About 12 years ago I was fortunate to obtain a 17th century English theodolite complete with its original, octagonal box and Jacob's staff adaptor (FIG. 1). At the time of acquisition I was not familiar with the names engraved on the arms of the azimuth plate. Once I began to research the names, I realized this was an important historical, as well as scientific, instrument.

The maker's name, Joseph Hone (FIG. 2) was mentioned in Gloria Clifton's book\textsuperscript{1} and J. R. Millburn's article, \textit{Some English Military Instrument Makers of the 17th Century}.\textsuperscript{2} In Millburn's article he noted, “The principal supplier of ‘mathematical’ instruments to the Government during the reigns of James II, William & Mary, and William III, seems to have been the relatively unknown Joseph Hone.” He continues, “No surviving signed examples of his products have been reported, so his abilities as an instrument maker - if indeed he was an actual maker – cannot be assessed.”

Gloria Clifton confirmed that John Rowley began his apprenticeship to Hone on 23 November 1682. Rowley became an important instrument maker and also a supplier of instruments to the Board of Ordnance, as well as Christ’s Hospital, as was Joseph Hone.

The signed theodolite serves as proof that Hone was a maker of exceptional quality, evidenced not only by the superior workmanship of the instrument but additionally by the very accurately engraved divisions on the theodolite's azimuth circle.
Research of the owner’s name, Sir John Colleton (FIG. 3) documented an important series of events. Colleton helmed the major organizational role in the initial settling of the Carolinas. “On September 8, 1663 the proprietors made their first land grant; it was to Sir John Colleton, and recognized his leading role in establishing the Proprietary. It is very likely that he commissioned Hone to build this particular theodolite for the surveying of lands granted to the proprietors of the Carolinas by King Charles II.

This instrument would most likely have been ordered between 1662 and 1667 — Colleton died in the latter year. This places the theodolite as one of the earliest existing instruments used for surveying in the American British colonies.
The diameter of the horizontal azimuth plate is 12.750 inches with very accurately engraved divisions down to 15 minutes of arc (FIG. 4). An eight-degree section of the scale was measured using an optical micrometer with 1/10,000 inch resolution. Every 1/4 degree mark (15 minutes) was measured and recorded. The diameter of the theodolite's scale is 12.0 inches and the scale divisions, as measured, were converted to the equivalent angles. For this diameter, every 0.0017 inch represents 1.0 minute of arc. A statistical examination of the 32 plotted points gives the standard deviation to be 0.6581 minutes. This tells us that the majority of the points fall within +/- ~1/1000 inch, with outliers not exceeding +/- ~ 3/1000 inch. The alidade was constructed with fiducial-scribed lines at each end with no vernier.

Earlier this year, I was able to purchase a very large, incomplete theodolite alidade with compass and socket assembly from England. Upon closer inspection, the mechanical construction and engraving style appeared to be very similar to the Colleton theodolite by Hone. If one views the photo illustrating the socket assemblies typical from the mid to late 17th century (FIG. 5), you will notice the pattern commonly used was a three-spoke design held to the compass body or azimuth plate by three wing screws.


The threaded shafts and nuts as seen in FIG. 6 display the fact that the threaded shafts were attached in a fixed manner so they would not unthread as the nuts were tightened and loosened to adjust the friction between the rotating alidade and the azimuth plate. The design of the hexagonal faceted nuts with a shoulder at the contact point with the spring washers are identical on these two examples. Individual makers had various designs for this attachment of the alidade to the azimuth plate. This particular design went out of favor due to its complicated pattern and difficulty of fabrication and was replaced by an engraved thrust washer assembly that controlled the end float in a much simpler manner as seen in FIG. 7, a photo of a Thomas Heath Theodolite from the second quarter of the 18th century.
As an engraver, one learns to pick out minor details of engraving that, when compared, illustrate engravings by the same maker. Chronologically, the instrument’s engraving can be dated based on the maturation of style and proficiency. Letter style, number style, and placement serve as good indicators of engraving by the same hand. If you look at the chart (FIG. 8) and compare the earlier numbers, 3, 4, 5, and 6 of the signed Joseph Hone theodolite to the later numbers of the unsigned alidade compass, you will see the style and treatment are the same – look at the flip-up on the top of the 5s and the angle of the radiuses and thick-to-thin ratios of the 6s.

### Joseph Hone Theodolite Engraving Styles

<table>
<thead>
<tr>
<th>Signed Jos. Hone Fecit Theodolite</th>
<th>Unsigned Jos. Hone Theodolite</th>
</tr>
</thead>
<tbody>
<tr>
<td>Circa 1665</td>
<td>Circa 1685</td>
</tr>
</tbody>
</table>

![FIGURE 7](image1.jpg)  
![FIGURE 8](image2.jpg)
When studying the placement of the word North in FIG. 9, the “h” foot is tangent to the left side of the sub-cardinal triangle as well as the identical treatment of the individual letters regarding their thickness proportions. Pay particular attention to the lower case “e” with the additional shading at 3 o’clock. The final clincher is the sub-cardinal triangles. As you can see, both are treated in the same manner. The outer lines and centerlines of the triangle are scribed perfectly straight, but the parallel shading lines both have a compressed saw-tooth pattern that I have not seen before on any of the other English instruments.

![Joseph Hone Theodolite Engraving Styles](image)

**FIGURE 9**
As one studies the two alidades side-by-side in FIG. 10, it becomes obvious the sophistication level of Joseph Hone’s work had greatly increased. The simplicity of the earlier alidade on the right had been greatly enhanced, not only in size for accuracy but also in the molding designs on the profile of the alidade and the incorporated window at each end.
To begin the restoration, a correct period design commensurate with the original alidade molding treatments was incorporated into the layout for the missing azimuth circle (FIG. 11). Secondly, the patterns for the division engraving were specifically designed to align with the alidade, which included both a window with internal pinholes to attach a fiducial hair (FIG. 12), as well as an external engraved centerline (FIG. 13). Since the earlier Hone theodolite of 12 ¾ inch diameter circle was accurately divided to 15 minutes, I felt that I would be able to utilize the same 15-minute division for this larger 16 ¾ inch diameter circle. The original Hone theodolite has a needle ring outside diameter of 4.375 inches and the later theodolite has a needle ring outside diameter of 6.218 inches, which is one of the largest compasses from that time period.
Inspection of the needle ring on the later compass shows the scale is accurately divided to 30 minutes of arc and the vertical wall of the needle ring is divided in degrees (FIG. 14).
After the focused inspection of the identical aspects of the engraving numbers and letters, I was convinced that the larger alidade was constructed by Hone. This information facilitated my decision to engrave “Jos. Hone fecit” in the same style as the earlier example on the 360° arm of the azimuth circle, but to make sure that it would never be represented as an original azimuth plate, I also engraved the date “2017” under the Hone signature (FIG. 15 & FIG. 16) as well as my name paired with “2017” on the reverse side of the same arm (FIG. 17). One of the most important details of a quality restoration is to sign and date all of the replicated pieces so as not to obscure the representation of the original pieces with the replacement pieces (FIG. 18 & 19).
FIGURE 20

One very important detail in the later, original alidade was the fact that it incorporated two threaded and two alignment holes that were originally set in place for an altitude-reading assembly. The challenge was to design an assembly that would blend in naturally with the completed instrument.

I was very thankful for the advice of Paolo Brenni, Science and Technology Foundation, Florence with whom I had discussed various intricate details regarding this project. I built several mock-ups considering different diameters for the protractor as well as different heights for the elevation of the protractor and its sighting arm.
Once Paolo and I agreed on the final proportions for the altitude assembly, I began to layout the fabrication for the final design. As can be seen in the photographs, the altitude-reading assembly was constructed of several pieces (FIG. 20) all hand-filed with very slight tapers to minimize the appearance of the joints, as well as the riveted tapered pins that held the assembly in place. The protractor was divided to 30 minutes. I constructed the protractor sights to resemble the molding pattern of the newly fabricated sight vanes (FIG. 21).
One of the challenges of the altitude-reading assembly was to design and fabricate a chronologically-correct method for leveling out the theodolite when the altitude unit was being utilized. The design that I chose can be seen in (FIG. 22).
The metallurgical composition of the brass chosen is critical in controlling the patination process. Matching the ratio of copper to zinc as closely as possible will allow the new brass to patinate very closely to the original alidade from the latter part of the 17th century (FIG. 23 & 24). Because these surveying instruments were used out in the field, the moisture condensation over several hundred years will age the brass very gracefully, and it speaks impressively to the fact that the larger alidade was left in its original condition and not polished in the past by an over-zealous collector.
I have included a photograph of a page from my documentation notebook where I recorded the initial designs and measurements, engraving patterns, and thread pitches for the screws being used by particular makers. This documentation is very helpful in showing the accuracy that was adhered to by the instrument makers of this time period (FIG. 25).
The restoration of this particular theodolite very closely resembled a similar restoration project that I presented in 2007 at the Harvard/MIT Symposium. That instrument was an incomplete David Rittenhouse Telescopic Theodolite that was also missing the azimuth plate.

The article regarding this restoration can be found at my website www.colonialinstruments.com under the “Articles” heading.
Major projects like these are very educational due to the research necessary to produce the appropriate replacement pieces. The quality and accuracy of the original instruments dictate the level of the replacement pieces, and there is no better way to understand the difficulties that the original makers went through to produce their finished projects than to attempt to recreate the replacement pieces commensurate to their level of workmanship. The completed project can be seen in FIG. 27, and in comparison to the earlier Hone theodolite in FIG. 26.

Acknowledgements:

Gloria Clifton, Head of the Royal Observatory Greenwich, National Maritime Museum, provided considerable research about the career of Joseph Hone and additional directions to guide me to other sources for works or documentation on Hone.

The late Anita McConnell, internationally-renowned historian of scientific instruments, helped with her lengthy research on Sir John Colleton; she located a PhD thesis from the University of Edinburgh written by John Buchanan in 1989 entitled, “The Colleton Family and the Early History of South Carolina and Barbados.”

Paolo Brenni graciously took the time to correspond on various technical aspects regarding the division patterns and the altitude-reading configuration for this restoration project.

Paul Temple who has helped me on many projects in the past and who performed the optical measurements of the scale on the original Hone theodolite.

I would also like to thank Stephen Johnston, Museum of the History of Science, University of Oxford, who I met at the 2003 SIC Symposium for inviting me to give a presentation on surveying instrument construction details and engraving to the Masters Class at Oxford. While there, he graciously allowed me to study, in close detail and for several days, instruments in the Museum’s collection. Much of my fundamental understanding of the construction details of 16th and 17th century instruments was initiated by this visit to the Museum.