Money and Glory

Upstart machinists Worcester Reed Warner and Ambrose Swasey built the world's largest telescopes, catapulting the name of the Warner & Swasey Company into worldwide prominence.

by Trudy E. Bell

"WE GET OUR MONEY OUT OF MACHINERY and our glory out of telescopes," declared Ambrose Swasey on October 12, 1920, during a dedication ceremony when he and his long-time business partner Worcester Reed Warner presented a fully outfitted astronomical observatory with a 9.5-inch refracting (lens) telescope to the Case School of Applied Science (now Case Western Reserve University) in Cleveland, OH.[1]

WARNER

That penetrating comment effectively summed up the distinguished career of Warner and Swasey since they had shaken hands and gone into partnership 40 years earlier. Only six years after starting their firm in Chicago, they had landed a contract to build what was then the largest astronomical telescope in the world [Fig. 1]. This achievement—toward which Warner may have been working even before his formal partnership with Swasey—focused worldwide attention on their fledgling (and yet unincorporated) firm, and crowned them with an instant and indelible reputation for precision engineering. Four times the firm built telescopes that were the world's largest in their class, as well as other astronomical equipment and accessories.

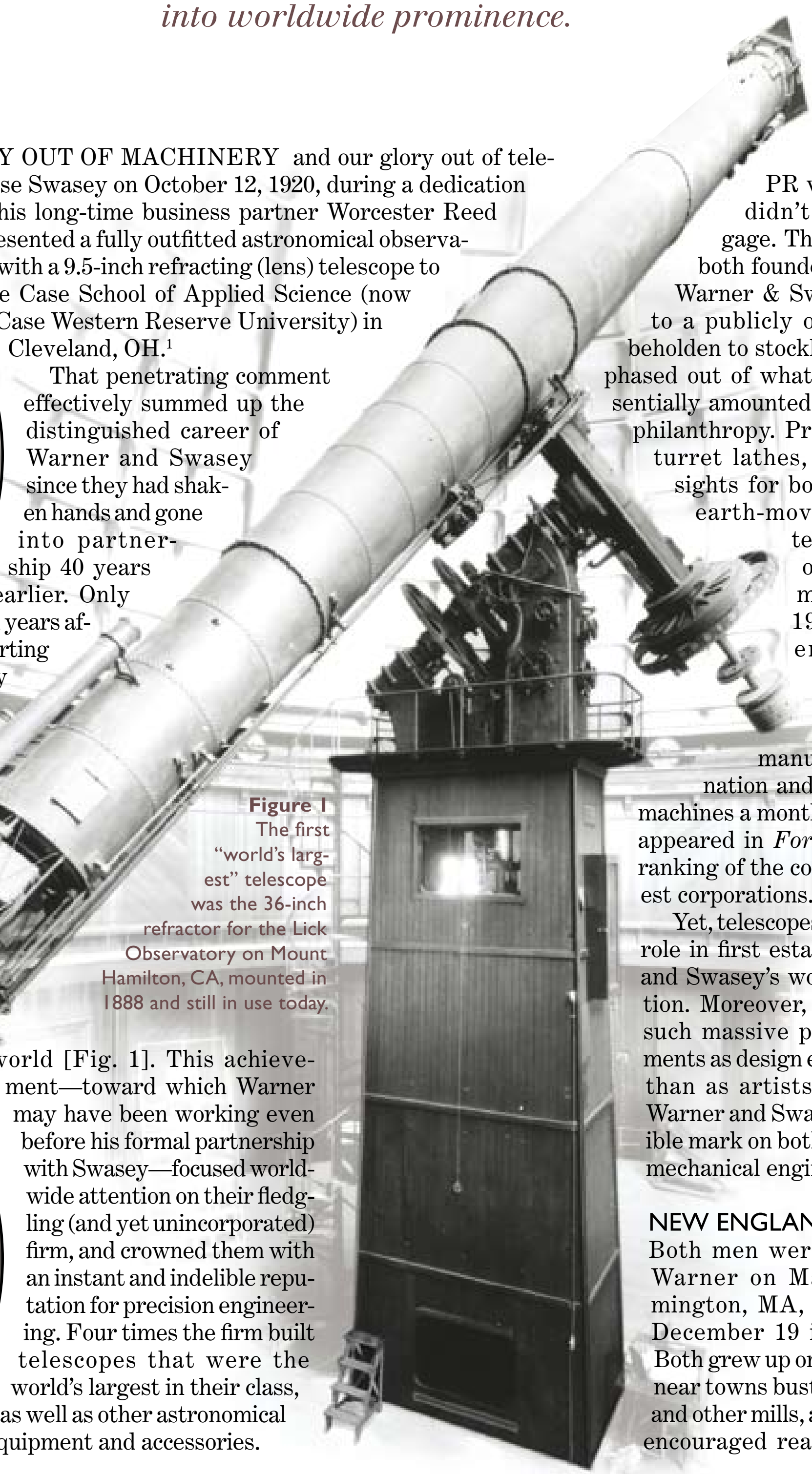

Figure 1 The first "world's largest" telescope was the 36-inch refractor for the Lick Observatory on Mount Hamilton, CA, mounted in 1888 and still in use today.

SWASEY

Despite their PR value, telescopes didn't pay the mortgage. Thus, in 1940 after both founders had died and Warner & Swasey converted to a publicly owned company beholden to stockholders, the firm phased out of what had always essentially amounted to astronomical philanthropy. Profits came from turret lathes, arms, and gun sights for both World Wars, earth-moving machinery, textile looms, and other specialized machine tools. By 1942, the 6,200-employee company was the fourth-largest machine-tool manufacturer in the nation and was selling 700 machines a month; by 1966 it first appeared in *Fortune* magazine's ranking of the country's 500 largest corporations.[2]

Yet, telescopes played a pivotal role in first establishing Warner and Swasey's worldwide reputation. Moreover, by approaching such massive precision instruments as design engineers, rather than as artists or craftsmen,[3] Warner and Swasey left an indelible mark on both astronomy and mechanical engineering.

NEW ENGLAND ORIGINS

Both men were born in 1846: Warner on May 16 in Cummington, MA, and Swasey on December 19 in Exeter, NH. Both grew up on farms, but lived near towns bustling with textile and other mills, and their families encouraged reading and learning. Warner's mother was an avid amateur astronomer who eagerly read current popular astronomy books and observed at least one partial solar eclipse, while Swasey's father welcomed the industrial revolution so enthusiastically that he allowed a railroad to build tracks across his farm fields.

As schoolboys, Warner and Swasey were individually fascinated with the humming and thumping of machinery at local mills. At age 19, Swasey apprenticed himself to the Choate Manufacturing Company in Exeter (later the Exeter Foundry and Machine Company), which produced boilers for steam engines. He joined around the time the firm was acquired by American Safety and Engine Company, whose Boston-based employees moved to Exeter to take over the works. Among those employees were George Brayton (who later invented a continuous-ignition-combustion engine that became the basis for today's turbojet and fanjet engines) and Brayton's new young assistant Warner. Warner and Swasey met, becoming fast friends and roommates.

In the spring of 1869, after their apprenticeships were finished, both young men applied to four companies. The most attractive offer to the pair came from the prospering firearms manufacturer of Francis Pratt and Amos Whitney in Hartford, CT.

Figure 2 Ambrose Swasey (above left) and Worcester Reed Warner are shown as they appeared in 1880 when they started their partnership in Chicago; below is their factory in Cleveland as it looked a half century later.

Figure 3 In the 1920s, Warner (below left) and Swasey posed next to the first observatory-class telescope they built, a 9.5-inch refractor sold to Beloit College and decades later donated back to the company.

PRATT & WHITNEY FOUNDATIONS

Pratt & Whitney had mushroomed during the Civil War, having itself been started just nine years earlier on $3,600 capital by two former employees of the Phoenix Iron Works and Colt's armory and pistol factory. Around the time that Warner and Swasey were hired, Pratt & Whitney incorporated with five partners, 500 employees, and a capitalization of $300,000. When Warner and Swasey walked into the huge (to them) Hartford plant, legend has it that one turned to the other and muttered something to the effect of "we'll have to work hard to get to the head of this crowd."[4]

The 11 years that they spent with Pratt & Whitney were fundamental to their success.

Swasey, an inventive genius, worked his way up to head the gear-cutting shop; he carefully studied the mathematics of generating ideal theoretical curves for gear teeth and solved the challenge of cutting metal to produce gears that meshed with minimal backlash. In the 1870s, he received at least two patents: one for an improved protractor and another for an epicycloidal engine, basically a rotary milling machine that Pratt & Whitney added to its product line of machine tools. Warner, whose flair lay in business and marketing, became intimately familiar with the final assembly of the firm's products and was sent to represent them at major trade shows, beginning with an exposition in Boston in 1873. There Warner demonstrated machine tools, innovatively entertaining judges and visitors with running patter while turning out little screws and gizmos that he handed out as souvenirs—capturing for Pratt & Whitney the show's gold medal.

As their experience grew, Warner and Swasey also began bidding in a peculiar institution within the nineteenth-century machine-tool industry called *inside contracting*. When an order for a large number of tools would come into Pratt & Whitney, an enterprising employee could negotiate a contract with the company's owners to fulfill the order at a fixed price, paying for all the raw materials and time of the employees he'd use. If he astutely estimated unit production costs and was skilled in managing his workmen, he could make a tidy profit; the risk, of course, was that he also could end up eating losses. The company liked the system, because it capped their costs; and Warner and Swasey liked it, because they could explore running a business and working with customers while still employed. Innovatively experimenting with techniques for improving both efficiency and quality, inside contracting honed their business skills and allowed the frugal pair to amass capital faster than they could just on salary.

One large issue preoccupying Pratt & Whitney was the question of making interchangeable parts a practical scheme for manufacturing. Not a new concept, the interchangeability of parts had been the subject of experiments by the cotton gin's inventor, Eli Whitney, (Amos Whitney's relative) and pistol-maker Samuel Colt (former employer of both Pratt and Whitney). One barrier to universal adoption of interchangeable parts, however, was the fact that even in the 1870s there was no commercial standard measure for the inch. Thus, there was no way of specifying standard—much less tight—tolerances among suppliers.

Pratt & Whitney partnered with Harvard professor William A. Rogers, who had co-designed a special measuring engine and arranged to borrow the precision metal bars from London and Paris that had established the British imperial yard and the standard meter. Between 1879 and 1882, the team determined the inch accurate to within millionths of an inch and produced a standard bar establishing the American standard inch—called Bronze No. 11.[5] In so doing, Pratt & Whitney learned not only about measurement techniques and devising accurate gauges, but also about methods of heat-treating steel so it could remain within tight tolerances. How involved Warner and Swasey themselves were in the painstaking inch-standardization project is not clear, but subsequent developments suggest that they took its principles to heart.

A HANDSHAKE AND TWO CITIES

In April 1880, with joint savings of $10,874, Warner and Swasey quit Pratt & Whitney and boarded a train heading west to Chicago to establish their own firm. Chicago, then booming with rebuilding after the Great Fire of 1871 and a nexus of rail service to both the East Coast and out West, seemed like a promising place to start a new machine shop. With a handful of employees (at least four from Pratt & Whitney), the pair rented a retail store front at 249 Canal Street. In the cramped shop, both partners donned aprons and operated machine tools alongside their employees, frugally bundling up against the icy Chicago winter rather than adding firewood to the shop stove, and making lunch-time sport of throwing rocks at the ubiquitous rats scurrying across the floor.[6]

Their shop was an instant success—so much so that by December they had orders three months in advance and by their first anniversary needed to seek larger quarters.[7] Meantime, they had begun to rethink their location in Chicago. Much of their business was still from the East Coast, and shipping was costly. Ohio was an established industrial center, and Cleveland was headquarters for several of their largest customers. So in 1881, they purchased land at East 55th Street and Carnegie Avenue east of Cleveland's downtown, built a three-story brick factory, and moved in that August. The Carnegie Avenue plant, expanded several times, remained the firm's principal factory until its doors closed more than a century later [Fig. 2].

Just as today's cosmetics companies manufacture make-up but sell beauty, Warner and Swasey manufactured machine tools, but sold productivity and efficiency. From the outset, their flagship product was an improved turret lathe. One limit to nineteenth-century factory productivity was the number of times a machinist

Figure 4 The design of the mount and controls of this portable 6.5-inch refractor for Lick Observatory was what made the Lick trustees take serious notice of Warner and Swasey as telescope designers. For use on astronomical expeditions, the trustees specified that the mount had to be adjustable for any geographic latitude; the result was the screw at the base of the polar axis, which could adjust the axis for any latitude down to 10 degrees. Moreover, it incorporated an innovative design for a self-correcting falling-weight clock drive inside the pier, as well as control rods (visible below the lower half of the tube) for adjusting the telescope's motions.

Figure 5 Warner and Swasey used telescopes aggressively in marketing their skills. For example, they used this image of a 9.5-inch refractor (right) they built for Hartford (CT) High School to appeal to schools, colleges, and wealthy individuals. It's no accident that their telescopes look so much alike; with this instrument, Warner and Swasey began standardizing their line of commercial telescopes.

needed to unclamp and clamp successive cutting tools into place when machining a work piece. Hand-setting of each successive tool both slowed the project and introduced tolerance errors. A turret lathe, however, mounted multiple tools in a rotating turret (often hexagonal) at one end of the lathe; each tool could be revolved into position and locked, immediately ready for use. Although Warner and Swasey did not invent the turret lathe, they recognized its immense potential for improving a machinist's speed and efficiency and for producing genuinely interchangeable parts. By the early 20th century, they had several distinct lines of turret lathes and celebrated the sale of their 50,000th machine.

Figure 6 The second *world's largest* built by Warner and Swasey was the 40-inch refractor for the Yerkes Observatory of the University of Chicago, here displayed at the Columbian Exposition in Chicago in 1893. Despite its many similarities to the Lick 3-inch, one major advance was the electrical system for controlling the telescope's motions. It remains the world's largest refractor.

Even within their own factory, they were constantly seeking methods to increase internal productivity in a forerunner of today's continuous-improvement culture. They institutionalized procedures now considered fundamental for efficient lean manufacturing: ensuring that every worker had every needed tool nearby in its own place, eliminating waste in both materials and motion, and having a sanitary workspace (unusual among turn-of-the-century firms in offering hot running water so each man could wash before and after work and assigning each man his own locker). And whenever they found a sure-fire way of increasing productivity, they offered that wisdom to their customers—in part by peppering the pages of their catalogues with productivity tips, thereby transforming them from throw-away sales pitches into indispensable handbooks.

But without doubt, their most effective and dramatic sales tool was their high-visibility design of the world's largest astronomical telescopes.

THE GREAT TELESCOPE RACE

With overtones similar to the 1960s in which the United States pitted itself in an international race against the former U.S.S.R. to be the first to set humans on the Moon, in the 1860s after the Civil War, the U.S. pitted itself against Europe in a race to build the world's largest astronomical telescope. Both were cold wars, highly symbolic of underlying international tensions and fierce nationalism—but unlike the space race, the *telescope race* was more cultural than political. Both Europeans and Americans still felt that Americans were cultural inferiors. Instead of literature or art being held aloft as the apex of cultural attainment, during the industrial revolution scientific achievement was heralded as a sign of the height of a civilization, with astronomy being crowned the queen of all sciences.

There was an unmistakable strain of utopianism in much 19th-century popular writing about astronomy; it was seen as an exalted pursuit that "purified" the spirit and cleansed it from the "taints of the struggle for existence." In such a climate, not only was an astronomical observatory seen as a symbol of high-fashion intellectualism and social distinction, but also as "a moral institution, an ally of the biblical institute" because through its instruments one viewed God's handiwork. Thus, possession of a telescope was viewed with civic pride.[8]

Moreover, the possession of a *world's largest* telescope was seen as a symbol of national distinction—and one crafted by a native son of the soil was especially to be prized. Throughout the 19th and 20th centuries, the balance kept teetering between the two sides of the Atlantic, as one nation's *world's largest* was superseded by another nation's. Nonetheless, as surely as the 20th-century space race pushed technologies ranging from materials to propulsion, the 19th-century telescope race pushed the science and technology of glass-making, optical design, and mechanical engineering. Moreover, any instrument-maker who crafted the world's largest telescope essentially attained fame and immortality.

There is tantalizing evidence suggesting that Warner and Swasey may have gotten an idea to enter this highly visible international telescope race while they were still at Pratt & Whitney. In 1876, Warner was put in charge of the firm's enormous 49-machine exhibit at the U.S. Centennial Exposition in Philadelphia, a huge agricultural and mechanical world's fair that ran from May to November to celebrate the nation's first centennial.

Although tied to the exposition exhibit six days a week, Sundays were free. One weekend Warner hopped a midnight train to Washington, DC, to the U.S. Naval Observatory (USNO), eager to see the three-year-old 26-

inch refracting telescope—then the largest and grandest refracting telescope in the world. Not only had the 110-pound achromatic (color-free) double-lens at the upper end of the telescope been fashioned by world-renowned master opticians Alvan Clark & Sons of Cambridge, MA, but also the telescope's tube, pier, and equatorial mount with its various ropes for controlling the telescope's motions.[9] When Warner arrived, the observatory was closed, but a passing assistant astronomer took pity on him and ushered him into the dome.

What a phenomenal break for the future firm of Warner and Swasey.

The assistant astronomer was Edward S. Holden, a West Point graduate of almost identical age (born November 1846) and a fast-rising astronomical star. Two years earlier, USNO Superintendent (i.e., director) Simon Newcomb—himself world famous and widely acknowledged as the dean of American astronomy—had recommended that Holden be made director of the new Lick Observatory being planned for California. According to the terms of the James Lick Trust bequeathing a then-princely $700,000, the observatory was to house the next telescope "superior to and more powerful than any yet made."

What Warner and Holden discussed, or whether the exciting Lick Observatory project was even mentioned, is not known—but the two young men remained in close touch. When Pratt & Whitney sent Warner to England and the Continent in 1878 (possibly to negotiate arms sales), Warner made a point of visiting major British and European observatories. Back in Hartford, Warner and Swasey spent free evenings tinkering with telescopes, eventually fronting $1,000 to purchase a 9.5-inch-diameter lens from Alvan Clark & Sons and then building a tube, mount, and pier for it to learn engineering considerations for a medium-sized observatory-class instrument.

When Warner and Swasey became partners in Chicago in 1880, they immediately began using the 9.5-inch refractor to advertise the shop's precision work. That summer, they exhibited it at the annual Interstate Industrial Exposition on Michigan Avenue, where it drew front-page notices about the new firm in town in both the trade press and general newspapers. During that time, Warner visited Holden, who had recently been made director of Washburn Observatory at the University of Wisconsin in Madison. In return, Holden visited the Chicago shop, waxing so enthusiasticly about the 9.5-inch refractor that he arranged for its sale to Beloit College in Wisconsin. This first Warner and Swasey telescope sold for $2,000, several times what the pair were being paid for their fanciest machine tools [Fig. 3].

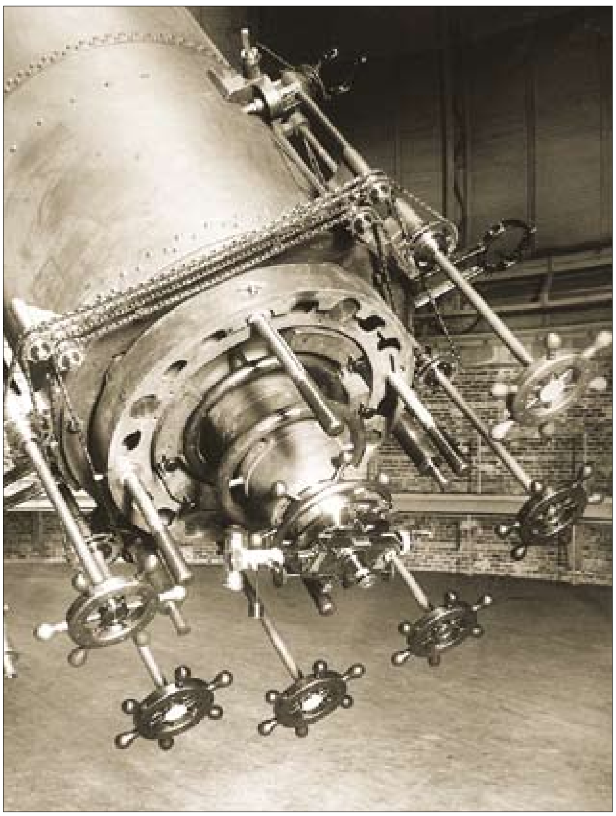

Figure 7 Eye end of the Yerkes 40-inch refractor shows all the knobs for operating the geared rods that controlled the telescope's motions—a major improvement Warner and Swasey made to telescope design.

THE FIRST *WORLD'S LARGEST*

Even while running the Washburn Observatory, Holden was an informal advisor to the James Lick trustees working out the design for the planned new California observatory, then under construction on Mount Hamilton east of San Jose.[10] Holden convinced the trustees to contract the two-year-old firm to build the revolving dome to house the observatory's smaller 12-inch Clark refractor, completed in 1881. Impressed with Swasey's novel design for an exceptionally lightweight dome and running gear (a rolling mechanism that ensured the dome would rotate smoothly without sticking, later patented in 1884), the Lick trustees entrusted the firm to design a mount for a portable 6.5-inch telescope. It was Warner and Swasey's ingenious design [Fig. 4] that made the trustees sit up and take notice.

But Warner had his sights set on the *world's largest*. While the firm's regular employees were busily manufacturing turret lathes and other standard machine tools, Warner and Swasey themselves intensely sought and filled orders for astronomical instruments and accessories to prove the young firm's worth to the Lick trustees. Of these, two stand out. First, they built a large 45-foot dome for the Leander McCormick Observatory of the University of Virginia, using it as a laboratory to scale up design innovations. Second, they designed a 9.5-inch refractor for Hartford High School in Connecticut, prototyping an improved system of controlling the telescope's fast and slow motions by rods and handles instead of by ropes and pulleys [Fig. 5].

At last, in 1886 the Lick trustees issued a request for competitive designs, a procedure standard today in seeking a superior design for unusual scientific instrumentation. But a century ago, traditional telescope design firms were incredulous that custom precision scientific instruments were being treated "like agricultural implements or steam engines."[11]

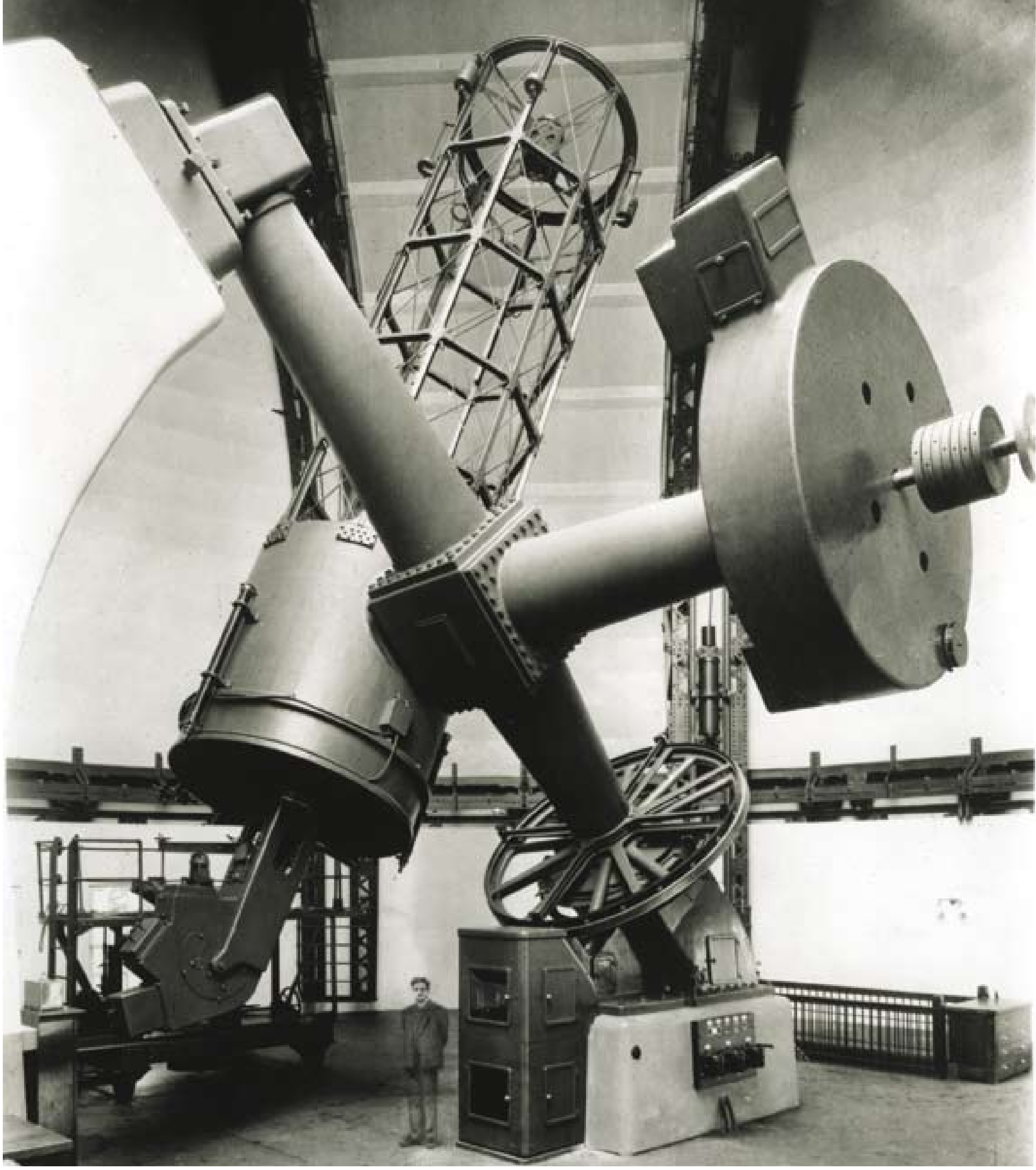

Figure 8 The first reflecting telescope built by the Warner & Swasey Co. was also briefly their third *world's largest* when completed in 1918 for the Dominion Astrophysical Observatory in Vancouver, BC. For it, they improved the so-called English mount (having one pier at each end of the polar axis). Note the sketch of a person included to indicate relative scale.

Warner and Swasey, on the other hand, shared with the Lick trustees what was then a novel perspective. Instead of viewing a telescope as a custom creation almost like a work of art, they viewed it as a machine subject to scientific law. Moreover, instead of viewing themselves as either artists or craftsmen, they viewed themselves as mechanical scientists who incorporated scientific law into metal. Although their biggest telescope so far had weighed under 1.5 tons and could have stood in a high-ceilinged living room, they had full appreciation for the monumental challenge of designing an instrument with the tonnage of steel and cast iron on the scale of the larger movable bridges of the time, yet controlled with the accuracy of a fine watch.

Their bid came in a third higher than any from their far more experienced competitors. But they blew their competition out of the water with their understanding of the telescope's load and flexure at all observing positions, their proposed methods for controlling the telescope's motions with a system of geared rods instead of ropes,[12] and for a spiral staircase up the pier to the mount that gave nighttime astronomers more sure-footed access than would a ladder.

The six-year-old firm of Warner and Swasey won the contract. In a year and a half, they had completed the tube, mount, and pier of the world's largest telescope for Lick Observatory.

THREE MORE *WORLD'S LARGEST*

Upon landing the order for the world's largest telescope for Lick, Warner and Swasey were rocketed into world fame. They lost no time in capitalizing on such publicity. As soon as the Lick refractor was mounted and dedicated in 1888, they mailed 600 picture postcards of it to colleges and universities around the nation, essentially saying *you, too, can own your own Warner and Swasey telescope.*

And they were in instant demand. Hardly had the Lick refractor been dedicated than rumors were already rumbling about the next *world's largest*—which turned out to be for a 40-inch refracting telescope for the Yerkes Observatory of the University of Chicago at Williams Bay, WI. Reprise: the massive lens was ground and polished by the master opticians Alvan Clark & Sons and was mounted by Warner and Swasey in 1897.[13] Before reaching its permanent home under its record-sized 90-foot revolving dome (also designed and built by Warner and Swasey), it was displayed at the international Columbian Exposition in Chicago in 1893 [Cover and Figs. 6 and 7].

At the dawn of the 20th century, Warner and Swasey were still partners working from a handshake. In 1900, however, they formally incorporated their firm as The Warner & Swasey Company. They also published a large-format commemorative picture album titled *A Few Astronomical Instruments*.[14] With virtually no text other than brief labels, the photographs display not only the pair's telescopes, but also myriad other specialized apparatus, showing how deeply their engineering work was contributing to forefront scientific research. This identification helped to raise the image of a professional engineer from that of mechanic to being an equal of the scientist. In 1897, Warner served as president of the American Society of Mechanical Engineers, followed by Swasey in 1904.

In 1912, the company was contacted again to build the *world's largest*—this time, a reflecting telescope with a mirror fully six feet across, for the Dominion Astrophysical Observatory in Canada. Astronomers had moved from refracting (lens) telescopes to reflecting (mirror) telescopes in a search for greater light-gathering power that could reveal fainter astronomical objects.

Warner and Swasey had never built a reflector. But that didn't stop them or the Canadian government. In 1913 they submitted plans for a novel design, for the first time incorporating the use of radial and thrust ball bearings, using the new technology of self-aligning precision ball bearings. The telescope, incorporating a mirror ground and figured by American master optician John A. Brashear, then in his seventies,[15] began operation in 1918 [Fig. 8]. It held title to being the world's largest working telescope of any design for just a few months, until superseded by the 100-inch Hooker reflector at the Mount Wilson Observatory.[16]

Although not a *world's largest,* Warner and Swasey did design and build one telescope larger than Dominion: the 82-inch reflector for the McDonald Observatory in Fort Davis, TX, a joint project of the universities of Chicago and Texas, completed in 1939. Warner and Swasey not only designed and built the entire mechanical mounting, but the firm's in-house optician Robert Lundin also ground and figured the seven-foot-diameter mirror. And it had a remarkable system of fractional-horsepower frequency-controlled synchronous motors for pointing the telescope and controlling its motions, even compensating for atmospheric refraction at various altitudes. Long after the company had gotten out of the telescope business, it still cited its design work for McDonald as an advertisement of its *tour-de-force* skills.[17]

The last *world's largest* telescope the company built was in a special category, a complex design called a Schmidt camera. Invented around 1930 and not usable for visual observing with an eyeball, it operates when light passes through a correcting plate (lens), is reflected from a large short-focal-length concave mirror, and comes to a focus on a photographic plate or film. The main advantage of a Schmidt camera is its wide, flat field of view. Its main challenge is the figuring of the correcting plate, a secret jealously guarded by its inventor for half a decade. Once the technique was known, a race was on to build the biggest Schmidt; the Warner & Swasey Co. did just that, building not only the mount but also the optics for a 24-36-inch Schmidt (the two numbers mean that the Schmidt had a 24-inch correcting plate with a 36-inch mirror). This last *world's largest*[18] was mounted in 1941 in the enlarged Warner & Swasey Observatory of the Case Institute of Technology in East Cleveland—21 years after the company's founders had originally donated the observatory with the words about money and glory.

Figure 9 After the company's destruction in the 1980s, the factory was purchased by the city of Cleveland; the five-story building is now boarded, and the assembly areas behind it abandoned and vandalized.

UNHAPPY ENDINGS

Glory and money may have their day, but neither they nor genius guarantee immortality.

Warner died in 1929, Swasey in 1937. The Warner & Swasey Company continued in excellent financial shape until four hostile takeovers during the merger-and-acquisitions feeding frenzy of the 1980s effectively dismantled and sold off all its operations by 1991. The five-story brick factory on Carnegie Avenue was sold to the city of Cleveland; it is still abandoned and is slowly being vandalized [Fig. 9].

The Lick 36-inch refractor on Mount Hamilton is still used for astronomical research, as are the 72-inch reflector of the Dominion Astrophysical Observatory and the 82-inch reflector at the McDonald Observatory.

The Yerkes 40-inch refractor has essentially been decommissioned by the University of Chicago, which is now seeking a buyer for the observatory and surrounding 80 acres of gracious parkland; as of the end of 2005, its future was unclear.

And the Warner and Swasey Observatory, which the two men had so proudly presented to Case in 1920? In the 1980s, the original 9.5-inch refractor—the very same that the two men built for their own enjoyment and mounted in an observatory between their neighboring houses on Cleveland's once-wealthy Euclid Avenue—was dismounted and remounted in a dome atop the university's astronomy building. The once-world's-largest 24-36-inch Schmidt camera was also dismounted and moved 40 miles east of Cleveland to Chardon, where it is now robotically controlled as the Nassau station of Case's astronomy department. Case sold the observatory's land and buildings to a small cable TV company, which ran its business out of the lobby until going bankrupt and abandoning the premises. Slowly, the domes were stripped of their copper coverings, and the windows smashed with rocks.

There is one ray of hope. In September 2005, the remains of the Warner and Swasey Observatory were auctioned at the minimum bid to its sole bidder, a young couple intending to refurbish it for their private residence.[19]

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References

[1] Case School of Applied Science, *Dedication of the Warner and Swasey Observatory,* October 12, 1920, Cleveland, OH, p. 11.

[2] Daniel Baracskay and Peter D. Rebar, *The Rise and Destruction of the Warner and Swasey Company: A Concise Case Study and Analysis* (Bookmasters Inc., Mansfield, OH, 2003), pp. 27, 42.

[3] This is a key conclusion of Edward J. Pershey in his unpublished dissertation *The Early Telescope Work of Warner and Swasey* (Case Western Reserve University, January 6, 1982).

[4] This anecdote appears differently in several references; see for example "Ambrose Swasey: Builder of Machines, Telescopes, and Men," by J.J. Nassau, *Popular Astronomy* 45 (8): 407-418, October 1937.

[5] Pratt & Whitney Co., *Accuracy for Seventy Years 1860-1930* (Hartford, CT, 1930), pp. 35-37; 2003 reprint available from *www.prattandwhitney.com/history* .

[6] A vivid reminiscence of the grim digs of the Chicago quarters appears in two slightly differing unpublished, untitled transcripts of the recollections of George Phelps on August 18, 1939; Warner & Swasey Co. papers, Box 20, Folder 7, SC/KSL.

[7] Ernest N. Jennison quotes 19th-century news coverage showing the Chicago shop's quick success in his unpublished, 80-page manuscript *The Story of the Warner and Swasey Telescopes,* 1951; original typescript is in Warner & Swasey Co. papers, Box 29, Folder 7, Special Collections, Kelvin Smith Library. That folder includes a seven-page list of telescopes of which Jennison could find record, compiled in 1951 and revised in 1957 and 1969 (which still has some gaps). A more complete list of Warner and Swasey astronomical instrumentation—including special-purpose instruments such as meridian circles and spectrometers—appears in Appendix A of Rudolph P. Snowadzky's unpublished dissertation *Twentieth Century Managerial-Technical Innovations in Weaving and Machine Tools at Warner & Swasey and Sulter Brothers Companies* (Case Western Reserve University, May 16, 1988).

[8] For background about this late 19th-century international telescope race and nobility of astronomy, see "In the Shadow of Giants: Forgotten Nineteenth-Century Telescope Makers and Their Crucial Role in Popular Astronomy," [condensation of master's thesis] by Trudy E. Bell, *Griffith Observer* 50 (9): 3-14, September 1986.

[9] An authoritative history of the U.S. Naval Observatory and its once-world's-largest refractor is Steven J. Dick's *Sky and Ocean Joined: The U.S. Naval Observatory 1830-2000* (Cambridge University Press, 2003); a photo of the original Clark mount with its ropes appears on p. 213, and the massive new Warner and Swasey mount with control rods and signature spiral staircase on p. 378. The instruments of the Clarks, the father-and-sons team of opticians who figured lenses for the world's largest telescopes five times over, are detailed in the classic reference *Alvan Clark & Sons: Artists in Optics* by Deborah J. Warner and Robert B. Ariail (second edition, Willmann-Bell, 1995).

[10] The definitive history of the 36-inch refractor is in *Eye on the Sky: Lick Observatory's First Century* by Donald E. Osterbrock, John R. Gustafson, and W. J. Shiloh Unruh (University of California Press, 1988).

[11] Pershey p. 103.

[12] As with the turret lathe, Warner and Swasey did not invent the idea of controlling telescope motions by rods instead of ropes, but significantly improved it after seeing European control rods on telescopes in the 1870s during Warner's visit overseas for Pratt & Whitney.

[13] The definitive history of the 40-inch refractor is in *Yerkes Observatory 1892-1950: The Birth, Near Death, and Resurrection of a Scientific Research Institution* by Donald E. Osterbrock (University of Chicago Press, 1997).

[14] *A Few Astronomical Instruments From the Works of Warner & Swasey,* Cleveland, OH, MDCCCC; 36 numbered plates, plus a frontispiece of the factory.

[15] W. Lucien Scaife, editor, *John A. Brashear: The Autobiography of A Man who Loved the Stars* (American Society of Mechanical Engineers, 1924).

[16] What's considered *world's largest* depends on what's considered a *first*—completion of mirror, mounting of mirror, first light, or first work. Every observatory has many firsts and many advocates. The Mount Wilson 100-inch was mounted in November 1917 and then sat idle for a year before research was begun, while the DAO was mounted and dedicated between April and June 1918 and immediately put into continuous use.

[17] E. N. Jennison, "Electrical Control of Astronomical Telescopes," *Cleveland Engineering* 40 (6): 5, 19-27, February 6, 1947.

[18] *The Warner and Swasey Observatory, Case School of Applied Science,* Cleveland, OH January 1942. In the 1930s, Warner and Swasey bid on the design and construction of the 200-inch *world's largest* on Palomar Mountain, but was not awarded the contract because it would have needed to rely heavily on third-party suppliers for the largest pieces; see David O. Woodbury, *The Glass Giant of Palomar* (Dodd, Mead, and Co., 1939), p. 212.

[19] Michael O'Malley, "Family's new focus: Turning historic observatory into home," *Cleveland Plain Dealer*, September 7, 2005, pp. B1, B5.

Image Sources

Cover Photograph: Randy and Yulia Liebermann Lunar and Planetary Exploration Collection–George W. Ritchey archive

Photographs of Warner and Swasey on p. 13: American Society of Mechanical Engineers

Fig. 1: Royal Astronomical Society

Fig. 2: Portrait: Copies of original in Department of Special Collections, Kelvin Smith Library, Case Western Reserve University, Cleveland, OH; engraving: *The Warner & Swasey Company 1880-1930*

Fig. 3: Copies of originals in the Department of Special Collections, Kelvin Smith Library, Case Western Reserve University

Fig. 4: *Publications of the Lick Observatory*, vol. I (1887), p.66

Fig. 5: *Sidereal Messenger*, vol. 4, no 10. Dec. 1885, rear cover

Fig. 6: Randy and Yulia Liebermann Lunar and Planetary Exploration Collection–George W. Ritchey archive

Fig. 7: Randy and Yulia Liebermann Lunar and Planetary Exploration Collection–George W. Ritchey archive

Fig. 8: Royal Astronomical Society

Fig. 9: Author

For further information: The Antique Telescope Society will hold its annual convention (open to nonmembers) September 29–October 1, 2006, at the McDonald Observatory in Texas, whose centerpiece instrument is the largest telescope Warner & Swasey built; for registration information, contact Walter H. Breyer at *whbreyer@alltel.net* .

Warner and Swasey's first turret lathe is on display at the American Precision Museum: *www.americanprecision.org* .

Much of the information in this article is derived from unpublished documents in the Warner & Swasey collection at the Kelvin Smith Library of Case Western Reserve University (noted in references).

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