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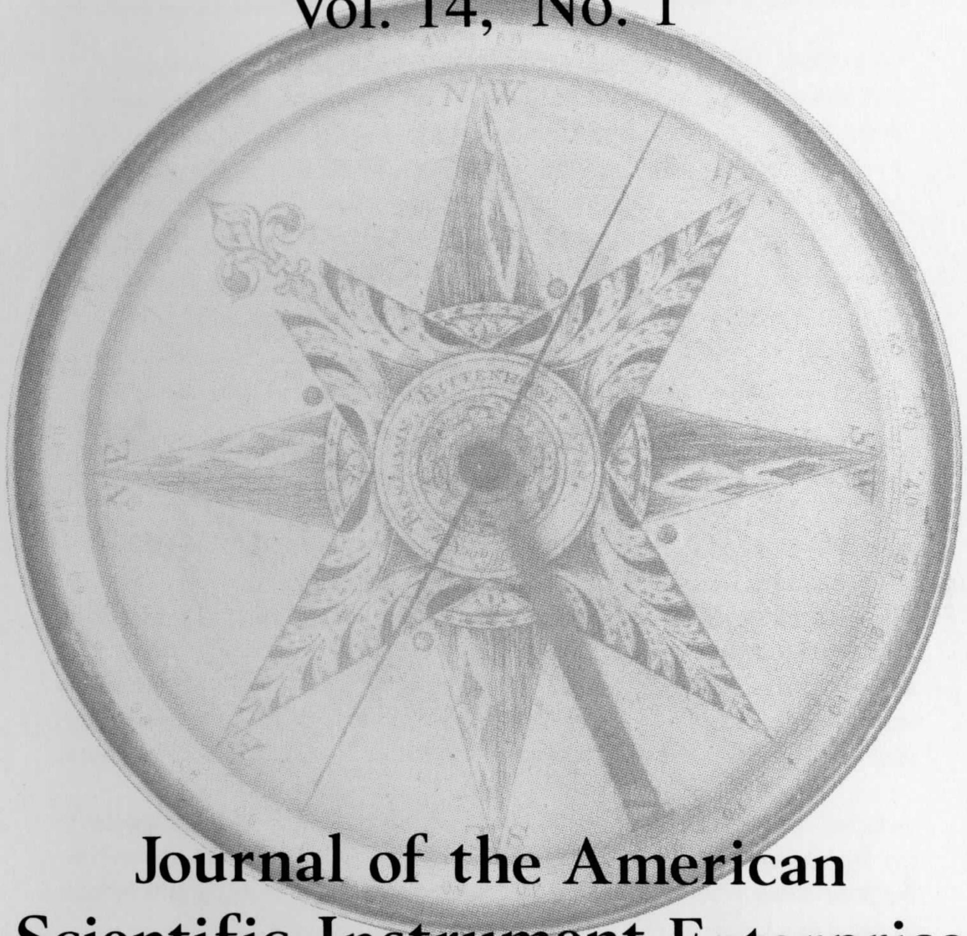

Journal of the American Scientific Instrument Enterprise

RITTENHOUSE

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This Journal aims to increase and diffuse knowledge about scientific instruments made and/or sold in the United States and the Americas. The areas covered include mathematical, optical and philosophical instruments, chemical, physical and electrical apparatus, sundials and globes. The time period covered is from the 17th to the mid-20th century.

Articles concerning instruments, instrument makers or other aspects of the instrument enterprise and biographies should be sent to the editor. Book reviews, reviews of web sites and collection profiles should be sent to the Associate Editor.

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DAVID RITTENHOUSE (1732-1796)

Silvio A. Bedini

Recognized as one of the major figures in the American Enlightenment and unquestionably one of the foremost men of science in early America, David Rittenhouse has been the subject of several book length biographies and numerous articles, yet there are certain aspects of his life that have never been satisfactorily resolved, and remain subjects for speculation. Although he produced some of the finest clocks made in his time, and some of the most sophisticated scientific instruments, it is not known from whom or where he learned his crafts. Emerging from these mechanical endeavors to experimentation in optics, the physical sciences and astronomy, he applied his scientific knowledge to public service.

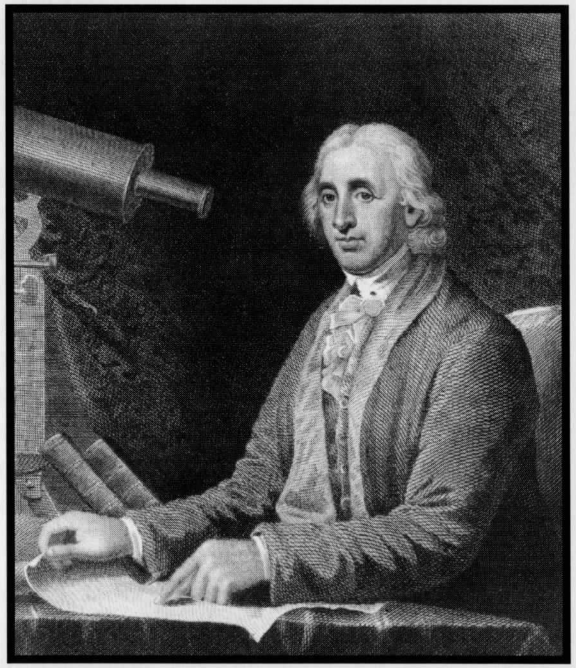

Fig. 1 Portrait of David Rittenhouse by Charles Willson Peale, 1791. Engraving from the painting.

Born on April 8, 1732 on his father's farm at Paper Mill Run in Roxborough Township, Philadelphia County, Pennsylvania, David was the older of two sons of Mattias and Elizabeth (Williams) Rittenhouse. His ancestry was mixed, his father being of German Mennonite stock, and his mother a Welsh Quaker. David was three years of age when his father moved the family to a farm in Norriton, where he and his younger brother Benjamin spent their boyhood and youth, sharing the farm work as they grew older.

His education was at best informal and for the most part he was self taught. David was able to teach himself from books on elementary arithmetic and geometry, and he found much to interest him in copies of Poor Richard's Almanac. It was soon apparent that he had a natural talent for mathematics and mechanics, which was stimulated by his maternal uncle and namesake, David Williams, a furniture maker, with whom he spent much of his time. When he was eleven, he and his uncle watched a total eclipse of the Moon in the evening of October 1, 1743, an event that opened up a whole new world to him. When David was twelve, he inherited his uncle's books and chest of tools; later a brother-in-law provided him with some scientific books from time to time, among which was the first volume of Isaac Newton's Principia rendered into English. In the course of his self studies, he taught himself French, German and Dutch.

Naturally skilful with his hands and with an interest in mechanics, he was only twelve when he constructed a miniature watermill. At seventeen he ventured to make a wooden clock followed some time later by a clock made of

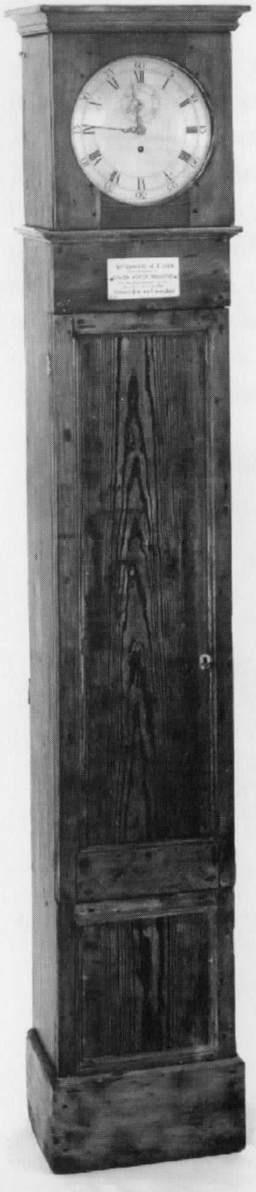

Fig. 2 Field regulator clock in plain pine case made by David Rittenhouse and used in the field on his boundary surveys. Courtesy of the American Philosophical Society.

brass. Eventually he was able to develop a working capability for theoretical and observational astronomy. At the age of nineteen, his father assisted him in constructing a shop at the farm along the road to Norriton, in which he made some of the tools he needed, and purchased others in Philadelphia from time to time. Thus equipped, he began to produce and sell tall case clocks, three of which incorporated small orreries, as well as mathematical instruments for surveyors and for use in astronomy.

Rittenhouse was married twice, first to Eleanor Coulston in 1766 and they were the parents of two daughters; after his wife's demise, in late 1772 he married Hannah Jacobs.

From about 1756 to 1785 Rittenhouse produced a variety of surveying and astronomical instruments, including surveying compasses, vernier compasses, draughting tools, surveying levels and transit instruments. He experimented also with the production of thermometers and barometers and a hygrometer. By 1770 there was a constant market in Philadelphia for surveying instruments, and his instruments, considered to be the finest available, were eagerly sought. For a time he employed his younger brother Benjamin to assist him in his shop due to the increased volume of orders for his work and because of the various other scientific endeavors in which he was engaged.

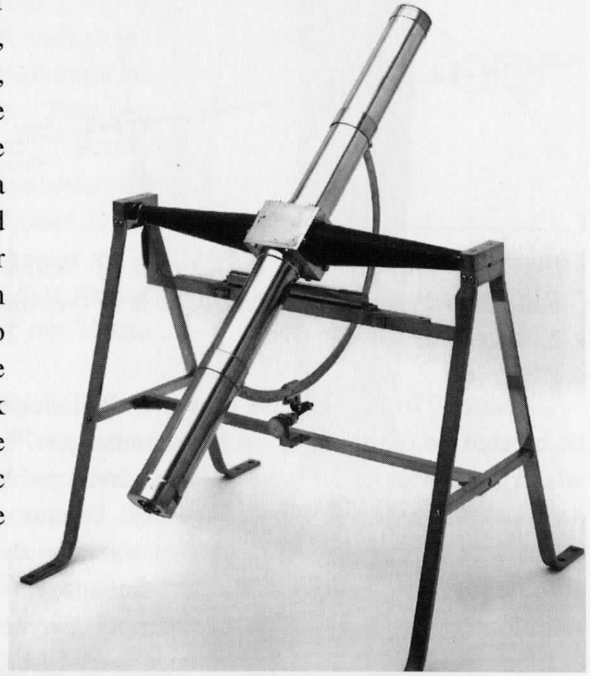

Fig. 3 Astronomical Transit Instrument built in 1769 by David Rittenhouse for his observations of the transits of Venus and of Mercury and later used it in his observatory at Norriton and later at Philadelphia. Courtesy of the American Philosophical Society.

Rittenhouse's scientific activities first came to public notice in 1769, during observations made by members of the American Philosophical Society of the transits of Venus and of Mercury that occurred that year. He was part of a group of the Society's members who observed the events from his observatory on his farm in Norriton, one of three observing posts selected by the Society. He constructed many of the instruments used for the observations, and it was at this time that he also constructed his first transit and equal altitude instrument, based upon the published designs of Pierre Charles Le Monnier. He assembled a prototype of the instrument, and although crudely constructed, it was used successfully during the transit observations. Later he assisted fellow surveyor Andrew Ellicott in making another improved version that Ellicott used in his major boundary surveys.

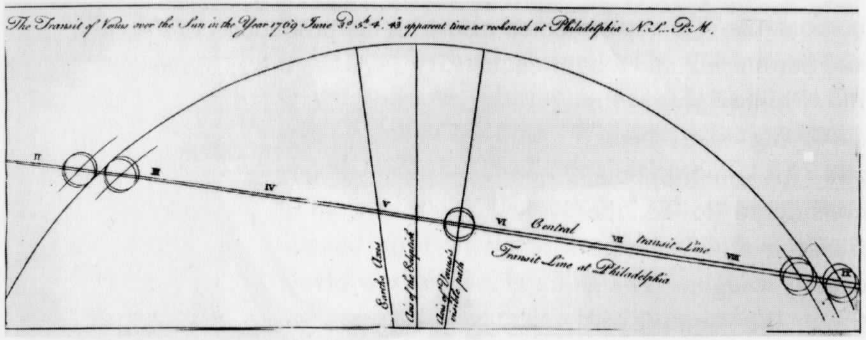

Fig. 4 Projection of the Transit of Venus, drawing by David Rittenhouse. From the *Transactions of the American Philosophical Society*, vol. **1**, 1771.

About 1770 Rittenhouse moved to Philadelphia, and soon thereafter he erected an observatory on his premises at 7^{th} and Arch Streets from which he continued to make observations, publishing calculations and data on Jupiter's satellites, Mercury, Uranus, comets, meteors, and eclipses that occurred. Rittenhouse was also the first in the American colonies to produce another of the most sophisticated precision astronomical instruments of the period, the zenith sector. The first example of the zenith sector had been made in 1727 by the English clock and instrument maker George Graham, and other examples subsequently were produced in England by John Bird and Jonathan Sisson for use in establishing the Mason and Dixon Line. The zenith sector is a fixed vertical telescopic instrument designed for measuring the zenith distances

of stars that come within its arc and serves also for discovering the aberration of stars and the nutation of the Earth's axis. It is used for determining the parallels of latitude by repeated observations of a number of fixed stars near the zenith as they cross the meridian at differing hours. Because stars near the zenith are free of refraction, they are observed in preference to others for determining latitude. The long focal length of the instrument's objective made the slightest deviation in a star's zenith distance readily perceptible as it culminated. About 1784 Rittenhouse produced for his own use in the field, the first example to be made in the United States, based upon Graham's design.

Rittenhouse also developed a collimating telescope for the purpose of adjusting instruments in the meridian when visibility of the distant mark was obstructed by intervening structures. Although his system was not the first, it nonetheless provided further evidence of his inventiveness. He also experimented with metal and wood for the development of a compensated pendulum that he had designed for regulating his clocks more accurately.

One of Rittenhouse's lesser known but equally important achievements was his successful application of spider's web for cross-hairs in the focus of his telescopic lenses. For years, while

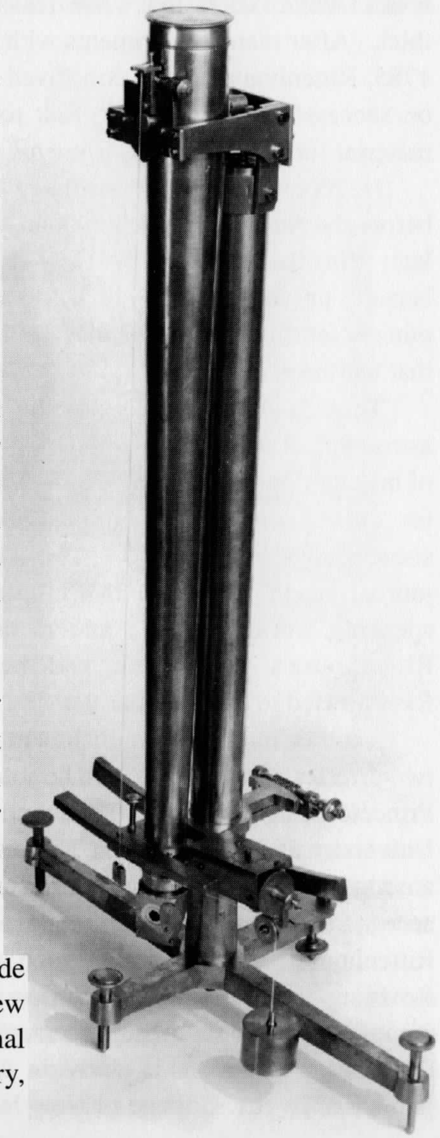

Fig. 5. Portable zenith sector made by David Rittenhouse for Andrew Ellicott. Courtesy of the National Museum of American History, Smithsonian Institution.

pursuing astronomical observations at his observatory in Philadelphia, Rittenhouse continued to experiment with cross-hairs of various materials for the purpose of measuring the relative distances of stars and planets.

A wide variety of materials had been tested for this purpose by many over the years in an effort to achieve a line of least diameter in a filament having sufficient durability. Animal and human hair, silk thread and many types of finely drawn wire were among the materials tested. Some proved to be reactive to humidity and temperature and either loosened or broke, while others that were resistant to vibrations proved to be too thick. After many experiments with a range of materials, in June or July 1785, Rittenhouse finally conceived of using spider silk which proved to be successful. He was the first to make practical application of this material for astronomic instruments.

He reported his experiment in a letter to John Ewing, which was read before the American Philosophical Society in November. Spider silk was later tried successfully by English astronomers, and in time, its use became universal. It was used experimentally as well as filaments in other scientific equipment and proved to be superior to other materials that had been attempted.

Though William Gascoygne had purportedly made the first astronomical micrometer after a spider had left a web in the focal plane of his telescope's eyepiece (1638-39), the first attempt to apply spider silk for cross hairs in astronomical instruments had in fact been made successfully in Italy in 1754. This was first reported in Italian in a remote journal in 1775 though the information did not reach the English-speaking world until the mid to late nineteenth century however, so Rittenhouse's application had been made independently without foreknowledge of its earlier use.

Another major accomplishment was the design and construction of two orreries, the first of which he sold to the College of New Jersey (later Princeton University) and the second to the College of Philadelphia (later University of Pennsylvania). These two orreries, of his own design, rank among Rittenhouse's major scientific achievements. Well informed with access to publications describing examples produced by English makers, Rittenhouse based his design upon a work published in 1758 by John Rowning, *Compendious System of Natural Philosophy,* and completed the first of the two instruments, originally intended for the College of Philadelphia early in 1771. Several months later it was purchased by the College of New Jersey, and Rittenhouse proceeded to make another, as he had promised, for the College of Philadelphia. Thomas Jefferson was so intrigued with the latter that he suggested that the instrument be re-named "Rittenhouse" to honor the maker and he proposed to have another commissioned to be sent to King Louis XIV. Rittenhouse agreed to make it but his poor health and other priorities forced him to abandon the project.

From his astronomical instruments and his observations grew Rittenhouse's reputation as the foremost astronomer in the American colonies in his time. As the statesman John Page wrote to Jefferson in

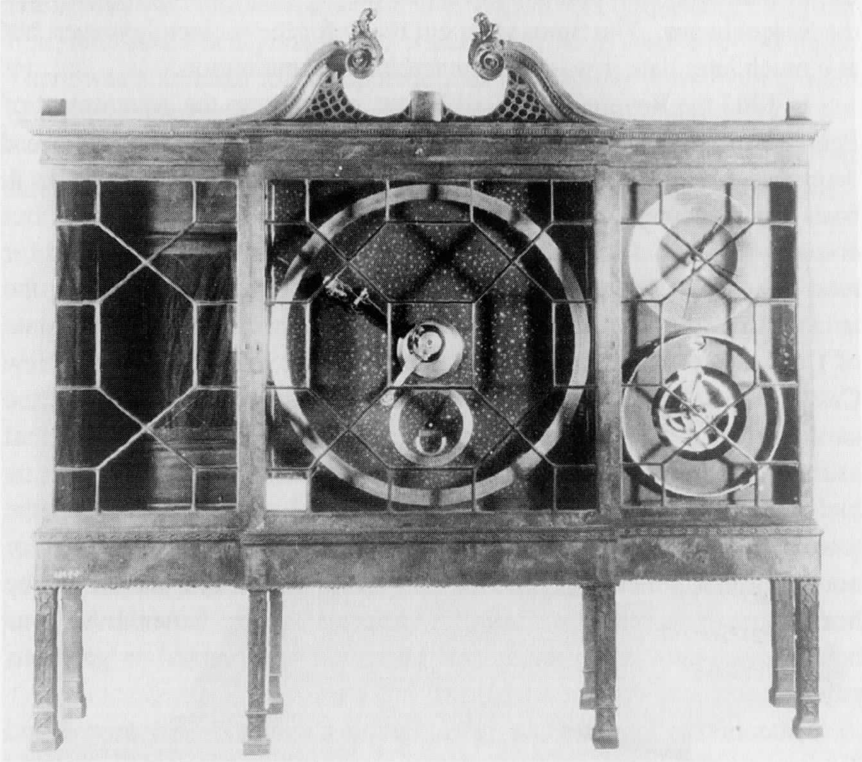

Fig. 6. Orrery designed and made by David Rittenhouse housed in a cabinet by John Folwell of Philadelphia. Courtesy the University of Pennsylvania.

praise of Rittenhouse, "As an Astronomer I doubt when the World can produce another for, if every Instrument and Book upon Earth which Astronomers use were destroyed, I am certain, from the Instruments which he made and the manner in which I saw him use them, that he himself without any Assistance could replace Astronomy in the present State of its Perfection."

Despite ill health, from which he suffered most of his life, Rittenhouse was one of the most prominent among the pioneering surveyors of his time. He specialized in boundary surveys and helped to establish several territorial boundaries. Among his achievements in field work was a traverse line of 69 courses that he ran between Norriton and Philadelphia to verify the difference in latitude and longitude. In his younger days he ran a survey and took levels across eastern Pennsylvania for a canal being contemplated between the valleys of the Schuylkill and the Susquehanna. The times were not ready for the project, however, but at a much later date it was constructed in the same region.

In 1763 the Reverend Richard Peters, secretary to the government of Pennsylvania, asked him to assist in preparing for the proposed determination of the boundary between Pennsylvania and Maryland. A basis for settlement of the boundary had already been established but commissioners and surveyors for both provinces had been involved for more than three years in resolving the difficult problem of running the tangent line from the point that is now the southwest corner of the state of Delaware to a point where it intersected a 12 mile circle about New Castle. It was because of these difficulties and the turgid progress of the survey that it was deemed necessary to engage two professional astronomers from England to complete the survey. With instruments he had made, Rittenhouse drew a circle with a 12 mile radius around the town of New Castle, the center of which intersected a certain parallel of north latitude which was laid out topographically and served as the beginning point for this project. For this work Rittenhouse was handsomely paid in the amount of £6 which he accepted as generous payment.

Rittenhouse's competence in surveying was widely recognized and his services sought and, in 1769 at the request of a commission appointed by New York and New Jersey, he fixed the point where the 41st degree of latitude, the northern point of New Jersey, reached the Hudson River. Although he participated in establishing the boundary between New York and New Jersey, Rittenhouse was not a commissioner for either colony and did not remain for the process of marking the line, his function being to determine the latitude at either end of the line. Two more latitudes were established, one for the Sandy Hook lighthouse and one for the southwest bastion of Fort George.

In 1779 Rittenhouse served with the Reverend John Ewing and George Bryan as commissioners for Pennsylvania in resolving the dispute over the Pennsylvania-Virginia boundary and he served once more in the same capacity in 1785, then in 1786 assisted in establishing the province's western boundary.

Rittenhouse's interests ranged into other sciences as well. He developed an improvement on the Franklin Pennsylvania Fireplace, which became known as the "Rittenhouse Stove," and in 1773 he calculated the ephemeris for the *Universal Almanack* printed by James Humphrey of Philadelphia for the region encompassing Virginia, Maryland and Pennsylvania and which were advertised with his name. There was a demand for his ephemerides for ensuing years from printers of other almanacs, which he continued to produce until about 1780.

Rittenhouse is credited with having introduced two important innovations in instruments for surveying and astronomical observation,

Fig. 7. Plain surveying compass made by David Rittenhouse and claimed to have been owned and used by George Washington after his retirement to Mount Vernon. Courtesy of the National Museum of American History, Smithsonian Institution.

neither of which are considered to have been exclusively his invention but he was the first to have produced them in the United States. The first is the vernier surveying compass which proved to be far superior to the plain surveying compass, and which became known in the trade as the "Rittenhouse Compass." Not long thereafter they were produced also by his brother Benjamin and by others as well. The improvement proved to be so important that it was widely adopted by other makers and the use of a vernier compass became a requirement for government surveys. On the basis of existing evidence, it appears that the vernier compass was first produced in the United Kingdom, possibly in Ireland, but Rittenhouse developed his version without having foreknowledge that others had preceded him. Rittenhouse also appears to have been the first to make the base of the instrument in a single piece by combining the body of the compass and the sighting arms.

Despite his prominence as a surveyor and as a maker of fine tall clocks and advanced surveying instruments, it was for his achievements in astronomy that Rittenhouse gained transatlantic recognition. All of his scientific papers on mathematics, astronomy, and the physical sciences were published in the first four volumes of the American Philosophical Society's Transactions. Rittenhouse produced significant data for Jefferson's report on weights and measures and he was appointed the first director of the first United States Mint, a position in which he served from 1792 to 1795.

Because of his mechanical talents, Rittenhouse fulfilled several important roles in the American Revolution. In 1775 he took part in formulating the radical Pennsylvania Constitution, was a member of the Board of War, an engineer with the Committee of Safety and later its vice president. He experimented with telescopic sights for rifles and cannon and, from 1777 through 1789, he served as treasurer of Pennsylvania. He selected sites for a gunpowder mill and for military stores, helped to design the defenses of the Delaware River and the manufacture of chains for protecting Philadelphia's harbor, supervised local casting of cannon as well as the production of saltpetre for ammunition.

An early member of the American Philosophical Society, having being elected January 19, 1768, David Rittenhouse served as its secretary, vice president, a member of its council and of many of its committees. Later Rittenhouse served as the Society's librarian and then as curator, and in 1790 he succeeded Benjamin Franklin as its president. Recognition of his many achievements came during his lifetime. He was

elected a foreign member of the Royal Society of London and had the degree of Master of Arts conferred on him three times -- by the University of Pennsylvania, William and Mary College and by Princeton University. When he died in 1796, he was eulogized by Benjamin Rush, the leading colonial physician, before the president of the United States, both Houses of Congress, the Assembly of Pennsylvania, the diplomatic corps and representatives of various learned societies. His body was laid to rest beneath the floor of his observatory at 7th and Arch Streets in Philadelphia. His grave was marked with a simple marble slab bearing only his name, his age and date of death. Later his remains were moved to a local cemetery. Three of his manuscript notebooks and other Rittenhouse papers are preserved in the American Philosophical Society's manuscripts collection and archives while his letters and business papers are in the Benjamin Smith Barton Papers and other collections of the Historical Society of Pennsylvania.

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Ed. Note: At the suggestion of the Associate Editor and to commemorate the completion of 50 issues of ***RITTENHOUSE*** (and perhaps even the passing of the millennium), we asked Dr. Bedini, the dean of American scientific instrument studies, to provide the above paper. This considerably expands Brooke Hindle's note on David Rittenhouse that appeared in Vol. 1, No.1 and provides a link back to Deborah Jean Warner's inaugural effort for the new journal. Eugene Rudd also pointed out that we are not the only group to honor David Rittenhouse; the Rittenhouse Astronomical Society is the oldest such society in the country, the Univ. of Pennsylvania's Physics/Astronomy labs are named for him and there is also a Rittenhouse Square, both in Philadelphia.

THE WILLIS NAVIGATING MACHINE
A FORGOTTEN INVENTION

Willem F.J. Mörzer Bruyns

Abstract

To avoid the arithmetic for solving navigational calculations, early seamen preferred to use scientific instruments such as Gunter's quadrant and the plane scale. Even after the introduction of logarithms, in the first half of the 17th century, seamen, scholars and inventors kept on looking for mechanical ways to avoid arithmetic. This accelerated with the coming of aviation in the 1920s. The speed of aeroplanes necessitated finding one's position faster than on board ship. For this purpose, Edward Jones Willis, a consulting engineer, inventor and author in Richmond, VA, designed a Navigating Machine. Marine and aviation versions were patented in 1932 which performed the arithmetic to find a position line. The test report of Lt. Commander P.V.H. Weems USN, was favorable and several machines were manufactured by Heath & Co. in London. However, the machine was not widely used. Willis arranged for his machines to be placed in institutions in the US and UK but a recent survey shows that most appear to be lost. One, along with the US and UK patents and Willis' personal archives, was presented to The Mariners' Museum in Newport News, VA.

Introduction

The process to find a position line by means of celestial navigation - other than for finding latitude at meridian passage - consists of a number of phases. First an altitude observation of a celestial body must be taken with the simultaneous observation of Greenwich Mean Time. Secondly the Local Hour Angle for the observer's dead-reckoned (assumed) position must be found, followed by a calculation. Finally, the resulting position line has to be plotted in a chart. When more lines are obtained from several stars at the same time, their intersection will indicate the observer's position at the time of the observations. The first phase necessitates the use of a sextant and a marine chronometer; for the