

1 - XX1st Century Steam

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Day of Modern Steam Traction

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Abstract: It is **false** that the STEPHENSONian steam locomotive attained the maximum possible degree of thermal efficiency, performance, productivity, and financial return on investment. This is a widespread opinion shared by steam engineers who, after the war, did not produce advances in parallel with other technologies. The author has kept to the STEPHENSONian configuration, albeit introducing a number of mechanical improvements largely of American inspiration. Three important developments have been made:

- advanced **thermodynamics** for drastically increased fuel efficiency,
- **biomass** as a non-polluting, regenerative fuel and
- "heavy duty" **feed water treatment**.

The proposed technology will be the most recent to be developed in the First World. Yet it must fit Third World requirements because diminishing natural resources (esp. oil) and pollution will be **global** problems in the 21st century [1].

¹ For a much fuller discussion than can be given in this paper, see the author's forthcoming book: Porta, L. D.: Advanced steam locomotive engineering facing the energy crisis.

1 Introduction

All over the world there is a steam renaissance. Whilst this is at present limited to tourist trains, new generations are beginning to realise that steam can be used to run trains in a manner far different from the one often portrayed by the media. There are a number of reasons for this new attitude, as will be discussed in this paper. The present is an era of admirable "super-technologies" (which also include "super-expectancies"). There are however problems which these super-technologies cannot meet, and these may be decisive. Steam enthusiasts will be delighted to hear what follows in this paper. However, they **must** realize from the very beginning that the advent of XXIst Century Steam is not a comeback of the steam locomotives which they once loved. Instead it incorporates the most advanced level of modern engineering, even if the wheels are still round, the boiler is still used to evaporate water and a bunker is still used to carry the fuel.

The title of this paper could be misleading: it should have read "the author's steam". It is not the intention here to discuss future steam traction in general, with all its possible variants, but simply to present **his** approach to the problem. This may be a pedantic attitude but, so far, he believes that there is merit in doing so. One day, if what follows in this paper is converted into a sound business, that attitude will be considered irrelevant: what will count is the essence of the proposal.

The steam locomotive proposals presented here do not refer to "super" transportation duties, super speeds, super tonnages, super traffic intensities etc. but rather to the more humble duties which make up everyday life for the majority of people. This does not mean that high speeds or heavy tonnages lie beyond the range of services: remember that 5,000 t coal trains were at one time considered for the Rio Turbio Railway, Argentina, 750 mm gauge, 30 kg/m rail. Millions of passengers will be happy if they can travel in a decent manner rather than on the roofs of the coaches!

2 The Background

The First World is saturated: everybody has a house, medicine, transport, motor cars, education, theatres, holidays, spare time etc. Production costs are constantly decreasing. Money (i.e. effort) which was at one time allocated to the arms race is now available for any use, but this use is no longer to be found in the First World. Therefore, if the process is to continue at the same momentum, a new market (in the broadest sense) is to be found: this is the Third World. An immense market! That World wants to become a consumer society, yet it must be taught how to consume, and its immense richness needs to be developed for useful purposes. Thus, the First World will take its tremendous potential of know-how and capital to the Third World, as is already happening. This will in turn lead to a huge industrial and trade explosion, in turn necessitating a transport explosion. This explosion cannot, by force, be a road transport explosion. A **railway** one is what is required. The question does however remain: **which form of motive power is to be used?**

Parallel to the above, **pollution** will develop exponentially. Whilst noxious gases resulting from the imperfect combustion of hydrocarbons are already creating a great deal of anxiety, the greenhouse effect, caused by CO₂-emissions, is perhaps overwhelming. What can be done to prevent this problem? Advanced, XXIst Century Steam can, as will be demonstrated, provide the answer by running trains on biomass fuels, i.e. on solar energy.

This answer must however be developed by the First World, as the Third World will not use locomotives if they are not considered to be of the latest technology. The engines proposed in this paper will certainly reflect the latest technology, as they do not harm the environment, do not use oil and are cheap to build and maintain. Furthermore, the First World should also start to use them, otherwise it will be suffocated by contaminants produced by road traffic and the other forms of motive power.

3 General Considerations

The development of steam traction may be divided into four generations of locomotives:

- Generation "zero", the bulk of which was built around 1920, which now probably makes up between 60 and 70% of the world's existing stock still in operation;
- First Generation, the most recently built steam locomotives: the NIAGARA, the South African 25 and 25 NC, the post-war British and German standard locomotives, the 141 P, 141 R, the BIG BOY etc.;
- Second Generation, the locomotives which it is possible to build today, incorporating the technological advances from 1950 to date;
- Third Generation, yet-to-be developed engines, the prototypes of which would cost US \$ 10⁹ to develop and build.

What follows in this paper refers to the Second Generation locomotives as an immediate answer to the challenges faced today. The author adheres to the classical, STEPHENSONIAN scheme. It does not hold true that, as many people (including steam engineers) believed, it reached the pinnacle of its potential development. This is a point first put forward by CHAPELON in 1926. CHAPELON had discovered that the way to progress was not through the fancy schemes then being proposed as a means of facing the challenge of electrification, but rather through the correction of a number of engineering imperfections which were accepted as natural at the time. Of these imperfections, the lack of sufficient internal streamlining was perhaps the most important. This of course was not (and is not) the sole step to improvement; the author has advanced along the same line of thought according to the following incomplete summary:

- cycle improvements: 20 to 25 bar steam pressure, 450°C steam temperature;
- compound operation without simple expansion and without direct injection into the receiver;
- utmost internal streamlining of which perhaps the most significant is that applied to the piston valves;
- advanced valve and piston tribology;
- advanced draught ejector design (halved back pressure for a given draught as compared to the KYLCHAP or GIESL ejectors) including the Kordina effect;
- economizer;
- feedwater and air heating by exhaust steam;
- Gas Producer Combustion System (GPCS) with cyclonic flame path;
- advanced feed water treatment;
- "exaggerated" cylinder and boiler heat insulation;
- elimination of wall effects in the cylinders;
- virtual elimination of wall effects;
- new concepts concerning compounding;
- elimination of the "dynamic augment";
- high rotational speed (504 rpm, AAR standard 1947);
- ergonomic operation;
- compliance with environmental protection regulations etc.

The above list should be completed by a myriad of details which together enable the **harmonious** operation of the various thermodynamic and mechanical components, each of which is integrated into that

admirable conception which is the STEPHENSONian locomotive. One should at this point remember its fundamental characteristics as **currently** understood:

- a cycle in which the steam, after having worked in the cylinders, is released into the atmosphere (no condensation);
- a draughting system consisting of static, non-moving parts which keeps the steam/air ratio constant over the whole boiler operating range, hence no boiler controls;
- a boiler which has a very high specific evaporation (up to 140 kg/m²h);
- a direct connection between the power pistons and the wheels (the connecting rod);
- no recourse to electricity and/or gears for power transmission;
- a boiler which forms the structural backbone of the engine;
- a rigid wheelbase leading to least forces exerted on the track;
- a non-enclosed motion;
- a performance not dependent on advanced metallurgy;
- a cab for the driver/crew which is protected against collision;
- a well adapted, natural tractive effort curve;
- no automatics required for driving;
- well trained, experienced drivers/crews necessary;
- it is not repaired by the replacement of spare parts, but by the reconstruction of worn-out components;
- it carries the energy and water supplies with it;
- an indefinitely long life etc.

XXIst Century Steam continues to keep to these fundamentals, albeit altered and improved. So, what makes the difference? The answer: **thermodynamics**. In reference to which BULLEID, the last of the English giants, said [²]: "It never sold a single locomotive."

Most importantly of all, it requires an investment per hp which is about a third of that necessary for an equivalent diesel fleet, not to mention its ability to work on a wide range of fuels.

4 Thermodynamics

A locomotive operates on the basis of extremely complex thermodynamic phenomena. This is true of most machines: an aeroplane also uses extremely complex aerodynamic phenomena. The point remains however that the following principle applies:

Nobody knows what he does not know until he knows it.

The English-speaking world behaved as if thermodynamics did not exist: this explains why BULLEID made the remark quoted above. Yet his post-WWII Pacifics ran daily at 130 km/h (80 mph), and a maximum of 200 km/h was reached by DRG's 05 and GRESLEY's A4.

The steam locomotive was already an admirable machine **before** scientific thermodynamics reached the engineering community. Its development progressed mainly by trial and error on an empirical basis. Long before **any** quantitative analysis was possible, the British were, as early as 1895, able to run the 869 km between London and Aberdeen in 8 h 29 min with three stops made during the night. The empirical genius of those engineers was however insufficient to produce, after WWII, engines which performed significantly better than pre-war KINGS for example, whilst at the same time their fellow engineers working on

² Click, J.: Personal communication, 1977.

aeroplanes had invented the jet. Mention should be made of the unhappy efforts of GOSS and YOUNG in America: the former took the "loss of tractive effort at speed" as inherent to the very nature of the steam locomotive, whilst the latter, after considerable theoretical and experimental work, achieved those worst-ever ejectors characteristic of most American locomotives: a thundering exhaust and a 3 m column of solid black smoke were far from correlating with power and efficiency!

Although the names of GARBE and STRAHL must be cited for the Continent, it was not until the work of CHAPELON appeared in 1938 [3] that a clear understanding of what a steam locomotive is became reality. Unfortunately, he wrote in French, not in English. His tremendous step forward was therefore a cry in the dark. It was not until after WWII that the British showed a blast of genius in understanding what a steam locomotive is, namely a machine to convert chemical energy into mechanical work: ELL was the new hero [4].

Thermodynamics does not however simply mean the description of the locomotive in terms of the theoretical heat engine affected by suitable coefficients as required to adjust it to practical experience. It is much more: it is to describe each of the particular phenomena as related to engineering fundamentals. This should make it possible to predict the work of each one of the parts.

Prediction based on such fundamentals is the key to progress because the designer can manipulate all the involved factors so as to achieve the most convenient result.

An example of such a prediction of performance is the formula for the pressure drop between the steam chest and the cylinder in piston valves at a given cut-off:

$$\frac{\Delta p}{p_s} = \frac{4\varepsilon(1-\varepsilon)}{2\varepsilon(1-\varepsilon) + \sqrt[3]{0,8v \cdot \gamma \cdot p_s \left[\frac{(\varepsilon_0 + \varepsilon)(V + 2e\varepsilon)}{0,71 + 1,5\varepsilon} \cdot \left(\frac{b \cdot m\gamma \cdot 100}{j \cdot u \cdot \pi \cdot \beta} \right)^2 \right]}}$$

where Δp [bar] pressure drop at cut-off ε ; p_s [bar] steamchest pressure; ε [-] cut off; v [m³/kg] steam specific volume; γ [-] coefficient to account for steamchest pressure oscillations; ε_0 [-] clearance volume/cylinder volume; V [cm] lead; e [cm] lap; b [cm] port length (circumferencial); μ [-] contraction coefficient of the stream at port opening; j [dm³] cylinder volume; u [1/s] revolutions per second; β [-] coefficient to account for wall effects.

A design aim should be to have Δp as small as possible. The above formula was developed by STRAHL in 1924 [3], later modified by the author. The influence of the various parameters is quite apparent so that the designer can play with them to the best advantage. Thus a large lead V , a large valve diameter (i.e. a large b), a large contraction coefficient μ , a low β (condensations!), small oscillations (γ) etc. can be quantitatively treated. How far is all this from the vagaries of the "long valve travel" of the GRESLEY era! All this was not even suspected in the English-speaking world. SCHÜLE treated these phenomena as early as 1906 [6].

In addition, the engineer must combine all relevant factors so as to produce a "commercially successful" machine – and nothing less! For certain, this is not textbook thermodynamics. The above formula is an example. What it represents should be extended to the myriad of phenomena occurring in a locomotive. This is not that machine of such a dazzling simplicity that most people (including most engineers) believe it to be. Fortunately for XXIst Century Steam, the computer makes a manageable matter out of it.

3. Chapelon, A.: La locomotive à vapeur. BAILLIÈRES et FILS, Paris, 1938.

4. Ell, S.: Paper No. 235. J. Inst. Locomotive Engineers, 1953.

5. Strahl, G.: Der Einfluß der Steuerung auf Leistung, Dampf- und Kohlenverbrauch der Heißdampflokotiven. Hanomag-Nachrichten-Verlag G. m. b. H., Hannover-Linden, 1924, on p. 99.

6. Schüle, W.: Zur Dynamik der Dampfströmung in der Kolbendampfmaschine. ZVDI 1906, pp. 1900, 1934, 1988.

5 The GPCS (Gas Producer Combustion System)

The GPCS is described in [7]. It essentially consists in transforming the firebed into a gas producer by making it very thick. Only 30 % (20 % in the case of biomass) of the combustion air passes as primary air through the grate, thus leading to an almost negligible particle entrainment. The secondary air makes up the lion's share of the air needed for combustion and creates an intense turbulence in the flame space so that the gas phase combustion can proceed to the degree of completeness required to meet pollution laws. While it appears to have that extreme simplicity characterizing great inventions, its thermodynamics are extremely complicated – after all just an intellectual problem!

The GPCS started to be developed in 1958 by the author in connection with the use of coal as fuel. But concerning XXIst Century Steam, its great merit is that it leads to a simple, most efficient use of **biomass** as locomotive and industrial fuel. Any kind of biomass may be used, as proven by tests in 1963 [8]. So far, the following fuels have been successfully fired: firewood in logs, sawmill rejects, bagasse (in stationary boilers), a wide variety of coals, bagasse-oil briquettes, charcoal fines mixed with oil etc. In the near future, rice husks, orange peels, bark, and dry peat will be tested. One of the blessings of the system is that smoke disappears. In 1963, tests were successfully carried out with charcoal fines (0-6 mm) under fluidized bed conditions. CO- and HC-emissions virtually disappear, and NO_x-emissions are very close to their theoretical minimum. The expectancy is that, by simply blending the fuel with a calcite-dolomite mixture, sulphur can also be controlled to a large extent.

6 Biomass as a railway fuel

During WWII, the author worked as a fireman on locomotives originally designed for coal, later converted to burn wood in log form. The sole modification was the suppression of the brick arch. No change in the performance was detectable provided that the firewood was seasoned so as to reduce the high initial moisture content, while for heavy services certain species were preferable because of the need to limit the physical effort of the fireman. As proven by the 1963 experiments, and later in Paraguay (in 1988), the GPCS gave complete satisfaction as a first class locomotive firing system. Developments in hand consist in mechanizing the feed by hogging the fuel, thus enabling it to be handled in bulk: any level of power can be developed.

Energetic plantations are not a novelty. The driving force behind them is that the CO₂ produced by the combustion of firewood comes from the fixing of the atmospheric CO₂. Thus no additional CO₂ is liberated to increase the greenhouse effect, a matter of **major concern**. Transportation is one major offender, and the possibility of reducing CO₂-emissions to a great extent thanks to the use of biomass must be considered as a great contribution to environmental protection. By no means is this limited to railways.

7 Mechanical and Operational Aspects

While advanced thermodynamics is a key element of XXIst Century Steam, other aspects of locomotive engineering are by no means less significant because they encompass all that must be done in order to convert theory into the actual economical pulling of trains. Perhaps the most important one is feed water treatment. Since 1944, the French TIA system guarantees an indefinite life for the boiler to the point that it can be welded on to the frame. Pure steam (contamination < 1 ppm) also guarantees an indefinitely long life of the superheater and reduces the abrasive wear in the cylinders. The advances made by the author since 1970 are reflected in the fact that the treatment is cheap and **heavy duty**, a most important characteristic for the Third World [9].

⁷ Porta, L. D.: Exemple d'une technique de progrès: la combustion gazogène. Conference de l'ICOHTEC, Paris, 1992.

⁸ Porta, L. D.: Tests on the combustion of wood rejects and charcoal fines, Gas Producer Combustion System. INTI Document, Buenos Aires, 1963.

⁹ Porta, L. D.: Steam locomotive boiler water treatment. 1975, revised 1987 (unpublished).

The following mechanical improvements are considered:

- roller bearings throughout;
- manganese axlebox rubbing surfaces;
- piston and valve rings lasting 1,000,000 km with perfect tightness;
- substitution of the crosshead mechanism by links;
- grinding the tyres every month without dismantling the wheels or the motion;
- virtual suppression of atmospheric corrosion;
- advanced packings for valves etc.;
- most important of all, attention to **detail** design: 50 % of daily maintenance is devoted to details!

The fuel and water consumption is expected to be reduced to **one fourth** of what old steam locomotives (generation zero) show. This results in much longer runs between stops to take water and fuel. In shunting duties, the fuel consumption should equal the diesel one. Last but not least, a most elaborated **ergonomy** should be achieved for all concerned.

8 Third Generation Steam

The possibilities of XXIst Century Steam are not exhausted with the previously described listing. Should the thermal efficiency issue become even more pressing, Third Generation steam locomotives could reach 21 % under test conditions, of course using biomass as fuel. The improvement is on the thermodynamic cycle:

- 60 bar/550°C steam;
- triple expansion;
- regenerative three stage feed water and air heating;
- other detail improvements etc.

All still keeping to the STEPHENSONIAN scheme.

Should it prove to be interesting, a further advance in thermal efficiency, a condensing scheme, could be envisaged. This condensation should occur in a "cooling-tower" tender like the SLM-ESCHER WISS machine (ca. 1926). The water treatment can be modified to accept raw water as boiler feed because the condenser is of the evaporative type. Optimistically, the overall thermal efficiency could reach 27 % at the drawbar.

9 Examples

To avoid speaking about entelechies, Figs. 1a/b and 2 are two examples of XXIst Century Steam. Fig. 1a/b is a small 1,000 hp engine for shunting and branch line services, whereas Fig. 2 is a 8,000 hp fast freight engine for American or Russian conditions. The hp figures are to be interpreted in terms of equivalent-to-diesel power. An infinite variety of designs could be imagined, although a spectrum of limited alternatives could probably cover 90 % of the actual requirements. All of them are to be fired with biomass, hence environmentally clean.

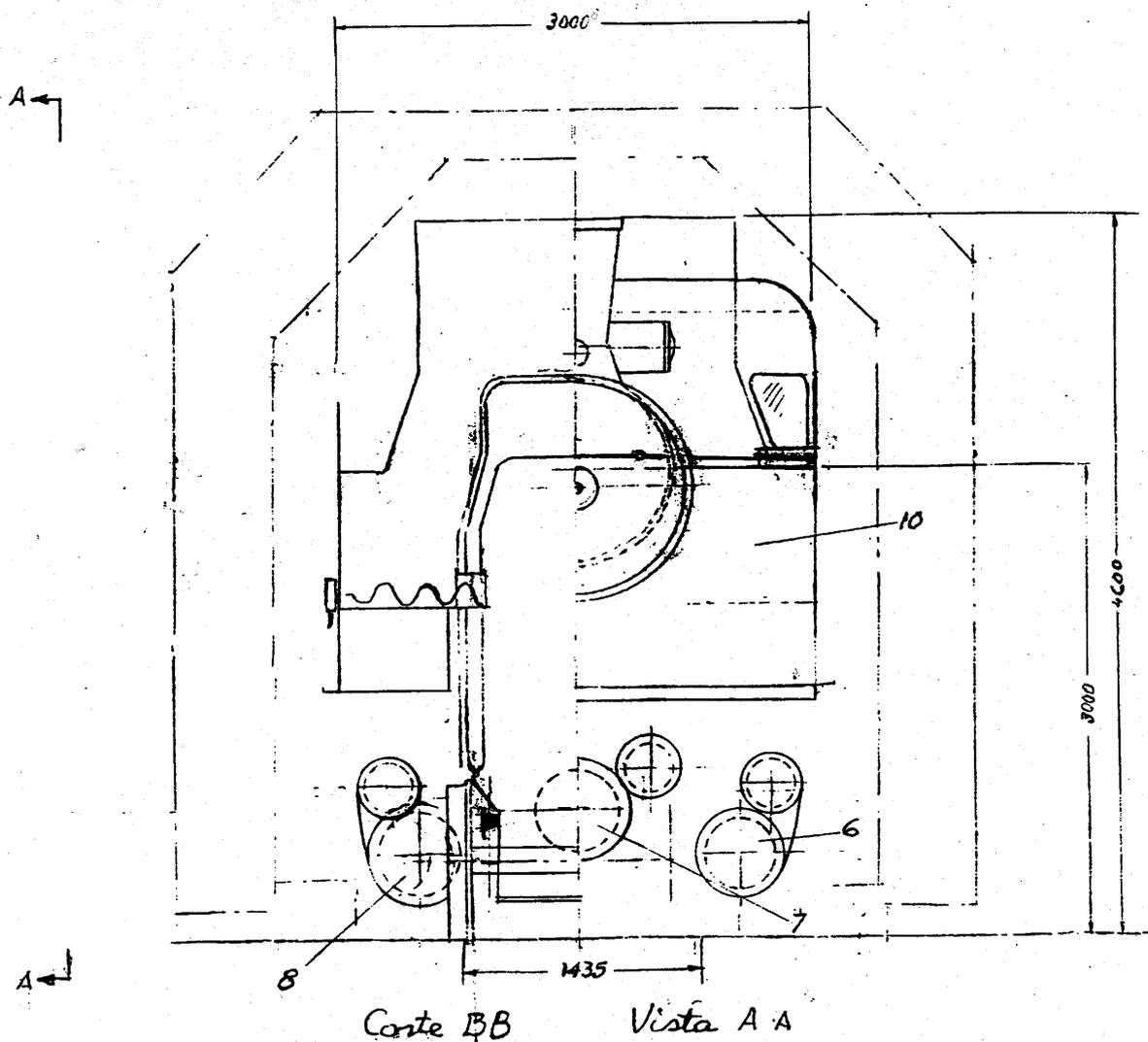


Fig. 1b: Shunting and branch line 3-cylinder compound locomotive.

1	Fuel space	6 m ³	10	Water tank	12 m ³
2	Fuel space	6 m ³	11	Water tank	6 m ³
3	Feed water heater	6 m ²	12	Economizer	
4	LEMPOR ejector		13	Air pre-heater	
5	Air pump		14	Sand box	
6	LP cylinder	(512 x 550)	15	Sand box	
7	HP cylinder	(440 x 550)	16	Sand box	
8	LP cylinder	(512 x 550)	17	Ash box	
9	Gas producer cyclonic firebox		18	Fuel inlet	
			19	Main air reservoir	

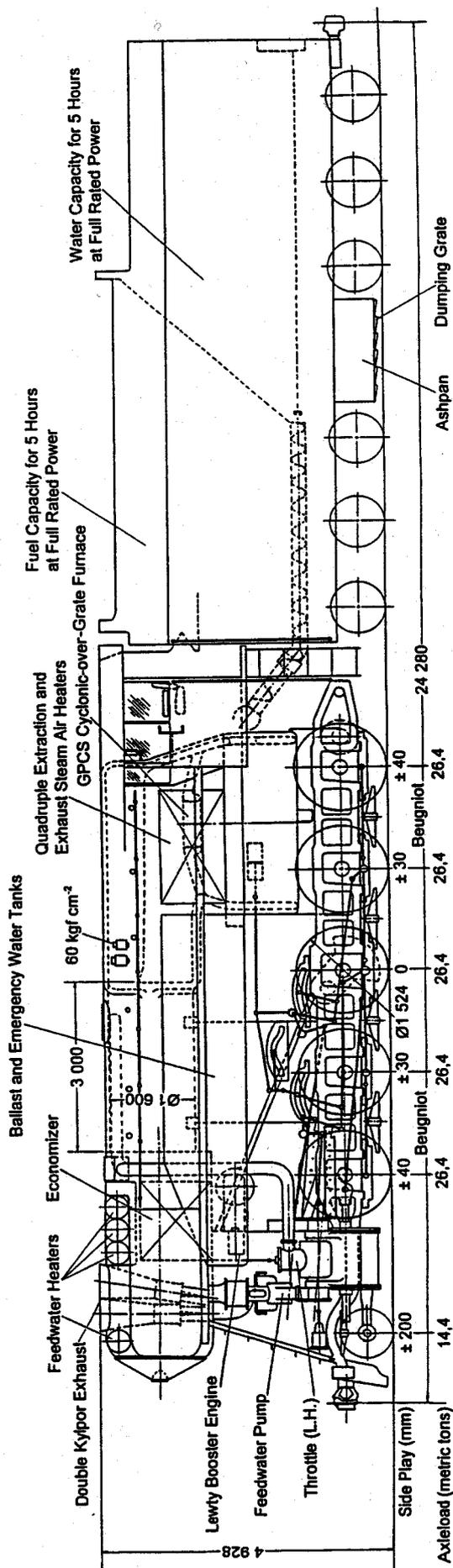


Fig. 2: Third Generation fast freight 8,000 hp locomotive.

The STEPHENSONIAN configuration is adhered to. The high thermal efficiency leads to a very small boiler for the high power output and a reasonably sized tender for 500 km non-stop runs. The locomotive is ballasted because of the very high power-to-weight ratio.

Although the 8,000 hp incorporate a special form of booster giving a very high tractive effort at low speeds, one should note that the generalization of roller bearings for the cars reduces the need for a high starting tractive effort. As seen, the familiar appearance of the STEPHENSONIAN locomotive continues to be the choice. Many people will be disappointed because they cannot perceive anything but bogies, individual axle drives, water tube boilers, electric drives etc. But the question is first one of thermodynamics, thereafter how this thermodynamics is transformed into a successful machine. They should point out what cannot be done within the proposed scheme as compared to the presumable advantages of the non-STEPHENSONIAN solutions. But, in the meantime, they should not forget the non-convincing or poor performance (in some cases to the point of utter failures) of the following engines:

- various Henschel-Schmidt (special cycle, water tube firebox, Germany, England, Canada)
- SLM 2-6-2 (60 bar, uniflow single expansion motor 1926)
- SNCF 232 P I (water tube firebox, two pressure cycle 60 and 20 bar, individual axle drive)
- LNER 10 000 (water tube boiler)
- DR-Schwartzkopff-Löffler (special cycle, high pressure)
- PLM 230 E 93 (Velox boiler)
- DR 45 024 (La Mont boiler, condensation, pulverized coal)
- three machines of the Delaware & Hudson (water tube firebox, high pressure)
- Sentinel for Colombia (water tube boilers, bogies)
- SNCF 232 Q I (turbine, individual drive)
- Heilmann, 1893 (steam electric)
- LMS Paget locomotive (individual motors)
- Egyptian Railways' Sentinel (individual motors)
- Lübeck-Büchener Railway's No. 71 (V-motor drive)
- DRG 19 1001 (individual motors)
- BULLEID's Leader (bogies)
- BULLEID's Leader (bogies, Ireland)
- SNCF-DABEG 221 TQ 1 (12 cylinder motor)

A number of turbine locomotives is to be added to this list of failures, which should be studied to avoid the repetition of mistakes. Why, in spite of a predictable failure, were some engines built?

10 Additional considerations and recommendations

It is impossible to summarize, for the uninformed reader, what XXIst Century Steam is. When one considers that for most people even CHAPELON's work is unknown, never mind understood, the gap to be bridged is enormous: lack of information has been a plague in the past. This is certainly not the case for the automotive industry where everybody knows what everybody else is doing as a must for successful competition. Furthermore, such information is essential in order to make investment decisions; for nobody will invest in what they do not understand. **Nobody likes the unknown!**

A second difficulty is that no masterpiece can be produced according to a recipe, as is the case for a cookery course: **talent** is essential, and the lack of it may explain some of the listed failings.

A third difficulty is the lack of a driving force: **who will convert the above technicalities into a large-scale business?**

11 Main conclusions on steam locomotives as railway motive power

- 1 A **XXIst Century Steam** railway motive power already exists in full development.
- 2 This motive power shows **clear advances and advantages**:
 - 2.1 It uses **non-polluting biomass**.
 - 2.2 It is compatible with the culture and resources of **both the First and the Third World**.
 - 2.3 It is based on **most advanced applied thermodynamics** and **gasification of solid fuels**.
- 3 By using **standardized components** as much as possible for various classes, **economies of scale** and thus **low unit prices** can be achieved.
- 4 A **great business** is just around the corner to provide steam motive power for the **railway boom** just starting in the Third World.