# The Making of a Legend — The Niagara Story

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(Continued from 3rd Quarter 1988 issue)

## Part VII
## Steam Locomotive Horsepower — Description and Measurement

There are more variables in the measurement of steam locomotive horsepower than in diesel or electric horsepower. In the steam era, the railroads who supported the most comprehensive test programs to measure steam locomotive performance, including horsepower, were the Pennsylvania Railroad and the New York Central.[73] Other railroads such as C&O, N&W, and Santa Fe ran dynamometer car tests, but the PRR and NYC were in the forefront of steam locomotive development and their efforts exceeded those of Alco, Baldwin and Lima.

All of the railroads which tested steam power used different techniques, and it is therefore difficult to compare maximum drawbar ratings of different steam locomotives. Differences in boiler evaporation due to the use of different grades of coal have been mentioned. Steam locomotives were custom machines, and were optimized for service on their home roads. There were differences in boiler construction, cylinder and driving wheel size for each wheel arrangement. There were some common laws of physics which applied to all steam locomotives, however. The maximum cylinder horsepower of any steam locomotive was determined by its boiler, and this in turn was a major indication of its drawbar horsepower, once losses to machinery, wind, and friction were subtracted. It was possible to overfire a steam locomotive boiler to obtain greater evaporation, and therefore greater cylinder horsepower.

### A) Cole Ratios

Up to the development of the mechanical stoker, the standarized firing rate for steam locomotives was 100 lbs. of coal per square foot of grate per hour. The Cole ratios for boiler horsepower performance were based on this standardized firing rate.[74] With the development of the mechanical stoker, firing rates in excess of 200 lbs./square foot/hour were possible, and steam designs were greatly enlarged to capitalize on the ability to sustain this greater firing rate. It may be said that this design trend forced the adoption of the four-wheel and eventually the six-wheel trailing truck. When a steam locomotive boiler was overfired, its evaporation rate increased, but at a great increase in coal consumption, effectively reducing boiler efficiency.[75]

### B) W. F. Collins Drafting Arrangement

The enlargement of heating surfaces and advances in superheating were not matched by refinements to improve boiler drafting, however. This subject was first addressed by New York Central in stationary boiler tests at Selkirk, New York in 1938 and 1940. During these tests, W. F. Collins, Engineer of Tests for NYC devised a way to test the steaming capacity of a boiler by using what he described as a "desuperheating" method.[76] This method, described in the Fourth Quarter 1983 edition of the **"Central Headlight,"** used sprays of water in the cylinders of the engine on stationary tests to closely approximate the volume of steam delivery to the exhaust nozzle which would occur in full capacity, over-the-road testing. In this way the smokebox design and its ability to draft the boiler could be improved. Up to this time, the smokebox proportions, the size of the table plate and the exhaust nozzle, their shapes and their relation to one another were largely guesswork. The first locomotives to benefit from these tests were the NYC Hudsons. There is no indication that any other railroad utilized this knowledge. For example, reference is made by Ralph Johnson that the front ends of the first two PRR T-1's had to be modified after they were placed in service to enable them to steam properly.[77]

### C) Flue Size and Effect on Performance

At about this time, additional work was being done to reduce the back pressure through the flues, probably as a result of the increased use of the Type E superheater in place of the Type A. A two-pass Type E superheater occupied a large part of the volume of each flue, restricting the passage of exhaust gases, increasing back pressure, and reducing drawbar horsepower. This was not a problem with short flues or nominal firing rates, but back pressure did increase drastically during periods of high boiler demand. Both Ralph Johnson of Baldwin and Paul Kiefer recognized this during the design phase of the PRR T-1's and the Niagaras respectively.

### D) Net Gas Area and Hydraulic Depth

The unit of measurement of the resistance of the gases to flow through the flues is known as hydraulic depth.[78] This resistance to gas flow was also known to R. J. VanMeter of The Superheater Company, who recommended the installation of four-inch diameter flues in place of the 3½-inch flues on the Santa Fe Class 5011 2-10-4's in 1942. Advantages claimed by VanMeter included lower gas restriction and a twenty-five degree increase in steam temperature.[79] There was only a handful of two-cylinder engines which ever received four-inch flues, including five different 4-8-4's,[80] and only one of the five utilized an advanced smokebox design to capitalize on the use of these larger flues and an enormous direct heating surface. The Western Maryland 4-8-4's, built in 1947, had four-inch flues and 573 square feet of direct heating surface, but 21-foot-long tubes and a standard smokebox arrangement. The other engine was the New York Central Niagara, with four-inch flues, an advanced smokebox design, and 499 square feet of direct heating surface. There were other 4-8-4's with more gas area through the boiler than the Niagaras, but the Niagaras had the lowest **restriction** to the gas flow, and therefore the lowest pressure drops and back pressure. The goal was to maximize the gas area through the flues while minimizing the energy loss through them. The table at the top of page 14 lists the gas area through the flues of several 4-8-4's and 4-4-4-4's:[81]

| RR | Type | Class | Net Gas Area (square feet) |
|---|---|---|---|
| NYC | 4-8-4 | S1b | 10.57 |
| PRR | 4-4-4-4 | 6110 | 10.61 |
| PRR | 4-4-4-4 | T1 | 9.55 |
| WM | 4-8-4 | J1 | 10.80 |
| N&W | 4-8-4 | J | 10.80 |

While there were several engines with more gas area, the flue system of the Niagaras had lower restriction due to its fewer, larger flues, with less wall surface to rob the energy from the exhaust gases.

The low back pressure gave this boiler the potential to provide significantly greater volumes of steam to the cylinders and therefore higher cylinder horsepower. W. F. Collins of New York Central discovered the key to higher cylinder horsepower in 1940.

**E) Wind Tunnel Testing for Smoke Trailing**

In 1947, J. R. Griffin, Chief Engineer of The Superheater Company, authored an ASME paper on the subject of "Streamlining Effect of Air Resistance and Smoke Lifting on Steam Locomotives." His paper addressed the problem of smoke trailing on steam locomotives, that is, the problem of smoke curling around the cab and obstructing the vision of the engineer and fireman. The traditional approach to solving this problem was to decrease the diameter of the exhaust tip, but this increased exhaust pressure and decreased cylinder horsepower. A one-twelfth scale model of a NYC Niagara was constructed of wood and tested in the wind tunnel at the Daniel Guggenheim School of Aeronautics at New York University. Various types of streamlining were tried, as well as the smoke deflectors with which the engine was outfitted, and no deflectors at all. Scale speeds were 60 mph and 100 mph, with winds from different directions. There were several interesting conclusions:

- The traditional smoke deflectors were quite effective in preventing smoke trailing.
- The bare locomotive had considerably higher wind resistance than any of the streamlined models tested and showed up poorly when compared with all other models from a smoke lifting standpoint.
- At a rate of 90,000 lbs. of steam per hour exhausted from the stack, a total of 850 horsepower was used to draft the locomotive. Of this, only 290 horsepower was used to move the products of combustion out of the boiler and the remainder, 560 horsepower or 66 percent of the total was used in imparting velocity to the mixture.
- At 100 miles per hour, drawbar horsepower was increased 9.1 percent with streamlining as opposed to the non-streamlined model.
- The smoke deflectors absorbed 16 horsepower at 60 mph and 60 horsepower at 100 mph.

Griffin concluded that streamlining the locomotive would increase its drawbar horsepower 9.1 percent at 100 mph. He also concluded that streamlining the locomotive would permit a further enlargement of the exhaust nozzle, freeing up almost 400 more horsepower used to impart velocity to the exhaust gases. This 400 horsepower would be available at the drawbar.[82]

## Part VIII
## THE NIAGARA AND ITS CONTEMPORARIES

In the measurement and rating of the horsepower of steam locomotives there are various horsepower terms used, including boiler horsepower, indicated horsepower, cylinder horsepower, rail horsepower, and drawbar horsepower. Some of these horsepower figures cannot be directly measured, but are derived from the laws of physics and thermodynamics. Additionally, because of losses within the steam locomotive such as drafting and friction losses, and from losses external to the locomotive such as wind resistance, these horsepower figures "peak" at different speeds. There are factors which affect the speeds, in turn, and these include cylinder size and driving wheel diameter. The figure on page 15 attempts to calculate the horsepower in the different portions of the locomotive "system," using a Niagara as an example.

It is difficult to appreciate the quantum performance improvement provided by a big 4-8-4 compared with other power on most railroad rosters.

**A) J3a Hudson vs. NKP Berkshire**

For example, a New York Central J3a Hudson had approximately the same heating surface as a NKP 700-series 2-8-4, in spite of an engine weight of 360,000 lbs. for the Hudson and 444,000 lbs. for the Berkshire. In terms of drawbar horsepower, both engines were in the 3900-4100 horsepower range (3880 hp for the J-3[87] vs. 3915 hp average maximum for the 2-8-4.[88] The slightly larger boiler (and boiler horsepower) of the Berk was offset by the reduced machinery and engine weight of the Hudson so that the drawbar horsepower of each engine was about the same. (The **speeds** at which each developed its peak drawbar horsepower were quite different, 62 miles per hour for the J3a and about 40 miles per hour for the NKP 700, due mainly to the differences in cylinder swept volume and driving wheel size.) Compare the capacity of these locomotives with a 6000. The Niagara produced more drawbar horsepower at 30 mph than the J3a could produce at its maximum! A Niagara produced over 4000 drawbar horsepower from 31 miles per hour to 100 miles per hour, and over 4500 drawbar horsepower from 38 mph to 88 mph. The Niagara also produced, with 275 psi, over 5000 drawbar horsepower from 52 mph to 72 mph.[89] The productivity of these locomotives was limited by timetable speed restrictions, not by hauling capacity.

**B) Niagara vs. N&W J Class Comparison**

The U.S. 4-8-4 wheel arrangement had many excellent and a few truly outstanding designs. The figure on page 16 reproduces the drawbar pull and drawbar horsepower curves which permit a comparison of the New York Central Niagara and the Class J 4-8-4 of the Norfolk and Western, another outstanding 4-8-4 design. The J class engine, designed for N&W topography and speed limits, produced more drawbar horsepower up to 50 mph, with the Niagara having the edge at all speeds in excess of 50 mph. **The N&W J had 1000 less drawbar horsepower than a Niagara at 100 mph.**[90] The N&W J with 300 psi boiler pressure was rated at 80,000 lbs. starting tractive effort. However, a review of the dimensions of the N&W J, with 288,000 lbs. on drivers, shows that the J would have to be able to maintain almost 28 percent adhesion to exert 80,000 lbs.

**C) Tractive Effort and Adhesion Compared**

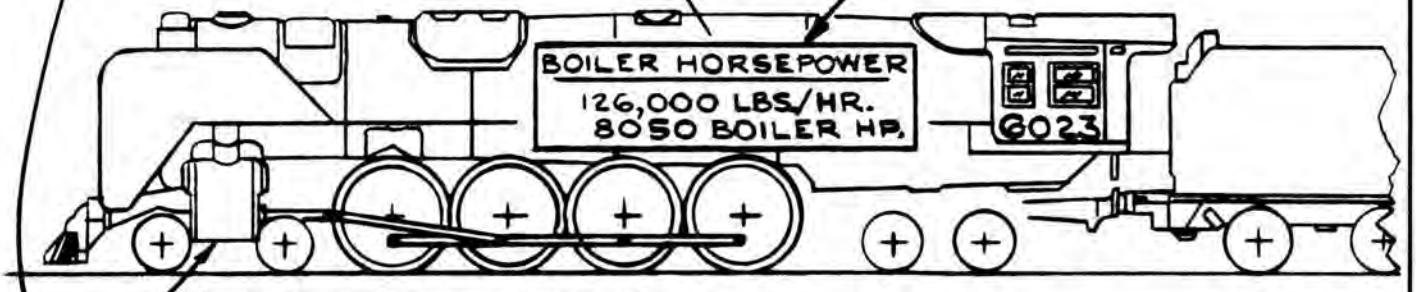
The chart at the top of page 17 tabulates the adhesive weight and tractive force of other large 4-8-4's, and some other passenger locomotives.[91] The highest adhesion level for any passenger engine (other than the N&W J) is 24.2 percent, while the J is fifteen percent higher at 27.8

## SUBTRACT: (83)

- HORSEPOWER USE TO "DRAFT" BOILER (850 HP @ 90,000 #-STEAM/HR.)
- HORSEPOWER (I.E. STEAM) USED TO RUN AUXILIARIES (FEED-PUMP, TURBOGEN., BLOWER, ETC.)
- PRESSURE DROPS HEAT LOSSES IN THE PIPES AND
- BOILER HEAT LOSS TO ATMOSPHERE 28% (84)

RESULTS IN

START HERE




6680 CYLINDER HP.*
@ 85 M.P.H.

*ALSO CALLED "INDICATED" HORSEPOWER MEASURED WITH AN INDICATOR CARD

## SUBTRACT:

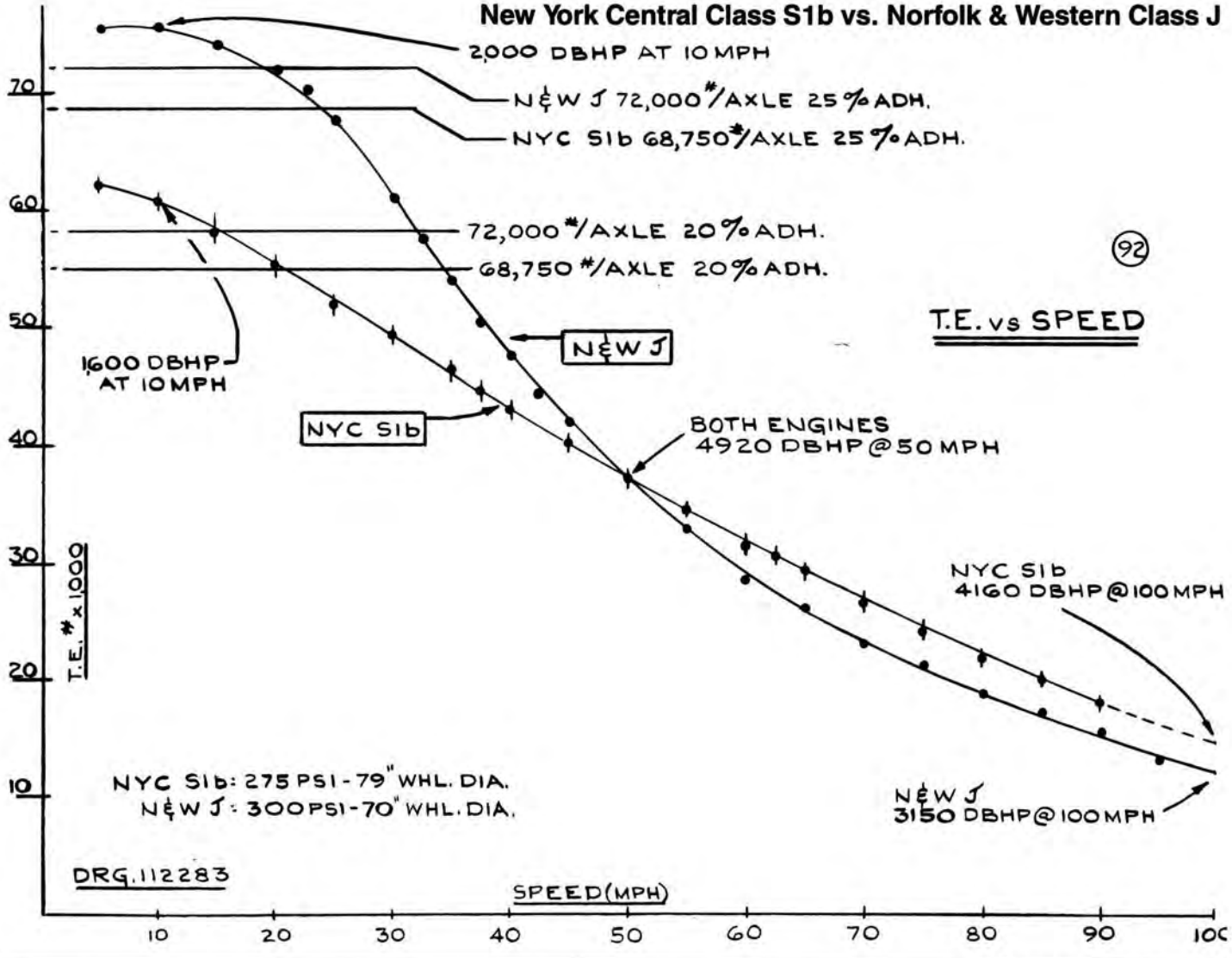
| | @ 85 MPH | @ 62.5 MPH | |
|---|---|---|---|
| - HORSEPOWER NECESSARY TO MOVE ENGINE & TENDER INCLUDING: WIND RESISTANCE, FLANGE & JOURNAL FRICTION | 1190 | 580 | (85) |
| - VALVE GEAR - H.P. TO OPERATE | 160 | 160 | (86) |
| - MACHINE FRICTION NOT INCL. VALVE GEAR | 700 | 680 | |
| - RADIATION LOSSES & PRESSURE DROPS IN CYLS. | 50 | 190 | |
| | 4580 | 5070 | |

DRAWBAR HORSEPOWER AVAILABLE AT REAR OF TENDER (1) (2)

(1) THIS IS MEASURED BY A HYDRAULIC OR ELECTRONIC SENSOR AT THE COUPLER IN POUNDS. (A LOCOMOTIVE WITH 30,000 LBS. DRAWBAR PULL AT THE COUPLER AT 37.5 MPH HAS 3000 DRAWBAR HORSEPOWER) THIS IS THE ONLY MEASUREMENT OF USEFUL WORK.

(2) ALL CALCULATIONS ASSUME ENGINE & TRAIN ARE ON LEVEL, TANGENT TRACK AT CONSTANT SPEEDS.

## New York Central Class S1b vs. Norfolk & Western Class J





**Class S1b No. 6001 at Chicago, Illinois, December 5, 1954. Photo from Joseph Brauner collection.**

# Calculated Tractive Effort and Adhesion[91]
# Northern Type and 4-4-4-4 Steam Locomotives and other Steam Designs

| Railroad<br>4-8-4 Types | Road Nos. | Weight on Driving Wheels & Booster if Equipped (lbs.) | Calculated Starting Tractive Effort (lbs.) | Percent Adhesion |
|---|---|---|---|---|
| New York Central | 6001-25 | 275000 | 61500 | 22.4% |
| Chesapeake & Ohio | 610-14 | 282400 * | 68300 * | 24.2% |
| | | 61000 B | 12400 B | 20.3% |
| | | 343400 T | 80700 T | 23.5% |
| Norfolk & Western | 600-613 | 288000 | 80000 | **27.8% C** |
| Pennsylvania | A 5500-49 | 270000 | 65000 | 24.1% |
| Santa Fe | 2900-29 | 293860 | 66000 | 22.5% |
| Southern Pacific | 4430-57 | 275700 | 64760 | 23.5% |
| | | 61400 B | 13000 B | 21.2% |
| | | 337100 T | 77760 T | 23.1% |
| Union Pacific | 835-44 | 270300 | 63800 | 23.6% |
| Western Maryland | 1401-09 | 290000 | 70600 | 24.3%[92] |
| **OTHER TYPES** | | | | |
| Chesapeake & Ohio 4-6-4 | 310-314 | 219500 | 52100 | 23.7%[93] |
| | | 64250 B | 12600 B | 19.6% |
| | | 283750 T | 64700 T | 22.8% |
| New York Central 4-6-4 | 5405-50 | 196000 | 43440 | 22.2% |
| | | 53800 B | 12100 B | 22.5% |
| | | 249800 T | 55540 T | 22.2% |
| Santa Fe 4-6-4 | 3460-65 | 213440 | 49300 | 23.1% |
| Pennsylvania 4-6-2 | 5400-75 | 201830 | 44460 | 22.0% |

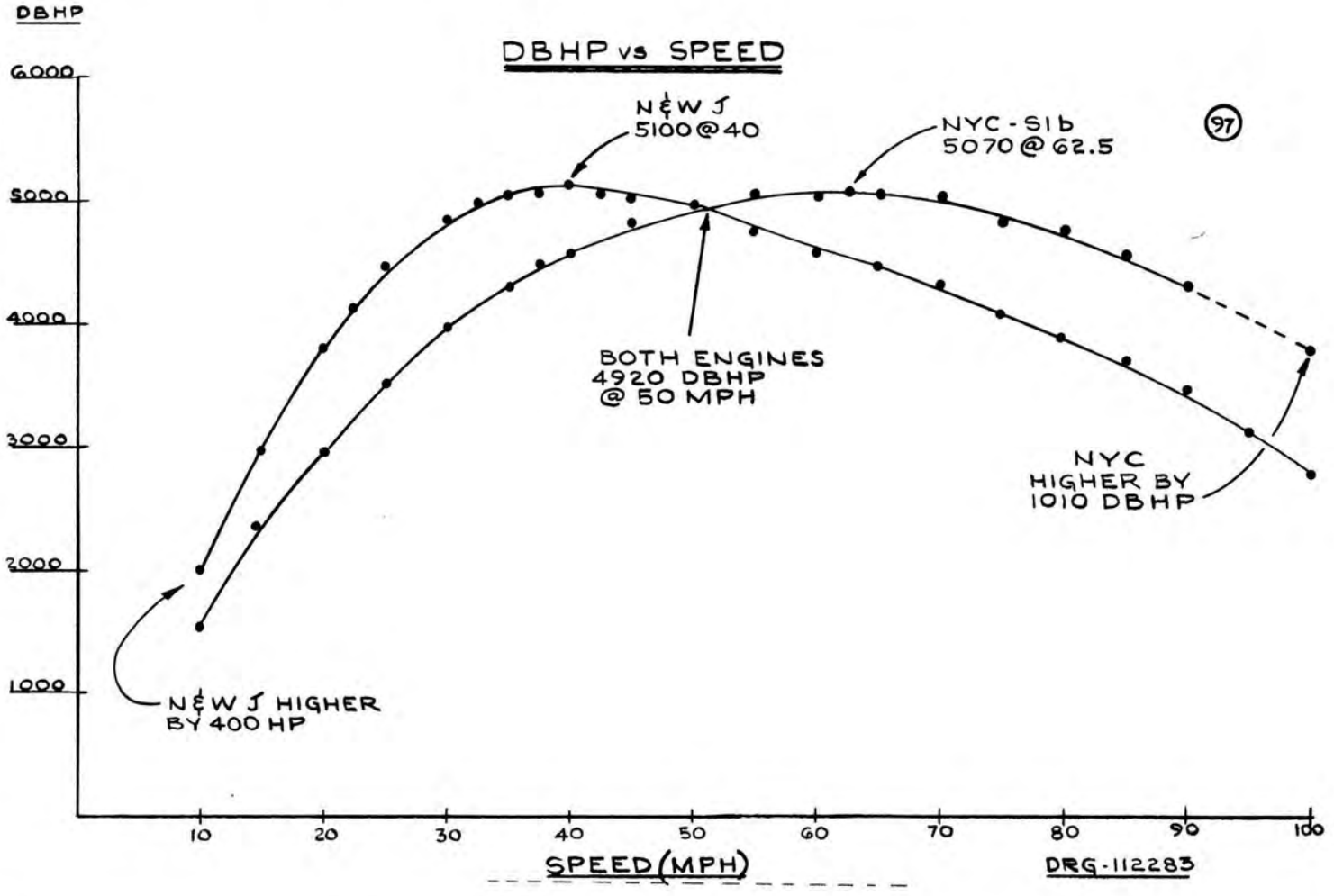
A =4-4-4-4 type comparable in capacity to 4-8-4
* = Weight on drivers variously given as 282,400; 285,200; or 290,000.
Tractive effort given as 66450 or 68300; driving Whl. Dia. 72″ or 74″[93]
B = Data for bosster axle weight and tractive effort
T = Total adhesive weight for main engine and booster
C = Adhesion level not consistently achievable, see comments

# Calculated Tractive Effort and Adhesion[94]
# Sample of Large Freight Locomotives

| Railroad | Road Nos. | Weight on Driving Wheels | Calculated Starting Tractive Effort (lbs.) | Percent Adhesion |
|---|---|---|---|---|
| Baltimore & Ohio 2-8-8-4 | 7600-29 | 485000 | 115000 | 23.7% |
| Chesapeake & Ohio 2-6-6-6 | 1600-59 | 504000 | 110200 | 21.9% |
| Chesapeake & Ohio 2-8-4 | 2750-59 | 293100 | 69350 | 23.7% |
| | | 64040 B @ | 14000 B | 21.9% |
| | | 357140 T | 83350 T | 23.3% |
| Chesapeake & Ohio 2-10-4 | 3000-39 | 373000 | 91584 | 24.6% |
| Nickel Plate 2-8-4 | 770-79 | 266030 | 64100 | 24.1% |
| Norfolk & Western 2-6-6-4 | 1240-42 | 432350 | 114000 | **26.4% C** |
| Norfolk & Western 2-8-8-2 | 2171-87 | 522850 | 152206 S | **29.1% C** |
| Santa Fe 2-10-4 | 5011-35 | 380300 | 93000 | 24.5% |
| Southern Pacific 4-8-8-2 | 4177-4294 | 531700 | 124300 | 23.4% |
| Pennsylvania 2-10-4 | J1 | 379493 | 95100 | 25.1% |
| | | 65923 B @ | 15000 B | 22.8% |
| | | 445416 T | 110100 T | 24.7% |
| Pennsylvania 4-4-6-4 | Q2 | 393000 | 100800 | 25.6% |
| | | 65025 B @ | 15000 B | 23.1% |
| | | 458025 T | 115800 T | 25.3% |
| Union Pacific 4-6-6-4 | 3950-69 | 404000 | 97350 | 24.1% |
| Union Pacific 4-8-8-4 | 4000-24 | 540000 | 135375 | 25.1% |

@ = Est. based on 50% of weight on trailing truck
T = Total
B = Data for booster axle
S = Simple operation yielding highest tractive effort
C = Adhesion level not consistently achievable, see comments

## New York Central Class S1b vs. Norfolk & Western Class J




**Class S1b No. 6002 leaving Harmon, N.Y. with train No. 15, the "Ohio State Limited," August 1946. Photo from Cal's Classics.**

cent. A more realistic maximum starting tractive effort for the J would be 72,000 lbs. at 25.0 percent adhesion which would be consistent with the design practice for other major users of 4-8-4's. It is interesting to note that the N&W J class was designed and the first ones were built and operated at 275 psi boiler pressure. At this pressure the tractive effort was 72,000 lbs., certainly more consistent and more achievable as an all-weather adhesion.

The N&W Railway was alone in their approach to locomotive design for tractive effort, but at unrealistic adhesion levels. The table at the bottom of page 17 reproduces the critical dimensions of some other notable steam locomotive designs from a variety of railroads,[94] including C&O which also served N&W territory. Without exception, all other railroad designs were based on adhesion levels of less than 24.6 percent. The N&W A with 300 psi supposedly was capable of 26.4 percent adhesion and the N&W Y was capable of 29.1 percent. The first N&W Class A engines were designed for 275 psi and the calculated starting tractive effort was 104,500 lbs.[95] consistent with realizable adhesions of other engines. It should be noted that on good dry rail with sand, adhesion levels higher than 25 percent are achievable. All-weather adhesion in the steam age was substantially less than twenty-five percent,[96] however, and most railroads dispatched trains and assigned tonnage at adhesion levels of 18 percent. PRR assigned power at adhesion levels of sixteen percent.

On a railroad with modest running speeds and plenty of curves, the use of oversize cylinders and smaller drivers was a good design approach, as long as adhesion limits were not exceeded. Engines designed this way exhibited good low speed acceleration and had low rail and flange wear. For N&W, economical use of steam was not a problem and there were no long sustained runs to limit locomotive fuel range. With low running speeds, reciprocating balance due to greater piston speeds and larger piston size and weight was not a problem. Summing up, the N&W J was a good design for N&W but could not compete with a NYC S1 Niagara in miles per month, availability, machinery wear, top speed, economical use of steam, or high speed drawbar horsepower performance. The graph on page 18 was developed from the actual NYC over-the-road testing of S1b No. 6023 in 1946. The N&W J curve was plotted from one issued by the N&W Engineer of Tests in 1946.[97]

Over the entire speed range from 0 to 90 mph, the NYC S1b and the N&W J at 300 psi are almost identical, with a slight edge in average drawbar horsepower of 0.5 percent in favor of the Niagara. The power vs. speeds are completely different, however, with the N&W J having a 400 horsepower advantage at 10 mph and the Niagara having a 1010 horsepower advantage at 100 miles per hour (4160 drawbar horsepower vs. 3150 drawbar horsepower.)

The NYC Niagara had one of the broadest, and the highest drawbar horsepower curves of any two-cylinder locomotive ever built. The increased drawbar horsepower of a Niagara over a J3a Hudson has been described, but the more you compare, the more you are impressed. The recorded maximum drawbar horsepower of a Santa Fe 5011 Class 2-10-4 was 5660 at 40 mph.[98] In test, the 6023 produced 5300 DBHP at 58 mph with 290 psi.[99] The Santa Fe engine had 74,000 lbs. more engine weight and 105,000 lbs. more weight on drivers than a 6000! An N&W Class A was credited with an hourly boiler evaporation of 116,000 lbs. per hour;[100] the 6000 evaporated 157,000 lbs. per hour!

In particular, the high speed horsepower performance of a Niagara was exemplary. On the basis of published tests, there were only two production locomotives which had the ability to sustain 4000 DBHP at 100 miles per hour, the New York Central Niagara and the PRR T-1. At the time they were tested, the Niagaras substantially exceeded the performance of two EMD E7 diesels, and over a majority of the operating speed range they were the equal of three E7 diesels. (A three unit E7 diesel set was over 210 feet in length and weighed 960,000 lbs. A Niagara was 115'-5 9/16" long and weighed 891,000 lbs.) In terms of locomotive productivity, that of the Niagaras was among the highest ever recorded for two-cylinder steam power. On a train such as the 20th Century Limited, the Niagaras could generate almost 102,000 gross ton miles per train hour in traffic, and the Niagaras as a fleet exceeded 20,000 miles per month in this service. Compared with most other Northern type steam designs, the Niagara not only ran faster, it ran longer in terms of monthly mileage.

**D) Ranking of Various 4-8-4 Locomotives**

It is impossible to determine the performance of locomotives on the basis of their physical dimensions alone. However, it is possible to evaluate specific locomotives on the basis of design features. For example, any comparison of 4-8-4's must also consider the type of fuel used and its heat content, as well as the way the engine was changed or optimized to burn its fuel. The coal used in the Niagara road tests had an average heat value of 13,800 BTU's per pound.[101] In terms of its heat value, it was almost the same as the coal NYC used for its freight power with the single exception that it had a lower ash content. This lower ash content would be desirable for longer sustained running without the need to dump ashes and clean the fire, a prescription for passenger service. The PRR in its Altoona test plant tested its locomotives with coal described as a high-volatile, run-of-mine, from Westmoreland County, with all slack under 3/4 in. screened out. The coal had a calorific value of 14,123 BTU's per lb., and an ash content of 7.58 percent. This was the coal used during the test of the PRR T-1.[102] The eastern railroads used the highest quality coal, and the western roads the worst. For example, Union Pacific in its coal burners used coal having less than 12,000 BTU's per lb.[103]

Similarly, Northern Pacific used Rosebud coal with a large amount of moisture which required a very large heating surface to burn this low BTU coal with its high moisture content effectively.[104]

Several western roads used oil as fuel, and oil used in locomotives had a heat value between 18,500 and 19,300 BTU's per lb. The higher heat value of oil was offset by several disadvantages. Oil had to be atomized to be burned. Steam was used for this purpose, and up to 4 percent of the boiler's evaporative capacity was needed to atomize the oil. In addition, the burning oil did not spend enough time in the direct heating surface portion of the boiler, the firebox and combustion chamber, to completely affect this large radiant heating surface. Therefore, much of the heat release in the oil-burning boiler occurred in the flues. For this reason, oil-burning locomotives generally had higher superheat temperatures than coal burners, and more tube and flue surface. However, oil burners could not take full advantage of the fact that the direct heating surface could generate steam

# BOILER COMPARISONS
## 4-8-4 and 4-4-4-4 STEAM LOCOMOTIVES

| | NYC S-1a | NYC S-1b | N&W J | ATSF 3776 | UP FEF3 | C&O J3x | SP GS4 | WM J1 | PRR T1 |
|---|---|---|---|---|---|---|---|---|---|
| Steam Pressure | 275 (290) | 275 | 300 | 300 | 300 | 255 | 300 | 255 | 300 |
| Inside Dia (inches) | | | | | | | | | |
| First Course | 90 | 90 | 89 7/8 | 90 | 86 3/16 | **** | 86 | 92 | 89 3/4 |
| Second Course | Conical | Conical | Conical | **** | **** | **** | **** | Tapered | Tapered |
| Third Course | 98 1/8 | 98 1/8 | 100 1/4 | **** | **** | **** | **** | 99 11/16 | 98 1/16 |
| Outside Dia (inches) | | | | | | | | | |
| First Course | 96 1/8 | 96 1/8 | 92 | **** | **** | **** | **** | 94 1/8 | 91 1/2 |
| Second Course | 98 1/8 | 98 1/8 | Conical | **** | **** | **** | **** | Tapered | Tapered |
| Third Course | 100 | 100 | 102 | 102 | 100 | **** | **** | 102@ | 100 |
| Tubes-Qty | 55 | 55 | 63 | 52 | 58 | 62 | 49 | 42 | 184 |
| Dia | 2 1/4 | 2 1/4 | 2 1/4 | 2 1/4 | 5 1/2 | 2 1/4 | 2 1/4 | 2 1/4 | 2 1/4 |
| Length | **19-0** | **19-11** | 19-2 1/2 | 21-0 | 19-0 | 21-0 | 21-6 | 21-0 | 18-0 |
| Flues-Qty | 177 | 177 | 227 | 220 | 198 | 220 | 198 | 178 | 69 |
| Dia | **4** | **4** | 3 1/2 | 3 1/2 | 2 1/4 | 3 1/2 | 3 1/2 | 4 | 5 1/2 |
| Length | **19-0** | **19-11** | 19-2 1/2 | 21-0 | 19-0 | 21-0 | 21-6 | 21-0 | 18-0 |
| Combustion Chamber | | | | | | | | | |
| Length | 92 1/2 | 81 1/2 | 103 1/4 | 72 | 90 | 54 | 80 | 72 | 84 |
| Superheater | | | | | | | | | |
| Type | E | E | E | E | A | E | E | E | AS |
| Square Feet | 1977 | 2073 | 2177 | 2366 | 1400 | 2305 | 2086 | 2170 | 1680 |
| Feedwater Heater | **Worth 7SA** | **Worth 7SA** | Worth 6SA | Worth 6SA | **** | Hancock TA-1 | **** | Worth 6SAS | Hancock -7-A2 |
| Heating Surface (Sq Ft) | | | | | | | | | |
| Total Firebox | **517** | **499** | 578 | 459 | 512 | 480 | 385 | 573 | 499 |
| Tubes and Flues | 4115 | 4320 | 4693 | 4852 | 3782 | 4343 | 4502 | 4401 | 3719 |
| Superheater | 1977 | 2073 | 2177 | 2366 | 1400 | 2056 | 2086 | 2170 | 1680 |
| Total Evap + Superhtr | 6609 | 6892 | 7448 | 7677 | 5694 | 6879 | 6973 | 7144 | 5898 |
| Firebox | | | | | | | | | |
| Length-in | 151 1/16 | 151 1/16 | 146 1/32 | 143-3 | 150 1/3 | 150 | 127-1 | 150 1/8 | 138 |
| Width-in | 96 1/4 | 96 1/4 | 106 1/4 | 108 | 96 3/16 | 96 1/4 | 102-1 | 102 1/4 | 96 |
| Grate Area-Sq Ft | 101 | 101 | 107.7 | 108 | 100.2 | 100.3 | 90.4 | 106.7 | 92 |
| Smokebox Drafting Arrgt | **Selkirk** | **Selkirk** | — | Stack Exten | Double Stack | — | — | — | Double Stack |

Combination of larger flues and shorter tube length equalled lowest hydraulic depth, less back pressure, more gas energy, and greater drawbar horsepower.

Largest size feedwater heater used. Loco can be greatly overfired. Preheats water so boiler does not have to, increasing boiler evaporation.

Large direct heating surface over hottest part of fire vs other designs with direct surface forward in combustion chamber area, for increased evaporation.

Tuned exhaust system (Selkirk) with much larger exhaust passages (vs just more stack area) to reduce back pressure, resulting in need for smoke deflectors.

x = There are discrepancies between the 1952 Loco Cyc and C&O motive power book re heating surfaces and driving wheel diam. Figures shown are from the 1952 Loco Cyclopedia.

@ = 1952 Loco Cyc shows max boiler O.D. as 102". There are other references showing a 106" figure. The 102" figure is from the bare boiler drawing.

**Class S1b No. 6021 with train No. 35 at Broadway, Toledo, Ohio, May 1953. Photo by Jeremy Taylor.**

in the boiler between six and ten times faster than the tubes and flues could. Because of the strong draft in a locomotive boiler, a particle of coal (or oil) in a firebox had to burn in less than one-tenth of a second. The use of a combustion chamber in a locomotive, along with a brick arch to cause the gases to travel a longer path, permitted more burn time and increased boiler efficiency. Coal would "flame" quicker than oil, mainly due to its gases becoming incandescent, and released more of its heat in the direct heating surface of the boiler.[105] For all of these reasons, oil burners of equivalent overall size would have a lower steam generation rate than coal burners. Additionally, in an oil burner, the heat transfer through the flues was lower than for a coal-burning engine because the oil had a tendency to "coat" the flues. Buckets of sand were sifted through the firebox to "scour" the tube surfaces and remove this coating.[106]

Several Northern type locomotives which burned oil are included in the following comparisons. In spite of their dimensions, they do not appear to have exceeded the boiler evaporation rates of some of the eastern coal burners. The following assessment attempts to define the performance of the best designs of the steam era.

**ATSF 3776/2900 CLASS**

Prime candidate for stardom due to its size. Expansive design for generous clearances. Largest total evaporative and superheating surface of any 4-8-4, along with 300 psi steam pressure, but:

A "tube and flue" boiler, with tubes 21 feet long, and a Worthington 6-SA feedwater heater. Large heating surface may have been a requirement for bad water. Use of oil as fuel had the disadvantages outlined above. The design may have been over-cylindered for good economy at high speeds. During the dynamometer test on the last series of Santa Fe Northerns. No. 2919 recorded a maximum cylinder horsepower of 5600 and a maximum drawbar horsepower of 4590.[107] This figure would have increased with the addition of Timken roller-bearing rods with which these engines were equipped after World War II. They were excellent locomotives, but their size and the use of oil for fuel placed them at a disadvantage with regard to peak drawbar horsepower. Rank: 3.

**UP FEF3**

Excellent mechanical design. Has 300 psi and a large direct heating surface of 518 square feet, along with a double stack to reduce pressure drop and improve draft, but:

This engine was designed to burn coal, but UP coal had only about 12,000 BTU's/lb., limiting the potential of this (and other) UP engines. The UP 4-8-4's were ultimately converted to oil, with the handicaps to evaporation outlined above. This locomotive also had a Type A superheater with only 1400 square feet of heating area, and two different sizes of flues due to the use of the Type A superheater[108], resulting in lower superheat temperature. These engines did not have roller bearing side rods, indicating higher machinery friction and relatively lower peak drawbar horsepower. Maximum drawbar horsepower is not available, but is probably 4500 horsepower as a coal burner. Rank: 4 (tied with PRR T-1).

**SP GS4**

Good mechanical design, used 280 psi. (The two similar but roller-bearing-equipped GS5's ran at 300 psi.) Credited by SP with 5500 cylinder horsepower. Had a booster. But:

Smaller boiler than any other Northern compared in this analysis, and used oil as fuel. This engine had the longest tubes of the Northerns compared, 21 feet, 6 inches. This engine also had only 385 sq. ft. of firebox direct heating surface. (The design was essentially correct for the use of oil as a fuel.) Maximum drawbar horsepower not available, but probably close to 4100. Rank: 7.

**C&O J-3a[109]**

Excellent mechanical design, and built at a late date (1948) when most successful steam technology was available. C&O used good coal. This engine had a booster. The application of a booster on this locomotive gives it unexcelled low speed performance capability by providing over 83,350 lbs. tractive force at a low 23.3 percent adhesion level. This engine is very near a 2-10-4 at low speeds with the booster in operation. The boiler pressure was only 255 lbs., probably in the interests of low maintenance. But:

The only obvious handicap in this design was the use of the Hancock TA-1 exhaust steam injector in place of a feedwater heater. A feedwater heater increased the evaporation of a boiler by preheating the entering water so the boiler would not have to, thereby freeing up boiler capacity for greater evaporation. Maximum drawbar horsepower occurred at a lower speed due to the use of 74-inch driving wheels, compared with the horsepower peak of the ATSF, UP, and SP engines which had 80-inch driving wheels.

Drawbar horsepower not available, but probably close to 4500. Rank: 5.

**WM J-1**

Built late, so should have had all the improvements. Largest diameter boiler used on a 4-8-4, and a large firebox. The use of 69-inch drivers made it a good freighter. But:

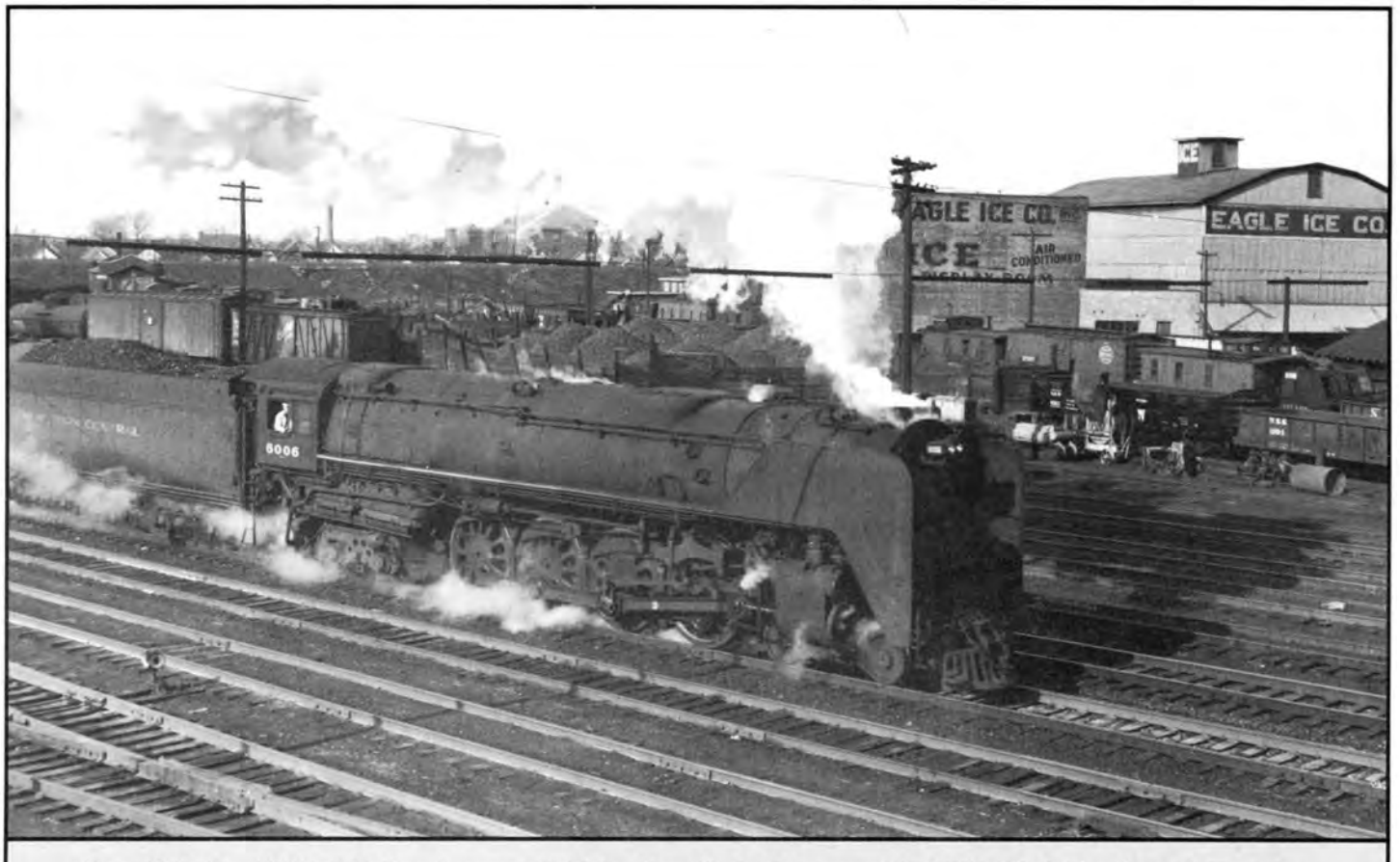
Low boiler pressure of 255 psi and 21 foot tubes, combined with a non-roller-bearing main and side rod arrangement, probably made this locomotive average in terms of drawbar horsepower. Baldwin credited this locomotive with 4300 drawbar horsepower.[110] Rank: 6.

**PRR T-1**

This engine is not a Northern, but in terms of boiler size and the application, the comparison is a fair one. This engine had 300 psi, a 100-inch O.D. boiler, and 18 foot tubes.[111] It had the same total direct heating surface as a NYC Niagara, probably due to its Belpaire firebox. But:

It had significantly less total tube and flue surface than any other engine in the comparison, and a Type A superheater, along with a Hancock 7-A-2 feedwater heater.[112] Its maximum boiler evaporation of 105,478 lbs.[113] places it in the evaporation range of a NYC L4 Mohawk, which evaporated 103,000 lbs. per hour.[114] (The L4 was measured at 4300 drawbar horsepower at 60 mph.)[115] The use of poppet valves on the T-1, along with four smaller cylinders which could be filled and evacuated with steam more quickly, would give it more horsepower at a substantially higher speed, and therefore excellent high-speed drawbar horsepower performance. PRR and Baldwin published Test Plant results of 6552 cylinder horsepower at 86 mph.[116] (The test plant also credits this engine with 6100 drawbar horsepower but this figure would not include wind resistance, tender weight and resistance, or flange friction. We do not know if the evaporation included auxiliaries.)


**Class S1b No. 6004 at Depew, New York, 1952. Photo by Joseph Brauner.**




**Class S1b No. 6006 at Bailey Avenue, Buffalo, New York, February 12, 1950. Photo by Joseph Brauner.**

This engine probably developed between 4500 and 4600 drawbar horsepower at or near 65 mph. The technical summary by Ralph Johnson of Baldwin quotes a drawbar horsepower of 4100 at the rear of the tender at 100 mph.[117] which supports the peak horsepower figure. The T-1 had severe operational problems due to the mechanical arrangement of its running gear, but this is not related to its boiler performance. Its drawbar horsepower performance may have been effected under low adhesion conditions, however. Rank: 4 (tied with UP FEF3).

**N&W J**

Prime candidate for stardom. This engine ran at 300 psi and had a 102-inch boiler. Tube length was 19'-2½",[118] and this engine had the largest value of direct heating surface of any engine in the table as the result of a 103¼" long combustion chamber.[119] But:

The boiler was a "tube and flue" design. There were 220 flues of 3½" diameter in this engine (vs. 177 4-inch diameter flues on a Niagara.)[120] N&W, during a series of dynamometer tests with the N&W A in 1936, reported a large pressure drop between boiler and steam chest, in spite of the use of 275 psi steam pressure.[121] The full use of 275 psi steam could not be realized, and working steam chest pressures as low as 220 psi were recorded in spite of the 275 psi gage pressure. The drawbar pull curve for the N&W J shows a significant fall off in high speed drawbar horsepower performance which cannot be attributed to driving wheel and cylinder size alone. At the speeds N&W normally ran, the limitations of front end arrangement of the boiler and its drafting may not have been encountered. This engine was equipped with a Worthington 6SA feedwater heater which had a capacity of 200 gallons per minute and 100,000 pounds per hour.[122] Given a margin of safety, N&W may not have expected this boiler to evaporate more than 100,000 lbs. per hour. This design was originally designed and built at 275 psi and at this pressure 4700 drawbar horsepower was developed. N&W reported a maximum of 5100 drawbar horsepower for this engine at 40 mph, with 300 psi.[123] A report exists that one of these engines on a special test reached 110 mph with a 1025 ton train. Using the W. J. Davis resistance formulas, we find that 3987 drawbar horsepower would be required to haul this train at 110 mph, and this figure does not include the power for the axle driven 20 kw axle driven generators used in those days for train lights and air conditioning. The published drawbar horsepower curve for an N&W J shows this engine capable of 3150 drawbar horsepower at 100 mph, far short of the horsepower required to attain 110 mph with this train on level tangent track. This engine is an excellent design and a good performer at low and moderate speeds, however. Rank: 2.

**NYC S1 NIAGARA**

Outstanding boiler design. Largest ratio of direct to total evaporative surface ever applied to a single expansion locomotive. **This engine was one of two in the comparisons to combine the use of a Type E superheater with a set of four-inch flues.** (All other engines in the tabulation used three-inch diameter flues with a Type E superheater, the only exception was the Western Maryland J1.) The use of four-inch diameter flues resulted in extraordinary gas flow through the boiler as a result of less flue restriction. The resistance of the flues to the passage of the gases of combustion depends upon the area of the openings through the flues and the hydraulic depth of the flues themselves. (Hydraulic depth is the cross sectional area of the flue divided by its gas swept perimeter.)[124] The use of this design concept, combined with the use of the large direct heating surface and the Selkirk front end developed by W. F. Collins in 1940, was an unbeatable combination. A boiler resulted which, when supported by **the largest size feedwater heater,** could be overfired to a very significant degree and yield very high evaporation. The steam passages were also oversize to reduce pressure drop to a minimum. This provided in principle, and was confirmed in test, to yield the highest **average** cylinder pressures in spite of having only 275 psi boiler pressure. **The Worthington 7SA feedwater heater, the largest offered by Worthington, could support a delivery of 135,000 lbs. per hour.**[125] This boiler was **designed** for 290 psi and the pressure was **reduced** in the interest of low maintenance cost and high mileage, as opposed to the N&W J which was designed for 275 psi and upgraded. **The flues of a Niagara were each 30.6 percent larger in cross sectional area than the 3½ inch flues used by other 4-8-4's with Type E superheaters, and their hydraulic depth was 9.6 percent better.** Although the combustion chamber of the S1b was only 81¼ inches in length, the **backhead of the Niagara boiler was nine inches taller** than the backhead of the N&W J.[126]

Additionally, the greatest portion of the direct heating surface of the Niagara boiler was directly over the firebed itself, where temperatures were highest. Other Northerns with longer combustion chambers had a significant portion of their direct heating surface "forward" in the boiler where mixture velocities were higher and temperatures were lower. The result of all these design concepts was an over the road evaporation rate of up to 117,000 lbs. and a published S1b evaporation rate of 126,000 lbs. per hour. The original S1a No. 6000 touted the heretofore unheard-of evaporation of 157,000 lbs. per hour at Selkirk.

Several fully documented drawbar horsepower tests exist for the S1b engines as follows:[127]

| | | | |
|---|---|---|---|
| 275 psi | 79 in drivers | 5050 DBHP* | @ 63 mph |
| 290 psi | 79 in drivers | 5300 DBHP | @ 63 mph |
| 275 psi | 75 in drivers | 5200 DBHP | @ 61 mph |

*The summary page of the technical report shows 5070 DBHP.

**The drawbar horsepower rating for S1b No. 6023 with 75 inch drivers is significant because it shows 500 more drawbar horsepower for this engine at 275 psi than that of the N&W J at 275 psi, and in spite of the greater horsepower required to move the Niagara at its drawbar horsepower peak of 61 mph than the streamlined J at its drawbar horsepower peak of 40 mph.**

In terms of boiler capability, we can "work backwards" to determine the probable boiler horsepower of the N&W J at 40 mph vs. the Niagara at 63 mph, the peak drawbar horsepower point with 79 inch drivers. Using the AAR resistance for level track, we can determine the difference in engine and tender resistance in pounds, and convert it to horsepower based on the speed of each engine. The N&W J has a resistance of about 220 horsepower to move engine and tender on level track,[128] excluding engine friction. The horsepower requirement to move the Niagara at 63 mph is approximately 560 horsepower,[129] due principally to its higher speed. The obvious conclusion is that the Niagara boiler is producing about 340 more cylinder horsepower at its peak than does the J


**Class S1b No. 6022 at Buffalo, New York, August 9, 1953. Note bell relocated at valve gear. Photo by Joseph Brauner.**


**Class S1b No. 6022 at Buffalo, New York, August 9, 1953. Note headlight generator relocated between third and fourth drivers. Photo by Joseph Brauner.**

at its peak, and disregarding the advantage of the N&W J due to its streamlining, which could have been worth up to 450 drawbar horsepower at 100 mph.[130]

The N&W J was (and is) a great engine, but it was narrowly optimized. It did not produce outstanding power or economy at high speeds, and it was incorrectly sized with regard to cylinder size and driving wheel size for low speeds, resulting in a much higher calculated starting tractive effort than could be consistently applied. In contrast, the proportions of the Niagara were such that it not only ran **fast,** it ran **long,** and with good economy.

Rank: 1 — and it's not even a contest . . .

## Part IX
## THE CHAMP AND THE ENIGMA

Paul Walter Kiefer quoted a maximum drawbar horsepower of 5300 for No. 6023 on over-the-road test under average operating conditions, using 79-inch drivers and 290 psi.[131] Yet we know from the Technical Summary that the boiler of S1a No. 6000 was approximately 7 percent **better** than that of No. 6023 in terms of its evaporative potential. Its superheater was 2 percent **better,** and yielded steam chest temperatures 25 to 30 degrees **higher** than that of No. 6023. If No. 6000 was able to convert **only half** of its boiler evaporation superiority to drawbar horsepower, we arrive at a maximum drawbar horsepower of 5485 for this engine with 79-inch drivers and 290 psi. In support of this hypothesis, Arnold Haas quotes a maximum continuous drawbar horsepower figure of 5374 for S1b No. 6023 at 290 psi.[132]

On the basis of fully documented boiler tests, there is no doubt that S1a No. 6000 was the most powerful 4-8-4 ever built, in terms of maximum boiler evaporation, maximum cylinder horsepower, and maximum drawbar horsepower. It is also true, based on test results, that the S1b Niagaras ranked second only to S1a No. 6000, in terms of total equivalent boiler evaporation and in maximum cylinder horsepower. They are essentially tied with the N&W J in peak drawbar horsepower, principally because the drawbar horsepower peak of the Niagaras occurs at a speed 23 miles per hour higher than the J, where engine and tender resistance is higher.

In retrospect, the tests of S2a No. 5500 may have been a step backward. The combination of the boiler of the 6000 and the reduced losses in activating the poppet valves (vs. piston valves) of the S2a should have yielded the additional 80 horsepower per side to enable such an engine to produce 5500 drawbar horsepower. There are several sources of information that the Type A1 poppet valves of No. 5500 were designed for a nominal steam rate of 100,000 lbs. per hour. If true, this could be one reason why No. 5500 did not reach the peak of the S1b engines. What No. 5500 did accomplish was fuel economy almost 15 percent better than that of the piston valve engines. The efficiency of the poppet valve mechanism certainly could be credited with part of the savings, but a detailed look at the test results revealed other reasons. The only difference **within the boiler** between the 6023 and the 5500 was in the intake and exhaust passages, caused by the poppet valve design, yet the test results revealed that in terms of hourly evaporation and combined boiler efficiency, the boiler of No. 5500 **was closer in performance to the boiler of No. 6000 than to the boiler of No. 6023.** The only possible explanation for the superior boiler performance of No. 5500 over No. 6023 would be that the poppet valve steam and exhaust passages made the boiler perform differently. One possible explanation might be that the activation of automotive type inlet and exhaust valves "drafted" the boiler differently than piston valves. Another reason for the reduced peak horsepower performance could have been that the Selkirk front end arrangement was not optimized for the poppet valve system. No. 5500 may have been tested with the same #242 valve pilot cam as No. 6023. Yet we know that the behavior of the steam and exhaust events of a poppet valve engine are significantly different, and **better,** than those of a piston valve engine. This would tend to penalize the performance of No. 5500 in the tests, but would be overcome to some degree by good enginemen (and NYC had plenty) who could "feel" what cutoff was best for the engine in over-the-road service. In support of this theory, the test records indicate that during the dynamometer tests the effective cutoff was based on a Franklin Railway Supply drawing B-80143.

It is not difficult to conclude a possible drafting deficiency and incorrect adjustment of the cutoff for this engine, in addition to the possible undersizing of the poppet valve system itself, may have prevented No. 5500 from reaching its design target of 5500 drawbar horsepower.

On the basis of available information, it is clear that New York Central had within two of the three variations of Niagaras all the building blocks for the ultimate 4-8-4:

- A boiler on No. 6000 good for over 8000 boiler horsepower, and one which could deliver almost 7000 horsepower to the cylinders,
- An engine system on No. 5500 which could yield 5500 drawbar horsepower with 15 percent fuel savings, if valve pilot and drafting improvements were made,
- or, An engine on No. 5500 with no fuel advantage and, with a larger poppet system, that magical 6000 drawbar horsepower . . .

## Part X
## THE NIAGARA VS. OTHER LARGE LOCOMOTIVES

The conversion by a steam locomotive of its cylinder horsepower into drawbar horsepower depended on 1) its cylinder size, 2) its driving wheel size, 3) the friction in each engine, including pistons and rods, valve gear, and bearings, 4) the total weight of the engine and tender and its resistance to motion, including wind, journal, and flange resistance, and 5) the total number of cylinders to be supplied with steam.

Consider the percentage of indicated, or cylinder horsepower, converted to drawbar horsepower for each of the following locomotives, the speeds at which both peak indicated horsepower and peak drawbar horsepower occurred, and the published boiler evaporation for each.

### A) Cylinder and Drawbar Horsepower vs. Evaporation

| RR | Type | Cyl. Hp. | Speed | Drawbar Hp. | Speed | Evap. Lbs./Hr. |
|---|---|---|---|---|---|---|
| NYC | 4-6-4 | 4725 | 77 | 3880 | 59 | 96,000 |
| SF | 4-6-4 | 4375 | 75 | 3600 | 50 | — |
| SF | 4-8-4 | 5600 | — | 4590 | — | 125,000 |
| NYC | 4-8-4 | 6680 | 85 | 5070 | 62.4 | 125,000 |
| PRR | 4-4-4-4 | 6552 | 86 | — | — | 105,475 |
| SF | 2-10-4 | 6700 | — | 5660 | 40 | 90,000 |
| UP | 4-8-8-4 | 7500 | 45 | 6190 | 42 | 125,000 |
| N&W | 2-6-6-4 | — | — | 6300 | 45 | 116,000 |
| C&O | 2-6-6-6 | — | — | 7498 | 46 | — |

Class S1b No. 6003 with train No. 43 at Rochester, New York, February 1953. Photo by Jeremy Taylor.

Class S1b No. 6005 with train No. 421, at Cumminsville, Cincinnati, Ohio, June 1954. Photo by Jeremy Taylor.

**B) Analysis of Various Designs**

The New York Central and the Santa Fe Hudsons both converted over 82 percent of their cylinder horsepower to drawbar horsepower. (It is important to note that the peak boiler horsepower and peak drawbar horsepower occurred at different speeds.) Hudsons had relatively low engine and tender weight, only three coupled axles, and a relatively small amount of machinery to move, such as side rods, etc. The Santa Fe 2-10-4 converted almost 85 percent. Its large cylinders would yield a fat indicator diagram in spite of its 74-inch drivers, and its large cylinders would permit it to utilize a higher percent of boiler capacity at low speeds, where friction and wind resistance losses were lower. The 2-10-4 obviously had much less machinery than any of the four-cylinder locomotives. Conversely, the articulateds and the PRR T1 could take advantage of boiler capacity at low speeds by having four cylinders to fill. The T1 in particular was a balanced design in that it made the best use of its modest evaporation rate.

The large-drivered Santa Fe and NYC 4-8-4's have relatively low cylinder to peak drawbar horsepower conversion percentages, in the range of 76 to 79 percent. At the speeds at which cylinders become limiting, wind and flange resistances are a significant detractor. The engine part of a large 4-8-4 had to be designed for large piston thrusts. Rotating and reciprocating machinery was heavier, and there were four coupled axles. The goal for the designer of a four-coupled two-cylinder engine was to convert a greater percentage of its boiler and cylinder horsepower to drawbar horsepower. In this regard, the four-cylinder PRR engine and the use of poppet valves were the wave of the future . . . The four-cylinder locomotives were able to convert a high percentage of their cylinder horsepower to drawbar horsepower for several reasons:

- With much more cylinder volume and smaller drivers they reached their horsepower peak at a lower speed.
- Four cylinders with four piston valves can use much more steam from the boiler at low speeds than can a two-cylinder engine.
- At speeds of about 40 mph where four-cylinder locomotive drawbar horsepower peaked, the horsepower required to move the engine and tender was low.
- The machine friction of four sets of valve gear and rods, wheel sets, and other machinery was relatively low at 40 mph.

The Santa Fe 2-10-4 with 30 inch cylinders used its boiler capacity well at low speeds, and with less machinery its losses were lower than any four-cylinder locomotive. The result was 5660 drawbar horsepower. The New York Central Niagara had the same cylinder horsepower as the Santa Fe 2-10-4, but at a higher speed. With the same cylinder horsepower as the 2-10-4, the boiler performance of both engines was about equal. In terms of evaporation, the Niagara boiler is of the same capacity as the N&W Class A 2-6-6-4. The "A" is able to deliver significantly more drawbar horsepower because its critical dimensions are sized so it reaches its horsepower peak at low speed where all losses are lower. The Union Pacific "Big Boy" has drawbar horsepower potential similar to the N&W A. (No amount of design excellence can overcome the deficiency of poor coal.) The potential performance of the UP engine can be estimated by reviewing the figures for the C&O 2-6-6-6, which recorded a peak of 7498 drawbar horsepower with easily duplicated readings in the 6700-6900 range. Even if the UP engine used coal of a higher heating value, it probably could not have achieved the same drawbar horsepower as the C&O engine, which had over 720 cubic feet of direct heating volume by virtue of its large firebox over a six-wheel trailing truck.

One thing is certain. Even on an absolute basis, the Niagara boiler and drawbar horsepower performance requires no apology.

## Part XI
## WHAT MIGHT HAVE BEEN . . .

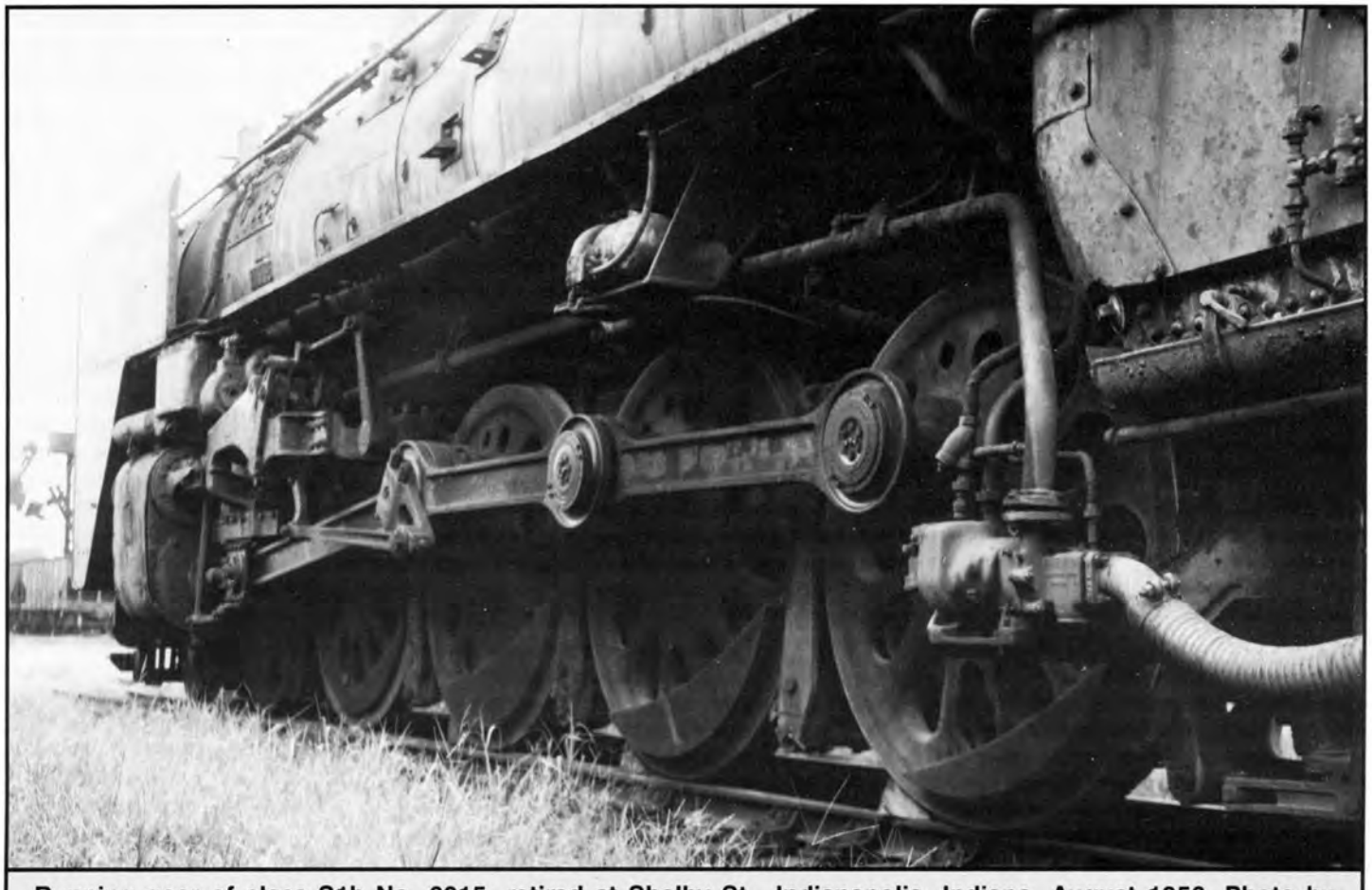
If the significance of the Niagara tests had been fully appreciated, and no decision had been made to dieselize, then the future course of steam development on the New York Central could have been charted. This is, of course, pure speculation. However, a sequence of events could have been anticipated as follows . . .

The performance problems of the PRR T-1's were well known by 1947, and the Central probably would have determined that divided drive engines had no future on NYC. The divided drive NYC Class C1a 4-4-4-4, sketched on a preliminary basis on 3/28/45, would not have been built. (The original Niagara was presented to the NYC on 3/10/45.) We can extrapolate that the Niagaras would have been developed, and it is not unreasonable to estimate a fleet of 50 or more as passenger engines. They would have had the boiler proportions of the original S1a No. 6000 based on its superior performance. The valve gear, however, would have been a refined version of the Franklin Type A sized to flow 150,000 lbs. of steam per hour. These engines probably would have had 79-inch drivers, but might have retained 275 psi steam pressure. S2b numbers 5501-5550 would have been capable of 6000 drawbar horsepower as the result of the successful combination of the S1a boiler and the improvements to the S2a valve gear. The tenders would have been a modified centipede and this, and the 15 to 18 percent economy improvement gained by the use of poppet valves, would have permitted a Harmon to Chicago tender with no coal stops. Minimum coal capacity would probably have been 57-60 tons based on one ton consumption per 15 miles and the 15 percent fuel economy improvement with poppet valves.

It is possible that, if freight power had been required, a 75-inch drivered version of the Niagara would have been built, in spite of the billing of the S1's as dual service engines. The wheel spacing would have been the same as the passenger engines, however, for driver diameter changes if warranted. (You will recall that Kiefer tested this design approach with S1a No. 6000.) If a passenger S2b already existed, the boiler of the freighter would have been identical. One change could have been in the tender. Depending on the weight, either a seven or eight axle design would probably have been applied, with no overflow vents and a different coal to water ratio.

The next step in this motive power evolution would probably have been a 4-8-6 or 4-10-6 wheel arrangement, depending on driver size, with smaller driving wheels — probably 75 inches — as a trade off to obtain as much furnace volume as possible with the firebox supported by a six-wheel trailing truck. This engine as a 4-10-6 would have weighed almost 600,000 lbs. and had 720 to 750 feet of firebox direct heating surface and a four-inch-larger diameter boiler if 75-inch wheels were used. It would have been a freight-only design. This engine would have had a driving wheel base of 26 feet, and for this reason alone the railroad would have had to

**Class S1b No. 6024 leaving Chicago, Illinois with train No. 28 in 1948. Photo by Jeremy Taylor**



**Running gear of class S1b No. 6015, retired at Shelby St., Indianapolis, Indiana, August 1956. Photo by Jeremy Taylor.**

seriously consider a 4-4-6-6 or 4-6-6-6 simple articulated as an alternative.

## Part XII
## THE NIAGARA - CHANGES OVER THE YEARS

### The Headlight

The most obvious change in the appearance of the Niagaras was the change to a twin sealed beam headlight. The exact date of this change is not available, but a one page article in **Railway Mechanical Engineer** indicates that the first change to a sealed beam twin lamp arrangement was made in October, 1947, and a photograph of J3a Hudson No. 5414 with the new headlight was included. A reasonable conclusion is that the Niagaras were changed after that date. Coincident with this change, the electrical conduit for the headlight which was on the smokebox was located to the engineer's side of the smokebox door, from the fireman's side.

### Feedwater Heater Cover

During their service lives the Niagaras ran with and without the feedwater heater covers with which they were built. There seems to be no reason for the removal (or reapplication) of these covers for the 7SA heaters located in front of the smoke stack.

### Sand Dome

At some time during their service, most if not all of the Niagaras had two vee-shaped drip lips added to each side of centerline of the broad, almost flat sand dome atop the boiler. The reason for this was to reduce the entrance of water into the sand supply. (A significant amount of the sand capacity was located in two aluminum sand boxes, one on each side of the engine, below the running boards in the vicinity of the valve gear yokes.)

### Headlight Generator

Some time after their construction, the Niagaras had their headlight generators relocated. The original location of the generator was on a frame-mounted bracket located between the trailing truck and the fourth driver on the engineer's side of the engine, with the exhaust piped to the ashpan. The new location was on the fireman's side, underside of the running board, on a bracket between the number three and number four drivers. Drawings for this change were prepared in April 1949.

### Bell

The original location of the bell on the Niagaras was on the engineer's side of the locomotive, behind the drop coupler pilot. The bell was later moved to the top of the valve gear yoke on the engineer's side of the engine. The drawing for this change was prepared in May 1950.

### Ashpan – Slide Rods and Pins

As indicated earlier in the review of maintenance of No. 5500 on March 5, 1947, new style ashpan-slide operating rods and pins were installed on this date. It is reasonable to assume that all of the Niagaras were updated.

### Front Air Pump Shield

On 3/5/47, four 3½ inch holes were drilled in the front air pump shield for access to the retaining bolts on the air cooler of No. 5500. Due to the ease of this modification, all Niagaras were probably modified within a very short time.

### Horn

A pneuphonic horn was installed on No. 5500 on 3/5/47. The drawing for this change was prepared in March 1946 and it is probable that all Niagaras had air horns applied within a short time after that date.

### Driving Spring Hangers

There was evidently a redesign made to the driving spring hangers of the Niagaras. In an earlier installment there are a few references to "driving spring hangers working out" and to "driver spring equalizer pins sheared off," particularly on engines 6007 and 6009 during the comparison tests of the six Niagaras and six diesels. The redesign of the hanger increased its lip depth to retain the driving wheel spring in its correct position. The 5500 had new hangers installed on 3/5/47.

### Automatic Blowdown

Main reservoir automatic drain valves (automatic blowdowns) were installed on No. 5500 on 3/5/47, and the installation was probably completed on all Niagaras shortly thereafter.

### Hot Water Delivery Pipe

A portion of the hot water delivery pipe (over the left cylinder) was flanged to permit its removal for easier access to the lubricator terminal checks on all Niagaras.

### Tapered Main Rods

A close inspection of several hundred Niagara photographs revealed that, at various times, a slightly tapered main rod was applied to locomotives 6000, 6009 and 6012. The detail drawing for the Niagara main rod notes that these are the original main rod set for the 6000. Although fully interchangeable, these rods did have to be maintained as a set.

### Trailing Truck

The trailing truck of the original S1a Niagara was designed for the application of a booster, and used a front wheelset of 36 inch wheels and a rear set of 44 inch wheels. The S1b's and the S2a used a trailer having two sets of 41 inch wheels, and a slightly revised brake cylinder arrangement. The newer trailer accommodated a different, and better, ash pan slope. With the retirement of the S2a, its trailing truck found its way to the 6000, and drawing records indicate the original S1a trailing truck was "no longer used" after May 1952. An April 1955 photograph, taken at Collinwood, shows the 6000 with the S2a trailing truck.

### Tender

Photographic documentation exists of S1a No. 6000 equipped with the tender from S2a No. 5500. Records of tender assignments in the 3rd Quarter 1985 **"Central Headlight"** article by H. L. Vail confirm this application.

### Paint/Lettering

On NYC tenders, the words "New York Central" were aligned with the engine number on the cab. On Niagara centipede tenders, this lettering was higher on the tender than on the centipede tender application on the Hudsons.

Several photos exist of Niagaras nearing completion of overhauls at Beech Grove shops in Indianapolis, Ind. On these engines, the wheels were not striped in white, but all the running gear including the wheels was painted in what appears to be a semi-gloss black.

Photos exist of Niagaras new or near new, and show a graphite smokebox with a range in shades from near white to medium gray. NYC men who remember the Niagaras recall that the smokebox color quickly became

very near the color of the boiler jacket, except that the smokebox was not shiny, but flat in color.

The cab interior of the Niagaras, as of August, 1953, was of tongue and groove wood construction. It was painted a fairly bright green (Spec. 1216 Locomotive Cab Enamel) similar to the BN green a modeler would use.

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**Class S1b No. 6016 with train No. 55 at Canastota, New York, 1953. Photo by Jeremy Taylor.**


**''Head of the Class'' class S1a Niagara No. 6000, the most powerful 4-8-4 ever built, at Harmon, N.Y., June 12, 1948. Photo by George Votava.**


**Class S1a No. 6000 at Cleveland, Ohio, June 16, 1945. Photo from Louis A. Marre collection.**