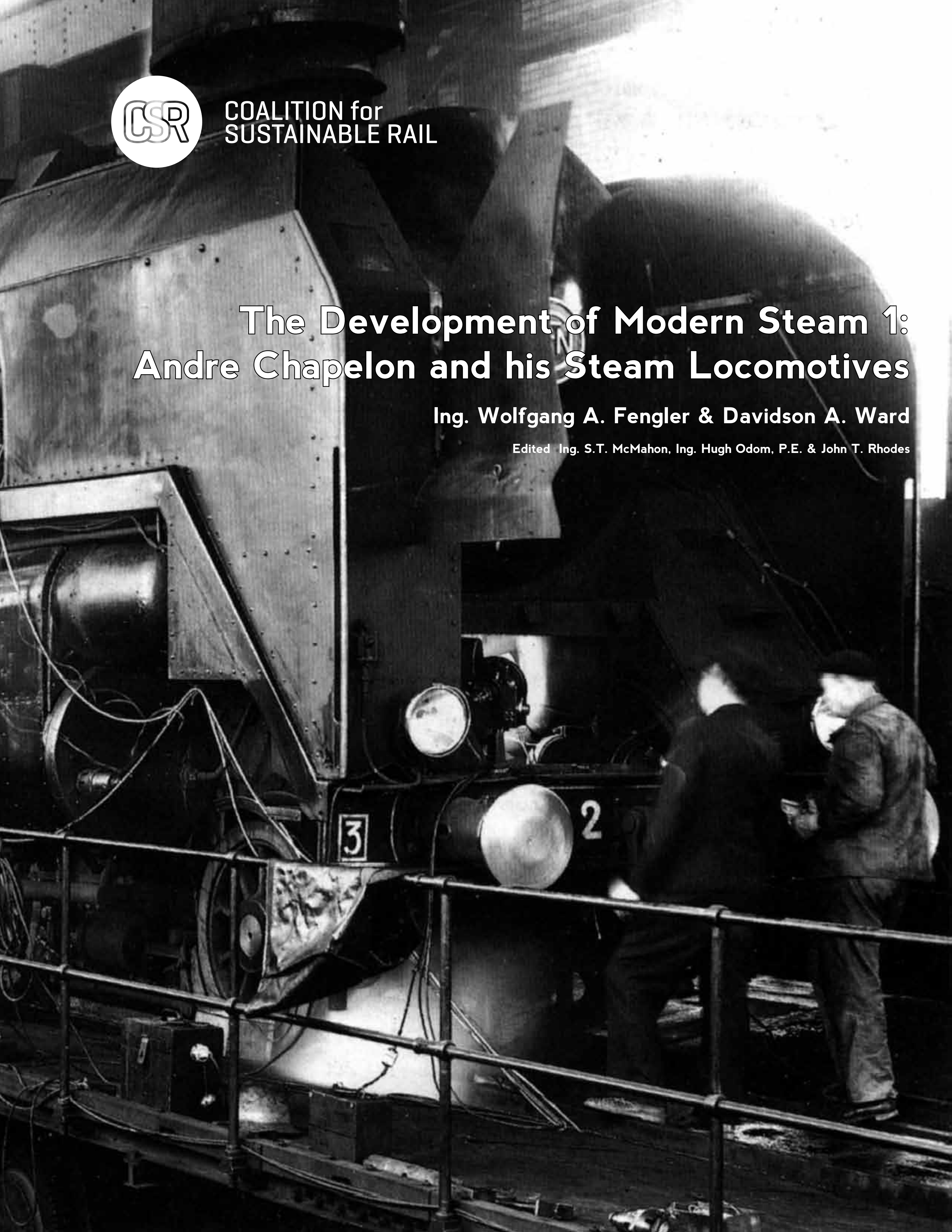
COALITION for SUSTAINABLE RAIL



The Development of Modern Steam 1: Andre Chapelon and his Steam Locomotives

Ing. Wolfgang A. Fengler & Davidson A. Ward

Edited Ing. S.T. McMahon, Ing. Hugh Odom, P.E. & John T. Rhodes

About the Coalition for Sustainable Rail

The Coalition for Sustainable Rail (CSR) is dedicated to the refinement of solid biofuel technologies for use in the world's first carbon-neutral higher speed locomotive. Our team is a combination of the University of Minnesota and Sustainable Rail International (SRI), a 501c(3) nonprofit dedicated to the research and development of modern steam locomotives. A scientific and educational organization, CSR's mission is to advance biofuel research and production; to research and develop sustainable railroad locomotives; to promulgate associated sustainable technologies; and to support and conduct non-partisan educational and informational activities to increase awareness of sustainable railroad locomotives.

About CSR's White Paper Program

Working in conjunction with the University of Minnesota (U of M), the Porta Family Foundation, and other not-for-profit rail and biomass research organizations, CSR's White Paper Program is bringing works pertinent to biofuel, modern steam locomotive and transportation research into the public discourse.

Cover Photo - *Chepelon's most advanced locomotive, a 5,000 horsepower 4-8-4 known as classification 141 A1, is run inside a large test facility on a roller dynamometer, gathering technical information pertaining to its power, fuel consumption and efficiency.* Image: Collection of Thierry Stora

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Foreword

Dear Reader:

The Coalition for Sustainable Rail (CSR) has invested significant time and effort into creation of its "White Paper Program" with the intent of providing significant bodies of information about the history, principles and viability of modern steam technology, advanced biofuel research and the union thereof. As 2013 comes to a close, CSR is venturing into completion of its most in-depth white paper series yet - a detailed history of the "Development of Modern Steam." This series will focus on the history and technological developments undertaken in Europe, South America, Africa and North America.

This first paper, "André Chapelon and his Steam Locomotives" focuses on the predecessor mechanical engineers of modern steam locomotives, primarily the French locomotive designer André Chapelon. The application of fluid and thermodynamics to the steam locomotive was most successfully undertaken by Chapelon on the Paris Orleans Railway and, once nationalized, the Société Nationale des Chemins de fer Français (SNCF). His understanding of the "steam circuit," the utilization of advanced front end exhausts paired with large steam passages and his successful utilization of "compounding," that is using steam more than once, were as successful in theory as they were in practice.

It is important to note that Chapelon and L.D. Porta were good friends, a transatlantic engineering collaboration that encouraged each other to produce quality work. Porta's development of the "Lempor" exhaust, as will be covered in later papers, is a direct outgrowth of the "Kylchap" exhaust discussed in this paper. Where Chapelon left off with combustion and boiler water treatment, however, Porta truly excelled.

CSR is thrilled to provide these papers as a resource, free of charge, to those interested in the technology, history and efficacy of its core research areas. The reader should feel free to forward this on to friends and colleagues, discuss it around the water cooler or whatever else they may be inspired to do.

That said, it is only through the support of donors that CSR can advance these resources and further its research into biofuels and advanced steam technology. Our 501c(3) not-for-profit allocates donors' money to advancing its mission, not paying any member of its all volunteer staff.

If, as you read this or our other materials, you feel inspired to support a grass roots advancement of modern steam technology, or you merely want to support future work, please do not hesitate to do so online or by mail: www.csrail.org/support.

Yours truly,

Davidson A. Ward
President

Summary:

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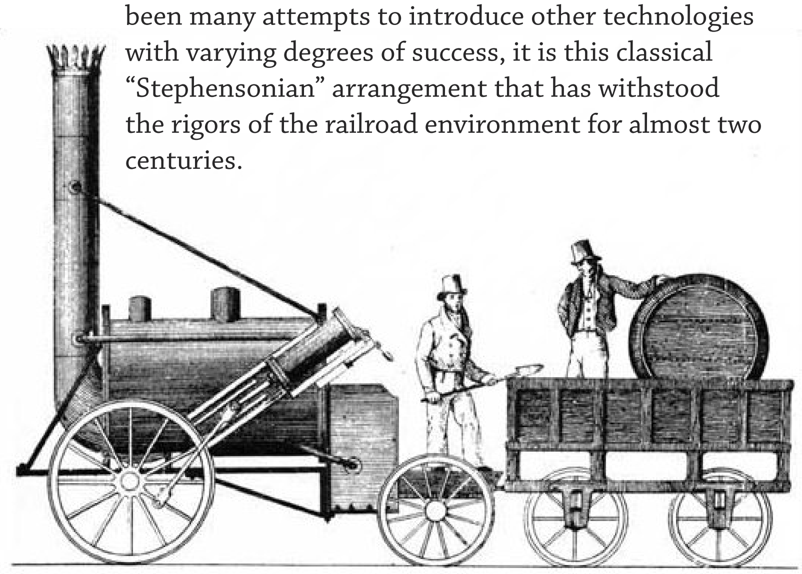
1. Introduction

While steam had been recognized for its potential to do work since ancient times, it was really Robert Stephenson's *Rocket* of 1829 [BELOW] that set the pattern for the vast majority of successful steam locomotives to come. *Rocket* included the now-familiar direct drive from cylinders to wheels, water-wall firebox, a multiple fire tube boiler barrel similar to Marc Séguin's 1827 design, and the use of exhaust steam exiting via a smokestack to pull air into the fire as an "induced draft" to facilitate more vigorous combustion.

The latter innovation was first introduced by Timothy Hackworth. In fact, the importance of using exhaust steam to induce the draft on the fire cannot be overstated as it instilled in the steam locomotive a natural self-regulating process. That is to say, the higher the demand for steam, the hotter the fire needed to be and the additional steam being used created the draft to make the fire yet hotter. While there have been many attempts to introduce other technologies with varying degrees of success, it is this classical "Stephensonian" arrangement that has withstood the rigors of the railroad environment for almost two centuries.



The latter 19th and early 20th Centuries saw great advances in both fluid mechanics and thermodynamics as evidenced by the still-foundational work of scientists such as Mach, Prandtl, Carnot, and Rankine. It was against this backdrop of innovation that the notable French mechanical engineer André Chapelon was born in 1892.

Following his graduation from university in 1921, Ing. Chapelon held several positions before joining the Paris Orleans Railway in 1925. A keen student of locomotive design history, Chapelon took careful note of the details of earlier successful designs. From the work of Thomas Russell Crampton, he recognized the benefits of steam pipes with large cross-sectional areas. Wilhelm Schmidt's work in superheating in the late 1800s was also an extremely important innovation he embraced as it enabled more of the energy from the fired fuel to be captured and transferred to the steam. Locomotives equipped with superheaters thus used less fuel and water and produced more power for a given steam pressure.

Proper boiler proportioning had been first recognized by J. E. M'Connell circa 1846 with additional contributions by J. F. McIntosh and A. Henry. Lastly, Gaston du Bousquet and Alfred de Glehn produced the first compound locomotive in 1891, just a year before Chapelon's birth. In a "simple" steam locomotive, the steam can only expand one time, with the amount of expansion being limited by the size of the cylinders. By contrast, a "compound" locomotive more fully extracts energy from the same steam by expanding it in smaller steps through several successive cylinders. The result is lower fuel and water consumption for a properly designed system.

While many of his contemporaries based their design work on "rules of thumb" or trial-and-error methods, Chapelon endeavored to use thermodynamics, instrumented testing, and the scientific method in his approach to improving steam locomotive performance. His best work was showcased in the rebuilding of five types of locomotives which resulted in remarkably performing fleets of 4-6-2, 4-8-0 and 2-8-2 locomotives as well as two experimental steam engines of 2-12-0, and 4-8-4 wheel arrangement.

Before describing in more detail the work performed and resulting improvements for each of the five, it is important to understand the environment in which Chapelon worked. First, the decision to electrify the

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Chapelon's first major project was the refitting of a 3500 class Pacific-type compound locomotive [LEFT]. In studying this class, Chapelon took careful note of their indicator diagrams [SEE BELOW]. These revealed significant throttling losses through the intake ports, excessive back pressure, and high pressure drop in the piping between high and low pressure cylinders. Despite superheating, the locomotives topped out at 2000 indicated horsepower.

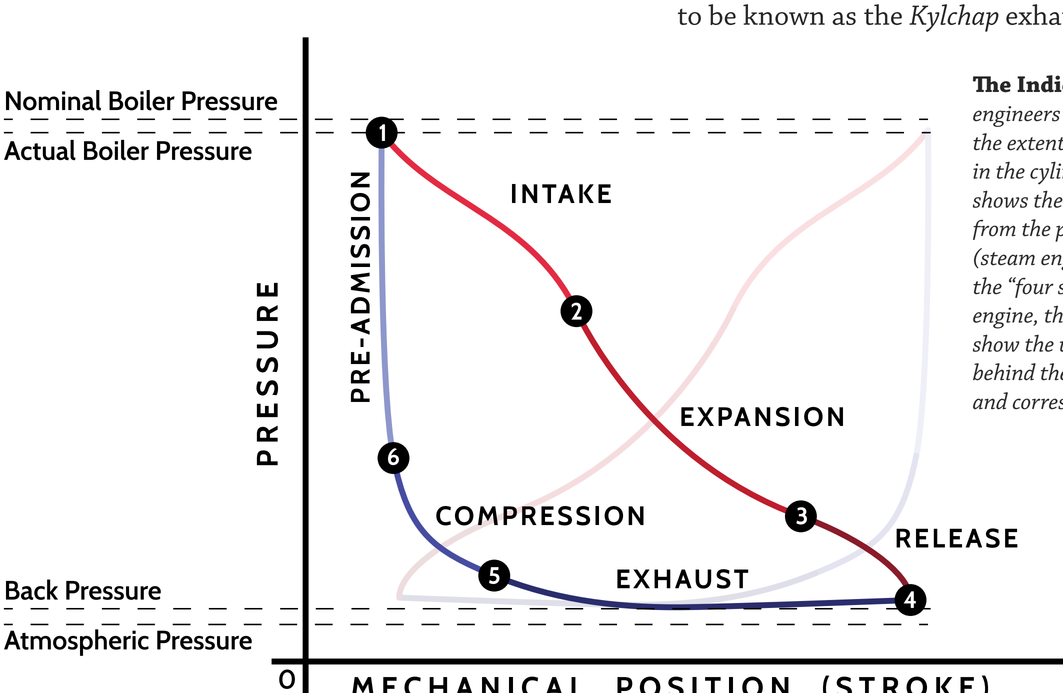
To address the back pressure issue, the cross-sectional area of the exhaust nozzle needed to be increased. However, if one were to simply enlarge the nozzle hole, the exiting velocity of the steam would decrease.

For the steam to create sufficient vacuum in the smokebox to draft the fire, it needed to exit the nozzles at a high speed. However, creating the vacuum was only part of the challenge. The exhaust steam need to not only create a draw on the fire, but since both the steam and exhaust gasses needed to exit the chimney, they had to be mixed together thoroughly and in a way that did not waste energy. In order to not waste energy, physics points to diffuser (chimney) dimensions which favor a taller, narrower stack. Unfortunately, a tall stack is difficult to achieve within the height restrictions placed on locomotives and is further complicated by a large diameter boiler barrel so typical of later steam locomotives.

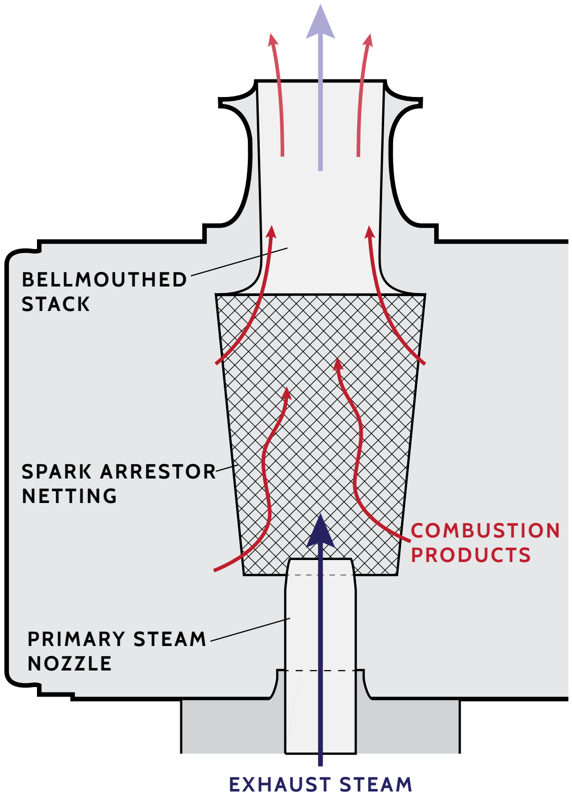
Not to be deterred, Chapelon, working with the Finnish engineer Kyösti Kylälä and building on some earlier work by Nozo, Geoffroy, and Legein, created what came to be known as the *Kylchap* exhaust.

French railways had already been made in the aftermath of World War I, although the justifications used for that decision were somewhat questionable. While the intent was to electrify, it was still recognized that steam was needed to support growing traffic demands which outpaced the rate of electrification. This is why Chapelon was allowed to work his magic – it was cheaper to upgrade existing locomotives than to pursue other options. Second, the various French railways were nationalized and combined into the SNCF system in 1938. Third, France declared war on the advancing Germans in 1939 and was itself invaded by Germany in 1940. Lastly, the post-war rebuilding of France included an accelerated electrification program, though again the economic justification was questionable.

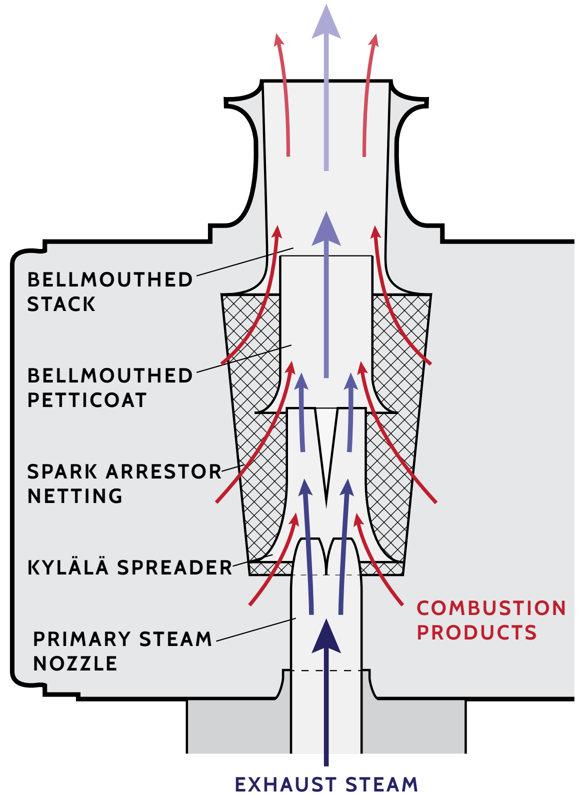
One can imagine the political and resource constraints at various levels associated with the above conditions which makes Chapelon's achievements all the more impressive.



The Indicator Diagram *Steam locomotive engineers used indicator diagrams to determine the extent to which steam was utilized effectively in the cylinders. The example diagram at left shows the six phases of the steam engine piston from the perspective of one side of one piston (steam engines are double-acting). Similar to the "four strokes" of a standard automobile engine, the six phases of the steam engine piston show the use and pressures of steam. Ghosted in behind the drawing is the other side of the piston and corresponding forces associated therewith.*



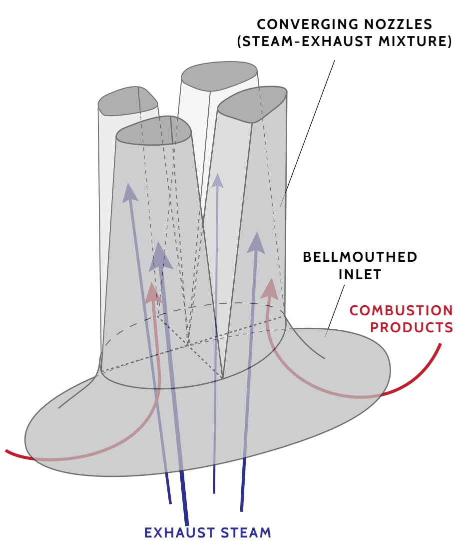
Standard Exhaust: *Traditional design of French steam locomotives had a steam nozzle on the bottom, and a bellmouthed stack at the top, of the smokebox. While this allowed easy access to the tubesheet, it did not provide optimal use.*



Kylchap Exhaust: *To get the greatest utility out of exhaust steam, Chapelon and Finnish engineer Kylälä devised a modern exhaust that optimized draft and minimized internal steam resistence.*

The Kylchap Exhaust included several notable features. The first was a petticoat divided into several smaller venturi-shaped sections. The concept was to create a more uniform vacuum across the boiler tubes and help the steam and exhaust mix better by doing the mixing in stages. The second was a streamlined splitter known as the Kylälä nozzle which divided the exhaust steam into four smaller jets, but was open at the bottom to also draw in some of the exhaust gasses [BELOW].

The astute reader is probably concerned that the four smaller jets might actually create more back pressure (resistance in the system) just like sticking a thumb over the end of a garden hose increases velocity but imparts pressure up the hose. This is certainly a correct assumption, except that the third innovation was to split the total exhaust steam flow between two of these Kylchap exhausts thereby increasing the total cross-sectional area while the localized jets retained the smaller openings needed for high speed steam flow. This also meant that instead of one larger stack that was proportionally too short, there were now two smaller stacks whose dimensions were much closer to ideal for maximized energy recovery. As will be described in later papers in this series, Porta continued to refine this critical exhaust system engineering with his Kylpor and Lempor designs.



While the Kylchap exhaust allowed for significant horsepower gains through reduced back pressure without sacrificing the strong draft needed for steam production, there was still work to be done.
Any amount of pressure or temperature drop between the boiler and cylinders results in wasted energy. Chapelon therefore doubled the diameters of the various connecting steam pipes and made the pipe curves as gentle as possible. This latter point reduced the energy loss associated with the high friction of a fluid going through a tight bend. The former reduced the speed of the steam flow without reducing the actual mass of steam flow again leading to lower energy loss by reducing the frictional drag associated with high speed flows.

When the valve opens to let steam into a cylinder, the steam chest undergoes an instant pressure drop as the steam rushes through the narrow valve passages to fill the volume of the cylinder. Depending on the piping sizes and locomotive speed, this manifests itself in a time delay for steam travelling from the boiler to replace the steam that has just filled the cylinder. That delay in conjunction with the closing of the valve often means that the pressure pushing against the cylinder at the start is much lower than it could be - a loss in power.

Chapelon, ever the student, remembered designs from 1850 and 1897 whereby enlarged steam chests mitigated this problem. New steam chests, the volume containing the incoming steam in the area immediately adjacent to the valves, were therefore designed. In the case of the low pressure (LP) cylinders, Chapelon figured that the steam chest volume should be essentially the same as the volume of the cylinders, which meant a four-fold increase in size! For comparison, AT&SF 4-8-4 3752 is quoted as having branch pipes sized at 10% of the cylinder volume, which is similar in size to those on CSR's locomotive 3463.

Two more improvements were included on each of the rebuilt 4-6-2's; a feed water heater and a Nicholson thermic syphon. The feedwater heater diverted some of the exhaust steam to a heat exchanger where the energy left in the steam is used to help pre-heat water going into the boiler. This means that less energy from the fuel is needed to make steam or rather, more of the energy liberated by burning the fuel is utilized in generating steam. The steam diverted for use in the feedwater heater also ends up being recycled, so the locomotive ends up using less water as well. The thermic syphon is a device that also helps improve boiler efficiency in two ways. First, it creates more surface area in the firebox to capture the energy of the fire. Secondly, the water heated by it becomes lighter and moves upward. This sets up a pumping action which circulates water through the boiler and this convection of water in turn allows the heat from the fire to be absorbed into the water faster.

Where possible, Chapelon conducted instrumented tests on individual components to verify their performance and identify areas requiring tuning or improvement. These early tests proved that Chapelon was on the right track with his new exhaust design. They also pointed out that the low pressure cylinders were not doing their fair share of work. As it turned out, by the time the steam reached them, all of the superheat in the steam had been extracted. This meant that as the steam expanded in the low pressure cylinders and cooled, much of it condensed back to water, which produced no useful work. With this data in hand, Chapelon reasoned that increasing the superheat would solve this problem and increased the size of the superheaters. Armed with thermodynamics, he predicted that the sum of the improvements would enable the modified locomotive to approach 3,000 indicated horsepower (IHP: power measured at the cylinders as opposed to drawbar horsepower which is measured at the coupler, the latter being somewhat lower due to losses in the running gear).

While critics initially doubted the effectiveness of the Kylchap design, the operational performance improvement of the locomotive as tested in 1929 – almost exactly 100 years after Rocket's successful trials - proved the effectiveness of the new exhaust and overall modification approach. To wit, the modified prototype Pacific #3566, went from a sluggish 2000 indicated horsepower (IHP) machine to a 3000 IHP speedster (as predicted) with both fuel and water consumption reduced by 25%!

A Survivor: *While almost none of Chapelon's locomotives survived into the preservation era, two of the E41 4-6-2 type locomotives did. This one, in a photograph by Didier Duforest of the locomotive sitting outside in Saint Pierre des Corps. It was moved in early December, 2013 to a warehouse for restoration to operation.*

The 18 modified Pacifics Chapelon championed certainly proved their worth on crack passenger trains, but by 1930, increased traffic pointed to the need for freight locomotives with more power and better adhesion. Several options were considered, at last, a proposal by Chapelon was accepted; albeit it was a somewhat surprising approach. The idea was to take the 4500 class of small wheeled Pacifics, originally capable of 2600 IHP and convert them into 4-8-0s with more than 4000 IHP.

The proposal called for a fourth driving axle to be installed behind the third axle via welded-on frame extensions. This change meant there was insufficient room for the original wide firebox. Chapelon selected a successful design used on the Nord Railways which featured a narrow Belpaire firebox with 40 square feet of grate. Some doubted this choice, but he noted that the narrow grate was easier to hand fire since the near corners could be more readily reached by shovel. Furthermore, the inclined grate and motion of the locomotive tended to work the fire forward and break up clinkers (impurities) that could form with certain qualities of coal. The fireman thus had to expend less effort in maintaining an optimal fire.

Taking cues from the work on the Pacifics, Chapelon also upgraded the boiler design with a thermic syphon. The same steam circuit improvements which had been applied to the Pacifics were included resulting in a 4000 IHP locomotive! A total of twelve of these locomotives were modified. A few years later, a further group of 25 locomotives was also upgraded in the same manner, but featured a mechanical stoker and other minor improvements.

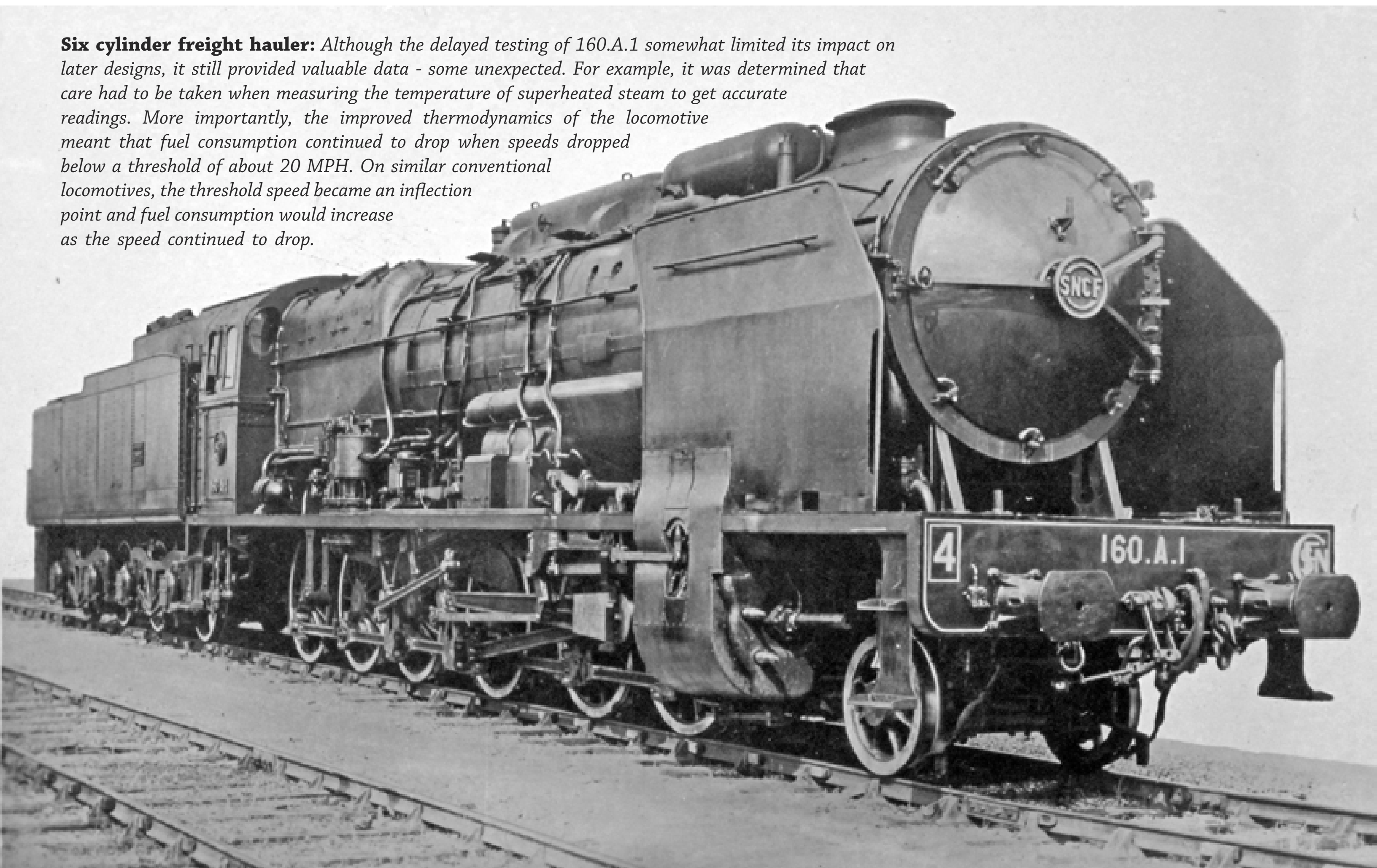
Chapelon was not only familiar with European locomotive design practices, but even undertook an inspection trip to the US in the late 1930s. Afterward, he compiled a compendium which chronicled the latest steam locomotive developments from around the world, his seminal 1938 La Locomotive á Vapeur. He would later remark that his vision for the ultimate locomotive would combine the robust frame and running gear found in US practice, with the refined thermodynamics which made French compound locomotives so efficient. His work was also noted by other European and even US designers. For example, Sir Nigel Gresley included a Kylchap exhaust system in the record setting A4 class Pacifics and some later US designs included larger steam passages.

Fast freight: *This locomotive is from the second group of Pacifics modified into 4-8-0s and featured slightly larger low pressure cylinders, a strengthened frame and mechanical stoker. Note the large steam pipes gently curving down to the sizable steam chests (compare with the cylinders), ovalized double chimney opening and torpedo shaped feedwater heaters behind the stack. Less noticeable is the experimental application of tandem-style side rods on this particular member of the 240.P class. An earlier hand-fired sister engine set a power-to-weight ratio record of 76.2 HP/sq.ft of grate area sustained at 62.5 MPH - a feat that has never been beaten, only matched - by Porta's first rebuild, a similarly designed 4-8-0 named Argentina.*

Following the success of the 4-6-2 to 4-8-0 conversions, Chapelon turned his attention toward locomotives intended for slow, heavy freight service. Efficient operation requires short cutoffs, but particularly at slow speeds, the highly expanded steam often starts to condense in the cylinders which robs the piston of power. Chapelon documented this phenomenon even in the high pressure cylinders of the converted 4-8-0s with high superheat and this gave him some ideas for improvements. The test vehicle was a 1907-built four cylinder compound 2-10-0.

To improve tractive effort, the locomotive would be transformed into a 2-12-0, but the thermodynamic calculations indicated that the original pair of low pressure cylinders did not have enough cylinder volume to efficiently use the steam. Furthermore, there was not enough room within the French loading gauge to increase the cylinder diameters to compensate. To solve this problem, Chapelon added a new pair of high pressure cylinders inside the frames toward the middle of the locomotive which drove the fourth group of wheels via a crank-axle. The large volume of low pressure steam could then be divided between a pair of inside cylinders driving a crank-axle on the second set of drivers and a pair of outside cylinders driving the third axle. This had the advantage of also dividing the piston thrust loads amongst more axles which reduced axle deflection and subsequently mitigated possible bearing problems. Special attention was given to the crank angles of the various cylinder groups in relation to themselves and each other which resulted in very smooth running. Thin flanges on the second, third, and fourth axles plus lateral motion on the first, fifth and sixth axles made for a surprisingly nimble machine. The stretched frame was, of course, suitably reinforced to withstand the anticipate power increase.

To address the cylinder condensation problem, Chapelon attacked the thermodynamics in two ways. He first designed jackets so the incoming steam would flow around the cylinder walls. The heated walls helped counteract the cooling affect which occurred inside the cylinders as the steam expanded, one of the prime causes of condensation; heat loss to the environment being the other – which was also taken care of by the steam jackets. The second approach was to apply superheating to the steam exiting the high pressure cylinders prior to it entering the low pressure cylinders. A technique termed reheating. While this had been attempted previously both in Europe and the US, these early attempts had been unsuccessful due to poor



Six cylinder freight hauler: *Although the delayed testing of 160.A.1 somewhat limited its impact on later designs, it still provided valuable data - some unexpected. For example, it was determined that care had to be taken when measuring the temperature of superheated steam to get accurate readings. More importantly, the improved thermodynamics of the locomotive meant that fuel consumption continued to drop when speeds dropped below a threshold of about 20 MPH. On similar conventional locomotives, the threshold speed became an inflection point and fuel consumption would increase as the speed continued to drop.*

detailed design. Chapelon paid careful attention to minimize pressure drop and optimize superheat which resulted in low pressure cylinder power production on par with that in the high pressure cylinders. Naturally, his trademark Kylchap exhaust and large cross-section steam pipes were incorporated as well.

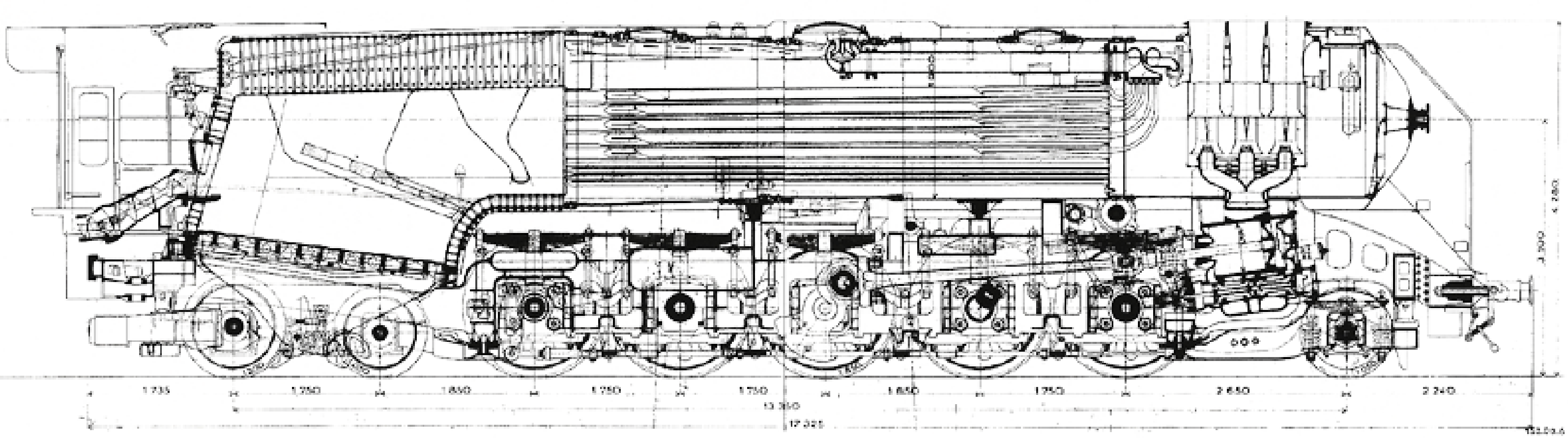
The engine also introduced another thermodynamic improvement adapted from the work of Italian engineers, Attilio Franco and Dr. Piero Crosti. This was an additional tube plate set about 7 feet back from the front flue sheet with a hole open to the boiler proper above the tube bundle. The incoming feedwater flowed into this space and being colder and thus heavier than the water already in the space, settled toward the bottom, the displaced warmer and lighter water in turn overflowed through the hole at the top of the plate and into the boiler proper. In test, this arrangement worked so well that makeup water could be introduced in large quantities with little drop in boiler pressure.

Other notable features included Lentz poppet valves with conical seats actuated by Walschaerts valve gear. This selection was based on tests run with a 4-8-0, the conical valve seats helping to counteract sealing problems typical of poppet valves that arise from temperature change-induced distortion. In other words, the valves were matched to their seats at ambient temperatures, but as the valves and seats heated and cooled at different rates in use, the mismatch in temperatures and thus component dimensions from thermal expansion or contraction caused leaks. Despite having four cylinders inside the frame, the valve gear itself was located outside the frame for ease of servicing. In addition, the cylinder liners were machined from chrome steel, instead of cast iron, to reduce wear.

The modified locomotive rolled out of the shop in June of 1940 – just as the German army was advancing. Like the plot of an espionage thriller, the untested locomotive was quickly moved to a nearby terminal and assigned to a 1,200 ton freight bound for Brive, in the south-central part of France. Under the control of one of the best drivers on the system, the new 2-12-0 successfully completed its fateful journey. Upon arrival in Brive, this remarkable design was hidden away until the end of the war. Circumstances were such that the engine was not tested until 1948, but it performed very well, particularly in terms of fuel and water economy. Speeds of 59 MPH were reached with 55 inch drivers and a drawbar horsepower of 2750 was recorded. Alas, by that point electrification was rapidly advancing and nothing more came of the project.

One interesting discovery that came out of the testing program involved the high pressure cylinders. In one series of test runs, the high pressure cylinders were provided with saturated steam, whilst the steam jacketing was retained. No changes were made to the low pressure cylinders. Despite the lack of superheat, the indicated horsepower throughout the power band of the locomotive only decreased by about 7%. This finding gave designers of compound locomotives more freedom for optimizing boiler and superheater proportions while being able to back away from very high superheat temperatures which make for material selection and lubrication challenges.

What could have been: *These drawings depict the never-completed three cylinder compound 2-10-4 which was to have been the first of a family of 6000 IHP locomotives featuring common cylinders, boilers, and other details. Designed with 320 PSI boiler pressure, 65 sq. ft. grate area, 65 inch drivers, and 40,000 lb maximum axle loads. As a point of reference, the AT&SF 5011 class 2-10-4s managed about 6800 IHP from a 310 PSI boiler, 121 sq. ft. grate area, 74 inch drivers, and 77,600 lb on the main axle. While caution should be used in drawing comparisons between the two locomotives, the data clearly illustrates that power production is not necessarily a function of "bigger is better".*



Chapelon next applied himself to improving a group of superheated, four-cylinder compound 2-8-2s whose basic design dated to 1914, though this order was constructed in 1941. While the layout and key dimensions of the original design were retained, as usual, the creative, scientific mind of Chapelon found ways to improve the breed. The boiler centerline was raised by 4 inches which provided enough space to better streamline the steam passages into and out of the cylinders. An increase in boiler pressure from 232 PSI to 290 PSI facilitated the use of smaller cylinder diameters and a flip-flopping of cylinder positions from the original. Having the low pressure cylinders inside the frames allowed for a shorter, straighter path for the exhaust steam to reach the double Kylchap exhaust. The low pressure cylinders were connected to the second driving axle and the high pressure cylinders were tied to the third driving axle. Special piston valves, a mechanical stoker and feedwater heating were included as well.

To handle the anticipated power increase, the main frames were thickened and cross-braced with the bolt-on cylinder block fabricated from a steel casting. The lead truck was interconnected to the front driving axle and this steering effect greatly improved cornering. The resulting 141.P class was an economical Mikado type with 65 inch drivers that could comfortably run at 78 MPH and reached a peak power of 3330 drawbar horsepower at 50 MPH.

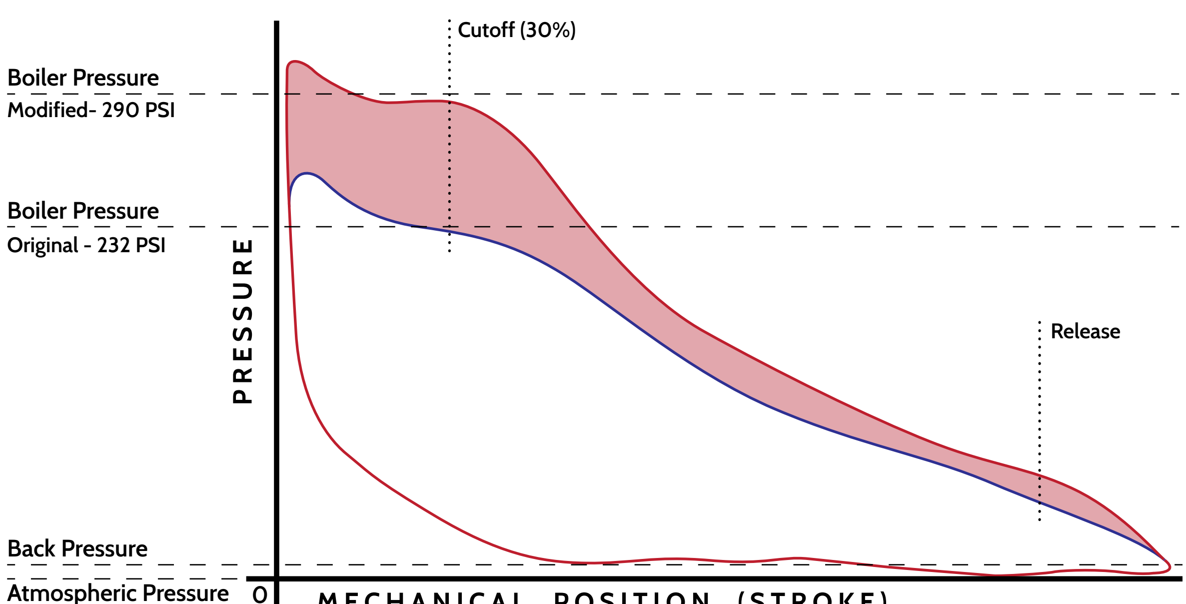
As World War II was drawing to a close, a delegation was sent to the United States to arrange for the manufacture of a large order of simple expansion, mixed-use locomotives which became the 1,323 member strong 141.R class. The locomotives were built in two orders by all three of the major US builders, although Baldwin was tasked with preparing the engineering. The design itself was an interesting combination of US and French practice that allowed for some variety in construction details.

About the only thing they had in common with Chapelon's 141.P class locomotives was the 65 inch driver diameter. Both orders of US locomotives had a lower boiler pressure of 220 PSI, a larger 55.5 sq. ft. grate area, thermic syphons, and a combustion chamber. The first order featured bar frames, roller bearings on the front and rear trucks, and a typical US type exhaust with a master mechanic's style spark arrestor.

The second batch came with more variety; some were oil burners, a subset had Boxpok driving wheel centers and roller bearings on the main axle while still others had Boxpok driving wheels and roller bearings on all axles. One subgroup even became the first locomotives in Europe to feature a cast steel frame.

More significantly, the second order was equipped with a Kylchap exhaust and allows perhaps a better glimpse into the differences between US and French

Indicated Difference: *These conceptual indicator diagrams hint at the additional power available from increased pressure. Note, however how for the same stroke and similar valve events, that the release point is at a higher pressure, indicating that some of the increased power is wasted. In general, the closer the release pressure is to the back pressure, the more efficient the machine will be at energy extraction from the steam. This can be accomplished by expanding the steam in multiple steps. In fact, a properly designed set of compound cylinders begins to approximate the multiple stages in a steam turbine. In both cases, the trick is balancing the costs of multiple expansions with the gain in maximum efficiency and the need for part load efficiency.*



practices than the various locomotives discussed in the two "Case for..." *Trains* magazine articles. To begin with, locomotive from the second order developed more power but with about 13% less fuel and water consumption than locomotives of the first order. A more interesting comparison is developed by putting data side-by-side comparing Chapelon's 141.P class (292 PSI boiler, 47.1 sq. ft. grate area, Kylchap exhaust, streamlined steam passages, large volume valve chest, etc.) with the two groups of US built Mikados (BELOW).

Chapelon was allowed to modify one of the 141.R class locomotives with improved superheaters, enlarged steam circuit and trapezoidal exhaust ports (to reduce the overly strong initial draft on the fire at the point of release) which reduced coal and water consumption per drawbar horsepower across the board by 15%.

This success resulted in a total of 100 of the 141.R class engines being similarly improved. Another interesting point of comparison was the riding qualities of the two cylinder 141.R class vs. the four cylinder 141.P class. The former were found to be rough riding and hard on track and were thus limited to 62 MPH. The latter, as noted previously, road very well and could easily reach 78 MPH.

SPEED	141.R (US Front End)	141.R (Kylchap)	141.P (Chapelon Rebuild)
25.0 MPH	*2197 HP*	*2269 HP*	*2142 HP*
37.5 MPH	*2600 HP*	*2737 HP*	*2970 HP*
50.0 MPH	*2633 HP*	*2928 HP*	*3300 HP*
62.5 MPH	*2509 HP*	*2700 HP*	*3223 HP*

American Durability, French Efficiency- *Built in February, 1947 by the Baldwin Locomotive Works in Philadelphia, 141.R. 1199 was sent to France as part of an order of 1,323 sister locomotives. More advanced than the majority of the remainder of the order, 1199 was built with a one-piece cast steel frame, Franklin automatic wedges, and Franklin radial buffer. This locomotive was also built with a Kylchap exhaust, which produced greater power at speed using less fuel and water.*

PHOTO: *Didier Duforest*

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It is somewhat ironic that the locomotive considered by many to be Chapelon's finest, began life as a three-cylinder simple expansion 4-8-2 which caused track damage and lost considerable power due to poor steam flow through the valves and heat lost to radiation. It was such a failure that it was quickly taken out of service and hidden away.

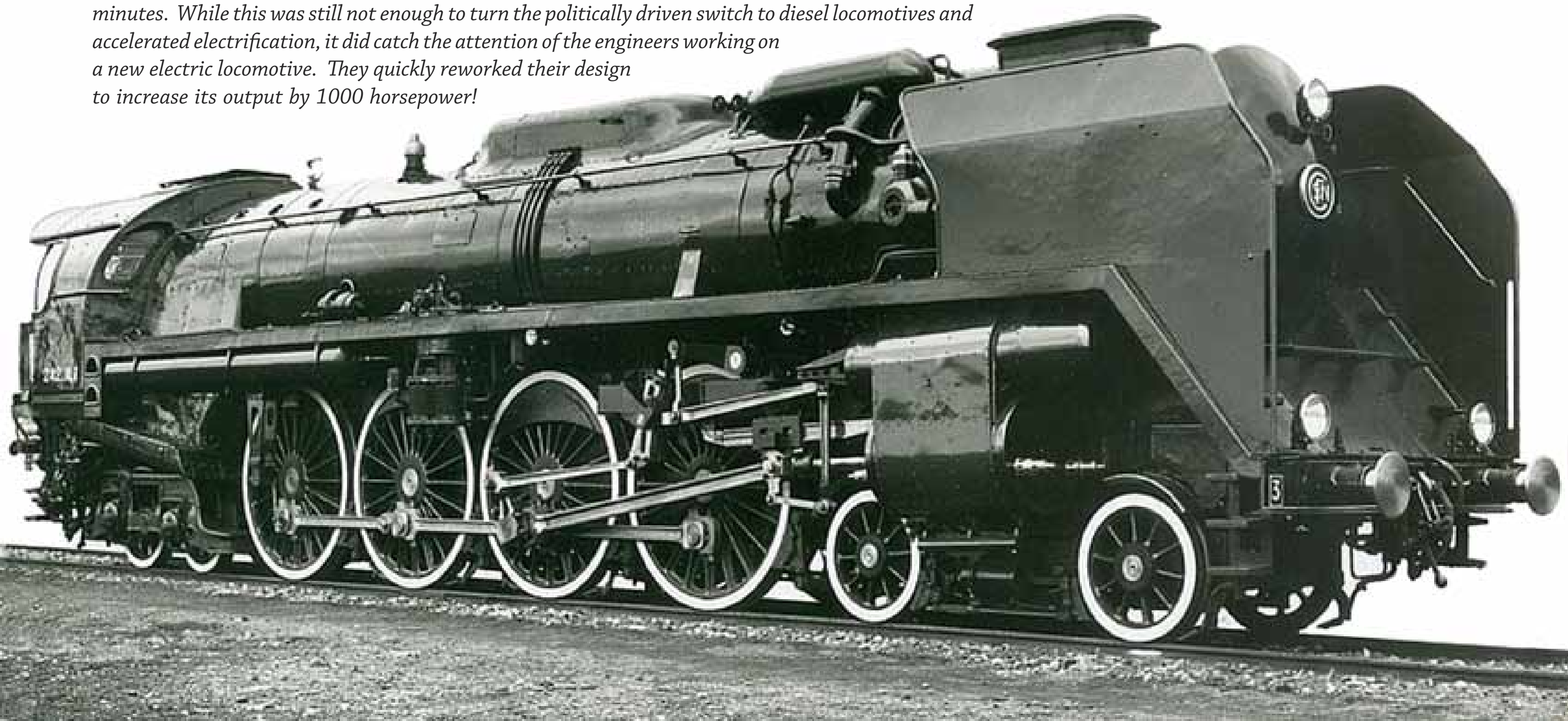
Chapelon was eager to correct the design injustices done to this locomotive, but had to wait until 1942 for the opportunity. By that point, his analysis of post-war traffic needs and experience with other rebuilds was pointing him toward a family of new-built three-cylinder compounds using many common parts to provide 4-8-4, 4-6-4, 2-10-4, and 2-8-4 locomotives of up to 6,000 IHP! This locomotive was to be the prototype for what would have been a most remarkable group of machines.

The first challenge was how to make the modifications within the restrictive axle weight limit and loading gauge of the French railways. For example, late-era US locomotive had axle loading often in excess of 72,000 lbs whereas the French system set its maximum at 42,000 lbs. This lead to the decision to change the 4-8-2 into a 4-8-4. Chapelon put the extra weight allowance to good use reinforcing the frame to withstand the anticipated extra power and to strengthen the crank axle. With some 2,500 IHP expected from the single, inside high pressure cylinder, the extra metal meant that the single throw leading drive axle would have less flexing and therefore fewer axle bearing issues. The two outside low pressure cylinders powered the second driving axle and were set at 90 degrees to each other. The high pressure cylinder crank was offset by 135 degrees to the others meaning that power and exhaust pulses came every 45 degrees of wheel rotation instead of every 90 degrees. This translated into reduced torque fluctuations with a corresponding decrease in slipping and a more steady draft on the fire.

To improve handling, the front truck was replaced with an ALCO design featuring a roller-centering mechanism and the new rear truck was of the Delta type with rocker centering. Both trucks included roller bearings. The driving axles were also fitted with Franklin automatic wedges, their first application in Europe. These changes resulted in a superbly riding locomotive that was easy on track, even when tested at speeds of up to 94 MPH, and this with 77 inch drivers.
The original boiler was designed for 292 PSI, but was modified to include a pair of thermic syphons.

The steam circuit and piston valves naturally received special attention for flow. However, given the amount of steam mass flow needed to reach the planned for power levels, the 4-8-4 introduced the first triple Kylchap chimney which required careful design and testing to assure symmetrical flow to each nozzle. What emerged from the shops in St. Chamond in May

Speed Demon - *In 1952, a special run took place with 242.A.1 hauling an 810 ton train over the electrified line between Paris and Le Mans. Accounting for a water stop, the superlative 4-8-4 bettered the schedule of the fastest trains by 16 minutes. While this was still not enough to turn the politically driven switch to diesel locomotives and accelerated electrification, it did catch the attention of the engineers working on a new electric locomotive. They quickly reworked their design to increase its output by 1000 horsepower!*



of 1946 was a 148 ton masterpiece capable of sustained drawbar horsepower in excess of 4,000 between 50 and 63 MPH and a peak indicated horsepower of 5,500! It is interesting to note the performance of Chapelon's 4-8-4 relative to the remarkable S-1b "Niagara" class of the New York Central:

	S-1b	242.A.1
Adhesive Weight [tons]	*137.5*	*84*
Boiler Pressure [PSI]	*275*	*292*
Driver Diameter [inches]	*79*	*76.75*
High Pressure Cylinder bore X stroke [inches]	*n/a*	*23.6 X 28.3*
Low Pressure Cylinders bore X stroke [inches]	*25.5 X 32*	*27 X 29.9*
Grate Area [sq. ft.]	*102*	*53.8*
Continuous drawbar power @ 62 MPH	*5050*	*4000*
Drawbar Power / Grate Area	*49*	*74*

Though the numbers above speak for themselves, the comparison photograph below speaks a bit more to the engineering genius of Chapelon. Not only was the drawbar power to grate area ratio 50% greater on the 242.A.1, but the horsepower to adhesive weight ratio was 30% greater.

It is also worth noting that the NYC Niagara is regarded as the most advanced steam locomotive constructed in the U.S. What the A.1. had in efficiency and power, the Niagara had in reliability and durability. Unfortunately, no example of either locomotive survives into preservation.

Conclusion

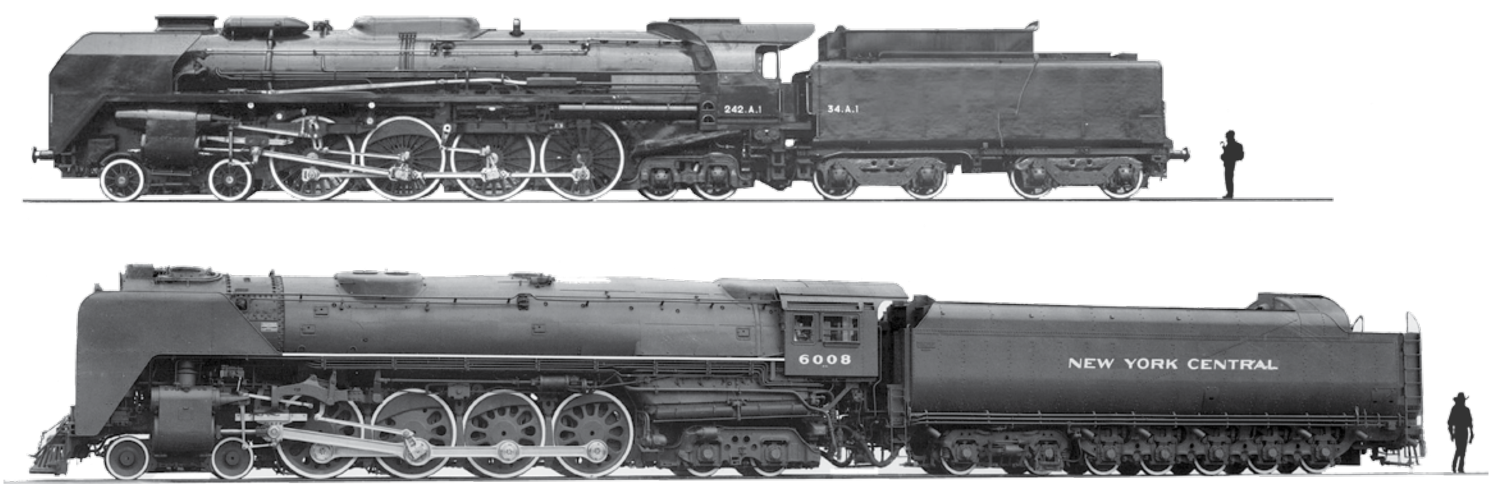
It is somewhat sad to note that M. Chapelon never had the opportunity to build a locomotive from scratch which fully incorporated the many design improvements he implemented during his career. Indeed only a few of the locomotives he designed have survived to the present day and tragically both the 160.A.1 and 242.A.1 were scrapped around the time of the demise of steam on the French railways.

Always working to better the breed, he was already looking beyond his family of 6,000 IHP locomotives to a generation of double and triple expansion compounds whose power and economy would have been remarkable [see image on page 10].

Chapelon died in 1978. While much of his material legacy has been lost, his scientific approach to locomotive design was passed on to a certain Argentinian named Livio Dante Porta who continued to build on the foundation established by Chapelon. More importantly, Porta himself educated a new generation of engineers, including CSR's own Shaun McMahon.

As the reader will see in subsequent installments of this White Paper Series, steam development did not cease with Chapelon's retirement. Indeed, some of its most important innovations were yet to come.

4-8-4's Across the Pond - *Both designers at ALCO who engineered the Niagara and Chapelon had to contend with size constraints. This scaled 1:1 comparison of the two 4-8-4's shows the styling and proportions of each. Note that the NYC locomotive has no steam dome, a design feature overcome with dual slotted dry pipes within the boiler.*



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