CHEVALIER DE BORDA

1733-1799

THE CHEVALIER DE BORDA

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The name of BORDA owes its great celebrity in France, in so far as the general public is concerned, to the fact that from 1849 to 1913, the various vessels acting as the Naval School and permanently anchored in the roadstead of Brest, were named *Borda.*

It is indeed a great honour to a seaman for his name to be chosen to symbolise a school that produces so many officers, and, it may be said without hesitation, so many modest or illustrious heroes. There was a reason for this choice ; there was a purpose in giving the name of BORDA to the nursery of our naval officers ; this name embodies a threefold significance : scientific, technical and military, typifying the triple ideals of our young seamen. For this reason, I shall endeavour in these few pages, to give a brief outline of the exceptional qualities of this man, who was not only an honour to our Navy, but who was still greater scientifically, and universally so, owing to the very wide scope of his work, the latter part of which resulted in the creation of the *Metric System.*

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Charles DE BORDA was born at Dax on the 4th May, 1733.

His father, Jean-Antoine DE BORDA, Seigneur DE LA BATUT, had married Mademoiselle Marie-Thérèse DE LA CROIX, who, like her husband, was "of good family". There were eleven children of this marriage. The ancestors of the DE BORDAS were all distinguished in the profession of arms, and this created in young Charles a kind of atavistic tradition. However, a very different career was planned for him. One of his uncles, Jean-François DE BORDA, held the position of *Président de Parlement* ; Charles' father, whose two elder sons were already serving in the Royal Armies, was anxious for his third son to study for the law and eventually to succeed to his uncle's position as President.

His parents sent him to study under the Jesuits in their famous college at La Flèche. Here he astonished his masters by the facility of his comprehension and his capacity to approach the most diverse subjects with equal ease. These admirable educators of youth were quick to recognise the real aptitude of their pupil, whose every thought was turned towards the exact sciences. This, however, did not prevent him from terminating his classical studies brilliantly. In passing, it may be remarked that this demonstrates the fact that a solid classical education, far from being an obstacle in a scientific career, constitutes a solid intellectual basis which, on account of the intellectual gymnastics to which it submits the mind, gives that reasoning capacity which later helps the mind to approach questions which demand the most persevering and audacious efforts without hesitation and with perfect clarity.

Charles returned to Dax and his father made it possible for him to "read for the law", as was already said then. But this did not suit the young man who felt an irresistible vocation to science. For him Roman Law and Pandects had no attraction. He therefore unburdened himself to his mother, who consulted his former masters at the College of La Flèche. They were unanimous in affirming that the exceptional talents of their former pupil seemed to have predestined him for the sciences. One of them personally interviewed the father, who finally consented and allowed his son to abandon the law for military engineering. Thus the young man had the twofold and valuable advantage of becoming familiar with military life, to which ancestral instincts called him, at the same time being able to carry out those scientific investigations to which he felt himself irresistibly drawn.

He showed very quickly that this attraction was justified by his exceptional aptitude; his first essay was, in truth, a "master stroke". In 1753, that is at the age of 20, he presented to D'ALEMBERT a paper on Pure Geometry, at which the distinguished mathematician was literally amazed, for with reference to it he wrote: "The young man will certainly go very far, and I wish that his position would let him think of the Academy: he will unquestionably become a very great man". And, realising the wish of the great geometrician, in the very same year the philosopher RÉAUMUR received young Charles into the Academy as a *Corresponding Member.*

This was an exceptionally brilliant début, which seemed to guide the young man towards investigations in pure science; but his natural bent turned his mind more towards the practical side, and especially towards the application of mathematics to physical science. It was into this grand sphere, which was to be still further enlarged during the next century by the most wonderful and useful discoveries, that Charles DE BORDA plunged as a true pioneer, using to the full his scientific talent and genius in numerous directions

An almost incredible event occurred at the commencement of his career.

It has been said that, in order to be able to follow his predilection for science, he had entered as a cadet in the Corps of Military Engineers; but suddenly, by what appears to be a fantastic decision, he requested and obtained permission to exchange into the regiment of "Chevau-légers". What was the reason for such an apparently paradoxical decision ? It was the following: the " Chevau-légers " were in garrison at Paris, i. e. in the centre of the scientific world, the place where were gathered the most illustrious savants of this time which was the real era of the birth of modern science. In Paris, and in Paris alone, was it possible for Charles, not only to continue his work, but to obtain the necessary advice and support from the leaders of scientific thought. Example is contagious, for hardly was he established in the somewhat frivolous world of the most fashionable cavalry officers, than several of them, recognising the ability and clarity of mind of their new comrade, spontaneously requested him to instruct them in mathematics, which he did with greatest amiability in the world.

This surprising "change of corps" became further accentuated as a result of the nature of the first investigations made by Charles. He began his career as an officer in the Engineers, *i.e.* as a "sapper", then he became a cavalry officer; but it was as a "gunner" that he was destined to take the first steps in his brilliant career as a savant.

In the month of May, 1756, he read a paper before the Académie des Sciences, on the resistance of air to moving projectiles and the effect of this resistance on their trajectories. He solved the problem by introducing into his calculations the hypothesis of a quadratic law to express the resistance of the medium. The Commissioners of the Academy, who bore such illustrious names as BOUGUER and CLAIRAUT, adjudged the paper as "excellent". Even in our days, the highest authorities in the very learned corps of Artillery consider that the importance of BORDA's work "is preponderant in the history of ballistics". To this appreciation, the following may be added: it was on the basis of BORDA's work and by means of his formulae that the English scientist, Sir John CAYLEY, was able to demonstrate mathematically in 1809 that it was possible to sustain in and propel through the air an object heavier than air, provided that it moved with sufficient velocity. Thus the demonstration of the possibility of conquering the air is due to the work of the young Lieutenant of Light Horse.

At this period there still was a "hierarchy" at the Academy: it was not possible to enter it directly, as may be done now after a single election; one rose in it "by degrees". It has already been said that BORDA was admitted as a *Correspondent*; as a result of his paper on the resistance of air, he rose one step, and reached, on 30th June, 1756, the position of *Assistant Geometrician.*

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It must not be forgotten, however, that BORDA was in the "Chevau-légers" and, owing to the war, his regiment was ordered to Dunkirk. He left this town to take part in the campaign in Flanders in 1757, as Aide-de-camp to Marshal DE MAILLEBOIS; on 2nd July, 1757, he took part in the battle of Hastenbeck, at which Marshal D'ESTRÉES defeated the army of the Duke of CUMBERLAND.

Neither camp life, nor the noise of battle were sufficient in any way to disturb the thoughts of the young savant; his brain did not remain inactive.

During the time he was at Dunkirk, he came in direct contact, for the first time in his life, with things connected with the sea: the ocean, with its waves, its storms and its tides which form a link between celestial and terrestrial forces, revealed a new world to him. When he saw ships leaving for distant lands, following a course through the waters with the heavenly bodies as their only guides, he understood the magnitude of that wonderful science: *Navigation.*

He had studied the resistance of air to projectiles; on viewing the sea, his thoughts turned to the question of the resistance of this new medium, the water, to the movement of ships. But, instituting the true scientific method in Applied Mechanics, he was not content to work out an ingenious hypothesis only, as he had done for the calculation of the trajectories of cannon-balls, but he resorted to direct experiment. Accordingly, he invented and constructed a completely new apparatus, by means of which he realised immediately that the laws assumed, at that time, for the drawings for the construction of ships, were in no way in relation to actual facts. He substituted new laws for them, deduced from his experiments, of which he gave a remarkable mathematical interpretation.

In the meantime, the campaign in Flanders having come to an end, he returned to Paris, where the Minister of War, struck by the great superiority which he had shown, reinstated him in the Corps of Military Engineers "with dispensation from examination".

From Naval Constructor, he once again became a "landsman" engineer ; but he still followed out his ideas logically. He had already turned to the question of the resistance of fluids : he continued along this line, investigating the laws of the flow of liquids from orifices and nozzles ; he did this work in 1766. In 1767, he turned his attention to the question of water-wheels.

By a real glimpse into the future, he recommended the use of horizontal short-vaned water-wheels, and thus he can and should be considered as a real precursor of "turbines", which the progress of electric industry has so prodigiously developed. In this same year, 1767, returning from time to time to Pure Geometry as an amusement, he attacked the problem of "isoperimeters", on which two of the greatest geometricians of this epoch, viz : EULER and LAGRANGE, had been working ; he found a solution of rare elegance. As a result of this work, he rose yet another grade in the Académie des Sciences, which gave him the title of *Associate Geometrician.*

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Charles DE BORDA was now 35 years of age.

The Academy had admitted him to membership in spite of his youth. His reputation as a scientist and as an engineer was definitely established ; others might have been satisfied to continue along these lines and to follow a scientific career the course of which appeared to be so clearly marked out.

But that would be a misconception of the character of this "universal" investigator, open to all new ideas, always searching for something fresh, for a subject not yet taken up or for an uncleared and virgin soil. He now arrives at a turning point in his life, which was to prove of great importance, for at this period he radically changed the course of his existence and the direction of his mind.

BORDA, once a Lieutenant of Light Horse, now an officer in the Engineers, was to become a *sailor*, and it was as a sailor that this remarkable man, this colossal genius, was to gain his greatest glory.

He had never been to sea ; it may have been that he had never even been on board the smallest vessel. Nevertheless, twelve years later he was appointed Captain ; he actually carried out the duties of this rank without having been through any naval college ; yet, in the next century his name was to become the synonym for that of the Naval School.

At that period our Ministers were more "stable", *i.e.* less subject to the incessant fluctuations of home politics, than those of to-day. Since they held their portfolios for long periods they possessed a deeper knowledge of their respective departments and were thus better acquainted with the value of the officers under them. The Duc DE PRASLIN was then Minister of Marine. Well acquainted with the highly scientific nature and the importance of BORDA'S work in connection with the resistance of water, he recognised that this officer could make valuable contributions to the art of constructing vessels. He caused him therefore to be appointed for service in the dockyard of Brest, with the rank of Supernumerary Port Lieutenant.

In actual fact, his work was more nearly that of a Naval Constructor than that of the ordinary ship's officer. Yet, being in immediate contact with naval affairs he rapidly gained a knowledge of everything of interest to the Navy, namely the science of navigation and the handling of ships, with that promptness of mind and prodigious ability to assimilate which characterised him. Unforeseen circumstances were to help him to show his worth as a "learned navigator".

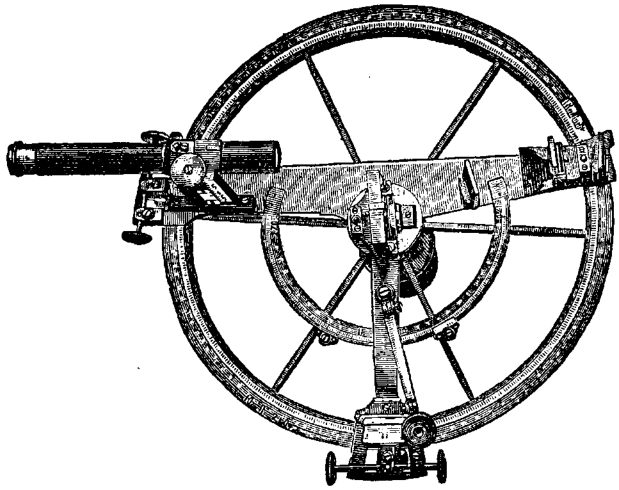
We must go back a little, to the period which was a turning point in the progress of astronomical navigation, in order to understand the events which gave a new direction to BORDA'S career.

Thanks to the invention of the sextant by John HADLEY in 1731, astronomical navigation entered a new phase: the latitude of a ship could be determined accurately by meridian altitude or by a culmination, to within one minute of arc; but the determination of the longitude could not be made with corresponding accuracy. To do this it is necessary to know the time at the prime meridian at the moment of apparent noon at the place of observation. In these days, thanks to wireless telegraphy, this is easier; but at that time there were no time signals and it was necessary to carry the time of the prime meridian with one, and this by means of watches the accuracy of which was by no means perfect. However, from 1740, such master clock-makers as HARRISON in England, BERTHOUD in Switzerland and LE ROY in France, had invented and constructed the first accurate chronometers, the first marine watches, which at that time were called by the attractive name of "timekeepers".

The first trial was made on board the *Isis*, under the command of M. DE FLEURIEU, with the object of studying the comparative values of the watches constructed by LE ROY and BERTHOUD. BORDA was ordered to study and discuss the observations and calculations of DE FLEURIEU; he came to the conclusion that "the clocks presented might be very useful at sea".

With this result before him, the Duc DE PRASLIN organised a fresh "longitude expedition"; *La Flore*, a 32 gun frigate, was commissioned at Brest in the early part of October, 1771. She was placed under the command of Lieutenant VERDUN DE CRENNE, Member of the Académie de Marine, who was joined by the two savants BORDA and Canon PINGRÉ and the astronomer MERSAIS, a pupil of the great mathematician LALANDE, who were sent by the Académie des Sciences. Two of LE ROY'S watches and one of BERTHOUD'S were taken on the expedition. The results were most successful, owing, in the main, to the methodical observations of BORDA. On his return the Académie accorded to him the last grade which remained for him to acquire, by electing him *Membre Pensionnaire*, on 12th February, 1772.

Our learned navigator had become highly interested by the *La Flore's* cruise; after conferring with the Minister, BORDA received orders to organise and direct another "longitude voyage" in 1775. This time he was given the command of the frigate *La Boussole*, with the sloop *L'Espiègle*, under the command of M. DE PUYSÉGUR, as tender. This second expedition resulted in considerable progress being made in the determination of the position at sea, for it allowed the positions of vessels to be obtained within one minute of arc for longitudes and a quarter of a minute for latitudes. This expedition was of great importance from the point of view of astronomical navigation, as it was on this occasion that the marvellous instrument called the *Borda reflecting circle* was devised.



Borda's Reflecting Circle

The accuracy of this remarkable instrument greatly surpassed that of HADLEY'S Octant and BORDA applied it in a manner which is still practised to-day, viz: its use in hydrographic surveys of coasts. He drew up, by means of his repeating circle, charts of the Canary Islands region, the accuracy of which has never been surpassed since that time. The learned Ingénieur Hydrographe BOUQUET DE LA GRYE, speaking of the reflecting circle, said that "the invention may be considered as one of the most useful to navigation that has ever been made".

On his return from this expedition, so valuable to the progress of astronomical navigation, Charles DE BORDA received from King LOUIS XVI the Cross of Chevalier of the Order of St. Louis.

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It was then that the period began when he was more strictly a *seaman.*

He had been appointed major in Comte D'ESTAING'S squadron; in this capacity he took part in the taking of Grenada from the British on 6th April, 1778, and in the naval victory which resulted therefrom. On 14th July 1780 he was promoted to the rank of Captain and later to that of

"Chef de Division". He hoisted his flag, in 1781, on board the ship of the line *Le Solitaire*; the division comprised another ship of the line, *Le Triton*, three frigates and a corvette. With this squadron, BORDA transported troops from France to Martinique. When the troops were landed, he continued to cruise in West Indian waters, where the British squadrons were also cruising. On 6th December, 1782, he was engaged by very superior forces, against whom he fought with true heroism, and with the indomitable energy which is the tradition of our Navy, fighting to the extreme limit even after all his ammunition had been exhausted. Having fallen into the hands of the British, his attitude inspired our adversaries of that time with such admiration, that he was spontaneously included in the first of prisoners exchanged after this naval engagement.

The Minister of Marine then decided to keep him in the capital, in order to use the value and, one may say, the great intellectual power of such a brain to the best possible advantage. In 1783, the direction of the School of Naval Constructors. which was then in Paris, was confided to him; the Minister declared to the King that "for practical construction of vessels, his experience at sea had taught him how to apply thereto the best scientific principles".

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This year saw the commencement of the last phase in the career of BORDA: that of "savant".

Not having any other occupation than his scientific work, he devoted himself to it with prolific activity, which was stimulated by the demands of an important work in which, by reason of his reputation, he had been called upon to collaborate: namely the drawing up of the *metric system*.

The original idea of devising a system of measurement based on decimals and of which the fundamental units of length, mass and time, would be derived from the dimensions and the movements of the Earth, had been germinating for some time; it had caught the attention of King LOUIS XVI, whose mind, which had a considerable turn towards science and more especially towards the exact sciences, had been struck by the advantages which such "rational" and uniform measures would have over the varied and arbitrary measures employed in different countries.

The Revolution prevented this royal project from coming to maturity immediately; but the Convention decided on its practical execution, and appointed a committee composed of savants and charged with the work of elaborating a basis for such system.

For this purpose it was necessary to measure an arc of a terrestrial meridian with an accuracy never yet attained, with the object of deducing from it the length of the new unit, the *metre*. which was defined as the ten-millionth part of a quarter of a terrestrial meridian; for this purpose metal rules had to be devised, the degree of expansion or contraction of which, under the influence of heat, must be accurately known at any moment. The accuracy of the angles measured at each station of the net of triangulation from Dunkirk to Barcelona (which was to include the development of the new "méridienne de France") had to be increased and the error in measurements of weight which had to be made in order to obtain the new standard of mass (the *kilogramme*) had to be reduced to a minimum. Finally, the acceleration of gravity or, in other words, the length of the *one second* pendulum had to be determined with a degree of accuracy not previously attained, the second being the unit of time.

BORDA carried out all these operations with a perfection which has not yet been surpassed.

For measurements of geodetic bases, he invented bi-metallic rules, composed of two bars of metal of unequal expansion, whose lengths were equal when the thermometer was at zero but ceased to be so at any other temperature; by measuring the difference between them, by means of a micrometer, it was possible to deduce the temperature which produced it, as the coefficients of expansion of the two metals had been previously determined in the laboratory.

For the accurate measurement of angles, he invented and caused to be constructed a wonderful instrument called the *Repeating Circle,* which allows the same angle to be measured n times, and the errors in the reading of this angle on the graduated circles to be divided by n; the arrangement which allows the "repetition" of angles is still in use to-day in all precision theodolites and goniometers.

In order to get accurate weight measurements for the purpose of fixing the mechanical unit, the *kilogramme,* BORDA invented the ingenious and simple method of "double weighing", whereby it was no longer necessary for scales to be accurate, but merely "sensitive". This not only allowed the accurate construction of the standard kilogramme, but was of extraordinary fertility in the history of experimental science.

It is, in fact, typical of the "zero methods" in use to-day in all physical determinations, in which the sensitiveness only of the measuring instrument is used in order to bring it to "zero" by opposing an action which is equal, but of contrary sign, to whatever is to be measured. This action is then replaced by known and standard multiples or sub-multiples of the unit of measurement. In electricity, particularly, for the determination of the values of resistance, of electromotive force and of capacity, no other methods are employed.

Finally, in order to determine, as accurately as possible, the acceleration of gravity at Paris, BORDA undertook experiments which may well serve as standards for accurate measurements; the results of these have never yet been surpassed.

He endeavoured to approach as near as possible to the practically unrealisable conditions of the "simple" pendulum, namely, a pendulum consisting of a "material point" suspended by a rigid thread, inextensible, yet "without mass", and oscillating without friction about a fixed point.

By taking as the suspended mass a small platinum sphere, as the suspending wire a fine wire of the same metal, and constituting the fulcrum of oscillation of the edge of a steel knife resting on an agate plane, he obtained conditions of minimum error. He went further: he succeeded in completely supressing the influence of the wire and of the suspension blade. By attaching to the blade a threaded vertical rod supporting a small movable counterweight, he regulated the position of this weight in such a manner that, oscillating alone, the wire, blade and counterweight system had the same period of oscillation as the entire pendulum: he thus eliminated the influence of the wire and of the blade, and only the dimensions of the sphere and the length of the wire needed to be considered in the calculation of the moment of inertia. The length of the wire was measured as accurately as possible and the period of oscillation was determined by the so-called "coincidence" method. Thus BORDA obtained, for the acceleration of gravity at Paris, the value $g = 9.80882$ m., accurate within a hundred-thousandth. As to the length of the pendulum beating seconds at Paris, oscillating in free air, he found it equal to 993.827 m/m to within the same accuracy. Thus the unit of time was determined.

In order to facilitate the dissemination of the system of centesimal division of the quadrant, the illustrious engineer became a calculator: he calculated tables of logarithms for the trigonometrical functions, on the new system, to seven places of decimals. These tables served as the basis for those published several years ago by the Geodetic Service of the French Army.

Reference has been made to the work of BORDA in the field of physics and metrology, which work alone is sufficient to immortalise his name. But there is another branch of science which benefitted largely from the conceptions of this powerful brain: namely astronomical navigation.

The progress made in this science brought about by the invention of the "reflecting circle" has already been mentioned. BORDA caused a further advance by improving the methods of calculation and determination of "position at sea".

First, for the determination of the "triangle of position" PZA (pole-zenith-celestial body), he gave the formula, which may be worked out by logarithms, by which it is possible to calculate the hour angle at P with three known quantities H, L and Δ, of which the sum $H + L + \Delta = 2S$.

This formula: $\sin \frac{P}{2} = \sqrt{\frac{\cos S \sin (S - H)}{\cos L \sin \Delta}}$ is still called the "BORDA formula" in all treatises on navigation.

BORDA, always preoccupied with the problem of the longitude, studied and perfected the method called "lunar distances", the calculations for which are extremely complicated. He established a valuable formula for the calculation of the correction of the geocentric zenith distance, which is indispensible on account of the close proximity of the body observed. This formula is still called the "BORDA formula".

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When the Institut de France was founded in 1795, BORDA became a member of the mathematical section of the Académie des Sciences together with BOSSUT, DELAMBRE, LAGRANGE, LAPLACE and LEGENDRE: he was in good company... and so were they!

This great man, one of the most brilliant figures of the French scientific world, died in Paris on 19th February, 1799. In spite of his profound scientific knowledge, or because of the profoundness of his scientific knowledge, he was modest to such a degree that he never allowed his portrait to be painted and the head of his statue at Dax had to be modelled from written information as characteristically vague as the descriptions found on passports or shooting licenses.

He was a profound Latin and Greek scholar—Homer was his favourite literature. This great savant was obliging and affectionate, trying before all to be of use to mankind and, to use the appropriate expression of our great geometrician, Maurice D'OCAGNE, he was "a magnificent example of humanity".

Open to all, his universal genius was able to follow freely the most varied directions, to which he always brought a personal note of accuracy, of clarity and elegance of solution of the most diverse problems, and an originality resulting from the absence of preconceived ideas. These last result in routine which is the beginning of misoneism.

It may be said in very truth that BORDA was really "a man of genius".

Many definitions of "genius" have been put forward; I find them all unsatisfactory and, often, even pretentious. I know of one only which is satisfactory. It is to be found in one of BALZAC's novels, *Le Médecin de Campagne* :

"The Genius has this peculiarity, he is like everybody and yet nobody is like him".

This definition is remarkably applicable to the personality and character and the immortal works of the great BORDA.

NOTE. — Among works which have been particularly helpful to me, I wish to refer more especially to that of M. MASCART, Directeur de l'Observatoire de Lyon : *La Vie et les Travaux du Chevalier Ch, de Borda* (introduction de M. Em. PICARD), published at Lyon by A. REY (1919) ; also to a remarkable article on BORDA which appeared in the *Figaro*, over the signature of M. M. D'OCAGNE, Membre de l'Institut ; and finally to two volumes by Captain MARGUET : *Le Problème des Longitudes à la Mer* and *L'Histoire générale de la Navigation* (Paris, *Société d'Editions géographiques, maritimes et coloniales*).