# The Early Development of the Fresnel Lens

## Part One

By Thomas Tag

Many companies were involved in the development and refinement of the Fresnel lens. Some supplied only the glass for the lenses, either in rough form, or both cast and polished. Other companies assembled the glass elements and performed finish work on the lens elements. Still other companies produced both the glass and the finished lenses. This story will be divided into several parts, each discussing one or more of these companies and their contribution to the development of the Fresnel lens.

Part One will describe the development of the early Fresnel lenses and define the companies and individuals who took part in this effort. Augustin Fresnel had assistance from many sources as he developed and perfected his lens. The players in this story have become blurred by time and confused due to their unusual interrelationships. Hopefully, this story will help to alleviate the confusion.

**Augustin Fresnel, age 37. Drawing from *Oeuvres Compzletes d'Augustin Fresnel.***

## The Lighthouse Work of Augustin Fresnel

(Pronounced: Au-gust-in Fray-nell)

The French Commission for Lighthouses was established on April 29, 1811. In 1819 Arago, who had become a member of the French Commission for Lighthouses in 1813, offered to make a systematic review of possible improvements in lighthouse illumination. He requested that Claude Mathieu and Augustin Fresnel be assigned as his coworkers on the project. His request was granted on June 21, 1819, and Augustin agreed to serve on the committee. Augustin produced his first report on optics and lamps for lighthouses on August 29, 1819, just two months after starting to work on the project.

Augustin Fresnel used information from his own scientific work on optics along with ideas from Buffon and Condorcet in his lens designs. He created a bull's-eye lens panel in early 1821 that was made with segments of rings and was specifically designed for use in lighthouse illumination. At first, his design used lens elements made from polygonal segments of glass created by the Parisian optician François Soleil Sr., and assembled with fish glue. He chose polygonal segments of glass, instead of curved segments, because he thought they would be far easier and less costly to produce. After the first bull's-eye panel was made, Monsieur Soleil determined that he could make curved lens segments for nearly the same cost, and the design was converted to a truly circular lens panel by late 1821.

During 1822, Augustin worked on completing his design for a flashing lens using eight of his circular bull's-eye flash panels. Each of the bull's-eye panels refracted (deflected) the light in both the horizontal and vertical directions, forming beams of light.

Augustin created several other forms of lighthouse lenses after his design of the first revolving, first-order lens. He took the basic design of his bull's-eye flash panel, revolved it around its vertical axis, and created the first fixed lens in 1824. This design was made from 12 flat vertical panels formed in a circle. The main panels collected the light from the lamp and refracted (deflected) it vertically into the horizontal beam. The original design of the fixed lens directed light into 12 beams, in a nearly complete 360-degree circle. The mariner would see a constant light unless he was looking directly at the area between the beams formed by the junction of the vertical panels. The fixed lens would be perfected, eliminating the 12 beams and giving light in a complete circle, by the Cookson Glass Company in 1836 (see Cookson Glass later in this story).

The fixed lens design was further modified in 1825 when Augustin added a set of revolving flash panels to create the first fixed lens varied by flashes. The fixed lens directed light in a flat disk shape, in a nearly complete 360-degree circle. The revolving flash panels refracted the light from the fixed belt horizontally creating two or four horizontal beams of light.

Fresnel's Assistants

Early in the development of the lighthouse lens project, Fresnel began using his younger brothers as his assistants. He had two younger brothers Léonor who had been born in 1790 and Fulgence who had been born in 1795.

**Léonor Fresnel** – Léonor was Augustin's major assistant and would remain closely associated with the development of lighthouse optics over the years. Léonor replaced Augustin on his death in 1827. Léonor also worked for a few years as a consultant to the English glass maker, Cookson, assisting in its manufacture of Fresnel lenses from 1834 through 1845. (See Cookson Glass later in this story). Little is known about Léonor Fresnel, the man, and no portraits exist of him. Léonor wrote part of the biography of Augustin's work, Oeuvres Completes de Fresnel, published in 1866. Léonor died in 1869.

**Fulgence Fresnel** – Fulgence worked with Augustin as a minor assistant for only a short time during the 1820s. He was very skilled in diplomacy and was used by Augustin in that capacity to solve problems and negotiate agreements. He had studied and become expert in many foreign languages and later became a specialist in oriental and mid-eastern culture. Fulgence died in Baghdad in the year 1855.

**Monsieur Tabouret** (Pronounced: Tabur-ray) – Monsieur Tabouret was Augustin's mechanical assistant and ran Fresnel's development shop and laboratory. Tabouret's first name is not known and he is always referred to as Monsieur Tabouret. Monsieur Tabouret worked for the French Department of Bridges and Roads as did Augustin Fresnel. He assisted Augustin in the physical production and assembly of the metal and glass work used in the lenses, clockworks and other lighthouse machinery. Monsieur Tabouret went on to work at Chance Brothers, in England, during its early development of lighthouse lenses. (See Chance Brothers Glass and Lens Works, Part 4 of this story in a future issue of *The Keeper's Log*).

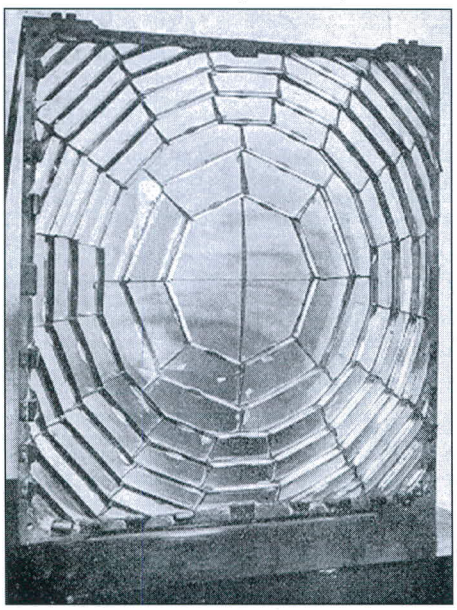
## The Soleil Family Dynasty of Lens Makers

**François Soleil Sr. Lens Works** (Pronounced: Frans-wah So-lay-ea) – Little is known about the Parisian optician, François Soleil Sr. There is also great confusion related to the name Soleil, and particularly the name François, due to the use of this name as a given name and a family name by several interrelated family members.

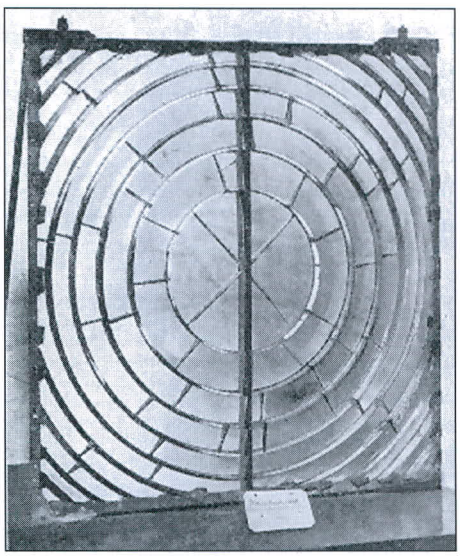
The patriarch of the family was François Soleil Sr. who worked directly with Augustin Fresnel in the creation of the first Fresnel lens. The date of François Soleil's birth is uncertain; he died in 1846. He had a son Jean-Baptiste Soleil (usually referred to as François Soleil Jr.) and two daughters. His daughter Adelaide married Jean Jacques François.

Up until 1820, when his work began with Augustin Fresnel, François Soleil Sr. had operated a small precision hand-crafted scientific optical instrument company. After the first lens was completed for Cordouan lighthouse, Monsieur Soleil Sr. saw the potential future demand for Fresnel lenses in France and elsewhere. He decided to expand his business and created an additional factory exclusively for Fresnel lens production. He founded and equipped his factory in 1825, at Chapelle, Saint Denis in Paris. Production remained limited because it was difficult to find good workmen and to find a supply of nearly optical quality glass. At that time, the products of the glass manufacturers at Choisy-le-Roi and Saint Gobain had great difficulty in meeting the requirements of this new industrial activity.

When François Soleil Sr. retired in 1838 he divided his business into two parts. The Fresnel lens business remained at Chapelle, St. Denis in Paris, and was rented to his son-in-law Jean Jacques François. The optical instrument business was given to his son Jean-Baptiste François Soleil (Jr.) and was located at 35 (later 21) Rue de l'Odeon in Paris.



**Fresnel's polygonal bull's-eye lens flash panel, early in 1821. Photo from *Centenaire D'Augustin Fresnel.***



**Fresnel's circular bull's-eye lens flash panel, later in 1821. Photo from *Centenaire D'Augustin Fresnel.***

Some of the early work of François Soleil Sr. on Fresnel lenses can be seen from the following letters written by Augustin Fresnel to Monsieur Tassaert, Director of the Saint Gobain Glass Factory.

Paris, 21 April 1822

Sir,

"The new glass arrived at just the right time; Monsieur Soleil had just made up a lens in reheated and remolded glass,* and was going to have to produce a second, in order not to leave his workmen without work.

"It will not be bad if you send us another tray, because one of the first pieces was found to have a defect; and, in general, there is not any inconvenience at all to cast one or two additional pieces of every type, in case of accidents. Moreover I hope that Monsieur Soleil will have several other lighthouse lenses to execute, and that the remaining pieces will thus be used.

"The request that he made of you is calculated for ten lenses: it is consequently necessary to have ten rings of every type. He will write you about how many pieces he selected for each of the new rings which he sent to you for the grinders last Monday. It is moreover a thing that you could verify with the grinders and with the cutting pattern for composing the complete rings. As for the ring numbers 2, 3 and 4, I remember that it is necessary to have for each ring, two pieces of number 2, three of number 3, and four of number 4. Therefore in deducting those that you sent from the total numbers required of 20, 30 and 40, you will know how much there remains for you to run.

"The glasses for which M. Soleil now has the most pressing need are those of the ring numbers 5 and 6, and he asks you to send him some as soon as possible.

Accept, [etc]."

A. FRESNEL

* Note: The French words used "en verre refoulé" are not completely clear in current French. The word refoulé today means repressed, not remolded. Indications are that Soleil received the first glass from Choisy-le-Roi, which was of poor quality with many bubbles. Soleil reheated the glass and remolded it to remove the bubbles and to partially form it into the required shape. When the first glass was received from Saint Gobain it also had to have this hand processing step performed. After the first few pieces of glass, Saint Gobain was able to correct the problem.

Paris, 26 June 1825

Sir,

"Monsieur Soleil complains, with reason, that your workers are not careful enough in the casting of his rings. I noticed at his place a large number of glass pieces that cannot serve, although they contain good enough material, because they were poorly cast. In one, the side plan presents a strong angle that renders its extremities too thin, while the other is too thick; in the others, the angles are so defective that, in removing even a considerable glass thickness, one could not obtain a sharp edge.

"Thanks to the exaggerated dimensions of the molds, most of the pieces that you sent present enough width and thickness to be machined, although all the ridges are extremely rounded. Would it not be possible to obtain sharper edges and a more correct casting, by heating the molds, if it was necessary, to expel all the material inside. If one was sure that with a little care one could exactly make the glass forms in the molds, one could employ a narrower mold that would thus diminish the work of the machining.

"I have the honor to be with your consideration the more distinguished,

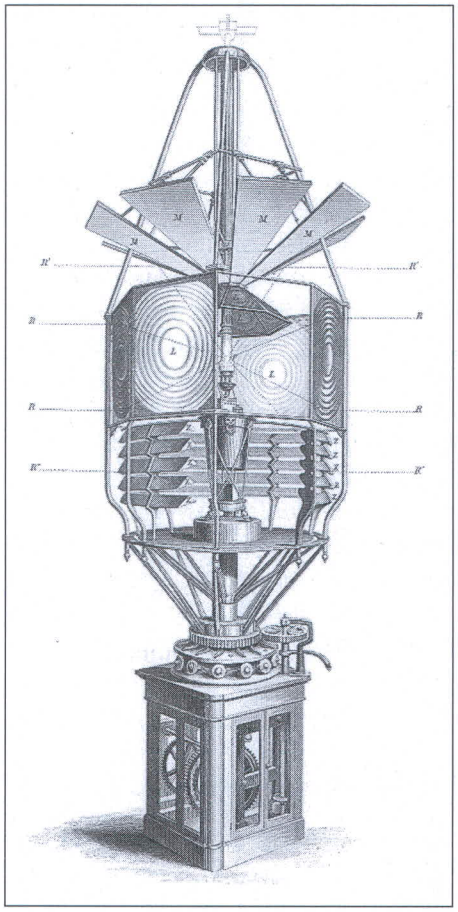
Sir, Yours, etc.

A. FRESNEL"

At the end of the year 1821, Colonel Colby, of the British Royal Engineers, reported on the early design and testing of the Fresnel system to Trinity House, the British Lighthouse Authority, and to Robert Stevenson, Engineer of the Northern Lighthouse Board in Scotland. Colonel Colby also tried to order a Fresnel lighthouse lens from François Soleil Sr., but Monsieur Soleil Sr. explained that it could not be completed until the lens for Cordouan was finished and installed; and Colonel Colby's order was cancelled.

On July 20, 1823, the first dioptric device was installed on the tower of Cordouan where it replaced twelve large parabolic reflectors, which had illuminated Cordouan since 1791. During the 1820s, Trinity House, in England, attempted to have a Fresnel lens produced by Cookson Glass. There were great difficulties at Cookson and no lens was made. The British had no lens for testing until Robert Stevenson was able to purchase two bull's-eye panels from François Soleil Sr. in 1824, which did not arrive until 1825. The British were not able to obtain a lens from Cookson Glass until one was made for the Northern Lighthouse Board in Scotland in 1831. In the meantime, the English and Scottish boards continued to report on the perfection of their catoptric (reflective) systems, which had been improved extensively with the passing of the years.

In France, more than twenty lighthouses were built and equipped with Fresnel optics during the following fifteen years. This number appears small, but it is necessary to understand that the builders needed to correct many technical difficulties to provide the wide range of lenses needed by the Lighthouse Service in France, and they were permitted to construct only one first-order lighthouse a year.



**Jean Jacques François' Skerryvore lens built in 1842-43. Drawing from *Account of the Skerryvore Lighthouse.***

**Jean Jacques François Lens Works** (Pronounced: Jean Zh-ak Frans-wah) – Jean Jacques François was the son-in-law of François Soleil Sr. In 1838, when François Soleil Sr. retired, Jean Jacques François took over Soliel's factory that produced Fresnel lenses. At this time, Jean Jacques François' lens factory and Augustin Henry's (later known as Henry-Lepaute) lens factory were the only factories producing Fresnel lenses in France. Jean Jacques François had a relationship with Augustin Henry whose factory supplied all of the clockworks needed to rotate the flashing lenses. Jean Jacques François built several important early lenses. He allied himself with Léonor Fresnel who wrote in a report to the French Lighthouse Commission as follows: "Soon after these first tests, young Monsieur François undertook, for Scotland, the execution of a lens device of the first order destined for the lighthouse of Skerryvore."

**Jean-Baptiste François Soleil Jr.'s Instrument Business** – In 1838, when François Soleil Sr. retired, Jean-Baptiste François Soleil Jr., Soleil's son, took over Soleil's optical instrument business. Jean-Baptiste had worked in his father's Fresnel lens business since he had completed school. After his father's retirement Jean-Baptiste continued to assist his brother-in-law, Jean Jacques François, in the lens business while continuing and growing the optical instrument business. In 1839, Louis Jules Duboscq (Pronounced: Due-bo-sk) married Jean-Baptiste François Soleil Jr.'s daughter and in 1849, on Jean-Baptiste François Soleil Jr.'s retirement, took over the optical instrument business. Duboscq later went on to develop one style of the electric-arc lamps that were used in lighthouses in the 1850s and later.

In the early 1820s, Augustin Fresnel had requested the construction, by Jean-Baptiste François Soleil Jr., of his demonstration instruments for the physics of light. Soleil Jr. produced a device with double mirrors that, for the first time, made the vibration of light experimentally observable.

**Theodore Létourneau Lens Works** (Pronounced: Lay-turn-oh) – Theodore Létourneau was the son-in-law of Jean Jacques François. Létourneau took over the former Soleil factory in 1844, which was then operated by Jean Jacques François and located at 37 Avenue Montaigne. He continued to manufacture Fresnel lenses and other lighthouse equipment until 1852 when his company was purchased by Louis Sautter. (See the Louis Sautter Lens Works in Part 2 of this story in a future issue of the Keeper's Log). Létourneau also had a working relationship with Augustin Henry (later known as Henry-Lepaute) during the years 1844 to 1852 and they jointly produced some lighthouse equipment. In the late 1840s the Letourneau offices were moved next door to 31 Allie Veuses, in Paris.

Theodore Létourneau was responsible for two major Fresnel lens design improvements. In 1848, Létourneau proposed lengthening the duration of the flash in rotating lenses by

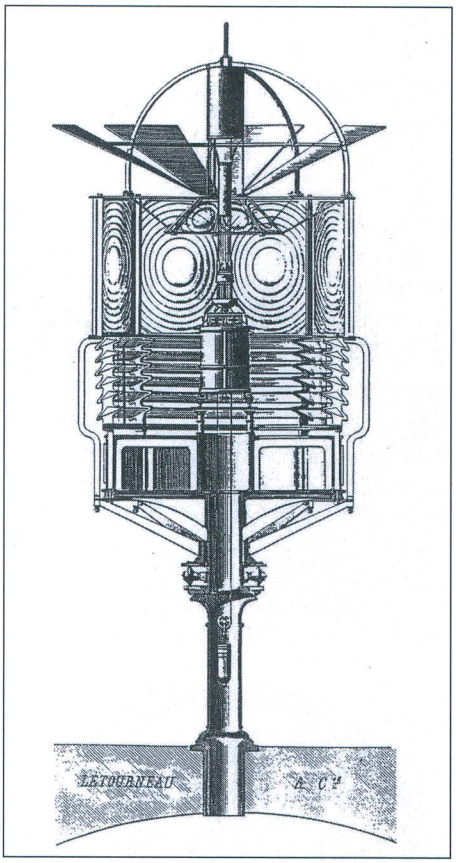
dividing each flash panel into two vertical portions. He then set the two halves of each panel at a slight outward angle (about 5 degrees) to each other. This change increased the divergence of the light from each flash panel, thus increasing its duration of observability to the mariner while only slightly decreasing its power output. Létourneau also proposed a way to improve fixed lenses varied by flashes. The problem with this style of lens was that the flash was produced by a rotating flash panel, formed of only vertical lens elements, revolving outside the standard fixed lens. The light was forced to travel through both the inner fixed lens and the outer flash panel in order to produce a flash. The light traveling through two glass lenses reduced its output by up to 20 percent. Létourneau's improvement was to build a combination lens with alternating fixed and 'bull's-eye' flash panels that rotated. The new lens still had the fixed varied by flash characteristic, but required only a single thickness of glass, thus increasing the power of the flash by up to 20 percent.

## Choisy-le-Roi Glass Works

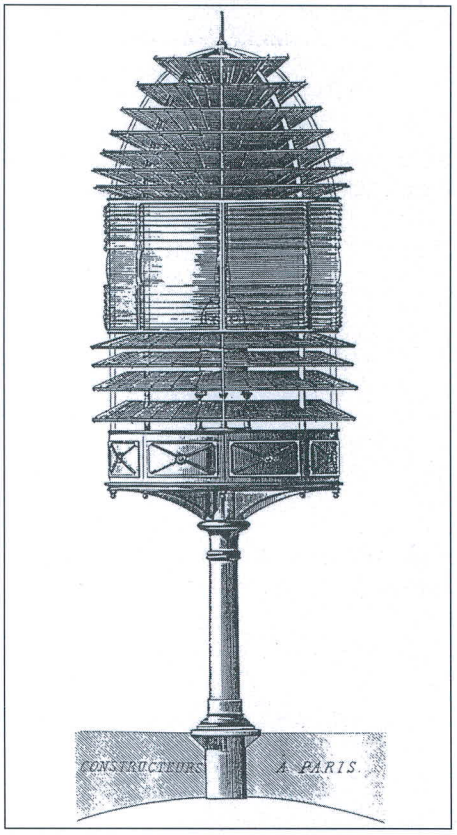
The Choisy-le-Roi factory was founded near Choisy-le-Roi located just south of Paris, France in 1820, by Monsieur Grimbolt and remained in operation until 1851. Between 1823 and 1848 the factory was directed by Georges Bontemps (Pronounced: Bon-tohm) a master in making crown and optical glass. The Choisy-le-Roi factory also became the pioneering establishment, in France, involved in the making of various types of colored glass.

In January 1822, during the construction of the very first Fresnel lens, we find the following report:

"The Director General of the Department of Bridges and Roads, after various experiments done at the observatory and at the Arch de Triumph de l'Etoile, decided that a lens lighthouse would be established on the tower of Cordouan; this was based on the drawings of Monsieur Augustin Fresnel, engineer of the Department of Bridges and Roads. Monsieur Soleil, engineer optician, was charged with the construction of the echelon lenses intended for the new lighthouse, the composition was of various related small pieces of glass of the thickness of 18 to 20 lines (Ed: a line is a measurement of a little less than 3/32 of an inch), these pieces, held together by means of fish glue, formed concentric rings that were difficult and expensive to construct.




**Létourneau first-order-flashing lens. Létourneau drawing.**




**Létourneau first-order-fixed lens. Létourneau drawing.**

"Monsieur Soleil requested the glassworks of Choisy-le-Roi to cast the rings, in one piece, or in four or six pieces; but the pieces thus prepared exploded while being worked." "Monsieur Darcet, who with Monsieur Soleil was part of this fruitless attempt, counseled him to inquire about it to the factory at Saint Gobain."

As can be seen, it was due to this first failure at Choisy-le-Roi that the Royal Glass Works at Saint Gobain became involved in the development of Fresnel lenses. Monsieur Soleil tried to have both Choisy-le-Roi and Saint-Gobain perform the work. However, problems continued with the glass from Choisy-le-Roi, as can be seen from the following extract from a letter dated August 4, 1826 from Fresnel to Monsieur Bontemps at the Choisy-le-Roi factory.

"I waited some days to answer you, wanting to first assure myself that the material of your last casting was as full of bubbles and striae that it appeared to me initially. For that, I cut and polished two facets on three pieces selected among those where the glass appeared the least bad, and I recognized that this matter was not resolved. I would expose myself to the just reproaches of my Administration in accepting glass so full of defects . . ."

Problems remained with the early glass procured from both sources and especially from Choisy-le-Roi during the 1820s, and therefore, virtually all production glass came from Saint Gobain by 1830.

Bontemps continued to direct the company and encouraged it to manufacture items with greater quality and of a more serious character. Of the four prizes awarded by the Encouragement Society at the competition in 1835, he won one for flint glass and another for crown glass, both used in optics. In 1848, Monsieur Georges Bontemps left Choisy-le-Roi and went to work for Chance Brothers, in England, where he headed production of optical and specialty glass manufacture. (See Chance Brothers Glass and Lens Works in Part 4 of this story in a future issue of the Keeper's Log). Bontemps leaving resulted in the end of Choisy-le-Roi's involvement with the making of glass for Fresnel lenses.

## Saint Gobain Glass Works

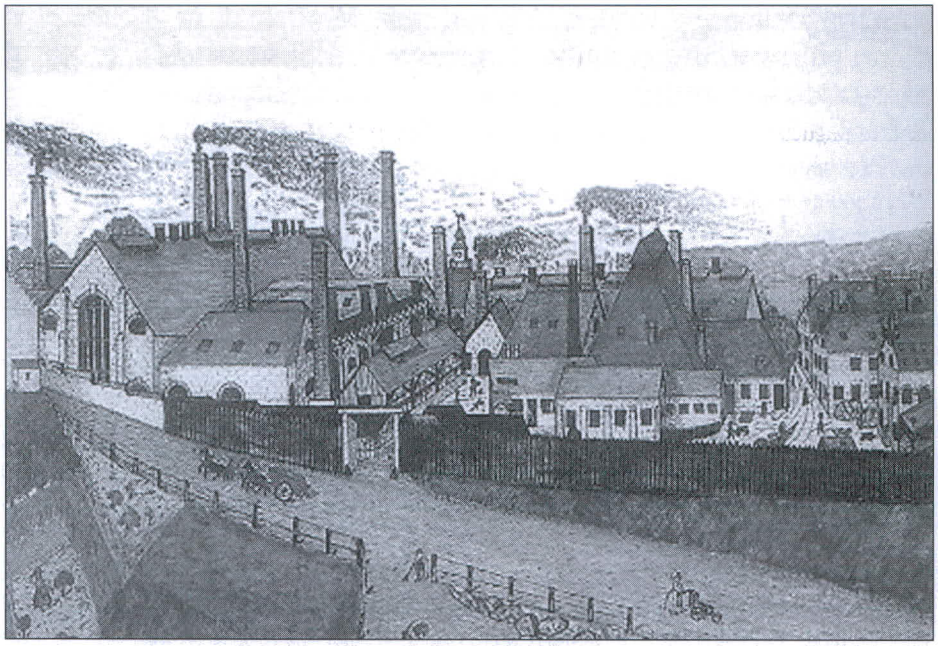
Saint Gobain was originally formed in October 1665 as the Royal Glass Works by Monsieur Colbert for French King Louis XIV. It received a royal privilege that allowed it to have a monopoly on the production of mirrors within France and had its factory in Paris. In early 1667, the Tourville Glass Company was merged into the business.

Glass companies at that time used wood to fire their furnaces and were located close to forests to allow the purchase of fuel at the lowest prices. The Royal Glass Works used the Tourville factory, located in Normandy, to produce most of its glass and to supply wood to the small glass making operation in Paris. Most of the Paris factory was devoted exclusively to the grinding and polishing of glass for use in large mirrors.

Still another glass company began operations in 1692 on the site of the Château of Saint Gobain some 130 miles northeast of Paris; in 1695 the Royal Glass Works bought out this company. Saint Gobain became its main factory due to the fact that it was located within the immense Saint Gobain forest and had a large plot of ground on which it could expand. In 1789, the royal privilege was revoked and the company became known as Saint Gobain Glass.

Saint Gobain was the first glass maker to successfully develop the process of casting large sheets of glass on iron tables, a process that would assist in the casting of prisms and dioptric lens elements some one hundred and twenty years later for Augustin Fresnel.

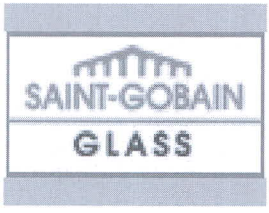
Monsieur Soleil asked Saint Gobain to make prisms and lens elements for some of the first Fresnel lenses after his earlier problems in obtaining quality glass from the Choisy-le-Roi factory. The glass used was the highest grade of what was known as 'Crown Glass,' but was not true optical quality glass. Saint Gobain produced the glass and the prisms and lens elements were formed in iron molds and were then sent to Paris for polishing. The early polishing process could not complete the very precise final polish. This was done by hand, using extremely fine English red rouge. The Saint Gobain factory, in Paris, actually contracted out the final polishing step to women in the local area. It is said that they were so proficient in polishing the prisms that the edges became razor sharp and the very last step in the hand process was to slightly blunt the edge of the prism so that it could be handled without cutting the hands of the final assemblers. Later, metal tables were used and the grinding machines were improved becoming faster and more accurate, allowing the hand-processing step to be eliminated.



***The Factory at Saint Gobain* in 1877. Painting by Lemoine.**


**Early Saint Gobain logo. Drawing courtesy Rakow Library – Corning Museum of Glass.**


**Saint Gobain crest. Drawing from author's collection.**




**Modern Saint Gobain trademark. Drawing from author's collection.**

One of the earliest connections between Augustin Fresnel and Saint Gobain occurred when Augustin asked Fulgence Fresnel, his youngest brother, to meet with Monsieur Tassaert, the scientist director of the Royal Glass Factory at Saint Gobain, in January 1822. After that meeting Augustin sent the following letter:

Sir,

"The obliging welcome that you had the goodness to give to my brother, and of which it pleases me to testify to you his recognition, makes me hope that you will want to interest yourself in the success of the casting of the curved prisms of Mr. Soleil. If it succeeds, as all believe it will, you will have performed a great service in the lighting of the lighthouses. While waiting, Mr. Soleil continues to construct lenses with small glass pieces; but you will accelerate his work greatly, if you have the goodness to send him, quickly, the first molded prisms.

Accept, etc."

A. FRESNEL

Soon, thanks to the competition between the Choisy-le-Roi Glass factory and the Saint Gobain Glass factory to build larger curved pieces of glass, Fresnel and Soleil were able to greatly reduce the number of the subdivisions within the concentric rings of the large

dioptric panels. This was an improvement that increased their useful light throughput by half. However, problems with their manufacture plagued Saint Gobain, just as they had Choisy-le-Roi, and the lens rings were being constantly sent back and forth between Monsieur Soleil and Saint Gobain until they could be produced correctly, as can be seen in this letter from Fresnel to Monsieur Tassaert:

Paris, March 12, 1822
Sir,

"Monsieur Soleil received the glass prisms that you had the goodness to send him, and found the material beautiful. He asks you to continue the molding and grinding, until the completion of ring numbers 10, 20, 30 and 40, and of ring numbers 1, 2, 3 and 4, while deducting the first ones received.

"He will send you, toward the end of this week, four ground rings for ring numbers 5, 6, 7 and 8, and you should indicate, at the same time, the number of remaining pieces that are necessary from him.

"He not having preserved the grinding patterns for 1, 2, 3 and 4, is going to try to send you a new ground one of every type, from the molded pieces of glass that he received.

"I ask you, Sir, to have the goodness to send him the pieces that you will mold of the numbers 5, 6, 7 and 8, as soon as possible, in order to complete the lens of which you sent him the first numbers.

"M. Soleil wants to know how much these glasses will cost him delivered. I ask you to treat this favorably, so that it can support the competition from the English, when they begin to copy our lighthouse lenses.

Accept, [etc]."

Augustin Fresnel

There is often discussion in lighthouse literature of the purchase of glass for Fresnel lenses from Prémontré. The glass factory at Prémontré was founded in 1827 as a rival to Saint Gobain. In 1843, Saint Gobain and another company, Saint Quirin, jointly purchased the Prémontré factory and split its assets. Through this purchase the distinction between Saint Gobain and Prémontré became blurred. Some glass for Fresnel lens production was purchased from Prémontré while it was a separate company, but most glass was purchased from it when it became just another factory location of the Saint Gobain Company after 1843.

Saint Gobain further expanded when it built another factory located in Chauny a few miles to the east of Saint Gobain. The Chauny factory began the development of mechanized grinding and polishing of glass in the early 1800s. However, only about 30% of the grinding was successfully mechanized by the 1830s.

Saint Gobain became the major producer of all glass used by the French manufacturers of Fresnel lenses. Jean Jacques François, Létourneau, and later, Henry-Lepaute, Sautter Lemonnier & Cie, and Barbier Bénard and Turenne purchased all of their glass from the Saint Gobain glass factories. In 1880, Louis Sautter wrote an interesting description of the work at Saint Gobain as follows:

"It was only with a lot of pain and after several fruitless attempts that we managed to cast the large glass pieces which compose the optic part of the first-order devices.

"We first had recourse to the process in use in the manufacture of the optical glass used for astronomical objectives, that is to say to the re-softening, and we could not obtain a complete ring in this way as well as we could with pieces of small dimension that we put together tip to tip to make rings. Today the glass is taken from the crucible by means of iron ladles and is cast directly in ingots or in a mold made of cast iron. We leave it there to cool slowly which leaves it with a shape that compares itself well with the one that it must have after the cutting.

"The glass of Saint Gobain that is exclusively employed for the construction of the lighthouses in France has the following composition:

| | |
|---|---|
| Silica | 72.1 percent |
| Soda | 12.2 |
| Lime | 15.7 |
| Alumina and iron oxide traces | |

"The large proportion of silica contained in this glass, renders it very hard and unaffected by the air. Its hue is lightly greenish; it is also lacking in lines and streaks, being a glass that did not undergo the operations of mixing, slow cooling in the crucible, sorting and re-softening reserved for the glasses used as objectives. The known defects under the name of bubbles or boullions, sand, stones, etc., that originate from imperfect refining, are very rare. It is good to notice that these defects that are harmful to the appearance of the lens have only a very slight influence on its optical properties.

"It would be easy to return to completely white glass by adding a certain lead proportion; but it would then become softer and more subject to deterioration.

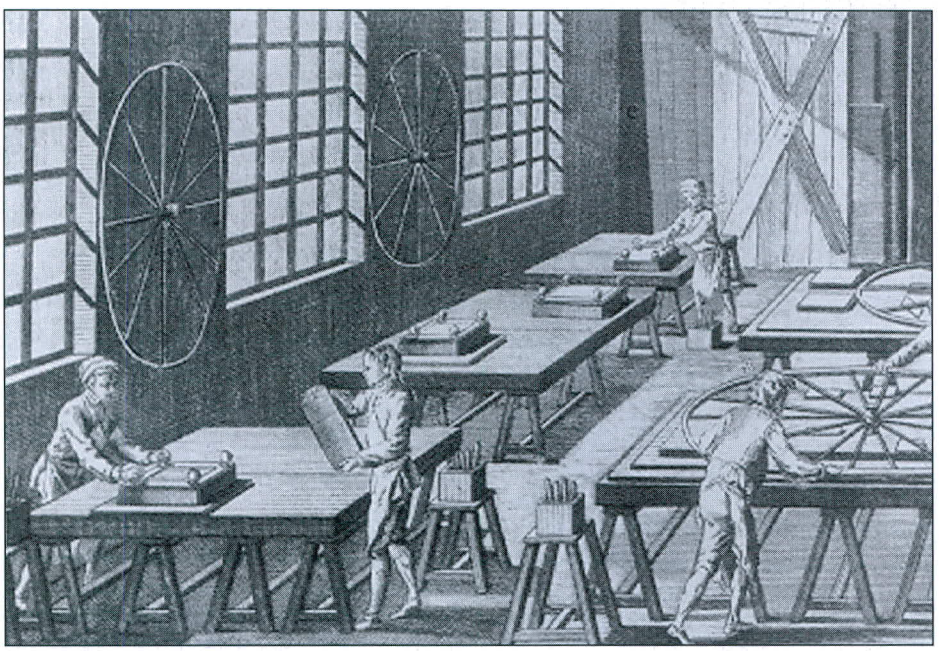
"The index of refraction of the glass for lighthouses from Saint Gobain is about 1.54.

"The losses that the light undergoes while crossing a glass piece originate from two different causes:

1. On one hand reflection of the rays of light at the entry and exit surfaces

2. Absorption during the passage from one surface to the other

"The loss by reflection varies following the degree of polish of the surfaces and the angle of incidence of the light. With the well polished



**Grinding tables at Saint Gobain, ca. 1820. Drawing from an early encyclopedia.**

glass of Saint Gobain, it can be valued at ten percent of the incident light, for the understood incidences between the normal and 45 degrees. Beyond 45 degrees, the loss increases progressively.

"The loss by absorption depends on the nature of the glass and its measured thickness. With the glass of Saint Gobain one can value it at ½ percent per centimeter of thickness.

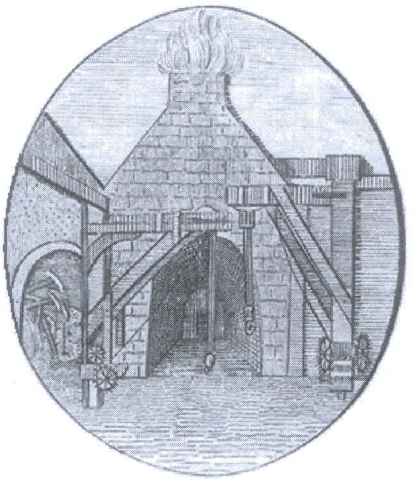
"The glass pieces of circular form that make up the greatest number of the pieces of lighthouse lenses are worked on turntables in both the vertical and horizontal planes. The ring, cast as a single piece or in several parts and previously heated in an oven, is stuck by means of melted pitch in a circle and is raised some centimeters above the turntable. During this operation the workman turns the turntable, and centers the ring by hand. Then the workman leaves it to cool and later begins the work on the rough-hewn piece. It consists of applying against the surface of the mounted ring in rotation on the turntable, a rubbing arm with a coating of wet sandstone that slowly wears the surface of the glass and makes its inequalities disappear. When it is sufficiently smooth, the workman imparts to the rubbing arm a dual movement designed to remove the grooves dug by the grains of sand and to give to the surface the calculated curvature that was assigned for it based on the place that the ring must occupy in the lens. To affect this, an arm is put on the tip of the rubbing arm which is forced to oscillate between two points. The length of the arm determines the radius of curvature of the surface, the position of the center determines its angle in comparison with the horizontal surface. Some gauges made with great care, are applied frequently on the surface during the course of the work and allow exact size verification. When the rough-hewn glass is completed and it cannot be seen to have a remaining rough surface, the workman stops the work with the sandstone and passes to the work with the emery. The ring, the turntable and the rubbing arms are washed with the greatest care, until all trace of sandstone disappears. Then the workman resets the tools and applies on the glass not more sandstone, but emery diluted in water. It is only gradually and while employing four more emery types and finally another with the name Douci that the workman brings the glass surface to the designated state that allows it to be polished. Between every change in emery the turntable must be washed and if the workman does not do this washing with enough care he exposes himself to produce scratched surfaces.

"After a last washing, the lens piece passes to the final polisher, who works it by means of English Rouge (iron peroxide) diluted in water and applied with a brush on the surface of the ring. During this phase of the operation the cast iron surface of the rubbing arm is covered with felts.

"Some details of the manufacture vary following the nature of the glass pieces, but all pass through the same series of operations to arrive from the crude state to the polished state. Their optical qualities depend principally on the exactness of their geometric forms and consequently on the quality of construction of the tools with which one works them. Slight curvature differences, which are impossible to notice, can increase the divergence and consequently diminish the intensity of the luminous beam by a large proportion. All shape inaccuracies translate into a loss of light.

"The distortions that cannot be avoided in the neighborhood of the edges of the prisms are a cause for loss that it is important to diminish while making the edges as fine as possible and while not multiplying the prisms beyond measure with a view to reduce their thickness. There would not be any advantage to drop below a width of about ten centimeters that is adopted today for the reflecting surfaces of the catadioptric prisms of the first three orders."

Saint Gobain continued to supply all of the French lens makers with glass throughout their years of production. It remains in business today, making glass, chemicals and ceramics of all types and is one of the largest firms in France.



**Cookson Works, circa 1810. Drawing from author's collection.**

## Cookson Glass Works

Isaac Cookson bought shares in a bottle glass company in New Castle, England in 1720. Isaac's son John became a partner in the Cookson Glass Company in 1737 and began producing crown and plate glass for windows at South Shields near New Castle. On John Cookson's death in 1783, his son Isaac took over control of the glass company with his two brothers. Later, he was assisted in the business by three of his sons one of whom was William Cookson who was directly involved during the time that Fresnel lenses were in production. The Cookson Glass Company also owned foundries and chemical plants. Cookson Glass was heavily involved in the early production of experimental Fresnel lenses in Britain and produced the first complete Fresnel lenses used in England, Ireland and Scotland.

In 1845, the Cookson Glass Company went out of business and was sold to a consortium headed by Robert W. Swinbourne. The consortium included Robert Stevenson, the famous Scottish lighthouse engineer and builder of the Bell Rock lighthouse, who was a close friend of Isaac Cookson. Robert W. Swinbourne was in business for about one year and did not produce any Fresnel lenses. The remainder of the company became the South Shields Plate Glass Works and remained in business until 1891. The Cookson Company returned to the glass business in the 1900s and remains in business today. Note: You may be aware of another connection to the Cookson family through reading of the many novels written by Isaac's great great granddaughter, Catherine Cookson.

## Cookson Lens Works

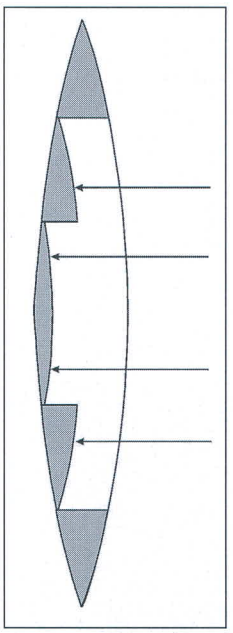
Fresnel lenses were only produced for a short time by Cookson Glass. Trinity House had requested the construction of a lens in the mid 1820s, but it could not be produced. The first Fresnel lens panel produced was ordered from Cookson glass by the Northern Lighthouse Board, in Scotland, in the year 1831 for testing purposes.

Cookson's first Fresnel test lens was very unusual in its construction. In 1748, the Count de Buffon proposed a new style of lens made by cutting a piece of glass into steps. As an example, if Buffon wished to diminish the thickness of a glass lens, he divided the exterior curved surface of the lens into parts and moved each of these parts toward the center of curvature until there remained only a thick-

ness of one inch in the center of the lens, a step being formed on each side by moving the corresponding parts an equal amount. Buffon produced a lens in steps, which had about the same focal distance and was only about one-third as thick as it was at first, which was a great advantage.

The lens requested by the Northern Lighthouse Board in 1831, was made from a single slab of glass as Buffon had proposed. The only known lenses to have been produced based on the Buffon design were a lens made in 1780, by the Abbé Rochon in France, which was only twelve to fifteen inches in diameter, and the aforementioned lens by William Cookson, which was nearly 30 inches in diameter.

In February 1833, the Northern Lighthouse Board held a trial, which Sir David Brewster and other important persons attended. They tested the one-piece lens from Cookson, a flint-glass lens proposed by Brewster, a true Fresnel lens bought from France, and their current reflectors. It was found that the French lens was comparable with the lens made by Cookson and was superior to Brewster's flint-glass lens. The French lens produced light equivalent to



seven of the best Scottish reflectors.

The English and Scottish lighthouse authorities wanted to produce all Fresnel lenses and other lighthouse equipment in their own country and persuaded the Cookson Glass Company to begin production of Fresnel lenses in 1834. This time Cookson brought in Leonor Fresnel, Augustin's brother, as a consultant and produced Fresnel lenses from individual pieces and prisms as done by the French lens companies. The first of these better designed Fresnel lenses, built by the Cookson Co., was installed in Scotland in 1835, in the Inchkeith lighthouse. This was quickly followed in 1836 when the first Fresnel lens, also built by the Cookson Co., was installed in England at the Start Point lighthouse. In all about 15 very early Fresnel lenses were made by the Isaac Cookson Glass Company for use in England, Ireland and Scotland.

A major improvement in Fresnel lens design was made by Cookson Glass Company in 1836. At that time it was thought impossible to construct the central drum of a fixed lens based on a truly circular form. The fixed lenses made up to that time were actually made in the form of polygons with 12 to 32 sides. In 1836, Cookson was able to construct the first circular drum segments for a fixed lens, dramatically improving their optical characteristics. The French lens manufacturers quickly followed Cookson's lead and from that time forward fixed lenses were formed from complete 360° circles of glass.

**The Early Development of the Fresnel Lens**

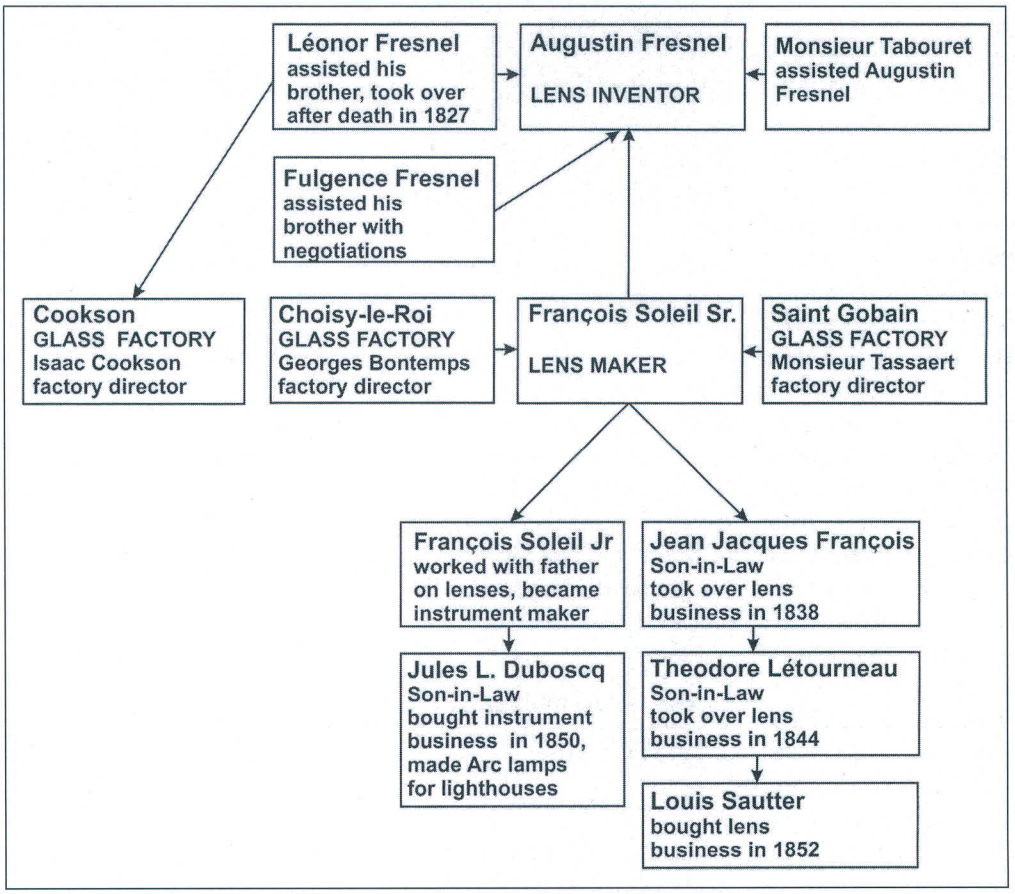



**Chart of the early glass makers and lens makers who assisted Fresnel. Chart by author.**

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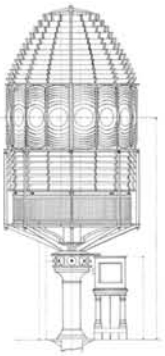

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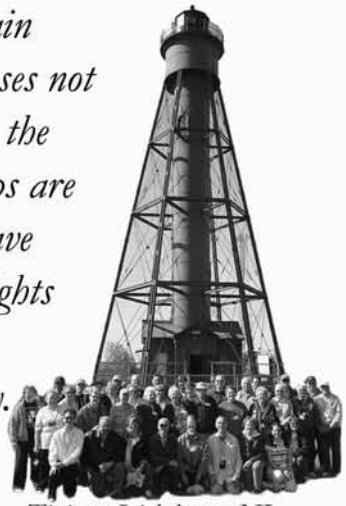

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