C. STEWART GILLMOR

Coulomb and the Evolution of Physics and Engineering in Eighteenth-Century France

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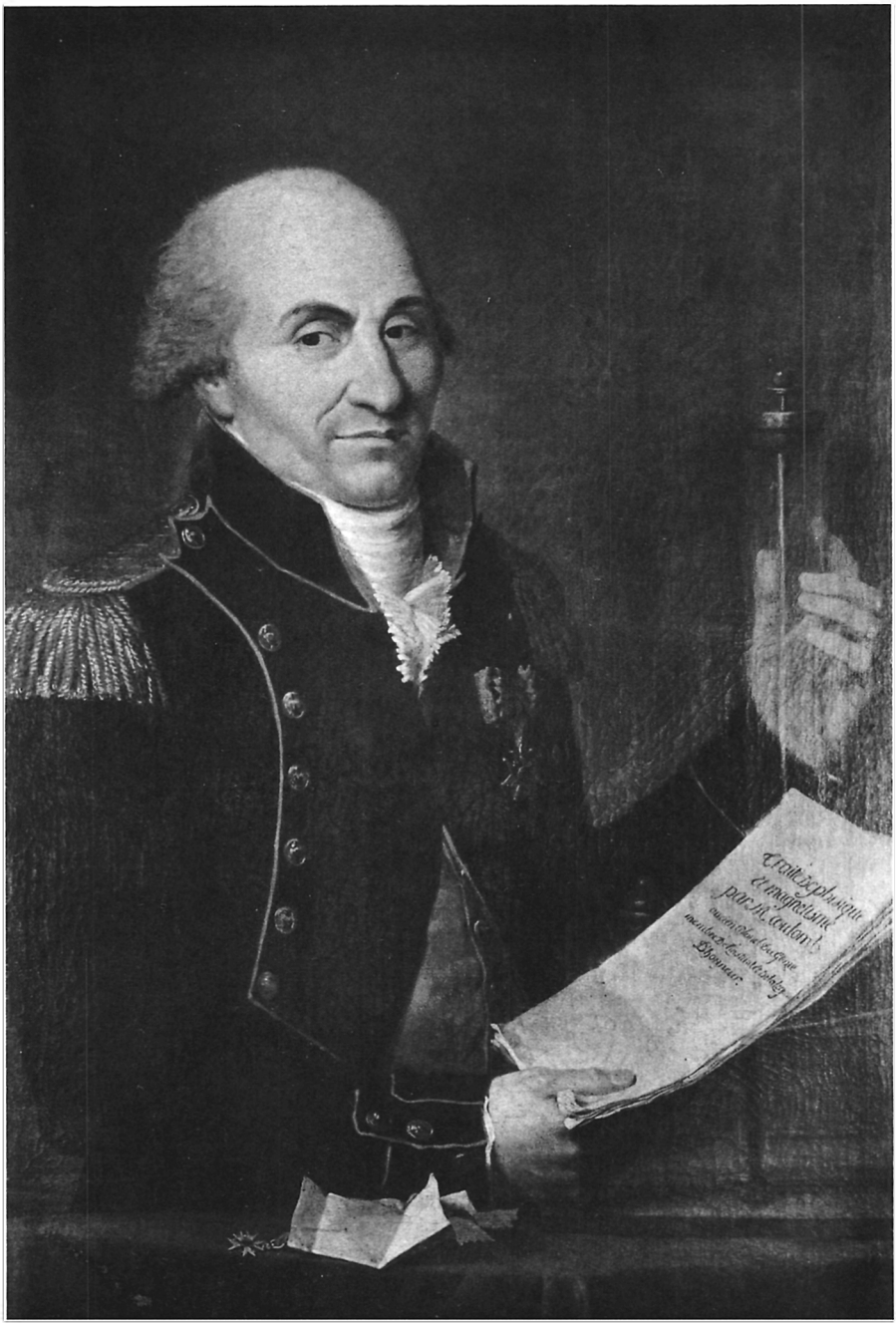
Coulomb AND THE EVOLUTION OF PHYSICS AND ENGINEERING IN EIGHTEENTH-CENTURY FRANCE

Charles Augustin Coulomb, in the dark blue coat with red piping and brass buttons of the *Corps royal du génie*. He is wearing the *Croix de Saint Louis* and holding his torsion balance and a paper artificially entitled *"Traité de phisique* [sic] *et magnétisme."* The medal awarded him by the *Legion d'honneur* rests on the table. The portrait was probably painted between 1803 and the year of his death, 1806; the artist is unknown.



C. Stewart Gillmor

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To E.N.G.
and to the memory
of C.S.G.

Preface

Charles Augustin Coulomb was a physicist and engineer of the first rank. Beyond this he held important positions of service to the French government both before the Revolution and in the first years of the Empire. Coulomb is known for his work in electricity and magnetism. His engineering studies, his personal life, and his career as a public servant are much less familiar to historians of science and to the general reader. This biography intends to give a full account of his life and to present as well a rather complete analysis of his work in engineering mechanics and in physics. It is hoped that this will be of use to those engineers and physicists who share with me an interest in the historical development of these disciplines. In addition, historians may profit from the discussions here of the relations between science and government in eighteenth-century France.

The body of this study consists of six chapters. Of these, the first two are devoted to Coulomb's biography and the last four to his studies in engineering and in physics. Engineering developed rapidly in early eighteenth-century France, and by mid-century there were well-established groups of men in several engineering disciplines. Even so, Coulomb's mathematical training at the *Collège de France* and at the *Ecole du génie* at Mézières provided him with the means to approach many basic engineering problems in new ways. Mathematics alone did not make him an engineer. Following his graduation from Mézières, he entered into a period of twenty years of engineering in the field, separated from Paris and most of the scientific activity of his day. It was during this time that he gained the experience which, coupled with his use of rational analysis, allowed him to conceive of attacking engineering problems through a "mélange du calcul et de la physique." Chapter I presents this part of his biography.

Chapter II discusses Coulomb's life and career after he turned to physics. He entered the French Academy of Sciences in 1781 but he was elected on his reputation as engineer rather than physicist.

His engineering, which had benefited from his early work in mathematics, now contributed to his development as a physicist. Biot said that one owes to Borda and to Coulomb the renaissance of exact physics in France. Delambre saw Coulomb's contributions to physics in the same way. Both men meant by this "physics" not rational mechanics but the emerging fields of heat, light, crystallography, electricity and magnetism. Coulomb's physics was colored by his conception of experiment. He brought to physical experimentation not only his instrumental ability but also a sense of significance and reality gained from his work in engineering.

Coulomb's twenty-five years as member of the Academy of Sciences and of its successor, the Institute, were filled with other duties in addition to those of Academician and physicist. He participated in the administration of waters and fountains, the reform of hospitals and the system of weights and measures, and after the Revolution, in the reorganization of French education.

Discussions of Coulomb's technical studies occupy their proper chronological place in the two biographical chapters, but separate, detailed examinations of these comprise the last four chapters of this book. Chapters III and IV examine his work in strength of materials, soil mechanics, structural design and friction. General questions of mechanics and of the nature of close-acting forces in friction and cohesion carry over into his later work in physics. Chapter V discusses Coulomb's work in the physics of torsion and its applications to research in other areas of physics. Chapter VI explores both his experimental work and his theories in electricity and magnetism. The work as well as the life of a biographical subject must be seen in the context of his times. Coulomb's lesser known works in engineering and applied mechanics are examined in terms of the history of certain problems or disciplines and thus Chapters III and IV, particularly, treat of seventeenth- and earlier eighteenth-century events in some detail. Finally, Coulomb's activities in his last years are presented in an Epilogue.

Beyond the life and career of Coulomb, this book considers the general development of certain fields in physics and in engineering. It has come to be acknowledged that the various sciences were affected differently in the scientific revolution. The physics of the early eighteenth century was not merely a less mathematized version as Clerk Maxwell knew it or as we know it today. Some have chosen to see the evolution of physics in terms of the mathematization of the natural philosophy: analysis as first applied to mechan-

ics eventually ordering heat and light and electricity and magnetism by the turn of the nineteenth century. These latter fields did not join with mechanics to form what we call physics quite so easily. They did, however, emerge from that somewhat disordered realm the French called *la physique générale* during the lifetime of men like Coulomb, Borda, and Lazare Carnot.

This biography is not a history of classical physics, but one of its themes is that engineering, particularly as it evolved in France, played a significant role in the emergence of physics. Coulomb's studies in physics were strongly influenced by his earlier work in applied mechanics and engineering. He and some of his contemporaries criticized the nature of some rational mechanical solutions to real, *physical* problems. They also criticized, however, the sometimes useless or randomly curious experiments of the early natural philosophers, practitioners of *physique générale*, or personalities of the *cabinet de physique* and the *salon*. The best early eighteenth-century natural philosophers, like Musschenbroek and Desaguliers, rejected overspeculative hypotheses and called for physics to be based upon experiment. At the same time, Bélidor, Frézier, and other engineering writers took engineers to task for dismissing *la théorie* and dealing only with *la pratique*. Each of these groups, however, tended to overestimate the ease with which the problems of their *pratique-théorique* duality could be overcome. They both wrote on most or all things of interest; their investigations were often sweeping, their nets too coarse.

The balance of physics often turns on fine-edged pivots. That Coulomb, for example, grasped the significance of exploiting fully the physics of torsion in thin cylinders and then moved to establish quantitatively the idea of Newtonian central forces in electrostatics and magnetism in place of the Cartesian-inspired vortices and effluvia, marks a major step in its evolution. Coulomb called not only for sophistication of mathematical techniques but for reality in experiment and in physical hypotheses. As I indicate later, perhaps natural philosophy gave the curiosity, engineering the reality, and rational analysis the harmony that characterize physics.

However one may wish to view its evolution, the period from about 1775 to 1825 was an exciting time for physics. Lavoisier, Laplace, Monge, Borda: close friends, or those with whom Coulomb worked, recognized this. Lagrange recognized it as well when he wrote d'Alembert in 1781 dispiritedly: "Physics and chemistry now offer riches more brilliant and easier to exploit; in addition,

the taste of the century appears to be entirely aimed in this direction, and it is not impossible that the chairs for Mathematics [*Géométrie*] in the Academies will one day occupy the same insignificant position that the University chairs in Arabic occupy at present." [*Oeuvres de Lagrange*, XIII, 368.] Charles Augustin Coulomb's career moved right through the heart of this period. I hope the reader shares my pleasure in following him as engineer and as physicist in eighteenth-century France.

There exists no previous biography of Coulomb, nor any single analysis of all of his work in science and engineering. I would have been unable to complete this work without the generous help of many persons, both in the United States and France, and it is a pleasure to express my gratitude to them. I am pleased to acknowledge a research grant from Wesleyan University and the editorial assistance of Mr. Andrew Gaus. The portrait of Charles Augustin Coulomb, reproduced here, belongs to Coulomb's great-great-grandson, to whom I am grateful. I owe a great debt to my teachers at Princeton University. In his seminar on the history of electricity and magnetism, and since that time, Professor Thomas Kuhn has helped me to recognize the opportunities and to understand the difficulties of investigating the history of physics. Professor Salomon Bochner of the Departments of Mathematics of Princeton and Rice Universities has been a welcome source of ideas and inspiration in my studies. Professor Charles Gillispie has continually given me aid and advice throughout the period of preparation of this work as dissertation adviser, constant reader, and friend. Finally, and most of all, I wish to thank my wife, Rogene Godding Gillmor, for her constant support and encouragement. The typing of the original manuscript and all of the drawings in this book are the product of her talents.

CHARLES STEWART GILLMOR
Higganum, Connecticut
October 1970

Contents

Illustrations

Tables

Coulomb AND THE EVOLUTION OF PHYSICS AND ENGINEERING IN EIGHTEENTH-CENTURY FRANCE

One · STUDENT AND ENGINEER

Introduction

This chapter considers that period of Coulomb's life and career from his birth until his election to membership in the French Academy of Sciences in 1781. Coulomb's major contributions in the first part of his career were in the field of applied mechanics and engineering. He entered engineering at a time when its better representatives were turning toward what one might call a rational rather than a traditional empirical engineering. His studies at the *Collège royal de France* with Le Monnier and at the engineering school at Mézières with Bossut aided him in obtaining a better grasp of mathematics than that possessed by those engineers practicing a generation before.

The experience he gained in Martinique, in Cherbourg, and in many other posts in France enabled him to bring to his engineering memoirs a realistic knowledge of the behavior of structures and materials and led to his fundamental studies in the strength of materials, earth-pressure theory, and friction.

By the time of his election to the Academy, Coulomb had already gained renown as an engineer. When he then turned to physics, both his mathematical training and his engineering experience supported his physical researches in profitable ways and led directly to his discoveries in torsion and indirectly to his quantification of the fields of electricity and magnetism.

Youthful Determination

Charles Augustin Coulomb was born June 14, 1736, in Angoulême, in the Angoumois. Two days later he was baptized in the parish church of St. André.[1] Little is known of his mother, Catherine Bajet, except that she was related on her maternal side to the wealthy French family of de Sénac.[2] His father, Henry Coulomb, had begun a career in the military, then left this for a petty govern-

ment-administrator post, that of *Inspecteur des Domaines du Roi.* Charles Augustin was born away from his ancestral province, for the Coulombs came from Languedoc, and the family had lived for at least several generations in Montpellier.[3] They had traditionally been lawyers and Charles Augustin's older cousin Louis was head of a branch of the family which was to remain active in politics and finance throughout the eighteenth century.

As an *Inspecteur* of the king's domains, Henry Coulomb was liable to be transferred in the course of the royal business, thus, early in Charles Augustin's childhood, the family moved to Paris, where Henry became involved in the tax-farm system. Catherine, anxious that her son become a medical doctor, saw to it that he began attending the *Collège des quartre-nations.*

The *collège*, sometimes called the *Collège Mazarin*, was founded by the will of Cardinal Mazarin upon his death in 1661.[4] Something like a private high school, it opened its doors in 1688 and for the next century taught rhetoric, mathematics, physics, logic, religion, and the classical languages to approximately thirty boys aged ten to fifteen. Although Louis XIV's *lettres patentes* stated that the *collège* would educate "gentlemen, or those children of prominent residents who live like nobles,"[5] it became more and more difficult for a potential student to be admitted without proof of four degrees of *noblesse.* Proof of such nobility was determined by the ubiquitous d'Hozier, *Juge d'armes de la noblesse de France*[a].[6] Coulomb's name does not figure on d'Hozier's lists, however, this does not completely preclude his having attended as a student. The *collège* had a good name as a school for mathematics (Nicolas Delisle, d'Alembert, Lavoisier, and Bailly studied there), and the abbé Lacaille built an observatory and taught astronomy there for many years.[7] It is probable that Charles Augustin was not a regular student but one of the many *martinets*—the numerous youths, who like little martin-swallows, flitted from place to place.[b] If Coulomb attended the *collège* at the normal age, he would have entered sometime between 1746 and 1751.

Coulomb learned of Pierre Charles Le Monnier's mathematical lectures at the *Collège royal de France*, and he began attending there. Soon, much against his mother's wishes, he announced that

[a] There was a succession of members of the d'Hozier (or D'Hozier) family as genealogists but this would be Louis Pierre d'Hozier (1685–1767).

[b] There exist no student lists for the decades during which Coulomb could have been a student, but one of his memorials[8] states that he attended there.

he was going to become a mathematician. Henry Coulomb had no strong views about the question although most likely he would have supported Charles Augustin's plans, but fate in the form of the financial market intervened and removed him from the scene. A contemporary description of Henry states that "good-natured and unsuspecting, he engaged himself in speculations which reversed his fortune. . . ."[9] Penniless, Henry returned to the family home in Montpellier and left Charles and his sisters in the charge of their mother. Charles Augustin continued to deny his mother's desire that he study medicine and was therefore temporarily disowned. Without funds, he was forced to join his father in Montpellier.

Henry Coulomb had no money but was not entirely bereft of resources; the Montpellier Coulombs held substantial positions in the community. Cousin Louis was a lawyer, subdelegate to the *parlement* from the Bas-Languedoc, and a member of the *Cour des comptes et aides de Montpellier* (the provincial financial court).[10] Louis could provide more than just the normal legal and financial contacts of a lawyer. In Montpellier, a lawyer active in politics and administration would also be close to the center of scientific activity in the city. The *Société royale des sciences de Montpellier* was fiercely proud of its 1706 charter making it the second royal scientific society in France. A majority of the founders were lawyers and professional men, and cousin Louis was in a good position to introduce Charles Augustin to the scientific circle in Montpellier.

Nothing is known of Coulomb's formal schooling in Montpellier. If, indeed, he did seek schooling he might have attended the *Collège des Jesuites.*[11] This would have provided him with more training in Latin and classical religious philosophy but little beyond Aristotle in physics. If one is to believe the *éloges* (eulogies) of members of the Montpellier *Société des sciences,*[12] the scientific instruction at the Jesuit college was such that some students came to the society itself for tutoring as student members. Coulomb was not old enough to join the organization when he first came to Montpellier, but the permanent secretary, Hyacinthe de Ratte, indicates that Coulomb was acquainted with the members for some time before his entry in 1757 as a *membre adjoint.*[13]

In spite of its title and charter, the little society must have been a rather intimate and friendly club. It was patterned after the Academy in Paris, with three regular members in each of five classes: mathematics, anatomy, chemistry, botany, and physics. In

addition to the regular members, there could be fifteen student (or adjunct) members, six honorary, and four foreign members, plus an unstated number of *associés libres* and correspondents.[14] In fact, there were never more than a handful in attendance; the average attendance at each meeting in 1757 and 1758 was nine.[c,15]

The society was in financial trouble from 1752 to 1757, and in this period it met on Thursday afternoons, at the home of Augustin Danyzy, one of its mathematicians. In 1757, it moved to its new home in an observatory built on part of the medieval city wall (today, the rue des Etuves). There was room below for a medical dissecting area and a chemistry laboratory; upstairs was a meeting salon and above this were towers and walkways for astronomical observations.[17]

To become an adjunct member, one had to live in or near Montpellier and be at least twenty years old. Coulomb was twenty-one when he read his first paper to the group assembled in Danyzy's living room on February 24, 1757. His paper, entitled a "Geometrical Essay on Mean Proportional Curves,"[18] met with general approval and was said by Jean Brun, who was appointed to examine the work and report to the members, to solve a "great number of problems."[19] Coulomb's paper was actually designed as an application for membership, and it seems to have been successful, for on March 23rd, Coulomb was elected: "The society in special assembly has named to the place of Adjunct for Mathematics, Mr. Coulomb, who has given various proofs of his ability. Mr. Coulomb has been elected in the usual manner, by ballot and with the plurality of votes."[20]

The organization stated that Coulomb "has, at an early age, made considerable progress in mathematics."[21] Coulomb took an active part in the work of the society and attended twenty-seven of the fifty-two meetings held during his sixteen-month period of membership. During this time, he presented five memoirs—two in

[c] During Coulomb's membership the mathematicians were Jean Brun, Hyacinthe de Ratte, and Augustin Danyzy. The physicists were Jean-Antoine Duvidal, marquis de Montferrier; Dominique de Senés, *fils*; and Jean Baptiste Romieu. Three of this number stand out for their abilities. Danyzy was a talented architect. Among other works, his theory of arch design was important in the history of this field and will be noted in Chapter III. De Ratte was a wealthy and talented young man who became permanent secretary at an early age and remained the backbone of the society until its dissolution in 1793. Both de Ratte and Romieu were lawyers and members of the *Cour des comptes et aides*. De Ratte would become Coulomb's closest friend and adviser at Montpellier.[16]

mathematics and three in astronomy. After his first paper on mean proportional curves, he presented another on the movement of bodies on mobile planes. In astronomy, he read memoirs on calculating a meridian line and on observations of a comet and of a lunar eclipse.[22] Much of his time was spent working with de Ratte on astronomical measurements. This field work would have had great appeal for the young man. In both the eclipse and comet measurements, where he assisted de Ratte, there was a sense of contributing to the efforts of the scientific community. The comet measurements were particularly important to him; he was still interested in the project when he wrote to de Ratte from Paris a year later.[23]

Coulomb could have had a fine career as a member of the Montpellier society, but this work provided only intellectual remuneration. He needed to find a post which would provide him a living and at the same time allow him the opportunity to continue his scientific studies. There were few options which would sustain a young bourgeois or petty noble; he could become an *abbé* and obtain a sinecure from the church, or he could enter civil or military service, possibly as an engineer. An engineering career seemed the better alternative. Other military branches—marine, artillery, infantry—offered easier advancement through the ranks but did not compare in the quality of their technical standards or the intelligence of their officer corps. The choice then fell between the civil engineers in the *Ponts et chaussées* (Bridges and roads) and the military *Corps du génie* (Engineer corps). At this time, the *Ecole du génie* (School of military engineering) at Mézières was the best technical school in Europe. With his father's blessing, Coulomb decided to enter the *Corps du génie.* It would be necessary, then, to prepare for and pass the entrance exam to the school at Mézières. Several times a year, the abbé C.E.L. Camus administered the exam in Paris, and successful candidates usually had prepared for Camus through tutoring in Paris. Coulomb decided to leave Montpellier and go to Paris. In the summer of 1758, he obtained from the Montpellier society a year's leave of absence from his position as adjunct member for mathematics and headed for Paris armed with letters of introduction to members of the Academy of Sciences in Paris.[24] De Ratte was a friend of several members of the Academy, including d'Alembert and Jean Baptiste Le Roy, as well as Pierre Charles Le Monnier, whom Coulomb had heard lecture at the *Collège royal de France.* In addition, Charles Le Roy, of the

Montpellier *Société des sciences*, was the younger brother of Jean Baptiste Le Roy.

Unfortunately for Coulomb, he arrived in Paris in September, just when the Academy began its annual two-month vacation. Apparently he was unfamiliar with its customs for he thought it very strange that though he knocked on many doors[25] the only two persons he met were Le Roy and Le Monnier. He sought lodging near his fellow Languedocians on the rue du Bouloy—just across the street from the Hôtel du Languedoc.

Coulomb's arrival in Paris marked a clear break with Montpellier and the *Société des sciences*. His friends carried him on the attendance books well past the end of his one-year leave of absence. Finally it became clear that Coulomb was indeed going to become a royal military engineer; when another young candidate[d,26] came along in 1761, the society removed Coulomb from the rolls.

Coulomb pursued his mathematical studies in Paris for nine months; the name of his tutor, if he had one, is not known. He then passed the abbé Camus' exam for entrance to the *Ecole du génie* at Mézières and prepared to take up residence at the school in February 1760.

Coulomb's reasons for leaving Montpellier to begin a career as a military engineer may not have been entirely financial; then, as now, it would be only natural for a brilliant young man to leave the provinces and seek his career in Paris. In spite of the conviviality and spirit of the Montpellier *Société des sciences*, it was clear that the center of continental science was Paris. It would be many years, however, before Coulomb could find a permanent post in Paris, and he would come as an engineer, later to become a physicist but not a mathematician. As interesting as his early mathematical notes might have been, they were the essays of a student. Coulomb certainly had an adequate knowledge of rational mechanics. One of the most distinguishing traits of his memoirs, compared to other engineering memoirs of the time, is that Coulomb had the right mathematics for each problem. He stressed the point repeatedly, however, that his mathematical treatment stopped at the edge of reality or practicality and that he left further abstract development to the *géomètres*.[e] His work is marked by a precision and

[d] Coulomb was replaced as adjunct member by Pitot de Launay, son of the famous physicist and Academician, Henri Pitot, director of the Canal du Languedoc.

[e] Until the late eighteenth century a "mathematician" would generally be

brevity not achieved by a Bélidor. Never, though, did he go back to "pure" mathematics. Every paper he wrote after leaving Montpellier was in applied mechanics or physics. Coulomb thought like a physicist rather than a mathematician. One of the fortunate features of his life is that he realized this.

Mézières: The Making of Engineers

The history of engineering in France rightly begins somewhere in the seventeenth century when considerations of the architecture and design of buildings and fortifications began to take on aspects of formal organization. Certainly ships, bridges, and buildings had been built for centuries, but toward the end of the seventeenth century, definite rules were formed for learning and practicing these arts. Textbooks and manuals were published, and certain scholars began to earn their living as teachers of engineering. In August 1681, Louis XIV ordered the establishment of chairs of hydrography in the large maritime cities of France.[27] From this date, officers in charge of the construction of naval vessels were required to take some training in mathematics, mechanics, and in what we would call today properties or strength of materials. From the late seventeenth century through the eighteenth, the men in charge of shipbuilding were known first as *constructeurs des vaisseaux* (shipbuilders) and later as *ingénieurs-constructeurs des vaisseaux* (shipbuilding engineers).[28]

Similarly, the civil and military engineering profession grew and defined itself during the reign of Louis XIV. The *Corps des ingénieurs du génie militaire* was founded in 1675.[f] Much of this was due to the work of Sebastian Prestre Vauban.[30] Vauban was the first famous military engineer in France; his thirty-three forts were treated with veneration for decades, as were apocryphal editions of his notes.[g] Vauban was instrumental in introducing the use of statistics in governmental studies, and he realized the value of mathe-

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known as a *géomètre*, or perhaps, if he worked primarily in rational mechanics and analysis, as a *mécanicien*.

[f] The *Corps des ingénieurs des ponts et chaussées*, however, was not established until 1720.[29]

[g] The history of what Vauban did and did not write concerning military fortification became subject for heated debate in the latter half of the eighteenth century. A good part of the supposed treatises of Vauban were altered considerably by the engineer Louis de Cormontaingne (1695–1752), who published them. For a discussion of this see Reinhard[31] and Augoyat.[32]

matical training for military engineers. He was named a *Maréchal de France* in 1703. Beginning in that same year, those wanting to enter the engineering corps had to take an examination in the mathematical sciences, introduced by Vauban. The first *examinateur des ingénieurs* was Joseph Sauveur, *Professeur royal de mathématiques* and member of the Academy of Sciences.[33] The original corps of military engineers evolved during the eighteenth century.

In 1725, about 300 engineers were formed into a *Corps du génie* headed by a *Directeur général des fortifications*, or *Commissaire*.[34] Early engineers had studied texts like Pierre Bullet's *L'architecture pratique*.[35] After the formation of the corps, more comprehensive texts were introduced—for example, the important *Traité de stéréotomie* of Amédée François Frézier[36] and Bernard Forest de Bélidor's[37] *La science des ingénieurs* and *L'architecture hydraulique*. These works exerted tremendous influence on the early growth of engineering. With the formation of the *Corps du génie*, the entrance examination required a knowledge of geometry, elements of mathematics, drafting and design, and principles of fortification.[38]

Until 1744, there was a military engineering corps, there were standard texts, and there was certainly an established tradition of engineering practice, but the *Corps du génie* still existed only in an amorphous state. A royal order of February 7th, 1744, gave the corps its first regular organization and regulations and fixed the number of military engineers at 300.[39] Impetus for the founding in 1749 of an engineering school at Mézières came from Nicolas de Chastillon, descendant of a long line of military officers[40] and later *Brigadier* and *Directeur des fortifications de la Meuse*.

The curriculum at Mézières was divided into theory and practice.[41] Three days of the week were reserved for theory with three hours in the morning for architectural design, drafting, and map work, and three hours in the evening for mathematics. Another three days were devoted to surveying, field mapping, and so forth. The "mathematics" consisted of the teaching performed by the abbé Camus, the school's examiner. In 1748, comte d'Argenson, then Minister of War, had designated Camus to prepare a course for engineers, comprising the "elements of the sciences." This course was published in three parts (in four volumes) in 1749–1752 as *Cours de mathématique*[42] and was used both at Mézières and also as preparatory material for entrance to the school. The

first two volumes covered arithmetic and geometry and some knowledge of these was necessary to pass Camus' entrance exam. Volume I detailed how to count, how to manage money and systems of units, as well as decimals, fractions, and logarithms. Volume II covered basic plane geometry and a little plane trigonometry and solid geometry.

At the end of Volume II, Camus introduced a discussion of the *anse de panier* (an empirical approximation to a semi-ellipse, composed of arcs of several circles), and its use in the design of arches. This taste of mechanics led to Volumes III and IV, which were concerned with statics. There the student was instructed in composition of forces, centers of gravity, empirical solutions to arch curves, the geometrical design of gear wheels; in general, the statics of the seven simple machines. Comte d'Argenson wished the students also to be instructed in the elements of hydraulics. Camus never published a text on this subject but utilized earlier material by Mariotte[43] and Varignon.[44] Though written at a rudimentary level, Camus' volumes were quite good, especially the first two on elementary arithmetic and geometry. It must be said, however, that Camus' teaching did not involve the students in problems of higher mathematics or indeed in problems of engineering construction requiring the use of infinitesimal analysis.

As for the subjects of mapping, fortifications, and surveying, these were usually taught by one or two regular engineers assigned to Mézières as assistant commandants. The standard texts by the 1750s would have been the works by Bélidor and Frézier, cited above. Practical subjects included the art of stonecutting, study of fortifications, empirical methods of designing and constructing vaults and arches, the design of retaining walls, the operation of hydraulic, animal, and manually operated machines, and methods of bookkeeping and estimating construction costs. All of the Mézières students spent much time outdoors directing local public works.[45] They constructed bridges and arches and if these structures seemed unsafe, they were torn down; if they appeared useful, they stayed in place.[h] The students gained practice as well at being paymasters and sometimes were required to round up peasants for labor gangs. In 1756, for example, the students supervised the con-

[h] Between 1755 and 1758 the artillery was united with the *génie* and therefore the work at the school during this period tended more than usual toward practical projects.[46]

struction of six bridges in the Mézières area. The school was not to reach its height until after the coming of the abbé Charles Bossut (in 1752) and especially of Gaspard Monge (in 1768), and in its early years it followed a practical line and eschewed a heavy reliance upon mathematics. It is probable that until this time, extra mathematical and theoretical training was to be obtained by separate work with the mathematics master and not as a part of the regular course. Nonetheless, Mézières soon became the outstanding technical school in Europe.

To enter, the prospective student was required to provide the Minister of War with four pieces of information: (1) place of birth, (2) age, (3) family status, and (4) financial help that he could expect from his relatives. Beyond this, he had to exhibit a drafting sample made under the eyes of the Mézières drafting instructor and then pass a preliminary examination in mathematics. If he successfully met these requirements, he was given a *lettre d'examen* permitting him to present himself in Paris before Camus for the final entrance exam. He was admitted to the school upon Camus' recommendation and was given the rank of *sous-lieutenant* or *lieutenant en second.* After one year, Camus again examined the students and wrote up a class ranking. At the end of the second or final year, Camus recommended the successful for graduation and promotion to *lieutenant en premier.*[47]

Most of the Mézières students were minor nobility, although until at least 1762 it was clearly permitted for bourgeois candidates to enter the school. Camus made this clear in a letter of December 16, 1751. If two candidates were of almost equal merit and one was noble, then the noble would be admitted; however, he said, "there is no policy of excluding those who are not nobles or who have not yet served in the Corps."[48] Even after the ordinance or *acte de notoriété* of December 4, 1762, which further strengthened the class-oriented admission policy, the school continued to admit promising candidates who lacked the proper credentials of birth.[49]

Coulomb is often listed in biographical sketches as Charles Augustin *de* Coulomb, implying noble birth. In none of several hundred extant examples of his signature and those of his family does anyone ever sign himself with the particle.[50] In *all* cases, Coulomb wrote his name only as "Coulomb." On engineering documents he often added "*Cap.ne au C. R. du Génie*" (*Capitaine au Corps Royal du Génie*). His father signed his name simply "Henry Coulomb." There is a 1739 copy of Charles Augustin's birth certificate in the

Archives de la guerre, but it gives no evidence of nobility.[1,51] His cousin, Louis, is listed once in Montpellier archives as "Louis Coulomb, noble"; however, on Louis' own baptismal certificate his father, Etienne, is "Etienne Coulomb, bourgeois."[52] In sum, with the exception of an unofficial listing of cousin Louis, none of the family were ever known to sign themselves as noble, to claim nobility, nor is nobility indicated on any archival records in Paris.[53]

The nobility in Europe had originated as a knightly class with military functions. After the sixteenth century, however, an increasing number of families in France gained position and status by being admitted not to the old military and landed "sword" nobility (*noblesse d'épée*) but to a new administrative "robe" nobility (*noblesse de robe*), in recognition of their service to the state. Though it never attained the social prestige of the older nobility, this much larger class grew in wealth and power, especially under Louis XIV. One could attain robe nobility by acquiring hereditary offices by purchase, by obtaining membership in one of the thirteen *parlements* (legal corporations) of France, by holding numerous types of administrative offices and by other methods. There were in reality not one or two, but many ranks within the nobility in eighteenth-century France. The highest noble, with direct access to the king, and the poor provincial squire were worlds apart.

A family, though not of the nobility itself, could gain some of the status attached to certain lower orders of the robe nobility by proving several generations of family service with officer rank in the military. It is most likely that Coulomb was admitted to Mézières by this method, on the basis of his military heritage. His father, Henry, and a paternal ancestor, Etienne, at least are known to have pursued military careers at one time. Other students entered Mézières in the 1750s and 1760s with credentials less noble than those of Coulomb.

Two types of student entered Mézières: first, young students of seventeen or eighteen years of age who had no military training and second, *ingénieurs volontaires* who had served some years in the corps.[54]

[1] It is sometimes assumed that because Coulomb quit Paris in 1794 during the Terror that he was therefore a noble. Nobility would have added little to Coulomb's dangerous situation at that time. He was a very close friend of Lavoisier; he had been purged from the committee on weights and measures; he was (or had been just previously) the king's intendant for waters and fountains, lieutenant-colonel in the engineering corps, and a member of the abolished Academy of Sciences.

A sense of the Mézières student body can be gained by looking at the class which entered in 1755.[55] Of the ten students that comprised the class, five were youths eighteen years of age with no previous military training, three were lieutenants aged twenty-one to twenty-seven with five to twelve years service,[j] and two were older officers. Nine of this number were noble and one was the son of a military officer.

The students were certainly not without class prejudice. In early 1760, for example,[56] a young bourgeois entered after making a good mark on his exam before Camus. Once at Mézières, he was asked by some of the noble students to show proof of his ancestry by exhibiting his *extrait baptistaire* or leave at once. The youth refused to show his certificate and a near-riot resulted. Chastillon severely reprimanded the students for this display and the young man remained. Things were not as dark for a bourgeois as Marcel Reinhard tells in his work on Carnot,[57] but poignant letters from the 1760 student and his father to the commandant Chastillon show that a non-noble at Mézières might have to endure much heartbreak. Noble or not, the students were subject to punishment for disobeying the rules of the school. They could be fined up to three *livres* (pounds), confined to quarters, or even sent to prison.[58]

All was not conflict at Mézières. In 1753, Chastillon had moved the school into the old palace and buildings of the deceased Governor of Mézières. These pleasant but formidable old structures faced right onto the Meuse river and the whole school was housed there. Classrooms and staff quarters were in the old mansion. The students and the engineer in charge of relief maps lived in adjoining buildings. The long axis of this three-story edifice ran parallel to the river. Several wings running at angles away from the river completed the structure. The ground floor contained a workyard for carpentry and stonecutting and space for the relief maps. The second and third floors held the library, the three classrooms for drafting and mathematics, the *cabinet de physique*, and lodging for the two commandants.[59] Each student was provided with a private room. As *sous-lieutenants*, entering students received a salary of 600 *livres* per year. The veteran *ingénieurs volontaires* received an additional post allowance of 100 *livres*.[k,60] This was not a great

[j] An officer could enter service at the age of twelve.

[k] Chastillon, *Commandant* and *Directeur des fortifications*, received 5,600 *livres*; Lescouet, *ingénieur ordinaire* and *Commandant en second*, received 2,000 *livres*.

sum to live upon if the student had to buy food, candles, wood, supplies, uniforms, and support his social life from it. It seems that few actually did exist upon the minimum salary because in 1772, Lazare Carnot was considered an unusual person to be able to support himself and even provide some maintenance for his brother from his 600-*livre* salary.[61] When one considers the social life at Mézières it seems that most would have used considerable sums from home. Sunday was the only official holiday at Mézières but other social evenings were arranged and the students led a not too dreary life.[l]

Coulomb entered Mézières in the winter of 1760 and studied there until his graduation in November 1761.[m,63] Circumstances at Mézières were more or less as they had been for a decade. Uniforms were "of royal blue cloth with cuffs of black velvet and red serge lining, the coat . . . trimmed to the waist with gilded copper buttons—five on each pocket and as many on the sleeves."[n,64] The students still received 600 *livres* a year and carried the rank of *lieutenant en second* until their graduation. The official student population was thirty—there were thirty-two in Coulomb's first year and thirty-four in his second.[65] Chastillon remained as commandant of the school, Camus was examiner and Bossut was now the

[l] Some precious indications of student life at Mézières just before Coulomb arrived are recorded in a notebook kept by Rigobert Joseph Bourgeois[62] during his first year at Mézières (1756–1757). Bourgeois was a local boy whose father was royal surveyor and Chastillon's personal architect. According to Bourgeois, the students passed their free time at music, dancing, and games. Several of the students were amateur musicians and performed in public, notably at a special concert in Charleville where thirty musicians, including Bourgeois himself, performed a score written especially for the celebration of the birth of the duc de Bourbon in 1756. The students also gave dances almost every Sunday "aux dames de Charleville." Others gambled, playing at "la mouche, ou 30 et 40, avec mises d'argent." The night of the great celebration they completed the concert, then danced until 4 A.M. in a room provided with four casks of wine—one in each corner of the room. They all then went for onion soup at a local restaurant.

The students took their meals in town, and Bourgeois relates that their favorite treats were waffles, ham, and *tourtelets* (small pieces of dough boiled and then dipped in milk or in a *sauce verte*). Then as today in small French towns, traveling carnivals and marionette shows passed through Mézières. The scope of these diversions is revealed when Bourgeois describes one carnival as having three monkeys and a lion.

[m] Coulomb passed Camus's entrance exam in Paris in the summer of 1759 and entered the school on February 11, 1760.

[n] Striking as these uniforms were they would later be changed, because it seemed that everyone mistook the gaily colored engineers for bourgeois city merchants who also wore pants and coat of red and blue.

professor of mathematics. The school continued to offer courses in carpentry, stonecutting, and drafting. Nicolas Savart[o] was employed as *aide de laboratoire* to the abbé Nollet, who began teaching a short summer course in *physique expérimentale* in 1760, during Coulomb's first year.[66]

From various secondary accounts and from archival material, it is clear that training at the school was heavy on the practical side,[p] at least until the death of Chastillon in 1765. Coulomb participated in Nollet's physics course and probably knew the material presented in his recently published six-volume work, *Leçons de physique expérimentale.*[68] This comprised general notions of matter and gravity, simple mechanics and elements of light, astronomy, electricity and magnetism, and diverse aspects of natural philosophy. Only the most rudimentary knowledge of arithmetic and geometry was necessary to study this course. For a man who was already a member for mathematics in the Montpellier *Société des sciences,* however, something more challenging than Nollet's simple textbooks would be needed. Coulomb would have had to turn to Bossut for further study. Bossut had been ordered to teach the course of mathematics as outlined in the four-volume text of abbé Camus: arithmetic, geometry and statics. He soon widened the presentation to include calculus, perspective geometry, dynamics and hydrodynamics. Coulomb would have received this in the form of lectures or notes as the texts were published after his graduation. Bossut's first text on statics and dynamics,[69] however, was presented to the Academy in Paris for its approval only six months after Coulomb left Mézières, and some of the experiments within the book were described as having been performed at Mézières. At this same time, Bossut circulated notes of his course in hydrodynamics, which appeared in print in 1771.[70]

Though a student might have learned much from Bossut (and

[o] Nicholas Savart was the father of the physicist Felix Savart (1791–1841), born at Mézières.

[p] This designation of studies at Mézières as mostly "practical" would seem at variance with Marcel Reinhard's statements[67] concerning "theoretical studies" at Mézières. First, Reinhard is concerned mainly with Mézières a decade after Coulomb attended and at a time when Bossut and Monge were both teaching there. Second, Reinhard uses "theoretical" in the sense connoted by the words "specific, empirical," such as Vauban's *theory* of retaining wall dimensions. I use the word "practical" here in the sense of learning Vauban's empirical tables of retaining wall dimensions in contrast with "theoretical" as here connoted by the words "general, analytic," such as Euler's *theory* of deformable bodies.

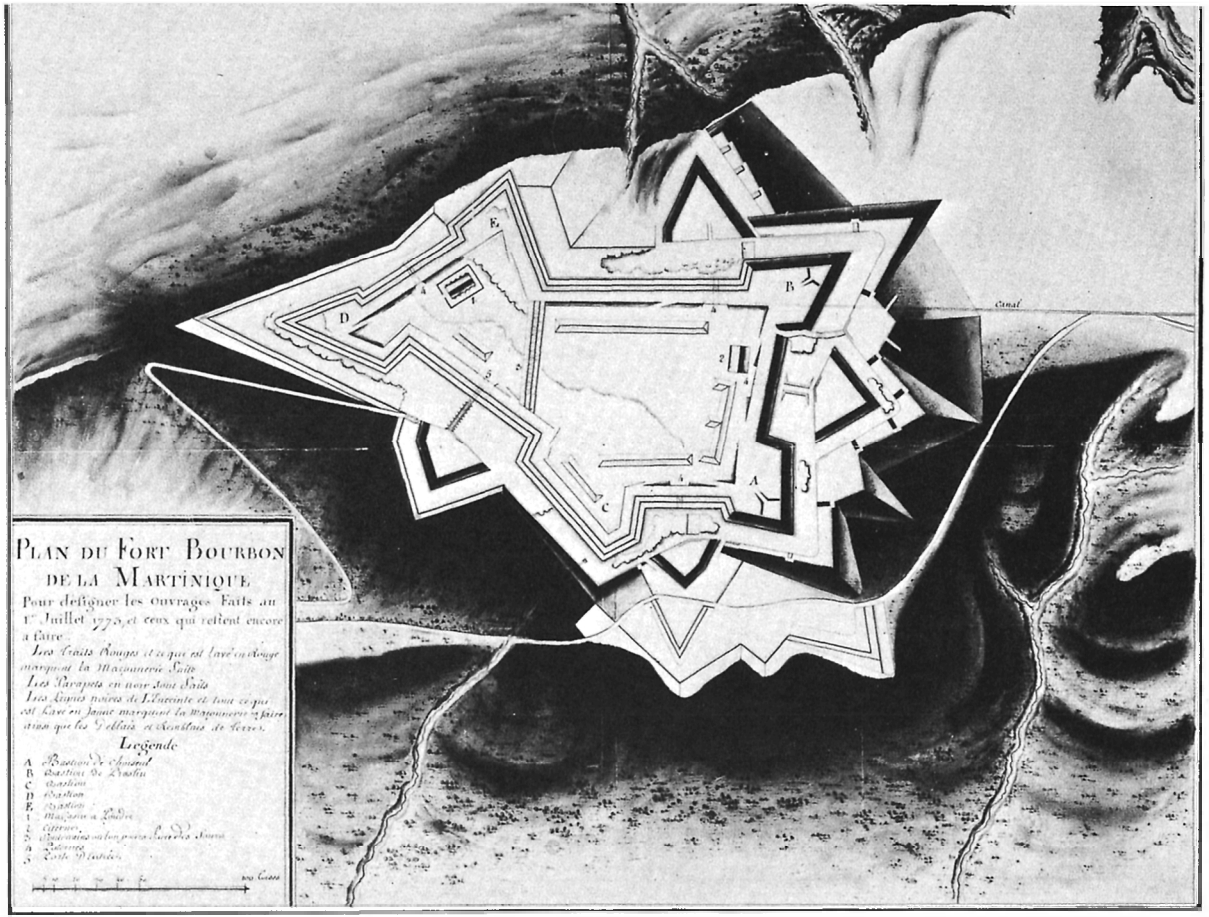

FIG. I.1. Map of Fort Bourbon, Martinique, July 10, 1773. From north to south (north is toward the upper right corner), the fort measured approximately 2000 feet; from east to west, approximately 1250 feet (Courtesy, Archives D'Outre-Mer)