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INTRODUCTION

Until 1815, the southern agricultural plantations, northern iron plantations, and small community-oriented sawmills and gristmills supplied services and products on a very small scale (Taylor 1951: 5-6). When population increase and influx required increased production of the basic necessities, home industry no longer sufficed. It became apparent that the United States would become an active participant in the growing international trade.

After the War of 1812, the United States realized its potential to produce certain basic, marketable products, such as iron, cotton, wood, and charcoal--components necessary to industrialization and economic and social growth. But the country was still agrarian, with few large, densely populated areas (Taylor 1951: 6), a primitive transportation system, and an almost nonexistent commercial transport network, consisting in limited river travel. The lack of adequate transportation systems became increasingly evident with the growing need to move people and goods (Taylor 1951: 13-14).

One of the few solutions offered for the problem of overland transportation was the construction of a network of canals. Overall, canals were a dismal failure. The tremendous sums of capital needed for construction and the long periods of time required for completion proved highly unsatisfactory for rapidly evolving industrial America (Taylor 1951: 55).

In the opinion of economist George R. Taylor, "It was the misfortune of most canals to become obsolete even before they were opened for traffic. The advantages of the railroad were so great that even the strongest canals could not long retain a profitable share of the business" (Taylor 1951: 55). Therefore, when early canals were still under construction, several pioneers became interested in the railroad as the possible primary transportation source for America (Taylor 1951: 76). Already, some 100 years earlier in Britain, Thomas Savery and Thomas Neucomens had perfected the modern type of stationary steam engine; within 50 years it had been improved steadily and used regularly for power in mining operations. These engines generally operated pumps that eliminated water from the mines, but they soon began to power loaded cars on tracks for hauling ore (Bruce 1952: 18-19).

Horse-drawn mining cars or wagons on tracks were also used in Britain, and, in some instances, in America. One such early example was Silas Whitney's 1807 inclined railway used to move bricks and kiln products at Beacon Hill, Massachusetts (Bruce 1952: 7).

With the English commercialization of the railroad in the early 1820's (White 1968: 3), a handful of American surveyors and engineers began to realize the advantages of motive power for mass, rapid, and overland transportation. On July 4, 1828, construction of the Baltimore and Ohio Railroad began (Joseph 1975: 146), and in 1829, the American engineer John B. Jervis's 26-year-old agent in England, Horatio Allen, in a transaction for the Delaware and Hudson Canal Company, imported the first four locomotives, including the *Stourbridge Lion* (Fitzsimons 1971: 86-87; Bruce 1952: 21). Some three years later, Jervis was to contribute one of the most important inventions to steam locomotive engineering--the leading truck (Fitzsimons 1971: 96). The leading truck

> ... is a frame supported by two pairs of small wheels. The frame itself is attached by a swivel to another frame which supports the front section of a locomotive's boiler. This arrangement steadies and guides the locomotive on

curved sections of track. (Fitzsimons 1971: 86)

The leading truck accomplishes the lead point on the necessary three-point suspension.

Despite the facts that hardly any track had been laid in America and most railroad companies were rapidly organized and financially unstable, the call for railway service was unprecedented and immediate. The need for locomotive engines was directly related to this new demand for railroads. By 1830, the British manufacturers had already perfected the basic design of their locomotive (White 1968: 7), whereas America was not yet equipped to produce engines. In fact, the first locomotive produced in the United States was in 1830, by the West Point Foundry Association of New York City. It was called the *Best Friend* (Bruce 1952: 22-23).

But the rapid growth rate of early 19th-century America was established, and the growth of railroads was corollary. As the processes of industrialization took place in America, increasing numbers of locomotive engines were needed and imported from Britain. "In all, between 1829 and 1841, about one hundred and twenty locomotives were imported" (White 1968: 7).

In 1833, "Judge Dickerson, then President of Paterson and Hudson River Railroad, ordered a locomotive, which was called the *McNeill*, from George Stephenson ..." (Forney 1886: 10). Stephenson and his gifted son Robert exerted the major influence in British locomotive construction during this early period (Fitzsimons 1971: 87). Several features that eventually contributed to the distinction of American engineering, with respect to the basic British design, were actually surviving, or reevolving, details of early Stephenson engines (Warren 1970: 309).

The Paterson and Hudson River Railroad received the *McNeill* in components (*The Railway and Locomotive Historical Society Bulletin 44* 1937: 43) and because of their previous orders for structural iron from the firm of Rogers, Ketchum and Grosvenor for the then under construction railway, hired Thomas Rogers to assemble the engine (Trumbull 1882: 114). It took Rogers nearly a month to complete the work, but when he delivered it it was in good running order and was well received (Lucas 1933: 34).

Therefore, by 1835, Thomas Rogers had been introduced to locomotive construction. In 1832, he had filled an order for 100 pairs of wheels and axles for Horatio Allen and the South Carolina Railroad (Forney 1886: 2). Equipped now with the patterns and drawings he completed during his assembly of the *McNeill*, Rogers responded to the demand for steam locomotive engines by preparing to construct a locomotive in his Paterson shops (Nelson and Shriner 1920: 352).

To understand Thomas Rogers' venture into locomotive construction, we should consider the condition of the field of steam engine building in America in 1835. British industrialization was flourishing, whereas American industry was in its earliest stages. In the United States, different climate, terrain, finances, and experience from those of Britain necessitated the evolution of similar but different areas of technology (White 1968: 7-8). In understanding the basic technology of steam locomotive building during this early period, we must remember that the mechanical, technological, scientific, and engineering fields were in their infancy, primarily concerned with the use of iron as the major component in the developing industries of the Industrial Revolution (Taylor 1951: 5). Also, these early American industries were still water powered; energy produced from other elements was virtually negligible.

In these considerations we must also realize that steam locomotive technology, like all technologies, developed over a period of time, having many contributors in many fields and areas of study and correlating past successes and failures with present designs. As information concerning locomotive construction evolved from raw data to proven fact, and as channels developed to communicate this knowledge, the realm of steam locomotive engineering was created. "The boring machine had been introduced in England in 1775, the shaper in 1808, and the planer a decade later ..." (Comstock 1971: 51). In America,

> The first steam locomotives were necessarily very crude in design and construction, since there was little or no accumulated engineering knowledge to draw upon, and no means available to produce and machine heavy castings and forgings or to roll and fabricate large boiler plates, all the parts entering into the construction of the locomotives were shaped by hand, requiring time and patience as well as skilled craftsmen. (Bruce 1952: 26)

Despite these conditions, many individuals and organizations brought progress to the field of locomotive construction. Certainly one of the major contributors to the design of the locomotive that became the standard for American railroads in the mid-19th century was the Rogers Locomotive and Machine Company. (Upon the death of Thomas Rogers in 1856, Rogers, Ketchum and Grosvenor reorganized, changing its name to the Rogers Locomotive and Machine Company.)

The following pages chronicle the development of the steam locomotive technology employed in the shops of the Paterson, N.J. locomotive builders, focusing on the Rogers Locomotive and Machine Company's progressive, innovative design. They attempt to show some of the valuable efforts championed by Thomas Rogers and William S. Hudson, his chief engineer.

THE SANDUSKY--ROGERS' FIRST LOCOMOTIVE

> In 1835 some additional buildings were begun by Rogers, Ketchum and Grosvenor with a view to the manufacture of locomotives; it was not, however, until eighteen months afterward that the first locomotive, the *Sandusky*, was turned out after many difficulties had been surmounted. On the 6th of October, 1837, the *Sandusky* was finally completed and a trip made from Paterson to Jersey City and New Brunswick and back.... The time actually required for the construction of the *Sandusky* was sixteen months, during which tools had to be made, numberless experiments tried and men instructed in the work.... The performance of this first engine was perfectly satisfactory.... It was continued in service many years, until the traffic of the road required a larger class of engines to do the work. (Trumbull 1882: 114)

In commenting on this first engine in 1882, John Cooke, a Paterson locomotive builder, noted the following: "With its round-top boiler, two drivers and wooden frame, it was quite a different affair from the locomotive of the present day" (Trumbull 1882: 116). But the *Sandusky* should not be dismissed solely as Rogers' first engine. It marks Rogers' introduction into the field of locomotive construction, and has a mechanical significance of its own as well. The *Sandusky* illustrates Rogers' mechanical creativity--his ability to innovate on a product.

During the year and a half it took to complete the *Sandusky*, Rogers made some very significant advances on the pattern and drawings of the Stephenson engine he had previously assembled. The *Sandusky* was a basic 4-2-0 with a wooden frame and two driving wheels about 4.5 ft. in diameter, which were situated in front of the furnace (Trumbull 1882: 116; Bruce 1952: 26); the truck had four 30-in. wheels (Nelson and Shriner 1920: 352). "The furnace, in plan, was semi-circular at the rear part, and it had a hemispherical top surmounted with a dome" (Forney 1886: 14). The cylinders were 11 in. in diameter with a 16-in. stroke (Nelson and Shriner 1920: 352), and the main valves were of the ordinary D-pattern, employing a simple hook-motion type of valve gearing (Forney 1886: 52). "The eccentrics were outside the frame, the eccentric rods extending back to the rock shafts, which were situated under the foot-board; the smokepipe was of the bonnet kind ..." (Trumbull 1882: 115). (See Fig. 3-1.)

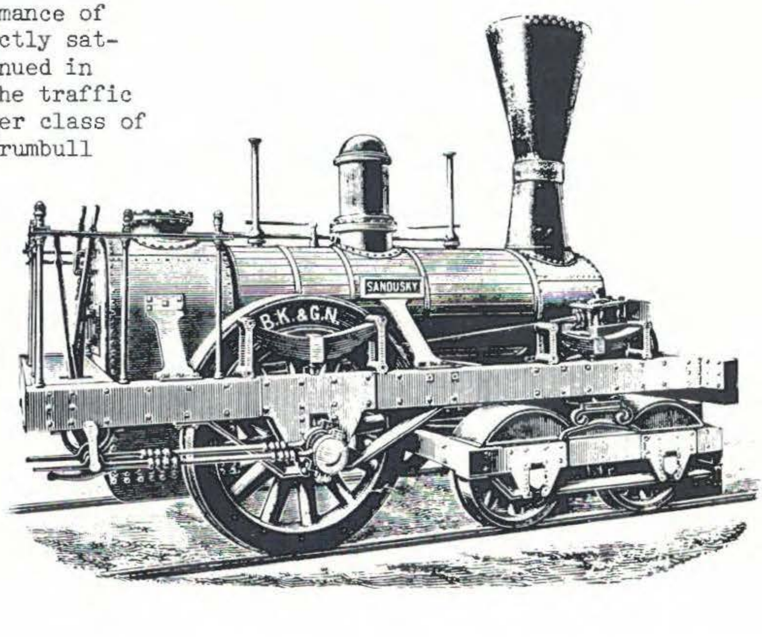


Figure 3-1. *The Sandusky*, Thomas Rogers' first locomotive, 1837. *(White 1972: Plate 16.)*

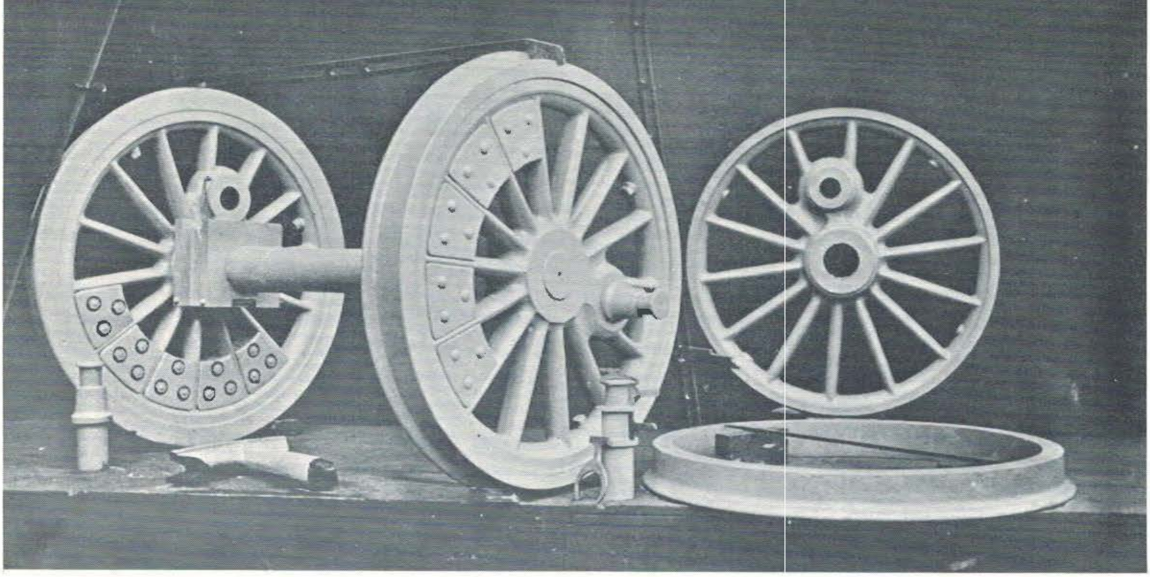


Figure 3-2. Driving wheels produced at the Grant Locomotive Works, Paterson, N.J., in 1871. Note the counterbalancing weights and the broken section of hollow-cast rim and spoke. *(A Description of Locomotives ... 1871.)*

Rogers did not invent the American 4-2-0; it was a design that evolved from the Stephenson 2-2-0 Planet types (Reed 1971: 73), and was displayed by John B. Jervis on the *Experiment*, built by the West Point Foundry in 1831 (White 1968: 33). Nor did he invent the round boiler, or any of the other basics from the British design; in fact, the wooden frames with outside bearings and the D-shaped firebox are directly evolved from Stephenson engines (Warren 1970: 309).

However, Rogers did create new methods of technology for achieving a better constructed 4-2-0. Some of those improvements survived better than 50 years as the accepted mode of locomotive building. Of these advances, the two most important were (1) a new scheme for the construction of locomotive wheels, and (2) the introduction of the idea of counterbalancing--i.e., supplying complementary weight to offset the weight of the crank, rods, and piston. "The driving wheels of the engine were made of cast iron, with hollow spokes and rim, which at the time was a remarkable novelty" (Forney 1886: 12). Not only was this scheme adopted in the locomotive centers of Philadelphia and Paterson (Norris 1853: 268; Ferrell 1971), but Matthias Forney, in his 1890 *Catechism of the Locomotive*, instructs that the central portion of the wheel--i.e., the hub, spokes, and rim--are cast in one piece. Usually the hub and the rim, and sometimes the spokes, are cast hollow (Forney 1890: 285-86; see Fig. 3-2).

In 1882, Trumbull wrote the following concerning counterbalancing: "Among the improvements introduced in this first engine perhaps the most important was counterbalancing, ..." (Trumbull 1882: 115). Thomas Rogers patented counterbalancing July 12, 1837: "The nature of my improvement consists in providing the section of the wheel opposite the crank with sufficient weight to counterbalance the weight of the crank and connecting rods, making the resistance of the engine less in starting and in running...." (Forney 1886: 12). Rogers achieved this by solid casting the rim of the wheel opposite the crank, whereas the rest of the wheel was hollow, as was the wheel on the crank side (Forney 1886: 12). "The importance of counterbalancing was not generally recognized as being necessary until several years after it had been introduced by Mr. Rogers, and when attention was finally attracted to its importance many yet doubted the necessity of balancing anything more than the cranks" (Trumbull 1882: 115). Yet, in 1890 Forney relates that counterbalancing is the method to be employed in overcoming the weight of the valve gearing (Forney 1890: 264).

Two lesser, but still noteworthy, improvements introduced in the *Sandusky* were a steam whistle and a bonnet-type stack on the boiler. The whistle was a steam-operated cup type, located on the top rear of the boiler; it was small and shrill (Comstock 1971: 94). The smokepipe rose from the front end and had a bonnet-type cap, with "... a deflecting

cone curled over at the edge in the centre, so as to deflect the sparks downward and thus prevent their passing through the wire bonnet...." (Trumbull 1882: 115).

A last consideration in this brief examination of the *Sandusky* is the progressive design in locating the driving wheels. At this early stage, Rogers realized that the power of a locomotive related directly to the amount of adhesion its driving wheels had to the rails, and that this adhesion drew directly from the amount of weight exerted downward upon the driving wheels (Roper 1888: 101). Therefore, he located the driving wheels between the furnace and the smokebox and let the weight of the furnace hang over behind the wheels. He obtained hanging weight forward from the cylinders, valve gearing, smokebox, etc., establishing a method for the engine's entire weight to be exerted downward on the driving wheels (Forney 1886: 21).

The success of the *Sandusky* was unparalleled. In an 1882 account, Rogers' first engine was still reported in serviceable condition some 45 years after its construction (Trumbull 1882: 114).

After the completion of the *Sandusky* and until 1840, Rogers, Ketchum and Grosvenor produced approximately 25 more locomotive engines (Trumbull 1882: 147), most of which were the basic *Sandusky*-type 4-2-0's. The *Stockbridge*, completed in 1842, is 4-2-2, incorporating the use of two trailing wheels behind the drivers (Forney 1886: 16).

Rogers experimented with driving wheel positioning and methods to increase adhesion (Trumbull 1882: 119); he also experimented with cylinder and rod positioning as well as general lengths and sizes of various systems and components. But, like all other major locomotive builders, Rogers had yet to arrive at a formula that would incorporate the technical improvements necessary to meet the fast-moving demand for train and locomotive service. "The necessity of securing regularity in the transport of trains, whether passenger or goods, was pressing and paramount, and afforded sufficient materials for thought and experiment" (Norris 1853: 208). However, the craftsmanship of these early Rogers engines was attested to in the *American Railroad Journal and Mechanics Magazine*, December 15, 1839:

> The truck frames, whether of wood or iron, were admirably stiffened by diagonal braces, and where the crank axle is used, the large frame is very strongly plated in manner of Stephenson's engines ... as a last remark we would observe, that there is more finish on the engines of Messrs. Rogers, Ketchum, and Grosvenor than we are in the habit of seeing; some parts usually painted black being highly polished. (Forney 1886: 14-15)

THE 4-4-0 LOCOMOTIVE

In Philadelphia in 1836, the chief engineer for the Philadelphia, Germantown and Norristown Railway, Henry R. Campbell, introduced a second pair of driving wheels on a locomotive he patented (Bruce 1952: 25). This engine had a four-wheeled leading truck and four-coupled driving wheels--a 4-4-0 (Forney 1886: 16). This first 4-4-0-type engine was huge for its time and particularly stiff in operating; by and large, it was highly unsuccessful (Bruce 1952: 25; see Fig. 3-3). It was not until a series of basic

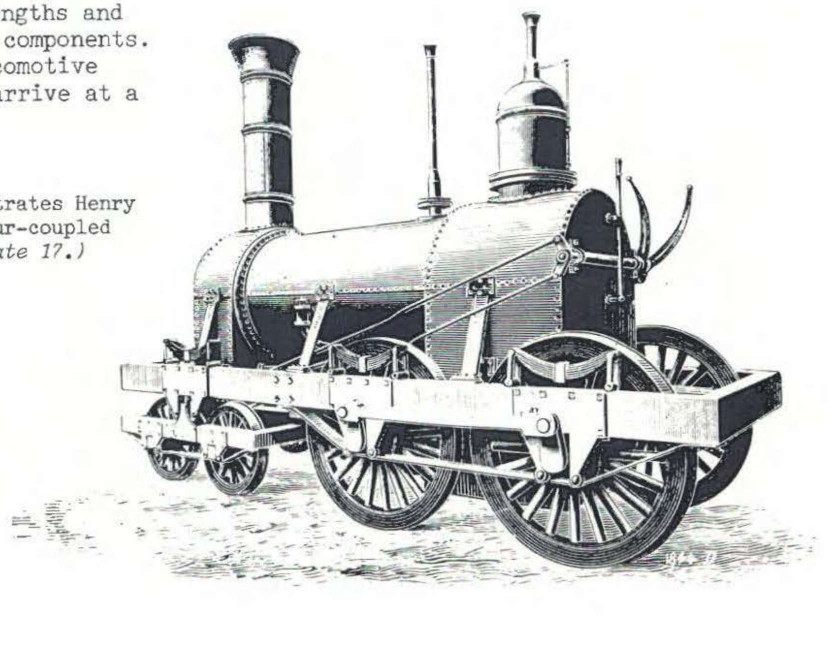


Figure 3-3. This drawing demonstrates Henry R. Campbell's 1836 patent for four-coupled driving wheels. *(White 1972: Plate 17.)*

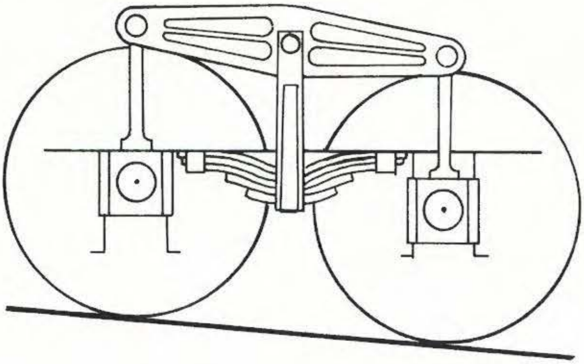


Figure 3-4. Joseph Harrison's equalizing lever, patented 1838. *(Comstock 1971: 66; redrawn by Lynda de Victoria.)*

advances were made in the design of suspension and running gears that the 4-4-0-type locomotive became suitable for American railway service. Running gear of a locomotive consists in those parts--truck, wheels, axles, and frames--that carry the rest of the engine (Forney 1890: 268). With the rear weight resting on one point on each side of the locomotive and the front end resting on one point in the center of the leading truck, there is formed the desired three-point suspension (Forney 1890: 13). "Now it is a well known fact that any tripod ... will adjust itself to any surface ... therefore it is of the utmost importance that a locomotive should be able to adjust itself on its points of support ..." (Forney 1890: 14).

For this adjustment to occur on three points, over uneven track, Joseph Harrison, a Philadelphia locomotive builder, perfected the locomotive equalizing lever in April 1838 (Reed 1971: 74). The equalizing lever enabled the entire weight of the locomotive to be spread equally over the driving wheels, creating maximum adhesion and minimum wear on bearings (Kirkman 1902: 82) and effecting smoothness of ride by keeping all wheels in firm contact with the rails (Comstock 1971: 66; see Fig. 3-4). "Nineteenth-century American locomotive building was distinguished by conservatism and a steadfast resistance to the acceptance of novel, or 'new fangled,' designs. This conservatism was essentially an intelligent rejection of many foolish reforms and patents eagerly promoted by impractical or even fraudulent inventors... however ... genuine improvements were recognized and freely adopted as they slowly evolved ...." (White 1968: 4). This was the case with the perfected 4-4-0, and from 1838 to 1840 the Philadelphia firm of Eastwick and Harrison was the only producer of coupled-driving wheeled locomotives, with less than 20 in service in the United States.

By 1840, Rogers recognized the significance of this coupled-wheel design and quickly began to produce it. Between 1840 and 1844, he constructed nearly 20 of these 4-4-0's of all sizes and capacities (White 1968: 48). This type of locomotive engine rapidly became the most popular on American railroads. It was well suited for all types of service, competent and reliable because of its few parts, inexpensive in its initial cost, and easily maintained. It also provided ample power with its coupled driving wheels (White 1968: 46).

By 1844, Rogers had adopted the 4-4-0 as his basic design, and had set to work to improve it. In the late 1840's, he experimented with positioning of driving wheels, locations of springs and equalizers, and several variations in bearing positions, inside or outside. He had also adopted independent cutoffs on the valves (Forney 1886: 17-18). But, generally, the basic design of the 4-4-0 remained constant from 1840 to 1850: boilers were built and set low on the frames; the leading trucks employed a short wheelbase; and the Bury firebox and hook-motion valve gearing commanded the most attention (White 1968: 52; see Fig. 3-5).

THE "AMERICAN-TYPE" 4-4-0

In the early 1850's a new, modern, locomotive was introduced.

> During the first few years after the opening of the railroads the class of improvements comprising the gradual enlargement of dimensions, as necessary for maintaining higher rates of speed and the transport of heavy bodies, the better disposition and proportionment of the component parts, and the selection of suitable materials capable of resisting heavy strains and various other causes of derangement and decay, demanded, in consequence of their direct influence upon the traffic of the companies, unrelenting attention. (Norris 1853: 208)

Although this new locomotive was still the basic 4-4-0, several very important changes had occurred: a new shaped boiler appeared; the wheelbase of the leading truck had been increased, allowing room for the cylinder to be lowered parallel

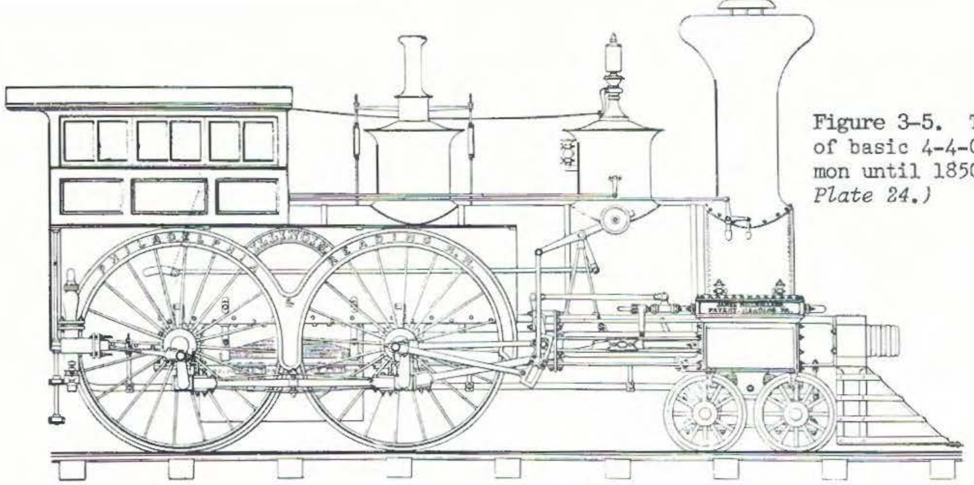


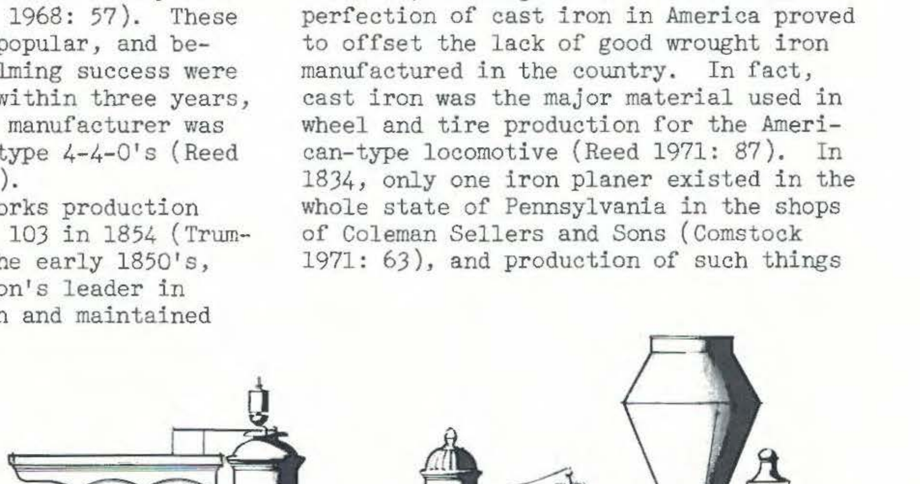
Figure 3-5. Typical example of basic 4-4-0 locomotive common until 1850. *(White 1972: Plate 24.)*

to the track; and the adoption of the new smoother shifting link motion replaced the old hook-motion form of valve gearing. This type of engine was first produced by the Rogers Locomotive and Machine Company in 1852 (Forney 1886: 19), and although Rogers himself did not invent these individual features, he was the first to realize their combined importance, and therefore rightfully deserves credit for their combined introduction (White 1968: 52). "It would be difficult to exaggerate the importance of this single class of locomotive to the nineteenth-century American railway. No other general purpose locomotive enjoyed a greater popularity, and few proved as useful or satisfactory in performing the work they were required to do" (White 1968: 57). These locomotives were very popular, and because of their overwhelming success were in tremendous demand; within three years, every major locomotive manufacturer was constructing American-type 4-4-0's (Reed 1971: 77; see Fig. 3-6).

Rogers Locomotive Works production rose from 1 in 1837 to 103 in 1854 (Trumbull 1882: 120). In the early 1850's, Rogers became the nation's leader in locomotive construction and maintained this position for nearly ten years (White 1968: 14).

There were many predisposing and precipitating factors for the evolution of the 1852 design and for its success in becoming *the* American locomotive. By 1850, locomotive construction technology had reached a point, with other coincidental industries, that allowed complex castings to be accomplished and increased the availability of manufactured iron stock. In other areas of construction technology, McQueen's cylinder saddle of 1848 allowed the locomotive's cylinders to be mounted between the truck wheels (White 1968: 207); heretofore, cylinders had to be mounted on the smokebox (Reed 1971: 75; see Fig. 3-7). The use and perfection of cast iron in America proved to offset the lack of good wrought iron manufactured in the country. In fact, cast iron was the major material used in wheel and tire production for the American-type locomotive (Reed 1971: 87). In 1834, only one iron planer existed in the whole state of Pennsylvania in the shops of Coleman Sellers and Sons (Comstock 1971: 63), and production of such things

Figure 3-6. "American-type" 4-4-0, a standard product of the Rogers Locomotive and Machine Company, *ca.* 1865. Note the wheel positioning, link motion, and wagon-top boiler. *(White 1972: Plate 27.)*



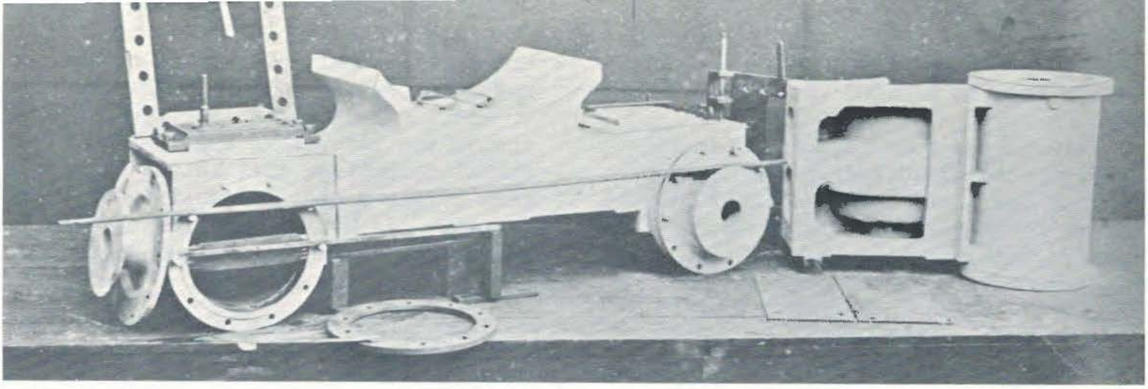


Figure 3-7. Cylinder saddle and cylinders, produced at Grant Locomotive Works, Paterson, N.J., in 1871. *(A Description of Locomotives ... 1871.)*

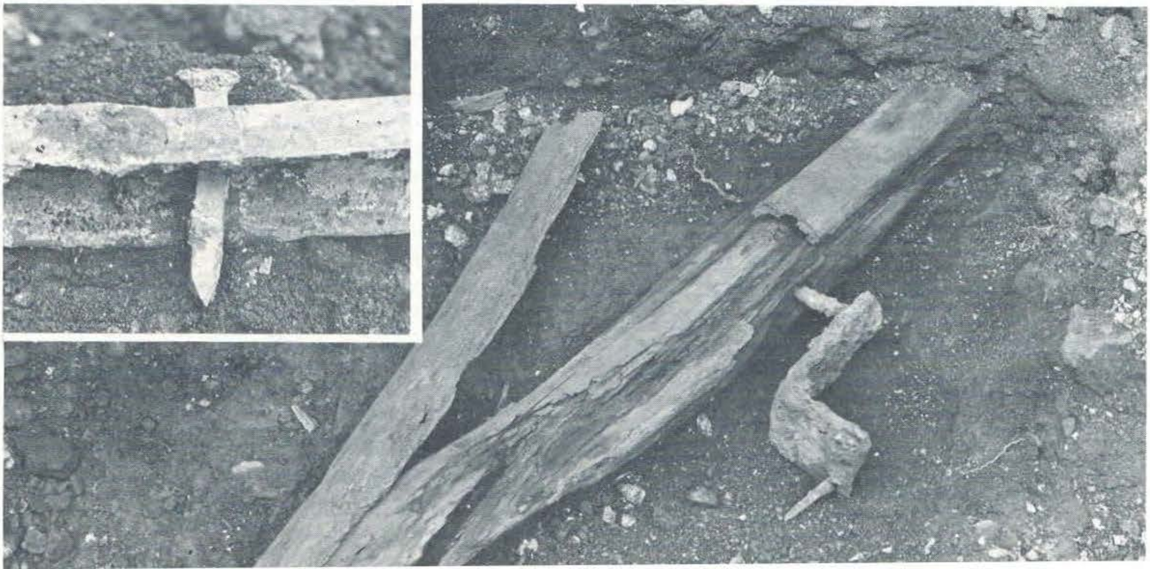
as locomotive cylinders was incredibly time-consuming. But by the mid-1850's, a locomotive cylinder 15 in. in diameter could be produced in approximately 20 hours (White 1968: 206).

Meanwhile, improved methods and materials in building the roadbeds had developed. Until 1840, over half the railroads operating in America were still using strap iron on wood rails and wooden crossties (Reed 1971: 74), but the demand for larger and more powerful engines caused more substantial roads to be built, more in the style of today's roadbed (see Fig 3-8). Also, the problem of enough downward force on the drivers had been temporarily overcome by the use of coupled driving wheels, and the focus turned toward tractive force as the need for larger machines was realized. Tractive force is the ratio of the load of the train on the locomotive drive wheels to the weight that can be pulled by the locomotive without the wheels slipping (Fitzsimons 1971: 88).

Another predisposing factor in the success of the American-type 4-4-0 is the direct influence the large commercial locomotive builders had on mechanical developments (White 1968: 13). The larger, more economically powerful industries could dominate design by sheer production numbers.

The Civil War was a major factor in boosting the Rogers 1852 design to prominence. Before the war, many 4-4-0 engines were used in the North and the South. During the conflict, southern locomotive construction was greatly inhibited, whereas northern builders produced many engines for the U.S. Military Railroad. Approximately 300 locomotives were in military service during the war, nearly 95% of which were of the American 4-4-0 design (Reed 1971: 79). One order from the U.S. Government to the Rogers

Figure 3-8. Example of wrought-iron cap on wooden rail, found in archeological excavations of Rogers boiler shop, 1974. *Inset:* Closeup of rail and spike. *(Courtesy of G.F.D. Archeology Project, Lynda de Victoria.)*



Locomotive and Machine Company was for 19 engines, at $20,000 each (Bishop 1868: 224).

Perhaps the most important precipitating factor involved in the development of the 4-4-0 design of 1852 was the hiring of 42-year-old English-born William S. Hudson. As John H. White, Jr., of the Smithsonian Institution points out, "... it should be noted that William S. Hudson became superintendent of the Rogers works precisely when the first modern engines were built, in 1852" (White 1968: 53). In 1850, Hudson attracted Thomas Rogers' attention when, as master mechanic of the Attica and Buffalo Railroad, he devised a plan to repair leaky boiler flues, a problem that had always plagued the steam locomotive boiler (Forney 1886: 29). As noted in *The Science of Railways*,

> The reason flues leak when exposed to cold air is that the fire expands the flues and flue sheet (to which the flues are fastened), and when the cold air strikes them they contract, and the flues being lighter than the flue sheet, they contract faster, leaving an opening between the flue and its hole in the flue sheet. Pumping a great quantity of cold water rapidly into a hot boiler will have the same effect. (Kirkman 1902: 36)

Other builders complained of this serious problem (Roper 1888: 223), and most agreed that employing tube-rings or thimbles would partially remedy it (Norris 1853: 249-50). The remedy was partial because the thimbles were exclusively wrought iron, and would react in the same way if massive doses of cold air or water prevailed in the boiler. After much experimentation, Hudson realized that cast-iron thimbles would react in congruity with the flues and flue sheets, thus eliminating the need for recaulking, once done (Forney 1886: 29). This design was so effective and it so impressed Rogers, that later in the same year a locomotive was produced with cast-iron thimbles on its boiler flues (Bishop 1868: 223).

When Thomas Rogers died in 1856, William Hudson was appointed superintendent of the works, and thus became chief of design and engineering of locomotives (Forney 1886: 20). Hudson continued to produce and improve the American 4-4-0 design that he and Rogers had introduced in 1852 (Reed 1971: 77). His many improvements principally concerned mechanics and logical integrations of moving parts, improved construction techniques, and upgraded reliability of engines (Forney 1886: 22).

Until his death in 1881, Hudson continued the innovative engineering of steam locomotives that became a trademark of the Rogers Locomotive and Machine Company. As Matthias N. Forney, the noted 19th-century author on steam locomotives, relates in 1886,

> ... the perfection of the modern American type of locomotive is due to the ingenuity, mechanical skill, and sound judgment of ... Mr. Thomas Rogers, and to his successor--Mr. William S. Hudson. Both of them have left a record of their genius and ability in their designs, which are imitated today, and which promise to survive until locomotives are superceded. (Forney 1886: Preface)

As previously stated, this new, American-type modern locomotive featured a level cylinder, employed in a spread-wheeled leading truck; a wagon-top boiler; and the link-motion type of valve gearing. British author Brian Reed has stated the following:

> The Rogers prototype was a front-drive locomotive with increased coupled wheelbase into which was dropped a deep round-top firebox; a wagon-top or coned boiler barrel; a long-spread truck wheelbase that allowed the cylinders to be brought down ... to the horizontal; ample distance between truck and first coupled axle, which permitted connecting rods of a length seven to eight times the crank throw and so gave light up and down thrusts on the slide bars; and three-point compensated suspension, the Harrison patent for which had by then expired. (Reed 1971: 77)

The locomotive also had supplementary outside frames to support the cab and running board, and employed both outside and inside bearings. The valve gearing was a shifting-link motion hung from below (Forney 1886: 19). A closer examination of these features is required, for their combination applied to a basic 4-4-0 locomotive became the most successful engine ever developed.

The leading truck served several major functions on the steam locomotive. It was mainly the front-end support for the weight of the frame, boiler, smokestack, smokebox, and cylinders, all of which rested on the truck's center pin, thus accomplishing the lead point in the three-point suspension (Forney 1886: 82,

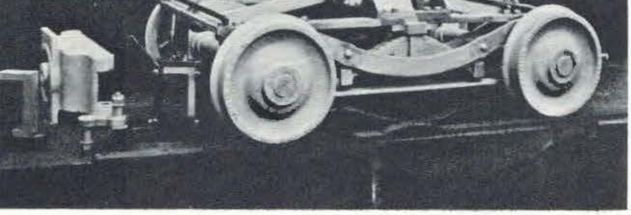
84). The truck could guide the engine through switches, curves, and uneven track because the axles were not held rigidly at right angles to the frame but could swivel to assume positions equal to that of the curves (Forney 1890: 269). According to Forney's *Catechism of the Locomotive*, a leading truck construction consisted in

> ... two pairs of wheels .... attached to a frame, ... The axles have truck-boxes, and brass bearings.... These boxes work in jaws .... The frame ... is of rectangular form and is forged in one piece. The legs which form the jaws for the boxes, are bolted to the frame.... To the lower end of these legs a brace is bolted, which thus unites them together. On each side one spring is placed under the frame and in the reverse or inverted position to that of the driving springs. A pair of equalizing levers is placed on each side of the truck, one of them on the inside of the frame and the other on the outside.... The ends of these equalizers rest on the top of the truck-boxes, and the springs are attached to the levers by the hangers. The truck frame rests on the top of the spring strap, which is ... rounded ... so that it can move freely about the point of support. (Forney 1890: 314-16)

This frame was of wrought iron, with either cast- or wrought-iron pedestals bolted to it (Forney 1886: 69-70; see Fig. 3-9).

As the need for larger and more powerful locomotives prevailed, it was certain that larger cylinders would be used. Mounting and positioning of the larger cylinder were problems, but the cylinder saddle allowed the cylinder to be placed lower, parallel to, and between the now spread wheels of the truck. On most locomotives, the wheels were spread from 5 to 6 ft. apart (Forney 1890: 280-81). This new spread truck not only distrubuted the front weight of the locomotive more evenly over a greater area, but also increased front-end stability because of the wider stance (Reed 1971: 87). The lower cylinder not only delivered more power but also reduced wear on reciprocating parts. By 1855, most builders had adopted this design (White 1968: 207).

Figure 3-9. A leading truck, as produced by the Grant Locomotive Works, Paterson, N.J., 1871. *(A Descriptiòn of Locomotives ... 1871.)*



Another major feature of the American-type 4-4-0 design was the wagon-top added to the basic straight boiler. Steam was generated in the boiler, where water came in contact with the heated surfaces. It then rose to the top of the boiler, where it was drawn off and utilized. As more power was desired and as fuel changed from wood to coal, the size and shape of the firebox also changed. The firebox end was made larger than the cylindrical section, making more room for steam to collect (Kirkman 1902: 50-51). This additional steam room, and thus more steam, was well received because the extra power moved more freight on heavier trains (Roper 1888: 173). Builders gained the additional space by raising the iron plates comprising the boiler top sheet by some 4 to 12, or even 18 in. above the cylindrical part (Forney 1890: 109-10). These iron plates were wrought and about 1/4-in. thick on the cylindrical sections, with 5/16-in. plate used for the wagon-top (Reed 1971: 87).

The advantages of the wagon-top boiler over the straight-top boiler were many, beyond the fact that more steam room was created. When impure water was used, a condition known as *foaming* could occur--i.e., the impurities would bubble up and be drawn off with the steam. This water in the steam would introduce water into the cylinder, a serious condition known as *priming*. The additional space in the wagon-top afforded greater control of foaming, thus reducing the chance of priming.

Another problem in boilers was the crown sheet, which received the major heat and needed constant repair and cleaning. The additional space in the boiler top allowed more room for workmen to make repairs. Also, this longer boiler spread the weight more evenly on the drivers and over a greater area, relieving some of the weight on the front truck. This distribution increased adhesion on the driving wheels and lessened wear on the truck's center pin.

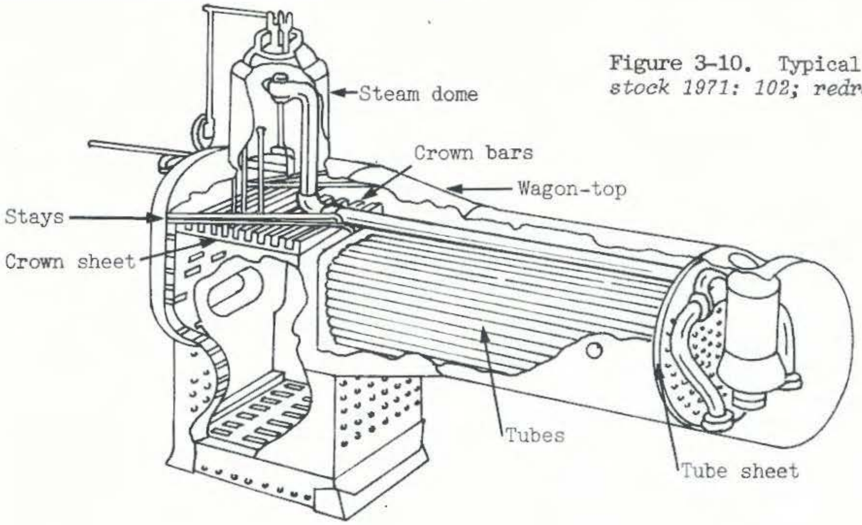


Figure 3-10. Typical wagon-top boiler. *(Comstock 1971: 102; redrawn by Lynda de Victoria.)*

The other advantages were in areas not then fully understood--fuel economy and preheating of water to reduce the amount of fuel needed to make steam. With a larger boiler and more steam space, more water was kept hot in the boiler, reducing the need to overcome large amounts of cold water introduced into the boiler. Also, this higher top space allowed dryer steam to collect, effecting fuel economy and providing more powerful steam (Roper 1888: 169-70). Rogers introduced the wagon-top boiler on locomotives in 1850, and rarely strayed from this type of boiler design (Forney 1886: 24; see Fig. 3-10).

The final new addition to Rogers' and Hudson's 1852 4-4-0 design we shall discuss was a new type of valve gearing; it marked an important step for the Rogers Locomotive and Machine Company, as well as for locomotive engineering in general. Actually, Rogers may have applied this form of valve gearing on locomotives for the Eastern Railway of Maine in 1848 and the Hudson River Railroad in 1849 (Trumbull 1882: 142). At this time, Rogers departs from the old hook-motion form of valve gearing and champions a new design. Born and applied in controversy, it was later regarded as one of the most important advances in steam locomotive technology (Warren 1970: 359), equal perhaps with the invention of the multitube boiler or the blast-pipe exhaust (Reed 1971: 153-54). As White points out, "Rogers' reputation as a first-rate practical mechanic and the position of his company as one of the largest locomotive works had an unquestioned bearing on the successful introduction of the link-motion to American practice" (White 1968: 197).

Valve gearing on a steam locomotive consisted in a series of levers, rods, and eccentrics that worked in an integrated way with motion of the valve, during the proper portion of the piston's stroke. The main objectives were saving steam, economizing fuel, gaining maximum force from available energy, and having a smooth operation of the valves, so that the piston's stroke was smooth (see Figs. 3-11 and 3-12).

Locomotive builders understood that a type of variable control was required to meet the demands of different operating conditions. Leaving the intake ports open throughout the entire stroke of the piston ensured maximum power for starting and hauling on grades. However, under normal conditions and at a higher rate of speed, the large portions of steam admitted to the cylinder did not have enough time to escape, which resulted in back pressure and engine bucking (Comstock 1971: 109-10). "Thus at anything above a crawl it was desirable to admit steam during only a portion of the strokes. This not only insured smoother motion but allowed the steam to work expansively while it was trapped in the cylinders ..." (Comstock 1971: 109-10). The earlier hook-motion valve gears were not sufficiently adjustable to meet the requirements of enough, but not too much, steam, and builders compromised by limiting the intake to one-half the piston strokes. This was called a 50% cutoff (Comstock 1971: 110). The link-motion form of valve gearing "... combined all the desirable features of locomotive valve gear in a remarkably simple and rugged arrangement. It was reversible and offered a variable cutoff in both forward and reverse--all with less than half the number of parts required in most hook-motion variable cutoff gears" (White 1968: 195).

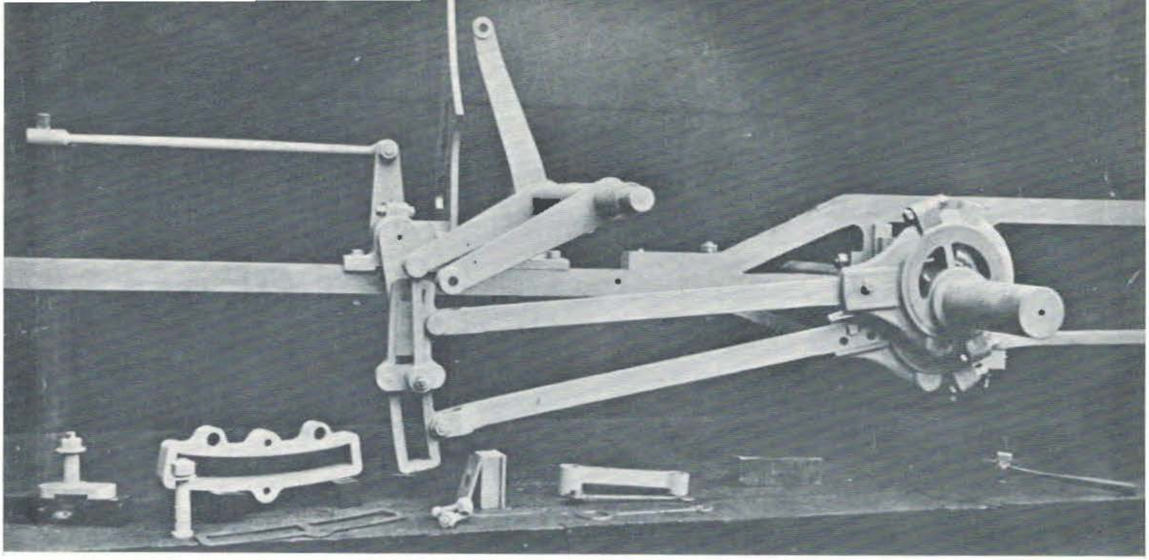


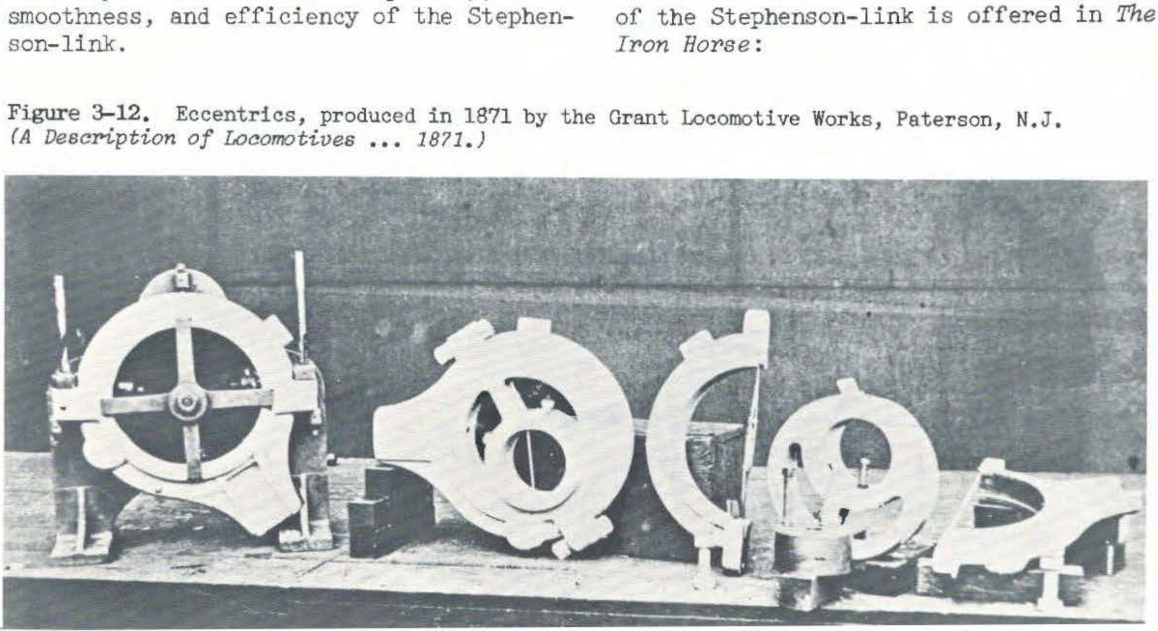
Figure 3-11. Link-motion type of valve gearing attached to eccentrics and frame, produced by the Grant Locomotive Works, Paterson, N.J., in 1871. Note individual link, lower left. *(A Description of Locomotives ... 1871.)*

The link-motion valve gearing was developed in the early 1840's, in the shops of Robert Stephenson in Newcastle, England (Warren 1970: 363-64). It was first applied to a locomotive in 1842 (Trumbull 1882: 142), and was used so widely by Robert Stephenson that many people adopted his name to it--i.e., the "Stephenson-link motion" (Warren 1970: 363). In the mid-1840's, Rogers received a working model of the Stephenson-link motion from his agent in England, and began to study it with his friend and competitor, Paterson locomotive builder John Cooke (Trumbull 1882: 142). When Rogers first introduced the link motion on his engines, most other builders opposed it for one reason or another (Forney 1886: 53), but Rogers, later joined by Hudson, realized the many benefits of the simplicity, smoothness, and efficiency of the Stephenson-link.

The major feature of the link motion was its efficiency or capacity to work steam expansively. At first, it was not fully understood or accepted as reasonable by railroaders. "The history of the locomotive engine may ... be divided into two periods--the first a period of increasing, the second a period of decreasing consumption, as respects the article of fuel" (Norris 1853: 208). The link motion enabled the locomotive engine to be worked, to an extent, expansively (Norris 1853: 276). Working a steam engine expansively means to set the valves in a prescribed manner so that the steam in the cylinder will complete the required work when the valves cut off the supply, thus economizing fuel (Kirkman 1902: 89).

An excellent mechanical description of the Stephenson-link is offered in *The Iron Horse*:

Figure 3-12. Eccentrics, produced in 1871 by the Grant Locomotive Works, Paterson, N.J. *(A Description of Locomotives ... 1871.)*



Its prime movers were two pairs of eccentrics mounted on an engine's main axle. Each pair controlled the action of one of the locomotive's two slide valves. In turn, one of each pair was set for forward running, the other for reverse operation. The far ends of the rods to which they imparted a push-pull motion were attached to the top and bottom of a crescent-shaped member called a "link," whose central slot accommodated a sliding block connected to the valve rod. When the engineer's reversing lever was in a vertical position, both links were held at a height which placed the horizontal axes upon which they rocked at a level with the blocks, and those parts remained idle. But if the lever was thrown all the way forward, the links were lowered until the blocks were at the upper ends of the slots. There the full motion of the "forward eccentrics" was delivered to them and they passed it along to the valves. Conversely, when the links were fully raised by drawing the lever to the rear, the "reverse eccentrics" gave the blocks and valves comparably long travel for backing up with maximum power. The beauty of the arrangement was the infinite choice of intermediate positions. A throttle artist could re-adjust the setting, notch by notch, until mere wisps of steam flicked into and out of the cylinders at high speeds. (Comstock 1971: 110-11)

The link motion effected a great saving of fuel and freely utilized the steam available (see Fig. 3-13).

Another fuel-saving accomplishment of the link motion was that it allowed innumerable settings of the timing for the valves, and accomplished the concept of *lead*. Lead was a valve refinement that enabled steam to enter into the end of the cylinder a split second before the piston reversed direction, cushioning the shock of reversal and providing a completely open valve port for peak performance at the onset of the next stroke (Comstock 1971: 112). By the late 19th century, the link motion is established as the valve gearing for all types and classes of locomotives (Roper 1888: 136-37).

The innovative practicality of the engineering that evolved from the Rogers shops is evident in their adoption of new designs; other manufacturers tended

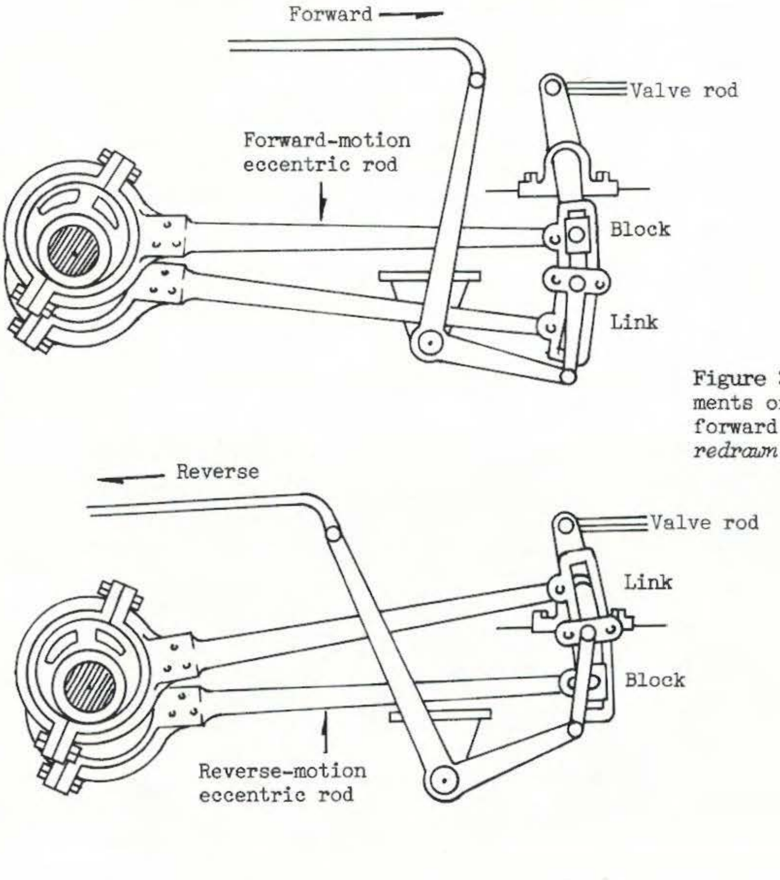


Figure 3-13. Example of the simplistic movements of the link-motion valve gearing, in forward and reverse. *(Comstock 1971: 110; redrawn by Lynda de Victoria.)*

to retain their old designs. Rogers and Hudson contributed greatly to creative locomotive construction, and to the evolving technology that made mechanical advancement possible. In 1888, Roper wrote, "Though locomotive building has long ceased to be considered an art, yet it requires the utmost attention in respect to general design, construction, and the selection of materials ..." (Roper 1888: 118).

The shops that Thomas Rogers began, and William Hudson so ably directed, continued to produce locomotives into the early part of the 20th century. They then merged with American Locomotive Company and relocated out of Paterson.

OTHER PROGRESSIVE TECHNOLOGY AT THE ROGERS LOCOMOTIVE SHOPS

A brief look at some other examples of the creative technology employed in the Rogers Locomotive and Machine Company's shops is a fitting conclusion to this study. In the area of boiler construction, the generally accepted manner of fastening boiler plates together was a lap of the plates wide enough for application of a double row of rivets. This had evolved from the method of single riveting used on lower-pressure boilers (Roper 1888: 181). In 1852, Rogers enlarged the lap of boiler plates enough to add a third row of rivets, while applying a covering strip inside the plates for added strength (Forney 1886: 32).

Another general practice in boiler construction was the application of wrought-iron plates with the fibers of the wrought iron running in the direction of the greatest stress (Norris 1853: 240). "In making boilers with iron plates, Mr. Hudson always took great pains to have the plates of such sizes and proportions that the 'grain' or fibres of the iron around the barrel of the boiler would be in the direction to resist the greatest strain" (Forney 1886: 31).

With the invention of the two-wheeled leading truck and the advent of 2-6-0 locomotives, Hudson became involved in improving the two-wheeled truck. Two-wheeled trucks were constructed under the same general principles as four-wheeled trucks, except that the frame extended some distance behind the axle and the center pin was placed at the rear end, with the locomotive's weight resting over the axles (Forney 1890: 430). The early 2-6-0's were too light in the truck and frequently derailed (White 1968: 63-64). In 1864, Hudson devised a plan for equalizing the truck to the front drivers. His plan was successful and employed a heavy equalizer between the truck and the drivers on the engine's centerline. The front of the lever rested on the truck frame, and the other end was attached to a transverse bar connected to the front spring hangers (White 1968: 174).

Other specific examples of the Rogers shops ingenuity follow. (1) Driving wheel brakes were applied as early as 1872 (Hudson 1872: 5). Almost no other builder used brakes on locomotives before 1875, and only half the nation's locomotives had brakes by 1889 (White 1968: 184). (2) Cylinder jackets appeared on Rogers locomotives as early as 1843. Cylinders were insulated, thereby conserving steam and fuel (White 1968: 207). (3) Hudson experimented in 1859 with feed-water heaters to effect fuel economy (White 1968: 137-38). (4) Hudson designed a boring mill, built by William Sellers & Company and acquired by the Rogers Works in 1871. The mill could bore a 16 by 24-in. cylinder in eight hours (White 1968: 206).

The technological contributions of the Rogers shops cannot be compared with the development of locomotive-industrial technology as a whole. However, given the time span in which the Rogers innovations occurred, few other manufacturers approached the performance of these Paterson shops.

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