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JAMES MILLHOLLAND AND  
EARLY RAILROAD ENGINEERING

*John H White*

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*James Millholland*

Figure 1.—JAMES MILLHOLLAND (1812-1875), pioneer railroad master mechanic. As this signature shows, he spelled his name variously. (From *World's Railways*, p. 45.)

# James Millholland And Early Railroad Engineering

*From the apprentice on the "Tom Thumb" to the master machinist of the Philadelphia and Reading Railroad, the career of James Millholland spanned nearly a half century in the early development of the American railroad. One of the great mechanics of the 19th century, he is remembered not only for his highly original innovations, the most outstanding of which was the conversion of the wood burner to the anthracite burner, but also for his locomotives, which were plain, practical machines, highly distinctive from the ornate locomotives of the period.*

THE AUTHOR: John H. White is associate curator of transportation in the Smithsonian Institution's Museum of History and Technology.

JAMES MILLHOLLAND is remembered today as one of the foremost railway master mechanics of the 19th century. He was fortunate in also having been esteemed in his lifetime for having perfected numerous railway mechanisms and, most particularly, for his work on anthracite-coal-burning locomotives. He was born on October 6, 1812, in Baltimore, Maryland, and there received a private education.<sup>1</sup> Gifted with

an aptitude for mathematics and influenced by his father, who manufactured ship fittings, young Millholland inclined naturally toward mechanics as a life work. In 1829, at age 17, he was apprenticed to George W. Johnson, a Baltimore machinist, there gaining his first experience in working on a locomotive engine, Peter Cooper's famous *Tom Thumb*.

Cooper, in an effort to persuade the new Baltimore and Ohio Railroad to adopt steam power, had started to build this light steam locomotive in 1829. He had worked out the general arrangement and assembled a

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<sup>1</sup> Railroad Gazette (August 28, 1875), vol. 7, p. 362. (Obituary notice.)

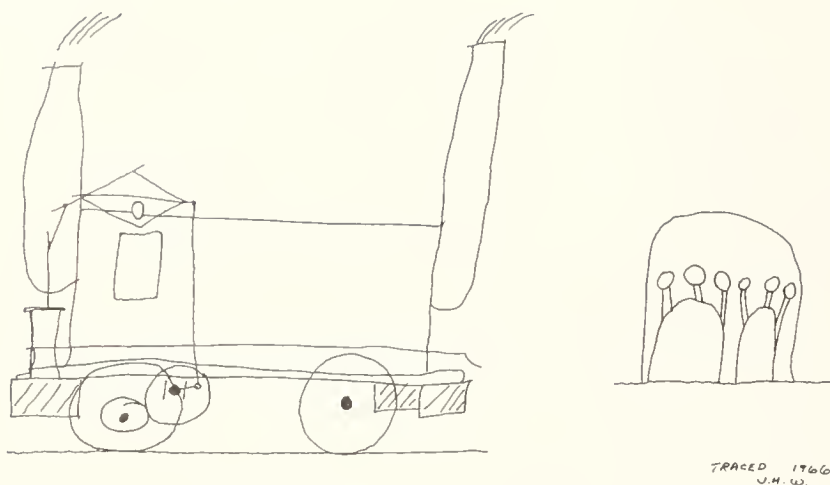


Figure 2.—TRACING OF MILLHOLLAND'S sketch of the *George W. Johnson*, built in 1831 for the Baltimore and Ohio Railroad.

boiler and cylinder, but, busy with other affairs in New York, he asked George Johnson to complete the machine. Thus young Millholland had a direct hand in the building of the *Tom Thumb*—completed in 1830—and shared in a pioneer effort to introduce mechanical transport in America. Considering Millholland's later involvement with anthracite coal, it was somewhat prophetic that the *Tom Thumb* was designed to burn this fuel.

Millholland next assisted his employer in building a second locomotive, named the *George W. Johnson* in honor of its designer. It was completed in 1831 and won \$1000 as second prize in a contest sponsored by the Baltimore and Ohio Railroad. The *Johnson* employed a curious assemblage of design features, including walking beams, geared transmission, and a divided firebox, but the machine was not a success and was retired after brief service.

The only authentic illustration of the *Johnson* is a little sketch made by Millholland in 1873 (fig. 2). The several illustrations which were subsequently published are based on this sketch.<sup>2</sup>

Millholland left his native city for New York in 1832 and entered the employment of the Allaire Works, a firm famous for marine engines. With the exception of a brief sojourn in Mobile, Alabama, where he worked on a sawmill during 1836, he stayed with Allaire until 1837. In his 25th year, like most other young mechanics, he was obscure and unknown,

but, unlike most, Millholland was about to embark on a distinguished career.

His great opportunity came in 1838 when he returned to railroad work in Baltimore and was appointed master mechanic of the Baltimore and Susquehanna Railroad. The prestige of his new position possibly was more apparent than real, for the Baltimore and Susquehanna was a threadbare little company whose serpentine road wound a distance of 58 miles between Baltimore, Maryland, and York, Pennsylvania. It had 80 bridges, too many curves, and too few locomotives or cars. The novice master mechanic soon was put to the test of keeping in working order the road's 10 engines, which could not have been more poorly adapted to the needs of the company. Three were British made. The rest were built on patterns similar to the British engines by the Locks and Canals machine shop of Lowell, Massachusetts. All of the engines proved too light for steep grades and too rigid to negotiate the road's sharp curves. Fortunately, the company had a fairly well-equipped repair terminal in Baltimore, adjacent to the present Mt. Royal Station, known as the Bolton shops. Millholland there began remodeling the road's motive power as fast as funds permitted.

One of the most extensive locomotive remodelings Millholland executed for the Baltimore and Susquehanna was the reconstruction of the *Herald*,<sup>3</sup> the first engine on the line. It was a Sampson-class

<sup>2</sup> Reconstructions of the *Johnson* appeared in *Railway Age* (July 7, 1893), vol. 18, p. 531, and in J. G. PANGBORN, *World's Railways* (New York: Winchell Printing Co., 1894), p. 52.

<sup>3</sup> The facts presented on the *Herald* are from the Baltimore and Susquehanna Railroad's annual report for 1854, and in *Railroad Advocate* (May 26, 1855), vol. 2, p. 2.



# BALTIMORE & SUSQUEHANNA RAIL-ROAD



THE PASSENGER & FREIGHT TRAINS

## ARE NOW RUNNING,

DAILY, BETWEEN

## Baltimore & Wrightsville,

The termination of the *Philadelphia & Columbia Rail-Road*; connecting  
with that Road and with the *Pennsylvania State Canals*, at *Columbia*.

“This Line of Rail-Road is constructed in the most substantial manner, with the heaviest Rail used in the United States!!  
The Cars and Locomotives are of the best quality.”

### The Hours of Departure and Arrival

Of the **PASSENGER TRAINS**, at present, are as follows, viz:

**BALTIMORE TO YORK**—  
Leave Baltimore at 8 A.M. Arrive York at 12 M.

**YORK TO BALTIMORE**—  
Leave York at 1 P.M. Arrive Baltimore at 5 P.M.

**BALTIMORE TO HARRISBURG**—  
Leave Baltimore at 10 A.M. Arrive Harrisburg at 4 P.M.

**HARRISBURG TO BALTIMORE**—  
Leave Harrisburg at 7 A.M. Arrive Baltimore at 1 P.M.

**D. C. H. BORDLEY, Superintendent.**

Transportation Office Baltimore and Susquehanna Rail-Road Co.  
Baltimore, Md.

Figure 3.—The *Baltimore* (1837) built by Locks and Canals and reconstructed by Millholland in later years with a leading truck and cast-iron crank axle. (From Thomas Norrell.)

0-4-0, a standard design of its English maker, Robert Stephenson & Co. The engine had proved entirely unsatisfactory for the Baltimore and Susquehanna, and had been rebuilt in October 1832—only a few months after its delivery—as a 4-2-0 wheel arrangement. By 1846, however, it was found too small for further service and accordingly was taken into the company shops for major remodeling. Millholland fashioned a powerful 13-ton 0-6-0, nearly twice the weight of the original *Herald*, from which only the boiler was used. Other major features of this remodeling were a gear drive for power and low speed, and a lateral-motion arrangement for each driving axle to permit navigation of sharp curves. The engine was intended for the movement of trains through city streets between the railroad's various Baltimore terminals. The *Herald* was still in service in 1857, but was sold for scrap two years later.

Millholland's gifts as mechanic and innovator first received notice in a report by the *American Railroad Journal* for November 6, 1845, on the use of cast iron for making crank axles. Inside-connected engines, which were then popular, were fitted with wrought-iron crank axles. Although wrought iron was the strongest material available, it was not only costly, but its variable quality and fibrous character made it unreliable for use in crank axles. These broke frequently, creating a costly hazard and serious accidents.

Millholland's insistence upon cast-iron crank axles seemed preposterous because the metal was brittle and unable to withstand great impact stresses. He eschewed ordinary cast iron, however, and insisted on the best cold-blast Maryland iron—the kind used for cannons and car wheels—which had a tensile strength of about 30,000 pounds per square inch.

In its report, the *American Railroad Journal* noted that Millholland's cast-iron crank axle had been used successfully since June 15, 1845. The engine in question, unidentified except that it was built in Lowell, was unquestionably one of the light Locks and Canals locomotives mentioned above. It was described as having a leading truck, a single pair of driving wheels, and a pair of trailing wheels, making it a 4-2-2. The crank axle weighed 1150 pounds before turning, which compared favorably to a similar unmachined wrought-iron axle weighing 1164 pounds. It had been cast by J. Watchman of Baltimore at a cost of \$69, whereas the wrought-iron axle cost \$291 before machining. Not only was the cast-iron crank cheaper, but it was equally as strong as the

wrought-iron one. The *American Railroad Journal* continued its report:

A few evenings since, the engine with the cast iron crank axle, was, together with its tender, thrown entirely off the track, by a large hog getting under the wheels behind the cow-catcher—no damage having been done to any part of the engine, it was thus shown that the cast axle can bear without injury the sudden and violent strain to which it was subjected by this accident, as well as the wrought iron crank axle. There is therefore good reason for believing that this improvement, which will so materially reduce the cost of replacing a broken crank axle, may with perfect safety be introduced into general use.

The Baltimore and Susquehanna subsequently fitted its other inside-connected engines with cast-iron crank axles. No evidence exists that other roads followed suit, but the Baltimore road seemed well pleased with Millholland's innovation. In a letter to Robert Stephenson and Co., dated March 8, 1850, Robert S. Hollins, secretary of the Baltimore and Susquehanna, stated: "Our preference is the *Cranked Axle Locomotive*, but repeated breaking of the axle: Every Locomotive having broken one or more, we were induced to try *cast iron*, and after an experience of 5 years, we have adopted them entirely, never yet having broken a *Cast Iron Crank Axle*."<sup>4</sup> This statement, made two years after Millholland had left the Baltimore and Susquehanna, testifies that the cast-iron crank axle was a success on its own merit and not merely because it was a "pet" of the presiding master mechanic. According to Millholland's eldest son, James A. Millholland, one of these crank axles was sent to his father years later, presumably in the 1860's, after the engine had been scrapped.<sup>5</sup> This trophy laid around the Philadelphia and Reading shops for some years, only to be junked during a clean up.

In addition to rebuilding existing machines and developing the cast-iron crank axle, Millholland built two new locomotives at the Bolton shops. The first of these identical machines, the *General Taylor*, was completed in October 1846; the other, the *Wm. H. Watson*, in March 1847.<sup>6</sup> Intended for freight service, these machines were large for the times, each weighing

<sup>4</sup> *Engineer* (May 29, 1914), vol. 117, p. 601.

<sup>5</sup> Letters dated May 11 and 18, 1888, from James A. Millholland to J. E. Watkins, a curator at the Smithsonian Institution.

<sup>6</sup> *American Railroad Journal* (December 19, 1846), vol. 19, p. 811, states that the *Watson* "was lately built." The March 1847 date is given in the Baltimore and Susquehanna's annual report for 1849.

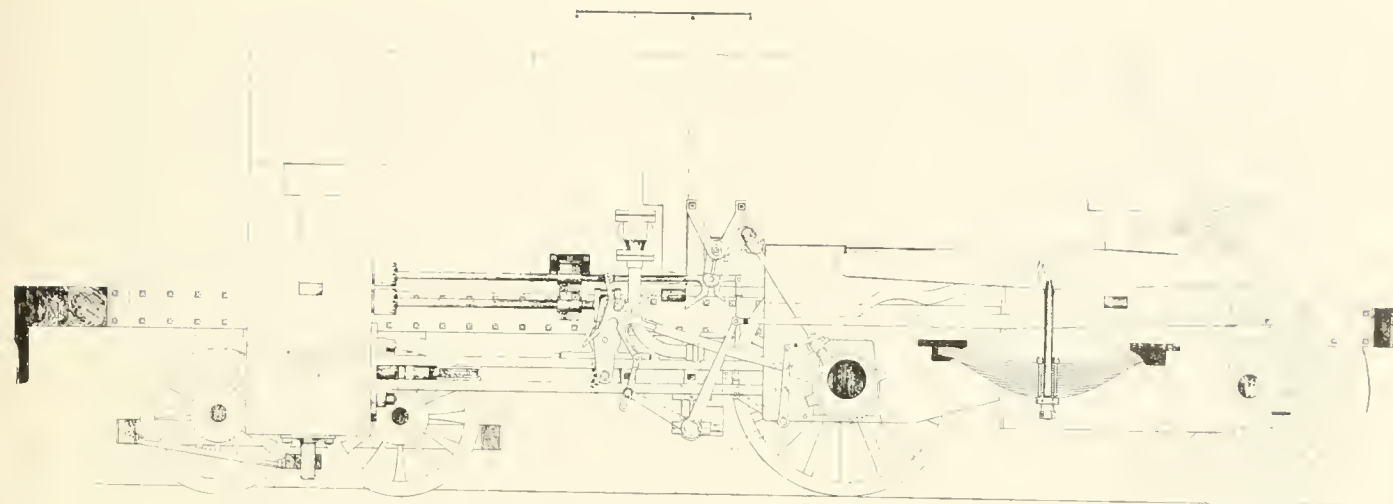


Figure 4.—THE FREIGHT LOCOMOTIVE *Wm. H. Watson* WAS DESIGNED AND BUILT BY JAMES MILLHOLLAND at the Bolton shops of the Baltimore and Susquehanna Railroad in 1847. It was fitted with a cast-iron crank axle. (From an original drawing in the Smithsonian Institution.)

26½ tons. They had 18- x 18-inch cylinders, 48-inch-diameter driving wheels, and were inside-connected, fitted with massive cast-iron crank axles each of which measured about 8½ inches in diameter (fig. 4). A separate cutoff was employed, both valves being driven by a single eccentric. Both the *Taylor* and the *Watson* appear to have been wood burners, since they had small, deep fireboxes.

Millholland's energies were not confined to locomotive work, for he also contributed improvements to car and bridge design. His advocacy of railway-car springs made of wood paralleled his cast-iron cranks as a bold substitution of a cheaper, unconventional material for heavy service. Millholland secured a patent (No. 3,276) for wooden springs on September 23, 1843, and their use by the Baltimore and Susquehanna was reported the following year:

The freight cars in general use on this road are superior, in many respects, to any we have seen, that is, they carry a greater amount of freight in proportion to the weight of the car, than on most roads. They have six wheels, the body is made light but strong, resting on *wood* springs, consisting of two pieces each 2 inches by 6, and 13 feet long, of white ash plank. Other companies will do well to examine them and either adopt, or improve upon them.<sup>7</sup>

The Baltimore and Susquehanna annual report for 1843 notes the construction of 29 six-wheel freight cars "on the plan invented by James Millholland." Such cars cost \$450, weighed 8500 pounds, and had a capacity of 12,000 to 14,000 pounds. The same report mentioned the construction of a "similar" car for passenger service, apparently meaning one with six wheels and on wooden springs. The 1844 annual report shows the construction of 37 more six-wheel cars, 24 of which were built in the company shops, the remainder by private contractor. By 1850 the road reported 159 six-wheel freight cars of various styles. Six-wheel cars were in themselves unusual. The only other United States railroad known to have them was the Baltimore and Ohio, which had over 200 six-wheel iron coal hoppers. Six-wheel tenders, however, were common in the 1840s and 1850s, and six-wheel cars were used extensively by foreign roads. In addition, wood springs were used later on thousands of four-wheel coal "jimmies" of the Reading, Lehigh Valley, Central of New Jersey, and other roads. Some of these continued in regular service through the 1890's. Millholland received \$1000 for the use of his wood spring and other patents while he was in the service of the Reading.<sup>8</sup>

<sup>8</sup> The Minutes of the Board of Managers, preserved by the Reading Company, Philadelphia, Pennsylvania. Cited hereafter as Minute Books.

<sup>7</sup> *American Railroad Journal* (October 1844), vol. 17, p. 292.



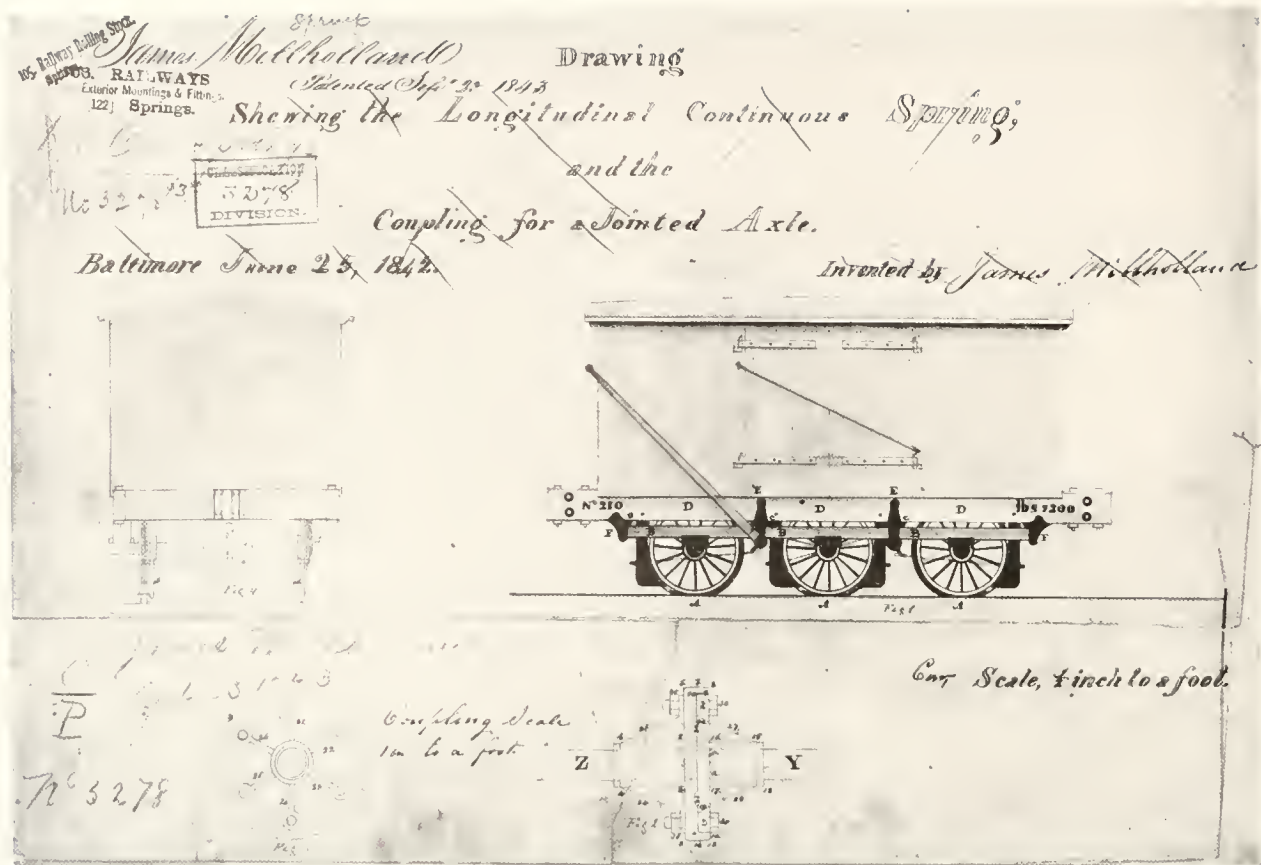


Figure 5.—The 1843 WOODEN-CAR-SPRING PATENT SHOWING A SIX-WHEEL FREIGHT CAR. The drawing is so well detailed and proportioned that it appears to be based on an actual car design, undoubtedly representing the type of car used on the Baltimore and Susquehanna Railroad. (From U.S. National Archives.)

Before leaving the subject of wooden springs, one canard about their origin should be put to rest. E. J. Rauch, an employee of the Philadelphia and Reading Railroad under Millholland, alleged in October 1893 that his former supervisor had not, in fact, invented the wooden spring.<sup>9</sup> Rauch claimed that about 1850 a hapless workman in the Philadelphia and Reading shops had patented the idea but, unable to effect its adoption, sold the patent to Millholland for a pittance. The allegation is without

<sup>9</sup> Rauch repeated his allegation in a biographical sketch of Millholland, published in *Railway and Locomotive Engineering* (June 1903), vol. 16, p. 276. It was a friendly recollection but repeated in part the wood-spring story. This and several other errors suggest that Rauch may have drafted his article mainly from memory.

basis, since Millholland, as we have seen, had patented the spring several years before joining the Reading. Such stories are commonly attributed to famous mechanics by lesser mechanics, possibly in the hope of reducing great men to common level.

In addition to the six-wheel freight cars, Millholland built two passenger cars for the Baltimore and Susquehanna in 1846 and 1847. Little is known about these cars except that one was splendidly fitted with crimson cut-velvet curtains and a body painted dark claret.<sup>10</sup>

Aside from his contributions to railroad equipment, Millholland's single most important engineering enterprise was the plate-girder bridge. This single-

<sup>10</sup> *American Railroad Journal* (July 17, 1847), vol. 20, p. 449.



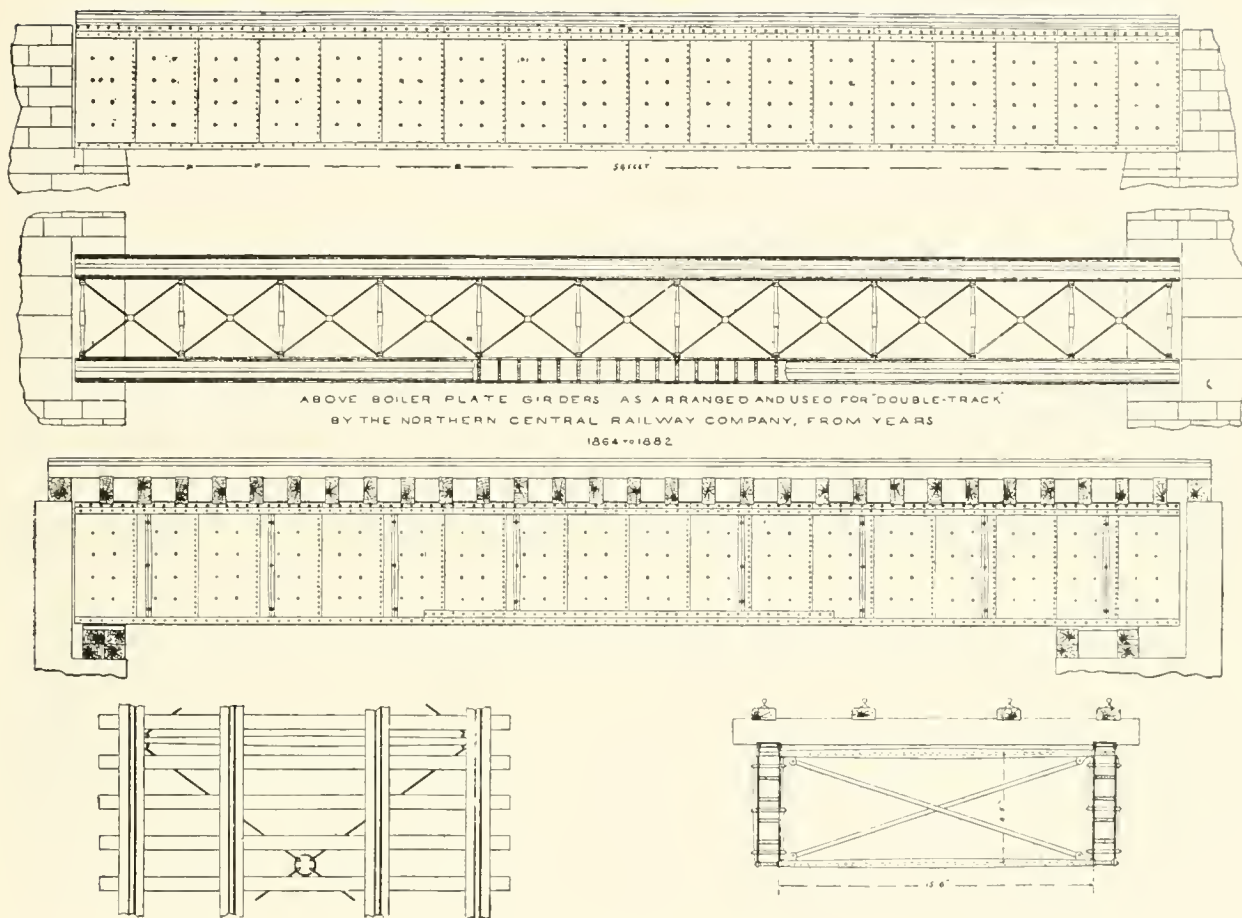


Figure 6.—THE PLATE-GIRDER BRIDGE COMPLETED IN 1847 BY MILLHOLLAND for the Baltimore and Susquehanna Railroad. (From *Engineering News*, October 20, 1888.)

track bridge was fabricated from  $\frac{1}{4}$ -inch boiler iron. It was 6 feet deep by 54 feet long, weighing 14 tons. Built at the Bolton shops in the winter of 1846 and placed in service 19 miles north of Baltimore in April 1847, it was the first such bridge in America—and probably the first of its kind in the world. In 1864 it was rebuilt for a double track and continued in use for another 18 years <sup>11</sup> (see Appendix I).

In 1848 Millholland was in the prime of life, a recognized mechanic and respected engineer whose reputation had outgrown his position with the strug-

gling Baltimore and Susquehanna. Accordingly, when in August 1848 the Philadelphia and Reading Railroad offered him the position of master machinist, he readily accepted.<sup>12</sup>

The Philadelphia and Reading was one of the best engineered railroads in the 19th-century United States. In contrast to most American roads, it was very well constructed, with generous curves, light grades, and heavy T rails. Its capitalized cost came to \$180,000 per mile, more than six times that of most other American railroads. Running from Phila-

<sup>11</sup> *Engineering News* (October 20, 1888), vol. 20, p. 305, contains a drawing and reproduces a letter (May 1, 1849) from Millholland to Herman Haupt describing the bridge. See also C. W. CONdit, *American Building Art: the 19th Century* (New York: Oxford University Press, 1960), pp. 106–107 and 301.

<sup>12</sup> Millholland gives the date of his employment with the Reading in a letter (November 9, 1860) to C. T. Parry of the Baldwin Locomotive Works. This letter is preserved by the Historical Society of Pennsylvania.

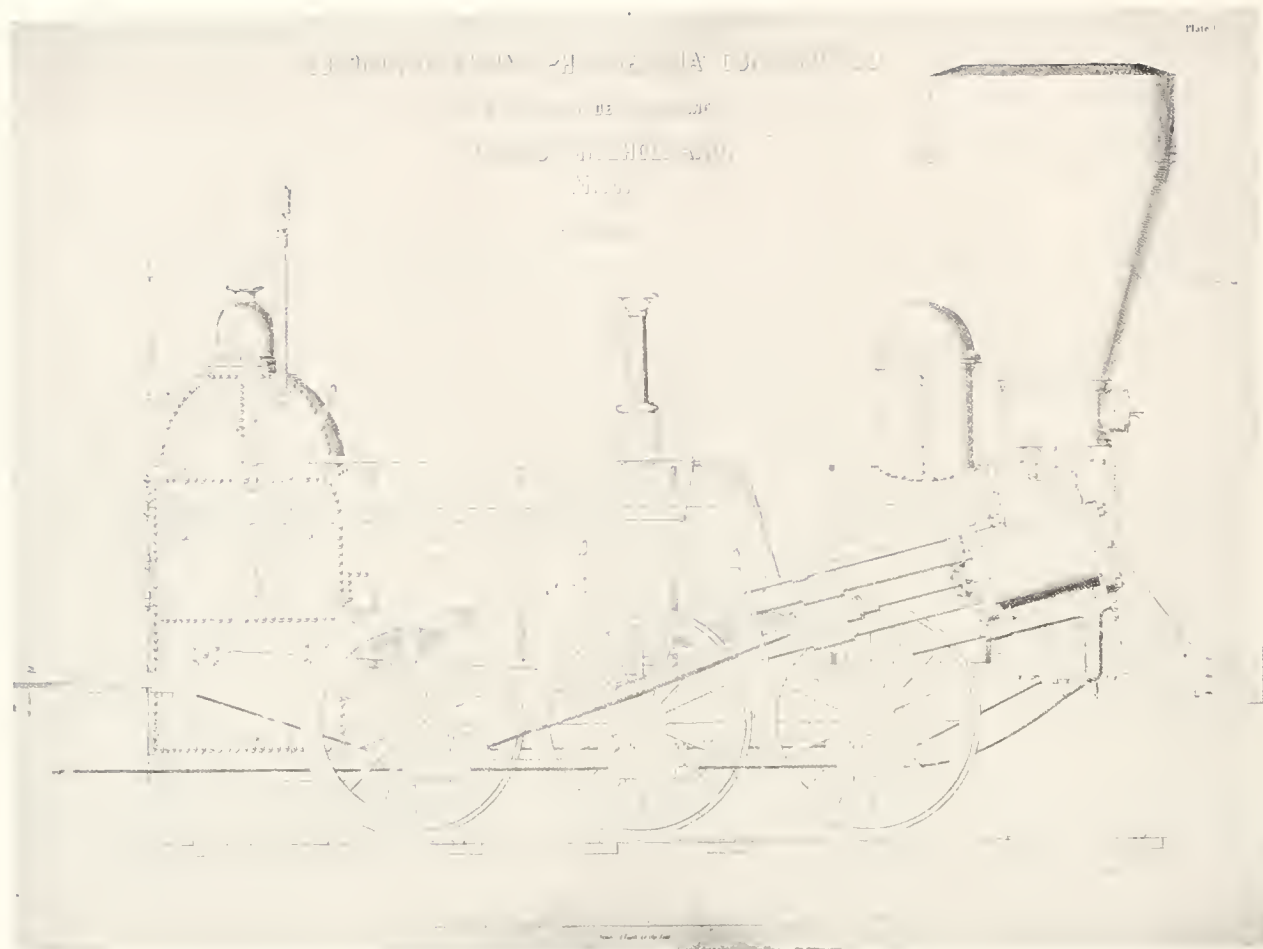


Figure 7.—THE *Philadelphia*, BUILT IN 1844 BY NORRIS BROTHERS for the Philadelphia and Reading Railroad. Shown as rebuilt 1848-1849 by Millholland. (From *American Locomotives*, 1849, by E. Reuter.)

delphia to the coal fields near Pottsville, the line was built as an anthracite carrier. In 1835, three years before it began to operate, the board of managers had decided it was "of the utmost importance that the locomotive engines to be constructed for this company be built with a view to the exclusive use of anthracite as fuel . . ." <sup>13</sup> This plan was frustrated when experience showed that anthracite was all but impossible to burn in locomotives, and the line had to resort to wood.

Millholland's major problem was not simply to build a coal-burning locomotive—difficult enough in itself—but one that would burn anthracite. This

dense, slow-burning fuel—sometimes called "stone coal"—was singularly inappropriate for use in the narrow and deep wood-burning fireboxes of the early 19th century. Anthracite burned best when spread thin over a large area. Wood, on the other hand, being highly combustible, was stacked thick and deep for best results in firing.

Because the Reading's primary traffic was anthracite, Millholland was expected to develop a practical plan for using this fuel in the company's locomotives. He labored ten years with the problem, and in the end, despite many failures, he achieved a remarkably successful design. Boiler and firebox improvement was Millholland's chief occupation, and he pioneered in this field. Most American motive-power officials of the period were content with wood burners, con-

<sup>13</sup> Minute Books, April 13, 1835.

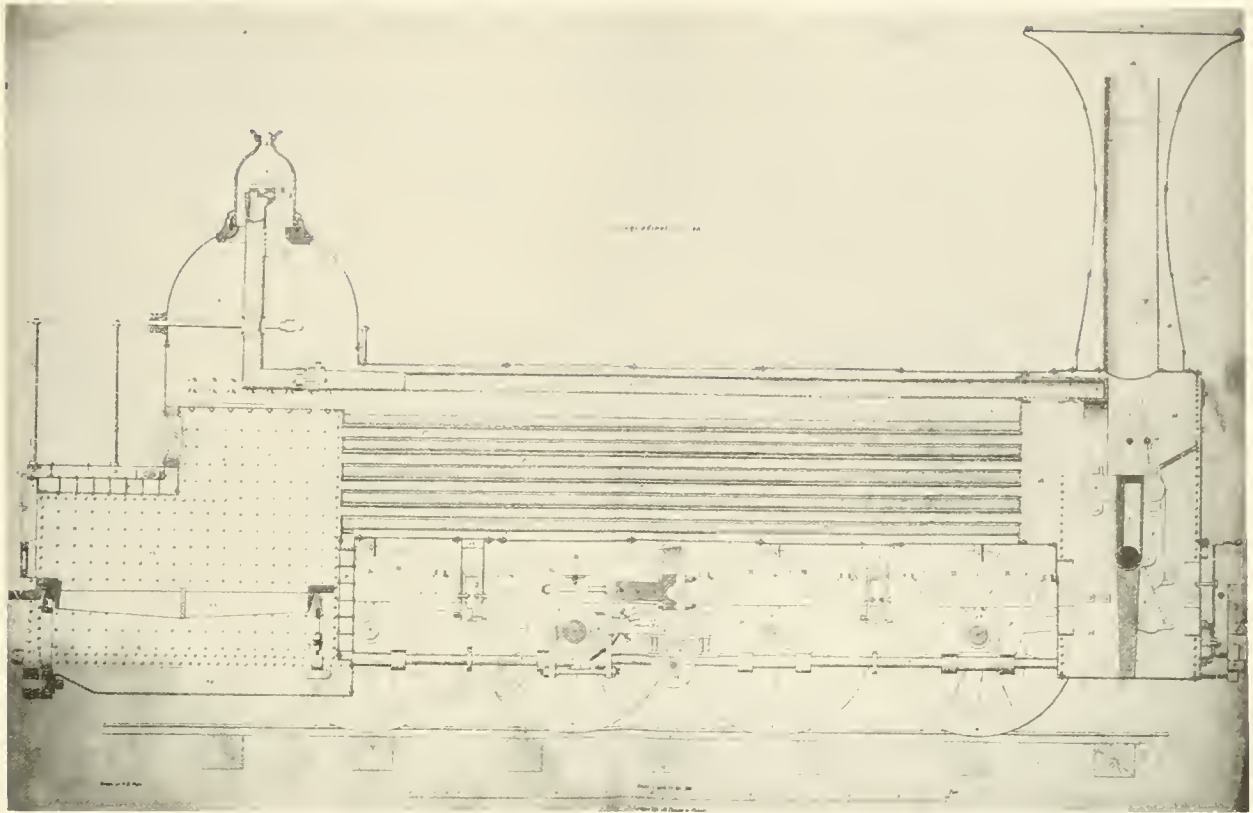


Figure 8.—THE *Delaware* AS BUILT IN 1846 BY ROSS WINANS for the Philadelphia and Reading Railroad. It was not a successful anthracite burner and was rebuilt in 1850 by Millholland with a central-combustion-chamber boiler. (From *American Locomotives*, 1849, by E. Reuter.)

centrating their energies on the other basic problem of perfecting flexible running gears for the uneven and cheaply built tracks that characterized most railroads in the United States.

Millholland's initial attempt to produce an anthracite burner was on a Norris six-wheel connected engine, the *Philadelphia*.<sup>14</sup> Built in 1844, this wood burner had exploded shortly after being placed in service and already had been rebuilt once in the company's shops before Millholland's remodeling of 1848 or 1849. He made an effort to increase the grate area, but the machine was a dismal failure as a coal burner. The rebuilt *Philadelphia*, however, is

noteworthy for its double-poppet throttle valve. (A valve of this type is shown at *n* in fig. 11.) This is one of the earliest recorded uses of the poppet throttle, which after 1870 became the standard throttle valve for all American locomotives. Millholland was probably the first in America to make large-scale use of this style of throttle.

Not long after the *Philadelphia's* rebuilding, Millholland attempted to modify the *Warrior*, an 0-3-0 flexible-beam freight engine built by Baldwin in 1846, for anthracite. The firebox was extended behind the rear driving wheels and widened to about 66 inches.<sup>15</sup> This was an enormous increase in grate

<sup>14</sup> ANGUS SINCLAIR *Development of the Locomotive Engine* (New York: Sinclair Publishing Co., 1907), p. 283. Sinclair mistakenly states that the *Philadelphia* was a new locomotive and the first engine to be constructed by Millholland for the Reading.

<sup>15</sup> Rauch makes this statement in his article on Millholland in *Railway and Locomotive Engineering* (June 1903), vol. 16, p. 276. The Philadelphia and Reading annual report for 1858, however, lists the *Warrior* as rebuilt in 1858.

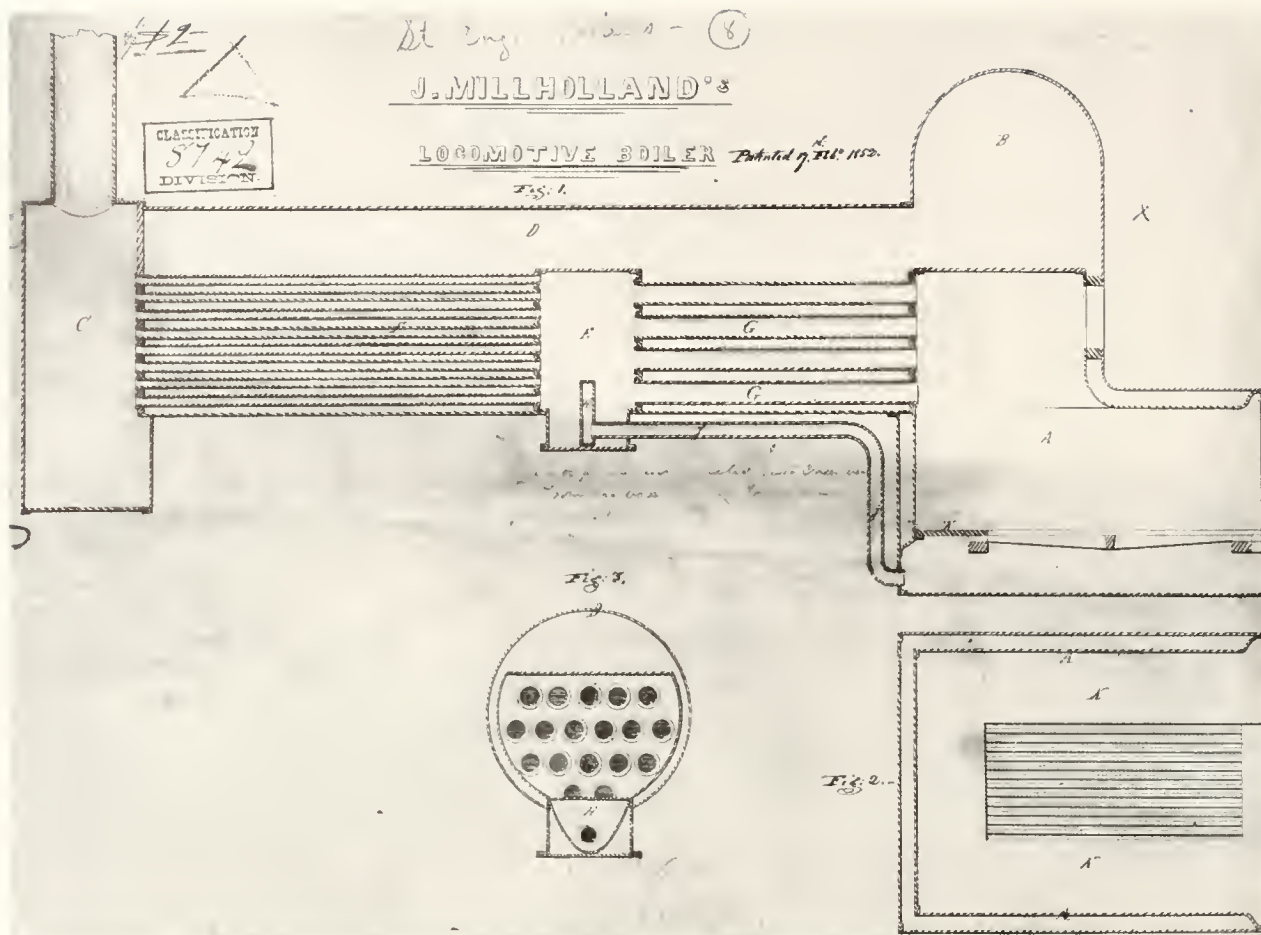


Figure 9. MILLHOLLAND'S PATENTED CENTRAL-COMBUSTION-CHAMBER BOILER with dead-plate fire grate. Note the similarity of this design to the general arrangement, excepting the patented features, of the *Delaware* boiler. (From U.S. National Archives.)

area, since the firebox in regular wood burners of the period was rarely more than 34 inches wide. Encouraged by the *Warrior's* performance, Millholland turned his hand to rebuilding more of the Reading's old engines.

Two years before Millholland joined the Reading, several coal-burning, eight-wheel engines had been purchased from Ross Winans, who had developed a successful coal burner some years earlier. Winans' engines were built to burn soft coal, a fuel far more readily combustible than anthracite. These engines did not succeed on the Reading, however, although Millholland recognized that their builder was correct in providing a large grate area. He rebuilt one of the machines, the *Delaware*, in December 1850, and two sister engines soon thereafter.

Some months later the *Scientific American*, commenting on the rebuilt engines, said that they were so successful that the Reading planned to rebuild all of their power on Millholland's new plan.<sup>16</sup> But the statement was premature, for the plan was, in fact, very defective. Whatever success was obtained with these engines should be credited to the method of firing and not to the firebox plan. Millholland had instructed the fireman to put only 7 inches of coal on the grates in place of the 18 inches previously used. (In the end, most locomotive authorities agreed that skillful firing was more important to successful coal burning than were the many complex boiler and

<sup>16</sup> *Scientific American* (October 18, 1851), vol. 6, p. 35.



firebox designs advocated by various inventors and engineers, Millholland among them.) The *Scientific American* went on to state that cast-iron plates 9 inches wide on each side and 16 inches wide at the rear were placed on the grates in an effort to protect the firebox sheets from the direct action of the fire, and thus only the center portion of the grates was open. This arrangement may have preserved the firebox, but it hampered combustion by restricting the free passage of air to the underside of the fire.

A second and more important modification was the placement of the combustion chamber near the center of the boiler waist. The central combustion chamber was connected to the firebox by a number of large (3- or 4-inch-diameter) tubes; the gases were carried to the smoke box by regular small (2-inch-diameter) tubes. Ideally, all of the combustible gases *not* burned in the firebox would burn in the central chamber before passing to the smoke box. In practice,

however, the temperature of the gases, already too cold for combustion, was further reduced in the central chamber, where they were mixed with more cold air. Millholland was overly concerned, as were many other engineers, with the quantity of air required for good combustion.

On February 17, 1852, Millholland secured a patent (No. 8,742) for the combination of dead-plate grates and central combustion chamber.<sup>17</sup> The

<sup>17</sup> The central combustion chamber had been patented in England six years earlier. See John Dewrance, British Patent, October 1846. The central-combustion-chamber boiler was revived in 1884 by A. J. Stevens, master mechanic of the Central Pacific Railroad. Seemingly unaware that this was an old idea, he reported in the January 1885 *National Car Builder* (page 2) on the successful tests of a locomotive boiler identical in plan to Millholland's. The incident aptly illustrates the many instances of inventors independently duplicating the work of others in attempting to solve identical problems.

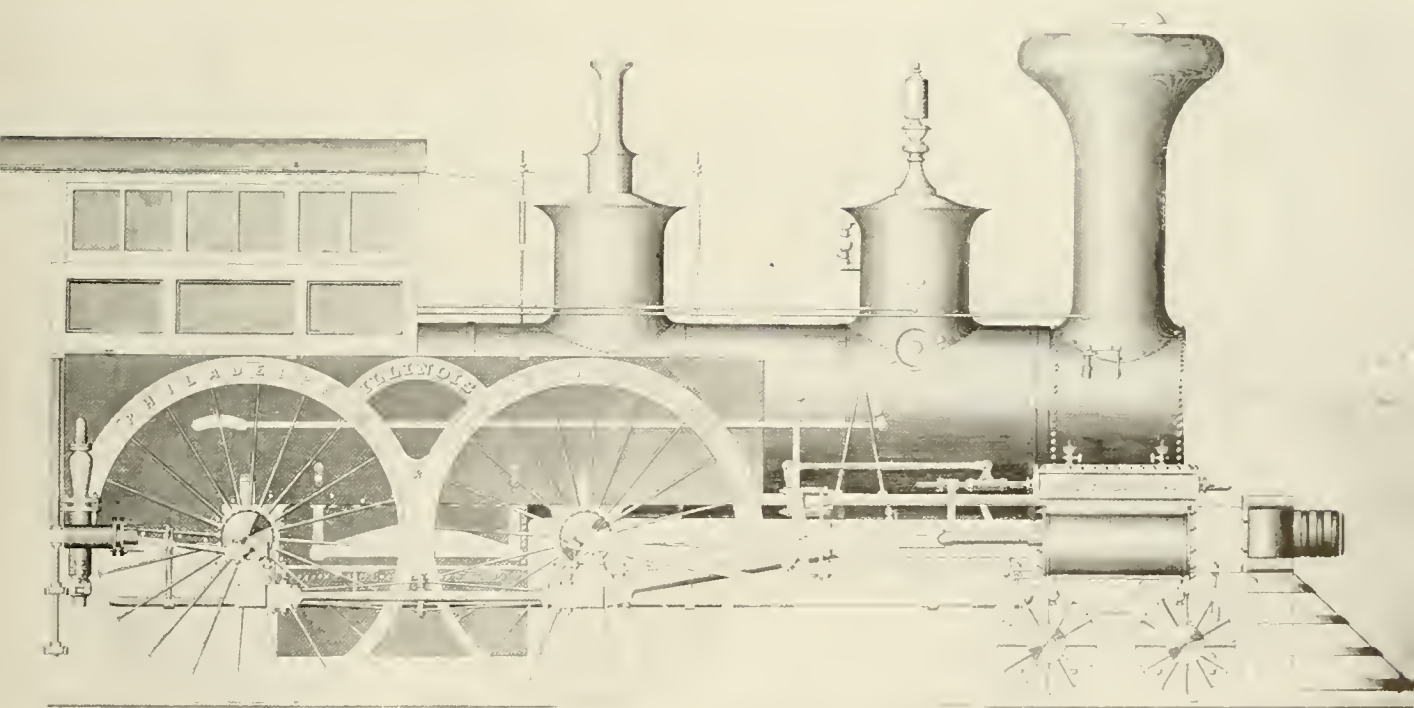


Figure 10.—THE ANTHRACITE-BURNING EXPRESS LOCOMOTIVE *Illinois*, built in 1852 by Millholland at the Reading Shops. The engine was not a success, but, after remodeling, continued in service until 1869. (Smithsonian photo 26807-G.)

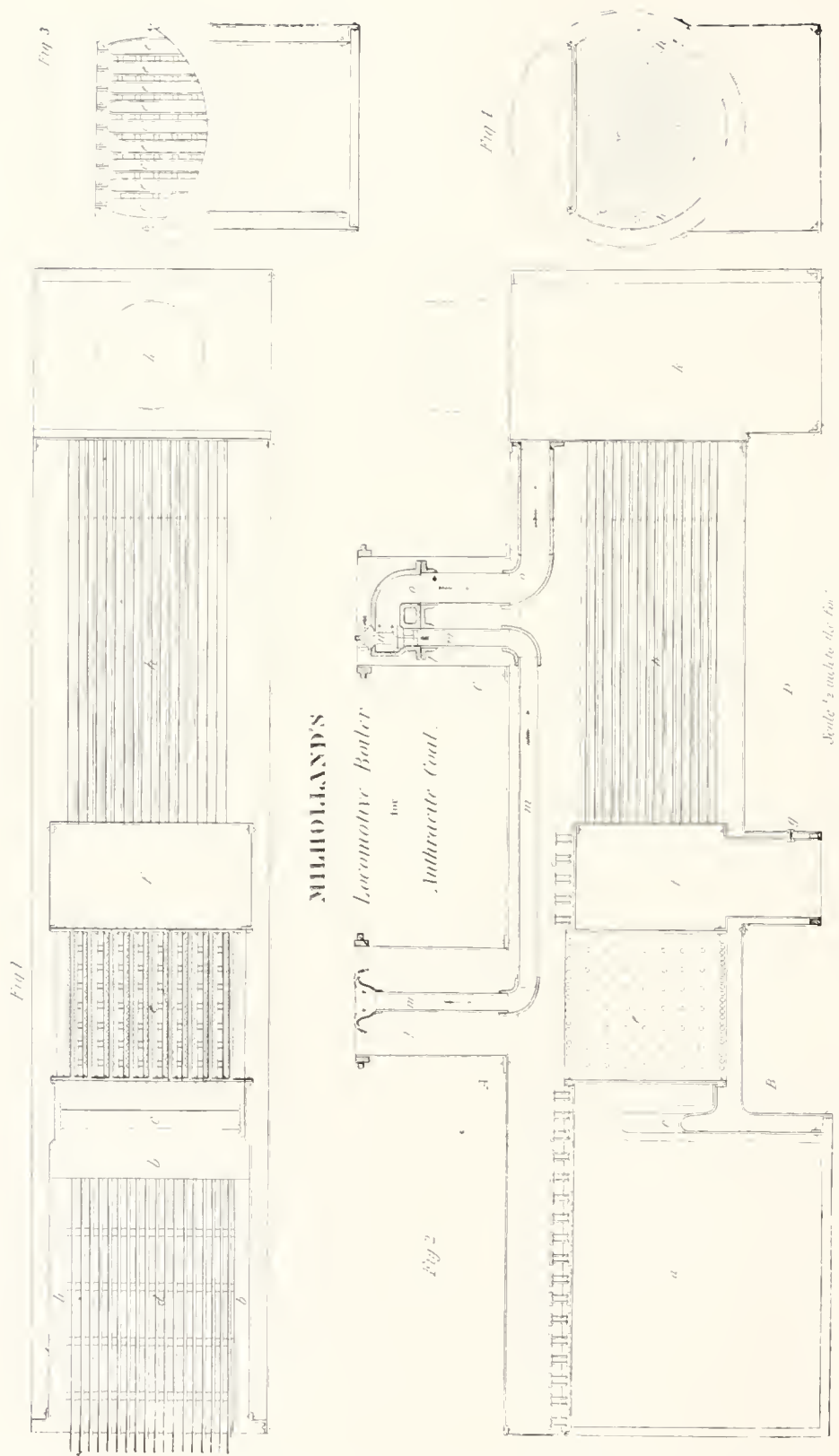


Figure 11.—BOILER OF THE *Illinois* VARIED SOMEWHAT FROM THE 1852 PATENT. Note the water tables *e* and the double poppet-throttle valve *n*. (From *Journal of the Franklin Institute*, April 1853.)

TRIAL OF PASSENGER ENGINE "ILLINOIS"  
Between Pottsville and Philadelphia

Trip	Time	Cars	Wt. of train and en- gine, tons	Miles	Fuel		Water		Lbs. water per lbs. coal	Lbs. coal per mile	Date of Test
					Wood, cu. ft.	Coal, lbs.	Gals.	Lbs.			
Pottsv. to Phila. ....	4.09	5	118	98	45.0	4,325	3,200.0	26,656	6.16	45.50	Nov. 19, 1852
Phila. to Pottsv. ....	4.28	5	118	98	45.0	5,000	3,700.0	30,821	6.16	52.60	Nov. 18, 1852
Pottsv. to Phila. ....	4.35	5 to Reading 6 to Phila.	127	93	31.2	4,175	3,196.0	26,622	6.37	44.88	July 15, 1856
Phila. to Pottsv. ....	4.27	6	132	93	29.1	5,079	3,600.6	29,992	5.90	54.59	July 7, 1856
Pottsv. to Phila. ....	4.35	5 to Reading 7 to Phila.	135	93	30.1	3,896	2,909.7	24,237	6.21	41.88	July 17, 1856
Phila. to Pottsv. ....	4.27	6 to Reading 5 to Pottsv.	127	93	29.2	4,308	3,339.0	27,813	6.45	46.32	July 4, 1856

general arrangement of this combination is shown by the patent drawing (fig. 9). Of the design's many failings, complexity and high cost were the chief defects. It was difficult enough to keep boiler tubes tight in a conventional boiler with two tube sheets; Millholland's had four. The boiler was weakened also by the large hole required for the central combustion chamber. Because of smaller surface area and greater wall thickness, the large tubes connecting the firebox and the chamber were less effective than the small tubes in transferring heat. The combustion chamber impeded the draft. The dead plates restricted free burning of coal to only the open center part of the grates. Despite these defects, Millholland followed this design for the next three years.

After the Winans engines, the next locomotive of record to be rebuilt with the patented boiler was the *Allegheny*. Originally an eight-wheel freight locomotive constructed by Baldwin in 1848, the Philadelphia and Reading annual report for 1851 notes that it was rebuilt with Millholland's "improvements" in November 1851. Other old engines were similarly reconstructed.

The next step, obviously, was to build a new locomotive with the patented boiler. Accordingly, Millholland completed the *Illinois* in May 1852 at the Reading shops. Aside from their boilers, the *Illinois* and its sister the *Michigan* were notable for several other mechanical peculiarities. Among these were 7-foot-diameter wrought-iron driving wheels, outside valve gear, truss connecting rods, and an unusually

long cylinder stroke of 30 inches. In appearance these locomotives were distinctive, if not beautiful, and they were certainly unlike any product of commercial builders.

In addition to the large lithograph of the *Illinois* (fig. 10)—issued at the time of its construction in an apparent attempt to advertise Millholland's patent—a detailed drawing of the boiler was reproduced in the *Journal of the Franklin Institute* (fig. 11).<sup>18</sup> This drawing shows the development of Millholland's ideas up to the time when the boiler patent drawing was prepared (February 1852). The patent drawing shows a dome boiler with an extended firebox identical to that used by Winans in 1846. The Franklin Institute drawing shows a "straight" boiler and two steam domes, but without the dome firebox—a remarkably improved design over the patent drawing. It should be noted, however, that Millholland introduced a new horror to a design already weighed down with liabilities. A series of nine water tables (marked as *e*) were used in place of the large tubes to connect the firebox and the central combustion chamber. These provided a new source of leaks and further diminished the boiler heating surface.

The *Illinois* was built to haul express passenger trains, and we are fortunate to have a record of her service between 1852 and 1856, shown in the table on this page.<sup>19</sup>

<sup>18</sup> *Journal of the Franklin Institute* (April 1853), vol. 25, p. 271.

<sup>19</sup> *Railroad Gazette* (October 27, 1882), vol. 14, p. 655.

JAMES MILLHOLLAND'S ANTHRACITE COAL-BURNING LOCOMOTIVE

built at the

R. R. R. WORKS, READING, PA.

1855.

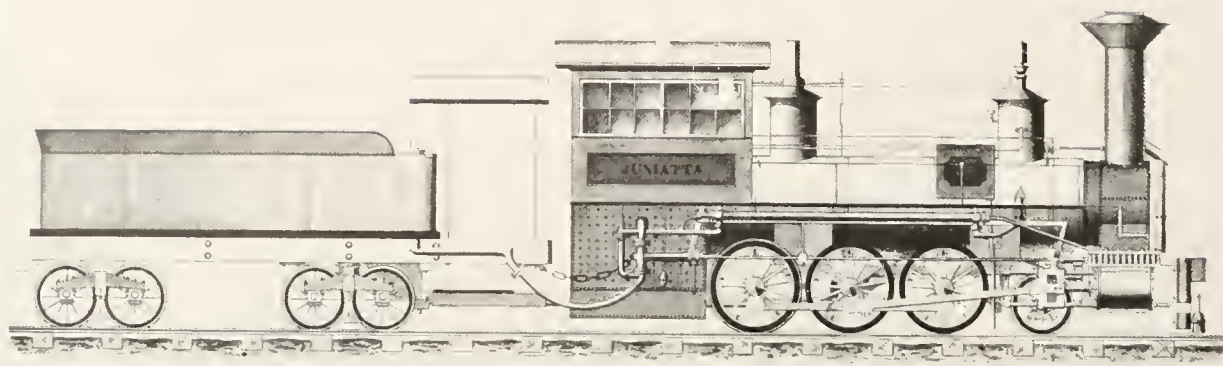


Figure 12.—The *Juniata*, a PAWNEE-CLASS FREIGHT LOCOMOTIVE BUILT IN 1855 at the Reading Shops. Note the misspelling of *Juniata* in this contemporary lithograph. (From the Reading Company.)

The table indicates that a large quantity of wood was burned with the coal, testifying to the inability of Millholland's boiler to make steam. The combination of wood and coal was not unusual, having been used as early as the 1830's by the Philadelphia and Columbia Railroad. The failure of Millholland's boiler was noted by the *American Railroad Journal*, June 3, 1854, which explained that because of insufficient steam the cylinders of the *Illinois* had been reduced in diameter by 2 inches.<sup>20</sup> After the *Illinois* and the *Michigan*, no other engines were built on this design.

Not many months after the *Illinois* entered service, Millholland brought out another new locomotive named the *Wyomissing*; it was the first of the Pawnee class and an odd-looking machine.<sup>21</sup> A six-wheel, connected engine intended for freight service, its

boiler was built on the 1852 patent, and like the *Illinois* it was a poor steamer. Unfortunately, no pertinent information or drawings exist for the *Wyomissing*. Two well-detailed lithographs were issued in 1855, however, of a sister machine, the *Juniata* (figs. 12 and 13). One view shows the complete machine, the other a longitudinal section of the locomotive. Again, the lithographs are thought to be attempts to promote Millholland's boiler patent. The backward-sloping outer wrapper of the firebox is the most remarkable feature shown in the illustrations. This distinctive form of firebox (adopted at about the same time by Winans) became the favored design for all subsequent locomotives built by Millholland. The elimination of crown bars and the substitution of stay bolts to support the crown (or top inside sheet) of the firebox was a progressive step. Unfortunately, the designer continued to use the abortive central combustion chamber. The boiler's efficiency was aided by a feedwater heater, a steam jet (meant to improve draft when the engine was stationary), and a variable exhaust. Millholland's use of these devices—none original with him—reveals his awareness of the innovations of other skilled mechanics.

<sup>20</sup> The *American Railroad Journal* does not specifically name the *Illinois* but mentions an express locomotive built by Millholland. The article erroneously gives the original cylinder diameter as 15 rather than 17 inches.

<sup>21</sup> Although the *Wyomissing* was the first Pawnee-class locomotive, the class was named for the *Pawnee*, the second of the design.



# Longitudinal Section

of

THE JUNIATA LOCOMOTIVE WORKS

READING, PA.

1853.

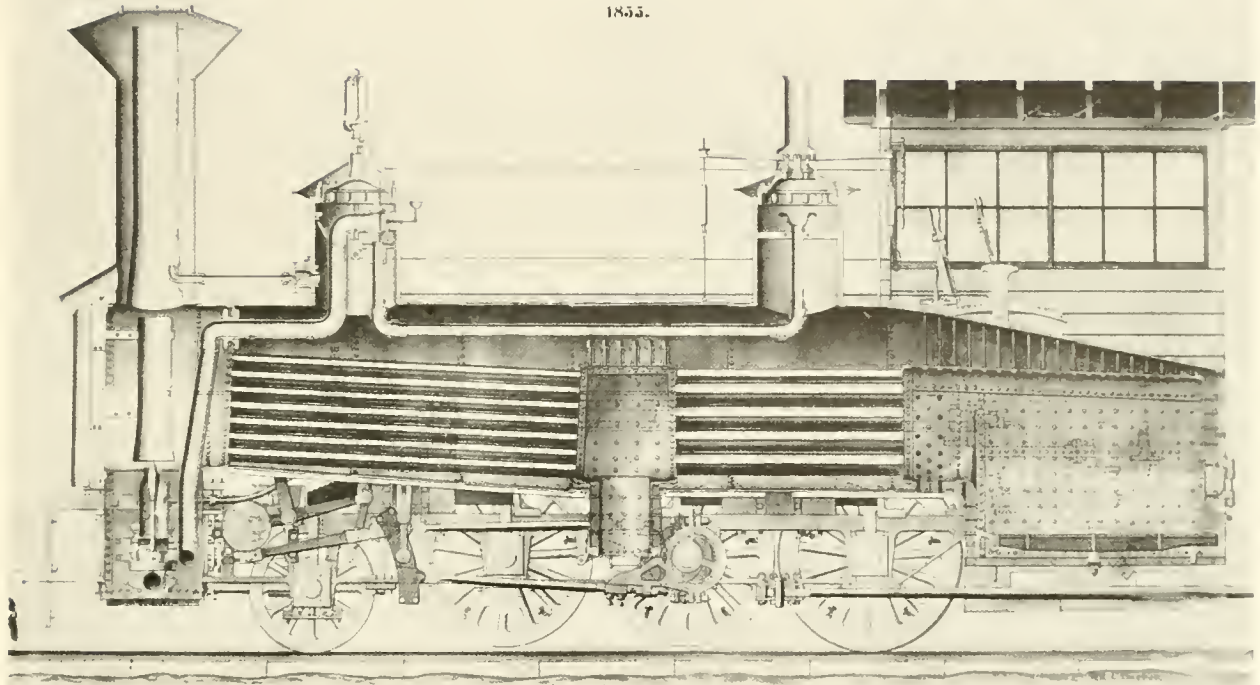


Figure 13.—A LONGITUDINAL SECTION of the *Juniata* from the companion to the lithograph shown in the preceding illustration. (From the Reading Company.)

Locomotives of the Pawnee class were more successful than the *Illinois*, and the Reading built about 15 over the next several years. The Pennsylvania Railroad and the Delaware, Lackawanna and Western Railroad, both desirous of finding good coal burners, had a small number of engines patterned after Millholland's Pawnee design. It might be added that the Pawnees were not true Mogul or 2-6-0 locomotives as is occasionally assumed. The leading wheels were attached to the main frame in the same manner as the drivers and could not swivel. Since the leading wheels were behind the cylinders, the Pawnees, like most coupled locomotives without trucks, were front-end heavy.

In January 1854 while Millholland was in the midst

of developing a workable anthracite-burning locomotive, a great fire destroyed the Reading workshops. It was imperative to rebuild the shops quickly so that operations might be maintained, and Millholland—never satisfied with half measures—immediately set to work on an elaborate and imaginative scheme. The fire occurred on a Sunday night; by the following Tuesday morning Millholland's draftsman had completed the preliminary drawings for a single-story, brick building measuring 482½ by 229 feet.<sup>22</sup> Its fireproof roof was made of corrugated sheet iron with an iron-truss frame supported by cast-iron columns.

<sup>22</sup> *Railroad Advocate* (February 10, 1855), vol. 1, p. 2.

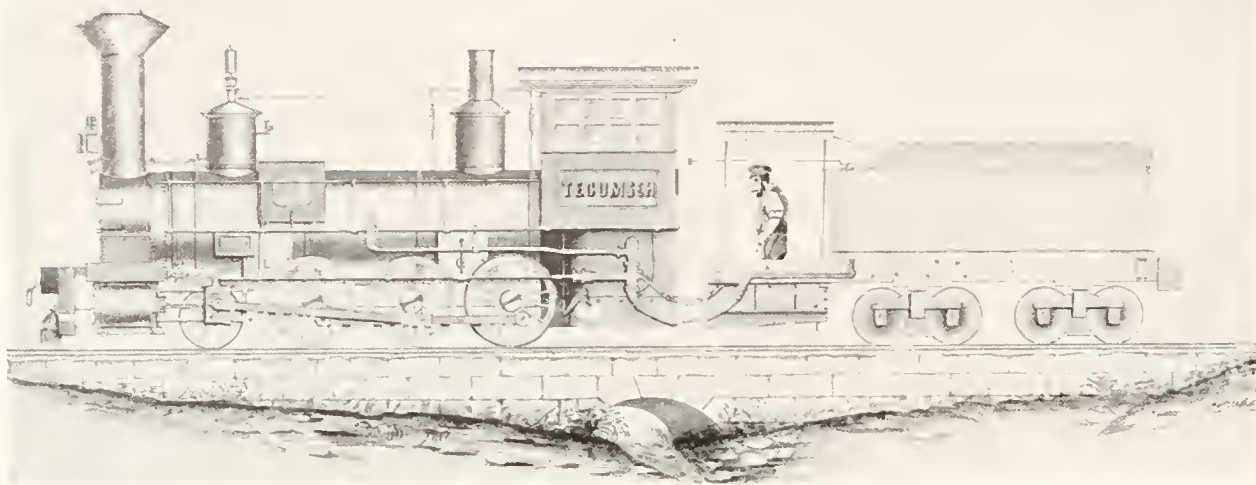


Figure 14.—The *Tecumseh* was completed in November 1853 at the Reading Shops. This Pawnee-class engine is illustrated by a contemporary watercolor rendering. (Photo courtesy of the Atwater Kent Museum.)

Half of this immense structure was completed within a year after the fire. It was fitted with a transfer table and stalls for 40 locomotives. A foundry, 120 by 30 feet, and a blacksmith shop, 163 by 30 feet, adjoined the main building. The car-repair, steam-hammer, and brass shops were on a separate plot not directly adjacent to the locomotive facilities. These shops were said to "surpass in extent and in convenience of arrangement, any similar works in the United States if not in the world."<sup>23</sup> A detailed diagram of the "grand plan" was published by the *Railroad Advocate*, January 24, 1857. While not all of Millholland's elaborate scheme was adopted, its essential elements were retained. By 1896, however, these shops were considered obsolete, and plans were underway to raise the roof of the main building to permit installation of a heavy-duty, overhead traveling crane.<sup>24</sup> It is uncertain if this remodeling project was undertaken, since new repair shops were

constructed in 1902 on another site in Reading.

Not until Millholland had recognized the failure of his central-combustion-chamber boiler did the Reading achieve its goal of operating as a coal-burning road. Apparently Millholland dropped the patented boiler in 1855 or 1856, for the Reading's fleet of coal burners grew rapidly thereafter. In 1852 only 24 of the Reading's 103 locomotives were coal burners; by 1857 the proportion had increased to 100 coal burners in a total of 142 locomotives. A large part of this conversion must be credited to the generous purchase of Winans' Camels. Yet these ponderous, eight-wheel engines—developed primarily for soft-coal burning—were modified by Millholland because they never were entirely successful for anthracite. Even so, the increasing number of company-built locomotives indicates that Millholland was perfecting a dependable hard-coal burner. Another indication that its own shops were at last supplying a successful product came in 1855 when the Reading stopped buying from Winans.

The final and most positive proof that the patented boiler was at last abandoned is the small engraving of a Millholland locomotive boiler published in Douglas

<sup>23</sup> Ibid.

<sup>24</sup> *Locomotive Engineering* (April 1896), vol. 9, pp. 307-309, describes and illustrates the old Reading shops.

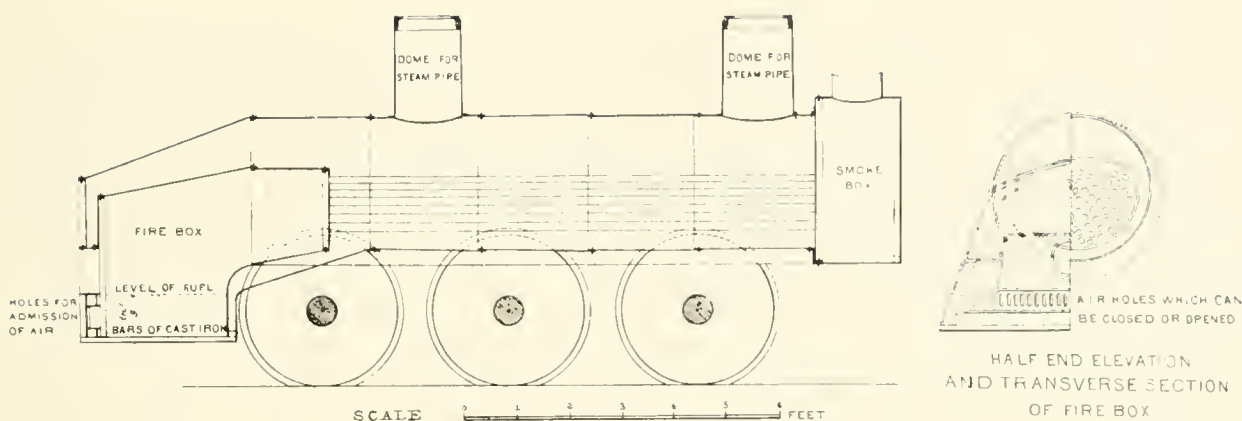


Figure 15.—THIS DRAWING OF 1856–1857 INDICATES that Millholland had at last abandoned his impractical central-combustion-chamber boiler. Note the wide firebox shown in the end elevation. (From Galton's *Report on the Railways of the United States*, 1857).

Galton's *Report on the Railways of the United States*.<sup>25</sup> Galton gathered his information in the fall of 1856 for the British Parliament. It is assumed that he acquired the boiler drawing at the same time and that it was Millholland's latest design. This would establish the demise of the patent boiler at least as early as the fall of 1856, possibly in 1855. The engraving shows Millholland's design for an anthracite-burning firebox and boiler. The general plan is similar to that of the Pawnees, but the central chamber is not shown. The design is plain and straightforward, showing a simple combustion chamber at the firebox end of the boiler. An end-elevation view shows the grate to be 66 inches in width (fig. 15).

About 1858 Millholland introduced water grates, thus solving a chronic problem long associated with anthracite burners.<sup>26</sup> Ordinary cast-iron grate bars burned out quickly because of anthracite's intense heat and lack of insulating ash, although it was the practice to use coal of poor quality, one that would produce a large amount of ash to insulate the cast-iron grates from the direct heat of the fire. The water grate was a series of staggered iron tubes connecting the front and rear water spaces of the firebox. Circulation of water through the tubes prevented the

grate's burning out. Although the idea was not original with Millholland, he introduced it in the United States and perfected its use. One advantage of the water grate, aside from its longer life, was that it permitted the use of better grades of anthracite.

By 1859 Millholland, for all practical purposes, had converted the Philadelphia and Reading to coal burning; only four wood burners remained on the property. The Reading thus became the first major railroad in America to convert from wood to coal, and it did so despite the attendant difficulties in devising a method to burn anthracite—a far greater challenge than if the native fuel was bituminous. Few other large roads converted until the early 1870's. The Reading might have converted even faster had it not been for Millholland's stubborn attachment to his patented boiler. But in all fairness, it must be agreed that his empirical rather than scientific methods solved the Reading's fuel problems years before any other major railroad achieved similar results.

Millholland paused to summarize his work in this field in a special memorandum published in the Philadelphia and Reading annual report of 1859 (see Appendix II). Previously his efforts had been alluded to sparsely in the road's printed reports,<sup>27</sup> and the

<sup>25</sup> London: Eyre & Spottiswoode, 1857.

<sup>26</sup> An exact date for Millholland's first use of the water grate cannot be determined. *Engineer* (February 8, 1861), vol. 11, p. 92, states that he used it for two or three years before he patented it April 16, 1861 (No. 32,076).

<sup>27</sup> Direct reference to Millholland in the Minute Books is also sparse: the management dealt directly with Millholland's superior, G. A. Nicolls, Superintendent of the Reading, and nearly all mechanical discussions mention only Nicolls.

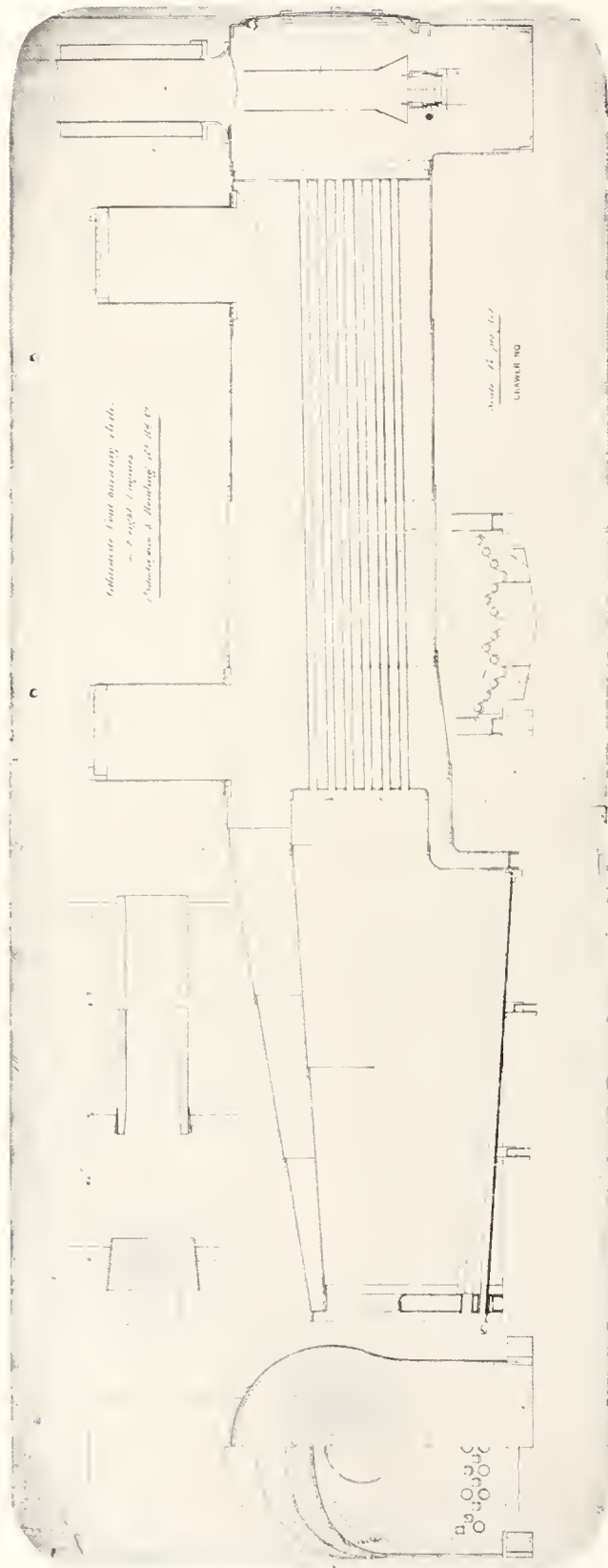


Figure 16.—AN EARLY BUT UNDATED DRAWING OF A MILLHOLLAND BOILER. The large-scale detail at the upper left shows the plug and method of setting the water grates. (From the Reading Company.)





Figure 17.—THIS CLEAN-LINE PASSENGER LOCOMOTIVE, THE *Hawatha*, WAS BUILT BY MILLHOLLAND IN 1859. It was the first of a very successful class of passenger locomotives and was not retired until 1883. (Smithsonian photo 40630.)

master machinist rarely was invited to make any direct comment. Obviously, the management recognized the importance of Millholland's achievement and now wanted him to report directly to the stockholders.

In his report, Millholland briefly reviews the road's experience with the Winans engines and his progressive enlargement of the grate area from 17.68 square feet in 1847 to 24.5 square feet in 1854. Understandably, he makes no mention of the 1852 boiler patent or its dismal record. He does comment at length on the water grate and the substitution of iron for copper in fireboxes, in which his work was of equal

importance. Copper had been favored for the inner wrapper of the firebox because it did not blister and break down as readily as the fibrous wrought-iron plate, but it was expensive, soft, and weak. Millholland reported that the renewal of a copper firebox cost \$454 compared to \$199 for iron, the difference lying in the price of materials. The copper sheets had to be made very thick, about  $\frac{3}{4}$  of an inch, because they were weak and became even weaker when heated. The last and most important objection to copper was that it was a soft material and was rapidly worn away by the abrasive action of the fly ash (unburned particles of coal) as exhaust drew the smoke

**JAMES MILLHOLLAND'S**  
**Anthracite Coal Burning Passenger Locomotive**  
*Philadelphia and Reading Railway*

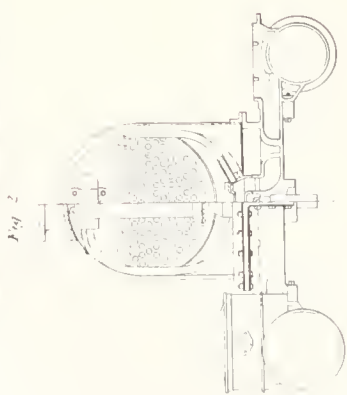


Fig. 2

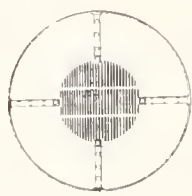


Fig. 4



Fig. 3

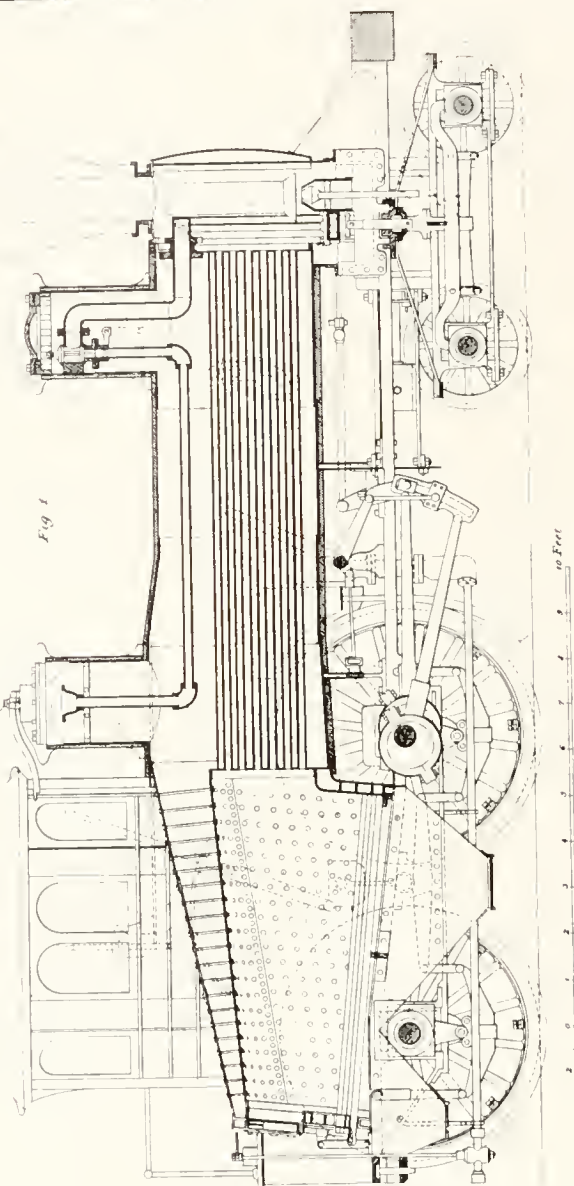


Fig. 1

10 Feet

Figure 18.—DRAWING OF A HIAWATHA-CLASS PASSENGER LOCOMOTIVE. The boiler shows Millholland's final design, which includes a sloping crown sheet, short combustion chamber at the firebox, and water grates. It also illustrates the smokebox superheater and cast-iron tires on the driving wheels. (From *American and European Railway Practice*, 1861.)

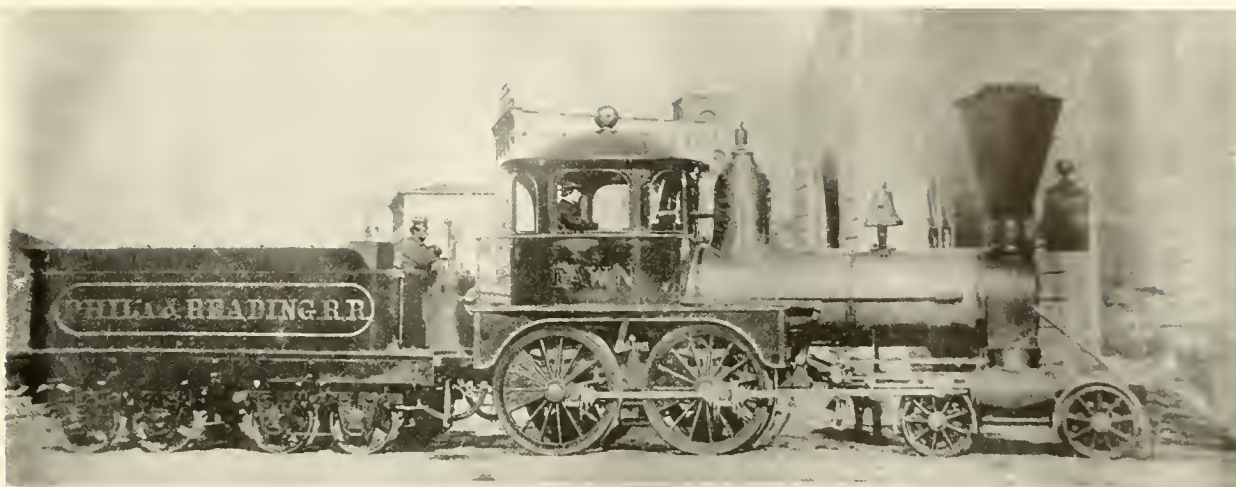


Figure 19.—The *Fawn*, a LIGHT PASSENGER LOCOMOTIVE built by Millholland in 1860. (Chaney neg. 14479.)

through the firebox at great speed. Iron fireboxes lasted for 59,866 miles on the average; copper fireboxes, from 25,373 to 39,254 miles, depending on their construction.

Despite the success of his water grate and firebox, a report on the performance of Reading engines for 1857 was not altogether flattering to Millholland.<sup>28</sup>

Annual mileage.....	12,023/	locomotive
Cost of repairs per mile.....	11.6¢/	locomotive
Cost of coal per mile.....	13.4¢/	locomotive

Most American locomotives averaged about 20,000 miles per year and cost about 10 cents per mile for repairs. Fuel cost was a less definite matter since it varied widely from railroad to railroad. A good general figure for the period, however, is 20 cents per mile for wood. On some roads where wood was scarce or efficiency low, fuel costs were as high as 31 cents per mile. But, in fact, no true comparison can be made, for no cost figures exist for wood-burning locomotives doing the same heavy service as that performed by coal engines on the Reading. Although mileage figures for wood engines are plentiful for the 1850s (some ran 30 miles to a cord), little information is available on train weights. In short, Millholland's 19 miles per ton must be tempered by the knowledge that 700-ton trains were hauled, while

the 25-30-mile-per-cord wood burners probably had hauled trains of no more than 200 tons.<sup>29</sup>

In theory, Millholland should have shown better economy than he actually achieved. Coal cost the Reading \$2.55 per ton; wood, \$4.33 per cord.<sup>30</sup> These fuels were even more disproportionate than indicated by cost, since 1 ton of anthracite is thermally equivalent to 1½ cords of wood. Hence \$2.55 worth of coal, if efficiently burned, should do the work of \$6.50 worth of wood. Millholland fell far short of this ideal, but he did produce a workable coal burner that performed with enough economy to drive wood burners off the Reading.

In the 1859 report Millholland confined his remarks to firebox and boiler improvement, yet he might well have mentioned his work on locomotive running gear. In 1857 he had built what is generally believed to be the first locomotive with a firebox *above* the frame.<sup>31</sup> This was achieved by a special design in which the top rail of the frame, rather than being straight, was set at about an 8° angle to the front pedestal, as shown in the drawing of the *Hiawatha* (fig. 18). The inclined arrangement permitted the firebox to pass over the top of the frame and yet keep

<sup>29</sup> Ibid.

<sup>30</sup> Ibid.

<sup>31</sup> The *Vera Cruz* is said to be the first locomotive with its firebox above the frame. There is some question, however, as to whether it was an old engine rebuilt in the Reading shops or a new machine constructed there.

<sup>28</sup> Z. COLBURN and A. L. HOLLEY, *Permanent Way and Coal Burning Locomotives* (New York: Holley & Colburn, 1858), p. 118.



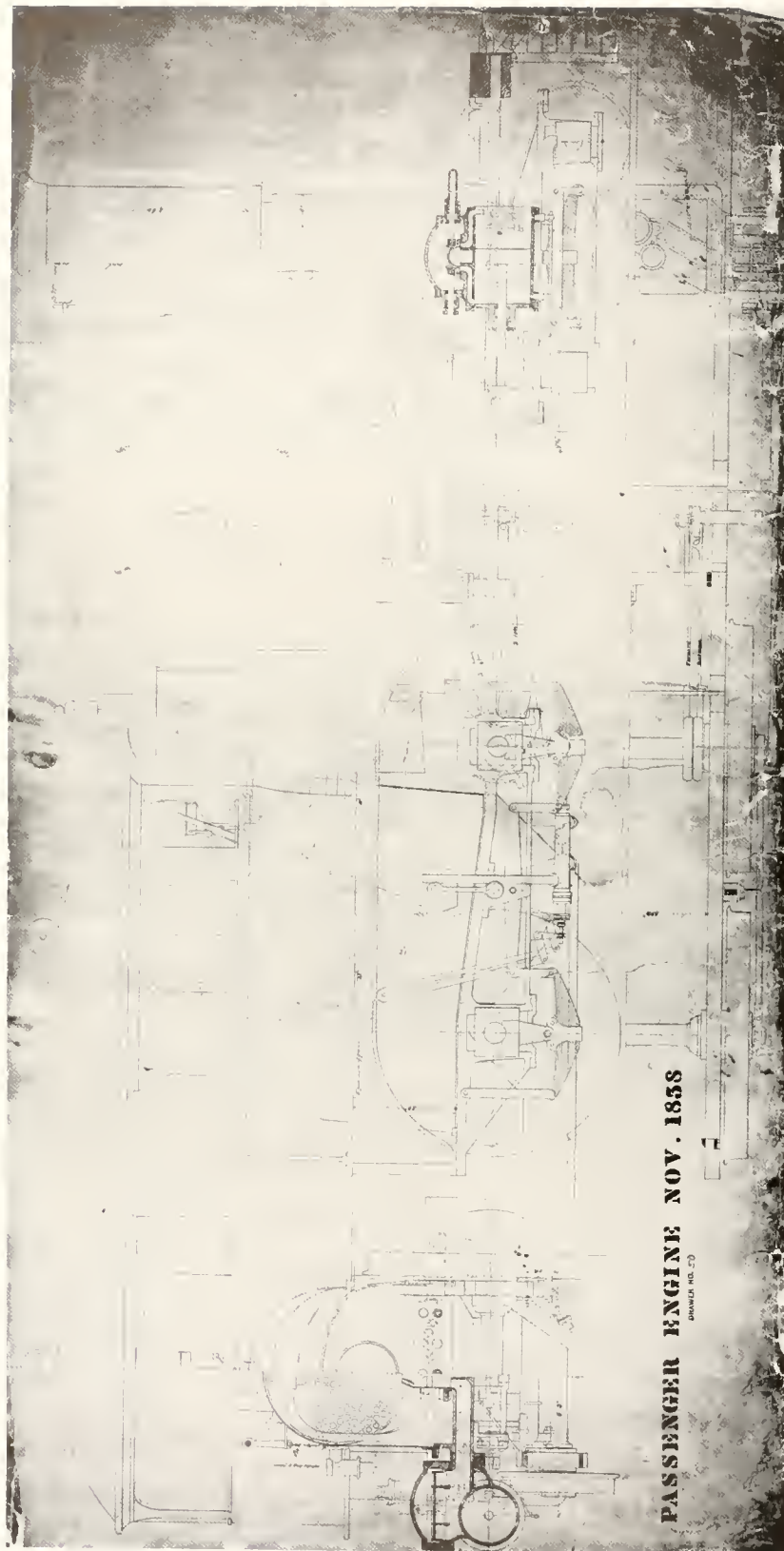


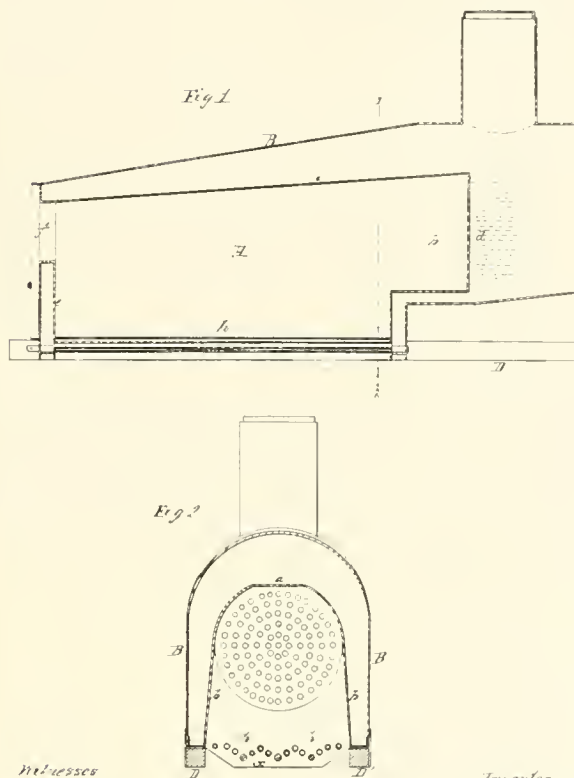
Figure 20.—AN ORIGINAL DRAWING, PRESUMABLY A DESIGN STUDY for a Hiawatha-class 4-4-0. The Mill-holland injector mounted horizontally under the frame between the driving wheels was added to the drawing in later years. (From the Reading Company.)



*J. Millholland*  
*Steam-Boiler Furnace.*

*N<sup>o</sup> 4,1316.*

*Patented Jan. 19, 1864.*



*Witnesses*  
*J. Millholland*  
*Charles H. H. H.*

*Inventor*  
*J. Millholland*  
*Henry H. H. H.*

Figure 21.—THIS 1864 FIREBOX PATENT shows Millholland's plan for a between-the-frames mounting of his water-grate firebox in order to achieve a lower center of gravity than his usual boiler-frame arrangement permitted. (From U.S. Patent Office.)

the entire boiler assembly low. It also provided a firebox some 10 inches wider than the conventional between-the-frame style. This Millholland frame was popular well into the 20th century.

Sometime in the early 1860s Millholland revived the old-fashioned riveted frame so popular with New England locomotive builders in the 1840s and 1850s. The frame's top rail was made from two wrought-iron bars about 1¼ inches thick by 6 inches deep. The pedestals were bolted or riveted between the top-rail bars, making a simple, heavy frame. No bottom rail

was used. This style of frame probably was used first on the Reading's Gunboat class of 1863 and was still in use by the Reading in 1880.

Unquestionably influenced by Winans, Millholland preferred cast-iron driving-wheel tires. These were cheaper than wrought iron, and were extensively employed by the Baltimore and Ohio Company and by the Reading for wheels under 50 inches in diameter. They also had been used on the Baltimore and Susquehanna in 1840 during Millholland's superintendence, where he was credited with introducing cast-iron tires for large-diameter wheels in 1845.<sup>32</sup> While showing no inclination to abandon the cast-iron tire, Millholland in 1851 or 1852 (about the time Krupp produced his first steel tires) produced some of the world's first steel tires. These were made at the Reading shops and were fitted to the locomotive *United States*. A few other sets were made and gave good service, but for economy he preferred the cast-iron tire. Unfortunately, no contemporary account of this early use of steel tires can be found, and we must depend on the recollections of E. J. Rauch.<sup>33</sup>

Another unusual design favored by Millholland was one for solid-end connecting rods. The vast majority of 19th-century locomotives were equipped with straps bolted to the rods and provided with keys for alignment. The strap-end rod was liable to work loose or become misaligned by inept adjustment of the keys. The solid-end rod, having no straps, bolts, or keys, was not subject to these defects. It should be noted that Millholland's preference for solid-end rods was shared by several other mechanics, notably Ross Winans.

With the question of a practical coal-burning boiler answered by 1858, Millholland turned his attention to the design of new locomotives. The first of these new designs was an eight-wheel passenger locomotive named *Hiawatha*. It was an elegant machine, remarkably modern in appearance. The water grate, poppet throttle, and slope-back firebox were familiar Millholland features, but several novel devices were added. The round iron cab was the most obvious departure from standard American practice. It should be remembered that the Reading had been a pioneer user of iron cabs (about 1845), but never before had such an elaborate and decorative iron cab

<sup>32</sup> *American Railroad Journal* (November 6, 1845), vol. 18, p. 714.

<sup>33</sup> *Locomotive Engineering* (June 1896), vol. 9, p. 500.

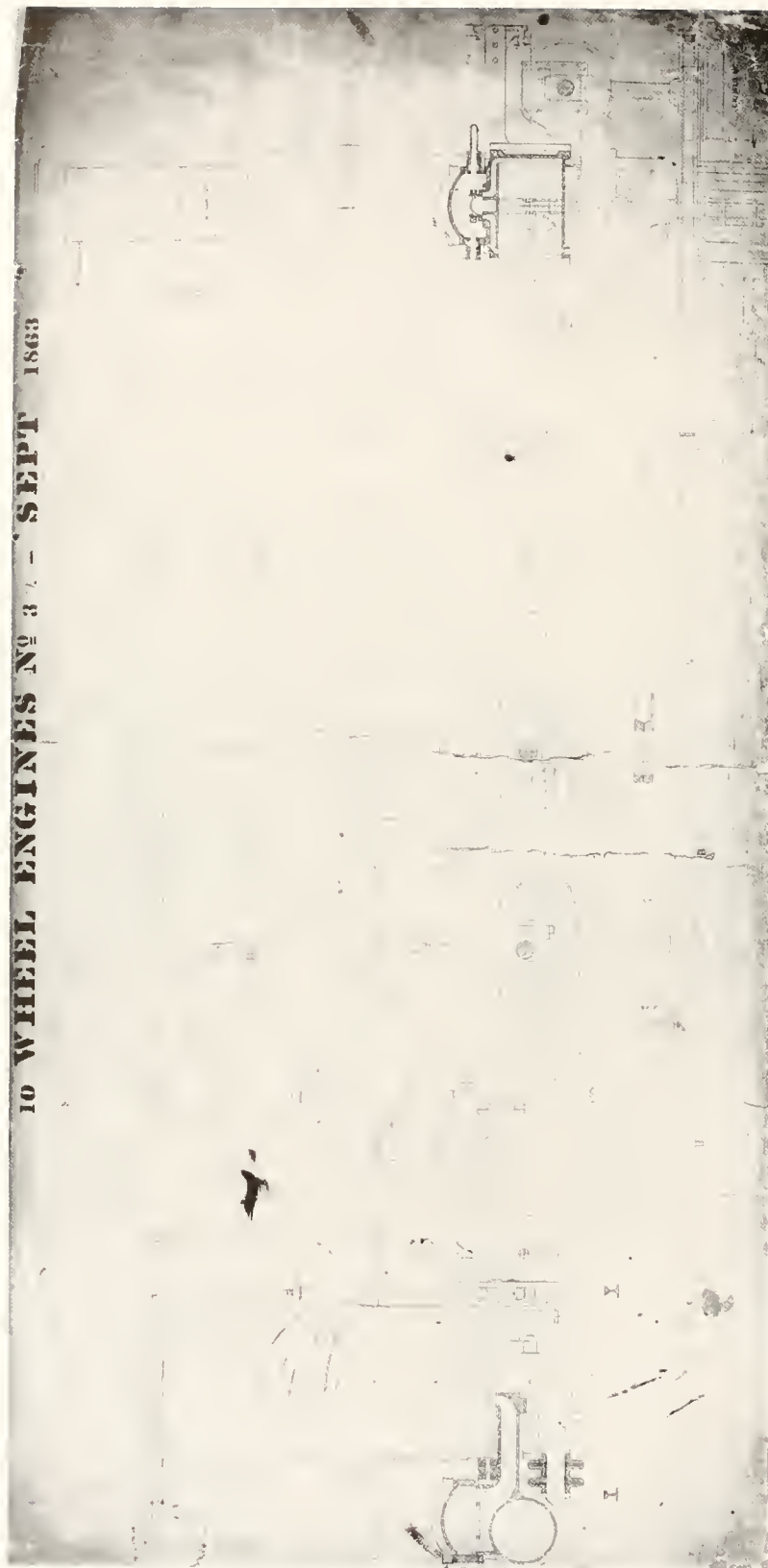


Figure 22. THIS ORIGINAL DRAWING OF A GUNBOAT-CLASS FREIGHT LOCOMOTIVE is dated September 1863.  
It was the third locomotive built on this standard Millholland design. (From the Reading Company.)

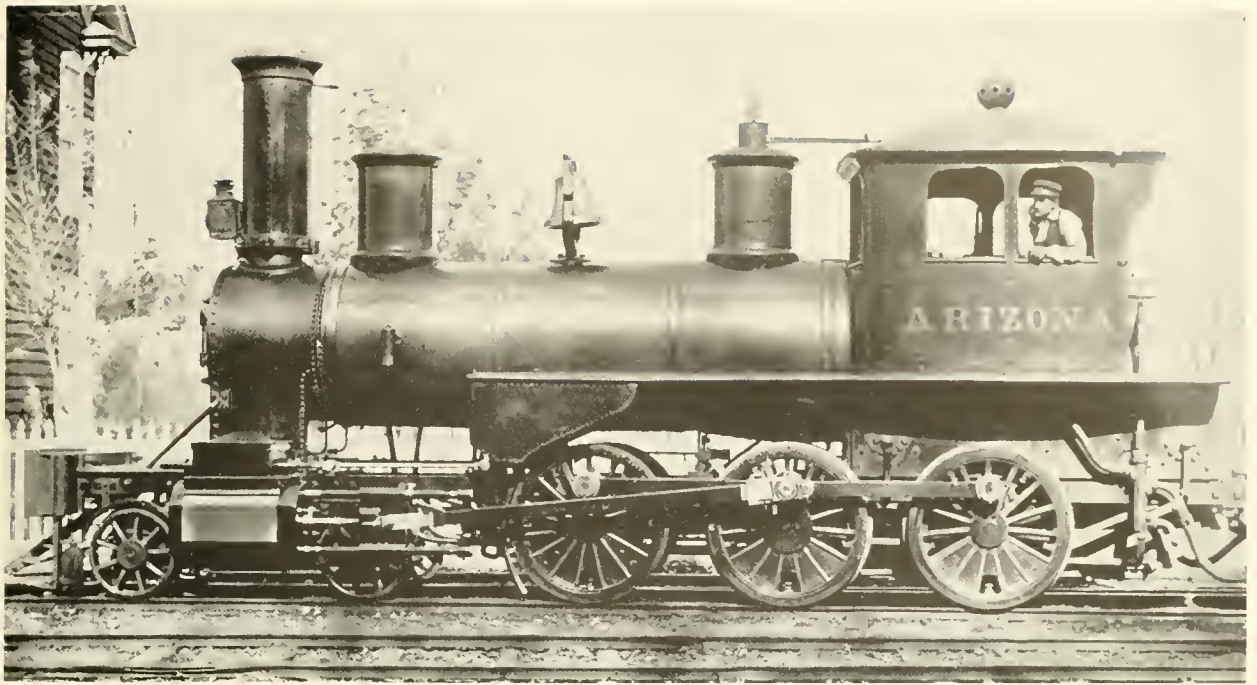


Figure 23.—The *Arizona*, a GUNBOAT-CLASS FREIGHT LOCOMOTIVE built in 1863 at the Reading Shops. Note the feedwater injector fitted to the firebox behind the rear driving wheel and the solid-end connecting rods. (Chaney neg. 5382.)

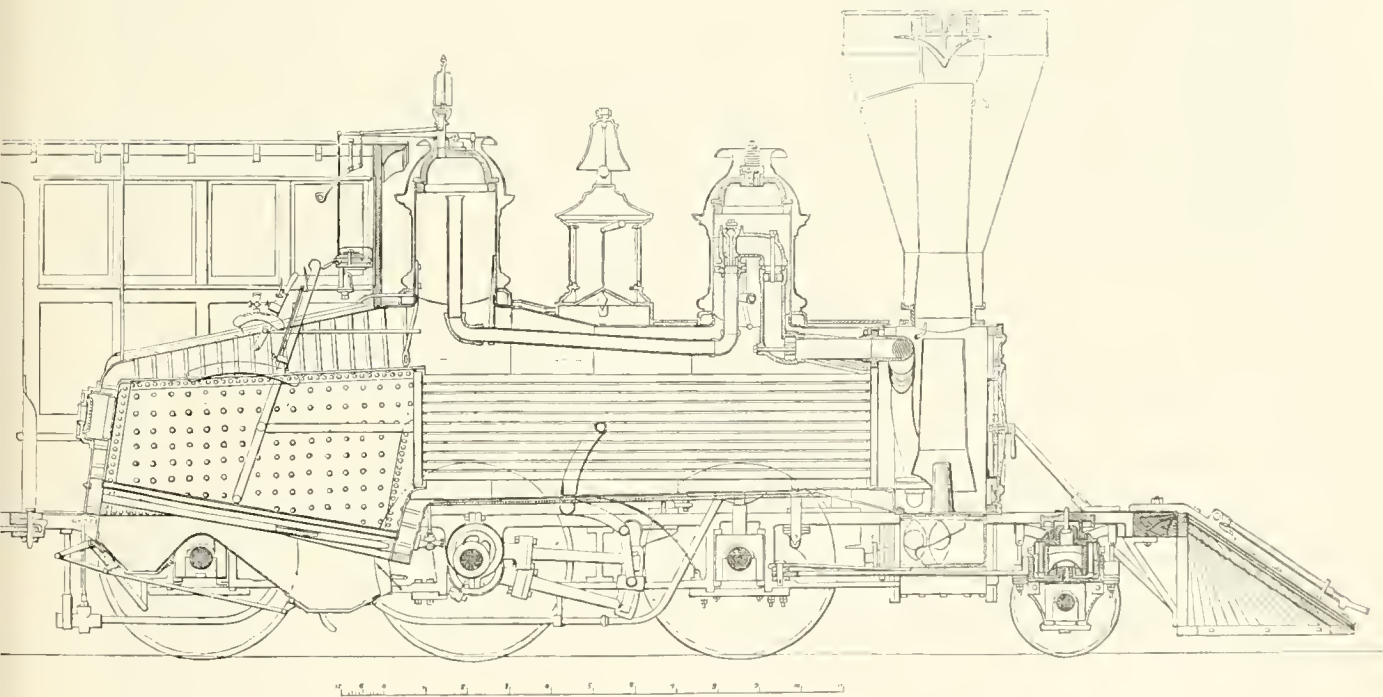


Figure 24.—ONE OF SEVERAL MOGUL-TYPE LOCOMOTIVES built in 1865 by Danforth, Cooke & Company for the New York and Erie Railway, fitted with a Millholland boiler. (*Engineering*, May 11, 1866.)





Figure 25.—THE *Robert Crane* BUILT IN 1864 for the Reading and Columbia Railroad by the Lancaster Locomotive Works. This engine was based on the design of Millholland's *Hiawatha* class. (Photo courtesy of the Lancaster County Historical Society.)

been seen on the road. The *Hiawatha* was also notable for its superheater, a nest of pipes placed in the smokebox. While the *Hiawatha* drawing is the earliest known illustration of Millholland's superheater, he is credited with using it "some time" prior to 1861.<sup>34</sup> A few other roads were experimenting with the superheater at this time, but it was not

<sup>34</sup> A. L. HOILEY, *American and European Railway Practice* (New York: Van Nostrand, 1861), p. 143.

adopted universally for locomotives until about 1910. In contrast to the *Illinois*, Millholland's first anthracite-burning passenger engine, the *Hiawatha* was a great success and served as the model for 44 other locomotives of the same design.

The adoption of Millholland's design by other roads provided sure evidence that his anthracite-burning firebox, patented (41,316) January 19, 1864, was a success. In 1860 the Central Railroad of New Jersey purchased three new locomotives with Millholland



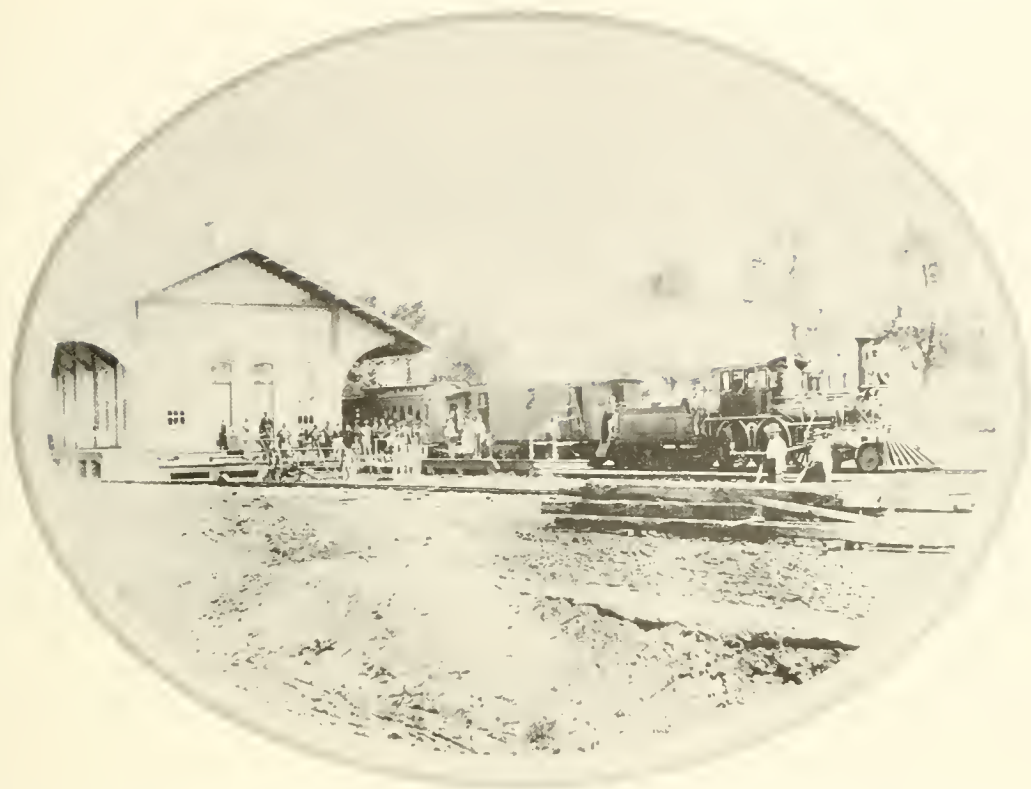
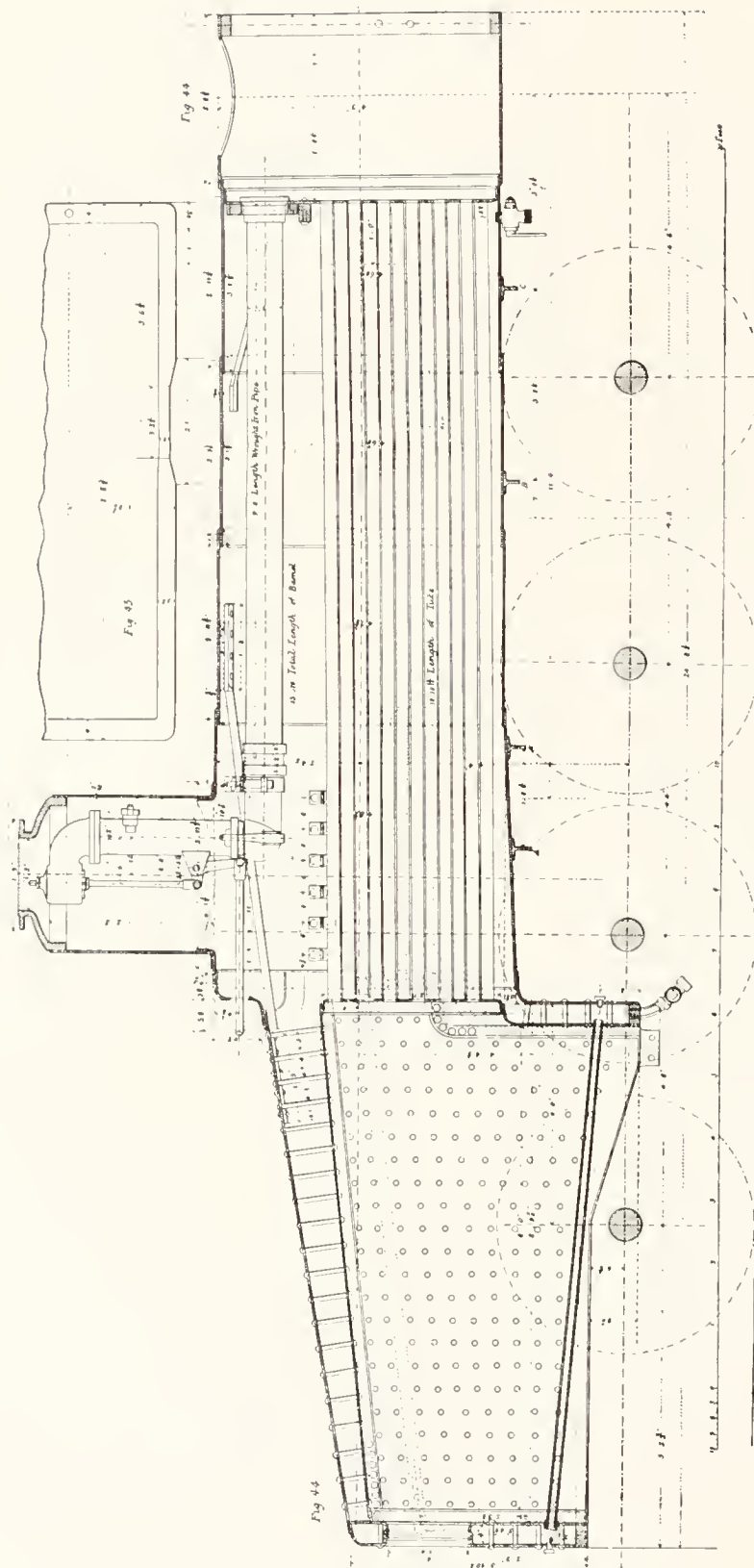


Figure 26.—THE EAST PENNSYLVANIA RAILROAD ACQUIRED THE *Easton* IN ABOUT 1860 FROM THE ROGERS LOCOMOTIVE WORKS. IT CLEARLY HAS A MILLHOLLAND BOILER AND OTHER FEATURES OF HIS DESIGN. THE SCENE IS KUTZTOWN, PENNSYLVANIA, IN 1870. (FROM THE READING COMPANY.)



Figure 27.—A GUNBOAT-CLASS FREIGHT LOCOMOTIVE BUILT FROM MILLHOLLAND'S DESIGNS FOR THE PENNSYLVANIA RAILROAD IN 1866 BY THE LANCASTER LOCOMOTIVE WORKS.



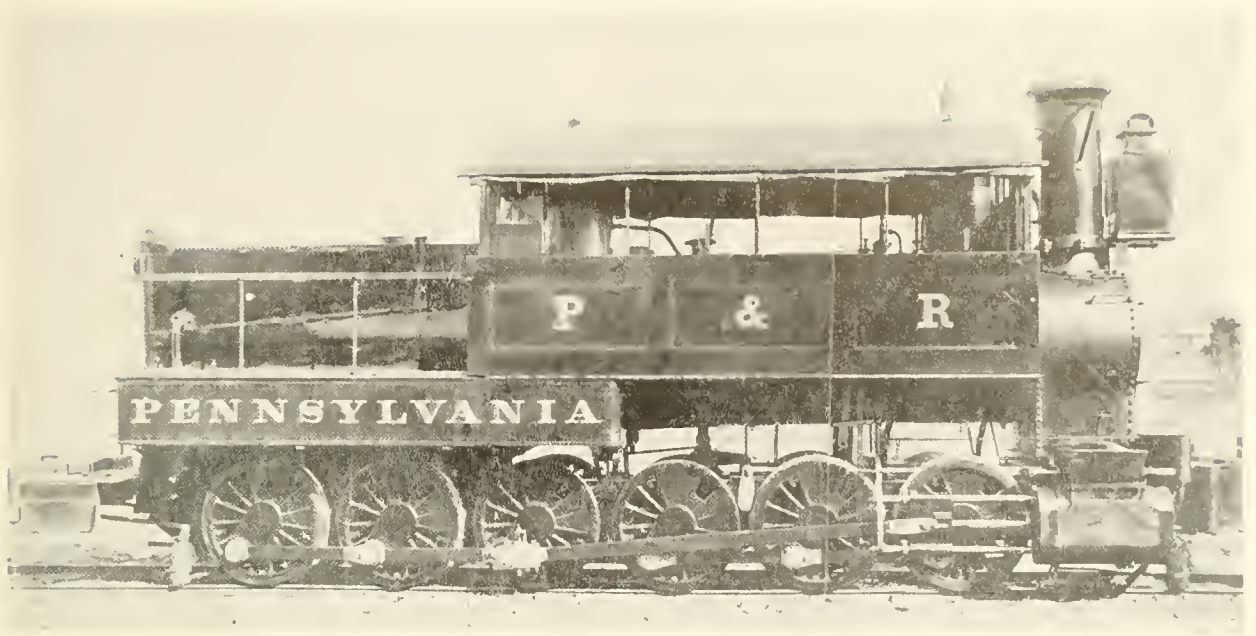


Figure 29.—The *Pennsylvania* WAS THE LARGEST STEAM LOCOMOTIVE IN THE WORLD when constructed by Millholland in 1863; this 50-ton locomotive was in service until 1885. One pair of driving wheels was removed in 1870.

fireboxes. These were pronounced superior to any other coal burners tested on that road and were said to have saved 7 cents a mile over the road's wood burners.<sup>35</sup> The Erie purchased a large number of Mogul freight locomotives between 1862 and 1865, all of which were built with Millholland fireboxes. The New Jersey Railroad and Transportation Company also acquired three engines similarly equipped. The Lancaster Locomotive Works in 1865 advertised that it would build locomotives with the "... celebrated coal burning boiler of Mr. James Millholland."<sup>36</sup> Probably the most impressive testament to Millholland was the trial of his firebox by the Paris and Orleans Railway.<sup>37</sup> Millholland sent his chief assistant Levi B. Paxson to France to supervise the reconstruction of the French engines.

Incidental to the use of the boiler by other companies was Millholland's injector for supplying water to boilers. The injector had been invented by Henri Giffard of France and was introduced in this country

about 1860.<sup>38</sup> While most master mechanics agreed that feedwater pumps were troublesome, early injectors were expensive and unreliable. Millholland sought to remedy these complaints with a simplified design. In his patent specification (No. 35,575) of June 10, 1862, the inventor claimed his injector could be made at  $\frac{1}{20}$ th the cost of an equal Giffard injector. Millholland's son James carried the argument even further by stating that an injector made by his father for \$4 was equal to a \$180 Giffard injector.<sup>39</sup> The actual cost and success of Millholland's injector remains a question, but the Reading was one of the first railroads to use injectors on its locomotives. The device did not gain universal acceptance in locomotives, however, for another 20 years.

In March 1863 Millholland completed a large 10-wheel freight locomotive called the *Nevada*. This machine was the first of the Reading's famous Gunboat class, of which 134 were constructed. The design was so sound that it was still being used many

<sup>35</sup> *American Railway Review* (February 28, 1861), vol. 4, p. 118.

<sup>36</sup> *American Railroad Journal* (August 12, 1865), vol. 18, p. 774.

<sup>37</sup> *Engineer* (February 8, 1861), vol. 11, p. 92.

<sup>38</sup> For a survey history of the injector, see FRANK A. TAYLOR, *A Catalog of the Mechanical Collections of the Division of Engineering* (U.S. National Museum Bulletin 173, 1939), pp. 125-133.

<sup>39</sup> Letter from James A. Millholland to J. E. Watkins of the Smithsonian Institution, May 18, 1888.



years after Millholland's retirement. (The first locomotive with a Wootten boiler, built by Millholland's successor, John E. Wootten, in 1877, was essentially an elaboration of Millholland's plan for the Gunboat class, except for the very wide firebox which was made for burning waste anthracite coal.)

In September 1863 Millholland finished the *Pennsylvania* (fig. 28), a mammoth "pusher" engine. This giant 12-wheeled machine was for many years the largest locomotive in the world. Nearly twice the size of a standard eight-wheeler of the period, it weighed over 50 tons, had 20 x 26-inch cylinders and a grate area of 31½ square feet, and could pull 2500 tons on the level. The engine was built to assist heavy coal trains up the Falls Grade (0.9 percent) near Philadelphia. The *Pennsylvania* was followed by seven smaller sisters. The first of these, the *Kentucky*, weighing 41 tons, was completed in 1864; the last was built in 1872.

In 1866 James Millholland resigned as master machinist of the Philadelphia and Reading to devote himself to other business and community interests. After a long illness he died in Reading, Pennsylvania, in August 1875 at the age of 63. Although his later

years were undistinguished by mechanical invention, he already had made outstanding contributions to railroad technology. His original works include the cast-iron crank axle, wooden spring, plate-girder bridge, poppet throttle, anthracite firebox, water grate, drop frame, and steel tires. He was also an early user and advocate of the superheater, the feed-water heater, and the injector. His general designs were followed by the Reading long after his retirement, and a number of his innovations were adopted as standard practice by the railroad industry.

James Millholland was an original mechanic whose designs were distinctive and different from those of his contemporaries. His locomotives were plain, practical machines; their simple lines favored European concepts rather than the gaudy and ornamental styles so typical of 19th-century American locomotives. One line in his obituary summarizes his career: "The science of mechanics was his lifelong study, and the locomotive the special object to which he devoted the energies of his constructive genius."<sup>40</sup>

<sup>40</sup> *Railroad Gazette* (August 28, 1875), vol. 7, p. 362.

## Appendix

### I

[From *Engineering News*, October 20, 1888, p. 305.]

The following letter, written by the designer to Mr. HERMAN HAUPT, soon after the erection of the bridge, gives many details which will be of interest:

READING, PA., May 1, 1849.

DEAR SIR:—Enclosed I send you the drawings of the three bridges I constructed on the Baltimore & Susquehanna Railroad while engaged as Superintendent of machinery and road. The one marked A was built at the Bolton depot in the winter of 1846 and 1847, and was put in its place in April, 1847. This bridge is made of puddled boiler-iron ¼-in. in thickness. The sheets, standing vertical, are 38 ins. wide and 6 ft. high, and riveted together with ⅝ rivets, 2½ ins. from center to center of rivets. You will observe by reference to the drawing, that each truss frame is

composed of two thicknesses of iron, 12 ins. distant from each other, and connected together by 5-16 iron bolts, passing through round cast-iron sockets at intervals of 12 ins.; which arrangement, together with the lateral bracing between the two trusses, ensured stability. The lateral bracing is composed of ¾ round iron, set diagonally and bound together at the crossing by two cast-iron plates about 4 ins. diameter, the sides next to the bracing being cut in such a manner, that when the two ⅝ bolts that pass through them were screwed up, it held them firmly together. There is also a bolt passing through both truss-frames and through the heels of the lateral bracing, at right angles with the bridge, which secured the heels of the lateral braces, and by means of a socket in the center made a lateral tie to the bridge, giving the bridge its lateral stability.

The lower chords were of hammered iron, there being some difficulty at that time to get rolled iron of



the proper size, and are in one entire piece, being welded together from bars 12 ft. long. There are eight of them, 5 x  $\frac{3}{4}$ -ins., one on either side of each piece of boiler iron, and fastened to it with  $\frac{3}{4}$ -in. iron rivets 6 ins. distant from each other. There are but four top chords, and of the same size of the bottom, two on each truss near the top, the timber for the rail making up the deficiency for compression, and answering the purpose of chords. This bridge was built at the time Messrs. STEPHENSON and BRUNEL were making their experiments with cylindrical tubes preparatory to constructing the Menai bridge; the cylindrical tubes failing, they adopted this plan of bridge.

The entire weight of the bridge is 14 gross tons, and cost \$2,200; but as the same kind of iron of which the bridge is composed can be had for at least 15 per cent. less now, than it cost at the time, it would be but fair to estimate the cost of the bridge at \$1,870, without any reference to the labor that is misapplied in all new structures of the kind, making the cost of a bridge 55 ft. long, \$34 per ft. And I have no doubt where there would be a large quantity of iron required for such purposes, that it could be had at such prices as to bring down the cost of bridges of 55 ft. length to \$30 per ft.

Very respectfully yours,

JAMES MILLHOLLAND.

## II

[From Philadelphia and Reading annual report for 1859, pp. 55-61.]

READING, Dec. 13th, 1859.

R. D. CULLEN; Esq., President Philada. and Reading Railroad Co.

DEAR SIR: I have your letter of the 7th inst., and most cheerfully comply with your request mentioned therein.

We have been burning anthracite coal in some of our locomotives for the past twelve years, and for five years in all the engines employed in coal transportation, hauling with them trains of 500 tons, exclusive of the weight of cars, and are now burning anthracite coal in all the locomotives on passenger, freight, and coal trains, employed on the main line of the road, and in all the engines employed on the lateral roads, except the two passenger engines on Lebanon Valley

Branch, and one running the Reading Accommodation Train, and one on the Chester Valley Railroad, burning wood.

There are now on the road,

4	First class Anthracite coal burning Passenger Locomotives.	
1	Second " " " "	
88	First " " Coal and Freight "	
3	Second " " " "	

These engines are much easier managed than wood-burners, and a much more uniform pressure of steam can be kept on them, as they are all provided with variable exhausts, under the control of the engineer, who can increase or diminish the draft at pleasure. To fire these engines requires much less labor than wood-burners, as it is not necessary to fire oftener than at intervals of forty minutes, and sometimes double that time may elapse without further attention than occasionally to clean out the cinder and ashes between the grate-bars. The best fireboxes for burning anthracite coal are those with the largest grate area. The first four large engines for burning this fuel, built by Ross Winans, Esq., of Baltimore, and placed on the road in 1847, had fireboxes six feet three inches long, by two feet ten inches wide, giving a grate area of 17.68 square feet; these engines did not make steam freely, and had to be run with a small exhaust, and in consequence produced a very strong draft, and threw a great deal of coal out of the chimney. The next five engines built by Mr. Winans for this Company, were placed upon the road in 1850 and 1851, and were different from the four built by him in 1847; they are what is commonly called the "Camel" engine, having a large dome and house on top of the boiler for the engineer, their fireboxes being five feet two inches long, by three feet six inches wide, giving a grate area of a little over eighteen square feet; they were also deficient in making steam, but gave much better results than the first four. The engines that have been placed on the road within the past seven years, also built by Mr. Winans, have fireboxes seven feet long and three and a half feet wide, making a grate area of 24.5 square feet, and perform very satisfactorily. One of the difficulties we have had to contend with in the use of anthracite coal as a fuel for locomotives has been the necessity of using an inferior quality of coal for the purpose of preventing the cast iron grate-bars from melting, as it makes a great deal of cinder and ashes, which, when once formed on the grate-bars, protects them from the immediate action of the fire, and the firemen have to be very careful

in cleaning the grate-bars, that they do not get so much of it out as to bring the hot coals in contact with the bars and melt them down, and being compelled to use this inferior coal has made the consumption appear more than it really should be.

The best coal could not be used in our locomotives with any certainty of success, until water grate-bars were substituted for cast iron; in fact, it was looked upon as a bad article for the purpose, because it would melt the cast iron grate-bars; but the water grates have shown that it is far preferable, as it not only takes less of it to perform a trip, but there is less required on the grate at a time, and the fire being thinner, a larger exhaust can be used, and consequently a much milder draft is produced; no fire is thrown from the chimney, and the increased area of the exhaust relieves the back pressure on the pistons, and thereby increases the power of the engine.

In using the best anthracite coal in our passenger engines fitted with water-grates, I have seen the fire run down so low, when near the ends of the road, that a portion of the grate bars would be bare. And I have no hesitation in saying, that, with a properly constructed boiler, fitted with water-grates, and the use of good anthracite coal, all classes of locomotives, both passenger and freight, can be used with as much reliance as to their performances, both as to speed and power, as engines burning wood or any other fuel; and that a more uniform pressure of steam can be maintained on them, than any wood-burning passenger or freight engines that have been on our road for the past eleven years. It is, however, a matter of experiment with us now, to know what is the best material for a firebox, and the proper shape to put it in for service with anthracite coal. In the fireboxes of Winans' engines, having a grate seven and a half feet long, and three and a half feet wide, with *vertical* side-sheets, we have been using copper, three-eighths of an inch thick; this, however, would not last more than about eighteen months, running about 25,373 miles, when the boilers had the entire back end of the firebox open, with two upper and one lower door to close when in use, and cast iron grate-bars.

In this kind of a firebox, the side-sheets would be worn down in places to not more than a sixteenth of an inch thick; and in others, it would retain nearly its original thickness, but from what cause I am not able to say; but probably from mechanical action, as the thin places are generally found about where the coal would strike the side-sheets when thrown in with

a shovel. To remedy this wearing away of the side-sheets, I put in a harder material, iron; but it does not last so long as copper placed in a vertical position, as it appears to become very much overheated, and cracks vertically, showing a crystalline fracture, which, I have no doubt, is caused by the absence of water on the opposite side of the sheet from the fire.

The steam generated on the side next to the water (in consequence of the sluggishness of the circulation, if any, in this part of the boiler), remains there in contact with it, and as it will not take up heat with as much facility as water, allows the iron to become too much overheated, and the first strain that comes upon it in the way of unequal expansion or contraction, causes it to crack; but copper being a more ductile material, is not affected in the same way, but becomes softer by the frequent heating and cooling, and therefore appears to be the best material of the two, for this kind of firebox.

I closed up one-half the open end firebox by putting a water back that took up one-quarter of the opening on each side of the firebox, leaving one-half the area of the end open from top to bottom; the lower half of the opening was closed by a grate door, which serves to admit air to the coal in that part of the furnace that would not be supplied with air if a solid door was used, and also for the purpose of inserting a slice-bar to break up the cinder on the grate. The upper half of the door is used for firing, and consists of two plates of cast iron, the inner one about two inches from the outer, leaving a space between, that was supplied with air through holes bored or cast in the outside plate; which air protects the inner plate to some extent from the heat, and also supplies air to ignite the gases, and not to allow them to pass from the furnace unconsumed.

This arrangement of doors increases the durability of the side-sheets, and engines whose boilers have been thus fitted, have run an average of 29,391 miles before the sheets required replacing.

To introduce the water-grates, I was compelled to close the back end of the firebox, leaving an oval door for firing, the same as in the ordinary wood-burning boilers, but with a number of small holes in the inner plate of the door, and larger in the outer; and in some of the boilers, I have put hollow stay bolts, with an opening about one-quarter inch in diameter, in the back end of the fire-box. The side-sheets in the first boiler fitted with water-grates and closed back end, run 39,254 miles; and as this is the only one that wants the side-sheets renewed, I have no

*Statement of the Number and Names of Wood-burning Engines that have been changed to Anthracite Coal-burners; when done; the number of Miles run, and the Duty these Engines are doing*

Names of Engines.	When altered to Coal-burners.	No. of Miles Run.	
Allegheny.....		168,588	Freight Train Main Road.
Gowen and Marx..	January 1855	25,385	
Tuscarora.....	June 1855	28,708	Assorting at Reading.
Shamokin.....	November 1855	43,969	Running at Palo Alto.
Empire.....	February 1856	35,363	Pusher, Richmond Wharves.
Mahanoy.....	June 1856	56,045	Work on Lateral Roads, Coal Region (on grades over 100 feet to the mile).
Amazon.....	June 1856	54,182	" " " "
Yorktown.....	November 1856	51,701	" " " "
Columbus.....	November 1856	31,782	" " " "
Rio Grande.....	June 1857	35,020	City Coal Trade, Philadelphia Branch.
Carolina.....	June 1857	41,626	Work on Lateral Roads, Coal Trade (on grades over 100 feet to the mile).
Missouri.....	July 1857	35,049	" " " "
New York.....	August 1857	30,722	" " " "
Manatawny.....	May 1858	27,011	Passenger Train, Valley Railroad.
Black Diamond...	May 1858	32,590	Freight Train, Lebanon Valley Branch.
Texas.....	June 1858	38,457	Freight Train, Main Line.
New England.....	August 1858	30,540	" " " "
Warrior.....	October 1858	31,386	" " " "
Oregon.....	December 1858	14,098	Freight Train, &c.
Pacific.....	May 1859	7,364	" " " "
Ontario.....			Assorting Cars at Harrisburg.

doubt as good results will be had from others fitted in the same way. I have now on trial, in a boiler with vertical sides, and same sized firebox as before mentioned, with closed back, and side and end sheets five-sixteenths of an inch thick, made of Mr. Clay's homogeneous steel, which is doing well; it has run 14,381 miles. Most of the fireboxes of the boilers of engines we have built in our own shops, and of those we have made to take the place of wood-burning boilers, differ somewhat in shape from those I have mentioned, and have a combustion chamber attached, extending from eighteen to thirty-six inches into the cylindrical part of the boiler; and some of the fireboxes are much wider than they are long at the bottom, which makes the side-sheets incline towards the fire. Iron has been used in all these with one exception, which is five feet long and five feet wide, making a grate area of twenty-five square feet. In this I put copper side-sheets, to ascertain if the shape had any influence on the wear. The experiment showed that copper would last longer in this shape with cast iron grate-bars, and the back end partly open, as they lasted to run 38,292 miles, while those

with back end partly open run but 29,391 miles.

The iron sheets, however, in other fireboxes, with inclined sides, show that this plan of constructing is much the best, as the side-sheets show little or no wear, and are not much thinner when taken out than they were originally, and the only cause for removing them arises from imperfect welding of the iron, which gives rise to blistering and cracking around the staybolts, so as to cause leaks; but they last much longer than the copper sheets in the vertical sides, and have run an average of 59,866 miles.

I think, from an experiment with an iron sheet in a firebox with vertical sides, that I have hit upon a plan that will prevent the radiating cracks around the staybolts. It is to indent the sheet at the hole the staybolt passes through, a little more than will receive the riveting of the end of the staybolt; this places the iron in such a shape in the sheet as to allow it to spring, when the expansion of the sheet and staybolt takes place. The experiment clearly shows an advantage from the indentation, as the opposite sheet, in the same firebox, is cracked and leaks, whilst the staybolts in this are as perfect as the day they were



put in, never having leaked at all, after having been in operation since October, 1858, and ran 22,388 miles.

The most durable firebox for burning anthracite coal we have had on the road is of iron, in a small boiler of one of our light engines, built by the Company, about eight years since, and has been but a few months replaced with a new one. It is four feet five inches long, and three feet seven inches wide, making a grate area of 15.82 square feet. The sidesheets, being smaller than in the large engines now in use in our coal trade, were made direct from the bloom, and are consequently homogeneous; the flue sheet was also set back from the firebox about eight inches. It ran 168,588 miles, but I have not included it in the average number of miles ran by our engines with iron fireboxes.

#### RECAPITULATION

Average number of miles ran with iron firebox sheets, .....	59,866
Average number of miles ran with copper firebox sheets, open end, .....	25,373
Average number of miles ran with copper firebox sheets, half closed, .....	29,391
Average number of miles ran with copper side-sheets, closed end, and water-grates, ..	39,254

#### *Cost of Renewing the Copper Firebox Sheets*

Labor "per contract," .....	\$100 00
870 lbs. copper, .....	278 40
635 lbs. boiler iron, .....	31 75
165 lbs. rivets, .....	11 55
273 lbs. staybolts, .....	21 84
49 ft. hollow bolts, .....	10 87
<hr/>	
Carried forward, .....	\$454 41
Brought forward, .....	\$454 41
Cr.	
By 530 lbs. old copper, ....	\$106 00
By 881 lbs. scrap iron, ....	11 75
<hr/>	
	\$117 75
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Balance, .....	\$336 66

#### *Cost of renewing Iron Firebox Sheets*

Labor, .....	\$100 00
1095 lbs. boiler iron, .....	54 75
165 lbs. rivets, . . . . .	11 55
273 lbs. staybolts, .....	21 84
49 ft. hollow bolts, .....	10 87
<hr/>	
	\$199 01
Cr.	
By 1190 lbs. scrap iron, .....	15 87
<hr/>	
Balance, .....	\$183 14

The consumption of fuel by our coal train engines, with a train of 100 loaded cars, with five tons per car, and 110 empty cars up, is on an average in the round trip of 190 miles, 9 tons of coal.

The performance of our anthracite coal-burning passenger locomotives, I think, will compare favorably with locomotives using wood or bituminous coal on other roads.

Annexed please find a statement of the performance of one of them, and it may be as well to state, that the engineer and firemen of this engine never ran a coal-burner before, and had not been on this more than a month when the experiment was made, having been taken off a wood-burning passenger engine, and I have not the least doubt, but a better result can be shown under similar circumstances, in future.

I would also call your attention to the performance of the Phoenix, the pushing engine at the Falls grade. This engine burns anthracite coal, is an eight wheel connected engine, and weighs 70,700 lbs., and is doing the work that required two eight wheel connected wood-burning engines, weighing 52,192 lbs. each.

The number of engines that have been changed from wood to coal-burners, and the miles ran by each up to the 30th of Nov. 1859, will be found in the following statement.

None of these engines have had new fireboxes, or firebox sheets put in their boiler since they commenced burning coal.

Very respectfully,

JAMES MILLHOLLAND.