Jorge Juan: Mathematician, Seaman, Engineer, Diplomat, and Spy of the Spanish Enlightenment

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Jorge Juan (1713–1773, Figure 1) was a mathematician and seaman who took part in the famous Spanish–French expedition to South America to measure a degree of meridian at the equator in order to calculate Earth's equatorial diameter. Throughout his life, he worked tirelessly to modernize mathematics, the nautical sciences, and engineering in Spain. In particular, the problem of the shape of the Earth was of paramount importance at the beginning of the eighteenth century, because it affected geodesy and astronomy—both then part of the mathematics curriculum in European universities—as well as physics, mechanics, and engineering.

This paper offers a look at the life and work of Jorge Juan y Santacilia from the perspective of current historiography.

In the mid-eighteenth century, scientific interest in the problem solved by the Spanish–French expedition, together with the difficulty of the challenge and the exoticism of South America for the Europeans of the time, generated numerous accounts of the expedition [18, 19, 44, 45, 47].[1] Subsequent exotic and successful expeditions, among them those led by Alexander von Humboldt and Charles Darwin, moved public attention away from Jorge Juan's legacy. Additionally, during the first decades of the nineteenth century, prominent professional mathematicians shifted their focus from the applications of differential and integral calculus to more theoretical subjects [26, p. 66]. It is significant that the professor of mathematics for engineering at the University of Madrid, José Echegaray,[2] appears to have forgotten entirely about Jorge Juan in his controversial speech on his admission to the Royal Academy of Sciences (Madrid, 1866) [31, p. 103]: "Mathematical science owes us nothing. It is not ours; there is no name in it that Castilian lips can pronounce without effort."

In the twentieth century, international authors turned to the history of the Spanish–French expedition [7, 36, 61, 85, 86], which has also been the subject of more recent popular books, such as [20, 28, 34, 38], which recognize the crucial role played by Jorge Juan in the successful geodesic expedition (even though some authors overdramatize certain events).

We open the present biography of Jorge Juan, the first written in English and published in an academic journal, by describing the political context of his life and early education; we then outline his participation in the Spanish–French expedition to Peru and his contributions to applied mathematics, engineering, and education, among other activities; finally, we summarize Juan's legacy in mathematical education in Spain.

[1] Different editions of Juan's books as well as many related essays in Spanish mentioned in this article are freely available at the Miguel de Cervantes Virtual Library, which is managed by the University of Alicante: https://www.cervantesvirtual.com/.

[2] Winner of the Nobel Prize in Literature, 1904.

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Spain and Science at the Beginning of the Eighteenth Century

The Spanish Hapsburgs' decision to assume the role of champions of the Catholic Church against the Protestant Reformation, which coincided with Copernicus's cosmological work, negatively influenced the development of science in Spain. Geocentrism was still part of Catholic dogma at the beginning of the eighteenth century, because in the Old Testament, Joshua commanded the Sun to stand still while the Holy Spirit affirmed that the world (Earth, that is) did not move. In addition, the doctrines of the incarnation and the redemption enshrined in the New Testament implied the centrality of man for the Creator, so that Earth must be a perfect, immobile body, specifically a sphere, and the orbits of the celestial bodies around the Earth had to be perfect circles [31, 78]. Many Catholic (and Reformist) theologians agreed with the Hungarian Jesuit Melchior Inchofer, who played a crucial role in Galileo's trial [39]:

> The opinion of the Earth's motion is of all heresies the most abominable, the most pernicious, the most scandalous; argument against the immortality of the soul, the existence of God, and the incarnation should be sooner tolerated than an argument to prove that the Earth moves.[3]

By 1700, while scholars in most European countries had broadly accepted Copernicus's heliocentric system, the geocentric system prevailed in Spain. Moreover, not only were the Spanish universities anchored in the stalest scholasticism, there was also an openly hostile attitude toward science [10, 11]. Nor did the change of dynasty in 1713 improve the situation. The first Bourbon king, Philip V (1700–1746), grandson of Louis XIV of France, gave new momentum to the Inquisition in order to secure the support he needed from the Church against the advocates of Archduke Charles [16].

Fear of reprisal and of being targeted by the Inquisition forced scientists to teach in public what they repudiated in private. The efforts of Philip V and, to a greater extent, of Ferdinand VI (1746–1759) and Charles III (1759–1788) promoted the applied sciences and technical knowledge in newly founded institutions, but not at the universities. In its interest to promote the so-called useful sciences, the monarchy chose to "militarize" them, superimposing an educational and scientific structure on top of the military structure. For this reason, much of the scientific–technical activity that developed in the first two thirds of the Spanish eighteenth century was closely linked to the state's armed forces and their institutions, including the Academy of Marine Guards of Cadiz (1717), the Military Academy of Mathematics of Barcelona (1720), the Colleges of Surgery of Cadiz (1748) and Barcelona (1764), the Cadiz Astronomical Observatory (1753), the Artillery Academies of Barcelona and Cadiz (1751), and the Artillery Academy of Segovia (1762) [52, 53].

It is in this political context that we describe Jorge Juan's life and professional career.

Figure 1. Portrait of Jorge Juan Santacilia painted by Rafael Tejeo in 1828. (Courtesy of Museo Naval de Madrid.)

A Teenage Sailor: Malta, Cadiz, and Oran, 1713–1734

Jorge Juan Santacilia was born in the town of Novelda (Alicante) on January 5, 1713, into a family of minor nobility without title. He was a son of the gentleman Bernardo Juan Canicia (Alicante, 1666–1715) and the lady Violante Santacilia Soler de Cornellá (Elche, 1681–1760), both widowed and with several children from their previous unions [22].

Jorge Juan lost his father at age two and was educated by his paternal uncle Cipriano Juan Canicia, a knight of the Order of Saint John, in which he would come to hold positions of great responsibility. Jorge went first to the Jesuit school in Alicante, then to that in Saragossa, where for a year he studied grammar, a preparatory subject for higher education. After a year, he applied for admission to the Order of Malta, which required mandatory tests of nobility, legitimacy, and purity of blood (Figure 2). Through Cipriano, Jorge Juan became a page to the grand master of the order Antonio Manuel de Villena. When Jorge Juan was barely twelve years old, his uncle sent him to Malta, where he remained for nearly four years. At sixteen, he was granted the title of commander of Aliaga. In mid-1729, Juan returned to Spain and applied to begin his training as an officer in the Spanish navy with the Royal Company of Marine Guards of Cadiz [3].

At the Academy of Marine Guards of Cadiz, Juan combined the study of scientific subjects such as geometry, trigonometry, cosmography, nautical sciences, and fortification with the acquisition of academic and social skills

[3]Cited in Galileo's letter to Deodati, July 28, 1634.

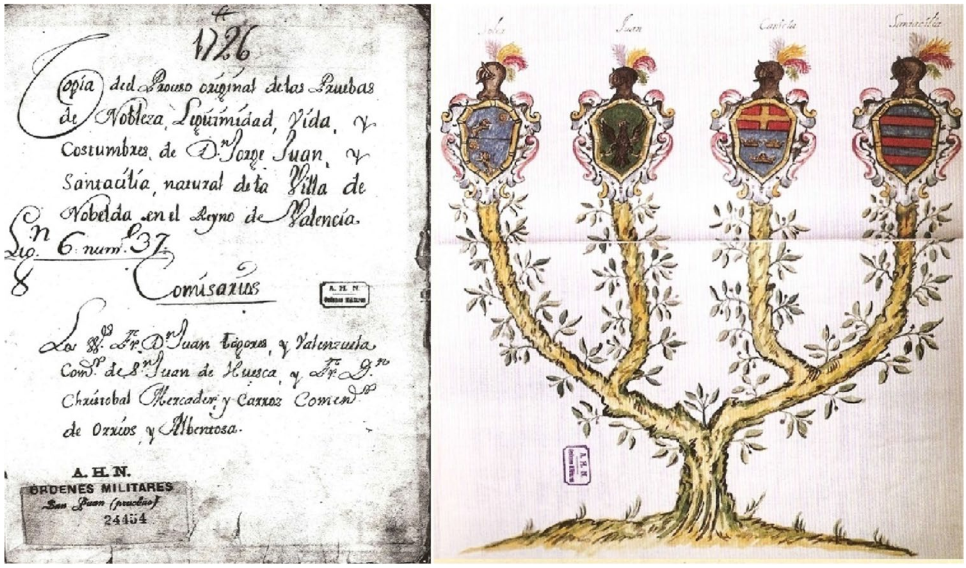


Figure 2. Tests of nobility of Jorge Juan (Archivo Histórico Nacional, Madrid: Órdenes Militares-San Juan, exp. 24454).

including foreign languages, fencing, and dancing [55]. For seamen, this was necessary for the performance of their commissions, since in the course of their professional lives, they represented the Spanish crown wherever they traveled and had to know how to handle themselves in all kinds of environments and situations. Thus they needed to be able to navigate and command a ship, plan military actions, repel attacks, negotiate surrenders, behave appropriately at receptions, and engage in diplomacy. During the following four years, Juan alternated studies at the academy with participation in various naval actions in the Mediterranean. Because of his remarkable progress in mathematical studies, especially astronomy, Juan was chosen to take part in the Spanish–French geodesic expedition to the viceroyalty of Peru [50, 63].

An Astronomer and Seaman: South America, 1735–1745

At the beginning of the eighteenth century, the scientific world was divided between two theories regarding the shape of the Earth. Based on their measurements, René Descartes, Jean Picard, Giovanni Domenico Cassini, and Jacques Cassini, the latter two father and son directors of the Paris Observatory, argued that the Earth was a prolate spheroid, that is, elongated in the direction of the poles. Alternatively, Isaac Newton's hypothesis that the Earth was oblate, that is, flattened at the poles, had been gaining popularity for years. The discussion between the Cartesians and Newtonians was by no means theoretical. Precision in navigation, the preparation of reliable maps, and other issues of scientific, political, strategic, and economic importance depended on an accurate knowledge of the shape and size of the planet. These considerations popularized the expedition organized in 1733 by the *Académie Royale des Sciences* to measure one degree of the terrestrial meridian at the equator in the viceroyalty of Peru [19, 20, 28, 34, 35]. The result would settle the debate on the shape and dimensions of the Earth.

The institution mobilized its most prestigious members. Along with the geodesist and astronomer Louis Godin, director of the expedition, were the seaman, naturalist, and mathematician Charles Marie de La Condamine; the seaman, naturalist, and hydrographer Pierre Bouguer; the naturalist Joseph Jussieu; the surgeon Jean Séniérgues; the naval engineer Jean Joseph Verguin; the mechanic-watchmaker Théodore Hugot; the assistant geographers Jean Godin des Odonnais and Jacques Couplet-Viguier; and the draftsman Jean-Louis de Moranville. Simultaneously, another expedition, under the command of Pierre Louis Moreau de Maupertuis, would go to Lapland to carry out identical work near the polar circle in order to compare results. Since Peru was Spanish territory, the French crown had to request permission from Felipe V, who granted it. But following the opinion of his minister, José Patiño, he demanded the incorporation of two young marine guards—Patiño chose Jorge Juan and Antonio de Ulloa—who were immediately promoted to Tenientes de Navío,[4] raising their rank to that of the French commissioners [82]. They were tasked with collaborating with—and monitoring—the French, developing their own observations, and preparing various reports on the situation of the viceroyalty.

[4]In the eighteenth century, Spanish naval ranking progressed in the following order: Alférez de Fragata, Alférez de Navío, Teniente de Fragata, Teniente de Navío, Capitán de Fragata, Capitán de Navío, Brigadier (created in 1773), Jefe de Escuadra, Teniente General, Capitán General, and Almirante General de la Armada.

Figure 3. Engraving from *La Lettre a madame* ... published in 1746 by Charles M. de la Condamine. It represents the mutiny against the surgeon Seniergues in the Cuenca bullring.

Juan and Ulloa set foot in America in July 1735, and a few months later, they met the French commissioners in Cartagena de Indias, thus beginning a true scientific adventure that would keep them in the American continent until the end of 1744. Measuring the meridian degree required triangulation. The expeditionaries established the base line in the Yaruqui plain, a strip of land 12 kilometers long located between two mountain ranges to the southwest of Quito. Once the fundamental base had been measured, the expedition divided into two groups, each traveling 400 kilometers to carry out triangulation operations in a north–south direction. The distance traveled was equivalent to a little more than three degrees of latitude.

In order to carry out the triangulation measurements, they had to ascend high-altitude peaks, such as Pichincha, Corazón, and Sinasaguan [60], and withstand extreme cold and violent storms. Juan and Ulloa described the great hardships [45, pp. 308–311] (translation from [28, pp. 138–139]):

> We generally kept within our hut. Indeed, we were obliged to do this, both on account of the intenseness of the cold, and the violence of the wind. We heard the horrid noises of the tempests, which then discharged themselves on Quito and the neighboring country .... We suffered from the asperities of such a climate. Our feet were swelled, and so tender we could not even bear the heat, and walking was attended with severe pain. Our hands were covered with chilblains, our lips swelled and chapped, so that any speaking or other movement of the mouth led to immediate bleeding.

In Peru, Jorge Juan obtained solid scientific training, the result of intense personal effort, long hours of study, and the teaching of Louis Godin and Pierre Bouguer. His years of apprenticeship in America were decisive. Jorge Juan would recognize this later, in a long letter to the Marquis of Ensenada written from London at the end of 1749 [25, pp. 72–73]:

> Of the many parts of which [Mathematics] is composed, Geometry, Mechanics, and Astronomy, each one in itself requires many years of work and, in my opinion, one should consider a man very skillful who makes some progress in any of them in 4 years. For my part, I confess that after 14 years of not letting these matters get out of hand, not counting the time I was at the Academy of Cadiz, I still have much to admire every day.

Juan and Ulloa, in addition to making the astronomical observations, geodetic measurements, and mathematical calculations necessary to determine the measure of the meridian degree, were also responsible for collecting data on the society, geography, history, military, and political situation of the territories. Their task was hampered by the continual disputes that arose among the French academics, who ended up divided into two groups. The expedition aroused misgivings among the indigenous population, as well as the animosity of the local authorities and the viceroyalty. They were also involved in very serious public altercations with the president of the high court of Quito, José de Araujo y Río, and another that cost the life of the expedition's surgeon, the Frenchman Jean Seniergues, who was lynched in the bullring of Cuenca by a mob instigated by the local clergy and oligarchy (Figure 3) [18, 35, 38, 48, 50].

When England and Spain went to war in 1740, the viceroy Marquis de Villagarcía commissioned Juan and Ulloa to organize the defense of Lima, Guayaquil, and other enclaves and strongholds on the Pacific coast before the attacks of the English squadron of Commodore George Anson, who had sailed around Cape Horn and sacked Paita's harbor (close to present-day Piura, Peru). Both seamen had to prepare, arm, and command a frigate with which they patrolled the coasts of Chile and the islands of Juan Fernández for months in

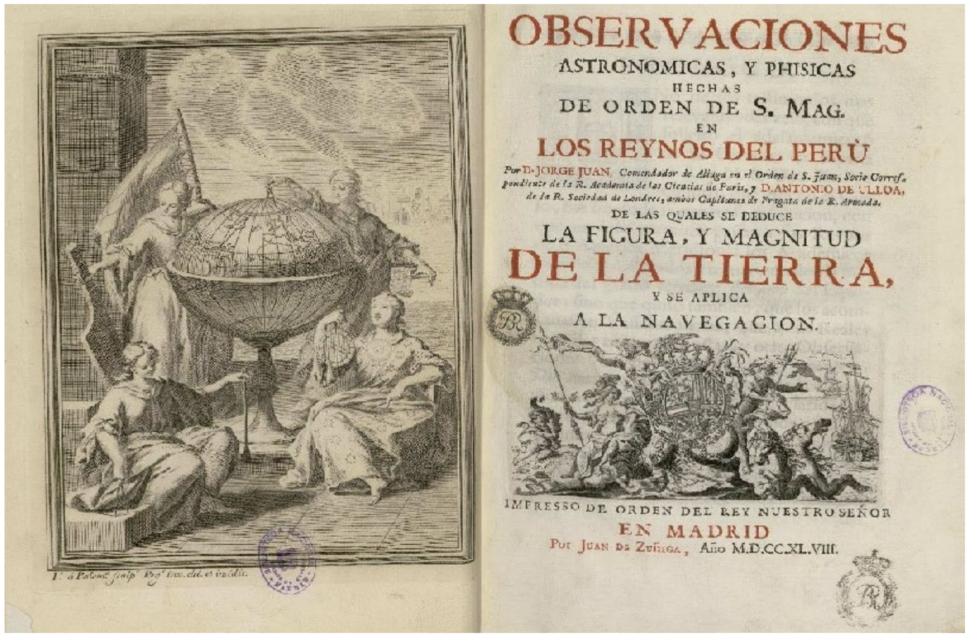


Figure 4. Frontispiece and title page of *Observaciones astronómicas y físicas*, published in 1748 by Jorge Juan and Antonio de Ulloa. (Courtesy of Biblioteca Nacional de España, Madrid.)

search of the squadron. They took advantage of this circumstance to write down courses, routes, currents, and winds; to make astronomical, barometric, latitude, and pendulum observations; and to draw plans of the coasts, bays, and cities along which they passed [63].

The endeavor to measure a degree of meridian at the equator lasted almost ten years. The Spanish seamen had to finish the task alone, since several of the French expeditionaries returned to Europe after they had completed their measurements. At the end of 1744, Juan and Ulloa embarked separately for Europe in two French frigates. The crossing was very eventful for Ulloa, for his boat fell into English hands, and he was taken prisoner. However, upon arriving in London and demonstrating his status as a scientist and member of the expedition for the measurement of the meridian, he was released and was later proposed and accepted as a member of the Royal Society. For his part, Jorge Juan, after ten months of sailing, landed in Brest at the end of October 1745. From there he went to Paris, where the *Académie Royale des Sciences* named him a corresponding member. He finally arrived in Spain at the beginning of 1746, a few months before his companion [25, 86].

An Applied Mathematician, Engineer, and Spy: Continental Spain and London, 1746–1754

Back in the Madrid court, Juan and Ulloa were received by the powerful minister Marquis de la Ensenada [76], who, noting the importance of the work carried out by the two young seamen, encouraged the publication of the results of the trip. But despite the support of the minister and qualified court intellectuals, such as the Jesuit Andrés Marcos Burriel, the inquisitorial censorship temporarily halted the publication due to its evident Copernicanism and Newtonianism. Certain pressures on the general inquisitor and the insertion of a brief comment alluding to "hypotheses" and not "theories" in the book's preface facilitated its authorization without requiring a formal retraction by Jorge Juan [3]. And so in 1748, Jorge Juan and Antonio de Ulloa, anticipating the French scientists, jointly published their separately written books.

Juan wrote the*Astronomical and Physical Observations Made by Order of His Majesty in the Kingdoms of Peru* [44] (Figure 4), where he systematized the astronomical observations, geodetic measurements, and mathematical calculations applied to determine the measure of the degree of the meridian. He established this value as 56,767.788 toises (an old French unit of length equivalent to 1.946 meters), a calculation later determined to be the most precise measurement of all those obtained by the expeditionaries [49]. The *Astronomical Observations*, organized into nine chapters (called books), reveal the great theoretical apparatus used by Jorge Juan. The introduction discusses Newton's, Huygens's, and the Cassinis' theories on the shape of the Earth, with references (starting with Newton's *Principia Mathematica*) interspersed throughout the text. The book is dominated by arguments based in Euclidean geometry (mainly plane and spherical trigonometry), which allowed Jorge Juan to obtain formulas for the precise estimation of longitudes, latitudes, and altitudes. In particular, the expedition measured the heights of mountains using Mariotte's and Halley's barometric leveling formulas. The experimental constants involved were independently determined in situ by the Spanish and French groups.[5]

Jorge Juan applied differential calculus to prove the formula for computing the degree of meridian at any latitude, which had been previously obtained by Maupertuis via infinite series [44, pp. 305–309]. The following account by Jorge Juan tells of a discrepancy between the Spanish and French expeditionaries about a strange movement detected by him and Ulloa in the latitude of the stars (from the constellations Orion, Antinous, and Aquarius) used to measure the degree of the meridian [44, pp. 271–272]:

> We reported this discovery to Bouguer and La Condamine, who, although they doubted it, wanting to attribute some defect to our instrument, were satisfied by several observations that they repeated with fixed glasses.

This episode illustrates the rigor with which the commissioners worked as well as the initial condescension of the veteran expeditionaries toward the two young lieutenants.

Antonio de Ulloa, for his part, was in charge of writing the four volumes of the *Historical Report of the Trip to Southern America* [45], in which he provided important information on history, geography, ethnography, and many other topics on the Peruvian viceroyalty. Both works exhibited various plans and drawings, including a map of the meridian measured in Quito and a chart of the South Sea. Despite the obstacles presented by the Holy Office, these books contained the first scientific conclusions of the trip and brought fame and recognition to their authors [28, 63]. In October 1748, Jorge Juan and Antonio de Ulloa were promoted to Capitanes de Navío.

In 1749, Juan and Ulloa jointly published a third book, the *Historical and Geographical Dissertation on the Demarcation Meridian between the Dominions of Spain and Portugal* [46]. In a detailed report, *Discourse and Political Reflections on the Present State of the Kingdoms of Peru*, reserved for the exclusive use of the government, they denounced the deficient defense of the ports and strongholds of the coasts of the Pacific and the social, ecclesiastical, economic, and administrative situation of the Spanish colonial empire in America. This report remained confidential until David Barry published it in London in 1826 under the title *Secret News of America* [7, 36, 61, 72]. Barry intentionally eliminated the preface, in which the authors had stated that the report describes only the evils and abuses they observed [85].

From 1748 onward, Jorge Juan was an essential part of the reformist projects initiated by the Marquis de la Ensenada, who undertook a vast plan of scientific-technical renewal, the promotion of naval construction, and the empowerment of the navy [1, 32]. The development of this reform program required the knowledge and application of all the novel technical advances circulating in Europe, especially all those related to the improvement and modernization of the navy. For this reason, the marquis sent Juan to England to carry out a mission of industrial espionage between March 1749 and April 1750. Carrying very precise secret instructions, using an encrypted code to send messages, and sometimes adopting a false identity, Juan hired nearly eighty specialists in shipbuilding and the manufacture of rigging, canvas, and all kinds of supplies [37], managing to transfer them to Spain with their families. He also obtained important technical information about the operation of steam engines, the activity of sail and rigging factories, the organization of English arsenals, and the progress made in the design and construction of ships. He acquired matrices for printing type, the formula for sealing wax, and technical details on the manufacture of English cloth. He also bought books and scientific instruments for the College of Surgery and the Academy of Marine Guards in Cadiz, the Academy of Engineers in Barcelona, and other institutions. Simultaneously, Juan frequented political and scientific circles in London and was admitted as a fellow of the Royal Society. But in April 1750 his espionage work was discovered. With the risk of being arrested and imprisoned, he fled, first to France and then to Spain, having satisfactorily fulfilled his mission [51, 64]. That same year, the king of Prussia, Frederick II, appointed him a member of the Royal Academy of Sciences of Berlin. He had been proposed by Maupertuis, president of that academy and former director of the meridian expedition in Lapland.

On his return from England, Jorge Juan was commissioned by the Marquis de la Ensenada to direct work on the arsenals, as well as the renovation and modernization of all naval construction. His experience with problems in ship manufacturing and mechanics went back to his days in Peru with Pierre Bouguer, who drafted the *Traité du Navire* (1746) during the expedition. Juan and Ulloa had also supervised and directed the conditioning of two merchant frigates to defend the coasts of the viceroyalty from English attacks. The Spanish ships, built with the Gaztañeta system, were heavy, slow, difficult to maneuver, and consumed an excessive amount of wood in their manufacture [33]. In London, Juan verified the advantages of the more agile and faster English ships and applied himself to the study of a new method based on practical experience, mathematical calculations, and principles of physics applied to the movement of ships in water. After multiple tests with scale models, in 1752 Juan gathered all the technicians brought from England to Madrid, and for nine months he designed and drew plans for all kinds of ships, establishing a uniform set of rules toward a new method of shipbuilding that applied his knowledge of mechanics, hydraulics, and differential and integral calculus. Innovations were not limited to the ship's carpentry, but included the rigging and its arrangement in the ship. This method, which was given the misnomer "English," was implemented by the Spanish navy and employed until 1765, when it was abandoned for the French system imported by the engineer François Gautier [65].

Between 1751 and 1754, Jorge Juan supervised works at the main Spanish arsenals of Ferrol, Cadiz, and Cartagena. He carried out fundamental modernization, such

[5] Bouguer's formula (based on Halley's proportion) appears with this name in the official history of meteorology, but those of Juan and Ulloa are omitted [29].

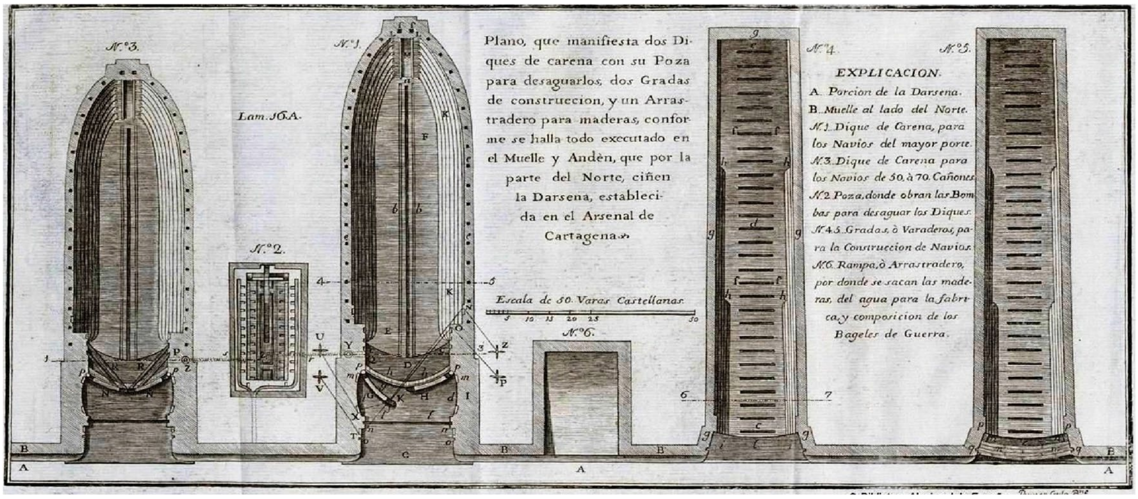


Figure 5. Engraving of *Tratado de Fortificación ... Vol. 2*, published in 1769 by J. Muller (translation by M. Sánchez Taramas). It shows the design of the two dry docks of the Cartagena arsenal. (Courtesy of Biblioteca Nacional de España, Madrid.)

as the incorporation of (dry) docks, an innovation that significantly increased the average life of ships [69]. In particular, Juan established in Ferrol's arsenal a series of improvements, including the location of the maintenance workshops and a planned village attached to the naval base to house workers and military personnel. With twelve tiers of construction, this arsenal was the largest in Europe in its time. Following Juan's instructions, twelve ships of the line were simultaneously built there. He also designed its two careening dry docks (Figure 5), supervised the construction of the first one, and planned to move the Sada rigging and canvas factories to Ferrol [21, 25, 62, 67, 70, 71, 84].

In addition to his numerous trips to direct the works of the arsenals, Jorge Juan held commissions in fields as diverse as cartography, mining, hydraulics, and the steel industry that would force him to move continually from one edge of the country to another. The mathematician Benito Bails says in his *Praise of Juan* (preface to [15, p. 16]) that by order of the court, he made more than "twenty-four trips from one edge of Spain to the other." Crisscrossing the country in the 1750s, he traveled to the Alcaráz Range to study the feasibility of a canal that would irrigate the lands of Lorca and Totana with the waters of the Castril and Guardal Rivers, he inspected lead mines in Linares and mercury mines in Almadén (where he reviewed the ventilation and drainage systems), assessed fire damage, and supervised the cannon factory installed in the Santander steel complex of Liérganes and La Cavada. In 1754, he was appointed a member of the General Board of Commerce and Currency with the task of studying how to improve the weight, alloy, and tuning of metals for the manufacture of coins. To satisfy one of the prime objectives of the Marquis de la Ensenada, between 1751 and 1752 Juan wrote, together with Antonio de Ulloa, some *Instructions for the Survey of the Map of Spain* following strict geodetic and astronomical observations [59, 77], and in 1752, together with Louis Godin and José Carbonel, he drew up the statutes for a Royal Society of Sciences of Madrid, which, as in other European states, was to ensure the teaching and dissemination of the physical and mathematical sciences. But both initiatives would be paralyzed after the Marquis de la Ensenada was exiled in the summer of 1754, first to Grenade, then to Puerto de Santa María, which lasted until Charles III ascended to the throne in 1760. His trusted man Jorge Juan would remain in Cadiz [2, 24, 74].

Educator, Diplomat, and Spanish Pioneer of Calculus: Cadiz, Morocco, and Madrid, 1755–1773

In 1751, Jorge Juan was appointed captain of the Navy Guards Company of Cadiz and director of its academy. He immediately put into practice an ambitious project of pedagogical reform, since he considered it essential that the students achieve a solid theoretical foundation in nautical sciences and mathematics, thus securing the status of officers as both military and scientific professionals. When Juan had written to the marquis of Ensenada in 1749 [25], he did not count the years of study he had spent at the Cadiz Academy as advancing his progress in mathematics and did not even mention his stay in Malta, an obvious sign that he considered it irrelevant for educational purposes. For him, only the last fourteen years (since 1735) that he had dedicated to his study counted. So to carry out the reform plan of the Cadiz Academy, Jorge Juan hired a new set of more competent teachers and modified the curriculum to promote the teaching of mathematics and in particular, to introduce the study of differential and integral calculus. He also instituted public contests in order to stimulate students' problem-solving abilities and demonstrate teaching quality. Moreover, he obtained permission to write and print new textbooks and scientific monographs in the academy itself without the need to go through prior censorship [17, 25, 55]. The first of these monographs, published

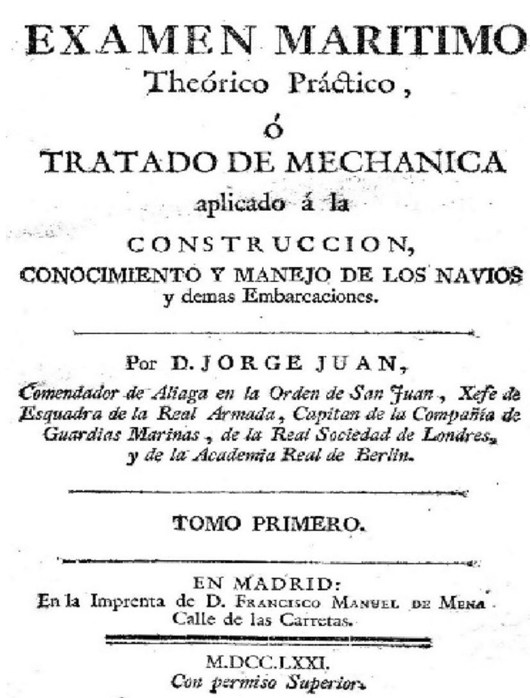
Figure 6. Engraving from *Historia de la Villa y Corte de Madrid*, Vol. 4, published in 1864 by J. A. de los Ríos and C. Rosell. It represents the Seminary of Nobles of Madrid. (Courtesy of Biblioteca del Banco de España, Madrid.)

in 1757, was his *Compendium of Navigation for the Use of Knight Midshipmen* [40].

However, among all of Juan's improvements, perhaps the most interesting was the application of ship mockups or scale models built as teaching tools to familiarize the midshipmen with the problems of naval construction and navigation, but also as useful instruments with which to experiment with the limits of a theory. Juan also used scale models to test specific projects and convince technicians, ministers, or even the monarch himself of their viability. For example, he went to the court in 1759 to show how to repair dikes according to his experience in Cartagena. He also suggested the use of a scale model to communicate the complicated maneuver of moving three sinking ships that were blocking the mouth of Havana Harbor in 1765 [3]. The use of mockups meant the introduction in Spain of a new technique that had emerged at the beginning of the eighteenth century in the English shipyards, which is another example of Juan's application of the experimental method as a source of knowledge [83].

Jorge Juan decisively contributed to the scientific modernization of the Spanish navy by updating the curriculum of the Marine Guard Academy of Cadiz [13]. In 1753, Juan and Louis Godin, who then served as director of the academy, created Spain's first astronomical observatory, in Cadiz. This observatory was conceived as an institution attached to the academy to complement the teaching of the cadets. It was equipped with books and scientific instruments acquired by Juan in London and was located in the old tower of the Marine Guards Castle in Cadiz, until it was moved in 1798 to the Island of León (today San Fernando) [55]. An example of the international prestige that the observatory achieved in a few years is the laudatory mention made by the astronomer Joseph Jerôme le François de la Lande in referring to the facilities of the establishment in Cadiz [56, T. I, p. 46]: "*L'Observatoire de la Marine à Cadix est très solide, très comode et garni de très bons instruments*."

In 1755, Juan began a salon called *Asamblea Amistosa y Literaria* (Friendly and Literary Assembly), which included



EXAMEN MARITIMO
Theórico Práctico,
ó
TRATADO DE MECHANICA
aplicado á la
CONSTRUCCION,
CONOCIMIENTO Y MANEJO DE LOS NAVIOS
y demas Embarcaciones.

Por D. JORGE JUAN,
Comendador de Aliaga en la Orden de San Juan, Xefe de Esquadra de la Real Armada, Capitan de la Compañia de Guardias Marinas, de la Real Sociedad de Londres, y de la Academia Real de Berlin.

TOMO PRIMERO.

EN MADRID:
En la Imprenta de D. Francisco Manuel de Mena
Calle de las Carretas.

M.DCC.LXXI.
Con permiso Superior.

Figure 7. Title page of *Examen Marítimo Teórico Práctico*, published in 1771 by Jorge Juan Santacilia. (Courtesy of Biblioteca Gabriel Miró, Alicante.)

professors from the Academy of Marine Guards and the College of Surgery of Cadiz. In its sessions, members prepared and discussed scientific reports, and Juan gave ten talks on astronomy and navigation [24, 66]. Jorge Juan continued his political assent. In 1760, he was promoted to Jefe de Escuadra, and in 1766, he was appointed plenipotentiary ambassador to the Moroccan Court to conclude a peace and trade treaty whose preliminaries had been negotiated during that year by Sidi Ahmet el Gacel on behalf of the sultan of Morocco. In May 1767, he signed the first Treaty of Peace and Trade between the Spanish Crown and Morocco under very favorable conditions for Spanish interests: peace between the two kingdoms on sea and land, freedom of navigation, use of Moroccan ports for Spanish ships, concessions of fishing factories in the Atlantic, express recognition of all the strongholds and prisons that Spain had on the Moroccan coast, establishment of consulates, etc. [9, 57, 58, 75].

Jorge Juan rendered his last services to his nation at a civilian educational institution after being appointed by King Charles III, in 1770, director of the Seminary of Nobles. This school had been created in 1725 by Philip V to educate the sons of the nobility and was aimed at training the future ruling classes in military and state administration. The institution went into steep decline after the expulsion of the Jesuits in 1767, with a small number of students and unsustainable expenses. Juan managed to revitalize the Seminary of Nobles after undertaking a profound academic and administrative reform. In particular, he reduced the price of the pension paid by each schoolboy, so that in the three years he was in charge, the number of students grew to 82. He also reformed the curriculum, promoting the teaching of mathematics, including calculus, astronomy, and physics, and modified the cadre of teachers, firing superfluous or incompetent ones and hiring highly qualified ones, such as the mathematician Francisco Subirás, as well as renowned instrument technicians, such as the watchmaker Diego Rostriaga, the first physics machinist of the Seminary of Nobles [8, 68].

The Seminary of Nobles of Madrid (Figure 6) was the scene of the first lectures on calculus delivered in continental Spanish civil institutions. There the Jesuit Tomás Cerdá had timidly introduced the teaching of differential and integral calculus following Thomas Simpson's *Doctrine and Applications of Fluxions* (1750), but his classroom notes did not reach the press. So calculus was only officially introduced to teaching in Spain at the Academy of Marine Guards of Cadiz, following the appointment of Juan and Godin as directors in 1752 and 1753, respectively [14].

In 1771, Jorge Juan published his masterpiece, *Maritime Examination* [41] (Figure 7), which was quickly translated into English and French and would be regarded in eighteenth-century Europe as one of the leading books on fluid mechanics and naval engineering [27, 80, 81]. Its first volume dealt with general mechanics and contained two novel studies on the theory of shocks and friction, while the second volume dealt with the application of mechanics to ships. In the first great mathematical polemic of the century, Juan had supported Newton's thesis on the shape of the Earth against that of the Cassinis and Descartes. In the foundations of differential calculus, he preferred the infinitesimals of Leibniz to Newton's fluxions.

But the intense pace of work that Juan had endured for years ended up affecting his health. In a later obituary [79], his personal secretary, Miguel Sanz, wrote that Juan's absolute dedication to work, constant travel, and growing responsibilities were undermining his health, forcing him to interrupt his activities frequently to go to spas to recover. Epileptic seizures that struck him with some frequency during the last third of his life left his hands disabled [3]. At the beginning of June 1773, after a stay in Alicante to restore his health, he returned to Madrid and resumed his duties as director of the seminary. But an attack of apoplexy again prostrated him, and on June 21, 1773, after a week of agony, he died at his home in Madrid at the age of 60 [23].

On his death, the reissue of the *Astronomical Observations* was in press. This book consisted of his 1748 publication [44], which had led to so many problems with the Inquisition, with a new introduction entitled *State of Astronomy in Europe* [42]. Juan had written the draft in 1765, which he read during a physics class at the Seminary of Nobles six days before his sudden death. So Jorge Juan did not live to see his project finished. Eventually, Miguel Sanz received permission from the Council of Castile to publish the work [42].

Epilogue: The Educational Legacy of Jorge Juan

We owe to Jorge Juan two of the first three books written in Spanish that used differential calculus. The first was his *Astronomical Observations* [44], published in 1748. The second was *Superior Geometry*, a textbook by military engineer Pedro Padilla, director of the ephemeral Body Guards Academy (1750–1761), inspired by Colin Maclaurin's *Treatise of Fluxions* (1742) [14]. Finally, the third book was Juan's masterpiece *Maritime Examination* [41], dictated to Miguel Sanz during his time at the helm of the Seminary of Nobles. It is no coincidence that both authors taught at military schools. In fact, around 1767, differential and integral calculus were already part of the curriculum of the artillery and military engineering schools, as well as that of the marine guard academies. In 1793, the seaman Gabriel Ciscar, responsible for teaching mathematics at the Academy of Marine Guards of Cartagena, reissued the first volume of the *Maritime Examination* [43]. This enlarged edition devotes 64 of the 114 additional pages of mathematical preliminaries to differential and integral calculus. Even though Ciscar preferred Newton's approach, he respected Juan's preference for Leibniz's approach, which would prevail during the next century once the controversial infinitesimals were interpreted as real-valued functions whose limit at the origin is zero. The following quotation from Ciscar [43, p. 51], who never met Jorge Juan, is evidence of the general consensus in considering the latter as having introduced calculus in Spain (see also [13, 14, 54]):

> By the method of fluxions the rules of this sublime calculation are demonstrated with more evidence, but as our Author [Jorge Juan] uses infinitesimals, to clarify it we will be forced to use them in spite of ourselves .... In infinitesimal calculus it is supposed that if two or more quantities decrease until they become equal to zero, or what is the same, until they become infinitely small, these zeros keep a certain ratio to each other. We consider this principle to be false, and we believe that equations between infinitesimal quantities are absurd, despite being extremely

useful because other true equations are deduced from them.

In contrast to the military schools, the anachronistic Spanish universities began only gradually to incorporate, by 1767, the teaching of calculus into their curricula. The first reform of the university system by the Bourbon dynasty, carried out with minister Campomanes's Royal Charter of 1786, was an excellent opportunity for the generalized updating of the curriculum in mathematics. Following the French model, the whole country was divided into educational districts, whose rectors, appointed by the king, supervised education at all levels. Moreover, the charter rationalized the pedagogical structure by systematizing degrees, syllabuses, and textbooks and by arranging for the provision of chairs. However, the reform failed due to the opposition of the major universities (Salamanca, Valladolid, and Alcalá) and the lack of financial resources. Consequently, the teaching of calculus in Spain after Juan's passing was in practice limited, aside from the military schools, to three institutions under his scientific influence, all of them located in Madrid: the Seminary of Nobles, to which he had dedicated his last efforts; the Royal Academy of Fine Arts of San Fernando, which trained future architects; and the Royal Studies of San Isidro, also conceived to educate the nobility [10–14].

Francisco Subirás, who had been appointed by Jorge Juan to direct the teaching of mathematics at the Seminary of Nobles, respected Juan's curriculum after his death and in 1776 initiated public mathematical contests, which, as he claimed, were inspired by those Juan had organized at the Academy of Marine Guards of Cadiz. These contests, based on the first volume of *Maritime Examination*, had two parts, entitled "Direct Method of Fluxions" and "Inverse Method of Fluxions," which were devoted respectively primarily to optimization problems and geometry of curves via derivatives and to the computation of areas and volumes via integrals. The Royal Academy of Fine Arts of San Fernando commissioned Benito Bails, nominated by Juan, to write a textbook in Spanish for a complete course on mathematics. Bails's *Elements* would appear in ten volumes between 1772 and 1783. Its third volume, published in 1779, included differential and integral calculus. Following the general intellectual framework of the Enlightenment, Bails's textbook was clearly influenced by French mathematical literature. Finally, the old Imperial College reopened its doors in 1770 under the name Royal Studies of San Isidro, three years after the expulsion of the Jesuits, with a cadre of teachers chosen through competitive examinations. Bails and Subirás were two of the four members of the jury that selected the first two professors of mathematics for this institution, and thus its curriculum benefited from Juan's ideas on mathematical education [14].

However, there was still a long way to go to achieve the modernization of mathematics in Spain. It was not until the death of the absolutist King Ferdinand VII (1814–1833) that the Inquisition was abolished. A year later, in 1834, the Academy of Exact, Physical and Natural Sciences was founded, while the science faculties for the Spanish university system were created in 1857 by the Moyano Law. The international mobility enjoyed by the scholars of the Enlightenment thanks to the government *pensiones* (grants) was reinstated in 1907 with the creation of the *Junta para la Ampliación de Estudios* (Board for the Extension of Studies). This international mobility came to a standstill again with the abolition of the Junta in 1938 during the Civil War (1936–1939). It was finally reestablished in 1977. Normality was achieved in the decade 1999–2009, in which Spain (ninth-ranked in the world by gross domestic product) was tenth in mathematical publications and eighth in citations.

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