

The 1769 Transit of Venus Observatory in Lewes, Delaware

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Abstract

The highest priority astronomical problem of the 18th century was to determine the distance from the Earth to the Sun, from which the scale of the entire solar system could be calculated. The most promising method of solving this problem was based on precise measurements of the rare event of a transit of Venus across the Sun's disk. Many expeditions were undertaken around the world to observe the 1769 Venus transit, some of which were quite successful while others endured terrible hardship and disappointment.

That year, the American Philosophical Society of Philadelphia embarked on an extensive transit observation program from observatories at Statehouse Square in Philadelphia, David Rittenhouse's farm in Norriton, PA and a temporary site in Lewes, Delaware¹.

This is the first in-depth analysis of the Lewes transit expedition. The Lewes team had only a very short time to establish an observatory capable of observing the transit, determining the observatory's geographic coordinates and documenting their observation of the transit. More than a year was required for the observatory's location to be determined to their satisfaction. The methods they used to determine the observatory's coordinates are examined in detail and the probable location of the observation site is derived. The subject is presented in two parts. Part I is a general overview of the mission, activities and results of the expedition. Part II is a more technical and detailed discussion of the survey; what they knew, how they used it and the probable location of their observatory.

The 1769 transit thrust Lewes and the American observation teams into world-class science and confirmed their ability to perform at the level of European astronomers.

A shorter and less technical version of this paper will be published by The Lewes Historical Society.

¹ What we now call the state of Delaware was the "Lower Three Counties" of Pennsylvania in 1769. For all practical purposes, Delaware became a separate entity in 1704, but was still officially part of Pennsylvania until statehood in 1787. Delaware was represented as a separate colony in the First Continental Congress in 1774. For simplicity, we refer to this area as "Delaware" in this discussion.

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Part I. The Transit of Venus Expedition

On Friday, May 26, 1769, a boat arrived at Lewes², Delaware carrying three men and what must have been a remarkable cargo for the time. The men were Owen Biddle, Joel Bailey and Richard Thomas, who had been sent by The American Philosophical Society in Philadelphia to set up an observatory and observe the June 3, 1769 transit of Venus.

Background

The “Holy Grail” of astronomy in the 17th to 19th centuries was to determine the size of the solar system and grasp the scope of interstellar space. The relative sizes of the planetary orbits were well defined as ratios at that time, but not in units of distance; miles or other measurement. If the distance from the Earth to the Sun, the so-called *Astronomical Unit* (AU), were known then the sizes of the orbits of all the planets could be calculated and the scale of the universe defined. Actually, the distance from the Earth to the Sun does not have to be measured. Finding the distance between any two planets or the distance of any planet from the Sun allows the distances between all to be calculated as the relative distances from the Sun for all of the planets were known.

In 1677, a young Edmond Halley (1656-1742), who became the second Astronomer Royal and was the discoverer of the famous Halley’s Comet, conceived a method of determining the distance between Venus and the Earth by measuring the duration of the transit at locations widely separated in latitude. Knowing the distance to Venus allowed the size of the AU to be calculated. He refined the details for 40 years and finally submitted it to the Royal Society in 1716. Theoretically, Halley’s method can be used with either Mercury or Venus, but Venus is the only practical option due to its size and proximity to the Earth, which offers the largest angle to be measured.

Planet	AU
Mercury	0.39
Venus	0.72
Earth	1.00
Mars	1.52
Jupiter	5.20
Saturn	9.52

The only time to make the measurements is when Venus crosses the Sun’s disk; a transit of Venus. This rare astronomical event occurs only every 121.5 years or 105.5 years, often followed by a second transit eight years later. Transits of Venus occurred in 1639, 1761, 1769, 1874, 1882, and 2004 and will occur on June 5/6, 2012³. The next transits are not until 2117 and 2125, so the 2012 transit is the only possibility for anyone living today.

The key events to be observed are the instant Venus’ disk touches the Sun’s disk on entry, when Venus is fully inside the Sun’s disk, the instant the edge of Venus touches the Sun’s disk on exit and when Venus completely exits the Sun’s disk (Figure 1). Halley’s method requires timing the entire transit and relies on observations taken at sites widely separated in latitude. A second method developed by Joseph-Nicolas Delisle uses the exact time of either ingress or egress from sites widely separated in longitude. Either method works, but both have problems. The requirement to time the entire transit for Halley’s method restricts the

² Called Lewestown in the primary sources.

³ The 2012 transit in North America is on June 5, but the date at Greenwich is June 6, for most of the transit.

observation site to a relatively small area of the globe, but needing only the time duration of the transit frees the observers from having to coordinate their local times. Delisle's method requires the time of either ingress or egress, not the entire transit. However, the accuracy of the result depends on precise knowledge of the longitudes of the observing sites, which was very difficult in the 18th century.

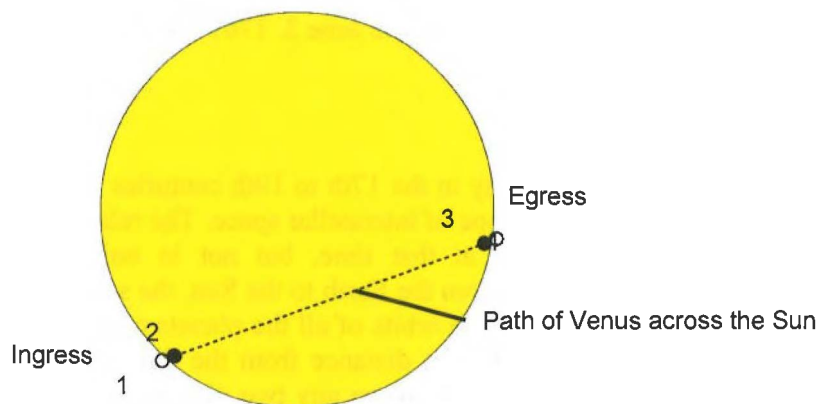


Figure 1. Observing the Transit

The angle to be measured is very small; $8''.794$, which is about the size of a dime viewed from half a mile away. Small errors in the parallax angle give errors of hundreds of thousands of miles in the AU. It was essential that the transit observations be as accurate as possible in both the time of the event and the location of the observations⁴.

Figure 2 is a photograph taken during the 2004, transit of Venus. The size of the Sun as seen from Earth is about $31'$. Venus, at about $1'$, is small but can be seen with the naked eye, if a dense filter is used to block the Sun's glare.

The first Venus transit observed by anyone was on November 24, 1639⁵, by Jeremiah Horrocks, from Hoole, a little north of Liverpool, England⁶. The first transit of Venus to be widely observed was in 1761, and observation of the transit was a worldwide undertaking. Britain and France both sent expeditions to remote locations, where some of them endured terrible hardship and disappointment. The 1761 transit was not visible in North America as it ended before sunrise. The results of the 1761 observations were not conclusive giving values for the solar parallax from $8''.28$ to $10''.60$ and the AU from 77 million to 99 million miles⁷, a range of nearly 30%. Observing the 1769 transit became an even higher priority, as there would not be another opportunity until 1874⁸.

⁴ The current value of the AU as determined by the International Astronomical Union is 149 597 870.7 km (92 955 807 statute miles) with an uncertainty of 3 m.

⁵ (Julian calendar, Dec. 4, Gregorian) The Gregorian calendar was not adopted in England until 1752.

⁶ William Crabtree of Manchester also saw part of the 1639 transit under Horrocks' tutelage.

⁷ Wulf [2012], p. 97.

⁸ See Sheehan and Westfall [2004] for a general overview of Venus transits and history.

The 1769 transit was not perfect for Eastern North America as it would end after sunset, but the predicted time of its beginning, near 2 PM, provided the opportunity to observe most of the transit and the opportunity for measuring the instants when Venus first touches and is totally within the Sun's disk. The Astronomer Royal, Rev. Dr. Nevil Maskelyne, distributed a 50 page manual with detailed practical instructions on how to establish and use an observatory for the transit.

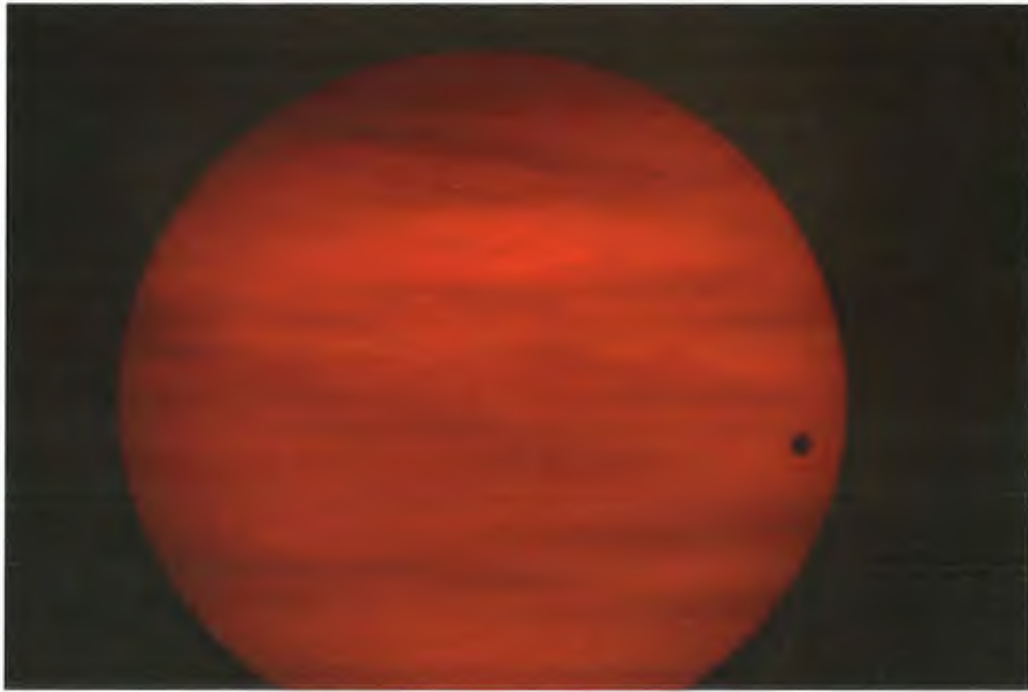


Figure 2. 2004 Venus Transit

The driving force behind American efforts to observe the transit was the American Philosophical Society in Philadelphia, which was a fully-functioning organization in 1768. Within the Society, David Rittenhouse, America's most accomplished astronomer of his time, led efforts to establish well defined observation sites in Statehouse Square in Philadelphia and at his home in Norriton, PA, about 20 miles northwest of Philadelphia. These sites were well measured and equipped, but presented one problem: If it were cloudy at one site, it would probably also be cloudy at the other. It was decided to sponsor an observing site at a remote, but reachable, location in an effort to provide some redundancy.

The reason for selecting Lewes is not recorded, but reasonable inferences can be made. Realistically, there was little development away from Philadelphia, and Lewes was one of the very few inhabited areas within a reasonable travel time. Being located on Delaware Bay made it much easier to reach as water transportation was much faster and easier than attempting to negotiate the rather primitive roads available. In addition, Lewes was somewhat in the public eye at that time because a lighthouse, the sixth in North America, went into operation there in the spring of 1769. The intent was to set up the observatory at the lighthouse, which was situated

near the Atlantic coast, just south of Cape Henlopen and due east of Lewes (Figure 15). A secondary mission was to determine the coordinates of the new lighthouse as an aid to mariners.

The Mission

The overall mission was to establish a temporary observatory in Lewes capable of observing the transit and to observe the transit and document all relevant details of the site and the observations. Knowing the exact geographical coordinates of the observation site is critical. The methods used to derive the AU depend on multiple observations of the transit elements from widely separated locations. The times are meaningful only if the coordinates of the observing sites are accurate. In particular, the observing site's longitude must be accurately known.

The Team

The men who would set up the observatory and observe the transit were chosen for their technical skills, independence, reliability and meticulous attention to detail.

Owen Biddle (1737- March 10, 1799) was the clear leader of the expedition. He had worked as a clock and watch maker, but later became a successful import/export merchant. He seems to have been widely respected and was elected the first curator of the American Philosophical Society. He was known as a man who, if given a job to do, he did it quickly, quietly and without fanfare. Biddle was a Quaker and was described by his daughter as "...a man of quick feelings and nervous temperament"⁹.

Joel Bailey (1732 - October 24, 1797), from Chester County, PA was, perhaps, one of the best surveyors in America. He could be counted on to make, modify, improve or repair any piece of surveying instrument and he was fully capable of taking on any surveying job, no matter the scale. He worked with Mason and Dixon on the survey of the West Line, which defines Pennsylvania's southern border and is commonly called *The Mason-Dixon Line*. He also made the precision levels used to measure the length of a degree of latitude and worked personally on the measurements with Mason and Dixon. Bailey was Mason and Dixon's "right-hand-man" and worked on every aspect of this critical survey¹⁰.

Little is known about Richard Thomas other than he was a competent surveyor who was engaged from time to time to do precision surveys for the Philosophical Society or the government. He was not an official team member, but paid his own way on this expedition, just to participate.

The Place

Biddle does not mention the time when they arrived in Lewes. The sailing distance from Philadelphia, down the Delaware River and through Delaware Bay is a little over 100 miles, depending on the exact course taken. If they left Philadelphia at first light, around 4:30 AM local

⁹ Biddle [1892], pg. 300.

¹⁰ Danson [2001], pg. 85.

time, and averaged about 8 mph, they would have arrived in the late afternoon. Sunset on May 26 was at about 7:30 PM, which left them some time to evaluate their situation. It is possible they made the trip over two days. There is no hint that any of the transit team had ever been to Lewes before, although Bailey was familiar with the area as the Mason/Dixon team had stayed in Dover and Bailey had traveled all of western Delaware.

The original intention was to assemble their observatory near the newly-activated Cape Henlopen lighthouse. The lighthouse was located on the aptly named Great Dune, which was less than ¼ mile inland from the Atlantic and somewhat elevated over the nearby terrain. Their first order of business was to inspect the site. The lighthouse is only about three miles from the center of Lewes, using the road that was cut to provide access during construction. They grasped the reality of Middle Atlantic coastal weather immediately; constant wind and blowing sand. Clearly, this was not a place to set up delicate instruments requiring a steady mount.

Later that same day, they made arrangements to rent a house about ¼ miles southwest¹¹ of Lewes on the South Street of the town¹². Biddle described the house as in a “retired state”, but made no comment about it otherwise except that the door faced south. We can infer that the house was unoccupied, but adequate for their needs. The property provided an unobstructed view of the sky, which was the most important factor.



Figure 3. Cape Henlopen Lighthouse

Weather became an issue the next day, with clouds and frequent rain. Based on their descriptions over the next few days, we can infer that their weather was the result of a low pressure system which also affected the Philadelphia and Norriton sites.

¹¹ [TAPS] pg. 84.

¹² [TRS] pg. 414. Now Savannah Road.

The Observatory

The report of the transit observations was very simple; the geographic coordinates of the observing site and the times of contact and complete ingress of Venus' disk. The temporary observatory had to be capable of allowing precise measurements of the beginning of the transit and recording the times to the second.

Times were to be reported as *apparent time*. That is, the time defined by the hour angle of the true sun. Setting a clock to show apparent time requires the clock to be set exactly to noon when the Sun crosses the local meridian, or is due south. This, in turn, requires a lengthy process of precise observations of the Sun and selected stars to establish the rate of the clock. The method advocated by the Astronomer Royal for this purpose involves timing when the Sun or star passes through a specific but arbitrary altitude above the horizon both before and after crossing the meridian using an equal altitude instrument with two horizontal crosshairs and a means to lock the telescope in place. The meridian is midway between the two equal altitude crossings and thus, the mid-time of the observations defines the time of meridian transit of the celestial body.

They set up their instruments the next day, May 27, and began the process of setting their clock to the exact local time by observing the Sun during the day and bright stars at night with their equal altitude instrument. The other critical element was the exact geographic coordinates of the observing site, which required performing a demanding survey. This topic is treated in detail below.

Their Equipment

They did not list all of the equipment they brought with them to Lewes, but we know it included three telescopes and mounts, a telescopic theodolite and an equal-altitude instrument. The telescope used by Biddle was a 3" Gregorian reflector made by Dollond and purchased by Thomas Penn as a gift to the Philadelphia Library Company. Mason and Dixon had used the same instrument. Biddle made an equatorial mount for it and modified the rack work which enabled him to track the Sun easily. Bailey used an achromatic refracting telescope of longer focal length, also made by Dollond. This instrument did not have a mount and they improvised a ball-and-socket attached to a post as recommended by the Astronomer Royal. A clock to time the transit was required and theirs must have been a full-size clock with a meter long pendulum beating seconds. The clock was attached to a sturdy post just outside the house.

They also had to have had the basic surveying gear, including the theodolite mentioned above, at least one 66 foot iron chain and the associated posts, hammers, axes and other items that constituted a surveyor's kit in those days, plus their personal effects.

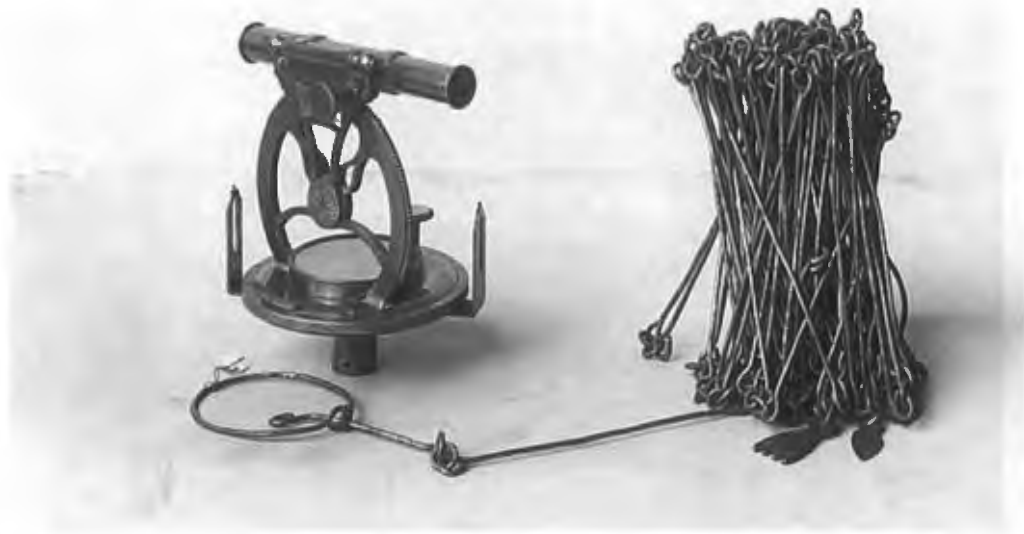


Figure 4. Colonial Theodolite and Chain

The Survey

One of the crucial elements of the transit measurements was exact knowledge of the latitude and longitude of the place where the observations were made. There was not enough time for them to determine their location astronomically, so they had to measure the site's geographical coordinates from an existing point of known latitude and longitude.

The southern border of Delaware is defined by a line surveyed in 1750/51. The general location of the line was the result of a 15-year legal action between the Penn Family of Pennsylvania and Lord Calvert of Maryland to settle border disputes that originated when Pennsylvania was chartered in 1681. The settlement stated that the line defining the southern border of the three southern counties of Pennsylvania (which became Delaware) would start at "Cape Hinlopen (sic)" and proceed west across the peninsula. The Pennsylvania border would end halfway across the peninsula.

This settlement is one of the most amazing events in all of American history. Lord Calvert thought he was agreeing to a line from Cape Henlopen near Lewes. But the map submitted mistakenly put Cape Henlopen at the location of Fenwick Island, about 23 miles south. The error was recognized quickly, but it was too late and the border originated by default at Fenwick Island. Thus, Maryland lost 25 miles of valuable beach front property due to a poor quality map.

The line, called the "Transpeninsular Line", was surveyed in 1750/51, by John Watson and William Parsons of Pennsylvania, and John Emory and Thomas Jones of Maryland. Note that the survey team had two men from each colony.

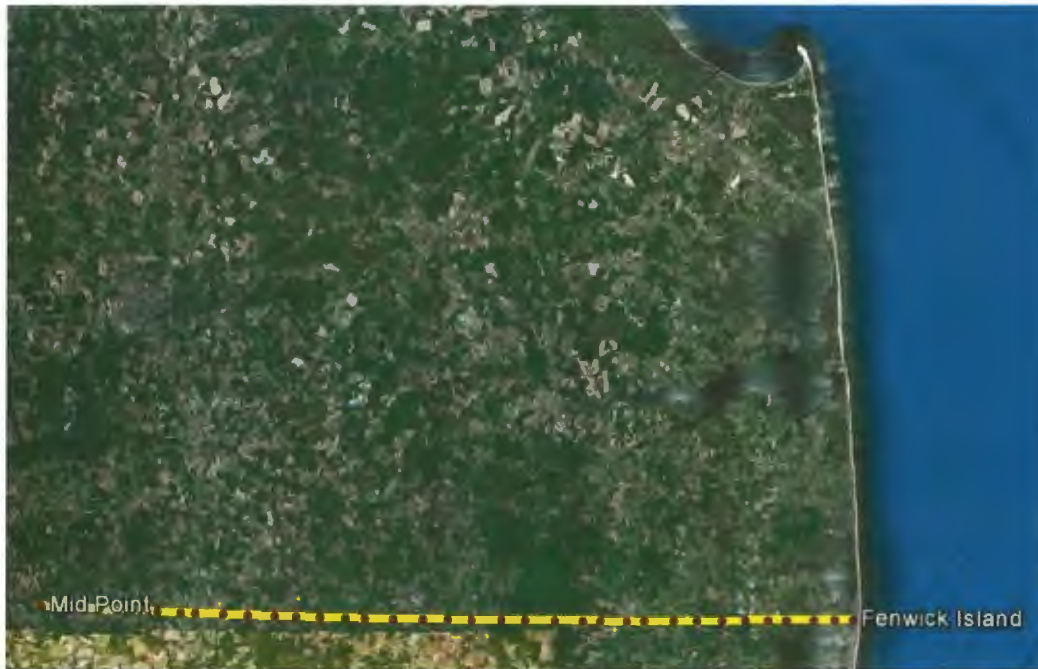


Figure 5. The Transpeninsular Line

The Transpeninsular Line was defined by stone markers and mileposts and was intended to follow the parallel of latitude west from the easternmost marker at Fenwick Isle (Figure 6), across the peninsula to Chesapeake Bay. The legal start of the line is not marked as it is in the ocean, 139 perches¹³ east of the Fenwick Island marker. The line was marked by stone markers at the 5, 10, 20 and 25 mile points and also at the Mid Point, 34 miles and 309 perches from the start of the line, with mileposts each mile¹⁴. The markers are native stone with the Calvert arms carved on the south side and the Penn arms on the north side. The dots on the line in Figure 5 accurately represent the current marker locations. The boundary was resurveyed by the National Geodetic Survey in 1974, and all monuments that were lost or had been moved were replaced and mileposts were installed about each mile¹⁵.

The most important point on the Transpeninsular Line is the Mid-Point Marker, which defines the center of the Delmarva Peninsula and the southwest corner of Delaware. The latitude of this marker was painstakingly measured by Mason and Dixon in 1767, as 38° 27' 34" N using astronomical observations¹⁶ and Bailey and Biddle assumed all of the markers on the line were on this latitude.

¹³ A "perch" is a distance measure of 16.5 feet, one-quarter chain, also called a "rod".

¹⁴ The original surveyors were instructed to set posts each mile, but there is no evidence this was done.

¹⁵ Meade [1982], pp. 7-8.

¹⁶ The modern latitude, which uses a different model for the shape of the Earth [NAD83(91)] is 38° 27' 36.29213".



Figure 6. Fenwick Island Marker

Owen Biddle wrote, “The four following days continued cloudy, with frequent rains. But that we might not be idle in the mean time, and have it in our power to ascertain our latitude and longitude, in case we should be disappointed of celestial observations for that purpose; Joel Bailey and Richard Thomas, went to take the courses and distances from our observatory, to the provincial west line, which was run from Fenwick’s Island to the *middle point* of the peninsula; so that our observatory might thereby be connected to Messrs. Mason and Dixon’s meridian line” [TAPS pg. 84].

This statement seems a bit disingenuous. They had brought all of the equipment needed to perform the survey and clearly intended to use it¹⁷. On the other hand, the surveying equipment may have been brought as a precaution against bad weather (which happened), with the intention of using it only as a backup. However, they could have just as easily not done anything and waited for good weather to do the needed astronomical observations to pinpoint their location. Even then, it would have taken weeks to perform all of the astronomical observations required.

His statement that Bailey and Thomas did the survey very likely understates the magnitude of the operation. Their mission was to determine the distance of the observatory north and east of a point on the Transpeninsular Line, which required an open traverse of over 20 miles, much of it through undeveloped land, and they had less than four days to complete it and get back to Lewes. And it was windy and raining.

An open traverse is a line-of-sight surveying technique that measures a series of connected line segments between two points. The distance between the start and end points is calculated using simple trigonometry. The sequence of steps is something like:

1. The starting point for each line segment is marked by a stake. The measuring instrument, a telescopic theodolite in this case, is mounted on a tripod and placed exactly over the stake using a plumb bob for precise positioning. The instrument is leveled and usually pointed directly north or south using a compass built into the instrument.

¹⁷ David Rittenhouse strongly implies they planned the survey from the beginning [TAPS 11].

2. A direction is chosen and a man is sent in that direction with a rod. He takes the rod to a point that is in the approximate direction desired and the man at the instrument and the man with the rod communicate with hand signals until a good place is found. The angle is recorded.
3. Another man or two drag the 66 foot long chain in the required direction taking care that the chain is flat over its entire length. The instrument man directs them to the exact line and a stake is driven to mark the end of the chain and the number of chains is recorded.
4. This is repeated until the chain reaches the rod and any partial chains are recorded or the end point of the segment is moved until it is an even number of chains.
5. The instrument is packed and taken to the rod position and they start over.

This was done 120 times for a total of 2148 chains before the traverse was complete.

Clearly, two men could not do this alone. Biddle had been advanced £20 for expenses, which was a considerable amount of money for the time. They probably hired a wagon and driver to carry the equipment and extra gear needed for camping out on the way. They would also have hired two or three burley young men to drag the chain, drive stakes and cut limbs and trees that were in the way. There were surely some hangers-on attracted by the novelty of the undertaking who probably helped when needed. Experienced chain-men were available in Delaware from the Mason and Dixon survey, but there is no mention that they were used. The crew was at least eight or nine men for the full traverse, with others involved to help cross creeks and the Indian River¹⁸. There were probably some men on horseback who could scout the best route.

Biddle did note that they stuck to established roads as much as possible, as it would have taken too long and been too expensive to try to clear a direct route through the woods. Colonial roads were quite different from modern roads. They were generally quite wide, up to 200', as a safety measure and to accommodate driving livestock. Unlike modern roads, there was often no defined roadbed.

It is clear that Bailey was aware of the location of the marker stones on the Transpeninsular Line and that he headed for the settlement now known as Selbyville, near the 10 mile marker stone. His traverse terminates at a point which he describes as being on the Transpeninsular Line at a distance of 9 miles 86 perches from the stone in Fenwick's Isle. We can infer he determined this by measuring 234 perches east from the 10 mile marker to his intersection point near the current milepost 9.

¹⁸ Mason and Dixon's crew was generally 35-40 men and included two wagons, eight horses, cooks, stewards, tent keepers, chain men and laborers. Their main instrument was transported in a wagon, on a featherbed.



Figure 7. Colonial Surveyors

By calculating the accumulated distances travelled in southerly and westerly directions and applying them to his termination point, Bailey was able to establish how far the observatory was located east and north of the Mid-Point.

The results of the traverse were sufficient to establish the latitude of the observatory from the known latitude of the Transpeninsular Line. However, Mason and Dixon had not completed the determination of the longitude of the Mid-Point before their return to England, so the longitude of the observatory could not be determined from the available information.

The unknown longitude of the Mid-Point was a critical missing element. In May, 1770, nearly a year after the transit, The American Philosophical Society commissioned Biddle and Bailey to conduct a further survey from the New Castle Court House to the observatory in State House Square, Philadelphia, to determine the longitude of the Mid-Point. The New Castle Court House was already connected to the Mid-Point through the Tangent Line, and the latitude and longitude of the State House observatory had been precisely determined by a survey conducted shortly after the transit. Thus, the final piece of the puzzle, the longitude of the Mid-Point, was supplied by this additional traverse.

Once this traverse was completed, Biddle and Bailey were able to declare that the Lewes observatory was located at $38^{\circ} 46' 38''.3$ North and $75^{\circ} 08' 30''$ West.

These values would place the observatory near the intersection of Pilottown Road and Shipcarpenter's St. in current day Lewes, using modern mapping methods. Although this position was adequate for measurements of the transit of Venus, it is unlikely that this is the precise location of the observatory for several reasons to be discussed in Part II.

Observing the Transit

The transit observation itself, on June 3, went perfectly. The weather was crystal clear, without a cloud in the sky, and the transit team documented the required times.

The results of the observation reported by Biddle in apparent time were:

Owen Biddle's external contact:	2 hr 11 min 53 sec
Owen Biddle's internal contact:	2 hr 29 min 53 sec
Joel Bailey's external contact:	Lost by accident
Joel Bailey's internal contact:	2 hr 29 min 53 sec

This information, together with the precise location of the observatory, would contribute to a determination of the size of the solar system and provided the justification for the expedition.

Simon Newcomb¹⁹ was rather complementary about the Lewes observations. Biddle had taught two boys to chant the seconds so the person logging the events would hear the notice of the event and the spoken second at the same time. By contrast, Rittenhouse had not made adequate provisions for exact time recording for all three observers and Newcomb did not use his observations as the times were suspect²⁰, but he did use the other two.

The solar parallax derived from the 1769 transit was 8".72, which was an improvement over the prior value, but was still not conclusive. Observational times were submitted by 171 professional and amateur astronomers. The published values of the solar parallax were derived from combining many reports and no single site dominated the analysis. It is not known what, if any, use was made of Biddle's transit observations when the Astronomer Royal calculated the solar parallax. Later astronomers considered only observations that met some technical criteria relating to how the observations defined the instant of ingress and egress, and the specific observations were not always listed. Encke combined many observations in 1824, probably including the Lewes results, to arrive at a value of $8''.571 \pm 0.037''$ for the solar parallax, which resulted in a value of 95,370,000 miles for the AU, a value that was used for many years. The uncertainty in this parallax value amounted to about half a million miles in the AU.

Great effort to refine the values was mounted for the 1874 and 1882 transits, including the use of photography, but the results were still not satisfactory and measuring the solar parallax in this way was abandoned. It proved too difficult to get sufficiently precise ingress and egress times for Venus on the Sun's disk. The modern value for the Constant of Parallax is 8''.794143, which gives a value of 92,955,807 miles (149,597,871 km) for the mean Astronomical Unit.

There were, however, many side benefits of the transit expeditions around the world and the exact coordinates of many remote locations were measured, along with detailed observations of eclipses, transits of Mercury and measurement of magnetic declination and gravity. In the case of Lewes, the survey also established the coordinates of the Cape Henlopen lighthouse. The modern

¹⁹ Newcomb [1890] pg. 387.

²⁰ Rittenhouse fainted, probably due to hyper ventilating, at the instant the transit started.

value for the AU was found by radar ranging of Venus and Mercury and by telemetry measurements from interplanetary spacecraft.

Epilogue

Owen Biddle was prominent in the American Philosophical Society. He was elected curator (1770), secretary (1773) and councilor (1782), and delivered the annual oration in 1781²¹. He was a Quaker, but was active in a non-combatant role in the Revolutionary War, serving primarily as Deputy Commissioner of Forage²², under his brother, Clement. In this role, he was responsible for finding, buying and distributing food, animal feed and raw materials, a thankless and frustrating job considering colonial finances. After the war, he was disowned by the Quakers, along with about a hundred others, for his participation in the war. He was instrumental in the formation of a new “Free Quaker” community. The war and its aftermath were not kind to Biddle. Three ships in which he had invested were captured during the war and he was forced to dissolve most of his property to avoid bankruptcy. He was not active in the American Philosophical Society after 1782. He worked as an apothecary merchant in Philadelphia²³. His later years were spent in the Community of Friends, where he was active in establishing a boarding school in Chester County. He had seven children.

Joel Bailey continued work as a surveyor. His role in the transit apparently impressed the membership and he was elected to the American Philosophical Society in 1770.

Although the objective of the expedition was to collect the required data for the Venus transit, the long term impact was much greater. The observers established the geographical coordinates of several important places with good accuracy. The study and discipline required to equip and use the transit observatories and to collect and process the transit data was the first venture of the colonies into world-class astronomy and their experiences were invaluable in building a foundation for American science.

²¹ Biddle [1892], *passim*.

²² Thomas Paine, author of *Common Sense*, was his clerk.

²³ Bell [1997], pg. 300.

Part II

The 1769 Transit of Venus Observatory Site in Lewes, DE

Background

Biddle, Bailey and Thomas were faced with a daunting challenge. They were responsible for determining the geographical coordinates of a place based on its distance from a point 20 miles away. It is useful to review the extent of surveyed locations in Pennsylvania at the time of the transit to appreciate the problems they faced.

In 1769, the geographic coordinates of most places in America were poorly defined. Relative locations were established by ground surveys, while azimuths and latitudes could be established accurately by astronomical measurement. The latitudes of many locations were known from relatively simple astronomical observations. It was not as easy to determine latitudes of a place accurately based on its north or south distance from another point of known latitude. It was accepted that the shape of the Earth is a spheroid (i.e. the Earth is flattened at the poles) by the middle of the eighteenth century. As a consequence the length of a degree of latitude changes with latitude. The extent of the flattening could only be determined by measuring the length of a degree of latitude at the equator, in the Polar Regions and at intermediate latitudes, undertakings that continue to modern time. Few measurements of this parameter had been made before 1769, which made it difficult for Biddle and Bailey to provide the latitude of their observatory with confidence.

The difficulty of measuring longitude before the introduction of the marine chronometer made independent measurements of longitude difficult and of uncertain accuracy. There were only two points in the Middle Atlantic colonies with measured longitudes at the time of the Venus transit; David Rittenhouse's farm in Norriton, PA and the so-called "Stargazer's Stone" marking Mason and Dixon's observatory on John Harland's farm near the Forks of the Brandywine, which was the base point for their surveys. The origin of the "West Line", commonly called the "Mason-Dixon Line" was at a post marked "West" due south of the Stargazer's Stone and, thus, inherited its longitude.

The longitude of the observatory at Philadelphia's Statehouse was determined a month after the transit by a careful survey from David Rittenhouse's farm.

Joel Bailey's survey from Lewes was designed to collect the data necessary to allow accurate determination of the site's coordinates once the required parameters and distances were confirmed.

Our objective is to determine the actual location of the temporary observatory from primary sources.

The Survey

Bailey and Thomas assembled a survey crew and ran an open traverse from the observing site to the Transpeninsular Line from May 28 to June 1, 1769. Their instrument was a theodolite equipped with a telescope and magnetic compass. Their measuring tool was a 66 foot surveyor's chain. Distances were recorded in *perches* of 16.5 feet or a quarter of a chain. It should be noted that it was rainy and windy the entire time they were in the field. As part of their commitment to provide a complete historical record, they published their field data to document the survey (Appendix).

The expedition and results were communicated in two papers. The first was published in England in the Philosophic Transactions of the Royal Society in 1770 [TRS]. This paper, which is more of a report, was requested from Biddle by Dr. William Smith, who sent it to Benjamin Franklin, who encouraged its inclusion in the Royal Society transactions. The second and more complete publication was in Volume I of the Transactions of the American Philosophical Society in 1771 [TAPS], and includes additional details on how the coordinates of the observing site were determined.

Biddle and Bailey's Initial Results

The first results of the survey were presented to the Royal Society by Benjamin Franklin in December, 1769. The surveyors explained that they did not know the latitude and longitude of the Middle Point as measured by Mason and Dixon, nor the exact measure of a degree of latitude, so they expressed the position of the observatory only in distances relative to the Middle Point. The position was given as 21.93 miles north and 30.6356 miles east of the Middle Point.

The Astronomer Royal had access to Mason and Dixon's results and this enabled him to calculate the latitude of the observatory and its difference in longitude from the southernmost part of Philadelphia. Unfortunately, he made an error in his calculations by equating 21.93 miles to 19' 53" rather than the true value of 19' 06" when converted using 68.896 miles per degree, and his calculated latitude was in error by nearly a mile, which placed the observatory in Delaware Bay.

Biddle and Bailey's Complete Results

In December, 1769, the Astronomer Royal wrote to Benjamin Franklin and asked him to inform Owen Biddle that the latitude of the Mid-Point according to Mason and Dixon was 38° 27' 34" N and that the length of a degree of latitude measured by them was 68.896 statute miles. This factor was applied to the field data to determine the site's latitude. Once the Courthouse survey was completed in May, 1770, Biddle was able to derive the site's longitude and they were in a position to present their completed results to the American Philosophical Society, which he did in July, 1770.

Based on the reduction of the survey data and the information supplied by the Astronomer Royal, Biddle determined the geographical coordinates of the Lewes observatory to be 38° 46' 38".3 N

and $75^{\circ} 08' 30''$ W. This completed Biddle and Bailey's contribution to the determination of the astronomical unit.

These coordinates, without any adjustment to allow for the use of a modern geodetic datum, place the observatory at the tennis courts near the intersection of Pilottown Road and Shipcarpenter St. in current day Lewes.

The results represent a significant accomplishment by Joel Bailey, considering the instruments available, the scope of the survey, the short time allowed and the weather. They are, however, not accurate enough to provide the precise location of the observatory. The remainder of this discussion is concerned with determining how the surveyors came to their conclusion and estimating the probable true location of their observatory.

Hints

The surviving source material provides some qualitative guidance for the site's location.

Biddle noted that the site was on South Street (now Savannah Road) [TRS pg. 414] and was about $\frac{1}{4}$ mile southwest of Lewes [TAPS pg. 84], which we take to be the corner of Savannah Road and 4th Street²⁴. Bailey's coordinates do not match either of these criteria.

Biddle states [TAPS pg. 84] that the traverse followed existing roads when possible. The observatory site can be deduced if the route defined by the data can be matched to actual roads.

The data itself suggests another hint. There is a striking visual clue when the route defined from the raw data is plotted on a Google Earth map (Figure 8). The first leg of the route is exactly parallel to Savannah Road (South Street), but displaced to the north and west, indicating the starting point of the displayed route should be shifted to match the roads.

Another cross-check is provided by the survey Bailey made of the coordinates of the Cape Henlopen lighthouse after the transit. He wrote that the observatory site was 182.83 perches (29.8") south of the lighthouse and 944 perches (3' 16.8") west [TAPS pg. 88]. The observatory site can be found with simple arithmetic if the geographical coordinates of the actual lighthouse are known. The approximate lighthouse coordinates imply the observing site was east of South Street, but not southwest of the town of Lewes. This element is discussed in detail later.

²⁴ The boundary of Lewes was defined as 4th St. when Lewes was subdivided when the town was chartered.

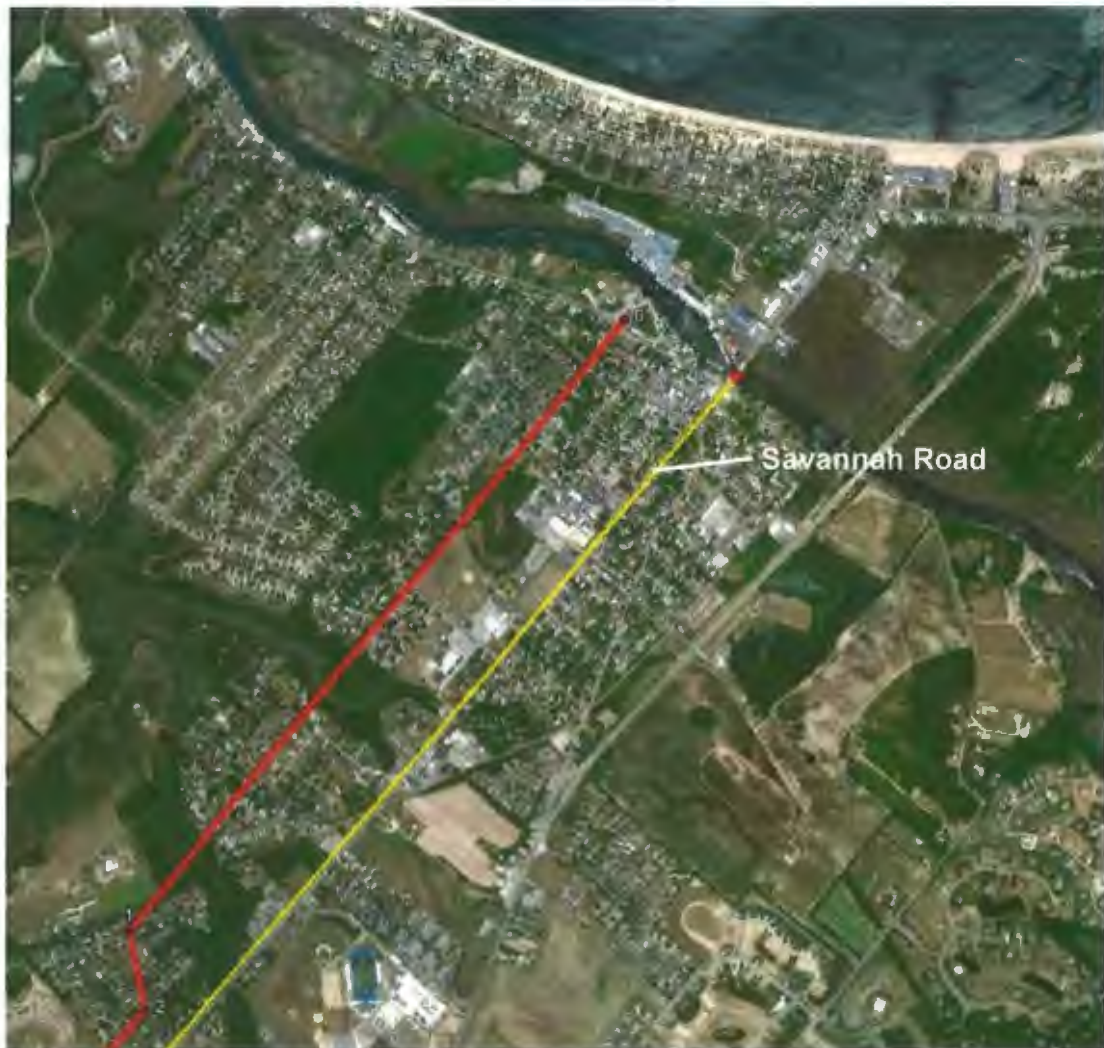


Figure 8. Start of Traverse from Bailey's Data

Reducing Joel Bailey's Log

On the surface, reducing Bailey's field data to latitudes and longitudes is simple. Each point in the traverse is described by the distance and bearing used to reach that point. For example, point 7 is:

S 35 30 W 52

This entry means the point was $35^{\circ} 30'$ west of south for a distance of 52 perches from the previous point. This data is reduced to the equivalent E-W distance and N-S distance with simple trigonometry. The distances are then converted to the change in latitude and longitude for the distances.

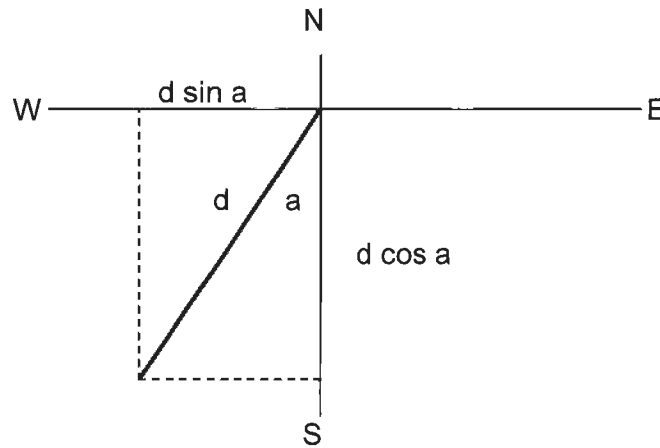


Figure 9. Point Reduction

East and North are taken as positive. For this example, $a = 35.5^\circ$ and $d = 52$ perches (858 feet). The bearing is magnetic and must be corrected for compass declination. If the compass declination is $3^\circ 15'$ west, we subtract 3.25° from the bearing to get 32.25° as the true bearing. The bearing is converted to the azimuth angle for calculations, 212.25° in this example.

The E-W distance is $858 \sin 212.25 = -457.84$ feet (west) and the N-S distance is -725.63 feet (south).

The change in latitude for this point is calculated using a parameter relating distance to latitude. For example, if the value chosen for the distance of one degree is 68.896 miles/degree of latitude (Maskelyne's value), the N-S distance represents $-457.84 \text{ feet} / 5280 \text{ feet/mile} / 68.896 \text{ miles/deg} = 0.0013^\circ$ ($4''.68$). In practice, the calculation can be simplified by combining the constants into a single parameter that is multiplied (added when using logarithms).

Relating the E-W distance to longitude is similar, but with some added complications. The distance of a degree of longitude depends on the latitude. That is, longitudinal meridians get closer together as you move north from the equator. To be perfectly precise, the change in longitude factor must be calculated for all latitudes considered. In fact, Bailey would not have taken this extra step as the change over such a short distance is small for a spherical Earth in the middle latitudes. This factor must be applied if working in WGS coordinates. For this application, the range of WGS values is from 4773 feet/minute of longitude at the Transpeninsular Line, to 4753 at Lewes, a difference of about 0.4%. Bailey does not mention the factors he used to reduce his data, and the values must be inferred from his published results.

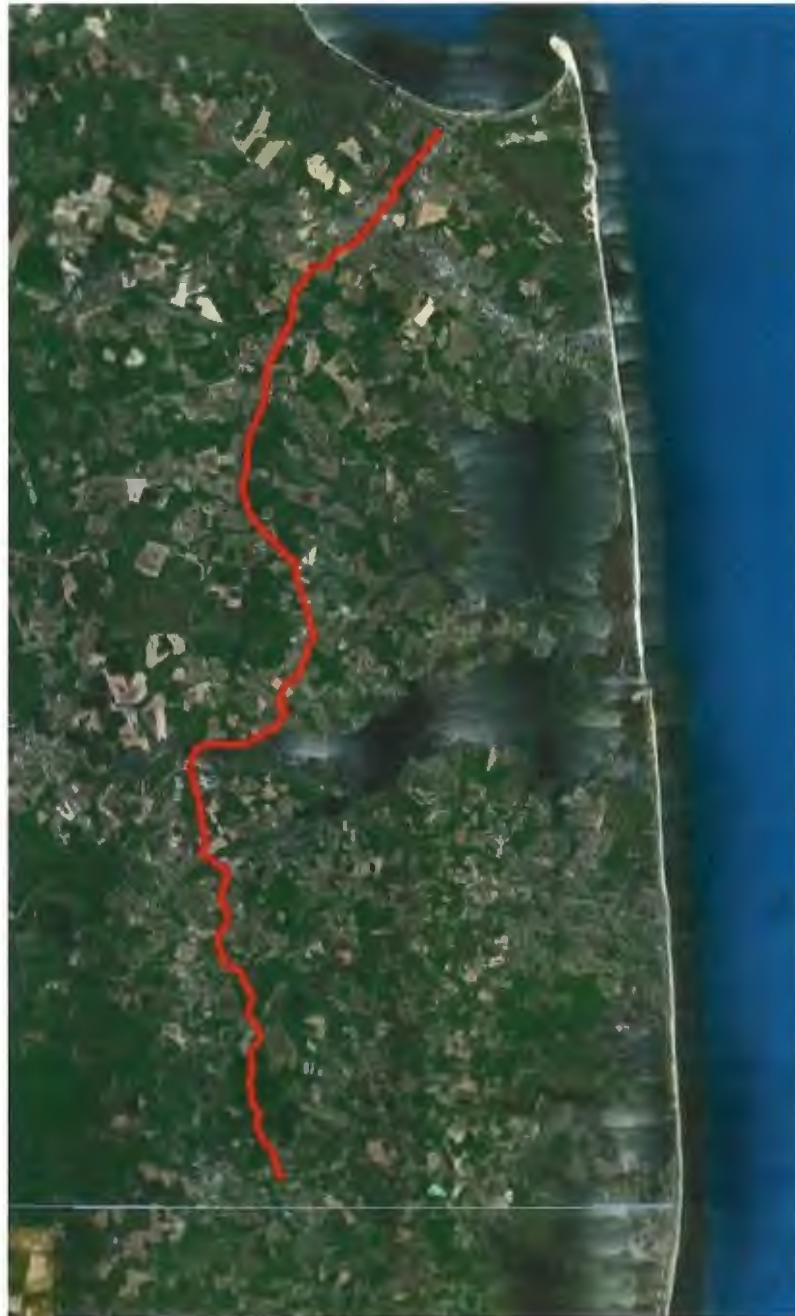


Figure 10. Bailey's Route

Figure 10 shows Bailey's route derived from the raw traverse data. It is not perfectly valid to plot Bailey's route on Google Earth as published because there are differences in the mapped coordinates of the route points between the spherical model used by Bailey and the ellipsoidal model used by Google Earth. That said, there is still value in seeing the shape of the route and deductions can be made that lead to better understanding of the actual route taken. For example, it is very clear from the path taken at the end of the traverse that Bailey intersected the Transpeninsular Line near milepost 9.

A Numerical Analysis of the Results

The first declaration of the survey results in TRS gave the position of the observatory as 21.93 miles north and 30.6356 miles east of the Middle Point. This is equivalent to 7017.6 perches north and 9803.4 perches east. The second declaration in TAPS was 7007.5 perches north and 9286.3 perches east. The TAPS paper gives greater detail of the survey and was generated more than six months later, providing more time for review and checking. The TAPS values are considered more reliable and will be used as Biddle and Bailey's values throughout the rest of this analysis. They adopted Mason's value for the length of the Transpeninsular Line of 35 mi less 100 yards.

Bailey and Thomas ran their open traverse from the Lewes site until it intersected the Transpeninsular Line at or near milepost 9. The bearings and distances to that point were used to calculate the site's latitude, and provided the basis for determining the site's longitude. His published results from TAPS pg. 86 are summarized in Figure 11.

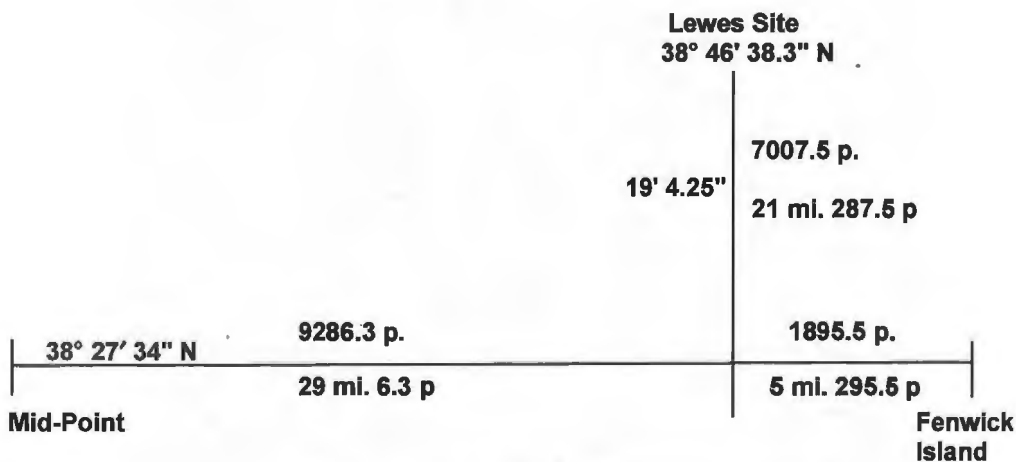


Figure 11. Published Traverse Results

Bailey's coordinates for the observatory may be plotted using Google Earth and the WGS84 datum with sufficient accuracy for our purpose.

The observatory was located at the junction of Pilottown Road and Shipcarpenter Street in modern Lewes using Biddle and Bailey's coordinates (Figure 18, location 1).

This position is clearly in conflict with the narrative description since Biddle noted that the site was on South Street (now Savannah Road) [TRS pg. 414] and was about ¼ mile southwest of Lewes [TAPS pg. 84], which we take to be the corner of Savannah Road and 4th Street. Bailey's coordinates do not match either of these criteria.

Site Latitude

The site's latitude is easy to calculate from their data. The total distance south of the Lewes site to the Transpeninsular Line is simply the total N-S distance from the point reductions; 7007.5 perches according to Bailey. Converting this distance to degrees of latitude, Bailey calculated the latitude difference to be 19' 4.25". Adding this factor to the presumed latitude of the Transpeninsular Line gives the latitude of the site published by Bailey: 38° 46' 38.3" N.

There are two problems with Bailey's latitude for the site, neither of which reflects poorly on his efforts.

When Bailey's traverse ended he was not at the latitude he assumed. Mason and Dixon's latitude of the Mid-Point was 36° 27' 34" N, and Bailey's assumed latitude for the entire line. Note the route shown in Figure 10 ends at this latitude, short of the Transpeninsular Line. However, the Transpeninsular Line is not a true parallel of latitude and the latitude of both milepost 9 and marker 10 is actually 38° 27' 04".4 N which is 29".6 (2995 ft.) less than the latitude assumed for the Mid-Point and the entire line. The difference in the reference latitude changes the site latitude to 38° 46' 8".3 N. This adjustment places the observatory position much closer to South St., as described by Biddle.

Site Longitude

The longitude of the observatory is much more difficult to determine than its latitude.

When Bailey's traverse intersected the Transpeninsular Line, he needed additional information to find his distance from the start of the line. Figure 12, shows the information they had and the conclusions drawn from it.

His intersection point was within one or two perches of the current milepost 9. It is not known what sort of marker, if any, was in place at that time²⁵ and its distance from Fenwick Island was apparently questionable. Bailey measured the distance from the intersection to marker 10, which he trusted. He found the distance to be 236 perches. He assumed milepost 10 was exactly 10 mi. from the Fenwick Island stone. 10 miles = 3200 perches.

$3200 - 234 = 2966$ perches to Fenwick Island = 9 miles 86 perches.

They do not state the exact steps executed to find the distance of the observatory meridian from the Fenwick Island monument, but we can infer the missing value from the final result.

They state the observatory is 1895.5 perches west of the Fenwick Island stone. Referring to Figure 12, the distance from the intersection at milepost 9 to Fenwick Island is 9 miles 86 perches (2966 perches). Therefore, the distance from the intersection at milepost 9 to the observatory meridian is $2966 - 1895.5 = 1070.5$ perches.

²⁵ The current MP 9 marker was set in 1974, and is actually below ground, which makes it hard to find.

The 1070.5 perches is actually the verifiable distance. The sum of the East/West distances was 1070.5 perches when the traverse reached the intersection. The value of 1895.5 perches from Fenwick Island is simply the total distance from the intersection point, less the total E-W distance from the reduction.

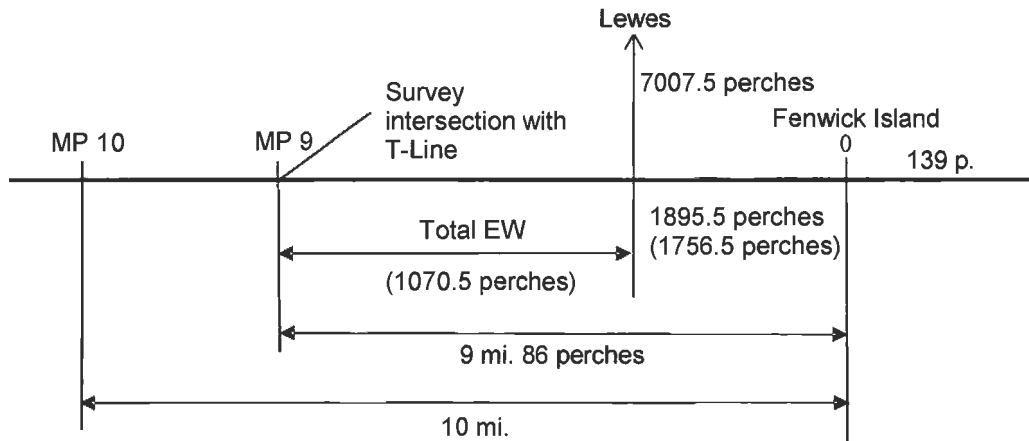


Figure 12. Bailey's Route Reduction (not to scale)

Unfortunately, Bailey was the victim of incomplete knowledge of the Transpeninsular Line. He assumed the line started at the Fenwick Island stone. In fact, the line begins 139 perches east of the Fenwick Island marker, just offshore in the Atlantic Ocean. They assumed the distances for markers 9 and 10 were from the Fenwick Island stone. The correct distance of the intersection point to the stone at Fenwick Island is $1895.5 - 139 = 1756.5$ perches. This refinement does not affect the results, as the distance from the Mid-Point marker is the critical measurement.

At this point, Bailey and Biddle were stuck. All they could calculate was the distance of the site meridian from the Fenwick Island and Mid-Point markers because the longitude of neither was known. Biddle seemed to think Mason and Dixon knew the longitudes of these and other points, but did not leave the values when they left after completing their colonial work. Mason and Dixon did take measurements at the Mid-Point during the length of a degree of latitude survey to confirm the latitude and logged lunar distances to be reduced in London to determine the longitude, but they did not determine the Mid-Point longitude before they left.

Biddle and Bailey had two options for finding the longitude of the observatory site; astronomical measurements or a careful survey from a point of known longitude. Astronomical measurements would have been very difficult and time consuming, so they had to do another survey.

There were few places with a well-defined longitude in all of America at the time of the 1769 transit. David Rittenhouse's farm in Norriton, Pennsylvania was one. Rittenhouse had timed eclipses of Jupiter's "first moon" (Io) over several months in the spring of 1769. He then had to wait until he had the records of eclipse timings from Greenwich to confirm the timings, which he

did not get until after the transit. The longitude he came up with was based on an observation made on April 12, 1769, by Rittenhouse in Norriton and John Bird at Greenwich. The circumstances of this eclipse were nearly ideal. At Norriton, Jupiter was at about 10° altitude and 122° azimuth and at Greenwich, Jupiter was at 31° altitude and 197° azimuth. The eclipse of Io was observed at 11h 14m 37s local sidereal time (9:54 PM mean time) by Rittenhouse and 16h 16m 8s Greenwich sidereal time (2:53 AM). The sidereal time difference of 5h 1m 31s gives the Norriton longitude of $75^\circ 22' 45''$ W.

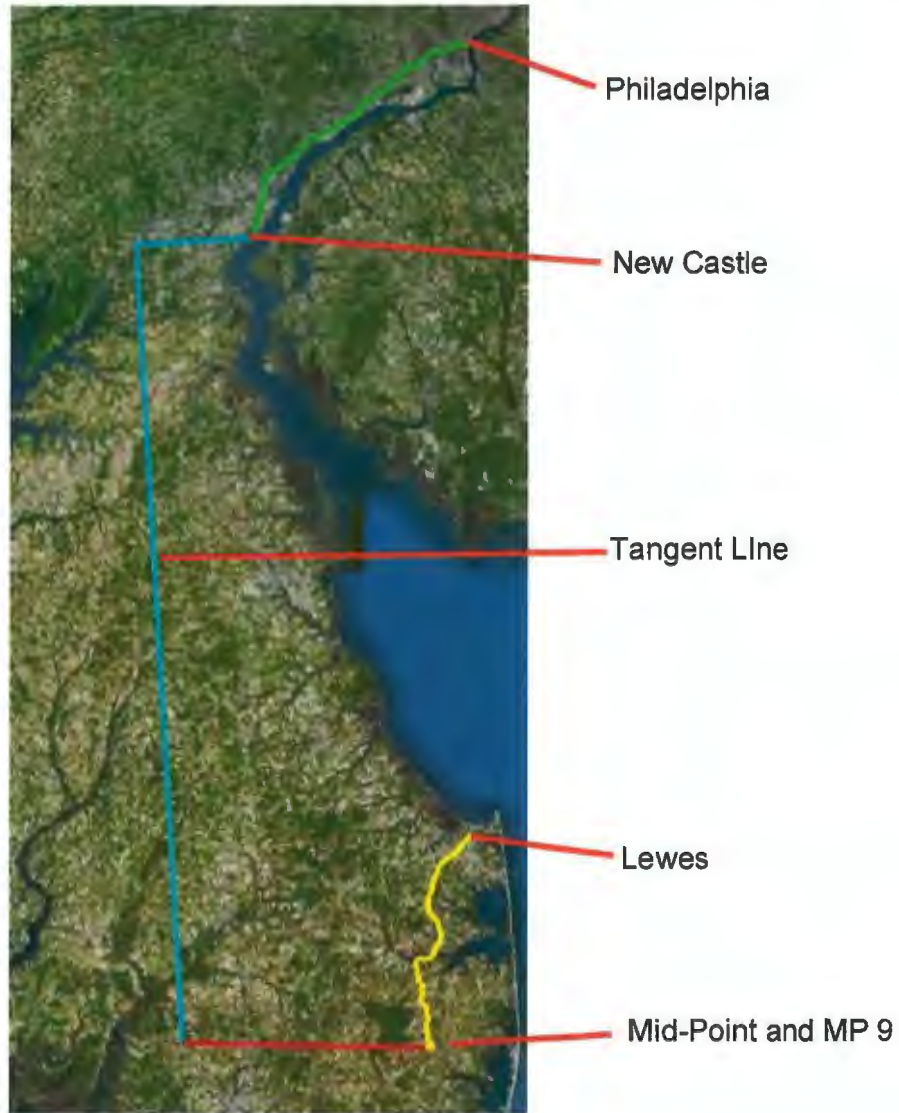


Figure 13. Connected Traverses

There were a number of men who appreciated the problem and could participate in finding a solution. Among them were John Lukens, Surveyor General of Pennsylvania, who had been a transit observer at Norriton, Rittenhouse, Biddle, Bailey and others. These men were all familiar with exactly what Mason and Dixon had done and surely had access to the report left with the

provincial commissioners when they completed their work. Mason and Dixon surveyed the Tangent Line from the Mid-point to the 12 mile circle originating at the New Castle Courthouse that defines the northern border of Delaware and connected the Tangent Point to New Castle Courthouse. Thus, the difference in longitude of New Castle Courthouse from the Middle-Point was known, or could be calculated from available records.

All that was needed to complete the connections between the key locations was a survey from New Castle Courthouse to the Philadelphia Statehouse observatory²⁶ to establish the geographic coordinates of the New Castle Courthouse. The longitude of the Mid-Point would then be connected to Philadelphia and the longitude of the observatory in Lewes could be connected to the longitude of the Mid-Point. Such a survey was sponsored by The American Philosophical Society and carried out by Own Biddle and Joel Bailey in May, 1770, nearly a year after the transit. Mapping the route from published logs indicates this survey was performed very carefully and it can be easily followed on modern roads and bridges. The linkages between the reference points and Lewes are summarized in Figure 14.

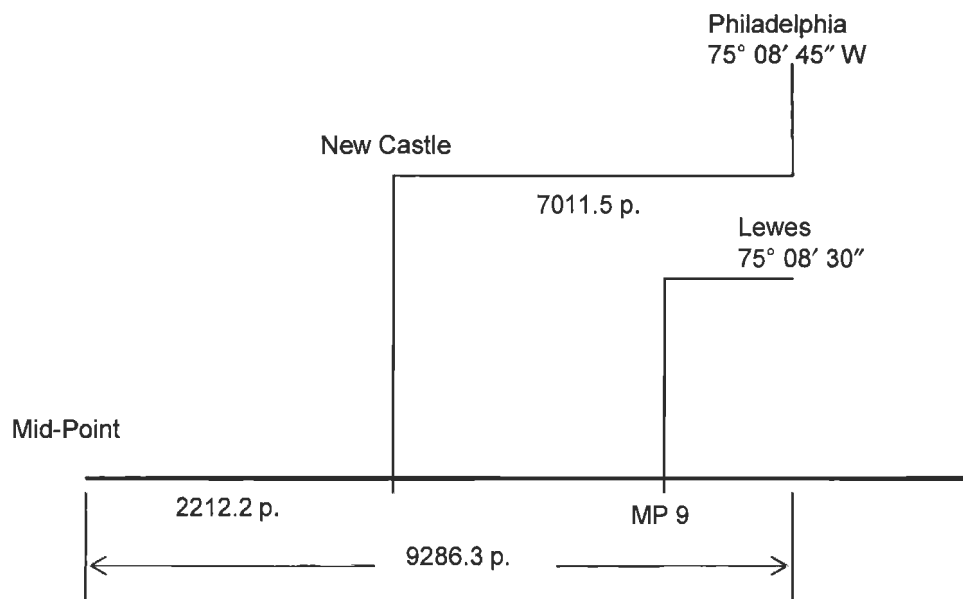


Figure 14. Longitude Difference

The assumed position for the State House observatory in Philadelphia was $75^{\circ} 08' 45''$ W, which was established from a carefully executed survey in early July, 1769, from Rittenhouse's observatory to State House Square. There are no extant remains of the State House observatory and its exact location is still not precisely known. Contemporary descriptions of the observatory's location place it within a second or two of $75^{\circ} 09' 00''$ W in WGS84 coordinates. If Biddle and Bailey had based their calculations on this value, they would have located the Lewes observatory 15" further west at a position $75^{\circ} 08' 45''$ W (Figure 18, location 2A), which is pleasingly close to Savannah Road.

²⁶ The first public reading of the Declaration of Independence on July 8, 1776, was made from the observatory platform.

It is easy to see from Figure 14, that the Philadelphia Observatory was measured as $2212.2 + 7011.5 = 9223.7$ perches east of the Mid-Point. The original survey had established the Lewes site's meridian was 9286.3 perches east of the Mid-Point. Thus, the Lewes site is 62.6 perches east of the Philadelphia observatory. They converted 62.6 perches to longitude expressed as time and then to a longitude difference of 15", making the site longitude $75^{\circ} 8' 30''$ W. This value was confirmed by William Smith using Mason and Dixon's results for the Mid-Point. A similar computer analysis using WGS84 coordinates for the key points results in $75^{\circ} 8' 42''.7$ W as the Lewes site's longitude.

Potential Errors

Bailey was a skilled surveyor who was well practiced in the painstaking methods employed by Mason and Dixon, and he could be relied upon to work to the highest accuracy within the time, weather and instrument constraints to which he was subject. However, even he would not have claimed that his results were free of all errors and it is worth considering the origin of the most likely sources of such errors:

- The magnetic declination used by Bailey is suspect. It is very hard to read a small compass to the accuracy needed. The published "variation" in Lewes was $3^{\circ} 55'$ W. Bailey also did the survey from the New Castle Courthouse in Delaware to Independence Hall in Philadelphia, presumably with the same theodolite, and reports the magnetic declination as $3^{\circ} 15'$ W. This value actually fits the data better. Changing compass needles also affects accuracy.
- All bearings are reported to $5'$ of arc, indicating his theodolite had a vernier scale with $5'$ resolution. It is unlikely reliable readings were possible to this precision with his equipment and differences would accumulate over the entire survey.
- Almost all distances are recorded in full perches. It is, of course, possible that the surveyors tried to execute their instrument sets in full perches, but this would be very hard to do accurately without changing the observed bearings.
- Bailey's model of the earth was a spherical one in which the degree of latitude was 68.896 miles long rather than the more accurate ellipsoid in current use in which a degree of latitude in Delaware is 68.977 miles. The differences are not great, but they do affect the accuracy of the overall results.
- It is also possible, even likely, that some of the published field data has typographical errors or incorrect values were printed due to setting type from handwritten source material. Several lines in the data are obviously incorrect, such as transposing digits (45 instead of 54, for example), or incorrectly declaring a direction (W instead of E).
- We cannot rule out computational errors. Bailey probably reduced his data using tables of logarithms, probably to seven places. It is very easy to make mistakes when performing such tedious calculations.

- It must be noted that it was raining for most of the time during the survey. It is hard to keep an accurate field journal in good weather and it is plausible that some of the recorded values were smudged and rendered difficult to read. The poor weather could have been a factor in many aspects of performing the traverse.

It would be very informative if we could now follow in Bailey's footsteps by recreating his traverse on the ground, but unfortunately this is impractical. However, we have a very powerful alternative in our ability to plot his traverse in the WGS coordinate system, which is a good fit to the geoid in Delaware, and display the results using Google Earth. Following is a comparison of the conversion between linear and angular measures in the two systems in the neighborhood of Lewes:

	Bailey	WGS 84
Length of a degree of latitude in statute miles	68.896	68.977
Length of a minute of latitude in feet	6062.8	6070.0
Length of a minute of longitude in feet	4748.8	4751.9

The length of a degree of latitude used by Biddle and Bailey was supplied by the Astronomer Royal based on work by Mason and Dixon and stands comparison with the modern value. Although Biddle and Bailey worked generally in linear measures East/West. Their one reported conversion to longitude suggests the value of 4748.8 feet/minute of longitude, which surprisingly matches the modern value, but is far from the value of 4726.5 obtained using a factor of cosine latitude appropriate to a spherical earth.

If we take Bailey's data as listed in the Appendix and plot it in WGS coordinates we find that his starting point is located 1311 perches east and 6999 perches north of the 10 mile marker. Modern measurements place this marker at 38° 27' 04".4 N, 75° 13' 56" W. By reducing the route data in reverse order, we determine a starting point of 38° 46' 5.9" N and 75° 09' 23" W (Figure 18, location 3). The East/West distance between positions 2 and 3 is a measure of the error in longitude attributable to the collection of long traverses from the 10 mile marker to the Statehouse yard in Philadelphia.

The Lighthouse Traverse

One objective of the expedition was to establish the geographical position of the newly-built lighthouse at Cape Henlopen so that it might be notified to mariners. To this end, Bailey conducted a short traverse between the observatory site and the lighthouse. The details of this traverse were not published, but using this data Bailey was able to deduce that the lighthouse was situated at 182.83 perches north and 944 perches east of the observatory and that its geographical coordinates were, therefore, 38° 47' 8".1 N and 75° 05' 13".2 W. These coordinates, derived directly from the observatory coordinates, suffered from the same errors plus any errors due to the additional short traverse.

At the time of its construction, the lighthouse was about $\frac{1}{4}$ mile inland from the Atlantic, on a very large sand dune. Over time, littoral drift has shifted the coastal sand north and eventually undercut the lighthouse's foundation until it finally succumbed and collapsed on April 13, 1926. Since then, the beach has continued to recede and what is left of the foundation is underwater, about 300 yards offshore. No primary sources with recent and reliable coordinates of the lighthouse have been located.

The coordinates recorded by the U.S. Lighthouse Board in the late 19th century were $38^{\circ} 46' 42''$ N, $75^{\circ} 5' 3''$ W. There is no record of how these coordinates were determined, but a curator at the Coast Guard Museum observed that the usual technique in the 19th century used a sextant and clock, exactly as if on a ship.

A more precise estimate of the lighthouse coordinates by the Delaware Geological Survey from careful measurement of a U. S. Coast and Geodetic Survey topographic map of 1916, gives $38^{\circ} 46' 41.2''$ N, $75^{\circ} 5' 1''.05$ W, which is only about 125 feet from the Lighthouse Board value, and more than a half-mile south of Bailey's.

Biddle does not say a word about how the lighthouse traverse was done, but there is only one realistic traverse route. The area was then, as now, covered by a dense pine forest. A road was cut to provide access for building materials during construction and the road continued in use as long as the lighthouse was in operation. The traverse (red line on Figure 15) went north from the observation site, across Lewes Creek and then down the access road to the lighthouse. This road is clearly shown on the 1916 topographic map. The exact start of the lighthouse traverse depends on the observatory site, which is somewhat conjectural. The traverse route from the north end of Savannah Road is clearer.

The green line in Figure 15, shows the application of Bailey's distances from the observatory. The observatory location derived from Biddle and Bailey's distances does not meet the qualitative criteria. It is not southwest of the town and it is not on South Street. It is about $\frac{1}{4}$ mile from the intersection of South St. and 4th Street. Starting the measurements using Bailey and Biddle's distances at any reasonable location for the observatory places the lighthouse in the middle of the Great Dune, which is physically impossible.

If we apply the distances from Bailey's traverse to the accurate lighthouse position we can derive the position for the observatory at $38^{\circ} 46' 11.4''$ N and $75^{\circ} 08' 18''$ W (Figure 18, location 4).

The distances indicated by the route following the access road and starting at the proposed site are 175.62 perches north of the observatory and 1040.9 perches east. No plausible explanation for the difference has been found.

We must face the possibility that the lighthouse traverse distances do, in fact, lead to a place close to the location of the observatory, but this seems unlikely given the evidence supporting the proposed site. By implication, there would have to be a meaningful error in the published traverse distances. The statement that the lighthouse is 182.83 perches north of the observatory indicates confidence in the value as few of their measurements are stated with this level of precision. Conversely, 944 perches are exactly 236 chains which, on the surface, seem a bit coarse. The issue is not resolved.

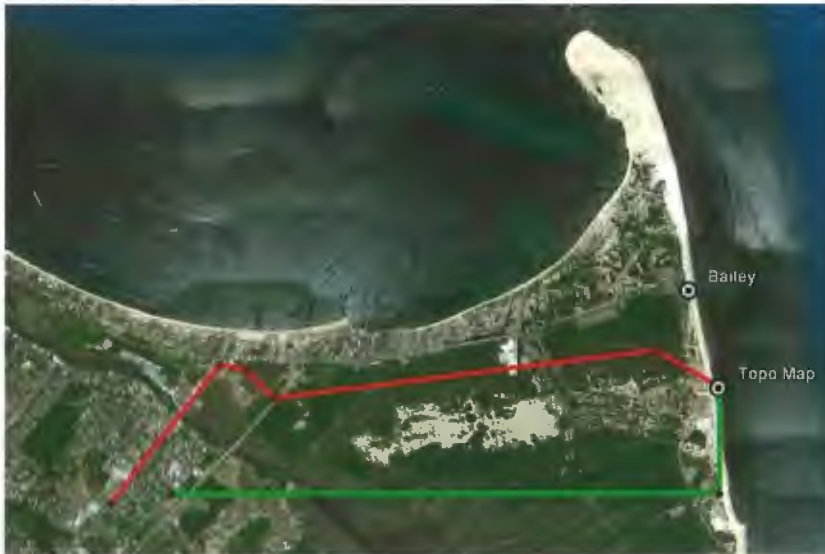


Figure 15. Lighthouse Traverse

A Graphical Analysis of the Results



Figure 16. Route Bias Adjustments

A segment of Bailey's traverse as described in TAPS is depicted in red in Figure 16. Its location is determined by its termination at the 10 mile marker on the Transpeninsular Line. Inevitably errors will accumulate throughout the traverse and the starting point will not indicate the true position of the observatory, but we are able to identify and adjust for some of the errors by comparing the shape of the traverse with the clearly corresponding shape of roads and traces of former roads.

We begin by trying to identify systematic errors in Bailey's measurements of distances and courses. There will be random errors in each of the legs, but these should average out over the many legs of the traverse and leave the bias errors to predominate.

The major part of the traverse follows a southerly course. Within this part, we can separate the effects of distance errors from bearing errors. There is a distinctive bend in the road at the top of the northerly section near the point labeled "10" in Figure 16.

We found through trial-and-error that, if all of Bailey's distance measurements are increased by 1.5% and each course is increased by $1^{\circ} 18'$ the resulting route, shown in the yellow line in Figure 16, matches the roads in this area very closely. This suggests that Bailey under measured distances for a number of possible reasons, including chain wear.

He was also measuring bearings which were too small despite having calibrated his compass against an astronomically determined meridian. We can cross check the compass error by comparing his course for the first leg which was $219^{\circ} 10'$ True, with the measurement from Google Earth of 220° True. This suggests an under measurement of $50'$ of arc so we can infer his compass was under reading by about 1° . Bailey did not mention if he changed needles or "stoned the post" during the traverse. An additional inconsistency would have been introduced if he did.

The adjustment for bias errors results in a route that follows the roads in the beginning of the traverse very closely. However, there are still places later in the route that diverge from the roads. Only one point was altered for this analysis. Point "3" in Bailey's route data is S 45 27 W. This entry is unusual because only one other course was shown at a precision other than 5' and the route has an obvious divergence from Shady Road. A better fit results from changing the line to S 51 30 W.

There are other points in the published route that probably have transcription or other errors. For example, if the bearing of point 26 is changed from E to W, the local fit of the route is much better. It would be possible to analyze the route point-by-point, but such detail is not relevant to answering the underlying question of the observatory location.



Figure 17. Map Overlay

The graphical analysis to this point has relied on the assumption that the current roads as shown by Google Earth are in approximately the same places now that they were in 1769. As a check, maps of Sussex County from Beer's Atlas of 1868, were overlaid on the modern map. These maps are the oldest available with sufficient detail to address the question. All of the roads in the path of the traverse match very well. Figure 17, shows the end of the route from Frankford to Selbyville with the route segment overlaid. Notice the divergence from the main road about $\frac{3}{4}$ of the way down. It appears they had to make a jog to cross a creek that no longer exists.

The Probable Position of the Observatory

In the final analysis, it is not possible to pinpoint the exact location of the observatory. We have identified and corrected errors in Bailey's traverse using graphic evidence, which would not have been critical for determining the length of the astronomical unit, but would have prevented us from establishing the location of the observatory.

We have identified five possible locations for the observatory as depicted in Figure 18. We shall now consider the merits and issues for each of these locations.



Figure 18. Possible Observatory Sites

Position 1:

Position 1, is the location of the observatory specified by Biddle and Bailey in their report to the American Philosophical Society. It was derived from the results of their own surveys and three others:

- The Transpeninsular Line (John Watson and William Parsons of Pennsylvania and John Emory and Thomas Jones of Maryland)
- The Tangent Line (Mason and Dixon)
- The radius from New Castle Courthouse to the Tangent Line (Mason and Dixon)

They based their calculations on the best available measurements of the latitude of the Transpeninsular line and the longitude of the State House observatory. Unfortunately, both of these parameters were in error, resulting in a displacement of the observatory by about 1000 yards even before any survey errors are taken into account.

Position 2:

Position 2, is based on position 1 corrected for the true latitude of the interception point of Baileys traverse with the Transpeninsular Line.

Position 2A:

Position 2A, is based on position 2, corrected for the true longitude of the State House observatory and represents the best result that Biddle and Bailey could have obtained if there had been better information available for the longitudes of the Mid-Point and New Castle Courthouse. This position appears credible because of its close proximity to Savannah Road, but its longitude is subject to considerable uncertainty since it depends on multiple long traverses.

Position 3:

Position 3, is the result of recreating Bailey's traverse in WGS84 coordinates with a termination point at the 10 mile marker on the Transpeninsular Line. If the details of the traverse recorded in TAPS were exactly correct, then this would be the location of the Lewes transit observatory. However, the fact that it lies nearly 800 yards from the nearest point on Savannah Road leads us to suspect that there are inaccuracies in the recorded traverse.

Position 4:

Position 4, is derived from the short traverse carried out by Bailey to determine the coordinates of the lighthouse from their calculated coordinates of the observatory. We have reversed the traverse to obtain the position of the observatory from our knowledge of the position of the lighthouse. This position should be accurate, but it lies 400 yards from Savannah Road and is not southwest of the town, which is in conflict with both Biddle's description and with the clear graphical evidence from the survey data that the first leg proceeded down Savannah Road.

Position 5:

Position 5, is based on Bailey's traverse data recreated in WGS84 coordinates and corrected by comparison with the road patterns visible on Google Earth. These corrections comprise small adjustments to the whole traverse to eliminate apparent biases in course and distance and one adjustment of 6° to one leg to match an obvious line feature. The adjusted route provides a significantly better match to the road patterns and suggests a very credible route for the traverse.

However, we do not need to match the whole traverse to locate the observatory. We need only establish the position of the first leg to identify the starting point, and this is made easier because we know that the first course was straight down Savannah Road. The adjusted traverse provides an excellent match to the first nine miles and, thereby, allows us to identify Bailey's starting point with confidence. Apart from Position 1 with its known errors, there is very little spread in latitude among the remaining positions and the latitude derived from the lighthouse traverse is only 1" or 100 feet different from Position 5.

We, therefore conclude the most probable location for the Lewes Transit Observatory of 1769, is near $38^{\circ} 46' 12''.3$ North and $75^{\circ} 08' 38''.1$ West. The site was within the boundaries of what is now Bethel Methodist Cemetery, which is on land originally intended for use as a Quaker cemetery, but was apparently never used for that purpose. It is about 0.2 miles southwest of 4th Street and is on South Street (Savannah Road), thus meeting all of the qualitative criteria mentioned by Bidle.



Figure 19. Observatory Site

The most probable site location is shown in Figure 19. The circle is about 1 arc-second in radius ($\cong 100$ feet), for scale. We are confident the Lewes Venus Transit Expedition observatory was within the circle. The complete traverse as reconstructed is shown in Figure 20.

The complete story of the 1769, Venus transit expedition to Lewes, DE has many technical elements and presents an interesting opportunity to explore the methods, equipment and results employed in colonial surveying. It is, however, more a human story of dedication and intelligence applied to resolving one of the great issues of science. We come from the study of this historical footnote with respect and admiration for the men who lived it.



Figure 20. Complete Traverse

Part III - Supplementary Material

WGS84 Reduction

Thurston reduced the survey data in WGS84 coordinates. His method calculates the change in latitude for each instrument set, from which is derived the latitude and the distance per degree of longitude.

Thurston's method is:

1. Calculate the azimuth angle of each course from the raw data and apply the compass declination.
2. Considering the route to be calculated as a map, calculate the change in x and y coordinates from:

$$\Delta x = D \sin Az, \quad \Delta y = D \cos Az$$

where D is the distance in feet of the stage. x is positive to the east and y is positive to the north.

3. Calculate the change in latitude of the current point from the previous point from:

$$\varphi_i = \varphi_{i-1} + \Delta y / M$$

where M = meridional distance of one degree of latitude. M was taken as 6,070 feet/minute of latitude for all points as the change in this factor over the scope of the survey was less than 1 foot.

4. Calculate the radius of the latitude small circle on the spheroid from:

$$r = \frac{a \cos \varphi}{\sqrt{1 - e^2 \sin^2 \varphi}}$$

The latitude used in this calculation is the mean of the latitude of this point and the latitude of the previous point.

5. Calculate the current longitude from the circumference of the latitude circle:

$$\lambda_i = \lambda_{i-1} + \Delta x / N$$

where N is the distance for a degree of longitude at the current latitude = $2\pi r / 360$.

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Newbury, MA (Williams)
Cambridge, MA (Prof. John Winthrop)
Providence, RI (Benjamin West)
Baskenridge (sic), NJ (William Alexander, Earl of Stirling) – from a 1770 letter to Smith of College of Philadelphia.
Lewes, DE (Biddle and Bailey)
Philadelphia, PA (Shippen and Williamson)
Norristown (sic), PA (Rittenhouse, Lukens, Smith)
Wilmington, DE (William Poole)

Fort Prince of Wales, Hudson Bay (William Wales, Joseph Dymond)
San Jose, Baja California (L'Abbe Chappe D'Auteroche)

Acknowledgments

The authors wish to thank:

Mike DiPaolo, Executive Director of the Lewes Historical Society
George Kent, of the Delaware Department of Transportation, Mapping Division
William ("Sandy") Schenck of the Delaware Geologic Survey

This project could not have been accomplished without their generosity.

Appendix: Joel Bailey's Reported Survey Data

Following are the field data reported by Joel Bailey in the Transactions of the American Philosophical Society, Vol. I, 1771 (Corrected and reprinted 1784). Each entry has a direction and a distance. Directions are shown as degrees and minutes East or West from North or South as read from the compass on his theodolite. These magnetic bearings were corrected for compass "variation" (declination) when the data were reduced. Distances are in perches, 16.5 feet. Bailey reported directions to the nearest five minutes, probably because his instrument had a vernier with this level of precision. All distances except one are in full perches. The original data did not include the index of the line.

1	S	43	5	W	495	53	S	65	0	W	131
2	S	7	30	E	51	54	S	64	0	W	78
3	S	45	27	W	446	55	S	79	0	W	76
4	S	74	0	W	70	56	N	80	0	W	52
5	S	68	15	W	44	57	S	85	30	W	42
6	S	45	0	W	31	58	N	76	0	W	63
7	S	35	30	W	52	59	S	86	0	W	70
8	S	28	0	W	32	60	S	65	0	W	66
9	S	82	15	W	56	61	S	24	0	W	50
10	N	76	0	W	38	62	S	18	45	W	73
11	S	42	5	W	102	63	S	12	0	E	24
12	S	27	0	W	57	64	S	6	0	E	48
13	S	64	0	W	33	65	S	11	0	E	174
14	S	44	0	W	46	66	S	6	0	E	73
15	S	2	0	W	45	67	S	10	0	W	38
16	S	10	0	W	138	68	S	11	0	E	112
17	S	30	30	W	216	69	S	6	0	E	35
18	S	28	40	W	76	70	S	19	0	W	16
19	S	25	0	W	104	71	S	13	0	W	22
20	S	0	0	W	55	72	S	29	0	W	46
21	S	8	0	W	96	73	S	50	0	E	145
22	S	19	5	W	56	74	S	61	0	E	48
23	S	26	0	W	80	75	S	10	0	E	36
24	S	27	30	W	159	76	S	21	30	W	110
25	S	8	0	W	270	77	S	10	0	W	56
26	S	29	0	W	58	78	S	8	30	E	55
27	S	11	20	E	164	79	S	27	30	E	34
28	S	25	0	E	44	80	S	12	0	E	38
29	S	28	30	E	58	81	S	10	0	W	30
30	S	40	30	E	200	82	S	28	0	W	30
31	S	30	5	E	45	83	S	38	0	W	75
32	S	40	5	E	76	84	S	10	0	W	56
33	S	58	0	E	44	85	S	14	0	E	111
34	S	10	0	W	58	86	S	23	0	E	54
35	S	18	0	E	42	87	S	75	0	E	25
36	S	12	0	E	84	88	S	64	0	E	65
37	S	14	0	E	178	89	S	29	0	E	22
38	S	10	0	E	44	90	S	13	10	E	81
39	S	5	30	E	56	91	S	39	0	E	61
40	S	21	0	E	60	92	S	9	0	W	24
41	S	41	0	W	62	93	S	6	0	E	36
42	S	21	0	W	40	94	S	25	0	W	84
43	S	5	0	W	18	95	S	21	30	E	40
44	S	27	15	W	171	96	S	40	0	E	57
45	S	43	0	W	23	97	S	18	0	E	26
46	S	64	0	W	58	98	S	12	0	E	78
47	S	50	0	W	26	99	S	40	0	W	96
48	S	20	40	W	78	100	S	10	50	W	86
49	S	30	0	W	41	101	S	13	0	E	56
50	S	39	0	E	74	102	S	28	0	W	70
51	S	44	0	W	52	103	S	16	10	E	48
52	S	21	30	W	69.67	104	S	6	0	E	26

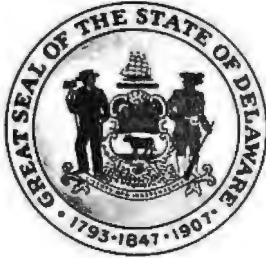
105	S	8	0	W	59	114	S	42	0	E	49
106	S	22	0	E	46	115	S	40	0	E	44
107	S	2	0	W	20	116	S	14	0	E	110
108	S	42	0	E	42	117	S	0	0	W	31
109	S	22	0	E	30	118	S	40	0	E	26
110	S	48	0	W	46	119	S	14	0	E	22
111	S	14	0	E	21	120	S	22	0	W	2
112	S	18	0	E	48						
113	S	12	30	E	52						

The Authors

James E. Morrison is retired from a 40 year career in computers, including 30 years with IBM. He is the author of “The Astrolabe”, a complete treatise on the history, design and uses of all types of astrolabes and related instruments. His sole qualifications for embarking on this project are two summers working as a surveyor, some background in positional astronomy and being a resident of the area under discussion.

Geoffrey Thurston served for 25 years in the Royal Air Force before managing a project to develop solar-powered, long endurance aircraft. He is now retired and spends a great deal of time in his observatory doing practical astronomy. He learned some mathematics in his youth and has had a life-long interest in mankind’s acquisition of astronomical knowledge through the ages.

STATE OF DELAWARE



**STATEMENT
IN OBSERVANCE OF
U.S. SPACE OBSERVANCE WEEK
AND
SPACE EXPLORATORY DAY**

Whereas, July 20, 1994, marks the 25th anniversary of the Apollo 11 first historic manned landing on the Moon and the 15th anniversary of the first Viking landing on Mars; and

Whereas, the Utah Section of the American Institute of Aeronautics and Astronautics (AIAA) is requesting participation in the celebration of the United States Space Observance during the period of July 16-24, 1994, and July 20, 1994, Space Exploration Day; and

Whereas, the purpose of the United States Observance is to stress the benefits of the space program to all mankind, to encourage increased public interest in the Nation's space program, and to commemorate all space achievements on the anniversary of the first historic landing of men on the Moon; and

Whereas, the United States Space Observance reminds us of our excitement and pride as we watched the Apollo Lunar Landings; Viking Mars Landings; the Voyager spacecraft close-up pictures of Jupiter, Saturn and Uranus; and the many successful Space Shuttle flights.

Now, Therefore, We, Thomas R. Carper, Governor, and Ruth Ann Minner, Lieutenant Governor, of the State of Delaware, do hereby declare the week of July 16-24, 1994, as:

U.S. SPACE OBSERVANCE WEEK

and Wednesday, July 20, 1994, as:

SPACE EXPLORATION DAY

in the State of Delaware, and urge all Delawareans to recognize the importance of this observance.



Thomas R. Carper
Thomas R. Carper, Governor

Ruth Ann Minner
Ruth Ann Minner, Lieutenant Governor

STATE OF DELAWARE



OFFICE OF THE GOVERNOR

STATEMENT IN OBSERVANCE OF SPACEWEEK 1994

Whereas, the purpose of America's space program is to expand all levels of human activity into space for the benefit of all mankind in peace and freedom;

Whereas, while opening new material resources and cultural insights for humanity's future growth, investigation of the space frontier has also provided scientific and technological breakthroughs involving many areas that affect us all; and

Whereas, 1994 marks the 25th Anniversary of Apollo 11 - man's first landing on the moon; and

Whereas, this special occasion deserves a momentous celebration across America of this historic event, bringing our attention on the success of past, present and future American space explorations.

Now, Therefore, We, Thomas R. Carper, Governor, and Ruth Ann Minner, Lieutenant Governor, of the State of Delaware, do hereby declare July 16-24, 1994, as:

SPACEWEEK 1994

in the State of Delaware, and urge all Delawareans and organizations which are involved with space, science and technology to have programs open to the public and urge everyone to learn about and participate in America's space programs.


Thomas R. Carper, Governor


Ruth Ann Minner, Lieutenant Governor

From the Desk of: Earle Baker
Bethel United Methodist Church -- Lewes, Delaware

January 16, 2015

Thomas M. Summers
Delaware Public Archives
121 Martin Luther King, Jr, Blvd North
Dover, DE 19901

2015 JAN 20 PM 12:00
DEL. ARCHIVES PUBLIC

Tom,

It was great to see you last week, and so good to have you bring your knowledge and skills to the Commission on Archives and History.

Here is the article I mentioned that suggests the observatory set up in Lewes in 1769 by the American Philosophical Society to determine the distance between the Earth and Sun, was in what is now Bethel Methodist Cemetery (The Society that became Bethel M.E. Church didn't organize until 1779.)

I hope you enjoy the article. Its from Volume 15 of the Journal of the Lewes Historical Society.

It seems to me at least that such an historic breakthrough merits a state marker. I have spoken to one member of the Bethel Methodist Cemetery Board of Trustees, and he was excited by the prospect.

Please let me know what steps we should take.

Grace and peace,



Earle

Phone: 302-645-9426

Email: pastorbaker@bethellewes.org

Open hearts. Open minds. Open doors.

The 1769 Transit of Venus Observatory in Lewes

By James E. Morrison and Geoffrey Thurston

In 1769, the American Philosophical Society launched its first large scientific project—observing the June 3 transit of Venus. This was the first opportunity for colonial America to participate in world-class science, and every effort was exerted to ensure success. Observation sites were established at Statehouse Square in Philadelphia (present-day Independence Square) and David Rittenhouse's farm in Norriton, Pennsylvania, about 20 miles northwest of Philadelphia. An additional expedition was sent to Lewes to set up a temporary observatory.

The complete story of the 1769 Venus transit expedition to Lewes, Delaware, has many technical elements and presents an interesting opportunity to explore the methods, equipment, and results employed in colonial surveying. It is, however, more a human story of dedication and intelligence applied to resolving one of the great issues of science. We come from the study of this historical footnote with respect and admiration for the men who lived it.

The Norriton and Philadelphia sites were constructed, equipped, and located over several months before and after the transit. The team members sent to Lewes had only a week to set up and adjust their equipment and to determine the geographic coordinates. Their story is an interesting chapter in the history of transit observations and an enduring footnote in the history of astronomy.

The purpose of the observations was to gather data from the transit of Venus to be used to calculate the distance of the Earth from the Sun, which is the Astronomical Unit (AU). Once the AU is known, the distances of all the planets from the Sun and from each other can be calculated. The actual objective was to measure the angle of the Earth as seen from the Sun, or the solar parallax. The AU is easy to calculate once the solar parallax is known. Defining the value of the solar parallax and thus the AU was the highest priority objective of 18th century astronomy.¹

Calculation of the solar parallax is based on combining observations made from sites as far apart as possible in latitude and/or longitude. The observation report from a single site was simply the times Venus intercepts and exits the Sun's disk, along with the geographic coordinates of the observation site.

The men who would set up the observatory and observe the transit were chosen for their technical skills, independence, reliability, and meticulous attention to detail. Owen Biddle (1737-1799) was the clear leader of the expe-

dition. He had worked as a clock- and watch-maker but later became a successful import/export merchant. He seems to have been widely respected and was elected the first curator of the American Philosophical Society. Biddle was known as a man who, if given a job to do, did it quickly, quietly, without fanfare. Biddle was a Quaker and was described by his daughter Anne as "...a man of Quick feelings and nervous temperament."²

Joel Bailey (1732-1797) from Chester County, Pennsylvania, was perhaps one of the best surveyors in America. He could be counted on to modify, improve, or repair any piece of surveying instrument, and he was fully capable of taking on any surveying job, no matter the scale. He worked with Charles Mason and Jeremiah Dixon on the survey of the Mason-Dixon Line, which defines Pennsylvania's southern border and is commonly called *The Mason-Dixon Line*. He also made precision levels used to measure the length of a degree of latitude and worked personally on the measurements with Mason and Dixon. Bailey was Mason and Dixon's "right-hand man" and worked on every aspect of their critical survey.³

An unofficial member of the Lewes team was Richard Thomas, a competent surveyor, who was engaged from time to time to do precision surveying for the Philosophical Society or the government. He paid his own way on the expedition, just to participate.

The Team Comes to Lewes

The team arrived in Lewes on Friday, 26 May 1769, a week before the transit, after a boat journey of about 100 miles from Philadelphia. The original plan was to erect the observatory at the newly activated Cape Henlopen lighthouse, only the sixth lighthouse in the colonies. This location allowed them to accomplish two objectives: observe the transit and establish the geographical coordinates of the lighthouse as an aid to mariners. However, a brief visit to the lighthouse shortly after their arrival demonstrated the reality of Middle-Atlantic springtime weather—wind and blowing sand. Clearly the lighthouse was not a place to install and operate expensive and sensitive instruments. Later the same day, they rented a house on South Street (Savannah Road),⁴ about ¼ mile from Lewes.⁵ They described the house as being in a "retired state," abandoned but serviceable.

The next day was spent unpacking and assembling their instruments, setting their clock to local time as told by a sun dial (*apparent* time). They used astronomical observations of the sun and a few stars to establish the true North-South meridian and to evaluate the accuracy of their clock. The functioning observatory was in operation by Saturday evening.

The bigger problem was to establish the latitude and longitude of the ob-

vatory. This could be done with astronomical observations over an extended time using the most accurate instruments of the era and rather complex calculations or by surveying the distance from a place of known coordinates. The weather turned windy and rainy on Sunday, which was sufficient to rule out measuring their location astronomically. In fact, they had neither the time nor the equipment to perform the needed observations. Thus, they needed to measure the distance from a place of known and trusted coordinates.

Reliable latitudes and longitudes derived from precise astronomical observations had been established for very few places in North America in 1769. The most accessible sources of trusted latitudes near the transit observatory were the markers installed at ten-mile intervals and mileposts each mile in the 1750/51 survey of the southern border of the "three lower counties of Pennsylvania" (which became Delaware) called the *Transpeninsular Line*. The eastern end of this Line is defined by a stone marker at Fenwick Island, although the actual start of the border is 2,244 feet east of the marker, in the Atlantic Ocean. The Line was intended to follow the same geographic latitude across the peninsula to Chesapeake Bay. The middle of the line, the *Mid-Point*, defines Delaware's southwestern corner. Mason and Dixon measured the latitude of the Mid-Point as $38^{\circ} 27' 34''$, and all markers on the Line were assumed to be at the same latitude.

Joel Bailey and Richard Thomas assembled a crew and from May 28 to June 2 surveyed the distance to the Transpeninsular Line marker 10 in the settlement now known as Selbyville. Clearly, two men could not do this alone. Biddle had been advanced £20 for expenses, which was a considerable amount of money for the time. They probably hired a wagon and driver to carry the equipment and extra gear needed for camping out on the way. They would also have hired two or three burly young men to drag the chain, drive stakes, and cut limbs and trees that were in the way. There were surely some hangers-on attracted by the novelty of the undertaking, who probably helped when needed. Experienced chain-men were available in Delaware from the Mason and Dixon survey, but there is no mention that they were used. The crew was at least eight or nine men for the full traverse, with others involved to help cross creeks and the Indian River.⁶ There were probably some men on horseback who could scout the best route.

The survey required 120 instrument sets and covered nearly 27 miles. It was rainy and windy the entire time. Based on the field data recorded during the survey, they determined that the observatory was 21.93 miles north of the Transpeninsular Line and 30.6356 miles east of the Mid-Point.⁷ These values were reported to the Royal Society in late 1769 through the efforts of Benjamin Franklin.

Recalculated distances were published in Volume One of the *Transactions of the American Philosophical Society*. The differences in latitude between the observatory and the Transpeninsular Line were calculated using a value of 68.896 miles per latitude degree supplied by the Astronomer Royal derived from Mason and Dixon's measurements. The result set the observatory latitude at 38° 46' 38.3" N.

The observatory longitude was much more difficult to determine. The closest location with a trusted longitude was David Rittenhouse's farm in North Pennsylvania, determined from an observation of the eclipse of one of Jupiter's moons in April 1769 and coordinated with an identical observation by Thomas Digges Bird at Greenwich, England.⁸

The coordinates of the observatory at Statehouse Square were determined from a carefully executed survey from Norriton to the Philadelphia observatory in July 1769.

A second survey run by Biddle and Bailey in May 1770, nearly a year after the transit, determined the longitude of the New Castle Courthouse by linking it to the Statehouse observatory. The Courthouse was tied to the Mid-Point by the so-called *Tangent* line surveyed by Mason and Dixon. Thus, separate surveys were required to pinpoint the Lewes observatory longitude.

Locating the Observatory Site

Based on the available survey data, Biddle and Bailey were able to determine the observatory coordinates as 38° 46' 38.3" North and 75° 08' 30" West. These values place the observatory near the intersection of Pilottown Lane and Shipcarpenter Street in current-day Lewes using modern mapping methods. Although this position was adequate for measurements of the transit of Venus, it is unlikely that this is the precise location of the observatory for a number of reasons. For example, Biddle mentioned that the observatory was on South Street (now Savannah Road) and about ¼ mile from the town center. Their derived coordinates do not meet either of these criteria. The question that arises is: Where was the Lewes observatory?

The reported observatory latitude requires a correction. When Bailey's traverse ended at the Transpeninsular Line, he was not at the latitude assumed. Mason and Dixon's latitude of the Mid-Point was 36° 27' 34" N, Bailey's assumed latitude for the entire Line. However, the Transpeninsular Line is not a true parallel of latitude, and the latitude of marker 10 is actually 38° 27' 04.4" N,⁹ which is 29.6" (2995 feet) less than the latitude assumed for the Mid-Point and the entire Line. The difference in the reference latitude changes the site latitude to 38° 46' 8.3" N. This adjustment places the observatory position much closer to South Street as described by Biddle.

The published longitude was derived from four separate surveys and was based on a single observation. Any errors in any of the surveys would be propagated through the calculations, resulting in a final value that cannot be confirmed.

Fortunately, there is an alternative method for deriving the observatory's position. Biddle noted that the survey from the observatory to the Transpeninsular Line followed existing roads whenever possible to reduce the time and cost of the survey.¹⁰ Google Earth supplies the technology to display the routes defined by Bailey's field notes. The initial analysis showed how closely the shape of the survey route followed today's roads. But are the current roads and highways the same as they were 243 years ago?



There are no 18th century maps with the detail required for the analysis. However, the authors scanned maps from the D.G. Beers Atlas of 1868 and overlaid them on current roads. The locations of the principal roads are, for our purposes, identical to the roads existing in 1769. We did not feel it would be proper to change the original field data published by Bailey, even though there are many possible sources for random and systematic errors, so an analytic approach was needed to match the route to the roads without modifying the source data.

There are two parameters that can be examined for their effect on the locations and distances of the route segment: the magnetic declination and accuracy of the distance measurements.

Magnetic declination (which Biddle calls "variation") is the difference between magnetic north and geographic north. Bailey measured the magnetic declination at $3^{\circ} 55' W$ ¹¹ at the observatory site by comparing north as shown on his compass with the astronomical meridian. Finding an accurate value for magnetic declination was a major weakness in 18th century surveying and cartography, and two surveyors using identical equipment at the same location would seldom get the same value.

Another factor concerns the lengths of the route segments. Bailey recorded all distances except one in full perches (a "perch" is $\frac{1}{4}$ chain or 16.5 feet) would be very difficult to position the stakes marking the route in even perches resulting in an unquantifiable rounding error.

It is very easy to find segments of the route with the same shape as roads when the route is drawn on the Beer's Atlas maps. The first segment went straight down South Street. Using Google Earth, we found a correction of $1^{\circ} 18'$ applied to each segment reproduced the shape of current roads very well. In addition, a 1.5% increase to each distance placed the calculated route almost exactly on the Beers Atlas roads. Thus, combining the error factors into a bias value applied to each point in the source allows us to locate the observatory with confidence. The detailed route analysis was performed on the first nine miles of the survey, which is adequate since our interest is in where the survey started.

The most probable location for the Lewes Transit Observatory of 1766 is near $38^{\circ} 46' 12.3''$ North and $75^{\circ} 08' 38.1''$ West. The site was within the boundaries of what is now Bethel Methodist Cemetery, which is on land originally intended for use as a Quaker cemetery but was apparently never used for that purpose. It is about 0.2 miles southwest of 4th Street and intersects Savannah Road, thus meeting all of the qualitative criteria mentioned by Biddle.

The transit observation itself on June 3 went perfectly. The weather was crystal clear, without a cloud in the sky, and the transit team documented the required times.

The results of the observations reported by Biddle in apparent (sun) time were:

Owen Biddle's external contact:	2 hr 11 min 53 sec
Owen Biddle's internal contact:	2 hr 29 min 53 sec
Joel Bailey's external contact:	Lost by accident
Joel Bailey's internal contact:	2 hr 29 min 53 sec

The solar parallax derived by Dr. William Smith of Philadelphia using Biddle's external contact and those recorded at several European observatories was $8.862''$ compared to the accepted modern value of $8.794''$.

After his transit observation, Owen Biddle was prominent in the American Philosophical Society. He was elected curator (1770), secretary (1773), councilor (1782), and he delivered the annual oration in 1781.

Joel Bailey continued work as a surveyor. His role in the transit apparently impressed the membership, and he was elected to the American Philosophical Society in 1770. ♦

¹ For a general overview of transit astronomy, see William Sheehan and John Westfall, *The Transits of Venus* (Amherst, NY: Prometheus Books, 2004).

² Henry D. Biddle, "Owen Biddle," *The Pennsylvania Magazine of History and Biography* XVI (1892) 299-329.

³ Edwin Danson, *Drawing the Line* (Wiley, 2001) 85.

⁴ "Observations of the Transit of Venus over the Sun, June 3, 1769; made by Mr. Owen Biddle and Mr. Joel Bayley, at Lewestown, in Pennsylvania, Communicated by Benjamin Franklin, L.L.D., F.R.S.," *Philosophical Transactions*, Royal Society 59 (1769) 414-421. [TRS]

⁵ *Transactions of the American Philosophical Society* I (1771, revised 1789).

[TAPS]

⁶ Mason and Dixon's crew was generally 35-40 men and included two wagons, eight horses, cooks, stewards, tent keepers, chain men, and laborers. Their main instrument was transported in a wagon, on a featherbed.

⁷ TRS 419.

⁸ TAPS 20.

⁹ Buford K. Meade, "Report on Surveys of Delaware/Maryland Boundaries," U.S. Department of Commerce, National Ocean Survey (1982) 25-26.

¹⁰ TAPS 84.

¹¹ TAPS 86.



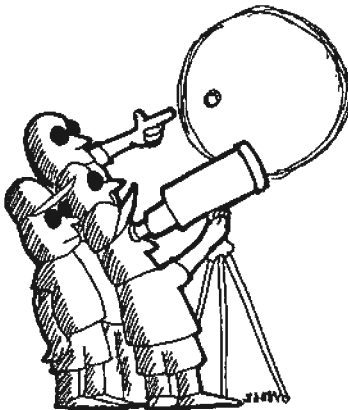
Transit of Venus: A Personal Experience

By Hazel D. Brittingham

The opportunity on 5 June 2012 to view the planet Venus as it commenced its transit across the sun took me back eight years to the early morning of 8 June 2004. It was shortly after 5 a.m. when LHS Executive Director Mick DiPaolo, and I were among a handful of people gathered at a spot in C Henlopen State Park. Dennis and Becky Forney were the only other people we knew. An unknown gentleman was generous in allowing us to view the phenomenon through his telescope. Our time there allowed us to safely view the little black speck—Venus—as it commenced its infrequent journey across the sun.

We knew at the time that the next identical event would occur in 2017, just eight years hence—and that the following occurrence would be in the year 2117.

My interest in the event back in 2004 was fostered by an item contained in my files. It was a copy of the report of the American Philosophical Society relating to the same astronomical event that had occurred in June 1769 when many observation locations had been established around the globe. Lewes was one! A team of three men led by Owen Biddle of Philadelphia had arrived in Lewes a short time before the known date and time of the beginning of the transit. They set up their equipment and reportedly used a telescope and chronometer purchased for the expedition by Benjamin Franklin. The weather was favorable enough for them to file their scientific report.



It was my privilege again to view the same event at Roosevelt Island this past June, where a number of people gathered and, aided by telescopes, binoculars, and the distribution of sun-viewing glasses, had a front-row seat for the show. A newspaper account that followed noted that this year's viewers received a once-in-a-lifetime glimpse of the transit. For me, it was the second-in-a-lifetime experience, without doubt I had reached my limit. ♦

Surveyors put Lewes on world's scientific map in 1769

On a day late in May 1769, the mathematical capability of the populace of Lewes spiked.

Three surveyor-scientists associated with Benjamin Franklin's American Philosophical Society in Philadelphia disembarked from a sailing ship and made their way into the Colonial village known then as Lewestown.

They were likely met at their anchorage by a rowing skiff that carried them and their equipment into Lewes Creek where they climbed ashore via a stone wharf at the foot of Market Street. Gilligan's Restaurant now stands by that old wharf. From there they could make their way to one of the inns of town, such as the Ryves Holt house, to get local bearings, satisfy their hunger and thirst, meet some of the town's citizens and figure out where best to be-



gin the celestial quest that brought them to town.

Spotting Lewes coming down Delaware River and Bay from Philadelphia that year would have been easier for the ship's captain than ever before. It was in that same spring that the Cape Henlopen Lighthouse, built by the British at the urging of Philadelphia merchants tired of losing ships on the shoals at the mouth of the Delaware, first went into service. Its commanding

height atop a tall dune at Cape Henlopen would have been visible up the Delaware for miles and miles.

The Philadelphia surveyors had the new lighthouse in mind as they plotted the strategy of their Lewes adventure. But that wasn't the primary reason for their trip.

Within just a few days of their arrival, they and other astronomers around the world would be peering through telescopes to observe the planet Venus crossing the face of the sun.

An astronomical phenomenon that comes along every 120 years or so, the so-called Transit of Venus, at that point in history, held the key to what Rehoboth Beach resident and author James Morrison has called the Holy Grail of Astronomy between the 17th and 19th



DENNIS FORNEY PHOTO

This is the view from the top of the hill in Bethel Methodist Cemetery in Lewes looking across Savannah Road toward Lloyd's Market and Manila Avenue. The hill is the highest point in mainland Lewes, and the Philadelphia surveyors may have set their telescope up here to observe the Transit of Venus.

centuries: the size of our solar system. By timing the passage of Venus across the sun from multiple locations around the planet, scientists would be able to use known mathematical principles to

measure the distance between the Earth and the sun. Knowing that distance, they could plot the size of the entire solar system.

Over the next several days,

Continued on page 8

Barefootin'

Continued from page 7

the visitors from Philadelphia set up their temporary Lewes observatory for the June 3 event. Because the value of timing the Transit of Venus depended on knowing the precise latitude and longitude of each observatory, the men also had to determine those numbers. Using surveying equipment including a 66-foot-long chain, the men assembled a crew to accurately

measure the distance between their temporary observatory in Lewes and an established geographical location. They were few and far between in Delaware at the time, but the Transpeninsular Line surveyed in 1751 to establish the southern boundary of Delaware did the trick. Chain length by chain length, the crew worked its way south from Lewes on established roads until a few days and 21.93 miles later as the crow flies, the crew reached Transpeninsular Line mile marker No. 9 near present-day Selbyville. The calculations

helped establish latitude for the Lewes observatory. A set of more complicated calculations, again with the assistance of chain-toting surveyors working from the Philadelphia end, allowed American Philosophical Society members to accurately place the longitude of the Lewes site.

Using a lot of those same numbers and techniques, the American teams were able to not only contribute to establishing the distance of the Earth from the sun at about 95 million miles, but they were also able to pinpoint

the latitude and longitude of the new Cape Henlopen Lighthouse, which considerably aided navigation in the mid-Atlantic. Morrison and Jeffrey Thurston - a colleague in England - performed an extensive study to determine the location of the temporary Lewes Observatory. Their investigation led them to place that location inside the Bethel Methodist Cemetery on Savannah Road. State and local officials - including Morrison - were scheduled to dedicate an historical marker at the

cemetery on Nov. 20 to commemorate Lewes's role in an important chapter in global astronomical history.

In a short piece presented to Sen. Ernie Lopez as potential language for the marker, Morrison concluded by writing: "The 1769 transit thrust Lewes and the American observation teams into world-class science and confirmed their ability to perform at the level of European astronomers."

Not bad for a salt-soaked, marshy little Colonial town along the coast.

LHS programs Nov. 20 to honor 1769 Transit of Venus observation in Lewes

Nov 11, 2015

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Transit of Venus

The Transit of Venus last occurred in 2012 and was observed in Lewes, as it was in 1769.

The Lewes Historical Society and the Delaware Public Archives will unveil a new historic marker commemorating the observation of the Transit of Venus in Lewes in 1769. The marker dedication will take place at 11:30 a.m., Friday Nov. 20, on Savannah Road in front of the main entrance to Bethel Cemetery.

Sen. Ernie Lopez, R-Lewes, provided funding for the marker. Lopez, officials from Delaware Public Archives and transit historian Jim Morrison are scheduled to make remarks.

"This was an important scientific endeavor in the 18th century, and Lewes was part of a truly global experiment to observe the Transit of Venus," said Mike DiPaolo, Lewes Historical Society executive director. "By observing the transit, 18th century scientists were able to more effectively calculate the distance of Earth from the Sun. The society and archives would like to thank Bethel Cemetery Corporation for allowing us to place a marker along Savannah Road that will help others better understand Lewes' place in 18th century science."

Following the marker presentation, Jim Morrison will be LHS' first Lunch 'n' Learn speaker of the season with an in-depth discussion about the astronomical and historical significance of the transit observation in 1769 as well as the more recent observations in 2004 and 2012. Morrison's talk will take place at the Hotel Rodney and will begin after the marker ceremony, about 12:30 p.m.

The Lunch 'n' Learn program is free and open to the public. Attendees are welcome to bring their own lunch or to order off a special menu provided by the Rose and Crown Restaurant. For more information, call 302-645-7670.