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Louis XIV: Patron of Science and Technology

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Louis XIV during the fifty-five years of his personal reign (1661-1715) created the institutional foundations for the science and technology of France. These institutions were outwardly an attempt both to meet the needs of the French state for technical advice and to provide professional scientists with the necessary support for pure scientific research. In a less obvious sense, the origin and evolution of these institutions represented an attempt on the part of the monarchy to disentangle the pursuit of knowledge from the prevailing system of political patronage and from the political and religious speculation that fed the social conflicts of the period. By the end of the seventeenth century, Louis XIV and his ministers had attained these goals and set French science and technology on the high road of success for the duration of the eighteenth century.

The institutions of science and technology took several forms. The Royal Academy of Sciences was established in 1666. Within the Ministry of the Navy and Colonies, several technical advisory bureaus were created, among them the Bureau of Maps and Plans in 1696. A large corps of professional engineers emerged within the Service of Fortifications in the 1670s and 1680s. Of these institutions, the Royal Academy of Sciences was preeminent in terms of its research in the sciences and the advisory role it assumed for the major technological enterprises of the government.

ORIGIN OF THE ROYAL ACADEMY OF SCIENCES

The fifty years preceding Louis' personal reign were both a period of scientific discoveries that changed the fundamental notions about physical reality and a time of general freewheeling intellectual speculation that tested the boundaries of political and religious orthodoxy. In 1610 Galileo had used a crude telescope to discover the mountainous terrain of the moon, and in 1644 Torricelli performed a number of convincing experiments to demonstrate the existence of a vacuum. Both discoveries challenged the accepted Aristotelian explanation of physical phenomena. In 1628 William Harvey proposed the theory that blood circulates in the body. For the first time perhaps in the history of mankind, a number of man's most perplexing questions seemed capable of definitive answers. The temptation to extrapolate this mode of inquiry into the realms of faith, law, and society was irresistible.

During the 1640s and 1650s, various groups in French society engaged in acrimonious debate and confrontation, often supporting their positions with either the ideas of the new learning or the traditional knowledge of the past.¹ At stake was not just the truth of their arguments but the correctness of a body of knowledge that justified the special privileges accorded these interest groups. The Paris Faculty of Medicine defended the traditional Galenic medicine against new ideas on the circulation of blood and the use of metallic compounds for medicinal cures. By law only graduates of the Paris Faculty of Medicine were allowed to practice in the northern part of France around Paris, yet proponents of the new medicine and graduates of other medical schools were attempting to establish themselves in the vicinity of Paris. The theologians of the Sorbonne strongly opposed the implications of Cartesian philosophy, especially the implications of the dualism of mind and body for the doctrine of the sacraments and Thomistic theology in general. Such a philosophy greatly undermined the prerogatives of the ordained clergy in the administration of the Eucharist, and

the Sorbonne was eventually able to create legislation forbidding the teaching of Cartesianism in the universities.

The most pervasive ideologically based conflict of the 1650s and 1660s was between the Jesuits and the Jansenists. The points of conflict were not just theological but ranged over moral conduct, philosophy, and the rights of the French Church. A number of Jansenists embraced the new ideas of Copernicus and Galileo, while the Jesuits in general supported a traditional cosmology. The danger of this conflict for society and the state was that other groups such as the Parlement of Paris, the Sorbonne, and the parish clergy in general all became engaged in the conflict.

Much of the debate and turmoil was centered in Paris, which was something of a magnet for many natural philosophers and intellectuals. They congregated in groups to discuss and argue Cartesian science, the meaning of comets, medical remedies, the proper functions of music and literature, or whatever came to mind. One such group was the Bureau of Address, which was a sort of public forum at which all types of topics were debated. More learned in approach were small groups that met in private homes.

Although these meetings were well suited to the discussion of history, philosophy, and literature - the host nearly always had a large personal library for the convenience of his guests - they did not serve the needs of experimental scientists. As a consequence, questions of science often degenerated into philosophical wrangling. The Montmore group finally disbanded because of the ill feelings generated from this type of pettiness. The more experimentally minded scientists began to meet at the home of Melchisedech Thevenot, but the very expense of experimental equipment limited the scope of their work.²

Many scientists and literary men sought protection and financial support from the leading figures of the realm. The death of Cardinal Richelieu in 1642 and of Louis XIII in 1643, followed by the revolts of 1648-52 known as the Fronde, had opened the way for a number of these leading figures, some of whom were related to the king or in the king's government, to build independent bases of political power apart from the king himself. The financial support offered by these "grandeess" to scientists and intellectuals, while often motivated by a genuine interest in the state of knowledge, was seldom disinterested or untainted by the political uses to be made of such patronage. Gaston, Louis XIV's uncle and a rebel during the revolts of the Fronde, subsidized a large number of intellectuals and took a special interest in the science of botany. Nicolas Fouquet, Louis XIV's Superintendent of Finances, whom Louis later imprisoned, gained a reputation in the 1650s for his generous support of literature and scholarly research.

To counter the political power of these "grandeess," Louis XIV in 1661 assumed responsibility for the daily business of government and surrounded himself with a select group of loyal advisers and ministers of state. The most prominent advisor to emerge at this time was Jean-Baptiste Colbert (1619-83), Secretary of State for the Navy and Colonies, Controller General of Finances, and Superintendent of Royal Buildings.

Colbert worked hard, not only to assert the authority of the king but to rationalize the procedures of government finance, the legal system, and the administrative bureaucracy. Colbert was not, however, ignorant of the fundamentals of politics. Hence he took steps to create a loyal group of supporters, both within the government administration and at court, to advance the cause of his policies, to offer advice on policy, and to gather information.

Colbert had grasped the importance of supporting the scientific and literary community, not only as useful servants of the government but as agents of his personal political career. In 1655, while still in the service of Cardinal Mazarin, he had commissioned Pierre Costar and

Gilles Menage to prepare a list of scholars worthy of royal financial support. The list was prepared, but it was Colbert's political rival, Nicolas Fouquet, not Colbert, who was successful in obtaining a number of government pensions for this group. Fouquet, who was Superintendent of Finances from 1655 to 1661, created a clientele of intellectuals beholden to him for patronage. They would often gather at Fouquet's country estate, Vaux-le-Vicomte, or at his Paris townhouse in St. Mande. Among Fouquet's clients were the mathematician Pierre Carcavi, the physician Marin Cureau de La Chambre, and the physiologist Jean Pecquet.

Fouquet's ambition was to replace Cardinal Mazarin as the first minister to the king, and his patronage of the intellectual community was a stratagem to gain their support. On Mazarin's death in 1661, however, Fouquet was blocked in his goal by Colbert, who convinced Louis XIV that Fouquet had embezzled state funds and was a threat to the king's own power. Fouquet's arrest in 1661 and his subsequent trial were a blow to the scholarly community. In 1662 no scholars or men of letters received their pensions. Colbert became Controller General of Finances and let it be known that he was in a position to find pensions for deserving scholars and men of letters. Most of those who had received pensions by the good graces of Fouquet now switched their allegiance to Colbert. Those who remained loyal to Fouquet during his trial received no financial support and a few even went to prison with Fouquet.³

In 1663 Colbert created a group of scholars who advised him on the arts, scholarship, and the distribution of pensions. At this time Colbert received correspondence from several quarters, all suggesting that it would be well to organize the king's support of the intellectual community into some sort of academy. The suggestions varied in the type of scholarship they emphasized, but all agreed that such an institution would benefit the king with good advice and greatly enhance his reputation among the nations of Europe. They also agreed that questions of government policy and articles of faith should not be discussed and that the principles of reason and objective discourse should govern the exchange of ideas.

Following the design for an academy suggested by Charles Perrault, a member of Colbert's advisory group, Colbert created in 1665-66 a General Academy composed of scientists, historians, linguists, and philosophers. This caused a good deal of opposition from the established professional academic groups, notably the Sorbonne and the Faculty of Medicine. After considering the consequences of doing battle with these groups, Colbert disbanded the General Academy and created in its place the Royal Academy of Sciences.

Having originated as a response to the political context of the intellectual community of France, the Royal Academy of Sciences and the technical institutions that were created after it now responded to the needs of the state. These in turn were dictated by the policy concerns of the particular ministers of state who handled cultural affairs. In the period 1661 to 1715, three ministers of state dealt directly with scientific and technical matters. They were Jean-Baptiste Colbert (1661-83), Francois Michel Le Tellier, the marquis de Louvois (1683-91), and Louis Phelypeaux, the comte de Pontchartrain (1691-1715). Each pursued different policies for the state of France, policies that in turn reflected the wishes of Louis XIV himself, and had direct effects on the demands made of the new institutions of science and technology and the work they produced.

SCIENCE AND TECHNOLOGY DURING THE COLBERT YEARS

The creation of the Royal Academy of Sciences in December of 1666 was but a first step in the institutionalization of science and technology. From a view of a contemporary in 1667,

no structural changes had really occurred. Colbert had simply replaced Fouquet and Mazarin as the principal power of the government and had managed to pension the more prominent lights of the intellectual community in such a way as to favor his own political cause. Colbert selected the members of the academy and determined its program. In the mind of the court, they were "his men" and dedicated to supporting "his program." It was several years before they were even referred to as the Royal Academy of Sciences, and at his death the academy had no legal basis that would assure its continued existence.

The relationship of scholars, and scientists in particular, to their patron had in fact changed. Colbert, despite his concern for building his own base of power, was not an independent "grandee" but very much Louis XIV's minister. Colbert saw to it that Louis received the gloire for the accomplishments of this coterie of scientists. The services performed by the academy supported Colbert's program, but that program was to make France a great maritime power - a goal that certainly transcended maintaining his personal power. In addition, by the creation of the academy Colbert had succeeded in compartmentalizing the speculative process. The members of the academy were free to investigate and were protected from the slings of the vested academic groups so long as they did not stray into politics and religion. In this respect, some of the spirited battles that had set one group against another and had so disquieted Louis XIV's attempts to moderate the various factions of society were brought under control.⁴

Some flavor of the work performed by the scientists of the academy may be glimpsed from their daily program. Colbert had created pensions for sixteen to eighteen scientists. Half of the scientists worked in mathematics or astronomy and the other half in anatomy, botany, or chemistry. They met twice a week in the Royal Library, alternating in subjects between the physical and biological sciences. A typical meeting might include the dissection of a crocodile, a report on the distillation of a particular medicinal herb, or a discussion of a recent essay on the moons of Saturn. When not meeting, the scientists devoted themselves to full-time research or to work on government engineering projects. To facilitate astronomical observations, Louis XIV had an observatory built on the outskirts of Paris. Anatomical and chemical laboratories were established in the Royal Library, and botanical research was conducted at the Royal Botanical Gardens. By the end of his reign, Louis XIV had spent between two and three million pounds to support the research of the academy and to build the Paris Observatory, a truly remarkable commitment.⁵

Whatever may have been Colbert's dedication to the enrichment of the mind, there is little doubt that his greatest enthusiasm was for those aspects of mathematics, mechanics, and astronomy that would improve the art of navigation. Colbert was at that time engaged in a plan to strengthen the French navy and expand France's commercial relations around the world. The principal obstacle to open-sea shipping was the inability to calculate longitudes with less than one degree of error. Reckoning latitudes was no problem, but navigation could be considerably improved from maps with accurate longitudes. An error of just one degree in reckoning the location of a ship or port resulted in a sixty-nine-mile error at the equator. Existing maps of the Mediterranean Sea, for instance, were in error by as much as six hundred miles in depicting its length.

The principal scientific and technical accomplishment of the reign of Louis XIV was nothing less than a revolution in the means of accurately mapping the world. The Mercator map of the world represented the best map of the mid-seventeenth century. It was accurate in helping mariners plot directions but distorted the shapes of land masses and the distances between them. The astronomers of the Academy of Sciences made two major advances in

geodetics that laid the cornerstone for all future cartography. First, they determined the distance represented by one degree of latitude; and second, they developed a method for the precise determination of longitudes.

Abbe Jean Picard, an original member of the academy, was able to calculate correctly the number of miles represented by one degree of the earth's circumference. In 1669 he began to survey an eighty-mile stretch of open country north of Paris, which lay on a meridian of longitude. The astronomers of the period assumed the earth to be a perfect sphere so that any degree on a meridian would equal any other degree on a meridian. A degree on a meridian would also equal a degree of longitude at the equator and a degree north of the equator could be calculated using spherical trigonometry. Picard's first task was to measure accurately the distance between two points on the meridian. He chose the Pavillon in Malvoisine and the clock tower in Sourdon as his two end points. By mounting two telescopes with filar micrometers on a large quadrant - itself a major advance in surveying - he layed out a series of thirteen triangles between them. One side of the first triangle was very carefully measured with a rod, and the sides of the other twelve triangles were computed from trigonometric tables. By using telescopes on the quadrant, Picard determined the angles of the triangles very precisely. Having measured the distance between these two points, his next task was to calculate the degrees between the two points. He used a zenith sector to determine the angle of elevation of a particular star from both these points and from this determined the arc between Malvoisine and Sourdon to be $1^{\circ}11'57''$. Picard took two years to make the measurement, but the value of one degree of latitude had been accurately established at 69.07 miles.⁶

Having determined the value of a degree of the earth's circumference, the only remaining obstacle to an accurate mapping of the earth was the determination of differences in longitudes between major cities and ports of the world. As early as 1663 Colbert had been in contact with the Dutch mathematician and inventor Christiaan Huygens concerning Huygens' progress in perfecting a pendulum clock capable of maintaining accurate time aboard ship. Were Huygens to accomplish this, it would be possible to determine precise longitudes not only for distant ports of the world but for ships at sea. By 1665 it appeared that Huygens had perfected his clock, and Colbert invited him to France with the offer of a large pension, a patent on his clock, and membership in a future group of scientists. Huygens' clock erred less than a minute over long stretches of time, but in order to be useful for navigation, it would have to maintain this accuracy during the rolling of a ship. The clock could be set to the local time of a port in France from the zenith of the sun. This clock aboard ship would thus always be set to the time of that port, and the time of a distant port or a ship at sea could be determined from the zenith of the sun. The difference in time between the clock set for the time of the port in France and a clock set for another port or a ship at sea represented the difference in longitude. Colbert sent Jean Richer, a member of the Academy of Sciences, on a tour with the Atlantic fleet in 1668 and to Acadia in 1670 to test Huygens' clock. The pendulum clock proved unsatisfactory in these tests at sea. Although Huygens continued to work on the clock, Colbert turned his support to other projects.

Since Huygens' clock had failed at sea, the most promising alternative means of determining longitudes was the simultaneous observation and timing of a predictable celestial event from two different points of the globe. In 1669 Colbert prevailed upon Jean D. Cassini, an Italian astronomer, to come to Paris to head the astronomical program of the Academy of Sciences. Cassini had published periodic tables of the moons of Jupiter that made it possible for two astronomers to observe simultaneously their eclipses from two distant points. In 1672

Cassini sent Jean Richer to Cayenne on the coast of South America to establish the longitude of Cayenne with respect to Paris. Cassini at the Observatory in Paris and Richer in Cayenne made several simultaneous observations of the eclipses of Jupiter's moons. Each had set a clock to local time by determining the sun's zenith at each observation point, and from the exact time of the eclipses they calculated the difference in degrees of longitude between the two places. Never before had two such distant points of the world been so accurately measured. Twentieth-century measurements have shown that Cassini and Richer erred by only three minutes of one degree. In 1679, when Louis XIV asked the academy to make a new map of France, Colbert was able to dispatch astronomers of the academy to the ports and borders of the country to establish longitudes using the methods developed by Cassini. Over the next fifteen years accurate coordinates were determined for a number of points around the world, and in 1696 Cassini was able to publish a new map of the world showing accurate locations and distances for forty- three locations in Europe, Asia, and the Americas.⁷

Colbert did not neglect the research program in the biological sciences, although it was clearly secondary in his own view. Mathematicians and astronomers had been included in his original General Academy but not anatomists, botanists, or chemists. Colbert had created the Academy of Sciences by appointing as academicians the mathematicians and astronomers of the defunct General Academy and by adding to them a handful of "physicians" to round out the research program in the biological sciences.

The anatomists led by Claude Perrault began to dissect and compare the structures and functions of the anatomical parts of various exotic animals. Their work was possible because Louis XIV gave dead animals from the Royal Menagerie to the academy. In 1681 Louis XIV himself visited the laboratory to watch the dissection of an elephant. The results of this work were published in the two well-illustrated volumes (1671 and 1676) under the title, *Memoirs on the Natural History of Animals*. The use of species that had evolved in other parts of the world helped to dispel fanciful ideas about these animals and provided a better understanding of the functions of the bodily parts. The work in anatomy was also used to support research in physiology. In one instance, however, this led Jean Mery to conclude that blood flowed to the lungs of a human fetus. His conclusion was based on a false comparison of the heart of a sea tortoise with the heart of a human fetus, but fortunately his ideas were rejected by other anatomists of the academy.⁸

The botanists and chemists worked together to define the differences between plants and to specify their uses. In the *Memoirs on the Natural History of Plants*, published by the academy in 1676 and 1679, one would find first a description of the parts of a given plant, its flower, roots, etc., followed by a list of the various salts and oils to be obtained by distilling the parts of the plant. Botany and chemistry had traditionally focused on finding the medical uses of plants, and this concern is quite prominent in determining the work and methodology used by the academicians. Within the context of the academy, however, they were also searching for more fundamental principles. They were seeking a foundation, both anatomical and chemical, by which plants might be classified; they wished to know what salts and oils were unique to plants - that is, which were produced by the plant and which were absorbed from the earth through the roots; and in the long term they hoped to find empirical verification of the corpuscular theory of natural philosophy. Chemical analysis through distillation yielded results beyond the analytical methods at their disposal, and after 1700 the chemists abandoned this type of analysis and turned to pneumatic chemistry.⁹

SCIENCE AND TECHNOLOGY UNDER THE MARQUIS DE LOUVOIS

When Colbert died in 1683 and his rival, the marquis de Louvois, became the new Superintendent of Buildings, it was not at all certain that Louvois would extend his protection to the Academy of Sciences - the academy, after all, had been the personal creation of Colbert, and Louvois was bent on driving from office the proteges of his former rival. However, Louvois accepted the role of protector to the academy and became involved in its affairs. He held summer *soirees* at Meudon for the academicians and he made plans for the academy to meet in new quarters, proposed but never built, in the Place Vendome.

Louvois, however, initiated some new directions in the activities of the academy that had major repercussions on the effectiveness of this institution over the next eight or more years. In an age when scientific discoveries in astronomy, physics, mechanics, and mathematics were revolutionizing Europe's view of the universe and its laws, Louvois directed most of the energies of the academy into natural history and withdrew practically all support for the physical and mathematical sciences. We can see this new policy unfolding during the first months of Louvois' protectorship in his reactions to projects that had been initiated by Colbert before his death.

During his last years as protector of the academy, Colbert had organized an expedition of members to Goree and to the French West Indies to determine their longitudes, and at about the same time he arranged for the other astronomers to extend the meridian of Paris both north and south in order to have an accurate foundation for a new map of France. He had also agreed to finance three publications, one on the voyages of the academy, one on the astronomical observations of Tycho Brahe, which members of the Academy had been verifying and correcting, and one on the natural history and anatomy of rare animals that had recently been dissected in the laboratory of the academy.

The two astronomers who had been sent to Goree and the French West Indies completed their mission just before Colbert's death, but the five astronomers who were to extend the meridian south of Paris left just weeks before Colbert's death and were recalled. Cassini broached the project to Louvois a few months later but could get no support to complete it. Louvois cancelled the publication of Brahe's observations, although ninety-six pages had already been pulled at a cost of over ten thousand pounds.

Louvois did agree to finance the publication of a book on the voyages of the academy and a book on the anatomy and natural history of rare animals. The actual support he gave to these two projects, however, was quite different. He gave a strong personal endorsement to the publication on anatomy and natural history. During 1684, the first year of Louvois' administration, the number of presentations on anatomy and natural history discussed at the biweekly meetings increased threefold. The book on the voyages of the academy, on the other hand, seems to have been a matter of indifference to Louvois. This book described the attempts of the astronomers to establish the longitudes and other geodetic data about distant places around the world. Louvois gave no endorsement to the project, and within several months it was no longer being discussed in the academy's meetings. The number of presentations on astronomy discussed at the academy decreased 38 percent over the next eight years, and those on mechanics and mathematics disappeared almost entirely.¹⁰

The marquis de Louvois had no particular desire to promote French overseas commerce or to expand its navy. He was Secretary of State for the Army and considered the fortunes of France to be tied to its forces on the land and the strength of its borders. For better than fifteen years he had competed with Colbert and the navy for funds to support the army; now after

Colbert's death he was still competing with Colbert's son, the marquis de Seignelay, who had succeeded his father as the new Secretary for the Navy and Colonies, for the same funds. Within the context of these policies Louvois had little need for astronomers and mathematicians. Rather, he relied on a corps of around two hundred highly skilled military engineers for technical expertise.

Engineers had held important functions in both the army and the Service of Fortifications since the time of Henri IV or earlier, but the increasing necessity of fortified places for the control of the terrain and the grand strategy of warfare raised them to major positions of responsibility in the mid-seventeenth century. A series of well-placed fortifications could secure a frontier. An army of that day could not bypass a fortified place for fear of being attacked on its flanks or having its supply lines cut. Louis XIV was a conservative warrior and gave special attention to the art and strategy of fortification. The correspondence between Louis XIV and Louvois reveals that both men had a good grasp of the technical requisites of fortification and siege warfare. Sometimes Louis XIV even argued with his engineers over the technical details for the construction of the fortress. In developing their war plans for the defense of France, Louis and Louvois preferred the advice of their chief military engineer, Sebastien Vauban, to that offered by Louis XIV's field marshals.

Sebastien Vauban was the preeminent military engineer of the seventeenth century. He did not invent the science of fortification but took its parts and drew them together into a rational system. His perfection of this science was so complete that his principles were considered the state of the art for two hundred years and were not superseded until the use of cannon with rifled bores became common in the late nineteenth century. Vauban's science of fortification is best understood from three aspects: his redesign of the bastion and detached outworks; his creation of a system of zigzag and parallel trenches for sieges; and his systematic location of fortresses on the frontier.

The design of the rampart walls themselves had been greatly advanced by Vauban's predecessor, Blaise de Pagan, in the 1650s. These walls were built to withstand the battering of heavy cannon and to position the defensive artillery in such a way as to shower the attackers with a crossfire. Using geometrical principles and good surveying techniques, Pagan planned a new fortress by establishing first an outer perimeter measured from the outermost points of the bastions, those arrowhead-shaped projections from the walls of the fortress. This procedure reversed past procedure, which laid the inner perimeter of the ramparts first and then worked outward, but often failed to have the bastions properly situated for covering its sides with musket and cannon crossfire. Vauban's advance over Pagan was to change the angle of the sides forming the points of the bastion in such a way that a projection of a line from one bastion's side intersected the rampart walls precisely where the neck of the adjacent bastion touched the walls. This gave gunners situated on the neck of one bastion a clear view and range of fire across the sides of the adjacent bastion without hitting the other bastion with shot or ricochet fire. This made it nearly impossible for infantry to approach the base of the ramparts in order to scale the wall.

Siege tactics prior to Vauban were haphazard and often ineffective. Vauban devised a logical system of attack using parallel and zigzag trenches to move the attacking forces from the distant hills around the fortress to a protected trench right on the edge of the moat. The attack would begin under the cover of darkness. Sappers would dig a trench parallel to one of the walls of the fortress, and when dawn broke the defenders would see enemy cannon protected by a trench some six hundred yards from the ramparts. The cannon would then begin a bombardment, and sappers would dig several trenches from the parallel trench toward

the rampart walls. These trenches snaked their way forward in a zigzag pattern, always at a forty-five-degree angle to the rampart walls to protect those digging the trenches from gunfire. After the zigzag trenches had advanced several hundred yards, another parallel trench would be dug and the cannon brought into closer range. Vauban would repeat these steps until he had placed cannon just across the ditch from the ramparts. At this close range, the twenty-four pound cannon could easily knock holes in the walls through which the infantry could enter. During his lifetime, Vauban directed fifty-three sieges and never failed in a single one.¹¹

In the course of his career, Vauban built thirty-three new fortresses, rebuilt around three hundred older fortresses, and razed many more that had lost their strategic importance. The extent to which Vauban was a leading strategist has been debated by historians. Some historians point out that for the most part he merely rebuilt existing fortresses and thus did not shape any grand strategy; others counter that he selected for rebuilding only those that conformed to his ideas of a strategic frontier and razed all the others. Prior to Vauban, fortresses had been built to defend a particular bridgehead or river junction but did not reinforce each other to create a "fortified zone." During the Dutch War, Vauban asked Louis XIV to acquire certain cities on the northern frontier in order to secure a more defensible line and to give up other fortresses in Flanders. Vauban conceived of the Rhine as a natural frontier for France and projected a double line of fortified places across the northern frontier, but his strategic ideas were still evolving and he never arrived at a comprehensive concept of a "fortified zone" before his death.¹²

Engineers in the royal service in the mid-seventeenth century were identified by a certificate from the government, but they had no institutional structure that advanced the practice and profession of engineering. This was partly in the nature of their work: during wartime they served mostly in the army; during peacetime they were attached to other projects. The institutional foundations for French military engineering were given their basic form during Louis XIV's reign. Louvois created a special reserve officer commission in the army for engineers that gave them a special status as engineers and protected their military careers. When not engaged in the army, most engineers worked on various fortification projects. In 1690 Louis XIV consolidated several sections of the Service of Fortifications into one administration. These two institutional changes together had the effect of creating a professional structure for engineers through which they might advance their careers and perfect their skills.

Except for the problems of fortification, Louvois tended to leave other scientific and technical needs unresolved. Matters of particular concern to Louis XIV himself were exceptions. Supplying enough water for the gardens of Versailles and Marly was one of those concerns, and both Louvois and his predecessor Colbert had to deal with water for the royal gardens. Some 1,400 fountains were built at Versailles and Marly, not to mention the canals and cascades. The half dozen pumps that had supplied the water when Versailles was just a hunting lodge for Louis XIII were totally inadequate. Colbert in his capacity as Superintendent of Buildings was responsible for resolving this problem until his death in 1683. It had been suggested that an aqueduct be constructed to bring water from the Loire River, but when Jean Picard of the Academy of Sciences surveyed the area in 1674, he found that the level of the Loire was some sixty feet lower than Versailles. In 1678 Arnold de Ville presented Colbert with a plan to build a pumping station on the Seine that would supply all the water needs for Marly and Versailles. His ideas were accepted and work began immediately.

The "Marly Machine," as de Ville's scheme came to be called, has been praised as a model of ingenuity and labeled the first hydraulic system to pump water through metal pipes under high pressure. It has also been damned as one of the most inefficient white elephants ever built. De Ville claimed that his design for a pumping station could move around eight thousand cubic yards of water per day from the Seine to a reservoir 502 feet above the level of the Seine and a mile from its bank. From this reservoir, water would flow by gravity through viaducts to run all the fountains at Versailles and Marly. One major problem in pumping water to any height in the seventeenth century was that the terra cotta and lead pipes of that day would burst at pressures greater than three or four atmospheres. Iron pipes were just coming into use at this time, and their first extensive use was at Versailles. Some twenty-four miles of iron pipe were laid in the 1680s, and when much of it was excavated in 1939 it was found to be still in good condition. The more critical limiting factor at Versailles, however, was that there was not a sufficiently tight fit between the piston and the cylinder of the pumps of that day to produce the pressure required to raise the water 500 feet.

The "Marly Machine" resolved these technical problems by generating large quantities of power and then transmitting that power across long distances. Fourteen undershot paddle wheels, each thirty-nine feet in diameter, were installed on the Seine, and the river was dammed to force the water under the wheels. Six wheels were used to drive sixty-four lift-and-force pumps to raise the water from the Seine to a reservoir 150 feet above the river. At this reservoir, another seventy-nine pumps raised the water to still another reservoir 175 feet higher in altitude, and here yet another set of pumps raised the water to the final reservoir. The pumps at the two intermediate reservoirs were driven by a string of rocker arms stretching for almost a mile up the slope from the river and receiving their power from the other eight wheels on the river. It has been estimated that 90 percent of the power was expended in friction and inertia to drive the rocker arms and only about 10 percent was actually available to drive the pumps at the reservoirs above the river. The whole system created a horrible racket. Although designed to raise eight thousand cubic yards of water to the top reservoir, it in fact never exceeded a capacity of four thousand cubic yards. Consequently, most of this water was used for the fountains at Marly and only the surplus reached the fountains at Versailles.¹³

Louis XIV was disgruntled over this state of affairs. It was a common practice to turn the fountains on just before Louis arrived at a particular point and then to turn them off as he moved on to another area of the gardens. It was not uncommon for them to fail to work altogether. Louvois proposed to bring the water of the Eure River to Versailles. The Eure was at a level higher than Versailles, but transporting the water across the valley at Maintenon was a major problem. Louvois asked Vauban for a plan, and the latter proposed the construction of a tube on the floor of the valley that would operate like a siphon to raise the water on the far side of the valley. Louvois, however, believed that a siphon would be too costly in that it would require nine miles of cast iron pipe one foot in diameter. Members of the Academy of Sciences had been doing the necessary surveying for the project in 1684 and suggested that an aqueduct be built across the valley. Louvois chose the academy's plan and used army regiments to undertake the construction. In the end, the aqueduct was never completed because the war with Europe beginning in 1688 drew money away from such a costly undertaking.

The Academy of Sciences had become moribund during the eight years under the direction of the marquis de Louvois. The reasons are not hard to determine. Colbert had aligned the scientific program of the Academy of Sciences too closely with his own projects and policies

and by extension with the politics of his career. Consequently, the sudden shift in policy and technical projects that resulted when Louvois assumed control of the academy was reflected in a radical alteration in the scientific program of the academy. The result was a decline in the academy's scientific research.

PONTCHARTRAIN AND REFORM

Louis Phelypeaux, comte de Pontchartrain, assumed control of the Academy of Sciences in 1691 on the death of Louvois. His position in 1691 was in many ways analogous to Colbert's position in the 1660s and 1670s. He was Controller General for Finance and Secretary of State for the Navy and Colonies. He resolved the dilemmas of scientific research and government policy inherited from his predecessor through a judicious separation of the research functions of science from those necessary to implement government technical projects. In 1696 he created the Bureau of Maps and Plans within the Ministry of the Navy and Colonies to deal with the technical and strategic problems of overseas commerce and exploration. In 1699 Louis XIV, at Pontchartrain's request, gave the Academy of Sciences a set of regulations that redefined the goals of the academy in terms of scientific research and provided for a separation of functions that insulated the academy from changes in policy. Yet the academy did not completely disengage itself from the government. It remained in the background as a group of experts ready to advise the government on projects of a technical nature, but it was no longer a springboard for the execution of projects.

When Pontchartrain assumed responsibility for the academy in 1691, his first task was to restore the vitality of the research program. Not only had most of the activity in the astronomical and mechanical sciences been curtailed by his predecessor, Louvois, but in 1689, two years before his death, Louvois had ordered a complete halt in all publications of the academy. Pontchartrain realized that publication was a necessary stimulus to research, and in 1691 he established a monthly, *Memoires*, to publish the academy's research. He followed this up with the appointment of his nephew, the Abbe Jean-Paul Bignon, as president of the academy. The result was a growth in the new research reported at the biweekly meetings of the academy and a resurgence of work in astronomy and mechanics. Cassini and the other astronomers were campaigning to resume the unfinished project of extending the meridian south of Paris, but Pontchartrain was unable to support this project until 1700. Still, the *Memoires* offered the scientists an incentive for research and the Abbe Bignon, who had Pontchartrain's confidence, was able to procure from his uncle the financial support needed for the academy's program.

Having the Academy of Sciences once again linked to the same administrative direction as the Ministry of the Navy was doubtlessly beneficial for the academy's research in astronomy and the mathematical sciences. Yet the war of the League of Augsburg (1688-97) was jeopardizing all of France's North American possessions. What was needed was immediate action, and in this atmosphere Louis Pontchartrain and his son Jerome created in 1696 the Bureau of Maps and Plans within the Ministry of the Navy and Colonies to focus France's scientific and technical expertise on the problem of empire. This bureau drew together a group of engineers, cartographers, and military strategists who planned France's ventures into the Louisiana Territory. Parts of the Mississippi had already been explored in the 1680s. With the treaty of peace signed in 1697, the immediate problem was to explore and fortify the Mississippi and its tributaries before the English could establish a foothold and cut the link between France's Canadian and Caribbean possessions. Based on the plans of this bureau,

Iberville set sail in 1698 to find the mouth of the Mississippi and establish a fort there. The maps for the expedition were prepared by Guillaume Delisle, and Vauban offered his strategic ideas.¹⁴ Several members of the Academy of Sciences prepared memoranda for the bureau. In 1699 Vauban became an honorary member of the academy, and in 1702 Delisle became Cassini's "student astronomer." The new interest in empire was certainly beneficial to the astronomical and mathematical research of the academicians, but the creation of a new bureau with the express mission of exploration facilitated the implementation of government policy and gave sharper focus to the research-oriented goals of the academy.

The academy, however, needed something more than a revived program in astronomy and the support of a sympathetic administrator. Despite the stimulus to research given by Pontchartrain in 1691, the academy was hard-pressed to maintain the momentum of these changes. The 1690s were years of war and famine for France, and research fell behind. The end of the war in 1697 offered a new opportunity for reform, and Louis XIV took this period to make some necessary institutional changes to repair the stresses of many years of war and death. These latter years had revealed the weaknesses of the older institutional arrangements. In order to give the academy more realistic goals and a greater institutional stability, Louis XIV promulgated in 1699 a set of fifty regulations.

How did the regulations of 1699 put scientific research on a firm institutional foundation? First, they outlined the work of the academicians in terms of research in specific scientific disciplines and limited their work on applied projects designed to forward national policies to an advisory role rather than an implementive role. Second, they gave legal recognition to the academy's existence and gave it a fixed place in the government's budget. Third, new appointments to the academy were based on nominations made by the members themselves, thus reducing the opportunity for government officials to appoint family and friends. Fourth, the scientists were organized into a hierarchy. A young scientist starting at the bottom of the ladder could advance through diligence to a fully pensioned position. Fifth, fully pensioned members were required to present the results of their research at regular intervals or face dismissal from the academy. Sixth, each of the six major areas of science was guaranteed an equal number of scientists; thus all areas of science advanced on an equal footing. Seventh, the size of the academy was increased to sixty active members. The assumption behind Pontchartrain's reforms was that a well-balanced program of scientific research, determined by the scientists themselves and propelled forward by promises of advancement and recognition, would best serve the interests of public and government.

Louis XIV's fifty-five-year reign is perhaps best characterized as the period when the sovereignty of the monarch was transformed into institutions that embodied the sovereignty of the state and would survive independently the life of the monarch and even the institution of monarchy itself. The institutionalization of science and technology also occurred in Louis' reign. Colbert accomplished the first stage in 1666 with the creation of the Academy of Sciences, an act that disengaged the activities of scientists from the independent milieu of the Parisian salons and from the speculative traditions of philosophy. Yet, although Colbert redirected the scientific enterprise to the concrete empirical questions of nature, the answers to which also served the practical needs of Colbert's national policies, the program and personalities of the academy became representative of his own political ambitions and party. The worst features of ministerial patronage and policy surfaced during Louvois' direction of the academy, and it became apparent that a successful program in science and technology needed some sort of insulation from the changes of ministerial policies and a new definition of goals. The regulations of 1699 served this purpose. Louis XIV's ministers were

concurrently creating other scientifically informed government units. These groups, most notably at this time the corps of engineers and the Bureau of Maps and Plans, were created to furnish the technical support for the more precisely defined national objectives. While independent of the Academy of Sciences, their work was to come under its scrutiny and review.

Louis XIV's patronage of science and technology established a pattern of government institutions that was to grow in the eighteenth century and to endure in a modified form down to the present. What was emerging was a constellation of scientific and technological institutions with the Academy of Sciences at the center. Each was devoted to a specific task and responsible to a particular governmental agency but was reviewed by the academy for quality and professionalism. This preeminent role assigned to the Academy of Sciences gave it considerable authority over the scientific and technological development of France.¹⁵ This institutional arrangement provided for France a golden age of sustained scientific growth and technical expertise unrivaled by any other European nation in the eighteenth century.

FOOTNOTES

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