

The Gribeauval system, or the issue of standardization in the 18th century

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[\[French version: September 2016 - n°125\]](#)

From the Revolution to the Napoleonic Empire, French armies had the upper hand in Europe — mainly owing to the standardization of the artillery at the end of the 18th century by Jean-Baptiste Vaquette de Gribeauval (1715-1789), an officer and engineer. This standardization of the caliber of canons and the design of carriages (wheels and axles) presupposed techniques of production and measurement, and implied training artillery officers in the basic and applied sciences. Everything had to change at once: military doctrine, industry and techniques. Like the *Querelle des Bouffons* in opera, this highly controversial shift sparked a major controversy during the last years of the monarchy: the so-called Quarrel of the Reds and Blues, with reference to the color of gunners' uniforms before and after the reorganization of the artillery. Initially backed by the king, Gribeauval fell out of favor but was then reinstated and conducted his reform successfully. A presentation of this first big battle of industrial standardization in its historical context...

Between 20 September 1792, the date of the Battle of Valmy (which amounted to an artillery duel that ended with the Prussian army beating a retreat) and 18 June 1815, the date of the Battle of Waterloo (which put an end to the First Empire), the Revolutionary and then Napoleonic French armies dominated the European military stage.⁽¹⁾ This supremacy came from their mobility, which astounded enemies. The most spectacular instance was the swing toward Germany in August 1805 of the Grande Armée, which, stationed in Boulogne, had initially been instructed to embark for England. Advances took place so swiftly that the general commanding the Russian army, Kutuzov, on whose support his Austrian allies were counting, thought that the French were still along the English Channel while they had just hemmed in the Austrian army in Ulm. The French army owed this mobility and its considerable firepower to its artillery.

The French artillery had been designed and standardized in the waning years of the monarchy under what has been called the Gribeauval system. This system is probably the archetype of all the big battles

for standardization in contemporary industry. This is not a matter of coincidence. The artillery is required to have sometimes contradictory and often incompatible characteristics: to be robust, powerful, precise, stable, simple for use and upkeep, light and fast — all of this, of course, at a low cost. The army resignedly accepted for a long time a “*more or less felicitous compromise*” between these contradictory requirements — a compromise resulting from a “*roughhewn price quote that depends on the moral, social, intellectual, technical and economic conditions at any given moment*” (CHALMIN 1968:466). How was this approach overhauled? How did the Gribeauval system develop? How was it put into application? The major quarrels about standardization are not merely technical and industrial but also, as we shall see, political and social owing to their implications.

⁽¹⁾ The authors would like to thank the participants of the AEGIS writing workshop of 8 April 2016, who helped them improve this text, which has been translated from French by Noal Mellott (Omaha Beach, France).

The military controversy

Invented in the 14th century, artillery had the function of demolishing the ramparts around medieval towns or defending them during a siege. Problems of standardization arose from the start. Each foundry felt it fully mastered the best techniques and tried to make innovations without giving thought, apart from the ambition to outstrip them, to what its competitors were doing. Consequently, the cannon parts were not comparable with each other: carriages, bores, the caissons containing cannonballs and gunpowder, etc. — everything depended on the mill that had made them. Each cannon (or nearly) had its own projectiles. This was an especially acute problem for the armies of Charles V, their equipment reflecting the diversity of the Holy Roman Empire. The cannons from Austrian, Spanish or Flemish foundries were not at all compatible with each other. The first attempt at standardization was to codify calibers so as to reduce the number of them.

The purpose of artillery changed during the reign of Gustavus Adolphus (Gustav II, 1594-1632) of Sweden. Upending current tactics, this king was the first to use light, mobile guns grouped in batteries. Cavalry could thus be sheltered from attacks by the enemy infantry and held in reserve for launching a potentially decisive offensive. French generals (such as Gassion, assistant to the young Condé) managed to gradually introduce the Swedish king's ideas in the French armies.

Nevertheless, wars at the end of the 17th century, in particular those conducted by Louis XIV, remained traditional. Armies moved slowly over routes, which could not be used all winter long and could barely be used in the summer during bad weather, before reaching a city to besiege and then moving on to the next. This sort of warfare was still being waged at the start of the 18th century. A distinction was made between “battery guns” (the heavy cannons used for sieges) and “field guns for a Swedish-type campaign”. Technically, these two types of cannons were quite different and were not at all handled alike. On the battlefield, the Swedish-type of artillery had to be positioned with regard to the infantry and cavalry, whereas the heavy cannons served only during sieges. It should be pointed out that the heavy cannons were 16- or even 20-pounders, the numbers indicating the projectile's weight in French pounds.⁽²⁾

The actions of one of the greatest generals, the Marshal of Saxony, illustrated this hesitation. Count Maurice's brilliant campaign in 1745 started with the capture of Tournai with the help of siege artillery. A little more than a month later, the Battle of Fontenoy was won because batteries (Swedish-type artillery) were quickly redeployed to curb an English attack that

was threatening to split the French army in two. Nonetheless, in his posthumous *Mes rêveries* (1757: book I, chapter 7), Maurice de Saxe stated his preference for an army exclusively equipped with 16-pounder cannons drawn by oxen. These beasts of burden, he wrote, could be put out to pasture more easily than horses and, when food was scarce, could be slaughtered so that famished soldiers would have something to eat. We might at least conclude that he apparently did not set store on the speed for moving troops!

Meanwhile, Frederick II, who did not like siege warfare and had little talent for it, was clearly orienting the Prussian army toward maneuver warfare. Prompted by this example, some pundits in France also called for a “*light and manageable*” artillery “*always in movement*” (CHALMIN 1968:487).

In the mid-18th century, two schools of thought stood at odds. This standoff — technical, political and industrial — sparked a quarrel. This controversy, violent in words, foreshadowed the battles of standardization in modern industry (CORBEL 2005).

Before Gribeauval

On 7 October 1732, Louis XV signed a royal order for a much needed reorganization of the artillery. It instituted, under the influence of one of the best artillery officers at the time, Jean-Florent de Vallière, what has been called the “Vallière system”. To put an end to the anarchy in calibers, only guns firing projectiles of 24, 16, 12, 8 and 4 pounds would be made in France.

This step was important but not decisive, since no account was taken of the choice between destructive firepower and mobility. All artillery guns, even those of lighter weight, were still long and, as a consequence, heavy. They were made for sieges, for attrition rather than maneuver warfare. For a 4-pounder Vallière cannon, the barrel's length equaled 26 times the caliber, in comparison with a ratio of 17 for a Swedish-type cannon. The weights were 1,150 pounds for the first and 600 pounds for the second. The variance for artillery of a Vallière type was much too large for regular windage (*i.e.*, the difference between the diameters of the cannonball and of the bore). Therefore, the firing range and precision were not optimal. Furthermore, only the sizes of calibers had been fixed. Everything else, in particular the carriages, still varied from province to province. In fact, Vallière refused to have any changes made to the carriages.

In late 1754, the minister of Warfare, Marc-Pierre de Voyer de Paulmy, Count of Argenson, learned that Frederick II had decided to adopt a light cannon for the Prussian army — barely one hundred times the weight of its projectile. Although Franco-Prussian relations were not all that cordial, Frederick II accepted, probably as a token of goodwill, for France to send an envoy. He said he would place at the French officer's disposal all requested information. The officer that the crown chose to send was Jean-Baptiste Vaquette de Gribeauval. Coming from the minor nobility and having a humble financial situation, Gribeauval had been oriented

⁽²⁾ Since the French pound, 489.5 g, weighed more than the English pound, 453.6 g., an English cannonball of 16 pounds was not compatible with a 16-pounder French cannon; and vice-versa.

toward the artillery, since he had neither the means nor the contacts that would have opened the way toward joining the infantry or cavalry. Gribeauval arrived in Berlin on 20 May 1755. Upon returning to Paris, he submitted to the king a report critical of the Prussian equipment. The king asked for proof. Gribeauval, the only person capable of giving it, was thus introduced to Louis XV.

The Seven Years' War (1756-1763) broke out a year later. Aware of her army's weak points, Maria Theresa of Austria, allied with France, asked Louis XV to send engineers trained in siege warfare. Since the time of Vauban, French engineers were known to be the best in this field.

Appointed *Oberstfeldwachtmeister* of the imperial armies, Gribeauval, 43 years old, conducted his first siege, the town of Neisse/Nysa (now on the German-Polish border). Within a few months, he became the specialist of this type of combat in the Austrian army and won fame at Schweidnitz/Swidnica, which he had been assigned to defend. The Prussian king would spend months taking back this town, which the Austrians had captured in a few days. Frederick II was piqued, as he stated in a letter: *"A certain Griboval [sic], who is full of himself, and ten thousand Austrians have stopped us up till now"* (quoted in NARDIN 1982:83). He was so vexed that he refused, at first, to meet Austrian officers after the town fell, but he then changed his mind and even invited them to his table. This battle created a considerable stir in Europe: a French officer had stood up for several months to the Prussian king personally in command of the siege. Following this event, this officer found himself in a sensitive position. The Empress wanted to keep him in her army and awarded him the Maria Theresa Order, a very rare distinction for a foreigner; but Louis XV definitely wanted him to return to his homeland. Gribeauval finally decided to go back to France.

Drawing lessons from the war, Count Étienne-François de Choiseul, secretary of state for War (but, in fact, quasi prime minister) proposed a reform of the army to Louis XV. His diagnosis was clear: France thought it had the best artillery in Europe. This fixed idea might still be true for siege artillery, he told the king, but it no longer held for field artillery. Modernizing the army was imperative. To do so, Choiseul proposed appointing Gribeauval while keeping Vallière as the nominal officeholder.

This would be a sound decision, since the prince of Liechtenstein had already reformed the Austrian artillery, which had proved to be the best in Europe during the war. Gribeauval knew the ins and outs of the reform adopted by Austria. Having analyzed its weak points, he thought he could fix them by making a system even better than the Austrian one: *"This artillery has a big effect in battles owing to the large number [of pieces]. It has advantages over France's artillery, which has its own advantages over it. An enlightened man, without passion, familiar with the details and creditworthy enough to go straight to the good solution, would take from these two artilleries what could be used to make one artillery that would be decisive in nearly all*

field warfare actions. But ignorance, pride or jealousy always interferes — the devil himself. We cannot change that like changing clothes. It costs too much, and there's too much danger if we are not sure of success" (quoted in HENNEBERT 1896:36).

The Gribeauval reform

Gribeauval decided to take on the devil's own job: he launched a sweeping reform. His starting point was to differentiate between siege and garrison artillery, coastal, naval and field artillery. For field artillery, a system was to be designed allowing for mobility and heavy firepower — which, at the time, seemed contradictory. To make a lighter cannon without reducing its projectile's weight, the simplest solution was to shorten the barrel. So the decision was made that the barrel's length would equal 18 calibers, *i.e.*, 18 times the cannonball's diameter. The Prussians had settled on a ratio of 15, but Gribeauval held firm: 18 was better for the gun's solidity. Time would tell that he was right: some of the cannons made during the reign of Louis XV would still be part of the Grande Armée's equipment.

With a shortened barrel however, a cannon could not shoot as accurately nor as far. It was agreed to maintain a range of 500 *toises* (about one kilometer, one *toise* being approximately six feet). To avoid fire dispersion, cannonballs had to be perfectly spherical, and the variance between the diameters of the ball and of the bore had to be kept small. A major industrial and technical problem cropped up.

Gribeauval turned to Johann Maritz from Berne. This founder of Swiss origin proposed a revolutionary method. Till then, cannons had been cast in a mold with a core inserted to create the hollow area corresponding to the bore. Once the cannon was cast, the core was taken out; and the hollowed out space was reamed so that the bore would be as even as possible inside. In contrast with this core casting, Maritz — and this was his strong point — cast a cannon as a solid piece and then bored a hole in it afterwards. He even claimed to have made a perfectly even bore down to a millimeter. He invented a brand-new machine for this feat.

The problem still hanging was to improve the roundness of projectiles so that shorter (and therefore lighter) cannons could be made with a firing range and a precision equal to traditional ones, which were longer and, therefore, heavier. The first guns made under this new system seemed satisfactory.

In late April 1764, Choiseul ordered Gribeauval to test and compare the new and old cannons in Strasbourg. As he full well knew, many in the artillery corps firmly opposed the new system. Everything was to be very carefully organized. In particular, several opponents of Gribeauval would sit on the committee in charge of writing the report. All the officers at the garrison were asked to attend the demonstration. The test was tightly designed. Two rows were erected of wooden posts spaced approximately sixty feet apart. Each cannon's

firing range would be measured accurately along with fire dispersion.

A report was forwarded in August to the minister. There was little difference in the firing range between the light and heavy pieces: from 5% to 10% depending on conditions. By elevating the angle half a degree for the lighter cannons, they had a range equivalent to the heavier pieces. Fire dispersion did not amount to much. An extreme test was ten run on the cannons: firing nine hundred shots in a row, conditions resembling actual warfare. Might the lighter cannons not overheat much faster than the heavier ones? The test proved that this did not happen.

Gribeauval thus demonstrated that the new cannons were as efficient as those from the Vallière system of 1732, but they were much lighter and easier to maneuver. He reckoned that only the 12-, 8- and 4-pounders should be retained,⁽³⁾ the 3-pounder being too inefficient. The 16-pounder cannons, too heavy, would be kept in reserve for eventual use against fortifications that withstood attack. But they would not accompany the army during campaigns, since the 12-pounders were more than adequate to breach the usual fortifications.

Gribeauval did not hold still at this point. For the lighter cannons to yield a decisive advantage on the battlefield, the whole system had to be redesigned (ROSEN 1975).

When a cannon was in firing position while being transported, its weight was unevenly distributed. The Austrian solution for the carriages was adopted: the barrel had a different position for transportation and for firing. However many technical improvements went far beyond what the Austrians had imagined. Wooden axles on cannons were replaced with iron ones. A screw replaced the wood peg that, pushed in at variable lengths, regulated the angular height. A compartment was added to the carriage for balls and powder; once positioned, a cannon could thus be fired without having to wait for the caisson carrying munitions. Besides, the caissons were lighter, and all vehicles now had much sturdier steel axles. Two standardized sizes were set for the wheels of carriages, caissons, forges, etc. Since axles might break, the decision was made to equip artillery units in the field with forges. The equipment was designed so that a cannon could be released from the team drawing it without having to unharness the horses; this considerably saved time when setting up a battery.

Besides his excellent work in the foundry, Maritz was a remarkable mechanic. He advised Gribeauval on all points in the new system. Although the report by Gribeauval to Choiseul was improved with additions till 1789, it was not substantially altered. The whole Gribeauval system was ready in 1764. Once implemented, it would stay pat till the French Revolution (NAULET 2002).

⁽³⁾ Demonstration of the firing of an 8-pounder cannon of the Gribeauval system on <https://www.youtube.com/watch?v=kx2lQViUmkc>.

Oddly enough, the royal order for reforming the artillery was never published. This was rare but not exceptional. Expecting lively opposition from the army, political authorities tried to avoid rocking the boat while retaining the possibility of reversing course if need be.

The new system also implied reforming how the armies operated. Till then, gunners formed a separate corps. In the field, they slept in the artillery camp with their equipment. During combat, they were on temporary assignment with the infantry. There was no specialization: a detachment might operate a 4-pounder one day and a 16-pounder the next. Now, each detachment was specialized in a type of artillery and made responsible for the cannon and its maintenance. The detachment could stay with the infantry unit where it was assigned. Knowing that it would (logically) be necessary to have the gunners mount horses, Gribeauval expected an outcry. He settled on proposing that they ride in carriages, a solution adopted in Germany. But Choiseul put this decision on hold. To signal that the reform marked a turning point, gunners would now wear blue instead of red uniforms.

From an industrial perspective, the new system could work only if standardization were complete. Previously, each province used its own system of measurement, whence variances in calibers. Gribeauval imposed on everyone the so-called Châtelet *toise*. Standardized copper measuring rods were distributed in all arsenals. No one had ever before worked under conditions sharing this degree of precision. Controls upon delivery were now systematic. They were facilitated by ongoing improvements in the instruments invented for the task, such as the callipers that, by measuring the bore with unprecedented precision, would help reduce windage (PEAUCELLE 2005:60). “*Now — something not imaginable previously — a rim made in Auxonne could be fully adjusted to a hub made in Strasbourg or Metz*”, exclaimed du Coudray, a captain who appreciated the interchangeability of parts (NARDIN 1982).

Costs were expected to explode. But nothing of the sort happened. On the contrary and to everyone’s surprise, standardization with such a high level of precision came at a relatively moderate price — owing to economies of scale and the learning curve.

A technical controversy and political about-face

Vallière was succeeded by his son as director-general of the artillery. The son had a book by his father, who had died a few years earlier, published in 1768. He added an appendix of his own to it: “Reflections on the principles of artillery”. Therein, he reiterated the usual criticisms: light artillery pieces had a shorter range, and their fire was less accurate. Besides, they overheated too fast; and the reduced windage prevented firing red-hot projectiles. This was true: a cannonball dilated by heat could no longer be loaded in a barrel more precisely calibrated to the ball’s diameter (whence the

invention of the howitzer). In conclusion, the system from 1732 should be preserved, since it had proven itself, especially with respect to mobility.

This first criticism of the reform of the artillery under Choiseul and Gribeauval opened a floodgate for what would appear in several memoirs — usually published in London or Amsterdam to elude censorship. Doubt was cast on the Strasbourg test, which Saint-Auban, one of Gribeauval's most vehement opponents, described as a set of “mysterious operations covered in a darkness inscrutable to any human eye that was not thought to be timid or accommodating” (quoted in NARDIN 1982:168). Recall that Choiseul had taken the precaution of putting opponents of Gribeauval on the committee and that the tests were performed in the presence of all officers at the garrison, who were mustered for the demonstration. In these memoirs, any old claim could be made: the new guns were less sturdy and less accurate than the older ones; the carriages were too fragile; gunners' specialization in given types of cannon was a regression compared with their former versatility, which had proven useful on the battlefield; the screw for adjusting the angular height became clogged with soot and wore out; promoting noncommissioned officers to the rank of officer of artillery made them arrogant and incompetent; and so forth. Above all, the cost of Gribeauval's full reform alarmed financial services, which would urge decision-makers to review their position.

The debate flared, and authorities felt it necessary to organize a new demonstration. The test conducted in Douai on 12 July 1771 showed that heavy cannons had a range 15% longer than light ones but that fire dispersion was the same for both. The lighter cannons also had twice the recoil of heavier ones. The test was made to add more gunpowder in an effort to increase the range of the light pieces, but to no avail. In some cases, the range was even shorter. This finding should have come as no surprise, since Bernard Forest de Belidor, professor of mathematics and artillery, had proven a few years earlier that the optimum range was attained using a dose of gunpowder equal to a third of the cannonball's weight. Following the Douai demonstration, Louis XV began having doubts. He decided to fall back on the former system. The symbol of this reversal: gunners would keep their old uniforms.

The only voice speaking up for the new system came from Philippe Tronson du Coudray, the scanty 32-year-old captain of the work crew. Coudray, whom Gribeauval had appointed, circulated several pamphlets in favor of his mentor's system and against the about-face. Besides, what to do with the equipment acquired over the previous seven years? The stock of projectiles and new guns would have to be modified for the sake of compatibility with the old equipment that would be redeployed. The circumference could be reduced, it was imagined... but Coudray explained how dangerous this was, given the friability of the cannonballs.

The Academy of Sciences joined the fray. Buffon, who liked to claim to be expert in metallurgy, emitted an opinion. Coudray refuted him. The fray involved

name-calling between “Reds” and “Blues”, the “fashionable” and “old whigs”! To make the quarrel resound, Saint-Auban started publishing articles in the *Journal militaire et politique*. According to the editor, “*There is more than the presumption that, had (as is the custom) he asked the ministers for permission to make public his remarks against adopting the new system, the examination of the manuscript would have been sent to his opponents and he would thus have been forbidden to express his opinion freely. Instead, the editors and censors of the learned journals of physics, encyclopedists and others have found nothing in M. de Saint-Auban's writings that could prevent the printing thereof*” (quoted in NARDIN 1982:286-287).

This dispute impassioned public opinion, even though it understood next to nothing about the topic. Meanwhile, since 1752 and the performance in Paris of *La Serva Padrona* [*The Servant Turned Mistress*], the country was shaken by the quarrel between supporters of French opera, descended from Lully and Rameau, and of Italian opera, revolutionized by Pergolesi (FABIANO 2005, KINTZLER 2011). These quarrels extended beyond a narrow circle of experts and drew enthusiastic attention of all strata of the population. Given that explicitly political debates were forbidden under the monarchy in the mid-18th century, they instituted what Jürgen Habermas (1988) has called the public sphere, in preparations for free, open debate, as would happen during the French Revolution.

A complication: while reforming the artillery, Gribeauval had tried, in addition, to have the guns used by the infantry replaced (PEAUCELLE 2005). Once again, the new muskets (Model 1777) would give an advantage to French armies during the Revolutionary and Napoleonic wars. However Gribeauval's opponents used a shady affair concerning the previous generation of muskets to stain his reputation. Gribeauval fell into disgrace.

Gribeauval's comeback: The peak of his career

The eclipse did not last long. Emmanuel-Armand de Vignerot du Plessis-Richelieu, Duke of Aiguillon, was appointed minister. Though favorable to Gribeauval, he knew he would have to play it tight. How to reverse, once again, the king's opinion? He cleverly put together a committee of four Marshals of France who had commanded an army in Germany: Richelieu, Contades, Soubise and Broglie. The selection was unquestionable: these men had gained the most experience in recent wars, during which they had won fame and used the equipment in question. But the selection was not neutral: Aiguillon knew that these officers had experience with lighter pieces of artillery and preferred them. Vallière (the son) and Gribeauval expounded their ideas before this prestigious group. As Aiguillon expected, the Marshals unanimously sided with Gribeauval.

After a stroke of hard luck — Louis XV died on 10 May 1774, and Aiguillon was dismissed — Louis XVI chose as replacement de Mouy, who was in

favor of Gribeauval. The royal order of 3 October 1774 adopting the Gribeauval system even foresaw that promotions for gunners would be made on the basis of their qualifications (through a vote by those in the rank above them). This provision — utterly contrary to what existed in the infantry or cavalry, which nobles dominated — vouchsafed the artillery corps's technical competence. When, in July 1789, noble officers emigrated, thus disorganizing the army, they were usually replaced with artillery officers selected for their qualifications alone. Among them would be a young Corsican from the minor nobility...

The quarrel smouldered in memoirs and pamphlets, until it burned out for want of combatants: Vallière died; and authorities forced Saint-Auban, the staunchest opponent of the Gribeauval system, to hold his peace. Du Coudray had to leave the country. Above all, the new system's 4-pounder cannons proved effective during the difficult campaign in Corsica in 1769, when Noël Jourda, the Count of Vaux, heavily relied on them.

Gribeauval could now try to fully deploy his system, in spite of the financial situation, which would deteriorate due to the support that France was lending to the American insurgents. It is worth mentioning Philippe Henri de Ségur, minister of War, who made a decision that would play a part in triggering the French Revolution: a royal order of 22 May 1781 required that nobles have proof of four quarters of nobility in order to become military officers. This decision eliminated the sons of the bourgeoisie and of Nobles of the Robe from the king's service. The discontent it sparked would burn on. All the same, this minister let the artillery to Gribeauval, since it had, it was believed, attained a degree of efficiency such that no major reform was required. A royal order of 3 November 1776, written under Gribeauval's supervision, enabled him to deploy his system. By the 1780s, it was in place. A last step was to finalize the new Gomer mortars, which would be used during all the Revolutionary and Napoleonic wars.

Gribeauval then devoted all his energy to training officers and gunners.⁽⁴⁾ Engineering theory was to be taught: mathematics, the physics of metal and wood, metallurgy, mechanics, smelting, draftsmanship, topography and lessons about military campaigns. The practical part of course work (three days a week) involved learning how to form batteries, maneuver, manipulate munitions and artillery pieces, and fire cannons.

As for industry, Gribeauval helped Ignace de Wendel and William Wilkinson set up in Le Creusot an ironworks with a forge for casting cannons using coke as fuel. He engaged in a last battle for a reform: Frederick II had created mounted artillery units a few years earlier. The cavalry was capable of capturing a position, such as a hilltop, but unable to keep it long enough for the infantry to arrive. Setting up an artillery battery in such a position would be a tactic useful for withstanding a counterattack. Austria had adopted this tactic, and it was impossible to imagine that France should not do so. But the situation

⁽⁴⁾ École Polytechnique is the Revolutionary heir of the Gribeauval artillery schools.

was blocked because transportation was in the hands of private operators instead of the army. The risk of a dispute was too high, and the ministry of War under Ségur (as under Choiseul previously) backed down. The French Revolution would make this additional step forward in 1791.

For twenty years, Gribeauval introduced the first major system of industrial standardization in history, even though we cannot explain exactly how, with no previous experience, he achieved such a colossal task: *“the realization and use of construction tables required a constant effort that continued till into 1789. They had to be made for all parts and materials: cannons, munitions, caissons, carts, field forges, carriages, axle units, drays, etc., as well as the tools and devices used for all sorts of control and verification (lunettes, callipers, etc.). There were, too, the drawings of the special machines for boring, reaming or cutting bolts. Related regulations, just as useful, set the sizes of the semifinished products to be used, such as pieces of iron (flat or square), sheet metal, bars (round or rectangular), wooden parts, ... the tools for artillery: drill bits, screw taps, tappers, etc. Each of these tools bore a standardized mark, a crowned ‘A’ (Royal Artillery Corps) followed by two letters indicating the origin (MA for Maubeuge, SE for Saint-Étienne, etc.)”* (NARDIN 1982:340). To improve on these parts and materials and foster ongoing innovations, Gribeauval supported setting up a special shop for designing prototypes in Saint-Étienne.

Epilogue

We expect that Gribeauval would have been promoted Marshal, but he did not meet the requirement of four quarters of nobility set by Ségur. He was not among the eleven Marshals of France appointed in June 1783. He died on 9 May 1789, as the Estates-General was meeting. He did not, therefore, witness his system's triumph on Europe's battlefields.

Taking stock of the Gribeauval system

It is worthwhile reviewing several points in this system.

The first, not all that important, has to do with the controversy about what Gribeauval himself actually contributed to his system. From the start of the quarrel, Saint-Auban accused him of not having invented his system, of having borrowed nearly all his ideas from the Austrians and Prussians. After all, Gribeauval had probably come upon the forecarriages with big wheels, the long shafts (which made it possible to pull the cannons while trotting or even galloping, and not just at a walking pace), the iron axles, the copper pads for the hubs, etc. in a publication dating from 1722, a book he did not mention by a certain Camus: *Des forces mouvantes*. Oddly enough, English-speaking historians have rekindled this controversy by claiming that the famous Gribeauval system was but the Liechtenstein (i.e., Austrian) system (MACLENNAN 2003). The question seems insignificant. After all, the superiority

of the French artillery and, therefore, of the Gribeauval system was repeatedly demonstrated on battlefields during the French Revolution and under Napoleon.

Two more important points have to do with standardization itself.

First of all, the originality and strength of Gribeauval's approach was, unmistakably, that it was systemic. Gribeauval introduced, for the first time in history, a standardized industrial system. This required inventing more accurate measuring instruments, setting up workshops capable of designing prototypes, devising methods of production capable of achieving the requisite level of quality, and instituting systems of control to make sure that all production sites had the same level of quality and produced exactly the components required. Given this systemic approach, everything had to change at the same time in the political, industrial, military, scientific and social spheres.

As for industry, this precise, detailed standardization boosted the integrated manufactories that implemented serial production with tight quality controls. Complaining about this, manufacturers called for higher prices.

As for education, schools had to be founded or reformed to provide the best possible scientific and technical training to the persons who would be using the new equipment on the battlefield.

As for the army, warfare had changed. Till then, it mainly consisted of laying siege to fortifications; but now it required mobility and firepower, with, as a consequence, the carnage under the Revolution and the Empire, the first slaughtering fields of modern times. This trend entailed an organizational change: the artillery, an autonomous corps during siege warfare, was now integrated with other army corps for maneuvers, even though its differences, owing to the skills and qualifications required, persisted.

As for science, prototypes were tested, and the science behind the working of metals came under discussion.

As for the political and social spheres, the need for expertise cast doubt on the monarchy, precisely: on the very foundation of an aristocratic society, namely the principle that the nobility was the only group capable of assuming military offices. Although the emigration of noble officers as of July 1789 disorganized the French army in the short run, it ultimately made room for deserving talents. Young officers who were not nobles but had been trained in artillery schools soon took the places left vacant by the *émigrés*. They would form the brilliant staff of French armies during the Revolutionary and Napoleonic periods.

Secondly, another lesson to draw from the Gribeauval reform is that battles of standardization are both technical and political, the two dimensions overlapping. Given the uncertainty that prevails when they are pitched, these battles are not purely technical. This falls in line with science studies of scientific controversies (LATOUR 1989, CALLON *et al.* 2001). The three tests run for settling the quarrel make this point.

The Strasbourg test had a rigorous methodology. Measurements were accurate, owing to the posts staked sixty feet apart. Furthermore, the cannons were tested under an extreme condition: continuous firing, which raised the temperature of the barrels. Choiseul fully understood that this technical demonstration had a political dimension. For one thing, he made sure to appoint to the official committee avowed opponents of the new system. For another, he tried to reach out, at least indirectly, to a broader public by authorizing all the officers at the garrison to attend.

The second test at Douai, though intended to be purely technical, was — as everyone knew — political. It induced Louis XV to make an about-face, in a return to the Vallière system. But the demonstration proved unsatisfactory for technical reasons. Either the persons who conducted it were not familiar with the technical and scientific discoveries made by Belidor; or else they willfully ignored them. Although the decision to be made fit into a political context, it had to be as rigorous as possible scientifically.

The third test, organized by Aiguillon, was highly political. The final users — the Marshals of France who had taken part in the last major war (with Prussia) — were entrusted with conducting it. They heard both parties, Vallière's son and Gribeauval; and then expressed an opinion. Politically, it was hard to challenge their expertise, even though, from the start, everyone knew they supported a Swedish-type of artillery.

Let us bear in mind that this quarrel concerned military equipment. The level of technical uncertainty is very high, since military equipment is actually tested only in a real-life situation — on the battlefield. For this reason, military officers usually prefer limited conflicts, which allow them to form a clear idea about the performance of the material at their disposal. The occasion for testing the Gribeauval system arose during the limited war conducted in Corsica, when the Count of Vaux made heavy use of the new 4-pounder cannons. This settled the quarrel in the most convincing of ways.

Conclusion

Beyond the history of industry during the 19th century, on the far side of the history of politics, much of what would occur between 1792 and 1815 — the establishment of democracy against the aristocracy and the growing power of expertise in democratic society — was played out during the often overlooked battle for the standardization of artillery. This battle was conducted by a man who imagined a system, who took interest in any inventions that could be incorporated in it, who set off “bunches” (to borrow from Schumpeter) of innovations, who managed to install the system over a twenty-year period, during the reigns of two kings, and who did all this in spite of political setbacks and the repeated appointment of new ministers.

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