ROBBINS & LAWRENCE ARMORY AND MACHINE SHOP

1846

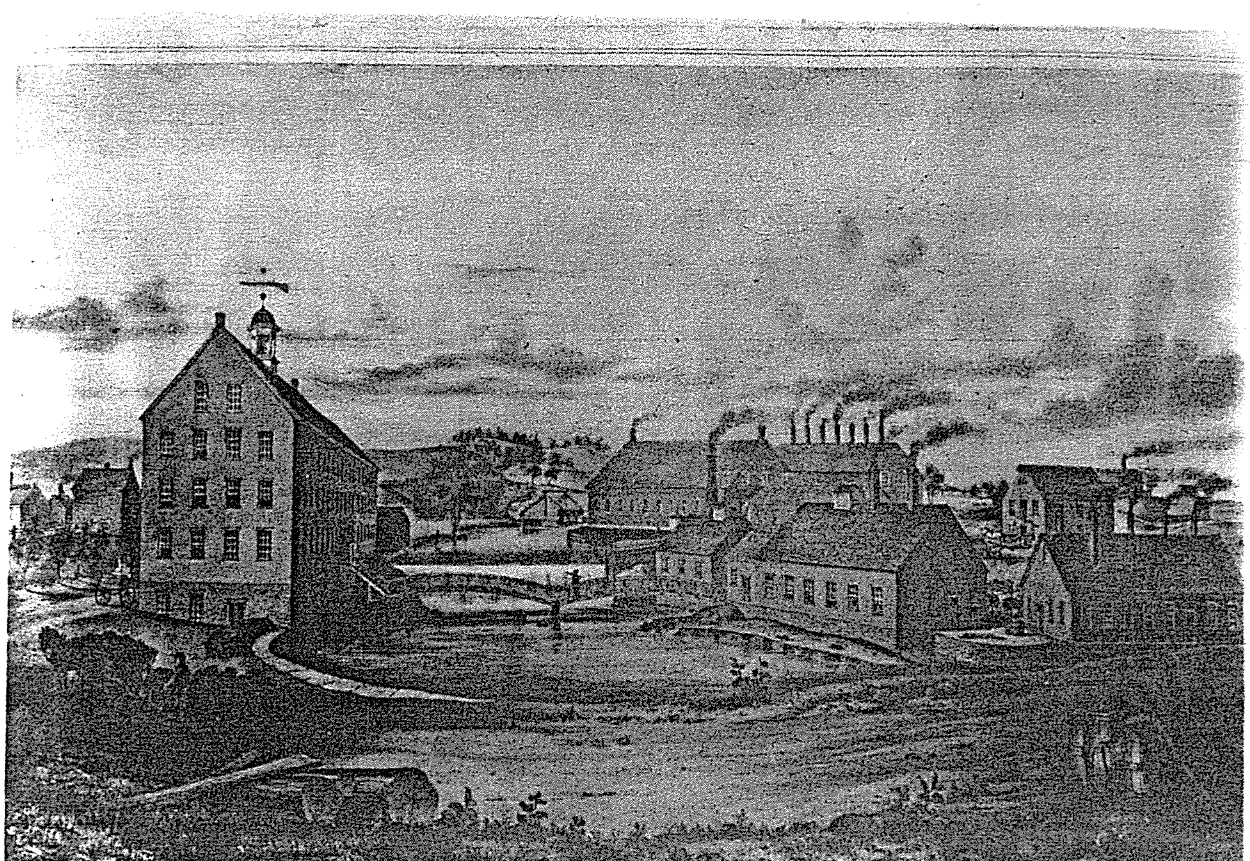
Windsor, Vermont

An International Historic Mechanical Engineering Heritage Site

and

An International Historic Mechanical Engineering Heritage Collection

THURSDAY, MAY 28th, 1987



The American Society of Mechanical Engineers

345 East 47th Street, New York, NY 10017

Copy for American Precision Museum brochure:

The artifacts at the American Precision Museum are designated the first International Mechanical Engineering Heritage Collection, and the Robbins and Lawrence Armory is designated the first International Mechanical Engineering Heritage Site in the ASME History and Heritage recognition program. In addition there are two national mechanical engineering heritage sites, 22 international mechanical engineering landmarks, 85 national landmarks and 9 regional landmarks.

ACKNOWLEDGMENTS

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Windsor, Vermont, rather far up the Connecticut River Valley, has played an inordinately prominent part in the industrialization of the nation. It is the place of origin for the first machine graduated rules, thus providing a uniform measuring tool for mechanics' use. This was patented by Lemuel Hedge, a local mechanic with several other patents to his credit, in 1827.[1] In this same year the favorable mechanical and financial climate, coupled with suitable waterpower, brought manufacture of the just invented Cooper "rotative piston" pumps to town.[2] This in turn sparked the invention of a gear pump by Ashael Hubbard, another of the local mechanics, in 1828.[3] Both of these pumps depended on closely fitted metallic gear surfaces to maintain suction so they called for an unusually high level of close machine work. Both companies were large producers of stationary and portable (fire engine) pumps. Then in the late 1830's Nicanor Kendall, son-in-law of Ashael Hubbard, began the manufacture of patented sporting rifles, pistols and shot guns on an extensive scale, with selling agents in Baltimore, New Orleans and St. Louis.

All of this refined mechanical activity set the stage for the manufacture which was to revise the way mechanical manufacturing has ever since been conducted: the Model 1841 U.S. Army Rifle.

The contract for these rifles lead to the creation of the most modern precision metal-working plant in the world, which soon found itself out of orders due to the end of the war with Mexico. This triumph was a long time in the making, and hundreds of minds contributed to it. The stimulus came from government support and partly from the contract system that gave an incentive to all parties to produce accurately and quickly.

Briefly: Military small arms were scarcely made in this country until a lot of 500 modeled on the British Brown Bess musket were made for the Province of Massachusetts Bay by Hugh Orr of Bridgewater, Mass. in 1748-1750.[4] From the completion of these to the outbreak of the Revolution in 1775 military arms making was not encouraged, but beginning then of course there was great demand. Far more of this demand was met by imports than by native made products. What native industry did develop during the Revolution in the various colonies ebbed away for want of support when peace returned.

The first efforts to revive native arms manufacture on a national scale were initiated by Thomas Jefferson. He, in 1785 was our Minister to the French court and participated in a demonstration of interchangeability made with cadet muskets just produced in a French Armory.[5] The tools for these were primative and tremendously expensive, still such success as the project had depended on the use of superlatively trained craftsmen.

Jefferson sent six of these muskets to our War Department where they served as an ideal devoid of any means of implementation. Jefferson had been unsuccessful in inducing any of the French workmen to emmegrate. Following adoption of the Constitution in 1789 and the consequent strengthening of the national government, Congress, in 1794, established an armory for small arms at Springfield, Mass.,one hundred miles down the Connecticut River from Windsor.[6] The next year 245 muskets were made, encouraging, but in view of the wars in Europe and the insecurity of transport from there, prudence dictated that quantities far in excess of this capacity were needed for security. Contracting seemingly offered government the only hope of quickly developing an adequate domestic industry. At one and the same time this was a challenge to the abilities of craftsmen and a prospect of making a good thing if they were successful. Sad to relate many of these contractors were never able to fully complete their contracts and few indeed had any concept of the inspection standards that their product would have to pass.

Jefferson's proposal that the arms be made interchangeable was not a part of these contracts either. Each contractor received a sample gun to reproduce, there were no drawings and the idea of dimensioned drawings was even more remote. There were no measuring instruments that could have accurately reproduced dimensions if they had been specified. Most of these contractors were scattered around New England, all of the states being well represented except what is now Maine, then a part of Massachusetts.[7] In general, the contracts were for small quantities varying from 200 to 2,000 among those who actually got into production.

One brash contractor, Eli Whitney, promised 10,000 in two years, all to be made by improved machinery. By his own admission this was an act of desperation:

> "Loaded with a debt of 3 or 4000 Dollars, without resources and without any business that would ever furnish me a support, I knew not which way to turn. An opportunity offered to contract for Manufacturing Muskets for the U. States. I embraced it. . . By this contract I obtained some thousands of Dollars in advance which has saved me from ruin."[8]

Thus did Whitney rescue himself from the collapse of the cotton ginning business and the debt incurred in defending his cotton gin patent. But still far from home safe Whitney required ten years instead of two to complete his 10,000 muskets. When the 2 years of his contract were about to expire and under threat that his contract would be cancelled, no guns were ready for delivery and all of the money advanced would have become due for repayment. In this desperate situation Whitney prepared 10 musket locks to fit one stock, called this interchangeability and demonstrated it to the Secretary of War, President John Adams, Vice President Thomas Jefferson, and other authoritative figures in the War Department, thus saving his contract. Fortunately for him there appear to have been no practical and critical observers familiar with the conditions prevailing in actual use.[9] Many complaints were lodged against Whitney muskets before the contract was finished as well as against later contracts. When this contract was completed a further contract was desired under the recently passed authorization by Congress of an annual appropriation of two million dollars for arming the militia, but was not granted. This in spite of such contracts being let to ninteen other bidders. There were two obvious reasons for this. The government had already discovered what Whitney could do both in respect to quality and delivery, and he offered a non-conforming model.[10] Better it seemed to them to stimulate others and discover what they could deliver.

The United States declared war on Great Britain on June 18, 1812 and Whitney immediately sought a second arms contract for his non-conforming model, and on July 18th received a contract for 15,000 muskets. All of these contracts of 1808 and Whitney's of 1812 were troubled by quality problems and poor guidelines at the time the contracts were made. Few contracts were completed. Whitney, who was to deliver at not less than 1,500 per year, commencing on May 1, 1813, and completion by the close of 1820, finally completed his delivery in July, 1822, or about one and a half years beyond the due date. Inflation and poor government inspections were complicating factors in all of these contracts.[11]

Meanwhile, Whitney's contremporary, Simeon North, born only five months before him, was well established in Berlin, Conn., about twenty miles from Whitney, as a pistol contractor. Pistols were just hand held versions of the muskets and North had completed four government contracts so satisfactorily that soon after declaration of the War of 1812 he was given a contract for 20,000 pistols. For this rush of business he moved to a new location and equipped a new factory. This was the first contract to specify the interchangeability of parts and included extra parts of those most commonly broken for use as replacements.[12]

Examination of pistols made under this contract reveals that the critical parts of the lock, heretofore always fitted together soft and marked so that after hardening they could be reunited in assembly, was eliminated. Inspection procedures were also improved in this period. The best thing about this new inspection program was that it was armory based. At Springfield Armory this meant that the New England area inspectors were working closely with a very able and dedicated Superintendent, Roswell Lee. The attitude of government was that all manufacturing improvements developed in the armories of the contractors were government property available to all others in the industry. The inspectors, noticing improved quality, often came to know of these improvements and some of the contractors, interested in improving their status, brought their improvements to the attention of government.

Such was the case with pistol maker, Simeon North. In 1816, when he thought his new factory was fully implemented (two years later he was to introduce the first milling machine) he requested that his achievements be reviewed by the superintendents of the two government armories, Springfield and Harper's Ferry.[13] Right after this was done we find Roswell Lee of Springfield Armory ordering a "cotton manufacturers turning engine" for turning musket barrels, and an improved water wheel, obviously on the basis of what had been seen at North's Armory in Middletown, CT. North was no longer marking the parts of his pistols because he was not fitting the parts individually. Parts were not as closely fitted under this system, but at least damaged arms could be repaired in the field simply by the replacement of the damaged parts by ready-made replacements. It would be many years before traditional U.S. small arms, with the exception of North's pistols, would meet this desireable end. There was, however, a non-traditional arm, the Hall breech-loading rifle, that was interchangeable from the first thousand completed in 1824. This arm combined the lock and chamber in one piece and these had to be moveable in relation to the body of the rifle for loading purposes and must return to correct allignment with the barrel before firing. It took considerable selling on the part of Hall and those in favor of his rifle, but he was eventually allowed to proceed with 1,000 pieces. The government, which earlier had made advances to contractors, had learned by this time the more or less futility of this method in the sense that in the case of marginal or unsuccessful contractors all the return to government was in the form of unsatisfactory products. If the contractor was successful he owned the means of production!

In the case of Hall, who was from New England, they required him to perform his work in Harper's Ferry, Virginia, where the government had established Harper's Ferry Armory in 1799. Thousands of Hall rifles and later carbines, were made with complete interchangeability, although the fitting was probably not closer than North's. Importantly the shape of the parts were much better adapted to machine production and Hall spent much time in producing machines before production of the rifles. He undoubtedly knew of all the latest achievements by others before commencing his own machines. Much to Hall's chagrin when he had well demonstrated the qualities produced by his system the government, against his will, took the next logical step, to determine if another armory could make the same rifle with parts that would interchange with Hall's. This opportunity fell to Simeon North, who in 1830 delivered arms that were acceptable although later improved in quality and interchangeability, but using somewhat different and advanced methods and machines.[14]

At this time the search for better manufacturing methods came nearly to rest and little was done again for a decade, except to improve armory equipment.

With the abandonment of the flint lock and the introduction of percussion lock small arms, a new level of precision was required. At this time also various contractors for flint lock arms, men well advanced in years, had no interest in the large investment necessary to conform to the new designs and new objectives in manufacturing standards. The two national armories at Springfield and Harper's Ferry were outfitted with the improved machinery as then known. This work was greatly facilitated by the introduction of the iron planing machine into American machine shops so that both the accuracy and economy of machine tool building was tremendously enhanced. Until this time linear surfaces such as guides and work tables had been produced by hand filing.

The first of the new arms in production was the U.S. Model 1841 rifle. Although the design originated with collaboration between the Harper's Ferry and Springfield Armories, production was another matter, even though the national armories had acquired numerous modern basic machine tools and were making and having made the special machines needed. One important impediment to converting the national armories was the resistance, both organized and tacit, to change on the part of the employees. To facilitate production contracts were let in late 1842 to Eli Whitney, II, who was operating the armory inherited from his father nearly twenty years before, and to John Griffith of Cincinnati. Griffith transferred his contract to Remington of Ilion, NY in 1845, as did N. P. Ames for the residue of a Jenks carbine contract and the machinery for making it. Before this Remington had been makers of sporting rifles and supplied barrels to many custom gunsmiths. From this date Remington was a U.S. contractor on many occasions. These contracts were small and in view of the slow delivery the war department opened up bids for 10,000 more of these rifles.[15]

The successful bidder at $10.90 each was Robbins, Kendall & Lawrence of Windsor, Vermont. Nicanor Kendall and Richard S. Lawrence had experience as custom gunsmiths while Samuel E. Robbins was a wealthy retiree from the lumber business and a recently arrived local resident. They received their contract on February 18, 1845, the work to be completed in five years at the rate of 2,000 per year. Their first move was to buy and/or build the necessary machinery. In April,1846 construction commenced on their three and one half story armory and machine shop, now dedicated by the American Society of Mechanical Engineers as an International Historic Mechanical Engineering Heritage Site. This is said to have been the largest armory in the country at the time, with the exception of the government armories. As events developed this was probably an injudicious investment considering the sporadic nature of the arms business. No doubt this investment also contributed to the achievements made.[16]

These are considerable: Delivery, which could have extended into early 1850, was completed in 1847, the only dates found on the rifles being 1846 and 1847. In 1847 this was ". . . the only Gun Contract finished within the contract time." Most importantly however, the quality of the work surpassed that of all others, including the national armories. None of the lock parts, always the most difficult to make interchangeable, were marked, yet fitted closely as required by the new and stricter standards. This achievement exceeded that of Springfield Armory where individual fitting of the lock components was continued into early 1849.[17]

The claim has been made that Ames, in what is now Chicopee, Mass., had made Jenks carbines interchangeably as early as 1842. Examination of these reveals however that "the serial number, such as '226' is on all major parts". This tip-off to lack of interchangeability does not occur on any of the Robbins, Kendall & Lawrence rifles, or on Springfield Armory products after early 1849, but does bear out the rejection by the Ames Co. of an interest as arms contractors with the government and the transfer of their machinery to Remington along with the unfinished contract.[18]

Soon after completing the contract so successfully for the 10,000 U.S. rifles, Messrs. Robbins and Lawrence bought out their partner, Kendall, the company name being changed to Robbins & Lawrence. Based on their past performance they received a new contract for 15,000 more of the same rifles on Jan. 5, 1848, to be delivered at the rate of 3,000 per year for the next five years. The treaty of peace between the United States and Mexico having been ratified on May 30, 1848, Robbins & Lawrence allowed completion of this contract to occupy the full five years permitted. This gave them a predictable income, and permitted them to hold on to a skilled labor force while they developed other products.[19]

Prior to 1849 there was no railroad through Windsor, but when this was anticipated Robbins & Lawrence began to manufacture railroad freight cars. For this they introduced a vertical boring mill by which they trebled the output over that of horizontal lathes previously used in boring the car wheels. They also built an innovative power press for putting the wheels on the axles on a taper without splining or keying. This proved car building to be a disappointing venture, not associated with the quality of the work. To make sales, stock in various pioneer railroads was taken in payment, which eventually proved to be worthless.[20]

But Robbins & Lawrence were out of their element in building railroad cars. When they first began the gun business they also began building "nice" machinery, principally for other gun makers. By the early 1850's, and no doubt earlier, "Robbins & Lawrence were the foremost builders of gunmaking equipment in the world".[21] It seemed obvious that they should stay in this business and this meant contracting to make some of the numerous arms being invented for the burgeoning market largely based on westward expansion, but there was always hope of further government contracts.

Their first venture in this line was the Leonard revolving hammer pistol, or pepper-box, as such multiple barreled arms were popularly called. The first part of this undertaking was a complete redesign of the pistol, both the general configuration and the operating mechanism. Thousands of these were made in two sizes, and several minor variations involving very slight tooling changes. In contract work it was normal to have a representative of the owner at the contractors factory as inspector. In the case of the Leonard pistol this representative was Daniel B. Wesson, later to become well known as the Wesson of Smith & Wesson.[22]

While work on these pistols was in progress Robbins & Lawrence were also contractors to make 5,000 of a repeating rifle with a tubular magazine. This developed around a bullet containing the propelling charge within it and fired by a percussion pellet supplied automatically from a separate magazine. Both the bullet and original rifle were patented by Walter Hunt, inventor also of the common safety pin. The rifle had enough defects to be unworkable, but was much improved by Lewis Jennings. At this stage all patents were sold to an investor, Courtland C. Palmer, for $100,000, who engaged Robbins & Lawrence as makers. Before the contract was completed it became obvious from trials that the transfer mechanism from the tubular magaine was not satisfactory. The rifle was redesigned at this point by Horace Smith, who eliminated a rack and pinion mechanism in favor of a lever system. Still the rifle did not sell as hoped. The project did apparently bring D. B. Wesson and Horace Smith together under the Robbins & Lawrence roof and expose them to the finest precision work extant. They went on to form the famous firm of Smith & Wesson, long famous in the arms field for the very high quality of their product.[23]

An even greater outcome of this contract was the invention of the lubricated bullet. This was the concept of Richard S. Lawrence, the technical leader of Robbins & Lawrence. It was one of those inspirations born of desperation. It came about in the winter of 1850 when Mr. Lawrence was called on to demonstrate the speed and accuracy of the Jennings rifle in the hope of selling rifles to Louis Kossuth, the Hungarian patriot and leader in a struggle for Hungarian freedom. Up until this time all breach-loading arms were plagued with the problem of the lead from the unlubricated bullets building up so badly in the barrel that "in firing twenty shots from a 50-100 calibre bore there would be a hole in the barrel less than 25-100." Faced with this challenging problem Lawrence was inspired to turn grooves in the bullets which he filled with common tallow. This lubrication made breech-loading guns successful.[24]

The greatest move made by Robbins & Lawrence in this period however was to exhibit their Model 1841 U.S. Rifles at the world's first great international exhibit, "The Great Exhibition of the Works of Industry of All Nations", commonly known as the "Crystal Palace" Exhibition in London, but this was in 1851 following earlier more localized exhibits in France. At the London Exhibition there were other and more strident exhibitors of arms, but none that showed the superb mass-produced interhchangeability of the ten army rifles exhibited by Robbins & Lawrence. This exhibit received an award and was subsequently to bear unforseen fruit of international significance.[25]

Meanwhile, also in 1851, both Robbins and Lawrence, as individual investors, each acquired 250 shares of the Sharps Rifle Co. stock, their combined holding representing about 13% of ownership. Whether this represented cash paid in or services to be rendered is unclear. Most likely the latter is correct and would account for the two separate organizations, Robbins & Lawrence, a partnership, and the Robbins & Lawrence Co., a Vermont Corporation.

The Sharps Rifle Manufacturing Company was founded at Hartford, Conn. on Oct. 9, 1851. Plans were rather fluid during 1851, but it is clear that the first 5,000 rifles were to be made in the Windsor Armory of the Robbins & Lawrence Co. However, a new contract of Jan., 1852 obliged Robbins & Lawrence [the partnership] to build and equip an armory in Hartford. Changes were found necessary to adapt the rifle to practical machine production. These changes were made at Windsor by Lawrence and a William Jones. Although Sharps was in Windsor at the time, he played no part in making the changes, no doubt because he was unfamiliar with the problems related to mass production. The first rifles produced were called Model 1851 and the first delivery was made Oct. 5, 1852, part of a lot of 200 for the U.S. Ordnance Department, ordered for trial purposes. A total of only 2,050 out of a total of nearly 2,700 were finished when Sharps production was halted at Windsor in April, 1855 and production shifted to the new Sharps factory in Hartford, Conn. on the failure of the Robbins & Lawrence Co. in 1856. Lawrence continued with Sharps in Hartford until leaving the company in 1872 when competition from repeating rifles began to seriously interfere with Sharps business.[26]

But some of the above is getting ahead of the great triumph of the Robbins & Lawrence Co., and indeed a great triumph for the United States as a manufacturing nation, a triumph for living standards in all those nations where the "American System" of interchangeable manufacture, as the English called it was adopted. This system being the use of pre-manufactured parts in assembly and repair work, and the lowering of costs through mass production. This developed from the exhibit by Robbins & Lawrence Co. at the "Crystal Palace" Exhibition in London in 1851, but it took the Crimean War and the Civil War to promote this.

It so happened that although the attempt made in France in the 18th century to produce interchangeable arms was known to many nations, and these nations made trials, none were successful. England, in 1853, was still having various small arms components made by different contractors to approximate size. These were all brought together in assembly workshops where the completed guns were made up by individual fitting as had been true in the United States until Simeon North's contract of 1813, mentioned earlier, and not finally discontinued at Springfield Armory until early 1849. This system also prevailed in other developed countries.[27]

It was also in 1853 that trivial international incidents involving Russia's smoldering expansionism toward dismemberment of the non-Christian Turkish Empire involved Britain, France, Turkey and Russia in the Crimean War. Britain had traditionally relied on the arms makers of Liege, Belgium for extra arms, but to meet the pressing needs of the Army in the Crimea the contract system was greatly expanded in Birmingham and Belgium. At this same time it was also remembered that there had been two impressive exhibitors of mass produced American made arms at the 1851 Exhibition. This lead to sending out a Committee on the Machinery of the United States. This committee was empowered to spend £10,000 (later increased to £15,000) for the proposed Small-Arm Factory to make the Model 1853 Enfield rifle, and £5,000 for the Royal Laboratory and Royal Carriage Department.[28]

Arriving at Springfield Armory they spent some days examining the machinery, particularly that for woodworking. From Springfield the Committee proceeded to Hartford where they called on Col. Colt at his pistol factory believing that he might be willing to make machinery to produce some of the metal parts of the rifle musket. He declined "on account of the press of buisiness."[29] It appears that they spent little time at the Colt Armory and were probably disappointed after the great build-up Col. Colt had given his factory and his methods at the Crystal Palace. Actually then, and for some years after, Colt did not produce work of the quality the Committee was looking for. The true level of Colt's work was revealed in testimony given before the

Select Committee on Small Arms [England] by his former armory supertintendent, an American, Mr. Gage Stickney:

[Q] "After using machines you find it necessary to use skilled labor to finish the articles, do you not?"

[A] "Yes, always; first class labor, and the highest price is paid for it."

[Q] "Do you consider it possible to interchange the parts of one pistol with another, as made by Col. Colt?"

[A] "I never saw a case of the kind. It have heard of it, but I defy a man to show me a case."

[Q] "When I was there, I saw a man fitting the parts up put a punch upon each part, what was that for?"

[A] "So that each part may go where it is designed to go as you put them together. The parts are given to the fitter and he fits them as he goes along. They get mixed in promiscuously [during subsequent operations], but are numbered, and then we pick them out; they are kept in separate boxes, or cases, that they may not be lost."[30]

The next stop of the Committee was at the Sharps Armory, where the reception and the prospects were more in line with their assignment.

"At Hartford the Committee went over the Armory belonging to Messrs. Robbins & Lawrence, of Windsor, Vermont in which they are manufacturing Sharp's [sic] Breech Loading Carbine and Rifle for the company who holds the patent on it. The factory is only just established, and all the machinery was not complete at the time the Committee visited it, but it seemed to be conducted on the best manufacturing principles, machinery being applied to every part of the arm. The Committee were so struck with the beauty and efficiency of the machines here used, that, finding they were made by Messrs. Robbins & Lawrence at their machine shop at Windsor, Vermont, they entered into the subject of the manufacture of fire arms by machinery with Mr. Lawrence, who accompanied them over the works, and who proved to be perfectly conversant with this branch of trade, and having showed him the different parts of the musket required to be produced, he undertook to make out and forward to them a tender for the necessary machinery, on behalf of the firm in which he is a partner.

They also went over Sharpe's [sic] rifle manufactory again with Mr. Lawrence, and were much struck with the neatness and easy working of the rough boring machines as compared with those they had seen in England."[31]

From Hartford the Committee traveled to New Haven, New York, Westpoint, Philadelphia, Washington, Harper's Ferry, Wheeling, Pittsburg, Buffalo, Utica, Albany, Windsor, and back to Boston. During this tour a great variety of industries were examined, many of these in no direct way related to arms manufacturing. Thus after their thorough examination of Springfield Armory and the fledgling Sharps Rifle Factory of Robbins & Lawrence, they visited many private armories, the U.S. Armory at Harper's Ferry and other industries as diverse as clock, engine, carriage making, hat making, a pail factory, nail factory, a shovel factory, sewing machine factories, and a biscuit factory. With all this background they arrived at Robbins & Lawrence Co. in Windsor, Vt. able to make judgements in a cool way compared with what must have been a dazzling experience when they had seen only Springfield Armory and the Sharps works.

"Windsor. -- Here they first visited the machine shop and armory of Messrs. Robbins & Lawrence, in company with the proprietors, who at their request submitted a formal tender for the machines which had been struck out of their first tender by the Committee, to which was added an estimate for additional machinery for producing different parts of the musket, which tender the Committee accepted on the 24th July.

They also submitted an estimate for some machinery adapted to the work carried on in the Royal Carriage Department, which the Committee caused to be converted into a tender and accepted.

Hearing that there was a firm who manufactured machines used in tin work, at a town called Woodstock, in the neighborhood of Windsor, the Company [Committee] accompanied by Mr. Robbins, went there and visited the works, and at their request Mr. Whitney, the proprietor, furnished them a list of the prices. On their return to Windsor they asked Messrs. Robbins and Lawrence to tender to them for these machines, and procure them from the manufacturer.

The same day they went with Mr. Robbins to Lebanon to see Messrs. Buck & Co., makers of wood machinery, with a view to purchasing some of his machines for the Royal Carriage Department and at their request a formal tender was made out which reached them at Boston, and which they accepted."[32]

The Committee, during the course of their tour, ordered some of the many novel and productive machines and tools discovered by them, since their mission was to introduce the "American System" as they called it at Enfield Armory. From Robbins & Lawrence of Windsor, Vt. they purchased 152 metalworking tools and associated apparatus. From the Ames Manufacturing Co. in Chicopee, Mass. 23 woodworking machines, in 15 varieties, for stock making. These were improved models of the machines developed at Springfield Armory by Thomas Blanchard in the 1820's. Ames also furnished 113 small tools consisting of gauges, jigs and patterns. These constitute the major purchases and provided the transfer of American precision, high-production machinery to Enfield Armory near London.[33]

This of course was all being done while the Crimean War was in progress and the need for small arms was great. The Robbins & Lawrence workmanship being much admired and realization existing that delivery of the machinery and the putting of it into smooth production would take more time, it was logical to look to the United States for rifles too. The British government had Robbins & Lawrence alter samples of their U.S. Rifles to Enfield bore. Before these could be received in England the Board of Ordnance received an offer in February, 1855 from Messrs. Fox, Henderson & Co. to supply 25,000 P53 "Enfield" pattern rifles of Robbins & Lawrence make. This offer was taken up March 8, 1855. On April 3 a report was issued on the samples which were apparently made up from parts left over from the U.S. Rifle contract completed in 1852, possibly reject parts.[34] In July, 1855 a contract was made to supply the British government with 1,000 of Sharps rifles. This was increased in August to 6,000. The machinery order occupied much of the Windsor factory so the making of the P53 pattern rifles was partly being done in the Sharps factory at Hartford, where the 6,000 Sharps rifles would also be made when design modifications were worked out.[35]

All of this work was a taxing burden on the Windsor and Hartford factories. To complicate the problem black walnut for gun stocks was not obtainable in the market, which retarded deliveries, and then on March 30, 1856 the Treaty of Paris ended the Crimean War.[36] Cancellation of the contract for the P53 rifles ensued. Both the Robbins & Lawrence Co. and the partnership of Robbins & Lawrence failed. The Sharps Rifle Co. took over the Robbins

& Lawrence Co. and completed the Sharps rifle contract with England. The Windsor Armory finished up all or part of the P53 British rifles under the name Union Arms Co. and sewing machines were also made, but the Armory and Machine Shop stood largely idle until the beginning of the Civil War.

An auction of the contents of the armory at Windsor was held in 1859. The purchaser, Mr. E. G. Lamson, also leased the buildings. During the Civil War there was a great demand for machinery for gun work and this kept the machine shop busy until this market was largely supplied. The special model Springfield Rifle of 1861, based on the "Enfield" P53 rifles made at Windsor in the 1850's, utilized tooling still existing in Windsor and perhaps Hartford. The most important carry-over from the Enfield to this model was the stirrup between the main spring and tumbler. This became a standard design feature of the lock used by U.S. rifles until adoption of the bolt-action Model 1892 Krag-Jorgensen rifle.

The first delivery of this model was made by Lamson, Goodnow & Yale utilizing the Enfield tooling acquired with purchase of the Robbins & Lawrence machinery. This delivery was made September 24, 1862 and was followed by deliveries from other contractors, Colt of Hartford, and Amoskeag of Manchester, NH, a total of 50,000 were produced at Windsor and a total for this model of 152,000. Final delivery by Lamson, Goodnow & Yale was made in December, 1864. During this period machine tools and tooling were made for other shops and armories including Colt and Amoskeag during work on the special model Springfield rifle contract. The armory was also at work on two rifled carbine contracts of 1,000 each. One was the Palmer, a single shot, bolt action, metallic cartridge arm, the first accepted for U.S. service. The other was the invention of Albert Ball. It also used a metallic cartridge but was a lever action repeater with a tubular magazine under the barrel. Delivery on these was so late in the spring of 1865 that they did not see service in the field due to the close of the war, but

> "they were the most advanced form of military weapon produced by the U.S. Ordnance Department to that date."[37]

Thus what was to be the last product of the armory was on the cutting edge of technical development as had been the first product, the new technology introduced in the Model 1841 U.S. rifle.

On the conclusion of the war the arms market changed in favor of civilian and sporting arms on improved and patented designs. In this field Winchester took the lead, but although their rifle had developed from the Jennings rifle made by Robbins & Lawrence, much evolution had subsequently taken place. The Ball and Palmer rifle actions were not competative with the Winchester rifle action, but in order to control the tubular magazine the Ball patent rights were purchased. They had pioneered the adoption of self-contained metallic cartridges in the Ordnance Department. This of course depended on the absolute interchangeability of millions of duplicate cartridges fitting thousands of rifles.

The specialized gun and pistol machinery of Robbins & Lawrence, as well as the machinery for making sewing machines, was sold to various purchasers. The demand for this was excellent and new machine tools became the dominant product, particularly turret lathes with a vertical axis turret. These had been sold as early as 1854 under the name "screw milling machines" as part of the equipment for Enfield Armory. Possibly they had been sold elsewhere even earlier.

The leadership of American manufacturing methods of accurate, high production was based in part, not on machine design, but on the general climate of working conditions. But the general atmosphere in American industry was part and parcel of the machine tool development, a phenomenon now to be seen among the new nations leading in machine tool production and as exporters to the United States. These American conditions are well stated by the Committee of three, Robert Burn, Lieut.-Colonel, Royal Artillery; Thomas P. Warlow, Captain, Royal Artillery; and John Anderson, Inspector of Machinery. Their summation of these conditions supplementary to the machines and tools follows:

> "Before bringing this Report to a conclusion, the Committee venture to offer a few observations on several subjects which strictly speaking do not fall within the province of their mission, but from their importance and bearing upon the general interests of the Departments at Woolwich, it is hoped that they may not be considered as stepping beyond their legitimate bounds in so doing.
>
> One distinguishing feature of manufacturing establishments in the United States, both public and private, is the ample provision of workshop room, in proportion to the work therein carried on, arising in some measure from the foresight and speculative character of the proprietors, who are anxious thus to secure the capabilities for future extension, and in a greater degree with a view to securing order and systematic arrangement in the manufacture.

Another striking feature is the admirable system everywhere adopted, even on those branches of trade which are not usually considered of much importance, this applies not only to the selection and adaptation of tools and machinery, and to the progress of the material though the manufactory, but also to the discipline and sobriety of the employed.

The observations contained in the Report upon American tools and machinery, will best explain the nature and adaptation of special tools to minute purposes, in order to obtain the article at the smallest possible cost; for this end capital is borrowed to a great extent and sunk in establishments not only adapted to a peculiar manufacture, but where a department is set apart for the express purpose of making the special tools and contrivances required in order to obtain that end in the most economical and effectual manner. This at least applies to establishments of any importance.

The contriving and making of machinery has become so common in this country, and so many heads and hands are at work with extraordinary energy; that unless the example is followed at home, notwithstanding the difference of wages, it is to be feared that American manufacturers will before long become exporters not only to foreign countries, but even to England, and should this occur, the blame must fall on the manufacturers of England, who [sic] for want of energy in improving their machinery and applying it to special purposes. The advantages in a manufacturing point of view are all on the side of our countrymen, and there is nothing made in which they ought not to be able to undersell their American competitors either in England or on the continent.

Another point, bearing on this important subject, is the dissatisfaction frequently expressed in America with regard to present attainment in the manufacture and application of labour-saving machinery, and the avidity with which any new idea is laid hold of, and improved upon, a spirit occasionally carried to excess, but upon the whole productive of more good than evil.

The care almost universally bestowed on the comfort of the workpeople, particularly attracted the notice of the Committee; clean places for washing being provided, presses to contain their change of clothes, and an abundant supply of good drinking water, in many cases cooled with ice.

The Committee also remarked with satisfaction, the regular attendance and cleanliness of the workmen, and the rigid exactness with which the work is continued up to the last minute of the working hours.

A remarkable feature in the character of the native American workmen is their sobriety, water is their usual beverage, and this they use inordinately in hot weather, but rarely anything stronger, clear headedness results from this and gives them a powerful advantage over those who indulge in stronger potations, which will eventually produce its effect on the national manufactures, as it now does on the intelligence and character of the individual workman.

In the Government and private manufactories in the United States, piecework when applicable is universally preferred to day-work, as this arrangement yields the greatest amount of work at the least cost to the employer, at the same time paying the best wages to the individual employed, and the Committee trusting the Honourable Board will not think them presumptuous, beg most respectfully to submit it as their opinion, formed after careful consideration, that the system of paying by the piece is that on which, after its machinery is in full operation, the proposed Manufactory of Small Arms, could be best conducted so as to reduce as much as possible, the costs of the arms made, and yet pay good wages to the workmen employed.

The following are their reasons for coming to this conclusion.

1. In a manufactory where payments are made by the piece, it is the interest of those employed to turn out as many as possible of the article they work upon, and to suggest any labour-saving device, that may occur to them as likely to increase the production of the machines they attend.

2. Because where work is conducted in this plan, the supervisors may be less numerous, as any time the workman may waste by decreasing the quantity of the article produced by him, affects his wages and entails no loss upon his employers.

3. When men are paid by the piece they can be held financially responsible for any work they may spoil through carelessness, which cannot be done where the payments are made by the day; this is particularly important when the parts made are required to be

identical, to insure interchange, and any workman who may be employed in some trifling operation on an article that is almost finished, by carelessness in looking after his machine may spoil and render useless a large number of parts on which a great deal of careful labour has been already bestowed.

The Committee are also of opinion that in order to keep the proposed establishment in a high state of discipline, which is absolutely necessary to enable it to work well, the superintendent should have absolute power over the men employed, as it is by this means only that combinations can be effectually checked, the contagion of dissatisfaction and idleness on the part of a few individuals prevented from spreading through the mass and vitally affecting the system of the whole manufactory.

This system is pursued in all the best Government and private works the Committee have anywhere seen, in which the order and regularity of the workmen was most observable, and they consider it their duty as they hold these opinions, formed after having seen so many first rate manufacturing establishments at home and abroad, and after much careful inquiry as to how these works were conducted, to express them freely to the Honourable Board.

Owing to the difficulty of getting special machinery constructed, and the high price necessarily asked for it by the first rate machine makers, who are frequently unwilling to undertake it at all on account of the trouble it entails on them, in devising and making models, the Committee beg to submit to the Honourable Board as their opinion, that a great saving would be effected to the Government, and the service would be much benefited by the establishment of a machine shop in the Royal Arsenal at Woolwich, for the manufacture of special machines only, the system of contracting for machinery in ordinary use, and which is one of the staple manufactures of the country being still adhered to.

In all the United States' armories and arsenals, &c, and most of the large private manufactories of America, this system is pursued with great advantage." [38]

THE COLLECTION

The evolutionary invention of the machinery to make precise elements at small cost in any quantity for everything from scientific instruments to household appliances owes its development to the "American System", as the British Commissioners called it. It was a system that evolved not from great publicly supported "Think Tanks", such as we have today. Instead it evolved in tiny increments within the contract system which gave the contractors and,(under the piece-work system) the workmen, incentive to think of incremental changes that continued the development of enduring predictable accuracy and productivity.

Not every change proved to be enduring, and no doubt many blind alleys, now forgotten, were explored experimentally. The result could have taken place long centuries before if the incentive system had been instituted and sustained. In this country was evolved a system of patronage, the patronage of a stable forward looking government instead of one encumbered by tradition where progress depended on the interest of individual rulers or wealthy enthusiasts. Human nature is the same today as before interchangeable manufacturing was developed. The unaided individual in the population is now no more able to produce work of modern quality than were the French workmen whose accomplishment Thomas Jefferson examined in 1785. The difference brought about since then is that the skill of those with outstanding ability was used to conceive and then build this skill into tireless machines that could work all twenty-four hours if necessary and that were not encumbered by recreational excesses or other distractions. The skill needed to tend these machines was obviously far below the level of skill needed to create and maintain them or to make the same quality product with hand tools.

Thus employment at good and predicable wages indoors out of the sun, rain, snow and wind was provided for thousands who would otherwise be eking out some precarious existance on the land at subsistance level. This explains why machinery is so eagerly adopted by developing countries and why old countries must maintain better work, design, and investment ethics than what we presently have.

The machine design ideas that were produced by the "American System" were to a substantial extend reinventions. The much touted invention of the slide rest generally attributed to Henry Maudslay in England is found in its most elemental form, now demonstrable, in the saw mill drawing of 1235 A.D. by the French architect Villard de Honnecourt. There the log being cut into strips or boards serves as the slide moving though guides against the tool, in this case a saw.[39]

How many of the vast store of mechanical drawings that form part of our heritage from Leonardo da Vinci are representative of concepts of his, or even original to his period, are now uncertain.

However, the very close correspondence between some of Leonardo's drawings and those of planetary dials on the clock driven astrarium of Giovanni de Dondi, completed in Italy between 1348 and 1364, are too important to be overlooked or brushed aside. These drawings suggest that Leonardo saw and copied from this or a similar instrument.[40] We can't be sure what he and other engineers may have copied because the Dark Ages and centuries earlier are largely shrouded in mystery except for what can occassionally be deduced from the examination of surviving objects. The ability to turn metal is well shown to have been practical in Roman times by Alfred Muntz in his *Die Kunst des Metalldrehens bie den Romern*."[41] But the turning and fitting together of surfaces is no accomplishment at all compared to the famous Greek *Antikythera Mechanism* of c-80 B.C., a very complex geared mechanism even containing a differential. This was used to calculate the calendar and to show star positions at any time, including past events and future predictions.[42]

All of the few ancient mechanisms that survive, and all of the mechanisms and machines that we know of by literary descriptions and drawings, of which many more exist than those of Leonardo only, were very expensive to build with hand tools. If these were built and were later sketched by artist/engineers it may be that these drawings include a record of machines and ideas far earlier than the sketches representing them. That these complex machines never became widely used appears clear, and that they were not supplanted by improved varieties seems to indicate that they were too expensive to construct in relation to their utility.

We have been speaking so far of the most sophisticated machines of their times partly because, being of metal, we have detailed surviving evidence. They may be looked upon as the scientific instruments of their day. There were countless repetitious examples of lesser machines well known to everyone, such as gristmills. Less well known were saw and fulling mills, although they too, through the application of wind or water power, greatly reduced the heavy physical burden on the muscle power of man and beast. Such machinery is best understood by the illustrated engineering and text books of the Renaissance, such books as the lavishly illustrated books on mining, refining, pumping techniques, and the art of war. The most general, influential, and widely reprinted and translated of these engineering texts being Besson's *Theatre des Instrumens Mathematiques & Mechaniques*, for which a combined Royal Patent and copyright for

> "the ten years next ensuing, to start from the day printing of the work shall conclude: all persons, whatever may be their rank or condition, are prohibited from making, reproducing, printing, selling and likewise from condoning the portrayal or manufacture, of any of the inventions contained in the present work, without the permission of the said author. Given at Orleans, this 27th day of June in the year 1569. By the King in Council signed Brullart."[43]

Regretfully these books represent many concepts that in all probability were never reduced to practice. More down to earth and practical books also began to appear, not to say that those of such authors as Biringucco and Agricola were not practical, but they described works calling for substantial investment. Such books as Moxon and Diderot were scaled better for the workman and included some simple and easily made machines to lighten labor. Much of the knowledge of individual craftsmen was not published but was communicated from master to apprentice, the apprentice usually making a large proportion of his own tools. Unfortunately nearly all books at this time showed more erudition in their subject than they showed by an address to the basic problem, ie: newer forms of tools including machine tools that were eventually to do so much to accelerate productivity thereby raising living standards.

Because of the scarcity of labor in the early English settlements of North America, machines known of, but not countenanced in Old England, became usual in New England. Commonly the first machine in a new settlement was a saw mill. The products of the grist mill and the spinning wheel could be brought in rather easily, but the saw mill which converted the abundant timber into saleable lumber both for building locally and for export, was essential. As early as 1630 boards were being sawn by hand for export and lesser products of rift timber, such as barrel staves, were prepared for shipment. Saw mills were erected in 1634 at what are now York and South Berwick, Maine. At least fifty saw mills were in operation in Northern Massachusetts, New Hampshire, and nearby Maine along the fall line of the numerous rivers by 1675. In addition, most of the less frontier settlements had a saw mill to supply the local market.[44] With all of these saw mills in contrast to none in England, it can scarcely be a surprise that development of the saw mill soon began to evolve. The most certain surviving evidence of this is the first patent, issued in 1646 for a saw mill.

"At a generall Courte at Boston
the 6th of the 3th mo. 1646
. . . with a few hands, & being sufficiently informed of ye ability of yet petitionr to pforme such workes grant his petition (yt no othr pson shall set up, or use any such new invention, or trade for fourteen yeares w'hout ye licence of him the said Joseph Jenkes) so far as concernes any such new invention, & so as it shalbe alwayes in ye powr of this Cort to restrain ye exportation of such manifactures & ye prizes of them to moderation if occasion so require."[45]

Colonial government was not only willing to protect inventors as had recently been commended in England, it took measures to stimulate the progress of local industries as in 1640 when the Massachusetts General Court instituted a colony wide inquiry "What men and women are skillful in the breaking, spinning, weaving, what means for the providing of [spinning] wheels; and to consider with those skillful in that manufacture. . ."[46]

The basic problem was not very well addressed by these efforts because the improvements still often called for a high level of strength, attention, and manipulative skill on the part of the users. As was well said in 1789:

"The farmer and the artisan have more to do than they can perform; scarcity of men makes labor very dear; to supply the want of labor and time the American is forced to invent, to think out new ways of augmenting his efficiency."[47]

It was in 1790 that the U.S. Patent Office was established in answer to this need and to protect the interests of inventors. A review of the first decade alone of Patent Office operation reveals a series of far reaching fundamental inventions. Probably the three most far reaching are the automatic grist mill by Oliver Evans, the begainning of integrated manufacturing; the cotton gin, claimed by Eli Whitney, but only successful when combined with almost immediate improvements by others; and third, the screw cutting machine of David Wilkinson, patented Dec. 14, 1798. This was not the first machine tool, already we have mentioned Hugh Orr as a musket maker in the mid-18th century. He had a boring mill, owned by the Commonwealth of Massachusetts, based on a French predecessor, used to bore cannon *from the solid* during the American Revolution. It was however dismantled following the war when nearly every conceivable want of the newly independent colonies was supplied from abroad, chiefly from England.[48] The Wilkinson family of nearby Rhode Island had also made cannon and for generations had conducted iron works. One of their products was large cast iron screws suitable for clothiers, oil, and paper presses. These were about seven inches in diameter and some six feet long and were finished with crude tools in a very imperfect manner not agreeable to young David Wilkinson. In Wilkinson's own words:

> "I told my father I wanted to make a machine to cut screws on centers, which would make them more perfect. He told me I might commence one. . . . About 1794 my father built a rolling and slitting mill, at Pawtucket, on the gudgeon of the wheel of which I put my new screw machine in operation, which was on the principle of the gauge or sliding lathe now in every workshop throughout the world; the perfection of which consists in that most faithful agent *gravity*, making the joint, and that almighty perfect number *three*, which is harmony itself. . . . I cut screws of all dimensions by this machine, and did them perfectly."[49]

This was a large machine some twenty feet long and employed three small wheels under the heavy tool slide to ease the friction. This arrangement allowed the slide to move easily yet there was no necessity for close fitting as the weight ensured that the three wheels were always in contact. The need for a smaller machine to turn the parts for cotton-mill machinery was keenly felt and various cotton-mill promoters brought over English mechanics who brought ideas and built lathes that were failures. However Wilkinson could find no support for his design scaled down to suitable size. As he said:

> "Whilst I was at work on Slater's machinery, the owners were unwilling that I should make a slide lathe, on the principle of my screw-machine, which was made for large turning; it was too heavy for cotton machinery. . . . About that time, 1806, my father [and others] purchased a water power on the Quinnebaug river, Connecticut, at Pomfret, and commenced building a cotton factory. These owners consented that I might build a gauge lathe, like my large one. . . I left out the three [anti] friction rollers. . . as for light work and slow motion, I was willing to risk the friction. . . . Captain Benjamin Wolcott. . . with Nathan J. Sweetland, put the "live center" arbor and the rack in place of the screw for the feeder, to a lathe they built afterwards. . . Mr. Pitkin, of East Hartford, had an Englishman named Warburton with him building a factory.

Warburton told me, *they* could never make our work in Europe, -- that Watt & Boulton [sic] gave it to a man for a month's work to finish a piston rod, with hand tools."[50]

The concept of a guide or slide rest was at least as old as the saw mill of Villard de Honnecourt of 1235 mentioned earlier, and reappeared perennially in sketches of Leonardo, Besson, Nartov (mechanic to Peter the Great), Ramsden, Vaucauson, and Sennot, but only those of instrument size are known to have been made, and then obviously at great labor and expense because all were conceived and designed so that their utility was dependent on geometrically perfect configuration.

Wilkinson's lathe, on the other hand, was so large that it would have been futile to think of making it geometrically perfect. Still, the tool had to travel accurately and easily and yet be so firmly supported that the interaction of tool and work would not cause chatter or deflection. The solution to the problem was simple even though it had eluded many with greater experience. Indeed, only with Wilkinson's second lathe were the patented features arranged to best advantage. Then with two of the three bearing points of the sliding tool carriage arranged in line they were able to travel without binding along a prismatic rib on the front of the lathe bed while the third carriage bearing was arranged to give stability to the tool by traveling on top of a flat way at the top rear of the lathe bed. Now the front prismatic guide way being made by hand was not perfectly straight. Whatever deviation from perfection was in it was of course transferred to the tool. Since the work revolved, whatever error there was was twice as great on the work, as this turned around in the machining process. *However*, in this design of lathe it was only a matter of filing down the top of the rear flat way opposite to the large places on the work so that at these places the tool slide and tool could rotate slightly around the front way, bringing the tool nearer center at these places, removing the large place on the work. Trial and correction would soon produce straight turning from guide ways that were not straight because one way was deliberately shaped to off-set the inaccuracy unavoidable in the other. The tool slide was able to follow these deviant guide ways because sufficient weight was hung on the tool slide to keep the three bearing pads always in contact.[51]

In 1848 Congress awarded Wilkinson $10,000.00 in belated compensation for his invention.[52]

Thus a whole new concept in lathe making was introduced in the United States just in time to speed the construction of the machinery for all the native industries that developed during the period of about a dozen years of the Jefferson Embargo, the Non-Intercourse Acts, and the War of 1812. During the long interuption of normal trade abroad foreign commerce was greatly disrupted in two ways, the importation of manufactured goods and the difficulty of exporting raw materials. This had the effect of swerving merchantile fortunes toward manufacturing and industry. In this the long established policy of England forbidding the export of machinery and craftsmen played an important part. The want of better machine building facilities was acutely felt. Oliver Evans had just built the Center Square steam pumping station for the Philadelphia Water Works and was building more advanced engines for boats as well as mill operation. Clearly he sent out part of the machine work as the following description made clear:

> "At this period 1801, the finest equipped engineering works in the country were the Soho works, near Newark on the Passaic River, in New Jersey which were owned by Nicholas Roosevelt. Here the large engines for the first Philadelphia Waterworks were completed.
>
> On July 3, 1800, Thomas Pym Cope, a member of the Watering Board, journeyed to Soho to inspect the progress of the engines then under construction there. Of this trip, Cope says:
>
> 'Took passage in the stage for Soho Works near Newark, N.J., on the morning of the 3rd of July 1800, arrived there about noon of the next day. Soho is named after the works of Bolton and Watt, in England, and is situated about three quarters of a mile north west of the Passaic on a small stream called Second River. The works consist of a smith shop, 90 by 40 feet with six fires and two air furnaces; next to this is a room 30 x 20, in which is the fire, for heavy work; four wooden bellows play into a regulator 15 x 15 feet, with pipes to the forge, and four furnaces for melting and refining copper. Then there is a stone building 20 x 24, two storeys high, with six stampers for preparing loam for the furnaces; next to this is a fitting shop with large lathe and drilling machine, and a water-wheel 20 feet diameter to bore cannon; next to this is a shop with a water-wheel 20 feet diameter for boring large cylinders; this is now boring a small cylinder for a steam boat; which belongs to Roosevelt, Chancellor Livingston and others. Higher up the stream is the furnaces, 60 by 50 feet with two air furnaces capable of melting 40 cwt. of metal each, two blast furnaces for melting, and refining copper, with coal house and pattern shop, with two foot

lathes; all are stone buildings. The stream affords a head and fall of 16 to 18 feet. The large cylinder for the engine to be used on the banks of the Schuylkill at the Water Works was cast in two pieces, and united by copper, the joint being secured externally by a strong band of cast iron 18 inches broad, weighing 1200 lbs. Seven thousand five hundred weight of metal was used for the cylinder; it is six and one half feet long, and about thirty eight and one quarter inches in the bore; about 3/4 of an inch through out was first to be cut away; one half inch has been accomplished; two men are required one almost lives in the cylinder, with a hammer in hand to keep things in order, and attend to the steelings [cutters], the other attends to the frame on which the cylinder rests which is moved by suitable machinery; these hands are relieved, and the work goes on day and night; one man is also employed to grind the steelings; the work is stopped at dinner time, but this is thought no disadvantage as to bore constantly the cylinder would become too much heated; the work also stands whilst the steelings are being changed, which require about ten minutes time, and in ten minutes more work they were dull again. I examined some of them and found them worn an eight of an inch in that time. Three of these steelings about three and one half inches on the edge, are fixed in the head piece at one time. The head piece is a little less than the diameter of the cylinder and six inches thick secured upon a rod of iron eight inches in diameter which forms the shaft of a water wheel. The workmen state that boring was commenced on the 9th of April and had been going on ever since, three months, and about six weeks more will be required to finish it.

(Signed) Thos. P. Cope,

July 4, 1800' "[53]

It is the same decade that saw the successful steamboats of Robert Fulton and his rivals. Although Fulton, who was associated with Roosevelt and Chancellor Livingston, sent to Boulton & Watt in England to have the engine for his first boat built, the engine design was his own, but it could not be practically built here. International events on the political front soon changed any hope of depending on imported engines and other technical objects. With the financial support of Robert "Chancellor" Livingston this problem was soon solved by a more modern shop than Roosevelt's.

" Mechanic Arts Improving

In the last twelve months, a large establishment of workshops has been erected by Messrs. Livingston and Fulton, in the northern part of Jersey City, expressly for constructing steam engines, and the machinery for steam boats. The first is a capacious building, two stories high, in which are the boring, turning and drilling mills; also the fitting, filing and model shops. The second building is a superb smith's shop, containing nine fires, in which shafts of one ton weight are forged. The third is a *boiler* shop, with its *oven*, *punches*, and *cutters*, complete, and of a capacity to construct within it at one time, two boilers 22 feet long, and of eight feet diameter.

To these works are added a dry dock, for building and repairing steam boats, which is 200 feet long, 40 feet wide at bottom, and 60 at top, sunk three feet below low water mark, walled, floored and well secured, with horse pumps, to exhaust the water left by the ebb tide; yesterday its large folding gates were thrown open for the first time, to receive the flood of our magnificant and bountiful Hudson, and at one o'clock, the North River Steam Boat entering, settled on the timbers prepared for her support. This to the best of our knowledge, is the only dry dock in the United States. . . The whole of these works occupy about three acres, and have cost the proprietor forty thousand dollars. The increasing demand for steam boats which Messrs. Livingston and Fulton have excited from one end of the union to the other, and the difficulty of getting the work executed promptly and in the best style, pointed out to them the necessity of forming the noble establishment. And so great is the facility it has given to the execution of heavy and complicated machinery, that in addition to constructing the shops with all their apparatus, there has been made in them, in the short time of one year, five steam engines, with the whole machinery for four steam boats, viz: One steam ferry boat for the north river, the (LI) Sound, the James River, and the Washington steam boats. Works of such great general utility, prosecuted with such ardour, do honour to our national industry and enterprise, and place the native American genius high in the ranks of talent and public spirit. They also contribute eminently to our national independence, and strengthen our claims to the respect of the European states, and consideration of the world. . . ."[54]

There seems no way now to determine if any of the tools were imported by Nicholas Roosevelt, but clearly his boring mill was inferior in design to that of Boulton & Watt devised by the English ironmaster John Wilkinson. It seems clear that the Livingston and Fulton shop, much larger, and located on the Hudson where water power seems doubtful, seems to have made their machines and a steam engine for power, this last accounting for their building five engines and only four steam boats in the account just quoted.

It is not likely that any of the early machines of these two early machine shops has survived, they became obsolete at an early day, were heavy iron, of value to the proprietors who had a constant need for iron castings, and in at least the instance of the "Soho" works of Roosevelt, could rework them with its own casting facilities.

Like these early machine shops, their product too has disappeared, even contemporary pictorial representations of all but a few of the earliest steam boats can't be found. Many of course were hastily built to qualify for charters on the inland and coastal waters.

In 1809 Nicholas Roosevelt and Robert Fulton joined forces to develop the steam boat on the western waters. In 1811 Roosevelt succeeded in decending the Ohio and Mississippi Rivers from Pittsburg to New Orleans in a steam boat, the *New Orleans*, built at Pittsburg.[55] This trip involved running the rapids at Louisville, Kentucky, an accomplishment not repeatable on up river trips. This placed steam navigation on the Mississippi only eight years after the Louisianna Purchase of 1803. Soon steam boats were ascending the wild Missouri River almost on the heels of the Lewis & Clark Expedition of 1804-1805. Steam boats also appeared on the Great Lakes in this era. Thus from the Atlantic Seaboard to the navigable inner recesses of the continent there were steam boats and, of course, machine tools to build and maintain them. These activities gave the United States the first extensive mechanized transportation system in the world. Fulton, being a man of vision and boundless ambition, was inspired by the prospects of success in navigating the interior of North America to aspire to introduce similar navigation to the vast hinterland of Russia beginning in 1811. Fulton obtained a charter containing many conditions which, working through John Quincy Adams, our Envoy in Russia, was issued December 10, 1813. This was never implemented due to distance and a need for more time than Fulton had. He died in February, 1815. The navigation of Russia was still much on his mind, his last steamer being named the *Empress of Russia*. Thus began the end of the flat-boat for down stream transport on the rivers of the world. No more graphic description of getting freight boats up stream past sand bars, submerged rocks, eddys and rapids by man-power may exist than that of P. P. Mel'nikov, a Russian engineer and steam boat proponent, who said some decades after the Fulton Charter:

> "Sometimes the workers with the towing rope had to clamber up the steep sandy cliff that would collapse under their feet, and bury some of them to death; sometimes they had to trudge along the foot of the banks, walking mostly barefoot on a surface covered with a layer of angular detritus; at places they had to enter the water to considerable depth, so as to present a picture of several hundred heads that were slowly moving above the surface of water: anybody who missed a step was trampled by the crowd and often remained there. While crossing over the river-beds or ravines the entire mass of people rushed to swim across and if there were some among them who did not know how to swim it was their ill luck."[56]

These sad conditions no doubt account for the hauntingly melancholy *Song of the Volga Boatmen*.

Reverting to the Museum Collection, there is a much simpler lathe and drill press, both wooden companion pieces, representative of the small, local, and typical mechanics shop of the 18th century. The oldest machine tools in the present collection date from the mid-1820's and are lathes made largely by hand. Casting and forging play a large part, but they incorporate Wilkinson's principles of the three point bearing and weight to keep the bearing surfaces together.[57] Other lathes show the later stages of this evolution.

The round parts in the early lathes were probably turned using hand held tools in a simple lathe as wood is turned. Both are back geared and that reminds us that the most essential machine tool needed to make these pioneer lathes was neither a similar lathe or an iron planing machine. The round parts could be turned with hand tools and the file could be substituted for the planer. The one machine tool that was essential was the gear cutting machine. Of these, also largely made with hand tools, we have two. One was in use in 1832, the other is signed and dated 1836 and has a bevel gear cutting attachment. Both are arranged to cut helical gears. An example of such helical gearing may be seen in the headstock of the large "Crown & Eagle" lathe with granite bed. These gear cutting machines used formed cutters to shape the teeth. The tooth shape of the gear cutter was produced either by a milling cutter controlled by a form of the correct shape, or by a correctly shaped forming tool. The tooth relief might be a product of milling cutter shape or, when made by a forming tool, eccentric or later involute relief was used. The early machines have large index plates to space the teeth in the work. We also have later machines with index wheels, and finally an early gear shaper which generates the ideal tooth shape using a gear shaped cutter. As yet our only real bevel gear machine is a grinder patented in 1896 and made by Leland & Faulkner of Detroit. The inventor, Henry M. Leland, who learned toolmaking at Springfield Armory during the Civil War, soon after introduced the interchangeable manufacture of Cadillac engines and later designed the original Lincoln automobile.

Metalworking, including machine tools, received a great impetus with the introduction of machine tools for planing iron. They were used in England a decade or so before a record has been found so far in this country. The Museum has the only known example of an iron planer in the western hemisphere that has its plane surfaces made by filing. The file marks are still very evident. It is a well designed and well made machine, but is entirely hand power driven through spur gearing, and has no power feed mechanism. Only one other equally pioneer planer has been identified anywhere, and that is in the Science Museum in London, England. Our example may date from the late 1820's.

The Museum also has a drill press where two screws are used to guide the cutter spindle straightly in place of a slide. In design it pre-dates the general introduction of planing machines.

These four types of machine tools are the basic irreducable number for practical purposes, gear cutter, lathe, planer, and drill press. These soon were used to produce machines better adapted for repetative and production purposes.

The earliest and most important of such machines was the milling machine. The Museum collection contains three original machines designed no later than the 1840's. In addition there are reproductions of the earliest known milling machine, the Simeon North design of 1818, and the so-called "Whitney" machine of c-1827. Of the three earliest original machines two are duplicates of machines made and sold here in 1854 as part of the original outfit for

Enfield Armory near London. One is a versatile "index" tool making machine that still bears the builders plate of "Robbins & Lawrence" and the date 1850. The third machine was made by Gay, Silver & Co. of North Chelmsford, Massachusetts for the Merrimack Manufacturing Co., an early textile mill in Lowell, Massachusetts.

Turret lathes for repetative work received a great impetus from the gun and sewing machine industries. The Museum has the oldest known surviving example made in the building in 1861, examples were exported to England as early as 1854. Soon these were automated for small work. Of these we have the important Spencer, patented in 1873, and other important examples, so automation is nothing new.

No finer example of the complex special machine tools for woodworking of the 1850's can be found than our machines for turning, barrel bedding, and lock bedding (or recessing), all refinements of machines originally designed for Springfield Armory by Thomas Blanchard in the 1820's. Two of our machines are by the Ames Mfg. Co. of Chicopee, Massachusetts, and one of them was a piece of the original machinery sent from America to the Enfield Armory, where it ran for about 100 years before it was recovered for the Museum.

All of these early machines were made previous to any convenient means of measuring the work, so the work was done to match a model instead of to a dimensional drawing or blue print. The facility of measuring with assurance that the same dimension could be reproduced to a thousandth of an inch where ever wanted had to wait for the introduction of the vernier caliper in the 1840's.

The Museum is fortunate to have the earliest American vernier caliper so far discovered, dated 1846. Micrometers and verniers had been known for many years, such as the famous "Lord Chancellor" bench micrometer of Henry Maudslay in England. But these instruments were for in-house use, not adapted, either in size or price, for general use at the machine or for general circulation throughout industry as the verniers introduced in the United States were. Later the micrometer introduced from France by Brown & Sharpe greatly extended the ease and closeness of measurement, and was priced so it could be in every tool box. In addition to examples of these the Museum has the Brown & Sharpe bench micrometer with microscope of 1878 and a later commercial example by Pratt & Whitney. These were like the earlier English instruments in that they were not portable. However, they measured to far closer limits, and were used for gage manufacturing. This gage business allowed industry to manufacture complex items to closely interrelated dimensions.

With this widespread ability to measure closely came a demand for new types of machine tools for grinding hardened materials and for the economical production of a fine finish on work in general. The Museum has the first commercially available universal cylindrical grinder, a Brown & Sharpe product, and an even earlier cylindrical grinder designed by Chas. E. Moseley, a former Robbins & Lawrence employee who later carried Robbins & Lawrence's methods and machine designs into the watch industry. Grinding with emery wheels instead of natural sandstones was a novel method of machine shop procedure to the English Committee on machinery who noted:

> "On a small lathe driven at high velocity, are placed small circular cakes, composed of glue and fine emery and which are made by casting this composition in metalmolds."[58]

But grinding soon advanced beyond just producing fine finish or correcting hard or warped surfaces. In the Museum there are also grinding machines that pioneered in high productivity combined with accuracy. One is the Heim centerless grinder and the other the Blanchard surface grinder, which is noted also for the very high quality of plane surfaces it will produce by the generating principle typical of an entire class of machine tools. These are the tools that rely on geometry to create a shape by the combined or interacting influence of elements of the total machine. Less sophisticated tools often operate on the principle of transferring their inbuilt accuracy directly to the work.

The Museum, as I am sure you all hope, is interested in developments in all areas, including the press working of metals, already represented in the collections. The most recent developments in all fields do not need to be in a museum yet, but the Museum is very concious of their existance and already has a numerically controlled machine and an early model of memory drum. We are alert to other modern developments and to incorporating them into our collection. Even these seemingly recent developments have a long history represented in the Museum. It is the incorporation of electrical and electronic features and consequently a further reduction of the human element that makes recent achievements seem so radical. We also have machines of 75 to 100 years old which functioned 24 hours a day, year in and year out, that abley handled the regulation of speed of an entire factory. In one word, we call them governors. They take a constant reading of speed and power and adjust water, steam, or electricity, according to the needs of the business as it fluctuates from minute to minute and they fill the need for sensitivity, promptness, and reliability better than a human attendant could.

It is most appropriate that the collection should be based in the Robbins & Lawrence armory building where precision manufacturing was developed to a saleable level, and from where it achieved international recognition. To try to furnish a long catalog of all the objects now in the Museum Collection, or that should be there, is not practical here. It is, however, important to say that many outstanding objects still remain to be collected in order that important topics may be better interpreted by exhibits. Obviously tools of whatever variety are not created to perpetuate themselves. Rather they are called into existance to make possible all the other secondary machines and tools of technology from which we have received, and will continue to receive, such enormous benefits. This collection will therefore have to include such seemingly unrelated fields as the chemistry of iron and steel, and the rare metals, in relation to their use in cutting tools. Hydraulics, pneumatics, electricity and electronics will also be collected for their relationship to tools and productivity all the way from the power hand tool to the CNC and FMS systems of today and beyond.

To make all the benefits obvious to our visitors, particularly to those in our educational system at all levels, we are collecting in fields readily recognizeable as having received great benefits from the quantity and perfection of the products made possible by machine tools just as the importance of hand tools rests in large part on their use in the creation of the machine tools that have power drive for stamina and precise guidance for accuracy. Some of these associated fields in which we are collecting are related to energy, publication, agriculture, communication (including transportation in its various forms) and personal and household appliances.

We have another site with the remains of a 1791 Grist Mill where we intend to install the integrated milling machinery patented in 1790 by Oliver Evans, and our energy related collections, including modern hydro-electric equipment to furnish warmth for the Museum. Off site storage is also required so that upper floors, presently used for storage, may be opened to the public and so that exhibits may be refreshed from time to time from the reserve collections.

The Museum is developing a research library which presently contains some very rare and even unique books. There are also growing business and patent record collections and portrait and photographic collections.

The Museum publishes a quarterly, *Tools & Technology*, a newsletter, and occassional other material on the history of technology.

Thanks to Doubleday & Co. we are favored to close with a slightly paraphrased quotation from *John Adams*, by Page Smith, copyright 1962.

> ". . . history's most essential task is to do justice to the motives and aspirations of individuals and groups of earlier ages, and in so doing keep viable those principles and ideals that have drawn man upward on his long climb from barbarism. Man must learn from his errors lest he repeat them; he must repeat his triumphs lest he fall into error. History as man's collective memory, must above all distinguish truth from falsehood."

Edwin A. Battison
Director, American Precision Museum

FOOTNOTES

1. "Engine for dividing scales", June 20, 1827. Hedge eventually established himself in New York City via Brattleboro, Vt. and Hartford, Conn.
2. "Pistons, rotative", John M. Cooper of Guildhall, Vt., July 16, 1827.
3. "Revolving hydraulic engine", April 22, 1828. This was the familiar gear pump but with particularly shaped gear teeth to increase capacity.
4. Small Arms Makers, by Col. Robert E. Gardner, Crown Publishers, NY, 1963, 144 pages.
5. Muskets to Mass Production: The Men and Times That Shaped American Manufacturing, Edwin A. Battison, American Precision Museum, Windsor, Vt., 1976, p. 23. Thomas Jefferson to John Jay, August 30, 1785.
6. Op. cit. footnote 4, p. 185.
7. Muskets, Rifles and Carbines, Arcadi Gluckman, Harrisburg, Pa., 1959, pp. 70-81.
8. The World of Eli Whitney, Mirsky & Nevins, MacMillan Co., NY., 1952, p. 146.
9. Op. cit. footnote 8, pp. 145, 146, 208.
10. The Whitney Firearms, by Claud E. Fuller, Huntington, WV, 1946, pp. 76, 77.
11. Op. cit. footnote 10, pp. 97, 98.
12. Op. cit footnote 5, pp. 10, 11, and Simeon North First Official Pistol Maker, North & North, Concord, NH, 1913, pp. 78-113.
13. Op. cit. footnote 5, pp. 10, 11, and Simeon North First Official Pistol Maker, North & North, Concord, NH. 1913, pp. 102-133.
14. Op. cit. footnote 5, pp. 12, 13, 26, and Hall's Breechloaders, R. T. Huntington, George Shumway, publisher, York, Pa., 1972, pp. 20-40.
15. Op. cit. footnote 7, pp. 216-220, and United States Military Small Arms, 1816-1865, by Robert M. Reilly, Eagle Press Inc., Baton Rouge, LA, 1970 pp. 33-37, and Arms Making in the Connecticut Valley, Felicia Deyrup. Northampton, Ma., 1948, p. 140.
16. American Machinist, "Development of Machine Tools in New England", by Guy Hubbard, Dec. 20, 1923, pp. 919-922; Jan. 24, 1924, pp. 129-132; Jan. 31, 1924, pp. 171-173; Feb. 7, 1924, pp. 205-209, and English and American Tool Builders, J. W. Roe, Yale University Press, pp. 186-201 (Chapter XV) and Appendix A, R. S. Lawrence biography, pp. 281-291.
17. Extra Census Bulletin, "Report on the Manufacture of Fire-arms and Ammunition", by Charles H. Fitch, Washington, Government Printing Office, 1882, pp. 4, 5.
18. Op. cit. footnote 14, pp. 48, 49.

19. Op. cit. footnote 16 , Roe, p. 286.

20. Op. cit. footnote 17, Part IV, "The Manufacture of Locomotives and Railroad Machinery", pp. 56, 57.

21. Sharps Firearms, Frank Sellers, Denver, CO, 1982, p. 32.

22. "Report of the Committee on the Machinery of the United States of America", Presented to the House of Commons in Pursuance of Their Address of 10th July, 1855", London, pp. 29, 30.

23. History of Smith & Wesson, by Roy G. Jinks, Beinfield Publishing, Inc., N. Hollywood, CA, 1977, pp. 3, 16-20.

24. Op. cit. footnote 16, Roe, pp. 292-294.

25. For a general overview see "Cyclopaedia of Useful Arts", ed. by Charles Tomlinson, London, c-1852, "Introductory Essay on the Great Exhibition of the Works of Industry of All Nations, 1851", I-XIIX (49), "The Great Exhibition 1851", by Yvonne FFrench, The Haverill Press, London, 1950.

26. Op. cit. footnote 21, pp. 28-48; and footnote 16, pp. 920-922, 172.

27. The British Soldiers Firearms 1850-1864, C. H. Rhodes, London, 1964, pp. 83-91.

28. Op. cit. footnote 22, pp. 9-11, 47-55.

29. Op. cit. footnote 22, p. 11.

30. The Story of Colt's Revolver, by William B. Edwards, Castle Books, NY, 1957, pp. 303-304.

31. Op. cit. footnote 22, pp. 11, 23.

32. Op. cit. footnote 22, p. 21.

33. Op. cit. footnote 22, pp. 75-84.

34. Op. cit. footnote 21, pp. 89, 90.

35. Ibid footnote 27, pp. 279, 280; and footnote 16, January 24, 1924, pp. 129-132.

36. The Influence of Early Windsor Industries Upon the Mechanic Arts, by Guy Hubbard, pub. in "Proceedings of the Vermont Historical Society" for 1921, 1922, 1923, p. 175.

37. Op. cit. footnote 7, pp. 415, 416, 433, 434, and Carbines of the Civil War, by John D. McAuley, Pioneer Press, Union City, Tenn., 1981, p. 113.

38. These conclusions by the Committee amply point out, by reading between the lines, the great difference then existing between American and British industry or between an alert and youthful industry and an aging industry shackled with regulations brought on by extreme positions taken by labor and management that should have been working together.

39. A History of Western Technology, Frederick Klemm (translated by Dorothy Waley Singer) Charles Scribner'sSons, New York, 1959, Fig. 4, and pp. 88-91.

40. Mechanical Universe, Bedini and Maddison, Transactions of the American Philosophical Society, Philadelphia New Series, Vol. 56, Part 5, 1966, pp. 30-33 and figs. 28-32.

41. Die Kunst dis Metalldreheus bie den Romern, by Alfred Muntz, Burkhauser Verlag, Basel & Stuttgart, 1972, see particularly pp. 18-30 and 39-40, also plates 31, 48, 66, 171, 173, 199.

42. Gears from the Greeks, Derek de S. Price, Science History Publications, 1975, A reprint of "Transactions of the American Philosophical Society" Philadelphia, 1974, New Series, Vol. 64, Part 7.

43. From a transaltion awaiting a publisher prepared for this author at the Smithsonian Institution. An Elizabethan manuscript translation into English recently discovered and belonging to the American Precision Museum is probably more important for publication. See also the following:

The Various and Ingenious Machines of Agostini Ramelli (1588), translated by Martha Teach Gnudi with supplements by Eugene S. Ferguson, John Hopkins University Press/Scholar Press, 1976.

De re Melallica, by Geogius Agricola, 1556, translated by Herbert Clark Hoover and Lou Henry Hoover, Dover Publications, Inc., New York, 1950.

Pyrotechnics, by Vannoccio Biringuccio, 1540, translated by Cyril Stanley Smith and Martha Teach Gnudi, MIT Press, 1963. See particularly pp. 307-318, concerning the finishing of guns and the arrangement of gun carriages.

A Theatre of Machines, by A. G. Keller, the MacMillan Co., New York, 1965. This book presents a very good overview and illustrations from the various early books on engineering and their authors, including much valuable material on the elusive Jaques Besson.

L'Art de Tourner en Perfection, by Pere Charles Plumier, Paris, 1749. This was written in 1693 and was first published in 1701. There is a little known English translation of the 1749 edition made and published by Paul L. Ferraglio, Brooklyn, NY, 1975.

44. The Timber Economy of Puritan New England, by Charles F. Carroll, Brown University Press, Providence, 1973, pp. 70, 110, 115.

45. American Science and Invention, by Mitchell Wilson, Simon and Schuster, New York, 1954, title page.