The Cultural Adaptation of the Astrolabe

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Introduction

Ancient societies had a universal curiosity about the heavens. This is no coincidence; astronomic cycles are highly important for determining expected daylight and nightlight, time of day, length of the season, and time of year, factors that affected everything from hunting habits to crop cycles. As a general rule, the knowledge to predict the course of the heavens was vitally important for daily life.

Astrolabes are a tool that collapsed observed heavenly rotations into a small, easy-to-use model, allowing a learned user to predict the state of the heavens at specific times. This one task allows the user to solve a wide array of astronomical problems, such as telling the current time or determining when the sun will set. In addition, the astrolabe also gives the user a framework for parsing the heavenly rotation into understandable, predicable phenomena, giving the illusion of power over the heavens.

The astrolabe was a portable celestial model and had a strong general utility, suitable for a broad range of problems involving the heavens. This utility made it easily adapted by various medieval cultures, but once adapted, astrolabe technology became specialized for the specific tasks valued by each culture. However, astrolabe adaptation was not limited to astronomic functionality, but to symbolic functionality as well. This adaptation is consistent with the theory of interpretive flexibility, where users determine how a technology specializes until the technology is replaced by an even more specialized device. Persian, European, and Mariner’s astrolabes all show this progression, either in the functional or symbolic aspects of the astrolabe.

Overview of the Astrolabe

The mechanics of the astrolabe are relatively straightforward. The rotation of the stars is visually correlated to where an observer would see them in the sky, depending on the time and date. This correlation, and how the correlation is made, is key to the functionality of the astrolabe. For example, if a star’s location in the sky is measured, and the date is known, then the time can be determined. The astrolabe consists of five basic parts that allow it to predict the location of the stars:

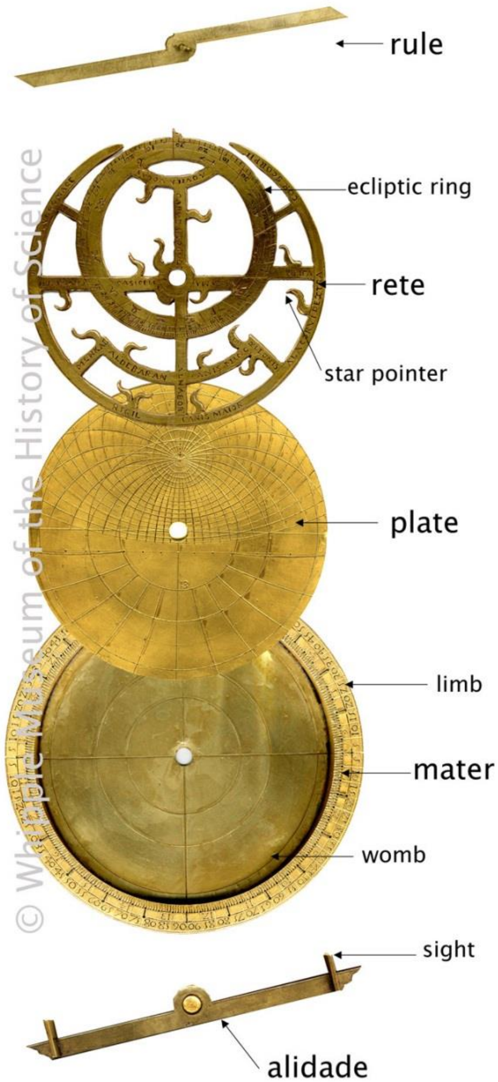

Figure 1: ***Parts of an astrolabe*** **– The typical planispheric astrolabe has five parts that allow it to observe and predict the state of the heavens. Picture credit – Whippie Museum of the History of Science[1].**

1) The *Plate*: The *plate* represents the *local coordinate frame* of the astronomer. In the local coordinate frame, two angles will locate any object in the sky. These two angles are *azimuth* (degrees east of north), and *altitude* (degrees above the horizon). The circles on the astrolabe plate are arcs of constant altitude. The small circle slightly above the center of the plate is the *zenith*, or the point directly up in the sky at altitude 90°. The arcs emanating from the zenith point are azimuth arcs.

The engraving on the plates is a function of the *latitude* of the user, so most astrolabes contained multiple plates that could be substituted in for various locations on the globe.

2) The Rete: The *rete* is a star chart, and represents the *celestial coordinate frame*. This coordinate frame stays fixed to the stars as they rotate in the sky. So if an astrolabe were always aligned with the state of the heavens, as the day passes, the rete would rotate, placing the stars in their new correct location over the grid on the plate.

The circle on the rete is the *ecliptic*, or the path of the sun. Depending on the day of the year, the sun is on a specific point on that circle. Essentially, the astrolabe treats the sun like a star whose location depends on the date of the year.

[1] "Explore Whipple Collections - The Parts of an Astrolabe." *History and Philosophy of Science, University of Cambridge*. Web. 24 Nov. 2010.

3) The Mater: The *mater* is the main body of the astrolabe, containing a large cavity (the *womb*) that holds the rete and plates. On the rim of the mater (the *limb*), there is an angular scale of 24 divisions, corresponding to the 24 hours of the day. This scale allows the user to measure the rotation of the rete, watching how many degrees on the scale the rete has passed through.

4) The Rule: The *rule* is a simple straight edge that is used to align the sun or stars to the 24 hour time divisions on the rim of the mater, making it easier to determine the rotation of the rete.

5) The Alidade: The *alidade* is located on the back of the instrument. It is used for taking altitude observations, finding the angle from an object to the horizon. To do this, the user holds the astrolabe vertically by its top and rotates the alidade until the object appears in the alidade sights. The altitude is given by an angle scale on the back of the mater.

Finding the time of day is a classic astrolabe problem that uses all these parts. First, the user finds the altitude of the sun using the alidade. Then, he determines the point on rete ecliptic that corresponds to the sun's location on the calendar date. He then rotates the rete until that point is at the correct altitude arc, previously measured, on the plate. Finally, he rotates the rule to strike through the point, and the rule shows the correct time on the rim of the mater[2]. Another classic astrolabe problem is to find the latitude. The latitude is simply the angle between the north star and horizon, which can be found directly by pointing the alidade at the star.

The astrolabe's history is a muddled mix of cultures, but the enabling technology was created by Greek astronomers. The astrolabe works by projecting the celestial sphere onto a plane (Figure 2), effectively making a rotating star chart. Earliest records of projection methods are from Agartharchus (ca. 470 BC), an Athenian artist, and Apollonius (ca. 225 BC), famous for his work with conic sections, likely derived some of the concepts necessary for astrolabe construction[3]. The astrolabe itself, with all the parts enumerated above, did not develop until much later, when Persian astronomers built on the Greek knowledge. However, the astrolabe as a model of celestial motion makes several interesting implicit

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[2] Morrison, James E. *The Astrolabe*. Rehoboth Beach, DE: Janus, 2007. 15-16. Print.
[3] Morrison, James E. *The Astrolabe*. Rehoboth Beach, DE: Janus, 2007. 32-33. Print.

assumptions true to these Greek roots. For example, the plates are fixed while the rete rotates, exactly like the Aristotelian worldview of a static Earth and rotating skies. In addition, the projection method almost hints of the Aristotelian prime mover. The makers of the astrolabe were faced with the difficult problem of mapping the celestial sphere onto a plane. To do this, the stars chart is drawn from an innovative viewpoint, as if the viewer were perched at the south celestial pole, looking at the stars and earth from the outside. These assumptions do not affect the utility of the device, but have cultural significance that change the context in which the device is used.

The astrolabe, therefore, is both functional astronomic calendar and timekeeping device, but also a

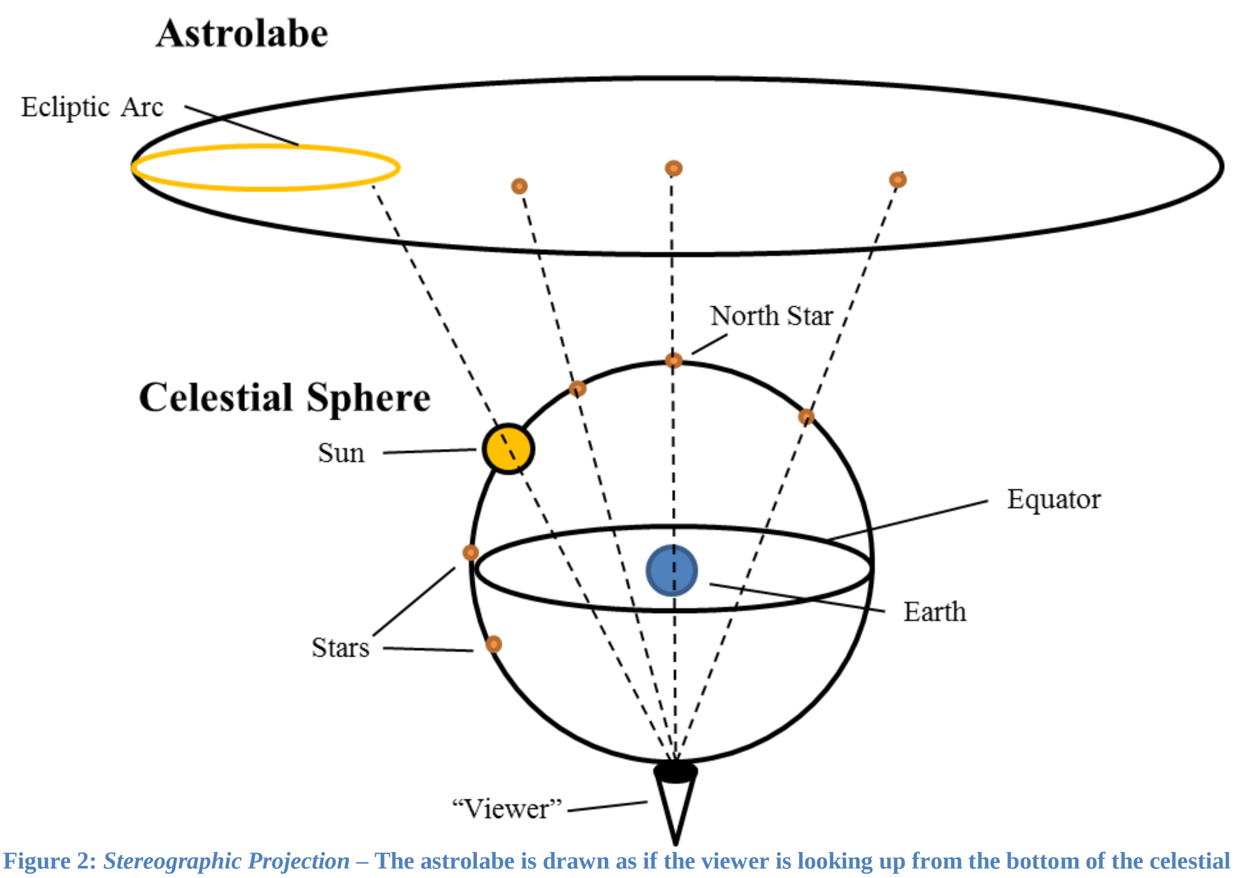

Figure 2: ***Stereographic Projection*** **– The astrolabe is drawn as if the viewer is looking up from the bottom of the celestial sphere. The location of celestial objects on the astrolabe are defined by their projection lines from the viewer's location.**

celestial model intimately interwoven with its user's culture. As the astrolabe spread, both these models of its identity were adapted by the people adopting astrolabe technology. This diversifying of the astrolabe use case is a common occurrence in the history of technology, and is at the core of the theory of interpretive flexibility.

Interpretive Flexibility

The adaptation of the astrolabe was a narrative of diversification, specialization, and finally substitution by even more specialized new technologies. Interpretive flexibility is an established framework for understanding this transformation. The theory consists of three main steps, which are classically illustrated by the adoption of the automobile in rural America:

1. As a new technology is introduced, there is no defined use case. Oftentimes, the inventor targets the technology for a poorly defined need scenario, so users instead generate their own need. In this stage of the process, the technology is *interpreted as being highly flexible*. Users apply the technology in ways the producer never intended. For example, early cars were used to tow plows, or used as snowmobiles, or were used with a belt drive from the real axle to run the household washing machine[4].
2. As the technology matures, the technology specializes for these user-generated needs. The producers of the technology respond to the user's needs or often multiple groups. This leads to diversification of the technology as producers attempt to respond to these needs. In the case of the automobile, producers advertised a "car for farmers" with convertible truck space and better reliability.
3. The technology is replaced in the user group when a more specialized technology performs better in the given use case. A technology that is half hazardly applied to many use cases usually is not optimized for any one case, so new technologies, developed to fit that need, outperform and replace it. For instance, the development of the tractor eliminated the car's use as a rural farm

[4] Ronald Kline and Trevor Pinch. "The Social Construction of the Automobile." Technology and Culture, Vol. 37, No. 4 (Oct., 1996), pp. 763-795

tool, and the car instead began to be optimized for paved road use, safety, and transportation efficiency.

The makers of the astrolabe were faced with a similar technological use problem. The astrolabe's true core, an accurate celestial model, could be applied to a wide number of uses. Original astrolabes were highly flexible as people began to understand the power of a celestial model; astrolabes were used to tell time, but also to navigate, determine the cardinal directions, or simply to sit as beautifully engraved brass plate. Many of these uses were eventually supplanted by specialized devices, such as the clock, the compass, and the sextant, while the astrolabe's natural beauty maintained it in symbolic contexts. The history of the astrolabe is therefore a story of adaptation as it spread; various cultures modified the astrolabe's celestial model to suit their needs, and then often abandoned it for more specialized instruments.

Persian Astrolabe

[2] وإذ قدمنا هذا الشكل فلنبين أن كل مخروط قاعدته دائرة تحيط
به كرة ويخرج قطر الكرة من نقطة رأس المخروط ثم يقام على نقطة طرف
القطر المقابلة لنقطة رأس المخروط سطح يماس الكرة ويخرج سطح المخروط
على استقامة حتى يفصل السطح المماس للكرة فإن فصله المشترك دائرة ·

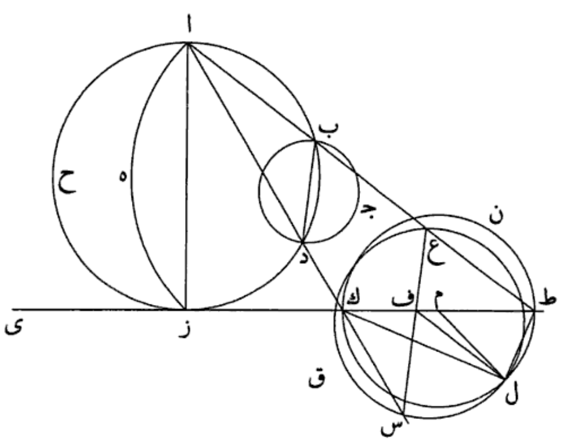

Figure 3: ***Stereographic Projection Derivation*** **- al-Farghānī's mathematical derivation of astrolabe curves from stereographic projection, based on earlier Greek sources.**

Astrolabe technology matured from its Classical roots during the Golden Age of Islam, while Europe was still wallowing in the Dark Ages after the fall of Rome. The invention of the astrolabe credited to the mathematician Muhammad al-Fazari in the 8th century. Later Islamic astronomers, such as Ahmad ibn Muhammad ibn Kathīr al-Farghānī, wrote substantial technical documents describing its use. In al-Farghānī 's document, he derives many of the relevant arcs necessary for creation of an astrolabe from basic principles, probably building on work from earlier Greek sources. Al-Farghānī also refers to substantial existing reference tables, indicating that the astrolabe had been widely spread by the middle of the 9th century[5].

The astrolabe was of substantial religious importance to the Islamic world because of its ability to both predict prayer times and determine the current time. All of the five prayer times throughout the day can be determined using the astrolabe. The first prayer time, maghrib, is said at exactly sunset. The second, isha'a, is said at nightfall, or when the evening sun is 18° below the horizon. The third, fajr, is said at dawn, again when the morning sun is 18° below the horizon. These locations are trivial problems to solve with a classic astrolabe. The last two prayers are defined from shadow lengths of a vertical ruler, which is a more complex problem, so Islamic astrolabes often included additional arcs specialized for this purpose.

Figure 4: Qibla Arcs – The arcs concentric to the astrolabe represent the days through the calendar year, and the roughly horizontal arcs give the sun's qibla altitude for various cities, notated near the astrolabe's rim on the right. The roughly vertical arcs give the sun's noon altitude for various latitudes. This astrolabe was made by Khalīl Muḥammad ibn Ḥasan 'Alī in 1710, and currently resides in the Oxford Museum of the history of science[6].

The back of Islamic astrolabes included another religiously significant tool, a diagram for determining the attitude of the qibla, or the direction to Mecca. This diagram consisted of curves for major cities that gave the altitude of the sun, if the sun happened to be in the direction of Mecca. To determine the qibla, the astrolabe's user would simply wait until the sun was at the altitude given by the diagram, and then noted the direction[7].

As the astrolabe's functionality was replaced by more accurate instruments, such as the sextant, Muslims retained their association of the astrolabe with its religious significance, allowing the astrolabe to remain popular in the Islamic world beyond its relative abandonment in Europe. Consistent with the theory of interpretive

[5]Al-Farghani, Ahmad. "On the Astrolabe." Google Books. Trans. Richard Lorch. Web. 24 Nov. 2010.
[6] "Astrolabe Report (inventory Number 33739)." *MHS - Museum of the History of Science, Oxford* -. Web. 24 Nov. 2010.
[7] Morrison, James E. *The Astrolabe*. Rehoboth Beach, DE: Janus, 2007. 139. Print.

flexibility, the uses of the astrolabe initially flourished, but as time progressed, the technology settled into a single niche, that of religious symbolism. Later Islamic astrolabes sometimes took this to the extreme, completely sacrificing utility for artistic form. One such astrolabe in the British Museum is a brass disc roughly two feet across, making it unrealistically heavy to hold with one hand to measure a star's altitude[8].

Astrolabes have the longest history in the Persian world, so it is unsurprising that the astrolabe's traditional value outweighed the forces of technological irrelevance. Interpretive flexibility can be applied to both technological function and cultural symbolism, so as the function was replaced over time with new timekeeping and navigation devices, the cultural use of the astrolabe remained in strong Persia.

Chaucer's Astrolabe

Astrolabes only became popular in Europe beginning in the 13th century, well after its development in the Persian world. European medieval culture was particularly ripe for astrolabe use. The medieval celestial model still retained Aristotle's concentric spheres, which loaned itself to the earth-centric astrolabe. European education, usually carried out through the church, was particularly heavy on the classics, including Latin, Greek, geometry, and astronomy. Christian holidays, such as Easter and Christmas, have strong historical roots in the astronomic solstices. The astrolabe's clear utility in telling time, prediction of astronomical events, and relationship with astrology, made it a natural fit for medieval practices.

While relatively late in acquiring the astrolabe, England certainly adopted the astrolabe with gusto. The first technical document ever written in the English language was about astrolabes, authored by Geoffery Chaucer of *Canterbury Tales* fame. Chaucer's *Treatise on the Astrolabe* is written as an instruction manual dedicated to Chaucer's son Lewis, although whether Lewis was Chaucer's true son, grandson, or son of a friend is uncertain. The framing of the *Treatise* as an educational document is very

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[8] "British Museum - Brass Astrolabe with Silver Inlay." *The British Museum › Welcome to the British Museum*. Web. 24 Nov. 2010

consistent with the astronomical curriculum of the period[9]. The Treatise is technically unfinished, according to the parts enumerated in its introduction, but does include a description of an astrolabe and instructions on how to use it[10]. The description is especially interesting archeologically, because it fits a surviving astrolabe from the period.

Typical of many European astrolabes, Chaucer's astrolabe contained a diagram for calculating "unequal hours", a popular method of timekeeping in medieval Europe, also described in his *Treatise*:

> "The unequal hours are called planetary hours. Some of the time they are longer during the day than at night, and sometimes the opposite. …Divide the arc of the day into 12 equal parts to find the length (ed. in equal hours) of an unequal hour during the day. If you subtract the length of the unequal hour during the day from 30, the difference is the length of the unequal hour of the night."[12]

Figure 5: *Chaucer's Astrolabe* – This astrolabe, dated to AD 1326, is of the same period and fits the description in Chaucer's Treatise. The astrolabe contains plates for Oxford, as well as other important cities, such as Jerusalem, Rome, and Paris. It is currently held in the British Museum.[11]

An unequal day hour is defined as one twelfth of the day, while an unequal night hour is one twelfth of the night. These hours are "unequal" for obvious reasons; their length depends on the season and latitude. While seemingly an odd timekeeping measurement, the unequal hour makes much more sense in terms of a ratio[13]. For example, at the third unequal day hour, the daytime is a quarter over. European society was widely rural at the time, driven by the solar cycle, so this timekeeping technique was easy to estimate and a useful division of the day.

Unfortunately for a rural astrolabe user, the astrolabe's time frame is consistent with the true, equal hour. Most European astrolabes, therefore, contained an easy additional measurement tool, the unequal

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[9] Karl Erik Elmquist. "An Observation on Chaucer's Astrolabe." Modern Language Notes, Vol. 56, No. 7 (Nov., 1941), pp. 530-534

[10] Chaucer, Geoffrey. "Chaucer's Astrolabe Treatise." Ed. James Morrison. Web. 24 Nov. 2010. pp. 1

[11] "British Museum – The Chaucer Astrolabe." *The British Museum › Welcome to the British Museum*. Web. 24 Nov. 2010

[12] Chaucer, Geoffrey. "Chaucer's Astrolabe Treatise." Ed. James Morrison. Web. 24 Nov. 2010. pp. 10-11

[13] Morrison, James E. *The Astrolabe*. Rehoboth Beach, DE: Janus, 2007. 41. Print.

hours diagram. Given a measured sun altitude (measured using the alidade) and the maximum altitude of the sun for the day (either looked up in a table or calculated from the astrolabe's front) the time in unequal hours could be calculated.

The unequal hour diagram, like most European astrolabe attributes, was not actually developed in Europe, but instead borrowed from earlier Islamic astrolabes[14]. However, after the 14th century, the unequal hours diagram became almost universally included in European astrolabes[15]. The adoption was highly practical, Europeans had no need for the determining the quibla, which opened a large portion of the astrolabe back for further development. Later European astrolabes sometimes even contained a complex equal hour-unequal hour conversion chart, eliminating the use of the alidade as an altitude pointer.

The European emphasis of unequal hours is indicative of a strong shift in what makes the astrolabe valuable. Unequal hours are a purely practical timekeeping metric that completely ignore the beauty of a celestial rotational model. As the unequal hour functionality of the astrolabe became more popular, the other side of the astrolabe with the rete and rule became less useful and less ornamented. This trend continued, until later forms of the astrolabe, such as the universal astrolabe (a device for performing coordinate transforms and other astrolabe problems without the need of a rotating rete), placed so much information on the astrolabe back that the rete and rule became largely obsolete.

European astrolabes are a quintessential example of interpretive flexibility. After their initial introduction, astrolabes in Europe were adapted for local uses consistent with the European culture. While the astrolabe in the Islamic world had substantial religious and artistic significance, astrolabes in Europe were a tool, which would be replaced as soon as more accurate tools emerged. The astrolabe's niche in Europe was largely functional, and it was therefore easily replaced. This quality is even more pronounced in the mariner's astrolabe.

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[14] Morrison, James E. *The Astrolabe*. Rehoboth Beach, DE: Janus, 2007. 117-21. Print.
[15] Morrison, James E. *The Astrolabe*. Rehoboth Beach, DE: Janus, 2007. 41. Print.

The Mariner's Astrolabe

Determining location at sea is a particularly difficult problem, and navigational errors can be dangerous for both crew and cargo. While ship latitude could be measured through a variety of means, including by astrolabe, accurate longitude determination was a particular thorny problem that remained unsolved until the late 1700's. To avoid longitude error, ships would sail until reaching the latitude of the intended port, and then sail along a constant latitude track until a shore landmark became visible[17]. Dead reckoning, the practice of estimating ship position based of a record of the ship's heading and speed, would add additional navigational information for short voyages.

Figure 6: *Mariner's Astrolabe*- This Spanish astrolabe, dated to around 1600, was found drowned in the Gulf of Mexico and currently resides in the Museum of History of Science in Oxford, UK[16]. Note the lack of rete or plates typical of land astrolabes; this instrument was purely a pointing device, not a map of the heavens.

The Mariner's astrolabe demonstrated a specialization of astrolabe technology for sea navigation, in this case stripping some functionality for a more accurate device. An example mariner's astrolabe can be found in Figure 6. The mariner's astrolabe includes only an alidade and angular scale, dropping the rete and plates typical of a land astrolabe. Instead, the mariner's astrolabe was used in conjunction with an almanac of stars and trigonometric tables, providing a substantially more accurate star position system than the geometric precision of a rotating rete. In this way, the mariner's astrolabe includes only the astrolabe's measuring functionality, leaving the rest of the calculations to the mariner's mathematical skills in spherical geometry.

The mariner's astrolabe was used in a similar fashion as a normal astrolabe. The instrument was held at arm's length above the head, with the weight of the astrolabe vertically aligning it perpendicular to the

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[16] "Astrolabe Report (inventory Number 54253)." *MHS - Museum of the History of Science, Oxford* -. Web. 24 Nov. 2010.

[17] "The Mariner's Astrolabe." *The Astrolabe*. Web. 18 Dec. 2010. <http://astrolabes.org/mariner.htm>.

horizon. The alidade was then pointed at the celestial object of interest, usually the sun or a star as it crossed the prime meridian (the north-south vertical arc in the sky). Given a table of the declinations of various objects, the observer's latitude could be determined by the equation 90-measurement+declination[18].

A useable astrolabe cannot be too heavy; otherwise it is impossible to hold in one hand to take an altitude measurement. For the astrolabe to be used practically on a heaving ship, however, the instrument was usually made as close to this limit as possible to avoid the ship's rocking from affecting the measurement. Several modifications were therefore implemented to remove unneeded metal parts, allowing the radius of the astrolabe to be made larger while maintaining the upper weight limit, thereby increasing the resolution and accuracy of the degree scale along the perimeter[19]. The lack of the plates, rete, and thick mater lowered manufacturing complexity, but more importantly, also removed unneeded metal. In addition, it is no mistake that the ornamentation on the mariner's astrolabe consisted of large artistic through-holes, cutting more mass and allowing the sea wind to pass through the instrument instead of tilting it[20].

It is no coincidence that the mariner's astrolabe is a relatively unknown instrument, despite its almost universal use in ships from the 1500s to 1700s. Once other instruments surpassed its accuracy, such as the sextant, there was no need for the mariner's astrolabe, and without artistic value to preserve, most mariner's astrolabes were probably sold back to smithy as scrap metal[21]. The mariner's astrolabe was significant only for its utility.

The mariner's astrolabe represented a shift in astrolabe use, perfectly indicative of interpretive flexibility. The astrolabe is a multi-purpose map of the heavens; latitude determination is only one of its many functions, including predicting sunset times, star locations, telling the time, and simply looking pretty. However, sailors removed all unnecessary functionality or symbolism. The mariner's astrolabe

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[18] S. A. Ionides. "Description of an Astrolabe." The Geographical Journal, Vol. 24, No. 4 (Oct., 1904), pp. 411-417
[19] Morrison, James E. *The Astrolabe*. Rehoboth Beach, DE: Janus, 2007. 165-166. Print.
[20] "The Mariner's Astrolabe." *The Astrolabe*. Web. 18 Dec. 2010. <http://astrolabes.org/mariner.htm>.
[21] R. T. Gunther. "The Mariner's Astrolabe." The Geographical Journal, Vol. 72, No. 4 (Oct., 1928), pp. 342-344

was a technician's tool, unornamented and optimized for a very specific user. The mariner's astrolabe, therefore, was like the European astrolabe in its focus on function, so was easily replaced when the sextant performed this function better.

Conclusion and Discussion - My Personal Astrolabe

The astrolabe is somewhat of a misfit in the modern context. At this time, all of the astrolabe's practical functions have been replaced by more accurate devices. Therefore, in applying the concept of interpretive flexibility to the modern context, it would be unreasonable to use the astrolabe as it was originally intended. The current expert in astrolabe technology, James Morrison, whom I have cited extensively in this paper, has designed astrolabes accurate to within minutes, therefore usable in everyday scenarios. However, I am perfectly happy using my watch and GPS, and I do not believe that people will adopt the classic uses of an astrolabe. Astrolabe models sell well in museum gift shops, but not as timing devices.

Figure 7: ***My Astrolabe*** **– The astrolabe is approximately 8.5 inches across, making it on the larger range for an astrolabe. Typical time measurements are accurate to within 5 minutes.**

Instead, a modern astrolabe is an artistic piece, designed to please the eye. Specifically, good modern astrolabe should be attractive enough to spark human interest, allowing it to be used as education tool for astronomy, history, and history of technology. The accuracy of the instrument as a timekeeping device is not as important, but it should include as many traditional elements as possible to enhance its educational scope.

In this vein, I designed and machined my own astrolabe (Figure 7). I attempted to make the device as artistic and educational as possible, while sacrificing accuracy for machinability. I included elements of both European and Persian astrolabes, but largely ignored the Mariner's astrolabe, as my focus was art, not function. The mater, rete, rule, and alidade are all engraved aluminum parts, machined on a CNC mill. The plates are laser-engraved blue acrylic, and the shaft is brass. I only engraved the angular scales on five degree increments, attempting to minimize the amount of engraving I had to do, but I still ended up spending two weeks living in the machine shop. I knew that, as an artistic piece, visual appearance was an integral part of my astrolabe's value, while I would have been less inclined to perfect my finish on a purely functional instrument.

My rete design is concrete example of this artistic adaptation. The rete is simply a star chart, and a good rete design points to these stars while covering the minimum possible area, making it easier for the user to view the plate beneath. I instead pushed the rete in a more artistic direction, with treelike imagery I have yet to see on another astrolabe, covering an unwieldy large portion of the plate. This sacrifices function for form, but is perfectly appropriate for my use case.

The astrolabe's days as a functional device are over. The Aristotelian celestial model is debunked, atomic clocks have replaced the earth's rotation as a timekeeping metric, GPS can position us on Earth to meters of accuracy, and Google sky will locate stars, the sun, and planets in ways that the astrolabe never could. However, we maintain our fascination with shiny old brass devices, and the astrolabe has finally settled into this singular niche. In its early days, the astrolabe was the quintessential example of interpretive flexibility. In the domain of celestial modeling devices, the astrolabe was the jack of all trades, master of none. Today, its single remaining function, however, is its artistic value. The Persians, with their seeming ridiculously large astrolabes, had it right after all. Ornamentation is more important than function for ancient devices in a modern world.

Appendix: Use of My Astrolabe

The machine shop staff has expressed interest in machining more copies of my astrolabe as gifts for Olin donors, etc. The following appendix explains the various diagrams and text on the astrolabe, as well as the machinability of various components.

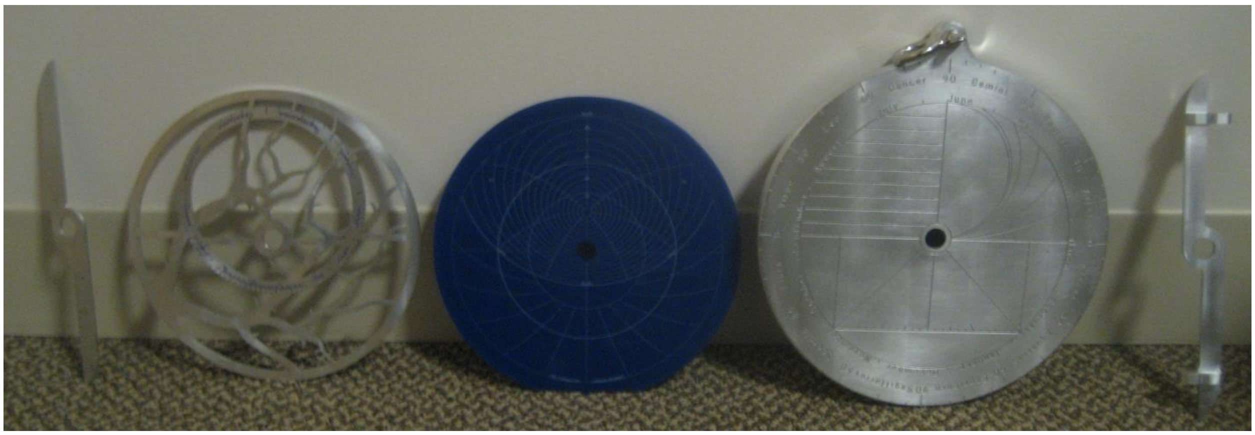

Figure 8 – Final Astrolabe, taken apart to show components.

Rule: The rule on the front of the astrolabe is marked with a declination scale in increments of 5°. My original design only includes up to ±30°, but this makes it impossible to measure the declination of some of the stars. The scale should go up to at least +60°.

The part is a CNC mill job, but was obnoxiously difficult to clamp in the vice. To mitigate this problem, I first machined a different profile with tabs for bolting and clamping, then milled off the tabs. Facing was done with a fly-cutter, because the facing endmill caused too much vibration on such a thin part.

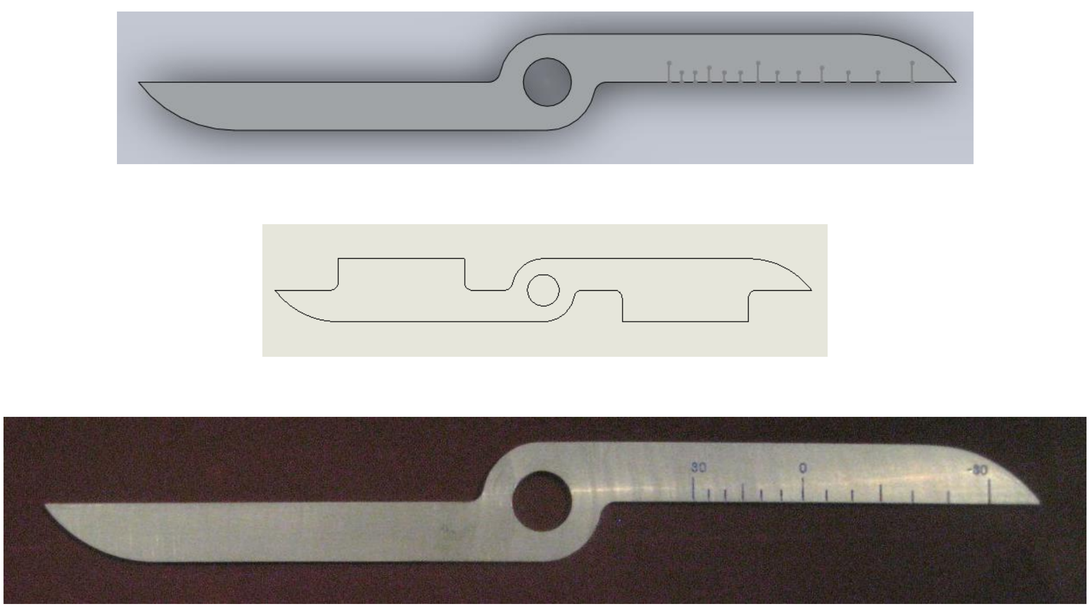

Figure 9: Rule CAD, DXF Profile, and Final Part

Rete: The rete was initially waterjetted with a square profile, including bolt holes so I could later clamp and face the part. Again, facing was done with a fly-cutter. As is traditional, the ring of the ecliptic is engraved with the zodiac, allowing the user to know the position of the sun relative to the stars as a function of the month. The star pointers point to Altair, Vega, Deneb, Capella, Alkaid, Arcturus, Etamin, Spica, Betelgeuse, Rigel, Aldebaran, Regulus, Procyon, Sirius, and Diphda.

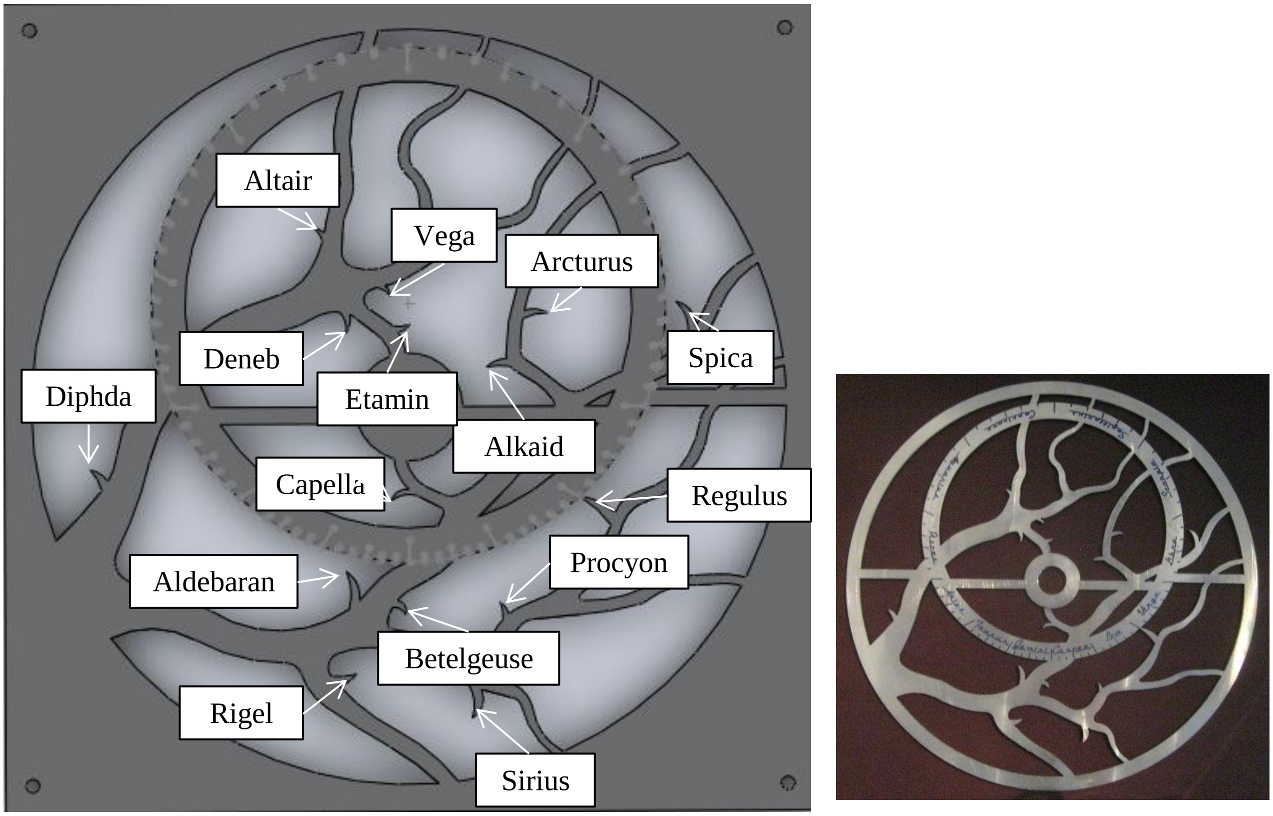

Figure 10 – Rete CAD and Final part

I designed the rete with an especially artistic support structure for the star pointers; however, this sometimes gets in the way of viewing the plate. Personally, I think it’s entirely worth it.

Plate: The plates of my astrolabe are made of blue laser-engraved acrylic plastic. For the astrolabe to work, the plates must be rotationally constrained to the mater, so I designed the plates with small protrusions that fit into a matching pocket in the mater's rim.

The engraving consists of altitude lines, in increments of 5°, and azimuth lines in increments of 45° degrees (corresponding to North, Northeast, East, Southeast, etc.). The horizon line is bolded, as is the equator. The lower half of the plate contains unequal hour arc for determining the percent of night passes, similar in function to the unequal hours diagram on the back of the mater.

The plate engraving is a function of latitude, so most astrolabes traditionally had many interchangeable plates. I have two plates, one for Olin latitude and one for Los Alamos, NM (my home town). Both plates are stacked inside the mater.

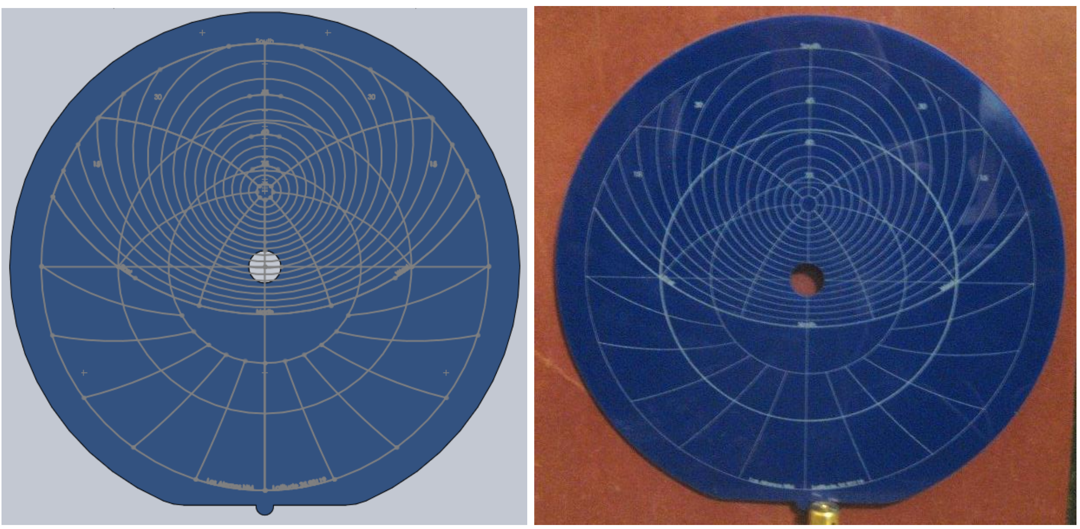

Figure 11: Plate CAD and Final Part

Alidade: The alidade, or star sight, is fashioned to look much like the rule. It has two large slits so that the user can accurately sight a star, and a straight edge for correlating that sight with a degree scale on the back of the mater. I made the alidade on the CNC mill from an aluminum block, much like the rule.

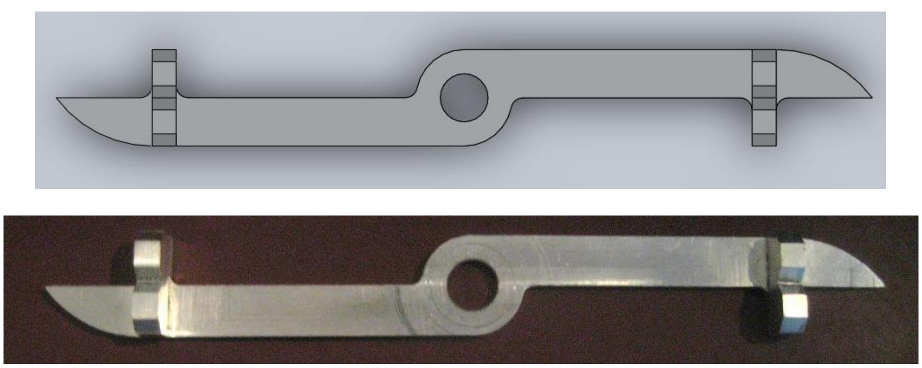

Figure 12: Alidade CAD and Final Part

Mater: The mater is a large aluminum part, machined on the CNC mill. The front side has the time engraved in roman numerals around the rim, and a large cavity for holding the plates and rete.

The back is more complicated. Around the outside is a 5° increment degree scale, used with the alidade, for taking an altitude measurement of the sun or a star. This scale is also divided by the months of the zodiac and the months of the year. One can therefore determine the sun's location in the zodiac by placing the alidade through the month scale, and looking at the angular scale on the mater's rim. I simplified this zodiac-to-calendric month conversion due to time constraints, but it is accurate to within the 5° resolution on the angular scale.

Figure 13 – Front and back of the Mater, Final Part

The center of the mater back contains 3 additional diagrams. The upper left is a sine table, common on Persian astrolabes, divided by a decimal scale. For a degree on the rim, the sine is given by the horizontal line closest to the alidade's intersection with the inner circle.

The upper right is an unequal hours diagram, common on European astrolabes. To use this diagram, the user first determines the altitude of the noon sun using the front of the astrolabe. Then, he places the alidade through that angle on the rim. Next, he notes the point that the smallest circle on the diagram intersects the alidade. Finally, he takes a sun sighting. The earlier noted point now rests near one of the other arcs in the diagram, giving the time in unequal hours.

The bottom of the central region is a shadow square, used for surveying. Given an alidade sighting of the top of a building, the shadow square gives the height of the building proportional to the observer's horizontal distance to that building.