The Mirror of Light

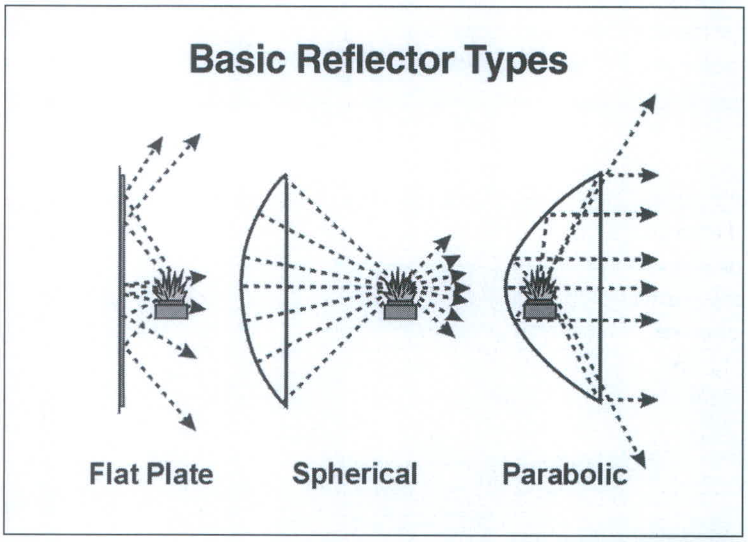
Part One

By Tom Tag

Introduction

This is a story about the Χατοπτρου system of lighthouse illumination. What is Χατοπτρου? It is the Greek word (catoptron) for mirror, or reflection, and the lighthouse illumination system based on the principle of reflection was given the name *Catoptric* System in English.

The major problem with early lighthouses was the small output of light from the wood or coal fires then being used. Lighthouse designers were constantly looking for ways to produce more light. Experiments were made with the types of fuel being burned, with the design of the braziers, which held the burning fuel, and with ways to direct or concentrate the light from the fire. The first method of projecting and directing the light started with the design of the reflector. In this story we will discuss the various types of reflectors that were used to create the 'Mirror of Light'.



Drawing by the author.

Reflector Designs

Reflection occurs when a ray of light hits a painted or polished surface and is reflected from the surface. Highly polished metal surfaces behave as mirrors, and when they are made in the shape of a parabola they concentrate the light from a light source placed in the focus of the parabola.

There are three basic types of reflecting surfaces, Flat, Spherical and Parabolic as shown in the drawing. Flat plate reflectors are seldom truly flat, nor are they always highly reflective. A flat plate reflector reflects light in many directions and only a small portion of the light is reflected forward in a direction useful to a mariner.

Spherical reflectors return the light rays to the focus of the reflector where the lamp is placed. A spherical reflector will appear to intensify the brightness of the flame, but will not form the light into a concentrated beam useful to the mariner.

Parabolic reflectors gather the light from the focus of the reflector and return it in a concentrated beam in the direction the reflector is facing. This concentrated beam of light can be directed to the horizon and can be manipulated to provide a very useful light for the mariner. However, approximately 30 percent of the total available light escapes from around the edge of the reflector and is not concentrated into the beam.

Problems with the manufacture of reflectors kept them from reaching their theoretical capabilities. The parabolic shape was very difficult to fashion by hand. Two general methods of construction were employed. In the early method, a sheet of metal, usually copper, was fashioned into a crude parabolic shape by hammering a flat sheet using only the skill of the craftsman as a guide. Later, wooden molds were carved by hand and checked against paper or brass templates. The sheets of metal were then formed into parabolic shapes by hammering into the mold, and still later, iron molds were used to create more refined parabolic reflectors. The copper reflectors were then polished to form a shinny surface to reflect the light. However, plain copper was not a very reflective surface and was soon abandoned. A second construction method used heavy silver cladding, which was bonded to the copper to improve its reflective qualities. Unfortunately silver oxidizes (tarnishes) rapidly leading to the need for continual polishing. The removal of the tarnish and also of the soot left on the reflector from the lamp flame, when chimneyless lamps were used, caused the need for polishing the reflectors on a very frequent basis. In many cases the silver cladding was polished so much that it was removed from the copper surface altogether, returning the reflector to a poor state of light reflection.

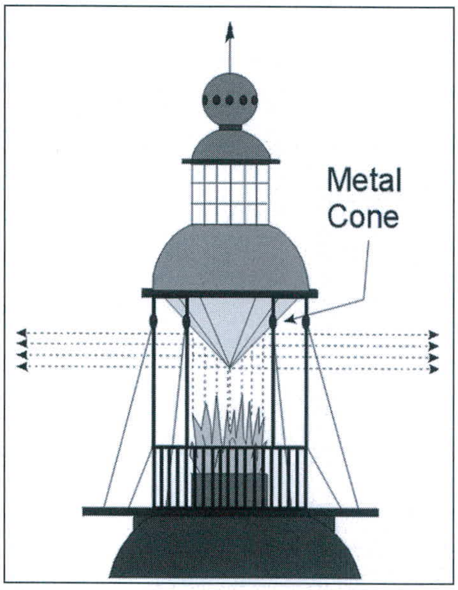
With any metallic surface, a portion of the light is absorbed into the surface by slight imperfections, scratches, soot, and the metal itself. It was found through experiment that the highest quality metal reflectors with the best silvering and polished surfaces still reflected just 55 percent of the available light. In addition, some of the light is lost around the edge of the reflector and it was determined that only 70 percent of the total light from the lamp was actually collected by the reflector. Thus the total light collected and sent in a useful direction by a nearly perfect reflector is a combination of the two factors just mentioned or about 39 percent, while an average quality reflector produced as little as 20 percent.

An Argand Lamp produced between six and seven candlepower at any single point of observation. A high quality 21-inch diameter-silvered-parabolic reflector collected and reflected 39 percent of the total available light from the lamp creating a concentrated beam of light that increased the power of the lamp by about 350 times, and thus the combination Argand lamp and reflector produced 2450 candlepower.

The most powerful light from a parabolic reflector is concentrated in the central axis of its beam. At positions as little as 8 degrees on either side of the central axis the effective candlepower is only ten percent of that in the center, and in areas beyond eight degrees the light drops very quickly. This narrow divergence of the light beam required the mariner to be almost directly in line with the front of the reflector in order to see the light beam at a distance. The divergence is a function of the size of the lamp flame and the focal distance of the reflector, with the average reflector's useful beam covering about 14 degrees of the horizon, and intense light covering about 5 degrees.

A Note About Candlepower

The determination of the light output of reflectors and lamps is usually measured in candlepower. In the early years of reflector development there were no accurate methods of measuring candlepower and later, in the early 1800s the methods used were very subjective and unscientific by our current standards. The candlepower is also dramatically affected by the size of the reflector, the type of oil used as a fuel, the maintenance of the lamp and polish of the reflector and by other factors such as the clarity of the air and alignment of the reflector with the horizon. In describing the various apparatus in this story I have used the candlepower ratings developed or estimated by the various inventors. However, the candlepower ratings should only be used as a very rough estimate of the relative power of each instrument as compared to the others and not as a true rating of its actual light output.



The open coal lantern room of the Cordouan Lighthouse in France with Bitry's Cone, 1727. Drawing by the author.

Early History

The first reflectors were whitewashed walls and later flat metal plates of polished brass or tin were used, set in the walls behind the open flames from the coal braziers in early lighthouses such as the lighthouse at Harwich, England. The earliest known use of these reflectors was on the Baltic Sea at the lighthouse of Gollenberg, now in Poland, which had a single candle lamp backed by a polished metal reflector in 1532.

In 1660, Johan D. Braun designed and manufactured cast steel reflectors in Sweden. They were used at the lighthouse at Landsort, Sweden, which used one reflector, shape unknown, and a single primitive oil lamp in 1669. Braun was given a patent for the use of these reflectors in lighthouses, in 1681. One of the more unusual reflector designs was invented about 1687 and used at the lighthouse of Orskar, in Sweden, which had 6 large Braun reflectors, shape unknown, each with 2 oil lamps.

Metal reflectors were also used in Germany at Travemünde in 1710, where the lighthouse had two reflectors and each reflector had a lamp with two wicks. The first reflectors in Germany were purchased from England or France. Later in the early 1800s, a German, Johann Georg Repsold, began making less expensive and optically improved reflectors for the German market.

A major attempt to intensify the light from a lighthouse wood or coal fire was made in 1727 by Monsieur Bitry at the Cordouan lighthouse in France. The mariners had complained they could not see the coal fire in the lighthouse from more than a few miles away. Monsieur Bitry covered a cone of wood with metal plates and suspended it, point down, above the fire. The reflection of the flames in the metal made the light appear brighter, but the system was not adopted elsewhere, probably because soot from the fire constantly dulled the reflector and made any increase in the light very difficult to sustain.

In 1738, the first mention of a parabolic reflector suggests that five parabolic Braun cast-steel reflectors, each with from two to six lamps were installed at the lighthouse at Orskar, in Sweden.

Glass Facet Reflectors

The first attempt at a true parabolic reflector in England, was a design by William Hutchinson in 1763. In his book 'A Treatise on Practical Seamanship' published in 1777, William Hutchinson described how his reflectors were constructed and employed:

"We have had in use here at Liverpool, reflectors of 1, 2, and 3 feet focus, and 3, 5, 7 and 12 feet diameter, the three smallest made of tin plates soldered together, and the largest of wood, covered with plates of looking glass, fixed as near as can be to the parabolic curve, and using a copper lamp. The cistern part of the lamp stands behind the reflectors, so that nothing stands before the reflector to interrupt the blaze from acting upon it, but the tube that goes through it, with a spreading burner mouth-piece, to spread the blaze of the lamp parallel to, and with the middle of it, just in the focus or burning point of the reflector. We have a feeding can with oil to stand upon the cistern of each lamp, with a small brass cock that is turned to drop or run a little according to the consumption of oil."

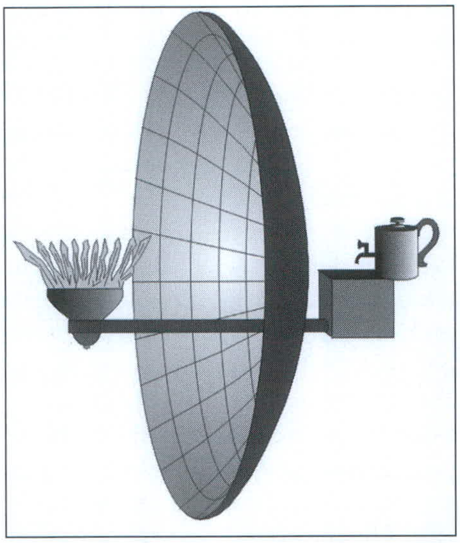
The Hutchinson oil lamps could be seen from ten miles away, and needed to have their flat rope wicks trimmed (snuffed) every 4 hours.

Ezekiel Walker of Lynn, England rebuilt the lighting for the Hunstanton lighthouse in 1776, and installed lamps with 18-inch parabolic reflectors made of pieces of mirror glass.

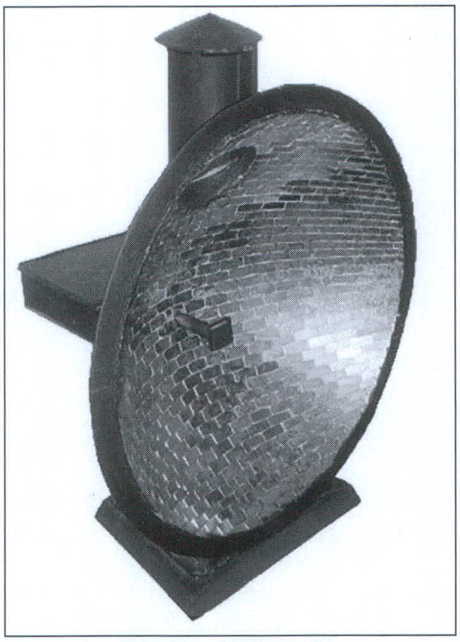
Ezekiel Walker used facets of mirror glass tapering in width arranged in long rows set into a parabolic plaster shell in a metal frame and fixed in position with varnish and white lead. Walker's reflectors used a single flat wick made of five cotton strands. Walker's glass facet reflector's gave about two thirds of the power of an equal diameter silvered metal reflector, and were estimated at about 1000 candlepower.

In 1777, a very unusual reflector and lamp was created and installed at the Lowestoft lighthouse in England. It was named the 'Spangle Light' because of its use of a concave drum on which 4000 glass mirror facets were placed. Surrounding the concave drum was a hollow tube ring with 126 holes into which short rope wicks were placed. This ring was fed from a common oil supply and when the 126 wicks were lit their light was reflected from the Spangle drum and out to the sea. The Spangle Light was first lit in 1778, but while the light was better than the previous coal fire, the 126 flames used a large quantity of oil, were difficult to maintain, and soot formed easily on the 4000 mirrors. The Spangle light was abandoned in 1796.

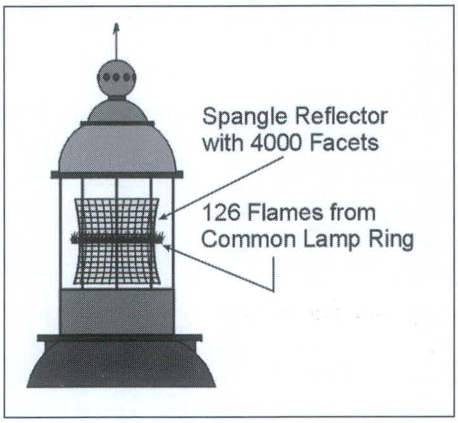
Thomas Smith, Engineer of the Northern Lighthouse Board in Scotland, built a parabolic reflector made of polished tin in 1786. During the following year, Smith changed from polished tin to octagonal reflectors twelve inches in diameter made of 48 pieces of mirror glass using Ezekiel Walker's design process. He also a made larger reflectors with 350 pieces of mirror glass set in plaster on a brass plate eighteen inches in diameter, which



Hutchinson's large glass facet reflector, 1763. Drawing by the author from Hutchinson's drawings.

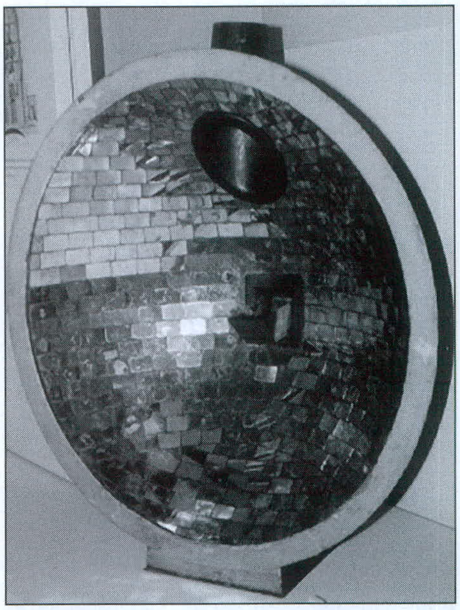


Ezekiel Walker style faceted glass reflector circa 1776. Photo from the author's collection.

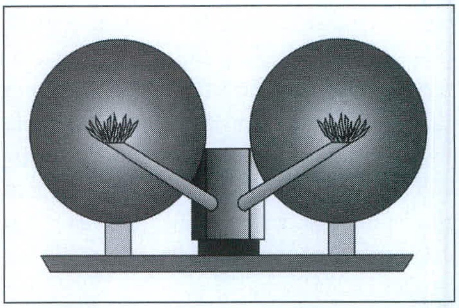


The spangle light used at Lowestoft Lighthouse, 1778. Drawing by the author.

were used at the Kinnaird Head lighthouse in 1787. These reflectors used a lamp with four rope wicks and this reflector and lamp combination produced about 1000 candlepower. The last glass facet reflector of this type was produced in 1801 and removed from use in Scotland in 1820.



Thomas Smith's glass facet reflector circa 1787. Photo from the author's collection.

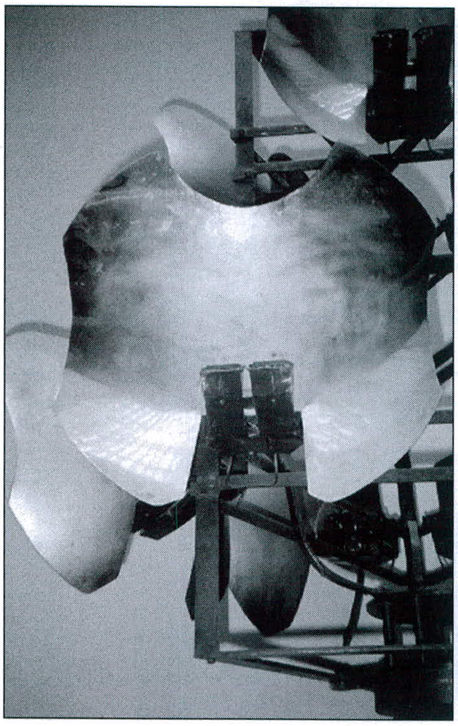


Hutchinson's 11-inch metal reflectors used at Point Lynus, England before 1790. Drawing by the author from Hutchinson's drawing.

Later Metallic Reflectors

During the 1770s, William Hutchinson designed a dual tin reflector with a lamp having a single reservoir and two wick tubes utilizing rough rope wicks. He suggested that a large number of such reflectors could be placed in a circle to form a fixed light. He also suggested that the reflectors could be stacked, as on a staircase, in different numbers at each lighthouse to provide a form of characteristic to distinguish one lighthouse from another. However, this suggestion would only have worked if the lights were placed more than six feet apart within the lighthouse, and the observer was within one mile of the lighthouse. Beyond one mile, the light from the various lamps would have blended in the eye of the mariner and become a single light, eliminating the ability to establish the lighthouse's characteristic.

Spherical metallic reflectors designed and manufactured by Pierre Tourtille-Sangrain in 1771 were used in the French lighthouse at St. Mathieu in 1773. The spherical reflectors provided little improvement over the power of the lamp itself, and were each rated at only about 30 candlepower. In 1782, the Cordouan lighthouse in France used 80 of Tourtille-Sangrain's smaller one-wick reflectors.

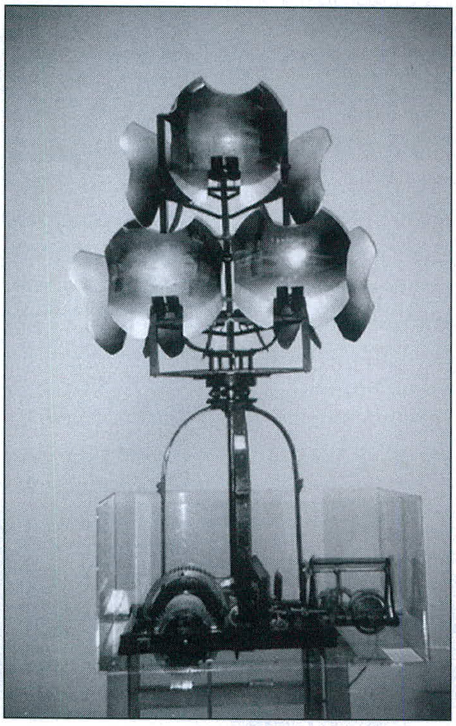


Detail of Tourtille-Sangrain's large spherical reflector of approximately 18-inch diameter with two flat-wick burners.

In 1780, the Chevalier Borda proposed a reflecting circle of spherical reflectors, which was put under test in France. Borda also designed reflector lamps mounted in several tiers on square or polygonal frames that were turned on a vertical central shaft, creating a revolving characteristic for the lighthouse. Joseph Teulere reviewed Borda's design and proposed the use of improved parabolic reflectors and lamps in June 1783, and Ami Argand proposed the applicability of the parabolic reflector with his lamp design for use in lighthouses. In 1790, Borda had Monsieur Lenoir, a young artist of Paris, create true parabolic thirty-one-inch diameter reflectors, made of steel and clad with four leaves of silver, based on Teulere's design, using Argand style lamps made by Antoine Quinquet without chimneys, and had him install them in the Cordouan lighthouse in France.

The first polished-metal-parabolic reflectors used in Germany were installed in the lighthouse at Memel, in what is now Lithuania, in the year 1796.

In 1803, the Inchkeith Lighthouse received Scotland's first polished-metal-parabolic reflector. Scotland's Northern Lighthouse Board standardized on 21-inch reflectors for fixed lights and 25-inch reflectors for revolving lights.



Tourtille-Sangrain's large spherical reflectors used from 1773 to 1805.

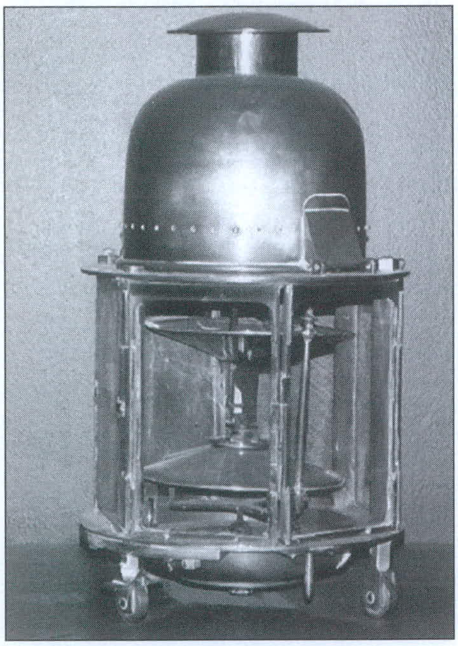
Small, approximately 6-inch diameter one-wick sperical reflector. All photos this page from the author's collection.

Bordier-Marcet's Reflectors

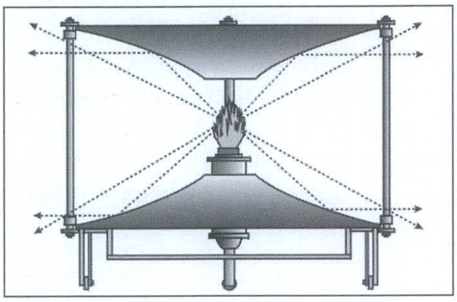
In France, I. A. Bordier-Marcet, who purchased Argand's lamp factory in France in 1801, and became successor to Argand, invented the 'Fanal a Double Effet' reflector in 1808, where two lamps were placed within what at first looked like a single reflector. Actually, it was a compound reflector made of two segments each with a different focus, thus allowing the two lamps to each be in the focus of a different reflector segment. This design was supposed to increase the amount of divergence produced within the compound reflector and there-by increase its output. However, the design produced only a small increase in divergence and power, while it used a far larger amount of fuel, and was soon abandoned. A 26-inch 'Fanal a Double Effet' reflector produced about 3800 candlepower. The word 'fanal' means lantern.

In 1809, Bordier-Marcet invented the 'Fanal Sidereal' reflector where two parabolic reflecting surfaces were placed one above the other. Each of the reflecting surfaces had a central hole where the lamp flame was placed. The Fanal Sidereal reflector was first used in the harbor lighthouse in Honfleur, France and the design was patented in 1812. This design allowed one lamp to give reflected light in a complete disk around the horizon although, as with all reflectors, 30 percent or more of the light was lost at the edges of the reflector, leaving light of 70 candlepower in any direction. One of the largest Fanal Sidereal reflectors, used in a lighthouse, had a diameter of 31.5 inches. The range of this design was much less than that of a standard parabolic reflector, causing Fanal Sidereal reflectors to be limited mostly to use in harbors. One of the major lighthouses to use this design was the Greifswalder Oie light in Germany, where a 'Fanal Sidereal' reflector was installed from 1841 to 1855. It is possible to see this design still in use today for the lighting of walkways in public places, using an electric light source. In 1860, Sir J. F. W. Herschel proposed a very similar design with the addition of a small reflector in the center near the flame that could be adjusted vertically to direct part of the light lower between the horizon and the lighthouse.

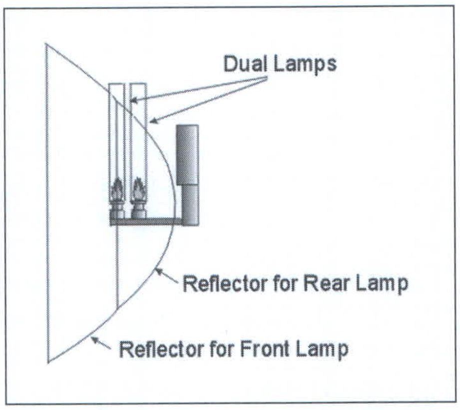
In 1823, Bordier-Marcet created another reflector design, the 'Fanal a Double Aspect'. In this design, the rear portion of each of two parabolic reflectors was truncated and then the two remaining portions of the reflectors were joined together facing in opposite directions. A third reflector was added behind the focus inside one of the reflector halves and facing the lamp. This reflector cut off any possible loss of light from the side it occupied (weak side) and reinforced the light projected in the opposite direction (reinforced side). Bordier-Marcet's idea was to place these triple-reflector combinations on a common rotating chandelier with some of the reinforced reflectors facing in one direction and some facing in the opposite direction. This design would have added only a tiny amount to the light produced. The design was developed just as the Fresnel lens came into use and the 'Fanal a Double Aspect' was never actually used in lighthouses.



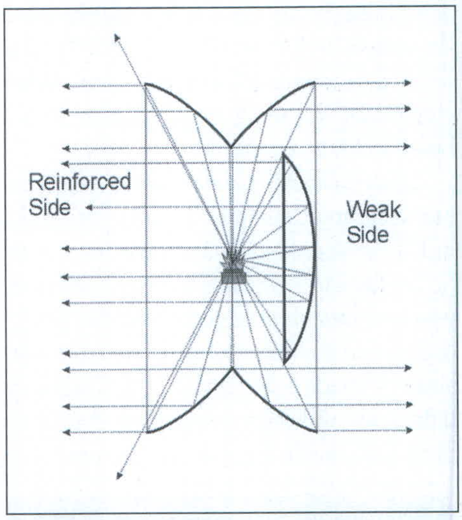
Fanal Sidereal lantern, 1811. Photo from the author's collection.



Bordier-Marcet's Fanal Sidereal reflector, 1809. Drawing by the author from drawing in *Fari E Segnali Marittimi.*



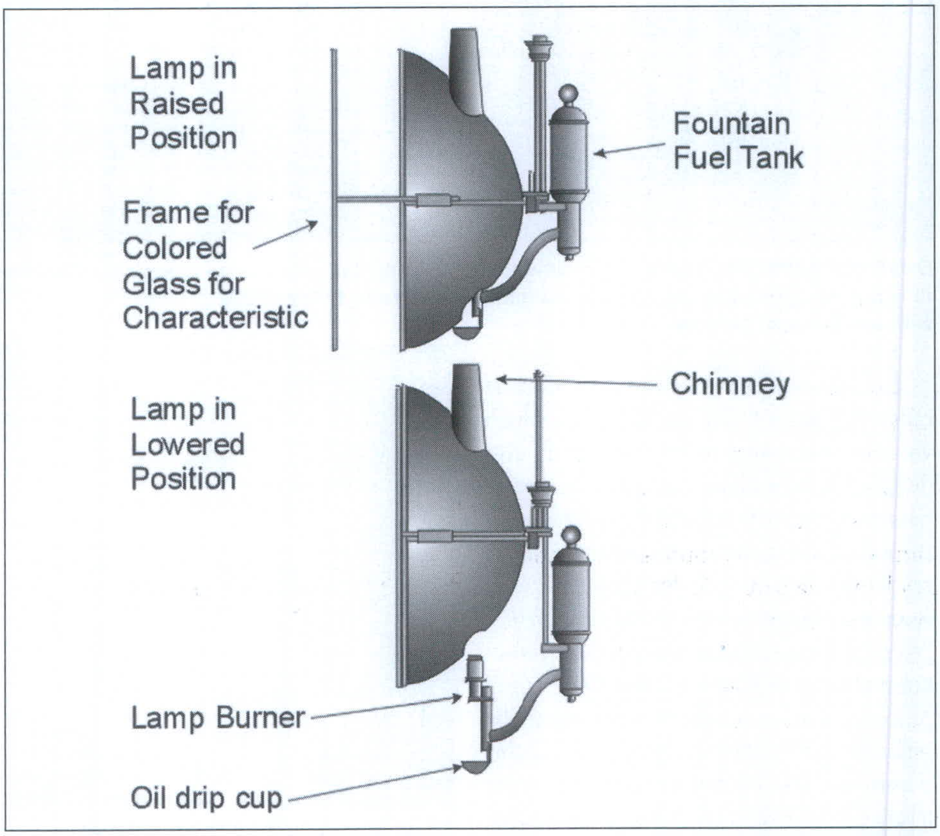
Bordier-Marcet's 'Fanal a Double Effet' reflector, 1808. Drawing by the author from a drawing in *The World's Lighthouses Before 1820.*



Bordier-Marcet's 'Fanal a Double Aspect' reflector, 1823. Drawing by the author from a drawing in *A Rudimentary Treatise in the History, Construction and Illumination of Lighthouses.*

Robert Stevenson's Reflectors

From 1803 to 1810, Robert Stevenson worked to improve the design of Scotland's copper parabolic reflectors and lamps. He chose an improved Argand lamp and a true parabolic reflector with a heavy cladding of silver. By 1809, he had succeeded in developing a design where the lamp was able to be released from the focus of the reflector by turning a locking ring, that let the lamp assembly slide down, allowing easy wick replacement or trimming, and allowing easy polishing of the inside of the reflector. When the work was completed, the keeper raised the lamp back into its preset position, in the reflector's focus, and locked it with the ring. Stevenson's new reflectors were first installed in the Bell Rock lighthouse in 1811, and produced about 2500 candlepower.



Robert Stevenson's retractable lamp reflector, 1811. Drawing by the author from a drawing in *Lighthouse Illumination 1859.*

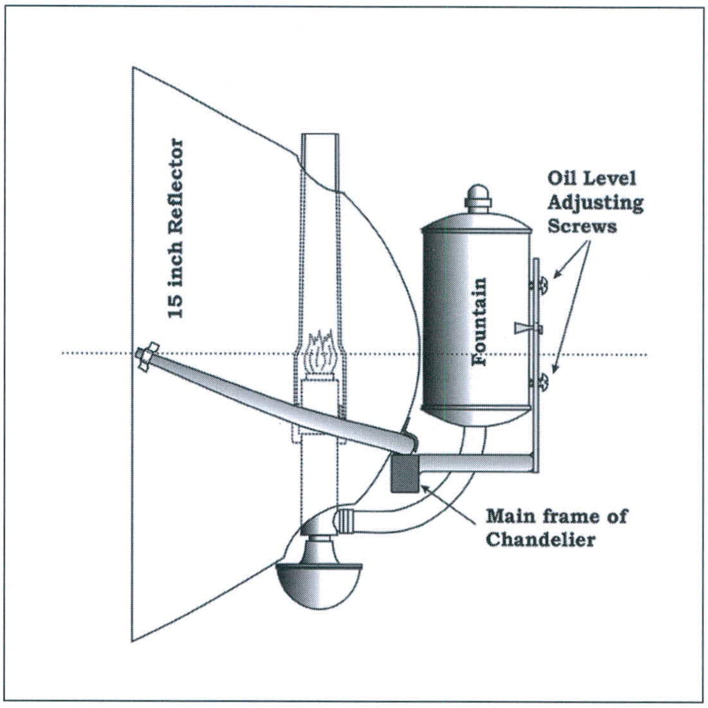
American Reflector Designs

In 1810, Winslow Lewis, a sea captain who confessed that he knew nothing about lighthouse optics, patented what he called a "magnifying and reflecting lantern" for lighthouse work. His design included a lamp, a reflector, and a magnifier.

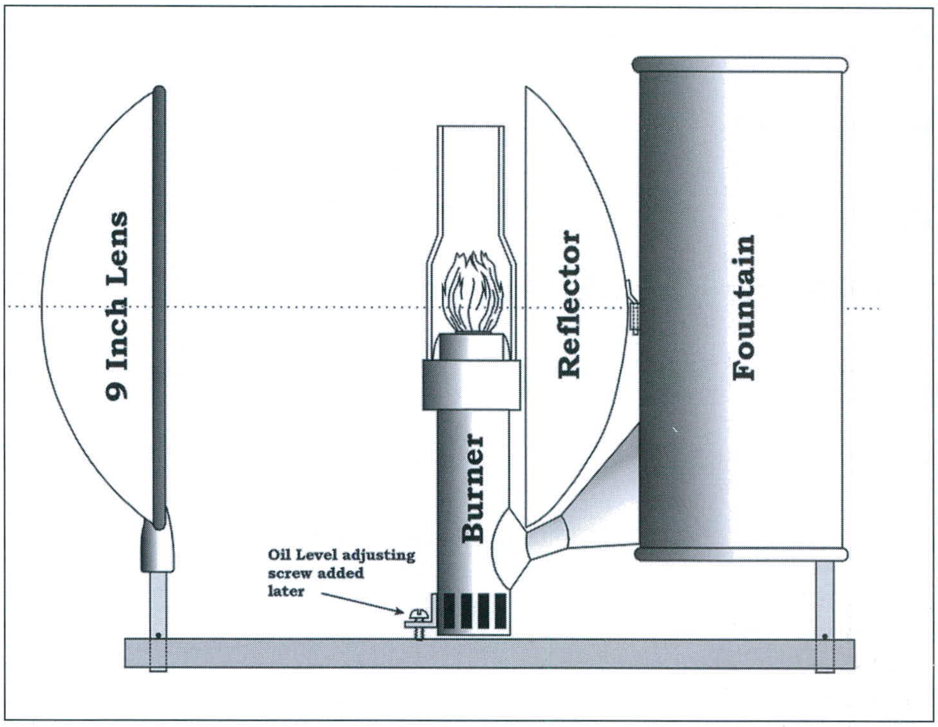
The reflector was circular in construction and made of a thin sheet of copper formed in a generally spherical shape. It was plated with a slight film of silver with the grain and luster of tin wear, and when a finger was held near the reflector no distinct image of the finger was formed on the silvered surface. The early reflectors varied in size from nine to 14 inches in diameter. The larger reflectors were so flimsy that when they were mounted on their wrought iron frame they were sometimes compressed significantly, altering their form and making their reflection capabilities still worse. In early models, the reflector was attached to the front of the oil reservoir and in most cases was set too far from the flame and therefore the flame was not in the focus of the reflector. A spherical reflector returns the rays of light back upon the flame and it is normal for a portion of the reflected light to be lost in passing through the flame. By accident, the Winslow Lewis design, where the flame was too far forward of the reflector focus, actually helped to allow more of the reflected light to be used. The light output of this system was very low, estimated to be less than 25 candlepower.

Winslow Lewis also produced lamps with larger reflectors, which were mounted differently and had oil level adjusting screws on the chandelier in a mounting plate behind the lamp fountain, as shown below. An 18-inch Lewis reflector produced about 1530 candlepower.

Nearly all of the American lighthouses from 1812 to 1840 used the Winslow Lewis reflector and lamp designs, and most continued to use them until about 1858. Winslow Lewis also reported that he supplied the first reflector lamps for lighthouses used in Denmark and in Nova Scotia. For more information about early American reflector designs see 'Early American Lighthouse Illumination' in *The Keeper's Log;* Volume 15, Number 1, pages 16-27.



Winslow Lewis-Benjamin Hemmenway lamp and reflector in chandelier mounting, circa 1834-1844. Drawing by the author from Patent #3692, and descriptions in 25th Congress, 3rd Session, Doc. 24, p. 46 and 27th Congress, 3rd Session, Doc. 183, pp. 52, 55. (Note: this drawing is based mostly on verbal descriptions and may not reflect the exact design.)



Winslow Lewis lamp, 9-inch reflector and 9-inch lens, circa 1810-1818. Drawing by the author from descriptions in patent drawings 1305 and 2901-X, in 25th Congress, 3rd Session, Doc. 24, pp. 22, 37-39, and from an actual lens assembly.

Fresnel's Reflectors

The early lens designs by Augustin Fresnel, in 1823, used flat mirrors to reflect portions of the light above and below the main dioptric belt of the lens. Later, Fresnel also used mirrors with a slight parabolic curve to improve his design.

Drummond's Lime Light with Reflector

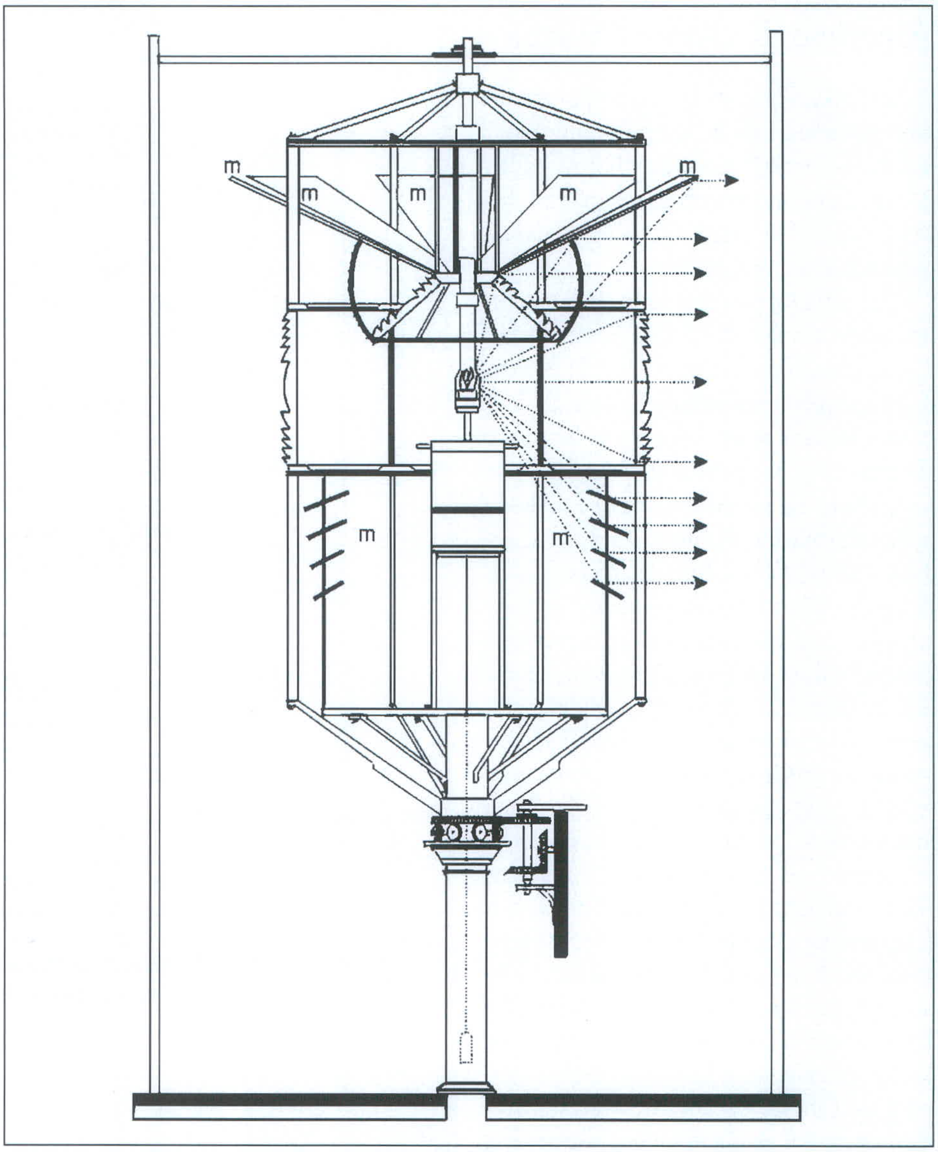
The Drummond Lime Light is produced by two jets of gas, the one of oxygen and the other of hydrogen, ignited upon a ball of lime (Calcium Oxide) measuring only three-eighths of an inch in diameter, and placed in the focus of a parabolic reflector. Its light is equal to about 264 flames of an ordinary Argand lamp used with the best Sperm-Whale oil. It bears the name of Lieutenant Thomas Drummond, Royal Engineers, who first applied it in the focus of a parabolic reflector for geodetic purposes, and afterwards proposed it for lighthouses. So intensely brilliant was this light, that in good atmospheric conditions, observers could see their shadows at about 13 miles from the lamp. The lamp with a 21-inch reflector produced an estimated 92000 candlepower.

In 1868, the American Lighthouse Board tried using the Lime light and reported on its usefulness as follows:

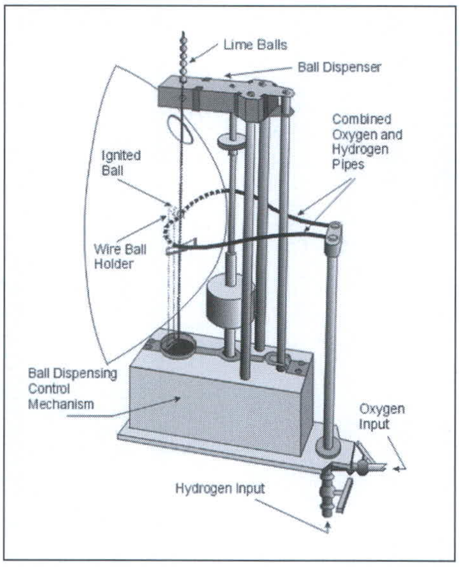
"The Lime light required much labor, there was danger associated with the production of the gases used, it required expensive apparatus, and the liability of the lime to become deranged far outweighed any advantages in the way of superior illumination which could be derived from it."

The Lime Light was never used in lighthouses, other than during trials, due to the great difficulty in keeping it operational for any extended period of time. You can read more about the Drummond Lime Light in *The Keeper's Log;* Volume 16, Number 2, page 13.

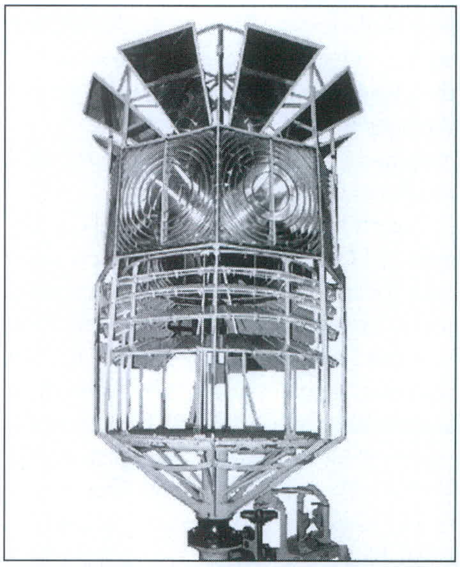
Thomas Tag's excellent, and well researched, article "Mirror of Light" will continue in the fall issue of *The Keeper's Log,* starting with lighthship reflectors, then explaining glass reflectors and the development of the parabolic reflectors used in modern optics today.



Drawing from *Oeuvres Completes d'Augustin Fresnel.* m = indicates a mirror.

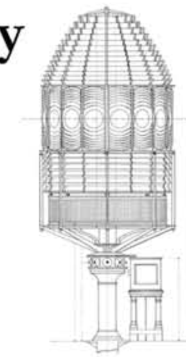


The Drummond Lime Light with reflector. Drawing by the author from *The Penny Magazine,* April 4, 1840.



Fresnel's first First-Order lens, 1823. Photo from the author's collection.

Join the U.S. Lighthouse Society Today
or
Give the Gift of Membership!



Restoration & Preservation

Thomas Point Shoal Lighthouse, MD

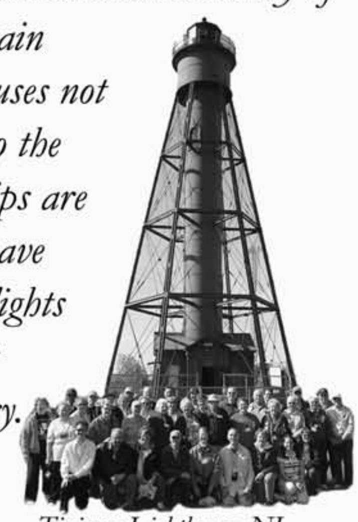
The U.S. Lighthouse Society has donated to many lighthouse preservation projects throughout the U.S. Most recently we were honored by being presented with the Preserve America Stewardship Award from The White House for our restoration work at Thomas Point Shoal Lighthouse.

Help Support Our Important Mission!

Education

The Keeper's Log *magazine is the only one of it's kind and has been published quarterly since 1984. Receive this award-winning publication as a benefit of membership.*

The Society organizes domestic and international lighthouse tours. Many of our excursions gain access to lighthouses not normally open to the public. These trips are a great way to have fun, see lots of lights and learn about lighthouse history.



Tinicum Lighthouse, NJ

To learn more visit

www.uslhs.org

or

call Headquarters at 415-362-7255