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The Dutch East India Company, Christiaan Huygens and the Marine Clock, 1682–95[1]

ALFONS VAN DER KRAAN

ABSTRACT *The story of the Dutch East India Company, Christiaan Huygens and the marine clock shows that in the seventeenth century Dutch Republic there was a tendency towards the formation of a modern partnership between business, science and technology. This emerging relationship was personified by Johannes Hudde (1628–1704) and Christiaan Huygens (1629–1695), men from entirely different walks of life except for their shared interest in science, especially mathematics. It was this shared interest in mathematics which brought them together and indirectly led to the marine clock research project. Hudde was a Director of the Dutch East India Company as well as a mathematician of international standing, whilst Huygens was both a brilliant theoretical scientist and extremely skilled innovator. Through his interest in mathematics, Hudde had come to know Huygens—he had corresponded with him and was broadly familiar with the work Huygens had been doing. So when Huygens, in 1682, returned to Holland from France, Hudde conceived the idea, which was entirely novel at the time, to enlist the support of the East India Company for one of Huygens' research projects, a project, of course, in which the Company had a direct economic interest, namely, the marine clock which it needed to find the longitude at sea.*

Keywords: Dutch East India Company, Christiaan Huygens, Johannes Hudde, longitude, pendulum clock, marine clock.

Introduction

The partnership between business, science and technology is one of the most fundamental characteristics of the modern world. Many business enterprises in the world today, especially the large multi-national corporations, routinely involve themselves in the pursuit of technological innovation. They do this not out of a love for technology per se, but because of a perceived need to catch up with, to match, and, if possible, to move ahead of rival corporations. The pressures of competition, increasingly on a global scale, compel the corporations to constantly streamline their organisational structures, update their production methods and improve and/or extend the range of products they seek to market. And since the ability to

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do all these things, and thus compete effectively, depends in great measure on technological innovation, the corporations have little alternative but to invest heavily in so-called research and development programmes. This means that the corporations are obliged to establish research institutes and laboratories of all kinds; that they must employ veritable armies of highly trained scientists and technicians, and that they need to make available R&D budgets which, in the case of the largest corporations, far exceed the GDPs of the majority of the world's developing countries.

Naturally, it was not always thus. In the pre-modern world, say before 1500, business interests were not nearly as dominant as they are today, for which reason they were rarely able to set the political agenda. Even in the few places where business interests were politically powerful, like some of the Italian city-states of the late mediaeval era (Venice, Genoa, Florence), they were unable in any systematic way to use science for technological innovation. Not only was the science of the pre-modern world too undeveloped to be of much use in this regard, there was also a deeply ingrained social separation between science on the one hand and technology on the other. Essentially, the science, or rather, the 'natural philosophy' of the pre-modern world, was an activity pursued by gentlemen of leisure for whom truth was its own reward and who rarely had any practical purpose in mind. Technology, by contrast, had always been the domain of the working people, the sphere of the peasants, artisans and tradesmen who, in the process of labour, through trial and error, and without scientific training, had invented new things and/or had made small incremental improvements to existing tools, machines and methods.

Most historians take the view that, like so many other features of the modern world, the close relationship between business, science and technology first crystalised in Britain during the industrial revolution. And, indeed, there is a lot of evidence in support of this hypothesis. During the industrial revolution, business interests, especially manufacturing interests, moved centre-stage in British society, enabling them to decisively influence the course of events. At the same time, many of these 'new' men developed an interest in science. Indicative of this new orientation was the formation in many British cities and provincial towns of philosophical societies of various types, associations of businessmen and scientists, of which the so-called Birmingham Lunar Society is probably the best known. The Birmingham Lunar Society, which was active in the late eighteenth century, counted amongst its members some of the most famous pioneers of the industrial revolution, people like Matthew Boulton (manufacturer), Erasmus Darwin (scientist, poet and grandfather of Charles Darwin), Joseph Priestley (scientist and clergyman), Jonathan Stokes (scientist), Josiah Wedgwood (manufacturer and scientist), and James Watt (scientist and innovator). The society met once a month to discuss scientific questions of mutual interest, and in addition to these monthly meetings, members living in close proximity associated with each other almost on a daily basis, whilst others kept in touch through frequent correspondence.[2]

The Birmingham Lunar Society, and similar associations elsewhere in Britain, had an essentially modern character, not only because they brought together men of business and of science, but also because they were intensely practical in their orientation. They were not simply debating societies devoted to philosophical speculation. On the contrary, their memberships studied science largely because they had come to recognise that scientific knowledge could be used to develop technological innovations which, in turn, could be applied to transport and production. Matthew Boulton, for instance, went into partnership with James Watt to develop the steam engine, which he then began to manufacture in his metallurgical factory. Josiah Wedgwood established a laboratory which he attached to his pottery factory and called upon Joseph Priestley to carry out chemical experiments for him. And similarly, at the invitation of local textile manufacturers, Erasmus Darwin attempted to improve the design of stocking frames, while James Watt began work which was to lead to the invention of steam drying machinery.[3] Many similar examples could be given.

So, whilst there is no doubt that a firm nexus between business, science and technology first emerged in Britain during that country's industrial revolution, the point needs to be made that Britain was not the only country in which this development occurred, and that tendencies in this direction existed in other European countries, particularly in the Dutch Republic of the seventeenth century. There, too, at this early time, men of business and science were beginning to associate with each other with a view to developing useful technological innovations. A particularly telling example of this emerging trend is the story of the Dutch East India Company, Christiaan Huygens and the marine clock.

Johannes Hudde: Businessman and Scientist

Johannes Hudde (1628–1704), one of the Directors of the Amsterdam chamber of the Dutch East India Company in the 1680s and 1690s, played the key role in marshalling company support for the marine clock project. Hudde was an exceptionally many-sided man. In addition to his Directorship of the VOC, he was for many years burgomaster of Amsterdam and, notwithstanding his position as a leading member of the Dutch regent class, he was a strong supporter of the House of Orange. In 1672, he backed Prince William III's accession to the Stadholdership of the Dutch Republic and, in the same year, he played a leading role in the defence of the Republic when he supervised the deliberate innundation of farmland with a view to halting the advance of the French armies which had broken through the Dutch defences along the Rhine. In his capacity as burgomaster of Amsterdam, Hudde, in subsequent years played an important role in raising the funding necessary for a build-up of the Dutch army and navy, and, in 1688, he was one of the people at the apex of power in the Dutch Republic to support Prince William in his plan to cross the North Sea and make a bid for the English throne.[4]

In addition to these varied activities in the spheres of business and public affairs, Hudde in his private life was a scientist of international renown. In his youth he had studied medicine which had left him with a lifelong interest in microscopy and the, at that time entirely novel, discipline of microbiology. He was also well-versed in physics and astronomy, but it was as a mathematician that he was to make his greatest mark, making a number of original contributions especially in the fields of algebra and geometry.[5] These catholic interests in virtually all branches of science brought Hudde into contact with the leading thinkers of his time. Keen to stay in touch with the latest advances in science, he corresponded on a regular basis with people like René Descartes, Baruch Spinoza, Gottfried Leibniz, and . . . Christiaan Huygens.[6]

Through his correspondence with Huygens, Hudde was familiar with the improvements this great Dutch scientist had made in the design and construction of clocks, and like Huygens himself, he was hopeful that as a spin-off of these improvements a solution might be found to the vexed problem of determining the longitude at sea. And, surely, this was not a trivial issue. Ever since Portuguese ships in the fifteenth century had begun to venture out into the open seas, 'finding the longitude' had been one of the greatest difficulties with which ships' captains had to deal. Essentially, the problem was that, whilst mariners were able by the length of the day, or by the height of the sun, or by the positions of the known guide stars (the Northern star, the Southern Cross etc), to fairly accurately determine the latitude, they were unable to do so in respect of the longitude. Out into the open sea, out of sight of land, there simply was no fixed point of reference upon which sea captains could orient themselves. Consequently, the best they could do was roughly to *estimate* their longitudinal position.[7]

This they did by means of a method known as 'dead reckoning'. Basically, this method was an attempt to measure the distance travelled east or west from the home port of which the longitudinal position was known. From time to time, the captain would throw a log overboard and, by means of a rope in which knots were tied at equal distances, he would measure the speed (i.e. the knots) with which the log receded from the ship and, on the basis of this measurement, he would estimate the ship's speed. Taking account of the direction in which the ship was sailing, which he did with his compass or by the position of the sun or stars, and taking account also of the ship's speed and the length of time it had been maintaining a particular course, he would then plot the ship's course on a chart and, in that way, 'determine' his longitude. Although experienced captains would also try to factor in such imponderables as the effects of ocean currents, fickle winds and possible errors in judgement, finding the longitude was and remained almost pure guesswork.[8]

Although various solutions to 'the problem of the longitude' were put forward, most of them by crackpots of various kinds, most scientific opinion in Europe had long been of the view that what was needed was a highly accurate marine clock. This approach was based on the understanding that the measurement of longitude meridians is governed by time. For a captain to determine his longitude at sea, he needed to know the time aboard ship and also the time at the home port (or at any other place of known longitude)—at that very *same* moment. The ship's time could be determined fairly accurately by measuring the sun at its zenith in the sky, when, precisely at noon, it appeared momentarily to stand still before beginning its descent towards the western horizon. If the captain, at that very moment, had available a clock set at the time of his home port of which he knew the longitude, then he could calculate the ship's longitude on the basis of the time difference between his home port and aboard his ship.[9] The two clock times would enable the captain to convert the time difference into geographical separation. Since the Earth takes 24 hours to complete one full revolution of 360°, 1 hour marks one 24th of a spin, or 15°. And so each hour of time difference between the ship and the home port, marks a progress of 15° longitude to the east or the west.[10]

Naturally, for this method to work effectively, two things were necessary. First, the clock set at the time of the home port had to be constructed in such a way that it kept ticking under all circumstances—during storms when the ship would roll and pitch violently, in the sub-zero temperatures of the arctic regions, in the temperate zones, as well as in the hot and humid tropics. And secondly, the clock set at home port time not only had to be constant, it also had to be absolutely accurate. If, for instance, the clock gained or lost as little as 3 seconds in 24 hours, then over a period of, say, a hundred days at sea, which was not at all uncommon, the discrepancy would amount to some 300 seconds, or, 5 minutes. And translated into geographical distance, these 5 minutes would mark a discrepancy of 1°15′ of longitude, a discrepancy which, especially in the earth's tropical regions, where the distances between the longitude meridians are the greatest, could amount to some 80 or 90 miles. And this, needless to say, could be enough for a ship to miss its mark entirely.

The construction of such a clock, then, was the challenge which Hudde, in 1682, hoped Christiaan Huygens might achieve. His thoughts went out to Huygens, partly because he knew that this remarkably versatile scientist had already been trying to adapt his clock for use at sea, but also because, earlier in that year, he had learned that Huygens had been forced to quit his position at the Académie Royale des Sciences in Paris and had returned to Holland. And this was indeed the case. Huygens had lived in Paris since 1666, when at the invitation of Louis XIV's great minister, Jean-Baptiste Colbert (1619–83), he had been offered a post as a foundation member of the newly established Académie, where he had enjoyed a generous living allowance, a luxurious apartment, and excellent research facilities.

As the years passed, however, Huygens' position in Paris had become increasingly untenable. His Dutch nationality was a problem at a time of increasing tension between an expansionist France and the Dutch Republic, although perhaps not an insurmountable one. A more serious difficulty was the rising tide of anti-Protestant sentiment in France in consequence of which many French Catholics came to condemn Huygens as a heretic, even though, in his personal life, he was actually a religious agnostic, equally critical of Protestantism as of Catholicism. But no doubt the greatest problem Huygens faced in France was the fact that his brother, Constantijn Junior, served as the private secretary of Prince William III, the scion of the House of Orange, who, since his assumption of the Stadholdership of the Republic in 1672, had emerged as the great nemesis of King Louis XIV. So for all these reasons, Huygens, in 1682, reluctantly left his plum job at the Paris Académie, bade France farewell, and returned to his parental home in The Hague.[11]

Aware of these circumstances, Hudde conceived the idea to enlist Dutch East India Company support for Huygens' marine clock project. On the last day of 1682, Hudde put his plan to the meeting of the Amsterdam Chamber of the Dutch East India Company. He told his fellow Directors on that occasion that 'he had recently learned of the invention of a certain type of new clock, so accurate that it does not lose even one second in the space of 24 hours, so that it would appear highly probable that it will be possible to discover the East and West'.[12] Although they may not have been as scientifically minded as Hudde, his fellow Directors well knew on which side their bread was buttered. They all realised that a reliable means to determine the longitude would greatly reduce the risk of shipwrecks of the type suffered in 1629 by the *Batavia,* the great East Indiaman which, on its outward voyage to Java, had come to grief on a small island off the Western Australian coast for no other reason than that its captain, Fran ois Pelsaert, had grossly misjudged his longitudinal position. This, however, was not the only consideration. In addition to reducing the risk of disastrous shipwrecks like that of the *Batavia*, a reliable means of finding the longitude would make for speedier passages across the oceans which, in view of the great expense involved in maintaining heavily-manned ships at sea, would greatly reduce the Company's operating costs.

So for all these reasons, Hudde's fellow Directors needed little time to react favourably to his proposal. After thanking him for his explanations, the Board resolved 'to request His Honour [i.e. Hudde] to direct this project, to take charge of it, and, if at all possible, to bring it to fruition and, at the same time, to authorize His Honour to conduct the necessary correspondence and to seek the assistance of Mr Huygens, who has a profound understanding of these matters, as well as that of a certain [Johannes] van Ceulen, who is building the afore-mentioned clock, and further, to authorize His Honour to lay out and spend for this purpose a sum of up to 2,000 guilders'.[13] Thus began the Company's involvement in the Huygens marine clock project, a project which, in the end, was to cost it a great deal more than the 2,000 guilders initially allocated. Nonetheless, the overall investment, while considerable, was well-considered. Even though construction of an effective marine clock was one of the greatest technological challenges of the age, there seemed to be at least a reasonable prospect of success because, as will be explained more fully below, the project could not at that time have been placed in more capable hands than those of Christiaan Huygens. In short, if Huygens could not do it, no one could.

Christiaan Huygens: Scientist and Innovator

Christiaan Huygens was born at The Hague in 1629 as the second son of Constantijn Huygens (1596–1687), the wealthy poet, classical scholar and man of letters, who was destined for many years to occupy the highly influential post of Secretary to two successive Princes of Orange, namely, the Princes Frederick Henry and William II. Christaan's upbringing in his father's French-speaking household was one of privilege. Apart from the typical pursuits of a boy of his social millieu, like dancing, riding, and fencing, Christiaan, and his brother Constantijn Junior, were educated at home by the best private tutors money could obtain. But while Constantijn, who was just a year older than Christiaan, proved himself a highly gifted student, especially in letters, it was Christiaan who, from an early age, displayed truly exceptional talents in an amazingly wide range of subjects.

Not only did he learn to draw with distinction, he also learned to play the viol, the lute and harpsichord, the Latin, Greek and Dutch languages, as well as logic, mathematics and geography, and everything with the greatest of ease.[14] It was, however, in the field of mathematics that young Christiaan showed the greatest promise. For instance, in 1637, when he was just 8 years of age, his Latin tutor, who had also taught him the rudiments of mathematics, was no longer able to teach him anything new, for which reason his father, Constantijn Senior, decided himself to take the matter in hand. But to his genuine surprise within a few weeks Christiaan, 'like a sponge', had absorbed all the mathematics he knew. 'It was a wonder to behold for all of us', confided Constantijn Senior to one of his correspondents, 'how quickly Christiaan understood and remembered everything, yes, how day after day, and entirely of his own volition, he invented new ways to prove hypotheses, which he was always able to substantiate with solid arguments. He made such rapid progress that I often used him to teach his brother, Constantijn'.[15]

Some 9 years later, in 1646, when Christiaan was 17 years of age, he had mastered just about all the mathematics known at the time, whereupon he moved into the forefront of the discipline. Symptomatic of his intellectual growth in this field was the correspondence he began with the great Père Marin Mersenne

(1588–1648), the Paris-based Minim Friar who, with René Descartes, was one of the greatest mathematicians and scientists of the age. In one of his earliest letters to Mersenne, the young Huygens, in the most respectful terms, took him to task for his assertion that 'no body can move at greater speed than a heavy rock dropped from a height of several miles', pointing out that this implied that lighter bodies would fall at lesser speeds, and arguing that 'only the resistance of the air prevents other bodies from falling with equal velocity'.[16] To his credit, Mersenne was not in the least offended by the young man's criticism. On the contrary, during the last 2 years of his life he maintained a frequent correspondence with Huygens, a correspondence in which he debated, on the basis of equality, many of the most difficult mathematical and scientific problems of the time. Young Huygens, for his part, was delighted with Mersenne's letters, which he received 'with joy and avidity'.[17]

It was, however, not only in theoretical science that Huygens excelled at an early age—as a child he also showed a remarkable aptitude for mechanics, or what we would call nowadays, for technological innovation. For instance, in 1643, when Christiaan was 14 years of age, his father, Constantijn Senior, recorded in the family chronicle: 'Anno 1643. [Christiaan] grasped with extraordinary promptitude anything to do with mechanics; he often makes models or other constructions with his hands, having read about it or heard of these things from others'. The following year he made a similar entry: 'Anno 1644. Not only does [Christiaan] understand and retain everything, but he invents all manner of ingenious things daily to everyone's amazement'.[18]

But while Constantijn Senior seems to have looked upon this side of his son's talents with a mixture of pride and amusement, not everyone shared these feelings. For instance, in June 1643, one of Christiaan's tutors felt it was his duty to sound the alarm. 'They had hardly finished their readings', the exasperated tutor wrote to Constantijn Senior, 'before Christiaan, who everyone thinks is so clever, yes, almost a child prodigy, immediately regressed to his self-made toys, to his constructions and to all those other instruments, very ingenious things to be sure, but entirely inappropriate. Surely, Sir, you do not expect him to become a tradesman? The Republic, for the future of which he has been born, expects him to follow in the footsteps of his father'.[19]

Needless to say, Huygens did not heed the warnings of his tutor. In adulthood, he shunned the diplomatic career of his father but, instead, he carried forward his early interests in both science and mechanics, making many original and important contributions in both fields of endeavour. In science, Huygens' principal merit was that he applied Galileo's methods to many new areas in the generation between Galileo (1564–1642) and Newton (1642–1727) and that, in so doing, he made a vital contribution to the scientific basis upon which Newton was later to found his grandiose synthesis. Following Galileo, Huygens treated natural science in a mathematical way. He took the view, for instance, that it was not enough to ask *why* an object falls to earth when dropped from a height, but that it was necessary also to ask *how* this happened. And this 'how', Huygens felt, could be explained through mathematics. With the aid of all the mathematical techniques available at the time, Huygens treated natural phenomena in such a manner that they became subject to calculations. In this way, he succeeded in formulating the laws applying to centrifugal and centripetal forces; he indicated the laws to which the movements of pendulums of various types are subject, and he described what happened to the masses and velocities of wholly elastic bodies in collision.[20]

In addition to Galileo, another principal influence on Huygens' scientific work was René Descartes (1596–1650), whom he had known personally in the 1640s when the French philosopher had been a frequent visitor to his father's house in The Hague. From Descartes, whom Huygens throughout his life was to hold in the highest esteem, he took the idea that natural phenomena should be described as a consequence of the impact and pressure of particles of matter. This idea, along with his mathematical method, Huygens applied in his study of light. He developed the theory that light, produced by a light source comprising rapidly moving particles of light, is propagated because the surrounding particles of matter are touched by the particles of light and themselves proceed to function as sources of light, thus producing a wave front. At the same time, he also demonstrated how the laws regarding the refraction of light moving from one medium to another (for instance, from air to water) can be deduced from his theory.[21]

Also in mechanics, Huygens' contributions were many and varied. In his early years, when he was still living in his parental home in The Hague (before 1666), Huygens, assisted by his brother Constantijn, took up lens-grinding. In 1654, he used his own lenses to construct a new, much-improved type of telescope, a 12-foot instrument with a magnification of about 50. This telescope had an unexpected scientific 'spin-off' in that it revealed the existence of Saturn's largest moon, later named 'Titan', thus once more confirming the validity of the Copernican conception of the universe. Spurred on by this success, Huygens, in 1656, built an even longer telescope, a 23-foot long contraption with a magnification of about 100. This instrument, too, had scientific consequences in that it allowed Huygens empirically to confirm a conclusion he had reached earlier, namely, that the planet Saturn was surrounded by a ring. And since his astronomical investigations required accurate measurement of time, Huygens also tried to design an improved clock. In 1658, his efforts in this area were crowned with success when he constructed the world's first effective pendulum clock, a clock of simple, but brilliant design, which measured time far more accurately than any of its predecessors.[22]

At the Académie in Paris (1666–82), Huygens continued his attempts to find technical solutions to the various problems that caught his attention. Consequently, during these years he was active on an astonishing number of fronts. For instance, he designed and constructed a much-improved lens-grinding machine which he used to make his own lenses. As he had done earlier with telescopes, he then proceeded to make various improvements to the simple microscopes that were used at the time, whereupon he began a systematic study of microscopic life, making sketches of various micro-organisms in his notebooks. And while he was studying microbiology, he was also active in the field of engineering. With the assistance of Denis Papin, Huygens built a gunpowder engine, a machine in which small gunpowder charges were used to drive a piston up and down in a cylinder and, in so doing, he took the first step on the long developmental journey which eventually was to lead to the steam engine. But this was not all. During his time in Paris, Huygens also designed a barometer, a spirit level, a system for the fountains at the royal gardens at Versailles, the springs of coaches, an air pump, a magic lantern, a planetarium showing the movements of the known stars and planets, and a host of other instruments and tools.[23]

In addition to all these innovations, Huygens made repeated attempts to adapt his pendulum clock for use at sea. In 1660, when he was still living in Holland, he designed the world's first timekeeper specifically intended for the purpose of finding the longitude at sea. This clock was equipped with a suspension mechanism so as to render it independent of the ship's motion; it was driven by a coiled metal spring and regulated by means of a verge escapement and a pendulum.[24] At the Paris Académie, Huygens continued work on his marine clock and, in 1671, he designed a new model in which he incorporated two improvements, namely, a Cardan mounting for the clock as a whole, and triangular suspension of the pendulum.[25]

Shortly after finishing his second design, Huygens decided to publish the results of his researches into the measurement of time. The result was his justly famous *Horologium Oscillatorium,* which appeared in Amsterdam in the spring of 1673. In this book, which he dedicated to his patron, King Louis XIV of France,[26] he described in detail both his original 1658 pendulum clock and his 1671 marine clock, and, for the first time, gave the correct mathematical theory of the motions of the pendulum clock.[27] But whilst Huygens in *Horologium Oscillatorium* evaluated positively his 1671 marine clock, claiming that it provided an effective means of determining the longitude at sea, he seems subsequently to have had second thoughts. At any rate, not long after his return to Holland in 1682, he began work on a third model.

The Zilverstein Trial

When, early in 1683, Huygens received a letter from Johannes Hudde offering East India Company support for his marine clock project, he had already started work on his third, experimental, model. Apparently, he had come to believe that it might be possible to design a more accurate clock by replacing the triangular pendulum of his 1671 model with a pendulum of a different type. At the beginning of December 1683, Huygens had found the solution in the so-called *pendulum cylindricum trichordon.* This new type of pendulum consisted of three equal silk wires, hanging parallel to one another from a fixed mounting, and attached below to the inside perimeter of a heavy ring. In this way, the ring could oscillate freely up and down within its cylinder.[28] Even though this highly imaginative device posed serious difficulties for mathematical analysis, tests soon proved it a practicable means of measuring time. In mid-December 1683, Huygens sent the drawings and a rough model, which he himself had constructed, to a The Hague clockmaker, Johannes van Ceulen, who, at the expense of the East India Company, a few months later produced two clocks with the new regulator.[29]

During 1684 Huygens made various refinements and improvements to his new clocks and by mid-1685 he was ready to hold sea trials, which he himself was to conduct. On 3 September 1685 Hudde wrote to Huygens that the Company had made available a galliot 'under a very able skipper who is accustomed to sailing it', and invited him to board the ship at the fishing village of Scheveningen, near The Hague. Huygens, however, was less than enthusiastic about the prospect of venturing out onto a stormy North Sea in a small ship, and travelled to Amsterdam intending to hold the trials on the calmer Zuyderzee. But when he arrived at Amsterdam, he was told by a 'very courteous, but resolute skipper' that he, the skipper, had orders from the Company Directors to head for Texel and venture out onto the North Sea. Having little choice in the matter, Huygens carefully installed his clocks and set sail.[30]

Unfortunately, the North Sea trial was disappointing in more ways than one. Unaccustomed to the conditions aboard a small ship, the heavy seas, the noises of the sailors, the wind and the flapping sails, unaccustomed also to any kind of physical exertion, Huygens became violently ill. And to compound his troubles, one of his two clocks stalled repeatedly. After 6 days at sea, he had seen enough, whereupon the ship set course back to Texel, whence he returned to The Hague. There he remained ill for several weeks, but on 26 October 1685, Huygens had recovered sufficiently to be able to write to Hudde reporting that his clocks had proven seaworthy.[31] This, however, was not strictly true, and, privately, Huygens seems to have realised that his *pendulum cylindricum trichordum* model, if it was unreliable even on a short trip into the North Sea, was unlikely to be suitable for long-distance ocean navigation. At any rate, when the Company, a few months later, asked Huygens to prepare two of his clocks for a more exacting ocean trial, he chose to test not his latest *trichordum* model, but his as yet untested 1671 model, namely, the spring-driven clock with the triangular pendulum.

In April 1686, the East India Company made available for the ocean trial the East Indiaman *Huis te Zilverstein,* a large, heavy ship which was to carry soldiers and military supplies to Batavia, via the Cape of Good Hope. The Company further appointed two experienced pilots, Thomas Helder and Johannes de Graaff, whose task it would be to install the clocks, to look after them, to make longitude measurements at regular intervals, and to keep careful logs of these measurements. They were to be assisted by a skilled clock-maker, a certain Van der Dussen. Huygens, for his part, was to provide the chief pilot, Thomas Helder, with instructions. This he did on 23 April 1686 when he sent to Amsterdam a lengthy treatise entitled: '*Instruction and Education Concerning the Use of the Clocks for the Finding of the Longitude of East and West*'.[32] In this pamphlet, Huygens not only gave very detailed guidelines on such mundane matters as the installation, the setting, and maintenance of the clocks, but he also explained such complex astronomical phenomena as the variations in the length of the day through the seasons, the changing positions of the sun, moon and stars in different geographical regions of the earth, various methods of measuring the time aboard ship, and so on. The treatise was highly technical and replete with tables and complex mathematical calculations, so that it is extremely doubtful whether poor Thomas Helder would have understood even half of it.

Be this as it may, the clocks were duly installed and, in May 1686, the *Zilverstein* left Amsterdam for the Cape of Good Hope with the so-called 'Easter' fleet. In accordance with their instructions, Helder, De Graaff and the clock-maker disembarked at the Cape and waited there for the homeward-bound fleet from Batavia. Upon arrival of that fleet, some 9 months later, they boarded the *Wapen van Alcmaer.* However, upon the *Alcmaer*'s arrival at Amsterdam, in August 1687, Huygens learned to his regret that Thomas Helder (along with 15 other men) had died of an unknown infectious disease shortly after leaving the Cape, but that, after Helder's death, the second pilot, Johannes de Graaff, had continued to look after the clocks. And fortunately, De Graaff had kept Helder's journal; he had maintained a journal of his own, and, at the same time, he had continued to make as many longitude measurements as possible.[33] When Huygens saw the material De Graaff had brought home, he knew that he could not fault the pilot's work, and that he had to take seriously the observations he had made.

In his report on the *Zilverstein* trial, which he sent to Johannes Hudde on 24 April 1688,[34] Huygens acknowledged that, on the outward voyage from Amsterdam to the Cape, the clocks had given the pilots a lot of trouble. The weight underneath the pendulum had sagged slightly in both clocks, the iron frames in which they were suspended had proven too weakly constructed to withstand the rolling and pitching of the ship, and, as a consequence of these and other technical problems, it was found upon reaching the Cape that both clocks were running some 42 seconds fast in the space of 24 hours. And this, needless to say, meant that the longitude measurements that had been made on the outward voyage had no scientific validity at all. At the Cape the technical problems had been remedied, but on the return voyage from the Cape to Amsterdam one of the clocks had broken its brass spring and had stopped running. The other one, however, had continued ticking throughout the voyage. On the basis of the measurements De Graaff had made with the one clock, Huygens was able nonetheless to plot the ship's course onto a chart which, no doubt much to his disappointment, showed that it had sailed right through Ireland and Scotland. This indicated that for much of the voyage the clock had run too slowly which had caused an easterly distortion in the longitude measurements.[35]

Notwithstanding the many problems the pilots had encountered, in his report to the Company Directors Huygens strongly defended the usefulness of his innovation. He attributed the clock's inaccuracy not to any shortcomings of design or construction, but to the effect of the Earth's rotation. Essentially, he argued that the earth's rotation produced a centrifugal force that diminished the weights of bodies by a factor dependent on their latitude. Since the earth spins around its polar axis, a body at either the North or the South pole suffers no dimunition; at the equator, however, where the centrifugal force is greatest, it underwent a maximum decrease of one 1/289th of its weight which, translated into horological terms, meant that a clock set at pole time would fall behind at the equator by a bit more than 2.5 minutes a day. In navigational terms, this meant that a clock carried along the same meridian from higher latitudes towards the equator would incorrectly indicate a specific, measurable, longitudinal shift towards the east.[36]

In his report, Huygens further made a number of practical recommendations for any subsequent trials. He informed the Directors that on the voyage there had been repeated arguments between the pilots and the clock-maker about the management of the clocks and suggested that, if another trial was held, the Company should issue clear regulations concerning their respective responsibilities. Huygens further mentioned that both Helder and De Graaff had frequently been mocked by the sailors, many of whom had laughed at them when they were conducting their measurements, adding rather wistfully that 'this, too, is something that ought to be avoided'. But, taking everything into account, Huygens was of the view that the trial had been a success. Providing the ships' captains learned to compensate for the easterly distortion caused by the earth's rotation, and they could do so by using the tables he had included in his report, his clocks would be a useful tool for finding the longitude at sea.[37]

The Company Directors, however, were not wholly convinced, for which reason they decided to seek a second opinion from Burchard de Volder (1643–1709), Professor of Mathematics at Leyden University. De Volder, who was a personal friend of both Hudde and Huygens, carefully studied all the material relating to the *Zilverstein* trial and, finally, on 22 July 1689, he issued his report. In it, he largely confirmed Huygens' view that, on balance, the trial had been a success. More specifically, De Volder argued that the clock longitudes, when corrected for the distorting effect of the Earth's rotation according to the tables Huygens had drawn up, differed so little from the measurements the ship's Captain had made by the traditional 'dead reckoning' method, that it was difficult to say which of these measurements was the more accurate. However, since the clock longitudes were based on sound scientific principles, while the 'dead reckoning' measurements were just guesswork, the clock measurements were likely to be closer to the truth.[38]

But while De Volder did not question Huygens' view that the distortion in the clock's longitude measurements was due to the effect of the earth's rotation, he was not quite certain that this was the only reason. 'I wonder', De Volder wrote, 'if no other causes can be found in Nature . . . that could explain why the clocks run more slowly in the equatorial regions than in more northerly or southerly zones, and whether, amongst other things, changes in temperature might not play a role. Heat causes also metal bodies to expand, and if excessive heat should cause a pendulum to become extended, the effect could be to make the clocks run slower'. But, clearly reluctant to give offence to the great Huygens, De Volder added that this was 'just speculation'. Only greater experience could reveal whether, apart from the Earth's rotation, there were other causes for the distortion of the clocks in the equatorial regions. And in order to gain this experience, De Volder respectfully recommended that a second ocean trial be held.[39]

The Brandenburgh Trial

The Company Directors accepted De Volder's recommendation and, in September 1689, Solomon van de Blocquery, one of the Directors, informed Huygens of the Company's decision to hold a second ocean trial. But since Huygens was away in England at the time, on a visit to the Royal Society in London, where he met such luminaries as Newton, Boyle, Halley and Locke, it was not until May of the following year, after he had returned to The Hague, before he was again able to give his full attention to the marine clock project. On 10 May 1690, Huygens wrote to the Company Directors informing them that he intended again to test his 1671 model triangular pendulum clocks; that he had had them completely repaired; that he had made some small improvements to his clocks, and that he would be very pleased if Master Johannes de Graaff, the pilot who had made such conscientious and accurate measurements during the previous trial, could again be employed to conduct also this second trial. He told the Directors that great care needed to be taken with regard to the installation of the clocks aboard the ship, offered to come to Amsterdam to do that himself, and confidently declared that he 'did not doubt that on the forthcoming voyage the clocks will prove even more reliable than on the previous one'.[40]

When Huygens, early in December 1690, received word from the Company that the ship *Brandenburgh* had been made available for the trial, he travelled to Amsterdam, checked his clocks for defects and accuracy and, assisted by Johannes de Graaff, carefully hung them up in De Graaff's cabin aboard the ship. He further engaged a second pilot, a certain Pieter van Laar, as well as a clock-maker, named Gilles Meybos, whose task it would be to keep the clocks clean and to carry out small repairs if this should be required. Finally, on 30 December, when all these preparations had been completed, the *Brandenburgh* set sail with the so-called 'Christmas' fleet, destined for Batavia, via the Cape of Good Hope.[41] As with the *Zilverstein* trial, this one was to be held only up to the Cape. There, De Graaf and his assistants were to disembark with the clocks and wait for the *Brandenburgh,* or another suitable ship, to return from Batavia, whereupon they were to re-embark, re-install the clocks, and perform the required longitude measurements on the Cape to Amsterdam route.

For Huygens, and no doubt for the Company as well, the *Brandenburgh* trial turned out to be a bitter disappointment. De Graaff and his assistants arrived back in Holland on 27 October 1692 and, on the same day, the chief pilot wrote to Huygens informing him of his return. From this short and business-like letter Huygens would have surmised that all was not well with the trial because in it, De Graaff only informed him of various peripheral issues. De Graaff told Huygens that he had had a difficult voyage to the Cape where he had arrived only on 3 June 1691; that at the Cape he had had to wait many months for a suitable ship to take him back to Holland; that upon arrival in Amsterdam, the clocks had been taken to the Company's East India House, and that he had sent the journal he had kept on the voyage as well as the results of his longitude measurements to the Board of Directors of the East India Company. But ominously, De Graaff made no comment at all regarding the success or otherwise of the trial itself.[42]

Reluctant to be the bearer of ill tidings, De Graaff twice failed to respond to invitations Huygens sent to Amsterdam inviting him to come to The Hague and report to him in person. In the end, an exasperated Huygens wrote to the Company's Board of Directors requesting De Graaff's journal and measurements. This brought results, and on 21 November 1692, Huygens at last received the materials.[43] Confronted with the evidence that the trial had been a failure, his first reaction, understandably perhaps, was to defend the effectiveness of his innovation. On 10 February 1693, Huygens wrote to De Graaff in Amsterdam pointing out various mistakes he had made in his calculations and suggesting that the poor performance of the clocks, particularly on the Cape–Amsterdam voyage, had been due to his negligence. 'I hereby request', Huygens wrote rather sternly, 'that you let me know whether, upon your departure from the Cape, you installed the clocks in the correct manner because failure to do so, without question, could have contributed greatly to their irregularity on the home voyage. I would like to know the truth about this matter'.[44]

A few days later, on 14 February 1693, De Graaff responded, denying in the strongest terms that he had made any mistake in the suspension and installation of the clocks. 'If Your Honour would only be so good as to examine my journal', De Graaff wrote not without dignity, 'you would discover why on the home voyage the pace of the clocks has been so irregular. Then you would see how many times the clocks stalled for one reason or another. Yes, they stalled so frequently that on many occasions I thought it unnecessary even to make note of it in my journal. And if you were to ask me why I did not have the clocks repaired, I have to respond that I have done everything possible as is noted in my journal. For instance, a piece broke of the spring of one clock on two or three separate occasions, so that the spring became too short. Eventually, the spring suddenly fragmented into countless pieces, whereupon we very laboriously had to fashion another one, which, as later became apparent, failed accurately to drive the clock.[45]

Still Huygens was not convinced and, on 24 March 1693, he sent all the material relating to the *Brandenburg* trial to Professor de Volder at Leyden University requesting his opinion on the performance of his clocks. A few weeks later, on 6 April 1693, De Volder replied pointing out that the longitude measurements made with the clocks had been uncertain by a factor of 5, or possibly, as many as 7° longitude. Rejecting any suggestion that the discrepancies were in any way due to De Graaff's incompetence or negligence, De Volder concluded, 'this trial has left matters much as before, namely, that the observer [i.e. De Graaff], as a consequence of the daily retardation of the clocks, has been unable to make measurements accurate enough for us to be able to assess with any degree of certainty the truthfulness of the longitude determinations'.[46] In other words, the clocks had not been reliable and accurate enough to be useful as a navigational tool.

This professional and impartial evaluation left Huygens no choice but to accept that his innovation had failed. Understandably, he was disappointed, so disappointed in fact that it seems to have affected him physically. 'Upon receipt of your letter', Huygens replied to De Volder on 19 April 1693, 'I became very unwell and had to take to bed with a very painful swelling on my hip'. Nonetheless, he did bounce back, and in the same letter to De Volder he hinted that he had already been working on an entirely new type of marine clock.[47] And this was indeed the case. The less than satisfactory results of the *Brandenburgh* trial reluctantly had led Huygens to the conclusion that pendulum clocks were unsuitable. He had come to realise, through trial and error, that regardless of how you constructed the pendulum, and regardless also of which type of suspension mechanism you devised, a clock regulated by a pendulum would not run true aboard a sailing ship in heavy seas. What was needed, Huygens now realised, was a marine clock regulated by a spiral balance spring.

Hoping to interest the East India Company in his new marine clock, Huygens, in March 1693, had travelled to Amsterdam where he had met Johannes Hudde. Concerned lest other innovators 'steal' his new design, which he was hoping eventually to patent, Huygens had explained its mechanism to Hudde on condition of secrecy (*sub side silenty*). And whilst it is unknown what Hudde's reaction was, it must have been sufficiently encouraging for Huygens to feel motivated in subsequent months to work out the details of his design. The result was his so-called 'perfect marine balance' clock of 1693. After he had worked out the design theoretically, Huygens built the spiral balance with his own hands, whereupon he took it to a The Hague clockmaker, a certain Bernardus van der Cloessen, who constructed the rest of the clock. After the clock was finished, early in 1694, Huygens took it home where he himself did much of the finishing and adjusting.[48]

The new clock, however, was not destined ever to be put to the test. In 1694 Huygens' health began to fail, and feeling death approaching, he seems to have lost interest in the marine clock project. Instead, he returned to astronomy, the queen of the physical sciences, a field of endeavour that had engaged his attention at various periods in his life. He began writing what was to be his last book, entitled: *Cosmotheoros, sive de terris coelestibus, earumque ornatu, conjecturae.*[49] In this remarkable book, which was by far the most reflective of his voluminous writings, Huygens advanced the to this day unproven, but much-debated hypothesis, that there is life, including 'animals, like man, gifted with reason', on other planets in the universe. And whilst Huygens, in his introduction to *Cosmotheoros,* stated that he did not pretend 'to assert anything as positively true, (for that would be madness) ', and that his 'only aim was to advance a probable guess, which everyone was at liberty to criticise and reject', he did make, if not a convincing, certainly a thought-provoking case for the existence of extraterrestial life. In support of his hypothesis, he advanced experimental proofs as well as scientific arguments.

In *Cosmotheoros,* Huygens published for the first time the results of a simple, yet ingenious experiment he had conducted many years earlier by which he had estimated the distance of the star Sirius to earth, compared to the solar distance. In this experiment he had allowed only a minute portion of the sun's disc into an aperture until the light admitted appeared equal to that of Sirius seen through the uncovered telescope. He had then calculated that this little hole admitted only a 1/27,664th part of the sun's diameter, and assuming that the actual sizes of Sirius and the sun were equal, he had concluded that Sirius was 27,664 times farther removed from the sun than the earth.[50] And even though this estimate had been based on a false assumption (Sirius is much larger than the sun), and was later proven to have been a great underestimate, at the end of the seventeenth century it was revolutionary because the experiment had demonstrated, for the first time, that the universe was much, much larger than anyone had hitherto supposed.

In addition to greatly expanding the size of the universe, Huygens in *Cosmotheoros* further advanced the Copernican view that the earth as a celestial body is no different from other bodies in the universe. He did so in two ways. First, Huygens conjectured that the countless stars that could be seen in the night sky were suns, and that many of them were likely to have planets revolving around them like the earth revolves around its sun. And secondly, he took the view that also as a planet, the earth was not unique. Saturn's moon, Titan, revolves around Saturn much like the earth's moon revolves around earth. Mars, like earth, seems to have surface features. Saturn appears to have an atmosphere. The earth's moon seems to have mountains. All planets have gravity. Comparing in this way the characteristics of the earth with those of other celestial bodies, Huygens arrived at the conclusion that the earth is not essentially different from other planets. And this being the case, he thought it highly unlikely that there should be life on earth and none on other planets, especially considering the vast size of the universe.[51]

Gazing at the stars night after night, and speculating about the many mysteries of the universe, Huygens became awed by the magnificence and grandeur of creation, a feeling which aroused in him a sense of humility and proportion in respect of earthly affairs. 'Oh, that our kings and potentates', Huygens sighed in *Cosmotheoros* shortly before his death, 'will learn and reflect how large are the heavenly bodies and how immeasurable the distances between them! Then they would realise that they strive after mere trivialities when, at great cost and to the ruin of countless people, they wage war on each other in order to become master of this or that corner of the earth'.[52]

Conclusions

The story of the Dutch East India Company, Christiaan Huygens and the marine clock has shown that, in the seventeenth century Dutch Republic, there was at least a tendency towards the formation of a partnership between business, science and technology. This emerging relationship was personified by Johannes Hudde and Christiaan Huygens, men of entirely different walks of life, except for their shared interest in science, especially mathematics. It was this shared interest in mathematics which brought them together and indirectly led to the marine clock research project. Hudde was a man of business and public affairs as well as a mathematician of international standing, whilst Huygens was both a brilliant theoretical scientist and an extremely skilled innovator. Through his interest in mathematics, Hudde had come to know Huygens—he had corresponded with him and was broadly familiar with the work Huygens had been doing. So when Huygens, in 1682, returned to Holland from France, Hudde conceived the idea, which was entirely novel at the time, to enlist the support of the East India Company for one of Huygens' projects, a project, of course, in which the Company had direct economic interest, namely, the marine clock.

Although small in scale by contemporary standards, the Huygens marine clock research project had an essentially modern character. Business (i.e. the Dutch East India Company) provided financial support and made available ships for ocean trials; a scientist (Huygens) designed the clocks and led the overall development project; various technicians (clock-makers like Johannes van Ceulen and Bernard van der Cloessen) constructed the clocks, and others (pilots such as Thomas Helder and Johannes de Graaff) carried out the tests; a number of controlled trials were conducted between Amsterdam and the Cape of Good Hope, and the results of these trials were independently evaluated by a Leyden University professor (Burchard de Volder). It goes without saying that this whole organisational structure, so unusual at the time, nowadays is commonplace.

The trend towards the formation of a business–science–technology partnership faded away in the Dutch Republic during the eighteenth century, to re-emerge more forcefully, consistently and comprehensively in England towards the end of that century. To inquire into the reasons why this shift occurred falls beyond the scope of this paper. However, it seems obvious that the fading in Holland of the business–science–technology partnership was part of the overall decline of the Republic, a decline which occurred on all fronts. Seventeenth century Dutch scientists like Anthony van Leeuwenhoek (1632–1723), Johannes Swammerdam (1637–1680), Herman Boerhave (1668–1738) and Christiaan Huygens (1629–1695) have no equivalents in the Republic of the eighteenth century, especially the second half of that century. What is true for the sciences is true also for the arts. Seventeenth century Dutch painters like Frans Hals (1580–1666), Rembrandt van Rijn (1606–1669), Johannes Vermeer (1632–1675) and so on, have no counterparts of equal stature in the eighteenth century. The same pattern applies to literature and to the military sphere. Where are the eighteenth century equivalents of people like Jacob Cats (1577–1680) or Joost van den Vondel (1587–1679), of Maurits van Nassau (1580–1625) or Michiel de Ruyter (1607–1678)? It seems as if the whole country fell asleep, only slowly to wake in the mid-nineteenth century, after the traumas of the Republic's inglorious collapse and the French occupation.

Even though Huygens' marine clock project did not in the end result in finding an effective means of determining the longitude at sea, it was not for that reason totally worthless from the point of view of the development of this technology. The benefits of the project were at least two-fold. First, in the process of searching for an effective (i.e. constant, and above all, accurate) marine clock, Huygens made many small, incremental improvements to the mechanisms of his clocks. In addition, the research process led Huygens to reject the pendulum in favour of the balance spring as the preferred marine clock regulator, which, as subsequent development was to show, was indeed the way forward. And secondly, Huygens' 'failure' to invent a true marine timekeeper (along with the 'failures' around the same time of Robert Hooke in England and Gottfried Leibniz in Germany) gradually led to the realisation that if such giants could not solve the problem, a truly extraordinary effort would be required. And it is a matter of record that not Dutch, but English business interests took up the challenge when, in response to a petition of merchants and seamen, the Westminster Parliament, in July 1714, enacted the so-called Longitude Act which offered a prize of £20,000 (an enormous sum at the time) to any person who would discover 'a method to determine longitude to an accuracy of half a degree of a great circle'.[53]

And, finally, a purely hypothetical question. Could Huygens have succeeded had he not died in July 1695, at the age of 66, but if, for instance, he had reached the life-span of his father, who lived until the age of 91? In that case, Huygens might have been active until 1720. At least one consideration suggests an affirmative answer to the question. In 1693, when faced with incontrovertible evidence that his pendulum marine clock had not performed satisfactorily, Huygens had designed a new model with a balance spring regulator, in principle the same mechanism that won John Harrison, in 1761, his £20,000 prize. This shows two things. First, that Huygens, although obviously strong-willed and single-minded, was not dogmatic and that, when faced with evidence he could not ignore, was prepared radically to change his design. And secondly, it shows that, towards the end of his life, Huygens chose what later proved to be the correct developmental path.

Another consideration, however, would support a negative answer. It seems clear that even if Huygens had lived long enough to test his 1693 model clock, the clock would have been unlikely to have performed to a satisfactory standard. Although the balance spring, which regulated the 1693 clock, would have made it independent of the rolling and pitching of the ship, it would have remained just as sensitive to changes in temperature as the 1671 pendulum model. The problem was that Huygens seems to have underestimated the extent to which changes in temperature, by expanding or contracting the clock's metal parts, affected the rate at which the clock measured time.[54] In fact, it was one of Harrison's most brilliant insights, arrived at experimentally, that it was necessary to use two metals, brass and steel, in the construction of his clock. These metals, Harrison had discovered, expanded and shrank at different rates, but if combined in bi-metallic strips in certain proportions, one metal could be made precisely to offset the other, so that the bi-metallic, brass/steel, clock-parts were able to withstand wide variations in temperature.[55]

Of course, Huygens, had he lived longer, might have learned more about the field of metallurgy. There is, however, one consideration which suggests he would have found this difficult. As has been pointed out repeatedly in this paper, Huygens was both a brilliant scientist and an innovator of genius, but temperamentally he probably was more of the former, than of the latter. His approach to technical problems was essentially scientific, in the sense that he would always first try to understand the mathematics of a particular problem. And the marine clock, a technology that was to be pitted against the totally unpredictable elements (the oceans, the wind and the weather), presented problems which could not be solved through mathematics. Apparently, in this particular instance of technological innovation a purely technical approach was needed, the kind of approach adopted by John Harrison, a man without scientific pretensions, but a brilliant clock-maker who, with great persistence, experimentally solved the various technical problems that, for more than a century, had baffled some of the greatest scientific minds of Europe.

Notes and References

1. The author thanks Eric Schliesser of the Philosophy Department, University of Chicago, for reading and commenting on an earlier version of this paper.
2. A. E. Musson (ed.), *Technology and Economic Growth in the Eighteenth Century*, Methuen, London, 1972, pp. 56–68.
3. R. E. Schofield, 'The industrial orientation of science in the Lunar Society of Birmingham', in Musson, *op. cit.*, pp. 136–47.

4. A. J. van der Aa, *Biographisch Woordenboek der Nederlanden*, B.M. Israel, Amsterdam, 1969, pp. 432–33.
5. The famous Leibniz, who visited Hudde in Amsterdam, had a high opinion of Hudde's ability as a mathematician and compared him with De Bernouillis, l'Hopital and Newton. Leibniz further testifies that Hudde was the first to find a complete solution to the question of the quadrature of the hyperbole, and that he discovered the rule concerning the determination of the equal roots of algebraic equations, an insight which came to be known as 'the rule of Hudde'. Some of his mathematical works appeared in: Francisci van Schooten, *Cartesii Geometrica cum Commentariis*, 2 vols, Amsterdam, 1659 (Aa, *op. cit.*, pp. 432–33).
6. P. C. Molhuijsen and P. J. Blok (eds), *Nieuw Nederlandsch Biografisch Woordenboek*, Sijthoff, Leiden, pp. 1172–76.
7. D. Sobel, *Longitude: The Story of the Lone Genius who Solved the Greatest Scientific Problem of His Time*, Methuen, 1995, pp. 1–10.
8. *Ibid*, pp. 13–14.
9. *Ibid*, pp. 4–5.
10. *Ibid*, pp. 4–5.
11. Although Huygens, in 1682, was forced to quit his research position in Paris and therefore lost his principal source of income, he was not destitute by any means. His father, Constantijn Senior, anxious that his son should continue his scientific work, gave him for his place of residence the country house 'Hofwijck' (presently the site of the Huygens Museum) at Voorburg, near The Hague, and signed over to him part of the generous annuity which he received from Prince William III.
12. Resolutie Kamer Amsterdam, 31 December 1682. Archief van de Vereenigde Oost-Indische Compagnie (VOC), Rijksarchief, Den Haag, VOC 241.
13. *Ibid.*
14. H. J. M. Bos, 'Huygens, Christiaan', in C. C. Gillispie (ed.), *Dictionary of Scientific Biography*, Vol. VI, Scribner, New York, p. 598.
15. Appointing one child, especially the younger child, to teach the other, can be a recipe for disaster for sibling relations because it can easily arouse the jealousy of the older child. Although it is not known what kind of pedagogy Constantijn Senior employed, his use of young Christiaan as a mathematics tutor for Constantijn had no detrimental consequences for the relations between the two brothers. On the contrary, throughout their lives Christiaan and Constantijn remained extremely close. They respected and loved each other, maintaining a regular and warm correspondence over more than four decades. (C. D. Andriesse, *Titan kan niet Slapen, een Biografie van Christiaan Huygens*, Contact, Amsterdam, p. 57.)
16. A. E. Bell, *Christiaan Huygens and the Development of Science in the Seventeenth Century*, Edward Arnold and Co., London, pp. 21–22.
17. *Ibid*, p. 22.
18. H. F.Cohen, *Christiaan Huygens: A Question of Time*, Museum Boerhave, Leiden, p. 5.
19. This contempt for manual work was of course typical for the social millieu into which Huygens was born. It was largely because of this attitude that we don't know precisely what kind of instruments the young Huygens constructed. In his father's letters there are some vague references to 'wind-mills', to 'models', and even to a 'lathe', but, while regarding his son's mechanical abilities as something extraordinary, neither Constantijn Senior, nor any one else, thought the matter important enough to describe the boy's constructions in any detail. It should further be noted that mechanical aptitude seems to have been fairly widespread amongst seventeenth century scientists. Galileo, for instance, constructed the world's first telescope, a real instrument of investigation, while Isaac Newton, as a 15 year old boy, is known to have built a windmill, complete with a complex gearing mechanism (Andriesse, *op. cit.*, pp. 62–63). But, whilst other early modern scientists also displayed an aptitude for mechanics, Christiaan Huygens seems to have combined a talent for science and for mechanics to a remarkable degree (Andriesse, *op. cit.*, pp. 62–63).
20. Cohen, *op. cit.*, pp. 8–9.

21. *Ibid*, pp. 9–10.
22. *Ibid*, pp. 22–23.
23. *Ibid*, pp. 45–48.
24. R. T. Gould, *The Marine Chronometer*, Holland Press, London, 1960, pp. 27–30.
25. M. S. Mahoney, 'Christiaan Huygens: the measurement of time and longitude at sea', in H. J. M. Bos and M. J. S. Rudwick et al. (eds), *Studies on Christiaan Huygens*, Swets and Zeitlinger, Lisse, 1979, p. 254.
26. Huygens wrote this dedication in 1671 just before he sent the manuscript of *Horologium Oscillatorium* to the publisher, that is, in the year before the outbreak of war between the Dutch Republic and France. Nonetheless, it is a remarkable testimony of the high degree of freedom which the press enjoyed in the seventeenth century Dutch Republic that Huygens' book, with its dedication to Louis XIV, could have been published at Amsterdam in 1673, that is, during the darkest days of the Dutch–French war (1672–78), when the greater part of the Republic's territory had fallen under French occupation.
27. Gould, *op. cit.*, p. 27.
28. Andriesse, *op. cit.*, p. 325.
29. Mahoney, *op. cit.*, p. 256.
30. Andriesse, *op. cit.*, p. 326.
31. *Ibid*, p. 326.
32. Christiaan Huygens, *Ouevres Complètes, Correspondence, 1685–1690*, Vol. IX, Nijhoff, La Haye, 1901, pp. 55–76.
33. *Ibid*, p. 266.
34. It will be noted that there was an 8-month delay between the arrival at Amsterdam of the *Alcmaer* and Huygens' report on the trial. This delay was due in part to the death, at the for that time remarkable age of 91, of Huygens' father, Constantijn Senior, and in part also to the onset of illness of Huygens himself. The delay may also have been caused by the receipt by Huygens during these months of Newton's *Philosophia Naturalis Principia Mathematica*, which gave him quite a bit to think about. It might further be noted that Huygens who, as an independent thinker had developed his own theories about the nature of the physical world, could not, as he put it, 'approve of the various hypotheses of Professor Newton' (Huygens, *op. cit.*, Vol. IX, p. 267).
35. Huygens, *op. cit.*, Vol. IX, pp. 272–91.
36. *Ibid*, pp. 272–91. Although Huygens was understandably anxious to present the result of the sea trial in the most favourable light, there is no suggestion here that his explanation of the clock's inaccuracy was anything other than purely scientific. Huygens, it should be remembered, had been the principal originator of the theory of centrifugal force so that it is entirely reasonable for him to have analysed the results of the sea trial in those terms. Moreover, the phenomenon he was trying to explain was certainly not imaginary. Gravity does change slightly with latitude due to the fact that the Earth does not have a perfect spherical shape, and these slight changes in gravity do affect the period of oscillation of a pendulum. (The scientific arguments underpinning Huygens' analysis of the sea trial are examined in depth in a forthcoming paper by Eric Schliesser and George Smith, 'Huygens' 1688 Report to the Directors of the Dutch East India Company on the Measurement of Longitude at Sea and the Evidence it Offered against Universal Gravity', Department of Philosophy, University of Chicago).
37. *Ibid*, pp. 272–91.
38. Report De Volder, Collectie Johannes Hudde, Inventaris 44, Algemeen Rijksarchief, The Hague.
39. *Ibid*.
40. Huygens, *op. cit.*, Vol. IX, pp. 418–19.
41. *Ibid*, pp. 567–68.
42. Huygens, *op. cit.*, Vol. X, p. 339.
43. *Ibid*, p. 341.
44. *Ibid*, p. 389.

45. *Ibid*, pp. 396–97.
46. *Ibid*, pp. 435–36.
47. *Ibid*, pp. 433–34.
48. J. H. Leopold, 'Christiaan Huygens and his instrument makers', in Bos and Rudwick et al., *op. cit.*, pp. 230–31.
49. This work was published posthumously in 1698 by Huygens' brother, Constantijn, who had also edited the original manuscript. It aroused great interest and shortly after its appearance it was translated from the Latin into the Dutch, French and English languages. The first English edition of *Cosmotheoros* appeared in 1698, only a few months after the original Latin edition, under the title: *The Celestial Worlds Discovered, or Conjectures concerning the Inhabitants, Planets and Productions of the Worlds in the Planets.*
50. Cohen, *op. cit.*, p. 25.
51. *Ibid*, pp. 37–38.
52. C. Busken Huet, *Het Land van Rembrandt: Studiën over de Noord-Nederlandse Beschaving in de Zeventiende Eeuw*, Vol. 2, Het Spectrum, Utrecht, p. 183.
53. Sobel, *op. cit.*, p. 53.
54. J. H. Leopold, 'The longitude timekeepers of Christiaan Huygens', in Andrewes, *op. cit.*, p. 112.
55. *Ibid*, pp. 71, 103.