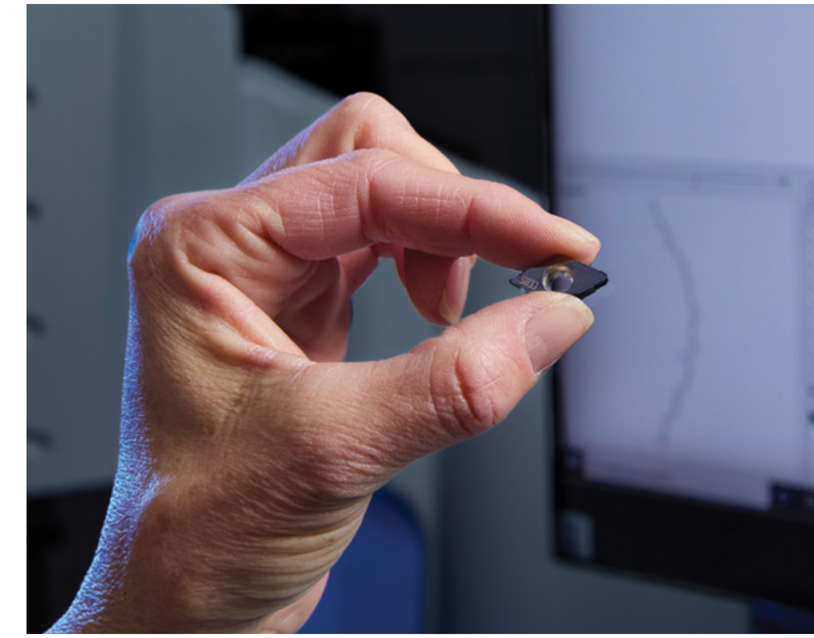
experiments are performed. Rich Seugling, the manufacturing engineering section leader, states, "We take pride in meeting the challenges and always strive to help the customer and program be successful." The complex manufactures higher-fidelity parts than typically demanded for industry because Livermore's missions require the most advanced technology. "We aim to maintain and expand critical capabilities that enable the manufacturing of successful components, responsibly steward taxpayers' money, fulfill orders, and surpass expectations," says Larry Sage, manufacturing superintendent. "The margin for error is often measured in micrometers."

Maximizing Capabilities

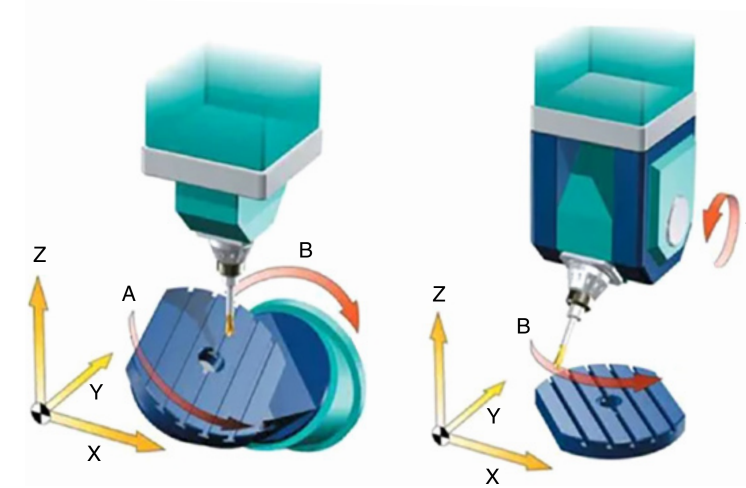
The manufacturing complex combines old and new technologies, from lathes and mills that cut and machine parts to powder-bed metal additive manufacturing machines and specialized grinders that achieve precise edge and geometry for custom-ordered tools and components. Some multipurpose equipment can machine structures up to 6 meters and 4,500 kilograms, as well as parts less than 2.5 centimeters, requiring tolerances less than 100 micrometers, thinner than a human hair. Other capabilities include metal forming with an 861-metric ton hydro form press or a 317-metric-ton mechanical press capable of handling common materials such as stainless steel and aluminum and more boutique materials such as tantalum and some radioactive metals.

The machine shop's manufacturing complex has added 929-square-meters to expedite non-destructive evaluation and characterization of manufactured work by collocating these capabilities and resources with production centers. The new space houses a large-scale coordinate measurement machine, a five-axis jig bore, three lathes, and three five-axis mill-turn machines that can complete complex projects quickly and accurately. The newest multipurpose five-axis milling machines, for example, can perform precise turning and milling actions—without having to transfer the part between machines—to make axisymmetric complex structures such as turbine blades or off-axis contours found on air foils for aerospace applications.

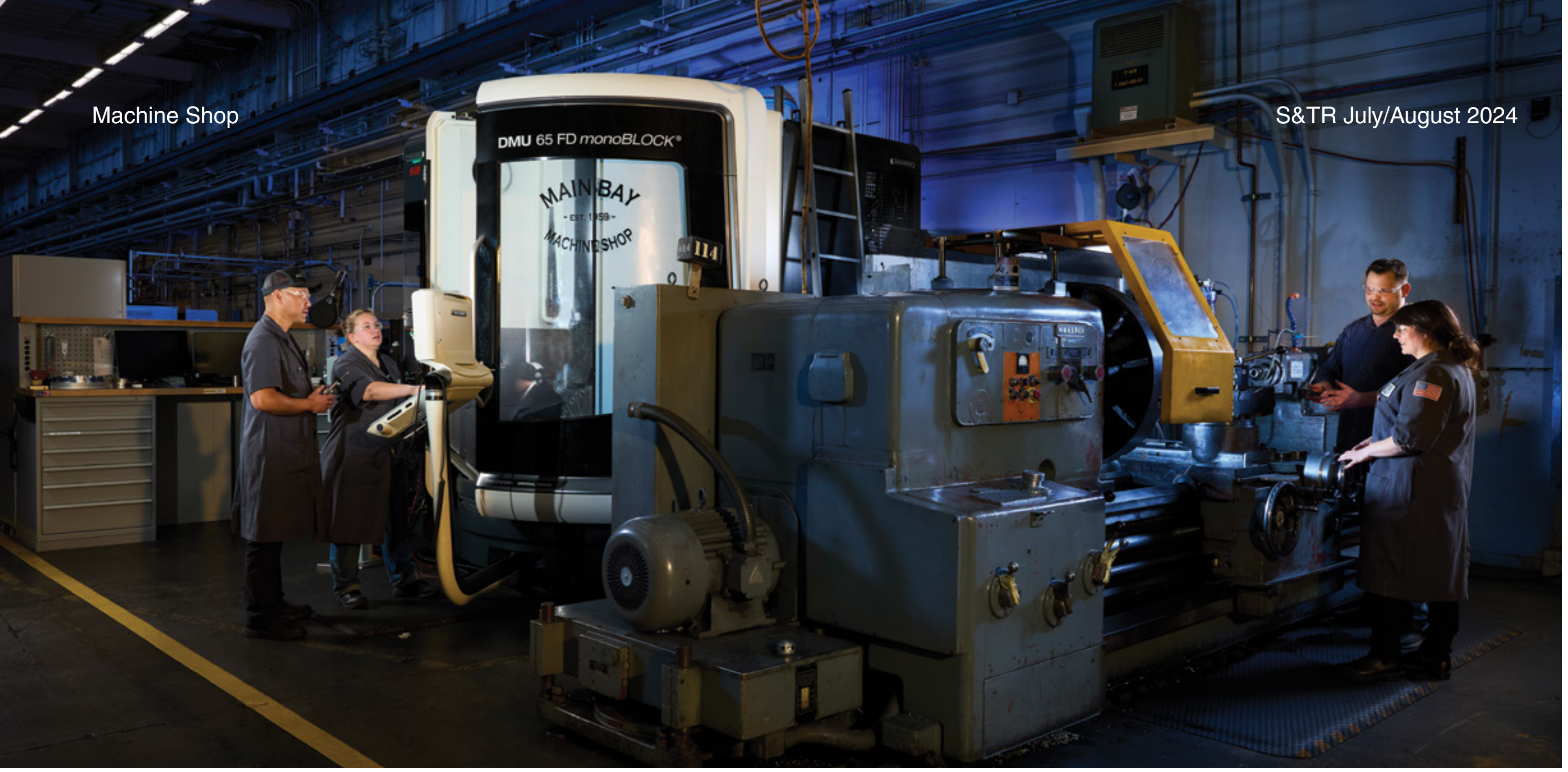
The machine shop's manufacturing complex offers heat treatment capability with both air and vacuum furnaces that keep materials hot to prevent oxidation and contamination. The heat-treatment process includes hardening of tooling materials to minimizing residual stress in additively manufactured metal parts. Annealing improves parts by removing internal stresses from previous fabrication processes such as cold or hot work, machining, stamping, and welding. Other capabilities include water, oil, and air quenching to rapidly cool heat-treated metal, changing its mechanical properties. In the manufacturing complex's dimensional inspection room, inspectors use a combination of contact and optical coordinate metrology



Using computer software to determine variations in geometry on a scale of micrometers, machinists can accurately shape and manufacture carbide inserts such as the one held before the computer screen. Use of such tools and equipment enables expert machinists to ensure the tools and parts produced are suitable for end use performance.



The five-axis milling machine uses standard X, Y, and Z axes (which move an object up and down, side to side, and inward and outward), as well as the A and B axes (tipping an object to the left and to the right and forward and backward). The versatility of the machine enables Livermore's machinists to efficiently shape parts and components without having to manually turn or set up parameters mid-operation.



Victor Jung and Dawn Hill use the futuristic five-axis milling machine (left). Supervisor Manuel Iñiguez instructs apprentice Ana Gallira (right) on legacy, manually operated equipment, installed not long after the machine shop opened in 1952.

equipment to measure and verify that manufactured parts meet specifications. To meet the stringent tolerances, the equipment is maintained in a stable environment and calibrated at regular intervals to meet or exceed performance specifications. In the manufacturing complex's dimensional inspection room, inspectors use a combination of contact and optical coordinate metrology equipment to measure and verify that the parts meet specifications.

Alongside new equipment, many legacy machines remain in operation due to ease of use and repair, lower electricity requirements, consistency, and reliability. New apprentices must master legacy machines in their first year, a practice that enables them to understand how the tools operate in different applications. "The younger people coming in typically have no problem picking up anything involving a computer, but we want to ensure they also understand the fundamentals of machining," says Jason Carroll, one of the manufacturing supervisors in the main bay machine shop. "We want them to turn a handle on a cut and feel it in the machine and be able to tell if they're being too aggressive for the feed or going too fast."

Enabling Operations

Operating as a service center offering support to any project at Livermore enables the machine shop locations to share resources and increase efficiency. The center serves as a critical research and development partner to design and produce better and easier-to-manufacture components. The team receives small orders for quantities from one to 50 pieces and ranging in size from millimeters (smaller than the top of a pencil eraser) to several meters in diameter and length, such as a 4,500-kilogram stainless steel vacuum chamber. The main bay machine shop processes between 1,800 and 2,000 work orders each year, many of which cannot be sent to external companies due to the complexity of the parts required and difficulty in meeting a Laboratory program's tight time constraints. Work orders begin when engineers, scientists, or coordinators send drawings, models, or sketches to the machine shop service center. A planner in the manufacturing complex reviews the job, and a machinist is assigned the project. To manufacture the part, the machinist must consider a combination of geometry, material, and tolerances.

For example, in 2022 researchers at the National Ignition Facility (NIF) experienced what could have been a significant set-back to their work schedule without the machine shop's expertise, flexibility, and agility when a ball screw in the positioner failed. Used to place diagnostics tools and other payloads in NIF's target chamber, the positioner requires the ball screw for insertion and retraction. Without a functioning ball screw, the entire mechanism could no longer operate, and NIF activities had to pause.

Scott Winters, associate division leader for Livermore's Laser Systems Engineering and Operations Division, worked with a team of researchers, engineers, machinists, and operations and business personnel to identify and evaluate the options for the ball screw, including procuring a new part, which could have taken significantly longer. The most cost-effective and timely solution was an in-house repair performed by Livermore's machinists. After reviewing the

case with machine shop managers, Winters and the NIF team removed the failed ball screw and gave it to the machinists for evaluation and repair. The agile and rapid repair process took approximately two weeks. The machine shop faced the challenge of repairing the part without being able to consult the original vendor. "The ball screw was over a decade old, and the original vendor wasn't available anymore," says Winters. "Our machinists had to do significant exploratory work to understand the part's requirements and to develop a plan for the repair, and they completed the work in such a way that we saw relatively minor impacts to the NIF work schedule."

Building Expertise and Partnerships

Throughout the research, development, repair, and production processes, the machinist and customers must maintain constant dialogue to exchange information related to the part's material properties and purpose. Communication is also essential to forming effective relationships between machinists and customers. "We enjoy working with our customers and helping them solve a problem. Working on science applications is always exciting, and watching people succeed because of modifications we've made and provided to them on deadline is a great feeling," says supervisor Manuel Iñiguez.

Carroll and Iñiguez are both graduates of the Lawrence Livermore National Laboratory Machinist Apprenticeship Program, a California-accredited four-year paid program providing candidates the on-the-job experience needed to jumpstart a career in the field. Now holding leadership positions, Carroll and Iñiguez have worked across the complex, building strong working relationships with fellow machinists and the customers whose projects they support. "At Livermore, the scientists and engineers talk to a machinist directly to express their needs and ask questions. In response, the machinists meet program needs and develop unique solutions. I think it's fair to say mission success is directly tied to the quality of those relationships," says Carroll. Apprentices move throughout Livermore's manufacturing complex during the program to gain experience and build skillsets across the range of equipment, capabilities, and types of work. The program's structure exposes each apprentice to the customers at Livermore with whom they will continue to work after graduating from the program.

Livermore's machine shop experts are expanding their collaborations with partners both at the Laboratory and within the broader nuclear security enterprise. At Livermore, the machine shops have partnered with the Manufacturing and Engineering Technology Development (METD) group to work directly with research and development staff at Livermore's Advanced Manufacturing Laboratory (AML). METD and AML collaborate to develop in situ diagnostics to reduce the barriers to qualifying additively manufactured parts,

Livermore's Machinist Apprenticeship Program offers participants the opportunity to become full-time machinists at Livermore and to advance their careers. Graduates of the apprenticeship program, Dawn Hill (left) and Victor Jung (right) work with supervisor Manuel Iñiguez (second from left) and apprentice Ana Gallira.

process optimization via machine learning, and residual stress compensation in additively manufactured components, among other tasks. Researchers at AML then develop early-stage technologies and transfer them to the machine shops when they are ready for manufacturing applications. This work supports Livermore's Advanced Manufacturing Development and Stockpile Responsiveness Program.

Outside of Livermore, the machine shop team partners with production agencies, such as the Y-12 National Security Complex (Y-12), to match equipment and demonstrate new techniques such as advanced ultrasonic machining. Through regular communication and formal engagements, Livermore, Y-12, Los Alamos National Laboratory, Kansas City National Security Campus, and the United Kingdom's AWE Nuclear Security Technologies collaborate and exchange process parameters, data, and lessons learned to co-develop machining strategies that apply to the most challenging materials. Special Materials Machining Facility foreman Vic Cantu says, "In the more than 25 years of my machining career, I've never seen anything as beneficial as this collaboration. We learn from each other, and we're able to zero in on problems and tackle them from all sides. As a team it's been very rewarding." Such partnerships and collaborations between the manufacturing complex and programs put Livermore in a position to meet its mission and continue to grow in the future.

—*Amy Weldon*

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