ROBBINS & LAWRENCE ARMORY
(American Precision Museum)
196 Main Street
Windsor
Windsor
Vermont

HAER VT-39
VT-39

PHOTOGRAPHS

WRITTEN HISTORICAL AND DESCRIPTIVE DATA

REDUCED COPIES OF MEASURED DRAWINGS

FIELD RECORDS

HISTORIC AMERICAN ENGINEERING RECORD
National Park Service
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1849 C Street NW
Washington, DC 20240-0001

HISTORIC AMERICAN ENGINEERING RECORD

ROBBINS & LAWRENCE ARMORY
(AMERICAN PRECISION MUSEUM)

HAER No. VT-39

LOCATION: 196 Main Street, Windsor, Windsor County, Vermont

The American Precision Museum is located at UTM zone 18, easting 711083.32m, northing 4816630.52m. The coordinate represents the center of the building. This coordinate was obtained on 7 August 2009 by plotting its location on the Windsor, VT, USGS Digital Raster Graphic in ESRI ArcGIS 9.2. The accuracy of the coordinate is +/- 12 meters. The coordinate datum is North American Datum 1927 CONUS. The American Precision Museum has no restriction on the release of this information to the public.

DATES OF CONSTRUCTION: 1846, 1853, ca. 1870, 1898, 1926

BUILDER: Unknown

PRESENT OWNER: American Precision Museum, Inc.

PRESENT USE: Private museum

SIGNIFICANCE: The period of significance for the private Armory is 1846-1856. The factory was constructed in 1846 and was the site of innovation and invention in the manufacture of firearms and machine tools under the ownership of Samuel Robbins and Richard Lawrence until the company bankruptcy in 1856. The Armory is significant in the areas of architecture, engineering and industry. The architecture is an excellent example of antebellum New England multi-story, brick, factory design that incorporated fire-resistant construction techniques, as well as a decorative cupola and rifle weathervane. The engineering is a good example of the design of a mid-century waterpower system, with a breast-type waterwheel, that was typical for mill seats in New England prior to the introduction of stationary steam engines. The Armory was a pioneer in the development of interchangeable parts for the manufacture of firearms for the federal government. The *in situ* remains of the waterwheel pit, millwork and headrace are a case study of a waterpower system of a mid-nineteenth century factory in New England. Documentary research and archeological

evidence from this industrial site adds to our understanding of similar factories and waterpower systems constructed at this time.

HISTORIAN: John P. Johnson, 2009

PROJECT INFORMATION: The documentation of the existing waterwheel pit and millworks at the American Precision Museum was undertaken by the Historic American Engineering Record (HAER) for the American Precision Museum (Ann Lawless, Executive Director). The drawings were prepared by Christopher H. Marston (HAER Architect), with Jessica Carpenito, German Osorio, Arvi Sardadi, Russell C. Wickham, and Pavel Gorokhov, HAER interns from Montgomery College, Maryland. John P. Johnson researched and wrote this historical report. Jet Lowe, HAER Photographer, produced the large format photographs.

The project also received invaluable assistance from Dr. Patrick Malone, Brown University; Charles Parrott, Architect, Lowell National Historical Park; Thomas Keefe, Keefe & Wesner Architects; Robert E. Dufresne, Dufresne Group Consulting Engineers; Jay Boeri, PE; Larry Lee, HAER Engineer; and Eric Gilbertson, Trustee, and John Alexander, Staff, American Precision Museum. The project was funded in part by a grant from the Society for Industrial Archeology, and trustees and friends of the American Precision Museum.

General Description

The American Precision Museum (APM) is a private, industrial history museum located at 196 Main Street in Windsor, Vermont. The building was originally constructed as the Robbins & Lawrence Armory in 1846 and has been operated as a private museum since 1966. Based on its architectural integrity, cultural significance and outstanding machine tool collection, the Armory was designated a National Historic Landmark in 1966 and a National Civil Engineering Landmark in 1970 and was listed in the National Register of Historic Places in 1972. The Robbins & Lawrence Armory was an important nineteenth century factory responsible for the growth of the Windsor Village Historic District, designated in 1975. The American Society of Mechanical Engineers designated the Armory a Mechanical Engineering Historic Landmark in 1987 and also recognized the American Precision Museum for maintaining an outstanding Mechanical Engineering Heritage Collection that same year.

Christopher H. Marston, HAER Architect, and John P. Johnson, an industrial historian from Vermont, conducted an industrial archaeological investigation of the remains of the first water power system at the former Robbins & Lawrence Armory in September 2007. This HAER investigation focused principally on the basement of the factory, site of the original waterwheel and remaining millworks, as well as the west and north elevations of the building. An examination of the *in situ* components provided evidence of the construction of the factory's original water-power system. These components included: remains of the headrace from the dam to the factory (approximately 5'-0" wide), a rock shelf (7' long x 18' 3" wide; site of a water box) at the south end of the waterwheel pit, a stone-lined waterwheel pit (18'-3" wide) and a stone lintel (approximately 10'-0" wide) visible on the exterior of the north elevation. There is also part of a large wooden gearing frame (11'-8" high x 7'-0" wide x approximately 22'-0" long), supported on five granite block sleepers (varying from 1'-6" to 1'-8" high x 1'-1" to 1'-8" wide and extending approximately 16' under the gearing frame) set into the dirt floor, near the eastern edge of the waterwheel pit. The diameter of the high breast wheel was probably 18' based on radial surficial markings up to ½" deep on the outside of the existing gearing frame and the depth and width of the wheelpit. The waterwheel was approximately 14' wide based on the width of the waterwheel pit.

It is unknown when the original 1846 waterwheel and part of the millwork for the power distribution system were removed. The following description of the original power system is conjectural and is based on field work at the American Precision Museum, research of similar waterwheels dating to the 1840s in New England and observations of reconstructed wheels at Old Sturbridge Village in Sturbridge, Massachusetts, and the "research by reconstruction" breast-type waterwheel at the Wilkinson Mill in Pawtucket, Rhode Island.[1]

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[1] Ted Penn, "Powerful Waterwheels," *Old Sturbridge Visitor* 23, no. 2 (Summer 1983); Robert B. Gordon and Patrick M. Malone, *The Texture of Industry: An Archaeological View of the Industrialization of North America* (New York: Oxford University Press, 1994), 16-20; discussions with Patrick Malone and Charles Parrott.

River water, stored behind the Middle Dam across the Mill Brook, was controlled by a gate at the top of a headrace, which may have been a stone-lined flume, and entered the basement of the factory at the west elevation. The water probably then flowed through a wood box flume into a water box at the south end of the waterwheel pit and turned 90 degrees to operate a high breast style, wooden waterwheel that was positioned in a wheelpit lined with stone walls and possibly wood flooring. After exiting the wheel, water flowed out of the factory on the north elevation and back into Mill Brook.

Components of the original 1846 vertical waterwheel and millwork were assembled on site. The Robbins & Lawrence Machine Shops located directly across Mill Brook on the north bank made the cast iron parts (gears, shafts and pulleys). The millwork probably consisted of a cast-iron, segmented gear attached to the outside edge of the waterwheel that drove a small, cast-iron pinion gear that was fastened to a horizontal, wrought-iron shaft. This shaft drove a large 7'-0" diameter wooden drum that was positioned in the existing wood gearing frame. That drum carried one or more leather belts up through the ceiling of the basement to a cast-iron pulley on a horizontal line shaft attached near the ceiling of the first floor. On the first floor of the factory were overhead wrought-iron line shafts, hung from ceiling beams, fitted with cast-iron pulleys that drove narrow, flat leather belts powering individual wood and metal working machines for the manufacture of rifles, guns and machine tools. Unfortunately the wood sub-flooring and top flooring of the first floor was replaced in 1981, so it can only be speculated exactly where the drive shaft projected up through the floor and where the main horizontal line shaft was suspended from the ceiling or fastened to the wood columns on the first floor of the factory.

Methodology

Both the documentary and the material record were examined to complete this documentation project. For example, an examination of "surficial markings" on the gearing frame revealed that the waterwheel had scraped the frame and had left wear marks as it revolved in the wheelpit (apparently this problem was corrected by adjusting the wheel so that it revolved freely). Edwin A. Battison (1915-2009), engineering historian, founder and the first director at the American Precision Museum, was a pioneer in using "surficial evidence" to solve a problem in industrial archeology.[2] The opportunity to study the remains of the original wheelpit at the Armory and illustrate the design and operation of the waterwheel provide direct insight into early nineteenth century water-power technology in New England. The results of this industrial archeological research of the *in situ* remains can be shared as researched-based "contextual interpretation" with a larger audience in future exhibits at the American Precision Museum.[3]

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[2] Edwin A. Battison, "Eli Whitney and the Milling Machine," *Smithsonian Journal of History* 1 (1966), 9-34.

[3] Robert B. Gordon, "Analysis and Interpretation of Artifacts in Industrial Archeology." *IA: The Journal Of The Society For Industrial Archeology* 26, no. 1 (2000): 103-111.

The fieldwork, consisting of field measurements photographs and field notes, was supplemented by research of the local and industrial history of Vermont and New England. Existing conditions drawings dating to 1999 by Keefe & Wesner, Architects of North Bennington, Vermont, provided useful information. Principal sources on eighteenth and nineteenth century waterwheel technology consulted for this report included the work of Zachariah Allen (1829), Oliver Evans (1850 edition), Frederick Overman (1851), Joseph P. Frizell (1893), Louis C. Hunter (1979), Robert A. Howard (1983), Terry S. Reynolds (1983, 1984), David Macaulay (1983), as well as Robert B. Gordon and Patrick M. Malone (1994).

Early Industries in Windsor, Vermont

After the closing years of the French and Indian War in the early 1760s, English settlers moved up the Connecticut Valley to what would become Windsor, Vermont, bringing the material culture of their colonial, agrarian and industrial economy. Homesteaders brought the plow, ax and oxen, as well as hand tools and the knowledge, skill and experience gained as farmers and craftsmen. Settlement was largely directed by the development of mill seats for the first grist and saw mills, the nucleus of every settlement. The origin of the town's name is presumably Windsor in Connecticut, the home colony of some of the grantees.

Windsor, Vermont, rises from the lowlands along the Connecticut River into a gently rolling landscape dominated by Mount Ascutney (3,144') an imposing monadnock along the southern border where the streams rise to feed Mill Brook. Windsor is considered the "Birthplace of Vermont" because its constitution as a "free and independent state" was drafted here in 1777. One of the state's five independent post offices was established here in 1784, before Vermont joined the Union in 1791. Windsor served as the first state capitol and meeting place of the general assembly until 1805 when Montpelier became the official and permanent capitol. By 1791 the population of Windsor had risen to 1,542 and by 1810 to 2,757. James Whitelaw (1748-1829), Vermont's second surveyor general, published a large map of the state in 1796. Mill Brook, where the town's principal stream enters the Connecticut River, became the focus of the Village of Windsor and here a ferry crossed the river to New Hampshire. The Cornish-Windsor Bridge (1796), the longest wooden bridge in the United States and the earliest bridge to New Hampshire, is located on the west bank of the Connecticut River immediately north of Mill Brook.[4]

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[4] Harold Fisher Wilson, "The Roads of Windsor," *The Geographical Review* 21, no. 3 (July 1931): 379-397. For a chronology of settlement in towns from the Massachusetts line from Vernon to Newbury in Vermont and from Hinsdale to Haverhill in New Hampshire, see Roger W. Foster, "The Early Architecture of Windsor, Vermont" (B.A. Thesis, Dartmouth College, 1946); Henry Steele Wardner, *The Birthplace of Vermont: A History of Windsor to 1781* (New York: Scribner & Sons, 1855). For historical context, see Richard J. Ewald with Adair R. Mulligan, *Proud to Live Here: In the Connecticut River Valley of Vermont and New Hampshire* (Charlestown, NH: Connecticut River Joint Commission, 2003). For information on Cornish-Windsor Bridge, which is a National Civil Engineering Landmark (1970), was listed in the National Register of Historic Places (1976), and was recorded by HAER in 1985 and 2004 (HAER No. NH-8), see Joseph C. Nelson, *Spanning Time: Vermont's Covered Bridges* (Shelburne, VT: New England

Vermont historian Thomas Day Seymour Bassett (1913-2000) published an exhaustive study of the urban impact on nineteenth century villages. Town proprietors planned from the beginning to provide water-powered mills for their neighborhoods, and these mills multiplied on the innumerable little falls of northern New England. Mill Brook enters the Connecticut River on the Vermont side; the course of the brook and the location of its three falls determined the distribution of the earliest water-powered industries in Windsor. Windsor County was full of these modest-sized water privileges, and these mills expanded beyond the local market as part of the shift to a national economy in the generation before the Civil War. The county enjoyed a more integrated network of roads and turnpikes than elsewhere in the region, and local agricultural and forest products drifted down the Connecticut on flatboats built at a shipyard at the mouth of the brook or were transported by horse team to Boston. By 1830, six hydraulic locks had made the "upper river" navigable, but the current was generally swift and the stream's natural condition did not suit it to efficient navigation. In 1849, the railroad arrived in Windsor. From 1800 to after 1860, Windsor was the most populous Vermont County and probably the richest in real and personal property.[5]

Connecticut Valley historian William N. Hosley, Jr. has written that Windsor was a center of trade, communication, industry and culture, making it one of the towns (like Hartford, Springfield, Northampton and Greenfield) that functioned as a "cultural conduit" bringing style and substance of urban life to the Connecticut River Valley cultural region. Hosley notes, "Windsor, like other urban frontier towns, attracted an educated, entrepreneurial, forward-looking, and aggressive class of individuals who promoted their town through business dealings and political contacts, and who self-consciously affected urbane pretensions both in their personal and public undertakings."[6] From 1800-1810, Windsor was the largest town in Vermont, the northernmost point of navigation along the river, the most important town for mills in the region, and a growing manufacturing center. In 1806 its artisans tried to organize the first professional trade association in the northern valley, the Windsor Mechanics Association. By 1810 there were half a dozen major buildings in the village, and its commercial district was unsurpassed in the northern valley.[7] Hosley argues that Windsor's unique role as the "arbiter of style" in the northern valley region can be documented by the town's outstanding architecture still visible in the Windsor Village Historic District (listed in the National Register of Historic Places in 1975, expanded 2006).

The development of the machine-related industries of Windsor is historically significant. By inclination and necessity, many of the early inhabitants operated mills or

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Press, 1997), 96-99, Robert McCullough, *Crossings: A History of Vermont Bridges* (Barre, VT: Vermont Historical Society, 2005), 288-289.

[5] T. D. Seymour Bassett, *The Growing Edge: Vermont Villages, 1840-1880* (Montpelier, VT: Vermont Historical Society, 1992), 49-54; Lyman S. Hayes, "Navigation of the Connecticut River" in *Essays in the Social and Economic History of Vermont* (Montpelier, VT: Vermont Historical Society, 1943).

[6] William N. Hosley, Jr., "Architecture and Society of the Urban Frontier: Windsor, Vermont, in 1800" in Peter Benes, ed., *The Bay and The River: 1600-1900* (Boston, MA: Boston University, 1981), 73-74.

[7] Hosley, 75.

became gunsmiths and inventors. From native timber and iron, ample water power, and under the protection of patents, these men established small factories. Investors from Hartford, Connecticut, determined to improve navigation and commerce, incorporated the Connecticut River Company (1824-1828) and the Connecticut River Valley Steamboat Company (1828-1832) to build canals and steamboats. New York Governor DeWitt Clinton (1769-1828) visited Windsor in 1827 as an advisor and promoter. Capt. Samuel Morey (1762-1843), who had experimented with steam boats as early as 1790, built the canal and locks at Bellows Falls, Vermont, and was an early inventor of steam and internal combustion engines, served as the canal engineer. Thomas Blanchard (1788-1864), who invented thirteen different machines for the stocking of rifles for the US Army at the Springfield Arsenal, was the company's steamboat builder and pilot. Blanchard built the 80' long steamboat VERMONT in Springfield, Massachusetts, and in 1829 navigated it from Hartford, Connecticut, to Windsor. Windsor businessmen incorporated the Ascutney Mill Dam Company in 1833 to construct the Upper Dam and reconstruct the earlier timber-framed Middle and Lower dams. These dams made Mill Brook the most developed water course in Windsor County through the nineteenth century.[8] Historically, Mill Brook, with its three rock-ledge falls dropping 60' in three-quarters of a mile, had three dams: the Lower Dam (the first dam built of logs for the operation of a grist mill between 1764-1769), the Middle Dam (the second dam built of logs between 1764-1769 for the operation of a sawmill), and the Upper Dam (the third dam built of granite in 1834, also known as the Ascutney Gravity Arch Mill Dam). The Middle Dam was reconstructed in 1835 to supply water power for Kendall's Gun Shops on the north bank and rebuilt in 1845 to supply water power for the Robbins, Kendall & Lawrence Armory on the south bank.[9]

The firm of John M. Cooper, Elisha Phelps and Edward R. Campbell incorporated in 1828 with a capital of $100,000 to manufacture a rotative piston, invented and patented in 1827 by John Cooper of Guildhall. Windsor resident Asahel Hubbard (1787-1845) came from Meriden, Connecticut, in 1800 and operated a grist mill, saw mill and machine shop. Hubbard improved Cooper's invention and also secured a patent in 1828 for a rotary pump (revolving hydraulic engine). Hubbard joined Jabez Proctor (1780-1839), the financial backer and manager in Proctorsville, a village in the Town of Cavendish, and incorporated the American Hydraulic Company (1828-1829) and the National Hydraulic Company (1829-1839). Windsor industrial historian Guy Hubbard claimed that "it was upon this patent (Hubbard's rotary pump) that the modern industries of Windsor were based." Isaac Watts Hubbard (1794-1871) acquired the company from

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[8] Guy Hubbard, "Industrial History," Vol. 1 (Windsor, VT: Town School District, 1922), 7; Guy Hubbard, "Genealogy of the Machine Industries of Windsor, Vermont" *American Machinist* 59, no. 1 (July 5, 1923); W. W. Waterman, "The Connecticut River Valley Steamboat Company" *Vermont History* 25, no. 2 (April 1957): 83-102. Note: Hubbard says there were two early dams, for a sawmill and a gristmill, near the mouth of Mill (Stream) Brook.

[9] Lyssa Papazian, "Building for Invention," research and text for exhibit, 2004, available at the American Precision Museum (hereafter cited as APM). The first officers of the company are listed in *The Public Papers of the Ascutney Mill-Dam Company* (Windsor, VT: Chronicle Press, 1834); William J. Wilgus, *The Role of Transportation in the Development of Vermont* (Montpelier, VT: Vermont Historical Society, 1945), 51-62.

his brother and began making pumps in the Windsor Prison (in operation 1809-1975) where he installed a machine shop with the first stationary steam engine in Windsor in 1835 to manufacture rotary pumps. The prison employed convicts and free mechanics for a variety of work, including cooperage, basketry, shoemaking, carriage making, blacksmithing and gunsmithing. Former New York Governor DeWitt Clinton was also an early promoter of the rotary pump. In 1835 a West Windsor gunsmith named Nicanor Kendall (1807-1861) married Asahel Hubbard's daughter and set up a gun shop in the prison to make rifles.[10] After N. Kendall & Company (1838-1843) stopped making guns at the prison in 1842, the company established a new gun shop at the "Old Hydraulic Shop" on the north bank of the Middle Dam of Mill Brook. Gunsmith and designer Richard Smith Lawrence joined the proprietor Kendall in 1838 at the prison gun shop.[11] When they moved to their new location, the enterprise became Kendall & Lawrence (1843-1844). Benjamin Tyler Henry (1821-1898), a gunsmith and inventor, joined the company to manufacture pumps and Kendall's "under hammer lock" style rifles.[12]

In 1832, the Federal Secretary of the Treasury reported a nascent industrial sector serving a regional market with an iron foundry, a scythe and axe factory, as well as a starch factory, three machine shops, two oil mills, two cotton factories, two hat factories, three saddle shops, three boot and shoe factories, eight woolen factories and twenty-two tanneries in Windsor County. Francis E. Phelps, superintendent of the American Hydraulic Company reported the manufacture of fire engines, force pumps and hydraulic machinery of all kinds. At the Windsor Prison a labor force of about twenty men (no apprentice boys) earned $25-35 per month for a twelve hour day, six days a week. Phelps also reported that the average rate of wages was $26 per month for mechanics and $11 per month for farmers and laborers in Windsor County. This small industrial base grew, and by 1840, the Census of Manufacturers listed the Town of Windsor as one of the "principal towns" with 270 people employed in "manufacturers and trades" along with twenty-six in the "learned professions and engineers."[13]

Vermont historian, naturalist and mathematician Zadock Thompson's (1796-1856) *History of Vermont, Natural, Civil and Statistical* recorded the Ascutney Gravity-Arch Mill Dam across the Mill Brook. The 47 square mile drainage basin of the brook was the fundamental factor in providing available power capacity. Thompson states,

> for the purpose of affording the village the advantages of water, in 1835 a stone dam was constructed across the Mill brook, half a mile from its mouth. It is 360 feet in length, 56 in breadth at the base, 12 at the top, and 42 feet in height,

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[10] Asahel's son, Coleman S. Hubbard (1816-1877), was also a machinist and gunsmith. Carlos Coolidge (1792-1866) was their patent attorney and later served as Vermont's Governor from 1848-1850.
[11] Richard Smith Lawrence (1817-1892) was born in Chester, Vermont.
[12] Hubbard, "Industrial History," Vol. 1; Katherine E. Conlin, Wilma Burnham Paronto and Stella Vitty Henry, *Chronicles of Windsor, 1761-1975* (Windsor, VT: Town, 1977), 215-219; Hubbard, "Genealogy of the Machine Industries," 389-392.
[13] U.S. Secretary of the Treasury, *Documents Relating to the Manufacturers in the United States, 1832* (The McLane Report), Document No. 308, 882-885, 909-910; Census of Manufacturers, Town of Windsor, 1840.

> forming a reservoir of water nearly one mile in length, with a surface of 100 acres, having an available fall of 60 feet in the distance of one third of a mile. The dam is built on the arc or a circle, over which, in flood time, the water flows in an unbroken sheet 102 feet in length, forming one of the most beautiful cascades in the country.[14]

The purpose of this dam, which was also known as the Upper Dam, was to create a large reservoir and increase the power available to the mill seats along Mill Brook by providing upstream storage of floodwater during wet seasons and for mitigating the shortages of water during the dry months. The reservoir collected water that had flowed into it during the night for use the following day, in effect doubling the power of Mill Brook. In 1835, assets of the Ascutney Mill Dam Company included this new dam and "two timber dams further downstream at the middle and lower falls plus associated buildings." In addition, "several small frame buildings at the middle falls were occupied principally by the American Hydraulic Company, manufactures of pumps and fire engines. A stone gristmill, built about 1816, stood at the lower falls." It was not until the Civil War that mills were developed at the Upper Dam, the Ascutney Gravity-Arch Mill Dam.[15]

The American Society of Civil Engineers credits Ithamar A. Beard (1789-1871), a prominent New England millwright and civil engineer, who surveyed the Mill Brook and selected the best site for this dam.[16] Beard, while superintendent of the Hamilton Manufacturing Company in Lowell, Massachusetts, ran a series of tests on the power used to drive machinery in his No. 2 mill in 1830. He published his observations three years later in the *Journal of the Franklin Institute*, the best-known technical publication in America. Beard found that the combined breast wheel efficiency for his installation was only 60 percent and that 40 percent of the potential energy in the water was lost in the normal operation of the waterwheels. Beard served as a consultant to the directors of the Ascutney Mill Dam Company for the building of the dam, but it is unknown how much he influenced the design of the subsequent water power development of the Mill Brook.[17]

In 1835, Thomas Emerson, variously described as a capitalist, banker and promoter, arrived in Windsor. Emerson became president of the Windsor Bank, built an impressive mansion and persuaded a noted metallurgist from Baltimore, Maryland, Isaac Tyson, Jr. (1792-1861) to relocate to Windsor. In 1835, while prospecting for minerals in

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[14] Zadock Thompson, *History of Vermont, Natural, Civil and Statistical* (Montpelier, VT: Walton, 1842), 194-196.

[15] Edwin A. Battison published documentation of this famous dam and mill pond for the Society of Industrial Archeology in 1975 while director of the American Precision Museum. The dam was designated a National Civil Engineering Landmark in 1970 and is the focus of the Ascutney Mill Dam Historic District (listed in 2006).

[16] Edwin A. Battison, "Ascutney Gravity-Arch Mill Dam, Windsor, Vermont, 1834," *IA: Journal of the Society for Industrial Archeology*, 1, no. 1 (1975): 57; "Ascutney Mill Dam," History and Heritage Committee, American Society of Civil Engineers.

[17] Patrick M. Malone, *Waterpower in Lowell: Engineering and Industry in Nineteenth-Century America* (Baltimore: Johns Hopkins, 2009), 55-56, 58.

the mountains, Tyson discovered an outcrop of iron near the southern Black River. When Tyson sent Joseph Martin, foreman of Tyson's copper mine in Strafford to prospect for ore, he found three deposits of workable ore. Tyson supervised the erection of a blast furnace on the southern edge of Plymouth (only 18 miles west of Windsor) in 1837. They began the Tyson Iron Company (originally incorporated as the Windsor and Plymouth Ascutney Iron Company, 1836-1872). To fuel the furnace, Tyson purchased 2,500 acres of woodland to provide timber for charcoal and erected a dam to supply a constant flow of water to power the furnace. He also built a post office, tavern, school and reading room. The furnace produced between 600 and 1,000 tons of iron annually and was one of the busiest iron-producing facilities in New England. Tyson employed 175 men in the smelting of pig iron, part of which was recast into stoves, hollowware, mill irons, machinery parts, water pipe and merchant bar that was shaped into a variety of hardware, edge tools and nails. The company ceased the manufacture of ironware in 1844 and sold only pig iron thereafter. In 1855, "the works" closed due to Tyson's failing health but reopened in 1864 due to increased demand during the Civil War. Iron was available from the Tyson Iron Company for the National Hydraulic Company and thus stimulated the development of the machine tool industry in Windsor.[18]

Windsor industrial historian Guy Hubbard credits Col. Benjamin Tyler (1733-1814), a pioneer from Wallingford, Connecticut, who settled in West Claremont, New Hampshire, in 1765 as the "first representative millwright of the Windsor district." In 1767, Tyler erected a grist mill and sawmill, as well as a forge, bloomery and slitting mill on the Sugar River, near where it empties into the Connecticut River (only 9 miles south of Windsor). The industries were known locally as the "Old Tyler Mills." As the area's first mechanical engineer and iron master, Tyler did a thriving business building saw and grist mills, with the millstones supplied by the granite quarries on the southeastern slope of Mount Ascutney. These were the first grist and saw mills on the Mill Brook in Windsor, and they became the nucleus for other small industries, such as a blacksmith shop, a wheelwright's shop, a carding mill and probably a cooper's shop. Tyler patented a Wry-Fly turbine (an ancestor of the axial-flow turbine) in 1800 that represented a radical improvement on the traditional tub wheel. Tyler's success at building grist mills caught the attention of Oliver Evans (1755-1819) who visited Windsor in 1818 and published in the local newspaper a dire "Warning to Millers" regarding the infringements of Evan's patent. Several generations of the Tyler family of Claremont and West Lebanon, New Hampshire, continued to be millwrights and inventors. John Tyler, Jr. (1818-1896), the grandson of Col. Benjamin Tyler, patented the famous "Tyler Water Wheel" and sold hundreds locally and nationwide for a variety of water powered factories.[19]

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[18] Hubbard, "Industrial History," 47-54; Victor R. Rolando, *200 Years of Soot and Sweat: The History and Archeology of Vermont's Iron, Charcoal and Lime Industries* (Manchester Center, VT: Vermont Archeology Society, 1992), 128-132, 140.

[19] Edwin T. Layton, "Benjamin Tyler and The American Antecedents of The Hydraulic Turbine," *Tools & Technology: The Newsletter of the American Precision Museum* 5, no. 3 (1983); Simeon Ide, *The Industries of Claremont, New Hampshire, Past and Present* (Claremont, NH: Claremont Manufacturing Company, 1879), 16, 21, and 29; Guy Hubbard, "Leadership of Early Windsor Industries in the Mechanic Arts,"

In 1843 at the "Old Hydraulic Shop," located at the Middle Dam, Kendall & Lawrence developed a manufacturing complex of at least seven buildings and filled it with twenty-five workers and the tools and machinery necessary for their expanded enterprise as a custom Gun Shop. At this shop skilled gunsmiths repaired, modified, designed and constructed custom firearms using hand and simple machine tools. By 1844 the company was advertising its ability to fill orders for "manufacturing and repairing rifles, fowling pieces, and pistols; as well as engine and hand lathes, dentist tools, and fine cutlery. Also all kinds of iron and wood turning, grinding and polishing done at short notice." Machine tool technology in Windsor continued to evolve through several companies at this site until 1888.[20]

Proliferation of manufacturing in early nineteenth century Vermont created a demand for millwrights who understood the sophisticated linkages required between waterwheels and machines. Machinery-dependent production also required a new type of craftsman, one who worked in a machine shop. These machine makers fashioned devices from wood and metal to fit individual specifications and repaired broken machines. Because completed machinery was often unwieldy to transport, machine shops were located at or near manufacturing complexes and on transportation routes, allowing them to serve small regions. The number of machine shops increased during the century's first three decades, but their form remained essentially unchanged. Kendall & Lawrence's complex was a departure from the traditional single building operations. The one-and-a-half story frame and brick buildings were fitted with a variety of measuring tools, foot-powered lathes, workbenches with vises, cutting tools and grindstones, and tool chests filled with assorted hammers, chisels, and files. Some of the buildings probably had water-powered lathes and screw-cutting engines, as well as water-powered machines for boring, drilling, milling, and planing. Metal-working machine shops, used for cold shaping of iron, depended on foundry castings, rods and sheet metal. The Kendall & Lawrence Gun Shops were known in nineteenthcentury terminology as "the works," a complex with several forges, a wood-working shop, a machine shop, a drafting room, a pattern room and a building to assemble finished articles. A famous 1849 illustration of "the works" and the Armory features at least seven one-and-a-half- and two-story buildings (with a total of sixteen chimneys), while an 1853 illustration features at least nine buildings on the north bank of Mill Brook.[21]

Construction of the Robbins & Lawrence Armory

Essays in the Social and Economic History of Vermont (Montpelier, VT: Vermont Historical Society, 1943), 161-163.

[20] *Vermont Journal*, October 10, 1844; "Evolution of the American Military Rifle," *American Machinist*, October, 5, 1916. For a description of guns and gunsmiths at this shop, see Warren R. Horn, *Gunsmiths and Gunmakers of Vermont* (Burlington, VT: Horn, 1975), 23-24, 56-59, 67; Henry Phillips and Terry Tyler, *Vermont's Gunsmiths and Gunmakers to 1900* (Dorset, VT: Two Damn Yankees, Inc, 2000), 130-141, 144-148, 151-154, 202-211.

[21] The earliest illustrations of these properties are 1849, 1853 and 1855**;** see Presdee & Edwards, *Map of Windsor, Vermont*, 1853 for the design of the power house. See Appendix for illustrations.

Samuel E. Robbins (1810-1874) approached Kendall and Lawrence to form a partnership and bid on a contract for manufacturing the Model 1841 Mississippi rifles for the Ordnance Department of the US Army. The partnership of Robbins, Kendall & Lawrence (R, K & L) was established in 1844, and a bid was sent to Washington. On January 25, 1845, Windsor attorney Jonathan Hatch Hubbard (1768-1849) sold land to R, K & L on the south bank of the Middle Dam (directly opposite the Kendall & Lawrence shops on the north bank) for $4,000 "subject however to the bylaws of the Ascutney Mill Dam Company." In February 1845, Robbins, Kendall & Lawrence received the first rifle contract from Col. George Talcott, which called for the 10,000 rifles to be delivered within three years. Successful operations at the Gun and Machine Shops gave these rural capitalists and entrepreneurs the investment capital to sustain a bold new enterprise, and the partnership began planning for the construction of a large, private Armory to fulfill the terms of the contract.[22]

The log and timber frame Middle Dam was probably reconstructed about 1835, just after the new granite Upper Dam was completed in 1834. Kendall & Lawrence moved their operation to the "Old Hydraulic Shops" on the north bank of the brook about 1843 (referred to later as simply Machine Shops). The Middle Dam was rebuilt again in 1845 to accommodate the increased demand for water power that would be created by construction of the Armory on the south bank in the spring of 1846. The dam was 122' long and 12' high and constructed of dry stone masonry.[23] A gate at the south side of the Middle Dam allowed water to enter a headrace that ran to the west wall of the basement of the Armory. An opening in the west wall directed water to a box flume that continued to a water box next to the original waterwheel.[24]

The heritage of industrial buildings in New England features a variety of architectural forms. The common materials of wood, stone, brick, metal in various forms (cast and wrought iron, cast metal, steel) and later concrete and glass, were combined in innovative ways and always with an eye toward function. Various construction solutions, adapted to a broad range of industrial building types, coexisted in a single period in history. The resulting architecture can be characterized by several factors, including stylistic eclecticism and a rigorous functionalism in the design of the factory. Industrial buildings were designed with the priorities of production and commerce in mind and for this reason, a certain repetitiveness and uniformity in the architecture was to be expected and even desired. Early New England factory design "reflected the adaptation of vernacular building traditions to the need of industrial production." Artisans and early mill builders "absorbed and diffused these innovations within the building trades. They relied on empirical knowledge and practical skills to modify their traditional building techniques." During this period, changes in factory design "occurred as a result of

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[22] Joseph W. Roe, "Early American Mechanics—Robbins & Lawrence Shop," *American Machinist* 41, no. 17 (October 22, 1914); Merritt Roe Smith, *English and American Tool Builders* (New Haven, CT: Yale, 1916), 186-201; Windsor Land Records, Vol. 20, Page 40.
[23] A concrete cap was poured atop the dam at a later date. The dam is currently breached.
[24] James Leffel, *Leffel's Construction of Mill Dams* (Springfield, OH: Leffel, 1881), 4-8.

diffusion, imitation, and innovation within the regional manufacturing community and building trades."[25]

Industrial architecture in Vermont began with very modest buildings, generally resembling barns, which have been stylistically typed as "production sheds." The materials used in the first phase of construction were wood for the framing and brick or stone masonry for the external walls. Early examples of this building type included ubiquitous grist mills, saw mills, fulling mills, carding mills, tanneries, and wood working shops. The design of the first textile mills exerted a predominant influence on nineteenth-century industrial architecture as a whole and these mills have been stylistically typed as "multi-story industrial lofts." In fact, this very simple, basic form was adaptable to all sorts of industries and easily lent itself to later expansion. The factory had to be narrow enough to allow daylight to penetrate effectively from the peripheral windows into the building's interior. The Armory's long narrow, rectangular, multi-storied design was typical of most antebellum textile mills and multi-purpose, water-powered factories. Stylistically the partners Robbins, Kendall & Lawrence chose the ubiquitous New England textile mill model as a symbol of promise and prosperity for their Armory.[26]

Entrepreneurs, builders and especially insurance companies were particularly concerned with the risk of fire. Early factory builders in southern New England had experimented with methods that made it possible to, if not eliminate the risks, at least limit the damage by slowing the progression of fire. Substantial exterior masonry walls of stone or brick, unpainted over-sized slow-burning wood beams and columns, the beams spanning between columns without intermediate beams, a minimum of concealed spaces and openings between floors, and thick plank floors became the preferred solution. By the mid-1840s, these fire resistant construction techniques for large factories were standard practice and were used in the construction of the 3-story brick Armory.[27]

The principal partners collaborated with a millwright to design and supervise construction of the Armory. In the early nineteenth century, a millwright was a master craftsman who designed and employed every type of known engineering operation in the construction of mills. He learned his trade through an apprenticeship format, on-the-job

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[25] Betsy Bahr, *New England Mill Engineering: Rationalization and reform in textile mill design, 1779-1920* (Ph.D. diss., University of Delaware, 1988), 10, 20, see Chapter One, "Building for Production: Vernacular Architecture and Textile Factory Design, 1790-1830," 10-34; Louis Bergeron and Maris Teresa Maiullari-pontois, *Industry, Architecture and Engineering* (New York: Abrams, 2000); Betsey Hunter Bradley, *The Works: The Industrial Architecture of the United States* (New York: Oxford, 1999).

[26] Louis C. Hunter, *A History of Industrial Power in the United States, 1780-1930*, vol. 1, *Waterpower in the Century of the Steam Engine* (Charlottesville, VA: University Press, 1979), Table 1, 1820-1825 and Table 2, 1840.

[27] Gary Kulik, "A Factory System of Wood: Cultural and Technological Change in the Building of the First Cotton Mills," in *Material Culture of the Wooden Age*, Brooke Hindle, ed. (Tarrytown, NY: Sleepy Hollow, 1981; Charles T. Main, *Notes on Mill Construction* (Boston: Southgate, 1907); Bergeron and Maiullari-Pontois, *Industry, Architecture and Engineering* ; Betsy Hunter Bradley, *The Works: The Industrial Architecture of the United States* (New York, Oxford, 1999).

training, typically itinerant and often handed down to family members and relatives. The "mill" in millwright refers to the genesis of the trade in building sawmills, grist mills and later textile mills. In designing mills, knowledge of dam construction and wood frame construction was supplemented with stone and brick construction. The decision as to wheel type, size, proportions, and rotating speeds (rpm) in relation to the mill seat and the power required to drive machinery largely determined the economy and effectiveness of the factory. Millwrights used common engineering knowledge and available handbooks. They also installed, repaired, replaced and dismantled machinery used in the manufacturing process. In addition, millwrights designed the patterns of waterwheel systems, carved or cast their gear mechanisms and erected the machines. A competent millwright combined the skills of a surveyor, carpenter, joiner, stonecutter, mason, blacksmith and wheelwright. A building that employed water power to drive machinery and included a division of labor to process raw materials into a finished product came to be known as a factory. Oliver Evans codified the early skills of millwrights as early as 1795 with the publication of the widely distributed *The Young Mill-wright and Miller's Guide,* and its many reprints and additions. The publication contained practical information for planning and building water-powered mills. The wide range of facilities and the development of new technologies required millwrights to continually update their skills. Each new community eagerly availed itself of the local millwrights' services. The deficiency of a mill was regarded, as one Vermonter put it, "inconsistent with the existence of civilized life." As the skills of civil, mechanical and structural engineering were adopted, the former millwrights became known as mill engineers. With the adoption of mechanical and structural engineering knowledge, the former on-the-job training became hydraulic engineering.[28]

Richard Lawrence would later recall, "We went to work with a determined will, bought land, built factories, bought and built machinery, and started the business in good shape." Traditionally, erecting mills and factories was undertaken in the spring, so the construction of the Armory began in April 1846. It is not known when the construction was completed, or when the building was occupied. The new factory site, on the south bank of the Middle Dam and parallel to the Mill Brook, was positioned to take advantage of the water power. The 40' x 100' factory was raised on a battered, dry-laid, rubble-stone foundation measuring 6' thick at its base and 2' thick at the top of the wall. On the north elevation, the foundation was set on exposed bedrock on the bank of the brook. The three-story building (4' x 12' bay with attic and basement), was constructed of 12" thick, load-bearing, brick walls, with a cornice composed of five courses of corbelled and turned bricks. The water-struck, hand-molded bricks were laid in ten-course American bond in a soft mortar, with internal end chimneys rising to corbelled caps above the peaked gable roof. The fenestration was highly regular, with rows of twelve-over-twelve-light double-hung wood sash (5 ½' high and 3' wide) set in a balanced symmetrical pattern in the brick walls with granite lintels throughout the building. Green slate shingles installed ca. 1870 covered the original wood shingles of the gable roof and a hexagonal-

[28] Ruth Schwartz Cowan, *A Social History of American Technology* (New York: Oxford, 1997), 54-57; Hunter, 28-36.

columned, ogee-style cupola located in the center of the ridge. The cupola is original and dates to 1846, while the operable bell from 1891 was installed in 1977. It is accessible from a wooden staircase in the attic. The rifle-shaped weathervane on the cupola is a reproduction (now gilded) of an original weathervane that may have been an actual 1841 "Mississippi" style rifle manufactured at the Armory. The interior of the Armory is standard mill-framing, pocketed into exterior walls, consisting of a regular grid of sawn timbers that get lighter in the upper floors as loads decrease. Interior wood columns that create open bays and double wood flooring set on a diagonal are typical of this standard of fire resistant construction.[29] The Armory was easily accessible from the earlier Machine Shops across Mill Brook over a long, wooden covered bridge on Main Street. An open, flat footbridge crossing the brook below the Middle Dam also connected the Machine Shops with the first floor of the Armory (through a door opening in the north wall, later enclosed with a comparable style window). Wheelbarrows and small wagons could be used to quickly transport rifle or machine parts over this footbridge from either side of the brook.

After the arrival of the Vermont Central Railroad in 1849, there was a convergence of resources in Windsor: adequate water power, proximity to an iron furnace, a tradition of small industry, and motivated entrepreneurs with investment capital. A skilled labor force of millwrights, mechanics and artisans, as well as the expanding markets, led to Windsor being known as the "birthplace of the machine tool industry." The Robbins, Kendall & Lawrence enterprise became known historically as the "Upper Shops" by mechanics in what later came to be known as the "Precision Valley."[30]

No architectural plans, building specifications, detailed illustrations or written descriptions have been located of the construction of the Armory or the first waterpower system. Fortunately the site was impressive to artists. The Machine Shops and the Armory on Mill Brook were featured in panoramic illustrations (1849, 1853, and 1855), a company check (1853), a landscape painting (1859), a stereopticon (ca. 1865) and Birdseye (1886). These illustrations feature "the works" during the decade of historic significance and productive years at the Armory (1846-1856).[31]

The historic images reveal much about the evolution of construction on both sides of the Mill Brook; however, they are not without contradictions (see Appendix). The monitor roof, common to factory construction at this time, is original to the 1846

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[29] Roe, *English and American Tool Builders*, 286; *Vermont Journal*, February 16, 1849; Thomas F. Keefe, "American Precision Museum: Conservation Assessment Program Grant," July 1, 1999.

[30] Robert G. Leblanc, *Location of Manufacturing in New England in the 19th Century* (Hanover, NH: Dartmouth, 1969), 13-21; Wayne G. Broehl, Jr., *Precision Valley: The Machine Tool Companies of Springfield Vermont* (Englewood Cliffs, NJ: Prentice-Hall, 1959), see "The Upper Shop," 1-25.

[31] Illustration of 1849; Presdee & Edwards. *Map of Windsor, Vermont*, 1853; Hosea Doton, *Map of Windsor County* (Pomfret, VT: Doton, 1855); *Windsor, VT* (New York: Endicott & Co., 1859); F. W. Beers, *Atlas of Windsor County, Vermont* (New York: P & E, 1869); L. R. Burleigh, *Panoramic View of Windsor, VT*, (Birdseye view) (Troy, NY: Burleigh, 1886); Hamilton Child, *Gazetteer & Directory of Windsor County, VT* (Syracuse, NY: Child, 1884); Sanborn Fire Insurance Maps, (1876, 1884, 1917). See Appendix for illustrations.

construction and numerous windows allowed ample daylight into the work space. The existing brick, stair tower was added ca. 1870. This stair tower supplemented an interior stairway and also offered some fire protection. The artist of the 1849 illustration may have overlooked the monitor as insignificant and from his perspective the stair tower was not visible. Also, this illustration shows the brick addition on the west elevation with three stories; however the artist of the 1853 illustration illustrates only two stories. A two-story brick addition on the west elevation was completed shortly after the original construction around 1848; this addition was later raised to three stories (ca. 1870, and removed ca. 1955). The 1855 illustration correctly depicts only a two-story addition, a monitor roof and no stair tower. A pedestrian bridge, which stretches across the brook on a center pier in the 1849 illustration, is illustrated as a two-part suspension type; the 1853 and 1855 illustrations show a two-part straight design, that was more likely for the transport of supplies. Perhaps this early bridge was removed in a freshet, because it was gone sometime between 1855 and 1876. Gas lights were added to the building around 1861 and were replaced with electric lights in 1901 when the building was converted to a hydroelectric facility. A 1917 post card illustrates a simple bow string truss bridge (now removed) across the brook closer to the dam. After the original waterwheel, subsequent power sources for the building included a steam engine (1849), a water turbine (ca. 1870) and electricity (1901).

The Vertical Wooden Waterwheel

The flow of the Mill Brook was controlled by the water cycle, a function of natural conditions such as precipitation, temperature, humidity, evaporation, vegetation, soil type and drainage. The system to supply water to the breast wheel in the Armory consisted of several parts. A head gate located at the top of a long headrace on the south edge of Middle Dam controlled the amount of water entering the race.. A trashrack, consisting of a screen of closely spaced wooden or iron strips, spanned the headrace just in front of the gate to prevent debris that might enter the headrace from damaging the breast wheel. The headrace extended above the dam and turned at a right angle to an opening on the west wall of the basement of the factory (see results of excavation p. 19). In the basement of the factory, a box flume was constructed under this archway and extended to a water box just above the wheel. In the water box another gate controlled the amount of water entering the buckets and thus the speed of the wheel. Unfortunately, wood flumes and wood water boxes were subject to deterioration, leakage and constant maintenance. The breast wheel was positioned in a central, sheltered location in the basement of the factory where the life of the wheel and gearing could be extended.

The millwright was responsible for deciding which type of prime mover to build for powering the wood and metal working machines that would be used in the Armory. The millwright chose a waterwheel to use water available upstream from the Ascutney millpond. He also decided on the placement and construction of the trashrack, gate, headrace, and possibly a spillway to drain the headrace for repairs, as well as how the water would enter and exit the factory. His design focused on the distribution of power, the methods and equipment by which power in the form of motion is conveyed from the

prime mover, located typically at some central point, to the machinery employed in production. He decided on the overall size of the wheelpit, the type of gate to let water into the buckets, the size of the high breast wheel, how the buckets would be shaped and how best to gear the waterwheel to drive the machines on the first floor of the factory. The wheelpit, with stone sides and possibly a wood plank floor, was constructed in the basement to protect the wheel from the elements of ice and floods, which allowed the wheel to be operated year round. The machinery for the distribution of power, known as millwork and consisting of gears, shafting, pulleys and belting, was expensive. Its operation usually consumed much of the power generated. One estimate is that about 50 horsepower was available from an 18' diameter wheel.[32]

Typically, vertical industrial waterwheels came in three forms: undershot, overshot and breastshot, to indicate where the water entered the wheel. Several developments led to the introduction of the breast wheel in America after 1750. The practical development for the introduction of the breast wheel was a close-fitting wooden apron (known as a breast). The theoretical development was the discovery of the superior efficiency of weight over impulse as a motive power. The economic development was the rising price of water power and the growing scale of water-powered industry on watercourses throughout New England. The close fitting apron surrounded the lower quadrant of the water-loaded side of the wheel and held water in the buckets. The breast increased the efficiency so that "at best, its efficiency was. . . 60-70% and up." However, "the additional first costs and operational problems inherent in the use of breast wheels meant that, despite their high efficiency, they were unlikely to enjoy extended use until economic circumstances made the gains acquired in efficiency more important than the additional costs required to build and operate them."[33] The widespread use of efficient horizontal waterwheels, know as turbines, was decades in the future.

The custom built wheel with wood breast was known in America by the late eighteenth century. The Slater Mill in Pawtucket, Rhode Island, erected in 1793, apparently used a breast wheel. The earliest published illustrations of American breast wheels were those of Oliver Evans and Thomas Ellicott's *Mill-wright's Guide*, published in 1795, that provided millwrights with a rational basis for the planning and design of water-powered mills. Jacob Perkins erected a 30' diameter high breast wheel with apron, iron buckets, and peripheral gearing near Newburyport, Massachusetts, in 1796. David Wilkinson (1771-1852) constructed and operated a breast wheel (12' diameter and 12' wide) for New England's first machine shop in Pawtucket in 1810, and Paul Moody (1779-1831) erected a high breast wheel utilizing a special design developed by Jacob Perkins to reduce backwater problems at the cotton textile mill built at Waltham, Massachusetts, from 1813-1814. In 1824, Eli Whitney recommended that the undershot and tub wheels being used at the Springfield Armory be replaced by several large breast

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[32] Hunter, vol. 1, *Waterpower in the Century of the Steam Engine*. The horsepower estimate is from email correspondence from Jay Boeri to John Johnson, September 11, 2009.

[33] Terry S. Reynolds, "The Emergence of the Breast Wheel and Its Adoption in the United States," in *The World of the Industrial Revolution: Comparative and International Aspects of Industrialization*, ed. Robert Weible (Andover, MA: American Textile History Museum, 1984), 55-56, 62-63.

wheels, "and by 1830 breast wheels had become the standard prime mover in textile mills all over New England." Perhaps the pinnacle of American breast wheel construction was achieved at Lowell, Massachusetts. The first of these breast wheels was installed in 1823, and by 1850, the Lowell textile mills had well over 100 breast wheels in operation. The Lowell, Massachusetts, engineer James B. Francis (1815-1892) observed in 1855 that "the waterwheels in use in the principal manufacturing establishments in New England were (prior to 1850) what are generally called *breast wheels*, sometimes know also by the name of *pitch back wheels*."[34]

In the early nineteenth century, the traditional process of erecting a waterwheel was known as "wheel setting." Construction of an 18' diameter breast wheel required several woodworking skills, including cutting, shaping and joining wood, as well as metalworking capability.. The wheel was built in place, piece by piece. After the wheelpit in the basement was hand dug, the walls were lined with fieldstone and the floor was covered with thick wood planks set on wood sleepers on the bottom of the pit. The curved space between the water box and the wheel was then enclosed by a continuous barrel-like surface of planks called the breast, or apron. The breast was secured to the stone walls and the plank floor. After each curved timber rib of the breast had been set into place, the ribs were tied together with a layer of thick planks. Next, the heavy, cast-iron shaft (axle) that would carry the weight of the wheel was suspended above the wheel pit and then balanced and leveled on bearing blocks. Both rims of the wheel, composed of thick wooden segments called felloes, were then constructed at each end of the shaft. Diagonal supports of wrought-iron tie rods held the shaft to these rims. The projecting cylindrical ends of the cast iron shaft, called journals, revolved in cast iron bearings (lined with brass seats) and were fitted with a lubrication hole on the top. The bearings were bolted onto wood beams, set on blocks of granite on the east side and blocks that were possibly wooden, but have since been removed, on the west side of the wheelpit. The shroud (rim boards) tied the sides of the wheel together and also served as the side of each bucket. Next, a series of carefully measured grooves were cut into the inside faces of the felloes to receive the soal boards. Soals ran the length of the wheel between the rims and provided the wheel with increased stability by binding both rims of the wheel rigidly together and also served as the back of each bucket.

The last pieces of the wheel to be assembled were the two-piece wood buckets. Before each bottom soal board was slipped into its grooves, holes were drilled through each board and covered on the inside with small leather flaps. These air holes acted as valves, which automatically closed as water entered each bucket. The valves would open again as the water left the bucket, preventing the formation of a vacuum in the bucket as it rose from the wheelpit. This was necessary because a vacuum would hamper the exit of the water and in turn slow the rotation of the wheel. Floatboards were installed between the rims and together with the soal boards formed a two-sided bucket. Water from the water box was released by a manually operated gate with a rack and pinion mechanism,

[34] John P. Johnson, "David Wilkinson: Father of the Machine Tool Industry," (M. A. thesis, Bridgewater State College, 1978), 35; Reynolds, 69-70, 73-74; James B. Francis, *Lowell Hydraulic Experiments* (Boston: Little, Brown, and Company, 1855), 1

and entered each bucket above the level of the central shaft of the wheel. Gravity pulled the water-weighted buckets down causing the wheel to rotate counterclockwise. After exiting the buckets, water descended on the wood-lined floor and flowed under the arch on the north wall and into the brook. The constant wetting and drying of the wheel caused the wooden rim to deteriorate more quickly than the buckets, but the use of seasoned white oak prolonged life expectancy. Inspecting the wheel daily, greasing the bearings with lard or tallow, and making small adjustments when necessary were required if a wooden wheel was going to provide efficient and long service.[35]

During HAER's investigation of the existing gearing frame, the field team noticed semi-circular scratches on the upright member of the wooden frame. These surficial markings were approximately ½" deep and led the team to calculate the diameter of the original waterwheel at 18'. The field team surmised that these markings were either from an initial testing of the wheel and were made by the perimeter gear because the wheel was not yet perfectly level, or that the markings were just normal wear after many years of operating with accumulated debris, bearing wear and/or loose parts. The east side of the wheel rubbed against the wood frame, leaving wear marks.

Museum Trustee Eric Gilbertson conducted an excavation of the original headrace that confirmed its location on the west elevation of the building. Water from the dam entered the headrace and flowed about 35' south to a corner point about 38' west of the building. Here the headrace made a right angle turn (90 degrees) and ran east about 38' to the west elevation of the building. At this point, the headrace entered the basement of the building through an opening in the west wall, 11' feet from the southwest corner. Gilbertson's excavation revealed that the headrace near the building was about 5' to 6' wide and about 9' deep, with side walls of mortared rubble stone. The headrace was cut through the stone ledge and presumably constructed in this configuration to avoid a large outcropping of ledge immediately north of the headrace, about 19' west of the building. All evidence of wood sides, or a wood penstock in the headrace have been removed. The archway through the west wall has also been altered and is not evident from the interior.[36]

Millwork: The Distribution of Mechanical Power in the Armory

The potential water power of the Mill Brook was mechanically distributed through millwork that linked the factory with machines that were operated by the machinists. Millwork in the Armory consisted of the *in situ* gearing frame and several essential items that have been removed: gears, shafts, pulleys and belting. The following

[35] Zachariah Allen, *The Science of Mechanics* (Providence, RI: Hutchins & Cory, 1829), 197-217; Frederick Overman, *Mechanics for the Millwright, Machinist, Engineer, Civil engineer, Architect and Student* (Philadelphia, PA: E. Claxton, 1881), 303-313; Joseph P. Frizell, "Old-Time Water Wheels of America," *Transactions of the American Society of Civil Engineers* 28 (1893), 237-249; Robert A. Howard, "A Premier on Water Wheels," *Association for Preservation Technology* 15, no. 3 (1983): 26-33; Terry S. Reynolds, *Stronger Than A Hundred Men: A History of the Vertical Water Wheel* (Baltimore, MD: Johns Hopkins, 1983), see Table 3-5, "Order of Assembly for a Traditional Vertical Water Wheel," 164; David Macaulay, *Mill* (Boston: Houghton Mifflin, 1983).
[36] Eric Gilbertson, "American Precision Museum Head Race Excavation," September 29, 2009.

description is conjecture; however, it is derived from research in publications on traditional early nineteenth century practice, surviving waterwheels in Connecticut from the period of significance (1846-1856), as well as field examinations of restorations at industrial history museums. The manufacture and assembly of the millwork required numerous metal and woodworking skills, and the cast iron shaft and gears were made at the foundry across Mill Brook.

A governing device, most likely a fly-ball governor that was common in the 1840s, controlled the rotation of the waterwheel. A governor would control the raising and lowering of the gate on the water box just above the waterwheel, which controlled the flow of water into the wheel and therefore the speed at which the wheel rotated.[37] Governors of this type were common; however, there is no evidence, either *in situ* or documentary, to suggest the type or size. A standard treatise (1909) on millwrighting stated that "there has not yet been perfected a waterwheel governor which will keep the speed within 2.5% under all variations of load. . . because the water gate can't be opened or closed quick enough to permit of the quick regulation of speed within the stated limit."[38]

The central shaft, probably a bolted cast iron polygonal form, of the waterwheel rotated on bearings located at either end of the shaft.[39] Since the operation was a low speed (usually 6-10 rpm), bronze bearings were quite satisfactory, even desirable. Bearing life is a factor of the shaft remaining in alignment and being properly lubricated. These bearings were mounted on wood beams that rested on the existing granite block sleepers partly buried in the dirt floor (*in situ* on the east side and removed on the west side of the wheelpit). Sections of a cast iron gear were installed in segments outside the rim of the waterwheel (on the east side). When the wheel revolved, the teeth of this segmental gear turned a smaller gear called a pinion gear. The pinion gear was attached to a horizontal shaft that extended to the gearing frame (mostly still intact). At the frame, the horizontal shaft was held in place on two bearing blocks (evidenced on the diagonal members of the gearing frame) and this shaft held a large wooden drum that was approximately 4' wide and 7' in diameter. A long, single leather belt or multiple leather belts traveled up through the ceiling of the basement to line shafting on the first floor of the factory. As mentioned earlier, an estimated 50 horsepower (hp) was delivered to the line shafting and available for the operation of individual wood and metal working machines.

On the first floor, the leather belt engaged a pulley fixed on a horizontal line shaft. This main horizontal shaft ran the length of the ceiling and was supported by cast iron brackets that were attached to the bottom of each ceiling beam. From the main shaft on this floor, power was distributed from cast iron pulleys via leather belts to pulleys on parallel line shafts. From pulleys on these line shafts, belts extended downward to individual machines on the factory floor. Power may also have been distributed from the

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[37] Malone, *Waterpower in Lowell*, 15-17.
[38] James F. Hobard, *Millwrighting* (New York: Hill, 1909), 379-380.
[39] Suggested by Charles Parrott from wheels at Wilkinson Mill, Pawtucket, RI and Lowell, MA.

main horizontal shaft on the first floor, upward through the ceiling, to run machines on the second floor; "in addition to pulleys for taking and receiving motion from the line shafts there were hangers for supporting shafts and countershafts, couplings, bearings and devices such as fast-and-loose pulleys and clutches for engaging and disengaging the driven machines, step or cone pulleys for changing speed ratios at the machines, lubricating devices and the like."[40] Power could not typically be distributed effectively over 100', the length of the Armory, because large amounts of gearing increased the amount of friction produced and decreased the amount of power available to the machines.[41]

Woodworking machines (lathes and copy lathes) and metal working machines (drill presses and milling machines) were installed on the first floor where operators worked at parallel rows of belt driven machines to manufacture precision parts for various rifles and guns. On each floor workbenches lined the exterior walls, or were placed perpendicular to them, to gain direct daylight for assembling rifles. In addition to workbenches, the upper two floors may also have provided space for drafting tables, pattern-storage and an office. Millwork throughout the factory, however, was not without problems: "costly in installation, troublesome in maintenance and repair, hazardous in use, and absorbing substantial power in operation, the traditional transmission equipment was tolerable only in the absence of a feasible alternative." The gears, shafts, pulleys and belting were also a common source of industrial accidents.[42]

Operation of the Robbins & Lawrence Armory, 1846-1856

After the Robbins & Lawrence Armory (R & L Armory) had been completed in 1846, the Windsor Grand List increased the real estate value of the properties from $2,040 in 1845 to $12,546 in 1846.[43] During the period of historic significance for the Armory, 1846-1856, the Armory and the Machine Shops would see company reorganizations, expansions and challenges. Here machinists employed a form of "Armory practice," which included the use of hardened iron gauges for quality control and inspection, a well-organized use of special purpose powered equipment, a division and specialization of labor, and a highly skilled workforce principally trained through apprenticeships to make interchangeable, dimensionally uniform products. Typically, machinists made their own equipment and machines. They also sold duplicate machine tools, as part of a diversified machinery business, to other machine shops and other armories, such as the Springfield Armory. Occasionally, improved or new equipment represented a quantum leap in metalworking capabilities, but incremental changes predominated. Most of the daily work at the benches was still hand filing of parts to obtain a precise fit of the lock, stock and barrel, but machine work (milling, slitting, profiling, boring, rifling, turning and drilling) was introduced as these mechanics strived

[40] Hunter, *Waterpower in the Century of the Steam Engine*, 473.
[41] Bradley, 92-95.
[42] Louis C. Hunter and Lynwood Bryant, *A History of Industrial Power in the United States, 1780-1930*, vol. 3, *The Transmission of Power* (Cambridge, MA: MIT, 1991), 118-120.
[43] Windsor Grand Lists, 1845 and 1846, Town Clerk's Vault, Town of Windsor, Vermont.

for "interchangeable parts." As the R & L Armory expanded operations and production, the waterwheel needed to be joined with the more reliable power of a steam engine. The US Army Ordnance contract of 1845 was a watershed in the development of the company. The Model 1841 percussion rifle and the Model 1842 percussion musket "were the first fully interchangeable firearms to be made in large numbers anywhere, one of the great technological achievements of the modern era."[44]

With the awarding of the Ordnance contract, the future of the private Armory in Windsor was linked to developments at the federal Springfield Armory in Springfield, Massachusetts. The Springfield Armory (1794-1968) was the primary center for the manufacture of US military small arms and the site of many important technological advances in gun manufacture. The federal contract system ensured a supply of firearms from private firms principally in the Connecticut River Valley (encompassing Connecticut, Massachusetts, and Vermont) and the Blackstone River Valley (encompassing Massachusetts and Rhode Island). The contract system required machinists to duplicate a model rifle, and government inspectors had to certify that firearms matched it and met standards established by the federal armory. A "community of practice" of entrepreneurs and mechanics emerged, establishing some private firms that continued into the twentieth century. This community of practice had started as early as 1828 in Windsor at the American Hydraulic Company. Owners and top mechanics used their wide-ranging social "networks" to share tacit knowledge about building metal parts and equipment and to share practical knowledge about organizing equipment in a production process. They experimented with a division of labor and with a mechanization of production through hand-powered equipment and water-powered machine tools. The federal armory "established a free-flowing network of knowledge exchange" with the private armories. A "community of practice" accelerated the adoption of technological innovations. Machinist networks, principally, and other venues such as patent disputes and technical publications, secondarily, constituted the main avenues for acquiring this knowledge. Firearms workers ranked among the most highly skilled and well-paid industrial workers. By about 1835 the Springfield Armory had developed a comprehensive practical gaging system for manufacture as well as inspection, and by 1845, "most of the machines, tools and skills needed to make large numbers of interchangeable small arms were in place." This federal Armory was a "clearinghouse" for the convergence and diffusion of metalworking technology in New England.[45]

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[44] Jacob Abbott, "The Armory at Springfield," *Harpers New Monthly Magazine* 5, no. 26 (July 1952): 13; Merritt Roe Smith, "Army Ordnance and the 'American System' of Manufacturing, 1815-1861," in *Military Enterprise and Technological Change* (Cambridge, MA; MIT, 1985), 64-65; Richard Colton, ed., *Forge of Innovation: An Industrial History of the Springfield Armory, 1794-1968* (Boston, MA: National Park Service, 2008), 21, 295.

[45] David R. Meyer, *Networked Machinists: High-Technology Industries in Antebellum America* (Baltimore, MD: Johns Hopkins, 2006), 73-103, 111, 217-239; Abbott, 145-161; Michael S. Raber, "Conservative Innovators, Military Small Arms and Industrial History at Springfield Armory," *IA: The Journal Of The Society For Industrial Archeology* 14, no. 1 (1988): 1-21; Merritt Roe Smith, *Military Enterprise*, 54; Colton, 19-20, 92; Felicia J. Deyrup, *Arms Makers of the Connecticut Valley: A Regional Study of the Economic Development of the Small Arms Industry, 1798-1870* (Northhampton, MA: Smith, 1948);

"Springfield was a center of technology sharing," as evidenced by the Springfield Armory loaning tools, patterns and skilled pattern makers and toolmakers, and performing services such as rolling iron. It shared knowledge of machine design, manufacturing techniques, gauging, and inspection methods. It learned from private firms, and private firms learned from each other. As a result, "the Armory supplied three services undersupplied by the market: information, labor education, and technology transfer."[46]

In the thirty years before the Civil War, twenty private firearms factories were established in the Connecticut River Valley and five in other parts of New England. When Robbins, Kendall & Lawrence Armory received the first Ordnance contract in 1845, the company distributed print advertisements in the Windsor region and used existing machinist networks in New England to spread the news about the construction of the new Armory. Employment in the Machine Shops soared from twenty-five workers to over 150 as machinists relocated to Windsor from the surrounding region and from leading firms such as the Eli Whitney Armory near New Haven in Connecticut, the Gay and Silver Machine Shop at North Chelmsford in Massachusetts, the Amoskeag Machine Shop at Manchester in New Hampshire, the Springfield Armory, and even as far away as the Harpers Ferry Armory in West Virginia, the only other federal armory.[47]

Francis Draper, superintendent of the Tyson Furnace, and Lycurgus C. Hammond established a large iron foundry in 1847, with a cupola furnace for casting stoves, directly across Main Street from the Armory at the Lower Dam. The 50' x 80' foundry was constructed of brick, and in 1849, it was valued between $3,000 and $4,000. G. Wardner (from 1855), Francis Draper (from 1869) and the firm of Harlow & Kelsey (from 1876) operated the foundry. The iron used here was transported from the Draper-owned ore beds, blast furnace and foundry in East Dorset, Vermont, because it was "peculiarly adapted. . .to the manufacture of machinery." This iron foundry supplemented the Armory's demand for special castings that may not have been available at their own Machine Shops or the Tyson Furnace in Plymouth.[48]

As early as 1844 a convention was held in Windsor to promote a railroad up the valleys of the Connecticut and Passumpsic Rivers. The Sullivan (a county in New Hampshire) Railroad was incorporated in 1846 and completed 24.3 miles of tracks in 1849 from Bellows Falls through New Hampshire to Windsor, crossing the Connecticut River just below the Cornish-Windsor Bridge. On February 13, 1849, the first passenger train of the Vermont Central Railroad ran 14 miles from White River Junction to Windsor.

Richard Greenwood, "A Landscape of Industry," in *Landscape of Industry: An Industrial History of the Blackstone Valley* (Hanover: Unversity Press of New England, 2009), 22.

[46] Ross Thompson, *Structures of Change in the Mechanical Age: Technological Innovation in the United States, 1790-1865* (Baltimore, MD: Johns Hopkins, 2009), 54-59.

[47] Deyrup, 121; Meyer, 243-254.

[48] *Vermont Journal*, February 16, 1849; Doton's Map, 1855; Child's Map, 1869; Sanborn Maps, 1876 and 1884; Rolando, 140-142.

The factories at Windsor were now connected to the commerce of Vermont and all of New England. A long spur track was laid south from the main line to the middle of "the works" on the north bank of the brook and was used for shipments of materials and freight. Samuel F. Belknap (1813-1849), the railway contractor, convinced Robbins & Lawrence to begin making railway cars. They incorporated as the Windsor Car & Rifle Company (1849-1850). About the time they finished the first car, Belknap announced that no cars could be sold to the Vermont Central, forcing Robbins & Lawrence to sell the cars to the Rutland & Burlington Railroad. In an 1890 letter to his son, Richard Lawrence said "it was a mistake in ever going into this business." He noted it became "a drain on the gun work and cramped us terribly." The company sustained "a total loss of $239,000 – all paid up out of the gun business."[49]

On March 22, 1848, Nicanor Kendall sold his interest in the gun factory and the car shop for $1,000 to Robbins & Lawrence. Afterwards the enterprise was known simply as Robbins & Lawrence (R & L). Kendall moved to Davenport, Iowa, and eventually returned to Windsor where he died in 1861.[50] By 1849 "the works" on the north bank was a beehive of activity and development increased from five shops in 1847 to eight shops in 1849. In addition to the Armory (a brick building measuring 40'x 100', standing three-and-a-half stories, and used as a rifle factory and machine shop), there was the "car shop" (a wooden building of about the same length and width as the Armory but not as tall), three "blacksmith shops" (constructed of brick, smaller than the Armory and containing a total of twenty forges and five trip hammers) were located on the south bank. Four other buildings of various dimensions and used for storage were situated on the north bank. By 1849, the Armory and "the works" were valued at $115,000.[51]

The construction of the Armory in 1846 did not include a steam engine, even though that emerging technology was available. In the late 1820s Daniel Copeland initiated the assembly of steam engines in Connecticut, and by 1846, there were six engine shops. The mechanic and inventor John Gore (1805-1880) of Brattleboro, Vermont, located 50 miles south of Windsor on the Connecticut River, had made steam engines since 1832. One of his engines was installed at the Windsor Prison (probably the first in town in 1835). Springfield Armory had purchased a 30 hp horizontal engine and boiler from Otis Tufts of Boston, Massachusetts, as early as 1843. Despite the extensive reservoir behind the Ascutney Mill Dam, water power was irregular and unreliable. Drought, floods and ice could either stop or seriously impede the operation of the waterwheel. As a result, only a certain amount of power could be developed at the Middle Dam. Among its deficiencies the wheel would "wear, decay, warp, and shrink,"

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[49] William J. Wilgus, *The Role of Transportation in the Development of Vermont* (Montpelier, VT: Vermont Historical Society, 1945), 70; Robert C. Jones, *Railroads of Vermont, Vol.1* (Shelburne, VT: New England Press, 1993), 73, 75, 171; Thelma Maddie Kistler, *The Rise of Railroads in the Connecticut River Valley (*Northampton, MA: Smith College, 1938), 19, 42, 59; Joseph Wickham Roe, *English and American Tool Builders: The men who created machine tools* (New Haven, CT: Yale, 1916), Richard S. Lawrence to Ned Lawrence, December 17, 1890, in Appendix A , 287.

[50] Hubbard, "Leadership," 173; Windsor Land Records, Vol. 20, 628.

[51] *Vermont Journal*, February 16, 1849; See also 1849, 1853 and 1855 illustrations; Windsor Grand Lists, 1846-1855.

and under conditions of intermittent use with alternate wetting and drying, it would loosen at the joints. It was estimated that "the power loss by friction in the wheel and gearing may well have totaled a fourth or more of that generated." In the early nineteenth century, water power still had an edge over steam power because of the engine's high acquisition, operating and maintenance costs, as well as the high cost of fuel to generate steam. As long as the demand for mechanical power at the Armory was still small, the wheel was simple to maintain and was a safe energy source, the waterwheel was the preferred option. There is no evidence to suggest that the original Armory wheel (dating to 1846) was an iron-wood hybrid, breast wheel or a cast-iron wheel; however, given the technological solutions available at this time, it can be speculated that the original wheel was an iron-wood hybrid waterwheel.[52] The Superintendent of the Springfield Armory reported in 1825 that wooden waterwheels would not last more than eight years without considerable repairs. A standard treatise on millwrighting stated that "old time wood construction used to last about 7 years before it needed to be repaired and by 10 years the whole thing had to be replaced with new material."[53] By 1849 the company had added an auxiliary steam engine in an addition on the east elevation of the factory and with the constantly expanding Machine Shops, "the works" became a state-of-the-art manufacturing facility. Certainly by 1856, or before, the original waterwheel had been repaired and was probably ready to be replaced or abandoned in favor of the more reliable steam engine.

Railroads were built throughout New England in the 1840s. Prior to the arrival of the railroad in 1849, the relatively remote Town of Windsor was not yet connected to the growing industrial sectors downriver in Springfield, Massachusetts and Hartford, Connecticut, as well as the distant Boston and the Albany regions. With the increasing demand by other companies for copies of their machine tools, the mechanics needed more power for production. The railroad brought a disassembled 20 hp steam engine, a large boiler, and necessary parts. The steam engine would supplement the irregular power supplied by the waterwheel and both were probably used at various times. The principals were eager to make the change because the deficiencies of waterwheels were common knowledge. In 1849 (or before the census of June 1, 1850), R & L had a Power House constructed on the northeast corner of the Armory. This expansion included a cordwood-fired boiler room, a steam engine room and a brick chimney (65'). These improvements first appear in the 1853 illustration. Long wooden roof trusses spanned the boiler and

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[52] For discussion of the reasons for the very limited use of stationary steam power in the late 1830s, see Louis C. Hunter, "Waterpower in the Century of the Steam Engine" in *America's Wooden Age: Aspects of its Early Technology*, ed. Brooke Hindle (Tarrytown, NY: Sleepy Hollow Restorations, 1975), 88-89, 172; Conversations with Patrick Malone and Charles Parrott.

[53] Hunter, vol. 1, "Waterpower in the Century of the Steam Engine," 89; James F. Hobart, *Millwrighting* (New York: Hill, 1909), 376; Louis C. Hunter, *A History of Industrial Power in the United States, 1780-1930*, vol. 2, *Steam Power* (Charlottesville, VA: Hagley Museum & Library, 1985), xix; Carroll W. Purcell, *Early Stationary Steam Engines in America: A study in the migration of a technology* (Washington. DC: Smithsonian, 1969), 103; Mary R. Cabot, *Annals of Brattleboro, 1681-1895* (Brattleboro, VT: Hildreth, 1922), 640-642; Michael S. Raber, *Conservative Innovators and Military Small Arms: An Industrial History of the Springfield Armory, 1794-1968* (Springfield, MA: Springfield Armory, 1989, edited in 2006), 191.

engine houses, eliminating interior columns. The separate boiler house kept the wood smoke produced by the stoking of boiler fires away from the machinery and gauges of the engine room. The square, brick chimney produced a steady draft that facilitated the combustion of firewood and gases. The Armory had joined the ”century of the steam engine” because the new technology provided flexibility of capacity, flexibility of location and all season reliability. The manufacturer of the horizontal steam engine first installed at the Armory is not known; however, this may be the same “20 horse power” stationary steam engine offered for sale by R & L during the reorganization of the company in August 1856. Museum founder Edwin Battison speculated that the first engine was similar to a type made by Woodruff & Beach of Hartford, Connecticut.[54]

In November 1849, Robbins and Lawrence, along with Shubael Wardner, Joseph D. Hatch and Warren Currier formed the Windsor Car and Rifle Company. In 1849 it was reported that “a large variety, as well as quantity, of machinery is employed in these manufactures, and its wonderful ingenuity and exquisite finish constitute a theme of admiration and applause to all who have witnessed its operation.” When R & L reclaimed the Robbins & Lawrence Company name in November 1850, the Armory and Machine Shops were at full production with a labor force of 150 workers that collectively earned an average of $6,665 per month. “The works” used raw materials that included iron and steel (260 tons), car wheels (800), copper (10 tons), charcoal (470 tons), lumber (230,000 board feet) and other articles, for a total value of $60,150. It produced rifles (9,500 valued at $114,000), railroad cars (120 valued at $54,000), machinery (valued at $9,000) and miscellaneous items (valued at $4,000) for a total value of $181,000 for their products in 1850. At this time an inventory of machine tools and job categories at the Armory and Machine Shops was probably similar, although fewer in number, to the inventory of tools (1851) and personnel (1852) at the much larger Springfield Armory.[55]

The 1850 Federal census of population (the first census to list occupations, professions and trades) enumerated individual men working in Windsor Village and at the Armory. This census includes the traditional occupations of blacksmith, brick maker, cabinet maker, cooper, printer and wheelwright. There are also numerous “artisans” listed, who were most likely operatives at the Armory. Other relevant professions included contractor, engineer (probably employees of the new railroad company in town), brass founder, iron founder, manufacturer, mechanic and molder. In the 1850 Federal Census of Manufacturers men in Vermont declared themselves as gunsmiths (22), machinists (213), mechanics (633), millwrights (140) and tool makers (57). Twenty-seven year old Frederick W. Howe (1822-1891) declared himself a “machinist.” Most interesting are the occupations of four men as “government inspectors” that were working at the Armory for a yearly salary of $800 and were employed by the Ordnance Department in Washington or the Springfield Arsenal inspecting rifles at the Armory.[56] Private contractors, as well

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[54] Presdee & Edwards, *Map of Windsor, Vermont*, 1853; Edwin Battison, “Woodruff & Beach Steam Engine,” *Tools & Technology* 9, no. 3 (1991): 22-24.
[55] *Vermont Journal*, February 16, 1849; Census of Manufacturers, 1850, Windsor, Windsor County, Vermont; Raber, 344-345.
[56] The 1850 Federal Census of Population gives their names as Mr.’s Harris, Patch, Chapman and Cooley.

as federal administrators, regularly corresponded, visited, and assisted one another in "working out the basic configurations of the uniformity system." The Ordnance Department's "open door" policy also insisted that the federal armories open their shops to visitors, who could make drawings, borrow patterns, and obtain other information pertinent to their special interests. This government practice led to the diffusion of information throughout the growing fire arms and machine tool industries. This reciprocity was "the key to the fellowship of machinery-firm managers and a potent force for the dissemination of knowledge."[57]

New England labor historian David A. Zonderman has written that "the machinist was a kind of industrial artisan, a human link between the two worlds of mechanized industry and craft labor, striving to balance his work life between the demands of traditional skills and the new possibilities of mechanized production." Machinists at the Robbins & Lawrence Armory and throughout the "machine tool network" of New England were often a key source of technological innovation as they saw problems in production and tried to develop new devices for solving those difficulties. The most skilled machine-builders were often inventors trained through careful observation and constant tinkering rather than theoretical education. Worker-inventors, if they were fortunate to retain legal control and patent rights over their new ideas and inventions, could use the new machines they devised as a means of upward mobility from employee to entrepreneur. Economic historian Ross Thomson has written about the experience of workers at Robbins & Lawrence, such as Joseph D. Alvord, Charles Billings, Frank Chase, George Fairfield, Frederick Howe and George Hubbard who were "trained machinists who left to make machine tools, hardware, screws, textile machinery and other machines."[58]

Industrial historian Donald R. Hoke challenged the prevailing theme that the adoption of the "American system of manufactures" deskilled the craftsman and reduced him to the level of a machine operative. Hoke pointed out that the new technologies required additional skills, including "invention, production, maintenance and repair" and that the "factory operatives running automatic or semi-automatic machine tools developed different skills than their craftsman fathers, but they were still very skilled people." In challenging the "Armory practice" theory, Hoke argued that the American system was "primarily a private sector phenomenon, the end result of mechanics and entrepreneurs joining together and taking risks. It was not merely the result of federal government military research and development that spread from the armories to the private sector." In his study of the "ingenious Yankees" of New England, the "mechanics

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[57] Federal Census of Population, 1850, Windsor County, Windsor, (Vermont Historical Society); Federal Census of Manufacturers, 1850, State of Vermont; Merritt Roe Smith, *Military Enterprise*, 76-77**;** Peter Temin, *Engines of Enterprise: An Economic History of New England* (Cambridge, MA: Harvard, 2000), 119.

[58] David A Zonderman, *Aspirations and Anxieties: New England Workers and the Mechanized Factory System: 1815-1850* (New York: Oxford, 1992), 53-61, 99; Ross Thomson *Structures of Change in the Mechanical Age: Technological Innovation in the United States, 1790-1865* (Baltimore: Johns Hopkins, 2009), 97, 148, 268-269.

and engineers stand out as the agents of technological change," and "the interaction between the mechanic and the entrepreneur is the critical relationship in nineteenth-century technological change and hence economic growth." At their private armory, entrepreneurs like Robbins provided capital and marketing skills while mechanical engineers like Lawrence supplied the technical know-how and the new ideas.[59]

In 1851 Robbins & Lawrence sent a representative with six Army Mississippi-style rifles equipped with the interchangeable system to the Great Exhibition of the Works of Industry of all Nations, held in Hyde Park, London, England,. The rifles were exhibited at the famous Crystal Palace and "excited great interest." Robbins & Lawrence received a medal for their rifles. The exhibit led to a parliamentary investigation into the development of labor-saving machinery in the United States. The English Committee visited many American industries in 1854, including the Springfield Armory and the Sharp's Armory in Hartford, Connecticut. The Sharp's Armory was built as the city's second fire arms company three years after the Colt Armory. The two-story, brick Sharp's Armory was constructed in 1852 and managed from 1852 to 1856 by R & L. The Armory manufactured Sharps Breech-loading Carbine and Rifle using Christian Sharps' (1811-1874) rifle patent (1848) until 1875. Lawrence led a tour of the new Hartford factory and disclosed that the gun machinery was actually made at the Armory in Windsor. The committee next visited Windsor, and R & L received a $23,585 contract for rifles and gun machinery, which was installed in the government-owned Royal Small Arms Factory (1818-1988) in Enfield at the north end of London. This factory "became a virtual duplicate of the American System." R & L also received a $5,121 contract for wood working machinery to be installed at the Royal Carriage Department. These developments led to the adoption of American equipment and manufacturing practice in British arsenals. The English, "through an examination of American products, with productive methods which seemed so novel and original that they promptly," named the methods the "American System of Manufacturing." Industrial historian Nathan Rosenberg has written that R & L "made many seminal contributions to the development of American machine technology in spite of its rather chequered financial history." As the key element of this system, "it was almost impossible to make interchangeable parts without extensive power-driven machinery embodying a great deal of transfer of skill" like that perfected by machinists at the R & L Armory.[60]

Company president Samuel Robbins reported in 1854 to the stockholders that the company was operating with four departments: gun, pistol, machine and car shops, and

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[59] Donald R. Hoke, *Ingenious Yankees: The Rise of the American System of Manufacturers in the Private Sector* (New York: Columbia, 1990), 12, 21, 35, 258, 266, 267 note 7.

[60] Roe, *English and American Tool Builders*, 191-192; Nathan Rosenberg, *The American System of Manufactures* (Edinburgh: University Press, 1969), 5, 61, 103, 115, 183-186; Russell I. Fries, "British Response to the American System: The Case of Small-Arms Industry after 1850," *Technology and Culture* 16, no. 3 (July 1975): 378, 386; Merritt Roe Smith, *Harpers Ferry Armory and the New Technology: The Challenge of Change* (Ithaca, NY: Cornell, 1977), 19, 281 footnote. For a broader understanding of the "American System" see David A. Hounshell, *From the American System to Mass Production, 1830-1932: The development of manufacturing technology in the United States* (Baltimore, MD: Johns Hopkins, 1984), 15-65.

that "the business and accounts of each being kept separately." The machinery, tools and material in the shops (including a fifth, the forging shop) were valued at $133,745.04 and combined with other assets totaled $153,292.60. The report also noted, "with the exception of the car department, the business of which is necessarily somewhat fluctuating, our shops have always been filled with business."[61] In 1855 "the works" included the Armory and Machine Shops (valued at $20,000), a double dwelling house ($1,700), a new, four-story boarding house ($2,000) for the convenience of their single workmen and those without houses in town, and a small house on the corner of River Street ($300); for a total in the Windsor Grand List of $23,000. The decade of historical significance for the famous Armory came to an end in 1856. Ordnance orders could not be completed and money had been lost on the car shops venture. These financial troubles forced R & L to sell the company in January 1856.

The Legacy of the Robbins & Lawrence Armory

Yale University mechanical engineering historian Joseph Wickham Roe (1871-1960) wrote a pioneering study in 1914 on the history of the American machine tool industry. Roe claims that "of all the older shops none had a greater influence than that of Robbins & Lawrence, Windsor, Vt., on the development of modern machine tools and specialized forms of them." In Roe's classic 1916 work, *English and American Tool Builders*, genealogical charts of individual machinists trace the "main lines of influence from the old shop at Windsor" to many of the formative industrial companies of nineteenth century America. Windsor industrial historian Guy Hubbard published the "Development of Machine Tools in New England" in a series of twenty-three articles in the trade journal *American Machinist* from 1923-24, as well as a more extensive genealogy of the industry that codified the enormous legacy of Robbins, Kendall & Lawrence. However, the genealogies of Roe and Hubbard must be verified with other sources because they are for the most part undocumented and seemed to be based largely on reminiscences. The Connecticut Valley small arms industry historian Felicia Johnson Deyrup wrote in 1948 of R, K & L, that "as a firm it was outstanding for the many expert mechanics who it trained and who later scattered throughout New England and played an important part in the development of arms manufacture and kindred industries, particularly the machine tool industry." For the 1830-1860 period Robbins & Lawrence was typical of the successful, though short-lived firm, while the Colt Patent Fire Arms Manufacturing Company of Hartford, Connecticut and the Ames Manufacturing Company of Chicopee, Massachusetts were examples of the highly successful, long-lived corporations. The Armory at Windsor contributed significantly to what came to be called the American system of manufacture as Armory "workers gradually abandoned the task-oriented world of the craft ethos and reluctantly entered the time-oriented world of industrial capitalism."[62]

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[61] *Report of the Directors of the Robbins and Lawrence Company, to the Stockholders* (Windsor, VT: Chronicle Press, 1854).

[62] Roe, "Early American Mechanics - - Robbins & Lawrence Shop," *American Machinist*, October 22, 1914, 729-734; Roe, *The Tool Builders* 186-201 Guy Hubbard, "Early Gun and Tool Making at Windsor," *The Vermonter* 23, no. 2 (1918): 40-43; Guy Hubbard, "Development of Machine Tools in New England,"

Joseph W. Roe credits "three brilliant engineers," Richard S. Lawrence (1817-1892), Frederick W. Howe (1822-1891) and Henry D. Stone (1815-1898). These men combined their talents to design, invent and patent machine tools at the Armory during the period of significance.

Richard Lawrence joined Nicanor Kendall as a gunsmith and became his business partner in Windsor in 1843. They were joined by Samuel E. Robbins and formed Robbins, Kendall & Lawrence in 1846. The partners operated the Machine Shops and built an Armory. Lawrence designed barrel drilling machines, rifling machines and a plain milling machine, as well as a process of lubricating bullets with tallow (1850). In 1856 Lawrence left Windsor for good and became master armorer at the Sharps Rifle Company factory in Hartford, Connecticut, where he manufactured Sharps carbines and rifles and patented breech-loading firearms.[63]

Frederick Howe joined the Armory in 1847 as assistant machine tool designer to Lawrence, was promoted to factory superintendent in 1848, and worked there for nine years. Howe designed a profile machine used in all the early gun shops in 1848, a barrel drilling and rifling machine that same year, and the first commercially successful universal milling machine in 1850. He also patented a metal planer in 1853. Howe exhibited rifles built on the interchangeable system at the famous 1851 London Exhibition and supervised the design and construction of gun building machinery for the British government from 1853 to 1856. Following the breakup of the Robbins & Lawrence Company, Howe left Windsor and later became superintendent of the armory for the Providence Tool Company before joining Brown & Sharpe Manufacturing Company in Providence, Rhode Island.[64]

Henry Stone learned the traditional millwright's trade in Woodstock, Vermont, before joining R & L. Stone collaborated with Lawrence in the development of a vertical turret lathe in 1855. E. G. Lamson, A. F. Goodnow & B. Buchanan Yale acquired the Armory in 1858 and retained Stone as their mechanical expert in the manufacture of machine tools, carbines, rifles and sewing machines.

Development of the Factory after 1856

Upon the dissolution of the Robbins & Lawrence partnership in January 1856, the company was sold to Charles Fox and John Henderson, both of London, England, and they sold the enterprise to Lt. Col. Henry Sebastian Rowan in June 1856. The reorganized

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American Machinist 59-61 (1923-1924); Deyrup, 122; Peter G. Smithurst, "The guns and gun-making machinery of Robbins and Lawrence," *Royal Armories Yearbook*, 7, 2002, 66-76; Merritt Roe Smith, *Military Enterprise*, 83..

[63] American Society of Mechanical Engineers (ASME), *Mechanical Engineers in America Born Prior to 1861: A Biographical Dictionary* (New York: ASME, 1980), 206.

[64] ASME, 180; Roe, *The Tool Builders*, 138, 143, 191-199, 207-209, 217, see also "Genealogy of the Robbins & Lawrence Shop," Figure 37, 187.

company was managed as the Vermont Arms Company and the Union Arms Company (1857-1859) led by Robbins, with former Armory workers, who leased the property to finish out the R & L rifle contracts. Lamson & Goodnow Manufacturing Company of Shelburne Falls, Massachusetts, purchased the Armory in 1858 and began to manufacture Windsor Sewing Machines designed by Henry Stone and Edwin Clark. In 1860 Lamson & Goodnow was the only sewing machine company in Vermont (out of twenty-two in New England) with forty-four men making 3,500 machines valued at $42,000. During the Civil War, Ebenezer G. Lamson (1814-1892) employed 500 men to manufacture rifles under the names Lamson, Goodnow & Yale (1858-1864) and E. G. Lamson & Company (1864-1865). After the war, the company was reorganized as the Windsor Manufacturing Company (1865-1870). An 1865 mortgage by the Windsor Manufacturing Company to the Windsor Savings Bank inventories the real estate and provides a detailed inventory of the machines at the Armory, many of which probably date to the period of significance (1846-1856). The company was reorganized in 1870 as the Jones & Lamson Company (aka Jones, Lamson & Co., 1870-1964) and continued to manufacture rifles, carbines and machine tools, as well as stone channeling machines for the granite and marble industries, small trip hammers, circular saw mills, punching presses, friction clutch pulleys, screw wrenches, etc., until they relocated to Springfield, Vermont, in 1888. Lamson sold the gun-making machinery in the Armory in 1870 to the Winchester Repeating Arms Company and, in association with Russell Jones, converted the building into the Jones, Lamson & Company Cotton Mill, which was in operation from 1870 to 1883. The historic Machine Shops on the north side of Mill Brook continued as Jones & Lamson Machine Company until 1888.

In the early 1870s, the original Armory building received a round, wood penstock that supplied water to a turbine waterwheel in a small addition on the north elevation (later removed). There were carding engines on the first floor, ring spinners on the second floor, mule spinners on the third floor and dressing machines and sprinklers in the attic of the main building. The three-story brick addition on the west elevation had weaving looms, a new brick addition on the east elevation had picking machines on the first floor and looms on the second floor, and the power house (steam engine room, boiler room and brick chimney) was expanded on the east elevation (later removed). The chief creditor of the cotton business, the merchant firm of Floyd Brothers of Boston, Massachusetts, continued to run the cotton mill from 1884-1888. The property was idle for about ten years until Windsor resident Frank A. Kennedy purchased it in 1898. Over the next three years Kennedy outfitted the building to generate electricity through a combination of waterpower and coal-fired steam equipment. Kennedy generated electricity from 1902-1926, and following his death his heirs sold the facility to Windsor Electric Company. Electricity generation ceased in the 1930s, but the property continued to be used as a transmission substation until operations ceased in 1965 when the American Precision Museum purchased the property.[65]

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[65] Windsor Land Records, Vol. 23, pp. 243, 330, 499; Guy Hubbard, "The Influence of Early Windsor Industries Upon the Mechanic Arts," in *Essays in the Social and Economic History of Vermont* (Montpelier, VT: Vermont Historical Society), 159-182; Horn, "From Nicanor Kendall to Jones & Lampson," 56; Federal Census of Manufacturers, 1860, Windsor County; "Windsor Manufacturing Company," Broadside,

Conclusion

The building was originally constructed as a private armory (1846-1856) and continued as an arms manufacturer, machine shop and sewing machine factory (1857-1870), a cotton factory (1870-1886), vacant (until 1901), a steam and hydroelectric power station (ca. 1902-ca. 1935), and a transmission substation (ca. 1935-65). The evolution of power systems in the building included the original waterwheel (1846), a steam engine (1849), a turbine (1870) and electricity (1902). The American Precision Museum (1966-present), a not-for-profit corporation that manages the building as a private machine tool museum dedicated to the legacy of the Robbins & Lawrence Armory, purchased the property in 1966. The goal of identifying, documenting, preserving and interpreting this legacy was the life work of Edwin Battison and because of his collecting efforts the story of this private Armory remains an important chapter in the industrialization of New England. Recently the museum has undertaken several projects to rehabilitate the former Armory, cotton factory and electric power station into a modern museum.

This HAER recording project documented the *in situ* remains of the original waterwheel, gearing frame and wheelpit of the building prior to any work to mitigate the chronic moisture problem in the basement. Today the wheelpit retains water year round, at levels that vary seasonally, allowing moisture to rise constantly throughout the entire building, adversely affecting the structure, the museum collections and interior air quality.

The date of the removal of the original waterwheel and gearing is unknown; however there was sufficient evidence to estimate its placement and operation. During a stabilization of the first floor (ca. 1980) several wood columns were positioned on the dirt-floor basement, as well as in the wheelpit, and these may likely remain, preventing a future restoration of the waterwheel in its original position. Although land west of the building has been disturbed, a preliminary excavation revealed the location and materials of the original headrace from the dam to the factory. The remains of the *in situ* water power system in the Armory are significant for what they reveal about the design and operation of similar installations in New England factories in the middle of the nineteenth century.

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c. 1865, available at Vermont Historical Society; Advertisement, *Vermont State Business Directory* (Boston, MA: Rand, Avery & Frye, 1870); Sanborn Map, 1876; Windsor Land Records, Vol. 28, 154, Vol. 30. 417 and Vol. 31, 329, Vol. 39, 363, 461, Vol. 48, 500.

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Images of the Armory

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Field photos by John Alexander, Eric Gilbertson, and Christopher H. Marston.

"Machine Shop Windsor," August 22, 1909. Photograph, Windsor Historical Society.

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"Windsor Manufacturing Company." Advertisement, *Vermont State Business Directory*. Boston, MA: Rand, Avery & Frye, 1870.

ILLUSTRATED APPENDIX

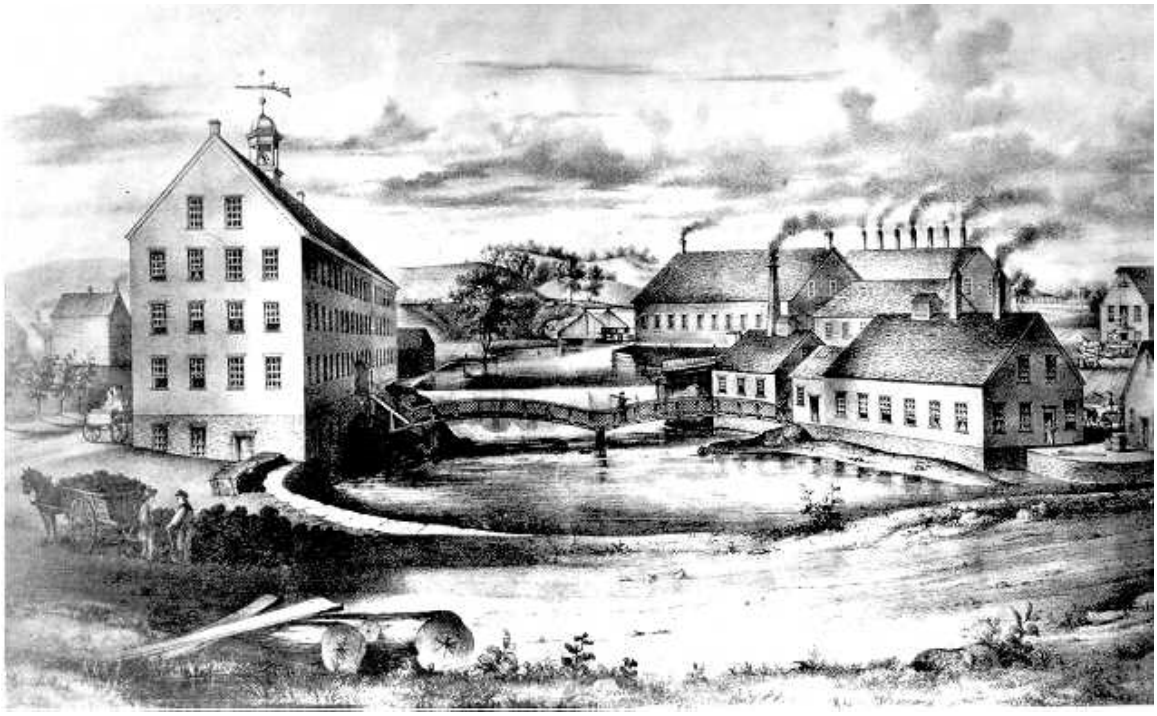

Figure 1. Robbins & Lawrence Armory, view west, 1849. The Middle Dam supplied water power for the breast wheel, the footbridge led to the machine shops and foundry, at right. Note rifle weathervane atop cupola (Ephraim W. Bouve, Collection of the American Precision Museum).

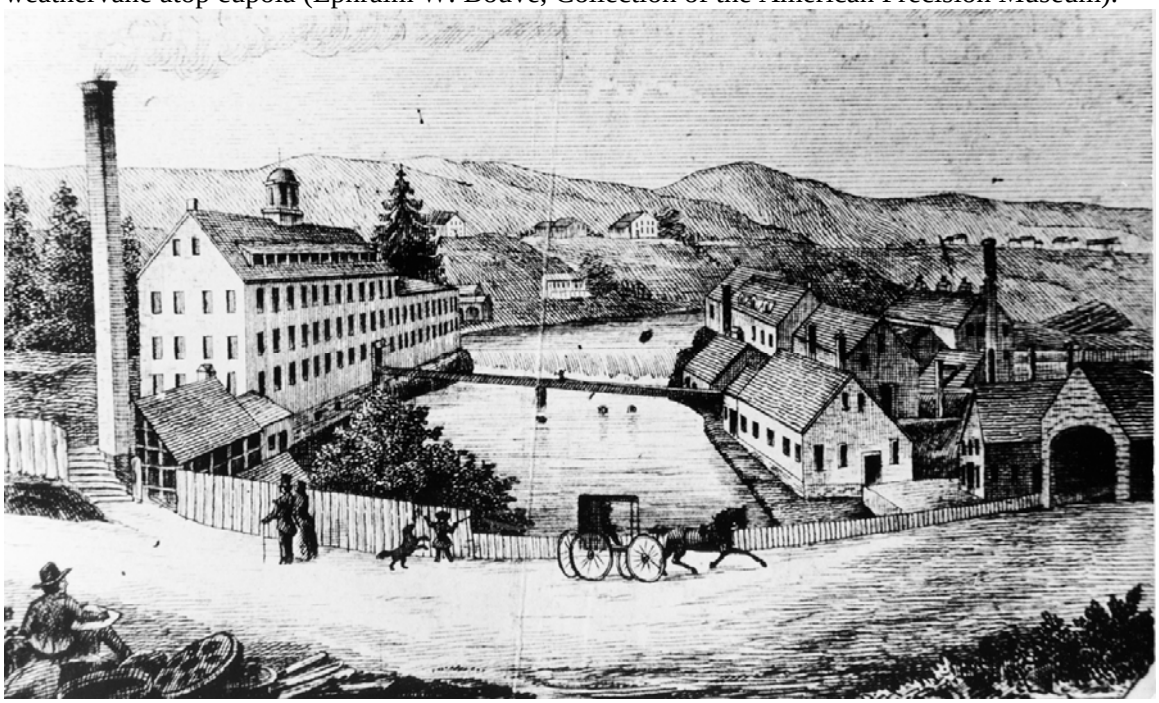

Figure 2. R&L added steam power by 1850, seen here with a steam engine house and stack in foreground, and two-story manufacturing addition in rear (Hosea Dotun, *Map of Windsor County*, 1855, Special Collections, University of Vermont).

Figure 3. View facing east, ca. 1865, showing machine shop complex on the left side of Mill Brook, the footbridge, and the Armory at right, with the two-story addition on the west end (Stereopticon, Special Collections, University of Vermont).

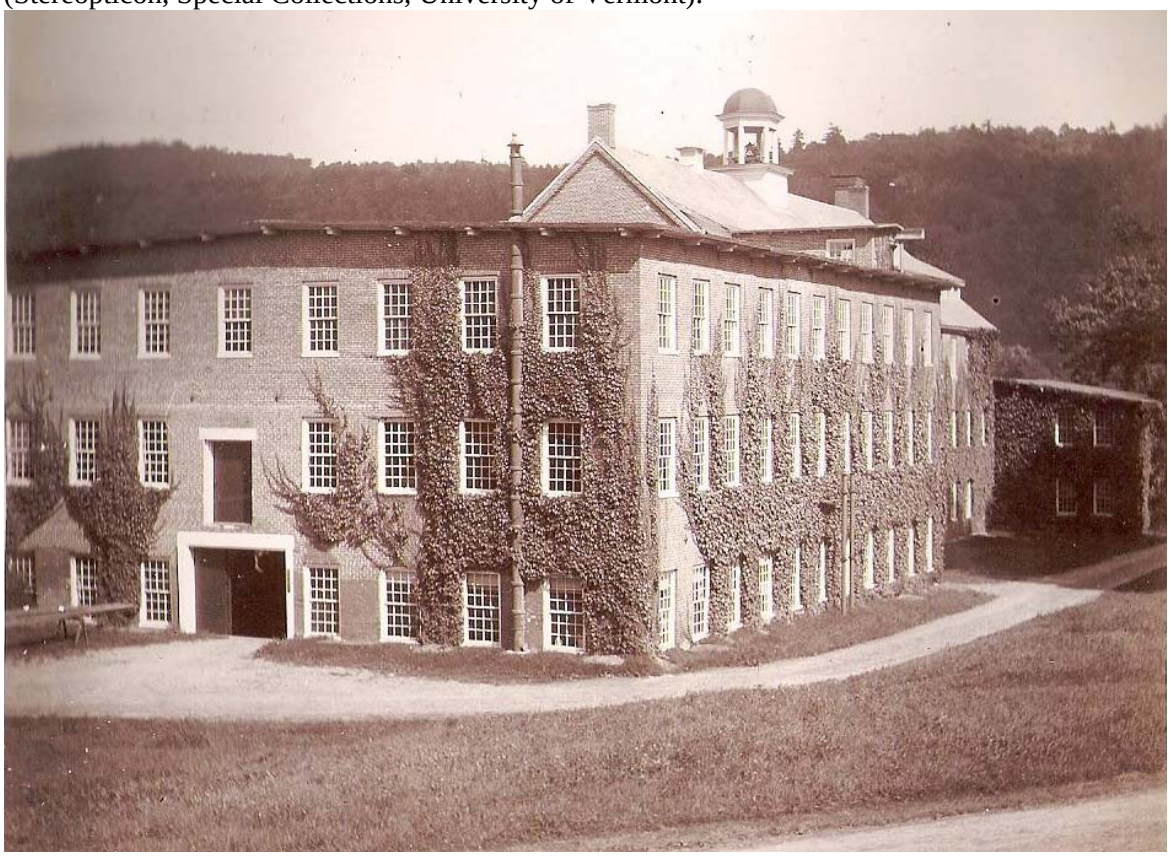

Figure 4. A third story was added to the manufacturing addition by Jones, Lamson & Co., ca. 1880. This view is from 1909, when owned by the Windsor Electric Light Co. ("Machine Shop Windsor," Windsor Historical Society).

Figure 5. The wooden penstock above, installed in the early 1870s, fed a water turbine which worked with a steam engine, housed in the steam engine house below, to power the site. (Sales Prospectus [ca. 1915], Windsor Historical Society).

Figure 6. Steam engine house in foreground, picker house at left (both added in the 1880s), shown ca. 1920 (Collection of the American Precision Museum).

Figure 7. West elevation of Armory, showing shadow lines of the roof of the two-story (ca. 1853) and three-story addition (ca. 1880). (Christopher H. Marston photo, 2009).

Figure 8. "Surficial markings" in the gearing frame, indicating an 18' diameter, show the location of the waterwheel (John Alexander photo, 2007).

Figure 9. Excavation at the west end revealed the location of the headrace (filled with water). The headrace measured 5' to 6' wide and 9' deep, and extended about 38' due west from the armory, where it made a 90 degree turn to Mill Brook, just above the dam (Eric Gilbertson photo, 2009).

Figure 10. Interior southwest corner of basement. The headrace entered at the back wall in the bay to the right, and came through an interior box flume. The flume then angled to the south wall at left, before following the south wall to the waterwheel pit (John Alexander photo, 2007).