NEWSLETTER No. 22 - AUG 2023

Smoke from Green Dragon Rapemeal Cake during the April BVR trials

Gwion Clark

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CHAIRMAN'S PIECE
John Hind

As our annual conference approaches, a lot has gone on behind the scenes to get to this point – selecting and booking venues, finding speakers and developing the programme, sometimes a spanner is thrown in the works, a speaker withdraws and a substitute has to be found and last year a late change of conference hotel. Part of the planning is setting a budget based on estimates of how many are attending and in turn setting a fee. We aim to cover our costs. Later in the newsletter, Chris Newman gives a more detailed update, but at time of writing bookings are slightly down on last year, but still sufficient to make it worthwhile event, so if you can commit to coming, book now, it makes the organiser's job less stressful!

There is a specific update on Revolution in this newsletter, but later in the year, we are planning a test of the rolling chassis at Stapleford, that will be a significant milestone. Assuming success, then there is a need to press on and finish the locomotive. That needs two things - money and also people who can help in a practical way by making parts to our drawings. If you have your own home workshop with a lathe or miller please get in touch with me at john.hind@advanced-steam.org.

We have a new book for sale 'Reminiscences of a Trainspotter'– while not technical it is written by David Wardale and tonight, I was talking to someone who has bought a copy and is enjoying it as it is written with a dry sense of humour.

MEMBERSHIP MATTERS
Chris Newman

Committee Members

ASTT's management committee members remain unchanged as below:

John Hind	Chairman & Trustee	Jamie Keyte	Trustee
Cedric Lodge	Secretary & Trustee	David Nicholson	Trustee
Chris Newman	Treasurer & Trustee	Alex Powell	Trustee
Richard Coleby	Trustee	Grant Soden	Ex-officio

In addition to the above, it is hoped that Gwion Clark will take on the role of Student Representative.

New Members:

We welcome three new members who have joined since our No 21 Newsletter of March 2023:

Matt Palermo from Tennessee, USA. Matt is studying Mechanical Engineering at University of Alabama till Dec 2023. He has undertaken modifications to a 24" gauge 4-4-0 park engine, and as been involved in the design of the frame for the T1 (new-build) project, the design of a new firebox for PRR K4 No. 1361, and in the rebuilding of the ACL (Atlantic Coast Line) Pacific No. 1504. He has also been involved in the design of a PRR S2.

John Dunn from John Dunn Engineering of East Caves, near Hull, Yorkshire. John Dunn Engineering specialises in steam loco projects, focusing on precision machining which he has undertaken for ASTT in machining the frames, wheels and axles for *Revolution*. John is the owner of a Barclay 0-4-0 saddle tank.

Nigel Cooper from Tameside, near Ashton-under-Lyne, Greater Manchester. Nigel is retired from a career in insurance, banking and the motor industry.

Dan Armstrong from Wellington, New Zealand. Dan is interested in promoting sustainability in heritage rail in New Zealand and is hoping to cooperate with ASTT in pursuing that interest. We await further information from him.

Full Membership: the number of Full Members remains at 38.

Student Membership: With the addition of Matt Palermo, student numbers have increased to 9.

Membership Numbers

Membership numbers are now:

Full Members:	38	UK members:	75
Associate Members:	67	EU:	14
Student Members:	9	USA	9
		Australasia:	10
Total Membership:	114	Asia:	2

PUBLICATIONS PAGE

Chris Newman

Book Sales

60 books have been sold in the four months since March when Newsletter No 21 was circulated. The sales numbers are listed as follows:

Publisher	Author	Title	Sales since N/L 21	Total Sales
ASTT	L.D. Porta	Porta's Papers Vol 1	3	137
	L.D. Porta	Porta's Papers Vol 2	2	129
	L.D. Porta	Porta's Papers Vol 3	1	88
	C. Newman (Editor)	Porta's Centenary Compendium Vol 1	4	69
	Ian Gaylor	Lyn Design Calculations	4	108
	David Wardale	5AT FDCs	4	213
	David Wardale	Reminiscences of a Trainspotter	26*	26
	Alan Fozard	5AT Feasibility Study	2	42
Camden	David Wardale	The Red Devil and Other Tales from the Age of Steam	0	260
	Phil Girdlestone	Here be Dragons	0	33
	Jos Koopmans	The Fire Burns Better …	4	11
	L.D. Porta	Advanced Steam Design	0	5
Crimson Lake	Adrian Tester	A Defence of the MR/LMS 4F 0-6-0	7	40
	Adrian Tester	Introduction to Large Lap Valves	0	19

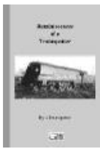
* The 26 copies of *Reminiscences of a Trainspotter* that were sold during the period include 6 copies sold "at cost" to the author, David Wardale. Dave declined the offer of free complementary copies. An additional two "proof" copies were also purchased from the printers (see below). These proofs are not included in the total sales.

New Printing Service: As noted above, two proof copies of David Wardale's *Reminiscences of a Trainspotter* were purchased. The first was printed by "Lightning Source" which has printed all of ASTT's books since 2017. However, this proof was rejected by David Wardale who was dissatisfied with the quality of the photo images. An alternative printing service called "Bookvault" was therefore tried because it offered a better quality "coated" paper which lowered ink absorption and thereby improved image quality. Wardale deemed its proof copy to be acceptable, so subsequent copies have been printed by Bookvault.

Happily, Bookvault's charges turn out to be generally lower than Lightning Source's, so it is probable that the majority of ASTT's titles will be produced by them in future. However, books (other than *Reminiscences of a Trainspotter*) that are sold to purchasers in the US and Australia will, for the present time, be printed by Lightning Source which operates printing works in both countries, thereby reducing postage times and costs. This situation may change in future once Bookvault opens its first overseas printing works in the US.

New Books: **Porta's Centennial Compendium Volume 2** (compiled by myself) is now complete. Two proof copies have been purchased from Bookvault, one of which will be delivered to Martyn Bane who has provided much of the text for it. Once these proofs have been checked and accepted, the book will be offered for sale through ASTT's website. The second volume has turned out to be larger than the first**:** it fills 331 pages compared to Volume 1's 226 pages.

Titles published by the Advanced Steam Traction Trust

	Year	Author	Title	Pages	RRP*
	2015	David Wardale	The 5AT Fundamental Design Calculations	556 (b&w)	£49.00
	2016	Alan Fozard and others	The 5AT Feasibility Study edited	230 (colour)	£35.00
	2018	Ian Gaylor	Steam Locomotive Design Specifications and Calculations for New Build Baldwin 2-4-2T 'LYN'	604 (colour)	£52.00
	2018	L.D. Porta transcribed and edited by Chris Newman	Selection of Papers – Volume 1 - Tribology and Lubrication by	556 (b&w)	£27.00
	2019	L.D. Porta transcribed and edited by Chris Newman	Selection of Papers – Volume 2 - Adhesion, Compounding and the Tornado Proposal	556 (b&w)	£27.00
	2021	L.D. Porta transcribed and edited by Chris Newman	Selection of Papers – Volume 3 - Steam Loco-motive Boilers, Fireboxes and Combustion	556 (b&w)	£27.00
	2022	Compiled and edited by Chris Newman	A Compendium of Articles and Papers to celebrate the Centenary of the birth of Livio Dante Porta - Volume 1	226 (colour)	£27.00
	2023	Compiled and edited by Chris Newman	A Compendium of Articles and Papers to celebrate the Centenary of the birth of Livio Dante Porta – Volume 2	331 (colour)	TBA
	2023	David Wardale	Reminiscences of a Trainspotter	67 (b&w)	£16.00

* the RRPs (recommended retail prices) shown include UK postage. Additional postage costs may apply to some titles. Paid-up members of ASTT are entitled to a 20% discount on these prices.

All these books can be purchased through ASTT's website at http://advanced-steam.org/books-for-sale/

ASTT ANNUAL CONFERENCE

Chris Newman

The conference will be held in the Leonardo Hotel, Swindon from 7th to 8th October.

Speakers: We are grateful to eight members and one non-member who have offered to present papers at the conference (see programme below). The one non-member is Roger Waller (of SLM/DLM fame) who has conditionally agreed to fly over from Switzerland to give a talk on "Alternatives to Coal" if his business commitments allow.

Another volunteer is Matthew Palermo, a Student Member from Tennessee in the USA who has offered to talk on "an economic analysis for a modern steam locomotive compared to a diesel electric" that he has undertaken as part of his application for membership of the American Society of Mechanical Engineers. However, he is unable to attend in person so his presentation will only be possible if we are able to link up with him via Zoom.

In the event that either Roger or Matthew is unable to present, Mike Stockbridge will stand in with a talk on "A modern high pressure steam turbine locomotive".

Location: We chose Swindon as the location for our 2023 conference because all but one of our previous conferences have been held in the north, the one exception being Loughborough in central England. We therefore chose to offer a conference in the south to make it easier for southern members to attend, and we therefore urge our southern members to take advantage of this opportunity.

We normally get some early bookings, then a late flurry. At the moment we have only 20 confirmed bookings, which is below what we normally have by now. So if you are planning to come along, please make your booking now rather than delay.

We base the admission fee on our estimate of the number of delegates. We currently estimate that the admission fee for the two days will need to be between £70 and £100 per person if we are to cover costs – the more attendees, the lower the charge. These fees are required to cover the conference room hire, lunches and refreshments, speakers' subsidies (free entry on the day of their talk) and a visit to the Swindon and Cricklade Railway to see 35011 *General Steam Navigation* which is under restoration there. A conference dinner will be available at the hotel at an additional cost of £30 per head for three courses, or £25 for two courses.

Accommodation: The hotel offers accommodation at a discounted price of £89 per night for conference attendees. Bookings should be made directly with the hotel either by writing to Keira Fontana (Meetings & Events Planning Executive) at Keira_Fontana@leonardohotels.com, or by calling her at +44 (0) 161 774 1743.

We urge members to come along to what has always been a convivial and worthwhile experience where like-minded people have an opportunity to get together. So please let us know if you would like to reserve a seat at the conference. Room space is limited to only 40 seats, so if you'd like to attend we urge you to let us know sooner rather than later.

The current version of the conference programme can be found overleaf. Updates will be posted on the News pages of ASTT's website.

Payment of attendance fees will be requested in early September and may be made by cheque, BACS transfer or via PayPal. In the meantime please reserve your seat at the conference by writing to info@advanced-steam.org.

2023 Conference Programme as at 25th July 2023						
	Start	***Dura-tion***	**End**		**Topic**	**Speaker**
Sat-urday 7th Oct '23	09:30	*00:30*	10:00		Registration & Coffee	
	10:00	*00:15*	10:15		Welcome	John Hind
	10:15	*01:00*	11:15	1	Why did BR give up on Steam Part 3 - Shunting Locomo-tives	Andrew Hartland
	11:15	*01:00*	12:15	2	Countering centrifugal and reciprocating forces in steam locomotives	Hendrik Kaptein
	12:15	*00:45*	13:00		Buffet Lunch	
	13:00	*01:00*	14:00	3	Bulleid's Turf Burner - is it a pointer to a future Biomass Loco?	Joe Cliffe
	14:00	*00:30*	14:30		Travel to Swindon & Cricklade Rly	
	14:30	*01:30*	16:00		Visit to Swindon & Cricklade Rly	
	16:00	*00:30*	16:30		Travel to back to hotel	
	16:30	*00:15*	16:45		Tea/coffee	
	16:45	*00:15*	17:00	4	Briefing:- on what can still be seen in the GWR Railway Village	Mike Stockbridge
	17:00	*02:00*	19:00		Optional self guided visit GWR Railway Village or Free time	
	19:00	*03:00*	22:00		Conference Dinner	
Sun-day 8th Oct '23	09:00	*00:15*	09:15		Assembly in meeting room; registration of Sunday-only attendees	
	09:15	*00:15*	09:30		Welcome	John Hind
	09:30	*01:00*	10:30	5	100 Years of Caprotti	Graham Shirley
	10:30	*01:00*	11:30	6	Alternatives to Coal *(see note 1)*	Roger Waller
	11:30	*00:30*	12:00		Tea/coffee	
	12:00	*01:00*	13:00	7	Report on trials and researches on coal substitutes	John Hind & Ian Gaylor
	13:00	*01:00*	14:00		Buffet Lunch	
	14:00	*01:00*	15:00	8	Economic analysis of Modern Steam *(see note 2)*	Matthew Palermo
	15:00	*00:30*	15:30		Tea/coffee	
	15:30	*01:00*	16:30	9	Progress report on the design and construction of "*Revolution*"	Jamie Keyte
	16:30	*00:15*	16:45		Wrap Up	John Hind

Notes:

1. Roger Waller's attendance is subject to his workload allowing him to travel over from Switzerland.
2. Matthew Palermo's presentation will depend on our ability to link up with him via Zoom.
3. Mike Stockbridge has kindly agreed to act as stand-in speaker if required, with a talk on "A modern high pressure steam turbine locomotive".

REVOLUTION FUNDING APPEAL

Chris Newman

Good progress is being made with *Revolution*, not least with the very elegant artwork by Robin Barnes reproduced above. It might not be an overstatement to claim that the great Sir Nigel would have been proud to have produced such an elegant machine.

Progress has also been made on the hardware front, which has now reached the stage where we have the rolling chassis illustrated below:

Revolution's rolling chassis assembled and painted.

However, a lot more work has been completed than seen in this photo. Those who attended our Darlington conference will be aware that Jamie Keyte has completed a number of other components including the coupling and connecting rods, to which he has now added the cylinder/valve-chest assemblies (see image overleaf).

As reported earlier, design of the valve gear assemblies. slide-bars and crossheads have been completed by Richard Coleby, so these items can be manufactured and assembled as and when funds allow.

Alex Powell is making good progress on the design of the boiler, but further funding will be needed before its fabrication can begin.

Cylinders & valve-chests test-fitted to chassis

We now have monthly donations coming in from five members. In addition, we have received a very generous one-off donation of £8000 from Hendrik Kaptein who will be well known to attendees at our conferences over the last four or more years. Thanks to them, and to an earlier £10,000 donation, we have so far accumulated £20,500 in our Revolution fund of which we have expended £19,000 as at the last count.

We expect to need a further £15,000 to £20,000 for the boiler and fittings, and perhaps £15,000 to complete the pistons, valves, valve-gear – or say £40,000 (optimistically) to complete the locomotive (excluding its tender).

We believe *Revolution* will be a worthwhile investment that will not only act as a guinea pig for research and testing of numerous aspects of steam technology, but that it will also offer the heritage railway industry a 21st century low-cost low-maintenance locomotive that could significantly reduce the cost of their operations while retaining the intrinsic appeal of steam traction.

Our aim remains to display *Revolution* at the celebrations for the 200th anniversary of the birth of railways in Darlington in 2025. So once again, we appeal to members to support this endeavour. So **please help by sending a donation or by setting up a standing order with your bank to send a monthly contribution to the Advanced Steam Traction Trust's HSBC bank account: Sort Code 40-28-14, Account No 4176 0947.**

If you are a UK tax payer and have not yet signed a Gift Aid declaration, we would be grateful if you could complete and sign the form below, and either email a copy to info@advanced-steam.org, or post it to Chris Newman, Flat 4, 2 Kimmerghame View, Edinburgh EH4 2GP. By so doing, we should be able to claim a rebate of 25 pence for every pound that you donate.

GIFT AID DECLARATION

Please treat all gifts of money that I make today and in the future as Gift Aid donations. I understand that I must pay an amount of Income Tax and/or Capital Gains Tax to the UK government each tax year that is at least equal to the amount of tax that the **Advanced Steam Traction Trust** will reclaim on my gifts for that tax year. I confirm that I have paid or will pay an amount of Income Tax and/or Capital Gains Tax for each tax year (6th April - 5th April) that is at least equal to the amount of tax to **all** the charities or Community Amateur Sports Clubs that I donate to will reclaim on my gifts for that tax year. I understand that VAT and Council Tax do not qualify.

I confirm that I would like all my donations to the Advanced Steam Traction Trust to be treated as Gift Aid:

Signed: ____ **Date:** ________________________.

Addendum: *If anyone reading this would like to be a Fundraising Co-Ordinator / Marketing Manager / Publicity Officer for the Revolution Project, please contact Chris Newman*

BURE VALLEY APRIL TRIALS
John Hind

Back in April, with the BVR we ran 4 days of trials, with in the end 5 fuels. John Scott, Ian Gaylor, Gwion Clark and myself were the test team and Scott Bunting from the BVR was the driver, as he has been for all the tests. The tests could only start after the last service train had run, so we were leaving Aylsham at about 1700 and finishing at about 2100 after the engine had returned to shed.

These tests were significant, as for the first time two products made from 100% renewable sources were tested. The biofuels are 'Harvest Flame' and 'Green Dragon'.

The supplier and fuels were:

(a) Eire based, Arigna Fuels 'Harvest Flame'; made from torrified olive stones which are agricultural residues from the production of olive oil and is imported from Mediterranean countries. 'New Heat' is commercially available in Eire and currently costs circa €465 /tonne.

(b) Phoenix Oils 'Green Dragon'; made from rapemeal cake which is the waste product from the production of rapeseed oil using domestically grown rapeseed. This fuel is still under development, is available for trials but not available commercially. Prices are expected to be circa £425/tonne.

(c) CPL's Wildfire contains up to 30% renewables in the form of crushed olive stones and currently costs £425/ tonne.

(d) CPL's 'Heritage Smokeless Steam Coal' uses anthracite as the base ingredient which is a fossil fuel. This is commercially available at circa £425/tonne.

(e) Oxbow's 'New Heat' uses between 60% and 65% petroleum coke as its base ingredient with the balance predominately anthracite. This is commercially available at £475/tonne.

The Arigna Fuels and Phoenix Oils have been trialled in steam locomotives before, but not under the demanding work and firing rates that are needed at the Bure Valley, where we use the same locomotive, same load, same test methodology and same driver to get to as near as practically possible consistent trial conditions.

As a quick update, the fuel consumption with the 100% renewable fuels is twice that of Welsh Steam Coal, meaning that the fireman shovels more and that coal bunkers need to be bigger. With Harvest Flame, we thought we had loaded enough fuel for a return trip, but in effect it was only sufficient for a single journey and we had to return using Heritage Smokeless Steam Coal.

Understanding fuel consumption is only part of the assessment of a fuel, other important characteristics we need to understand are: clinkering, birdsnesting, fire throwing and spark emissions and chlorine and sulphur content.

High levels of sulphur and chlorine in fuels leads to corrosion of boilers through the formation of sulphuric acid and hydrochloric acids and their deposition in the firebox, firetubes, superheater, smokebox and chimney surfaces, when the surfaces are lower in temperature than the dew point of the flue gas results in corrosion. This occurs when a boiler is cooling down after a period of duty and boilers that are used intermittently will be at a greater risk of this type of corrosion.

The DRAFT report is out for comment with the fuel suppliers and Ian Gaylor and I will be giving a full update at the October Conference. At the moment, we are acting a bit like the Consumer's Association and their 'Which' magazine reports. At the end of the process, we will hopefully have a balanced report that gives the best comparison in one place of how the fuels perform, but to get there is taking longer than expected.

Thomas Bright of 'Steam Railway' magazine joined us for the last day of trials and is planning to write an extended article on the trials.

The HRA now pass onto us, questions they receive from other operators of steam locomotives about alternative solid fuels and updates have been given to operators in Denmark and Sweden.

THE COMBUSTION TRIANGLE

Chris Newman

I'd like to congratulate Martin Johnson for his excellent article on the "Derivation of the Locomotive Energy Balance" in the March 2023 edition of our Newsletter. As readers will have discovered, this is a challenging subject, especially for people like myself who long ago forgot the chemistry that they learned at school. For whatever reason, my university engineering course only offered Physical Chemistry in its first-year curriculum which, so far as I can remember, included nothing in the way of combustion theory. I recall Martin telling me (to my astonishment) that he too missed out on Chemistry in his education and that he'd had to teach himself what he now knows about the subject - which is a great deal more than I will ever understand.

In his article, Martin mentioned the concept of the "Combustion Triangle". This has prompted me to offer the following corollary which I've copied from my transcription of Porta's paper titled "Boiler Combustion Calculations - Criticism of the Lawford Fry Method". This appears in Volume 3 of Porta's papers which I published in 2021, and which some of our members will on their bookshelves. However, sales of Volume 3 have trailed behind those of the first two volumes, from which I conclude that many of our members will not have seen it. (It contains some excellent papers that we can all learn from, so I'm encouraging everyone to buy a copy!)

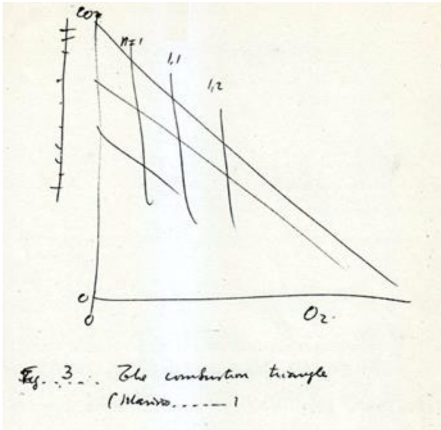
Of all the 40+ Porta's papers that I've transcribed so far, this short commentary on combustion calculations was technically the most challenging for me. Indeed, I barely understood a word when I first read through it. I therefore purchased a copy of Fry's 1924 "Study of the locomotive Boiler" - at modest cost, in the form of a "reprint" from Gyan Books PVT. LTD. in India - see https://www.gyanbooks.com/ if anyone wants to purchase a copy. I learned much from reading this, but it revealed nothing about this mysterious Combustion Triangle that Porta alluded to in a scribbled pencil sketch in his manuscript. This left me with no option other than to call for help from our resident guru who, it turned out, had never heard of the Combustion Triangle either. Imagining this to be the end of the line in terms of understanding Porta's paper, I was astonished when Martin wrote back a week or two later, to say that he's figured out what the Triangle was all about. What's more, he had managed to "reverse-engineer" a method of creating it. This in itself stretched my understanding to its limits but, with Martin's help, I was not only able to understand it, but able to write an explanation of how to create it which I incorporated as an appendix to my transcription of Porta's paper.

I'm therefore killing two birds with one stone (i) by taking the opportunity to thank Martin for the enormous help he gave me, and (ii) by publishing the appendix for those members who have not yet bought a copy of Volume 3 of Porta's papers.

If this short corollary helps to sell a few more copies of Volume 3, then it will have served to benefit both its buyers and ASTT's coffers.

Postscript: I've posted a copy of my spreadsheet onto AST's website for anyone who wants to download it - see http://advanced-steam.org/combustion-triangle/.

APPENDIX 1 - Combustion Triangle



Porta makes several references to a Combustion Triangle in the text and calculations of this paper, however other than his scribbled sketch (copied at right), no evidence as to what he was referring to has been found through Internet or other searches.

From this snatch of evidence, Martin Johnson has been able to recreate the diagram in Excel as illustrated in Fig 3A below.

The main features of the diagram are:

- One or more diagonal lines are drawn, each representing a hydrocarbon fuel comprising a mixture of Carbon, H_2 and O_2 and other molecules;
- Each line is drawn along a set of points representing Air Ratios over the range 1.00 to 1.50;
- The vertical and horizontal scales represent the CO_2 and O_2 contents of the combustion gas, measured in % by volume.

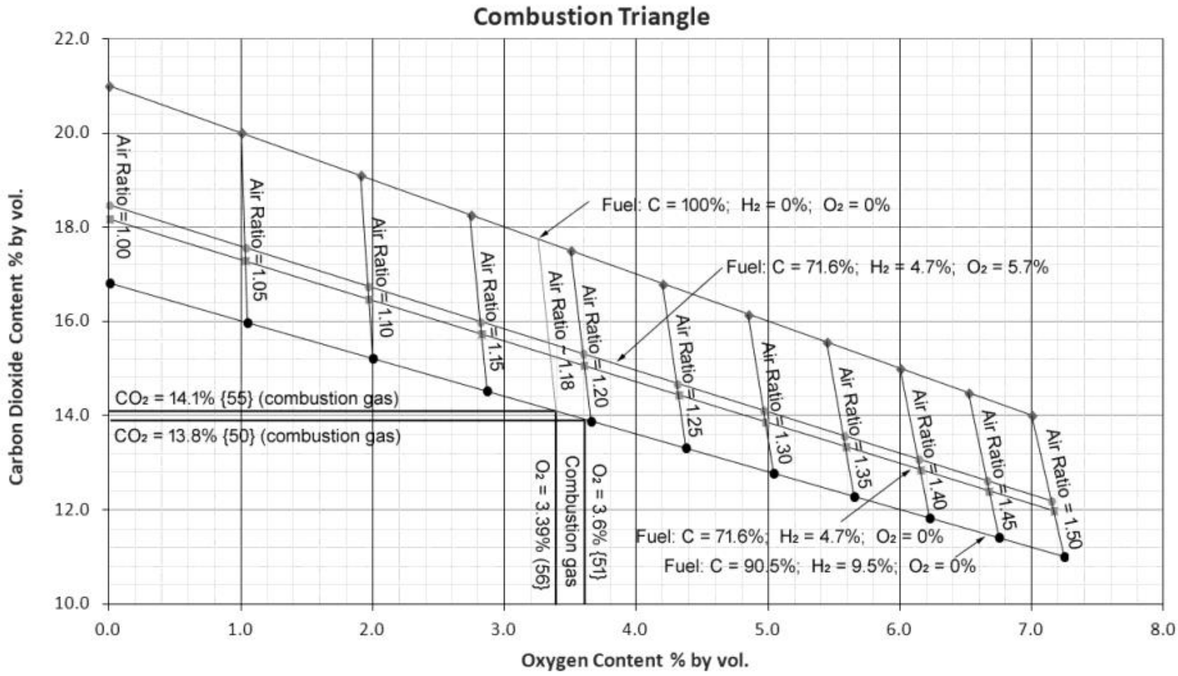


Fig 3A – Combustion Triangle

The diagram provides a ready means of determining:

- the combustion gas make-up from any combination of fuel and air ratio;
- the air ratio for any combination of fuel input and combustion gas output;
- fuel input from any combination of air ratio and combustion gas output. [1]

Since readers are unlikely to find independent source material to explain the derivation of Porta's Combustion Triangle, an explanation of Martin Johnson's derivation is provided in the following pages as follows:

1. An example of the spreadsheet format developed by Martin Johnson, and
2. A calculation sheet (set out in Porta's style) spelling out the calculation sequence upon which the spreadsheet is based.

1 Each fuel line is unique to a particular combination of carbon and hydrogen. However if oxygen is also present in the fuel, a fuel line may be derived from more than one combination of the three. For instance the lowest line representing a fuel consisting of C=90.5%, H_2=9.5% and O_2=0% coincides with a line for C=71.6%, H_2=8.0% and O_2=5.0%.

Spreadsheet Format

Note: shaded cells indicate parameter values. All other values are calculated.

	A	B	C	D	E	F	G	H	I
1	**Fuel**	**Fuel Ultimate Analysis**		**Carbon / Hydrogen ratio** = {6}/{7}		**15.23**	**Molar Mass**	**O2:N2 ratio in Air**	
2	From Lines {6}, {7} & {11} of	Carbon	71.60%	Carbon mass		15.23	12	O2	21%
3		Hydrogen	4.70%	Hydrogen mass		1	2	N2	79%
4		Oxygen	5.70%	Oxygen % by mass		5.7%	32		
5	**Fuel Mass analysis (%)**			**Fuel Molar analysis (mols)**			**Molar analysis %**		
6	**Oxygen**	**Hydrogen**	**Carbon**	**Oxygen**	**Hydrogen**	**Carbon**	**Oxygen**	**Hydro-**	**Carbon**
7	5.70%	5.81%	88.49%	0.18	2.90	7.37	1.70%	27.78%	70.52%
8	**Air ratio**	**1.00**	**1.05**	**1.10**	**1.15**	**1.20**	**1.25**	**1.30**	**1.35**
9	**Molar basis C to CO_2**								
1	C & CO_2	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5
1	O_2 used	70.5	70.5	70.5	70.5	70.5	70.5	70.5	70.5
1	**Molar basis H to H_2O**								
1	H_2 & H_2O	27.8	27.8	27.8	27.8	27.8	27.8	27.8	27.8
1	O_2 used	13.9	13.9	13.9	13.9	13.9	13.9	13.9	13.9
1	O_2 in coal	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
1	Total O_2 use	82.7	86.8	91.0	95.1	99.2	103.4	107.5	111.7
1	N_2 mols	311.1	326.7	342.2	357.8	373.4	388.9	404.5	420.0
1	O_2 left over	0.0	4.1	8.3	12.4	16.5	20.7	24.8	28.9
1	**Combustion Gas volumes %**								
2	CO_2	18.5%	17.6%	16.7%	16.0%	15.3%	14.7%	14.1%	13.6%
2	O_2	0.00%	1.03%	1.96%	2.81%	3.59%	4.31%	4.96%	5.57%
2	N_2	81.5%	81.4%	81.3%	81.2%	81.1%	81.0%	80.9%	80.9%

Notes for creating a spreadsheet in Excel or similar:

- The grey cells contain parameter values that can be changed manually. Unshaded cells contain values that are calculated automatically by the spreadsheet.
- In order to generate a spreadsheet that will generate the Fig 3A Combustion Triangle, three extra columns are needed to accommodate results for Air Ratios 1.40, 1.45 and 1.50.
- "Fuel Lines" for each fuel type can be generated using values in Lines 20 and 21 for its ordinates and abscissa.
- The calculation should be replicated using different fuel values in cells C2, C3 and C4 to generate additional "Fuel Lines".

The Air Ratio lines can be generated by joining up the Fuel Line values for each air ratio. This can be achieved by copying the relevant values into a separate table from which the lines can be derived.

Calculation Methodology

Note: shaded cells indicate parameter values. All other values are calculated.

Item	Constituent	Formula	#	units	Value	Cell
Fuel Analysis (Ultimate) by mass	Carbon – C’		{1}	-	71.6%	C2
	Hydrogen – H’		{2}	-	4.7%	C3
	Nitrogen – N’		{3}	-	1.3%	
	Sulphur – S’		{4}	-	1.7%	
	Ash		{5}	-	15.0%	
	Oxygen by difference O’	100 - ∑{1}-{5}	{6}	-	5.7%	C4
		Total		-	100.0%	
Carbon / hydrogen Ratio		= {1}/{2}	{7}	-	15.23	F1=F
Grams H_2 per {7} grams of carbon			{8}	g	1.00	F3
Oxygen content		= {6}	{9}	-	5.7%	F4
Molar mass	Carbon		{10}	g/mol	12	G2
	Hydrogen		{11}	g/mol	2	G3
	Oxygen		{12}	g/mol	32	G4
Air content	Oxygen		{13}	%	21.00	I2
	Nitrogen		{14}	%	79.00	I3
Fuel Mass Analysis	Carbon	= (1-{9})x{7}/({7}+{8})	{15}	%	88.49	C7
	Hydrogen	= (1-{9})x{8}/({7}+{8})	{16}	%	5.81	B7
	Oxygen	={9}	{17}	%	5.70	A7
Fuel Molar Analysis	Carbon	={15}/{10}	{18}	mols	7.37	F7
	Hydrogen	={16}/{11}	{19}	mols	2.90	E7
	Oxygen	={17}/{12}	{20}	mols	0.18	D7
Molar Analysis %	Carbon	={18}/({18}+{19}+{20})	{21}	%	70.52	I7
	Hydrogen	={19}/({18}+{19}+{20})	{22}	%	27.78	H7
	Oxygen	={20}/({18}+{19}+{20})	{23}	%	1.70	G7
Air Ratio			{24}		1.00	B8
Molar basis C to CO_2						
C & CO_2		={21}	{25}	mols	70.52	B10
O_2 used		=(25}	{26}	mols	70.52	B11
Molar basis H_2 to H_2O						
H_2 & H_2O		={22}	{27}	mols	27.78	B13
O_2 used		={27}/2	{28}	mols	13.89	B14
O_2 in coal		={23}	{29}	mols	1.70	B15
Total O_2 used		=({26}+{28}-{29})x{24}	{30}	mols	82.71	B16
N_2 mols		={30}x{14}/{13}	{31}	mols	311.1	B17
O_2 left over		={30}-{\$30}	{32}	mols	0.0	B18
Combustion Gas volumes %						
CO_2		={25}/({25}+{31}+{32})	{33}	%	18.48	B20
O_2		={32}/({25}+{31}+{32})	{34}	%	0.00	B21
N_2		={31}/({25}+{31}+{32})	{35}	%	81.52	B22
	Repeat calcs for Air Ratios 1.05 to 1.50		{36}	exam-	1.20	F8
Molar basis C to CO_2						
C & CO_2		={21}	{37}	mols	70.52	F10
O_2 used		=(37}	{38}	mols	70.52	F11
Molar basis H_2 to H_2O						
H_2 & H_2O		={22}	{39}	mols	27.78	F13
O_2 used		={39}/2	{40}	mols	13.89	F14
O_2 in coal		={23}	{41}	mols	1.70	F15
Total O_2 use		=({39}+{40}-{41})x{36}	{42}	mols	99.25	F16
N_2 mols		={42}x{14}/{13}	{43}	mols	373.4	F17
O_2 left over		={42}-{\$30}	{44}	mols	16.5	F18
Combustion Gas volumes %						
CO_2		={37}/({37}+{43}+{44})	{45}	%	15.32	F20
O_2		={44}/({37}+{43}+{44})	{46}	%	3.59	F21
N_2		={43}/({37}+{43}+{44})	{47}	%	81.09	F22

2. This is the percentage of carbon within the combination of C, H_2 and O_2, i.e. excluding N_2, S and ash.
3. Likewise, this is the percentage of hydrogen within the combination of C, H_2 and O_2, i.e. excluding N_2, S and ash.

DERIVATION OF THE LOCOMOTIVE ENERGY BALANCE - PART 2

Martin Johnson

1. INTRODUCTION

I demonstrated in Part 1 that Fry's method of deriving an energy balance introduces errors since it assumes that fuel lost is the same composition as fuel fired. In fact fuel lost is mainly carbon (soot, smoke and cinders), which modifies the composition of the fuel burnt and also affects the derived gas flows. The two graphs comparing Fry's and my method in the first part of this article were affected by conversions between file types, so I show the two graphs as they should have appeared here:

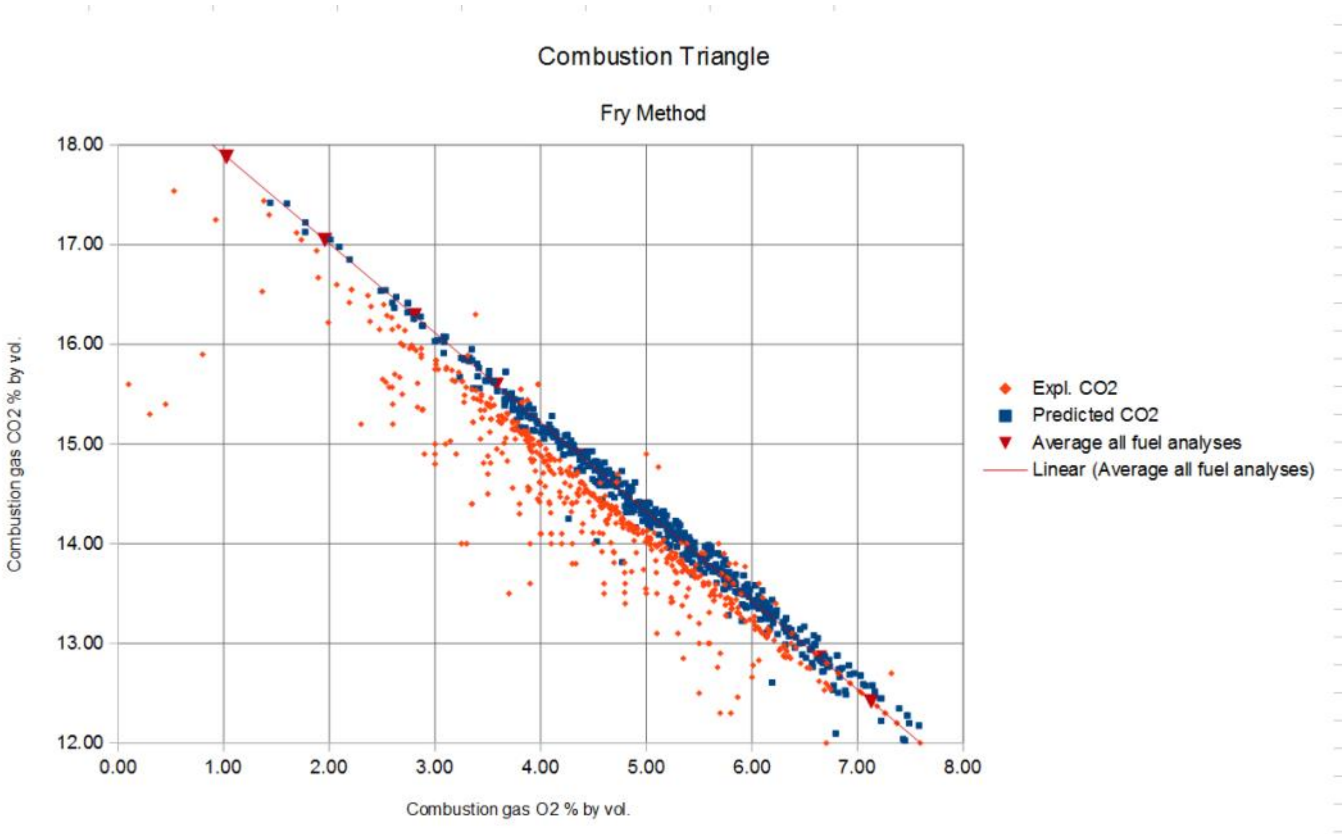


Figure 1: Combustion triangle for Rugby test data using Fry's method.

Figure 1 shows that using Fry's method to back calculate combustion gas readings results in a significant shift between observed gas readings and back calculated, indicating errors in the method.

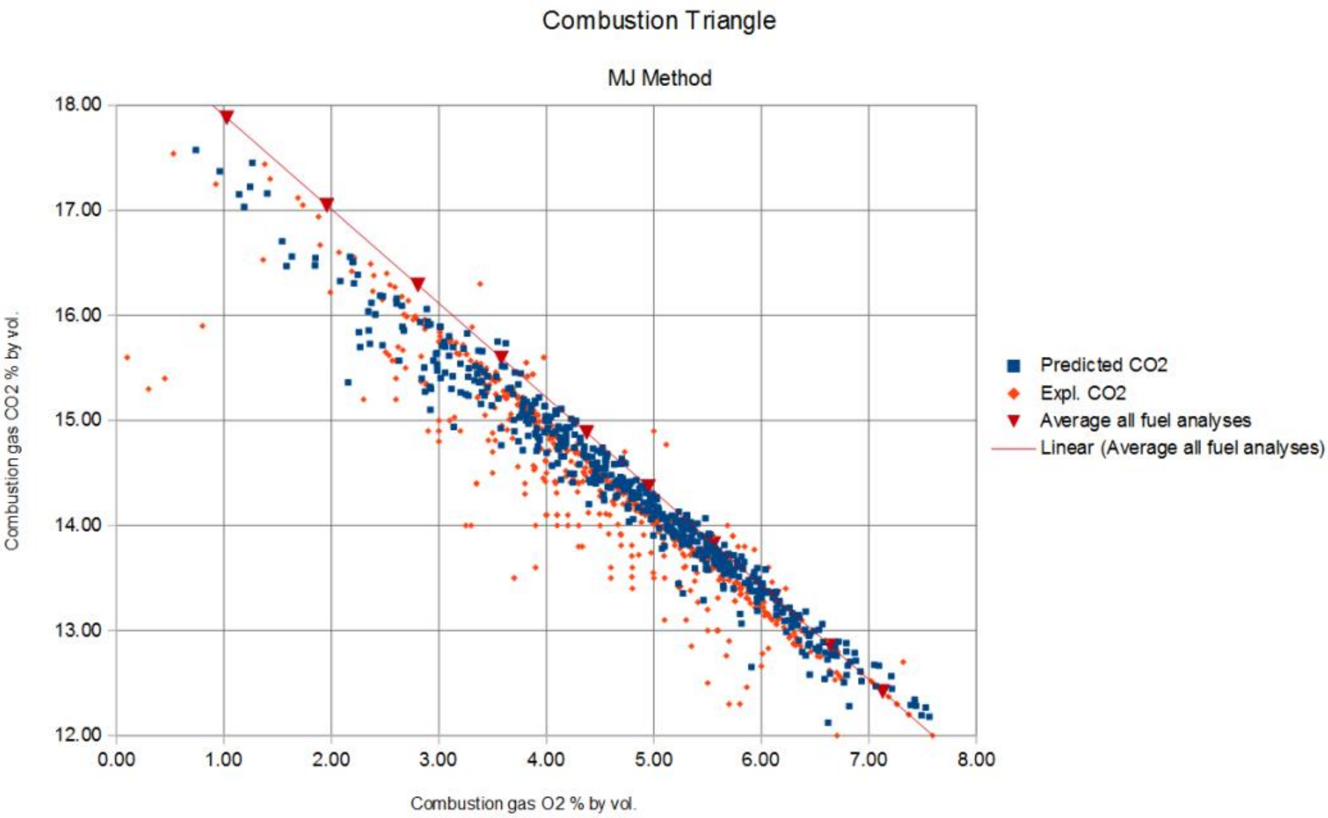


Figure 2: Combustion triangle for Rugby test data using MJ method.

My modified method assumes that fuel is lost as carbon and by an iterative process derives the correct amount of combusted carbon and hence gas flow. The benefit of this approach was demonstrated by back calculating the combustion gas composition and comparing it with experimental results as shown in Figure 2 above, which no longer shows such a clear discrepancy between experimental and back calculated gas results.

This article moves on to examine the implications of the improved calculation method.

2. DOES THE PROPOSED METHOD GIVE A DIFFERENT ANSWER?

The proposed method of calculating energy balances predicts a significantly lower gas flow than Fry, and hence lower loss of heat from the chimney. Figure 3 shows a comparison of specific air flows as derived by my proposed method compared to Fry's method. The straight line shows a unity correspondence between methods. At specific air flows below 13 kg air/kg fuel (generally associated with higher grate loadings), my calculations give lower predictions by about 20% depending on air flow. So at high combustion rates, a locomotive front end is handling lower gas quantities than previously thought, but will be handling significant amounts of lost carbon in addition to combustion gas.

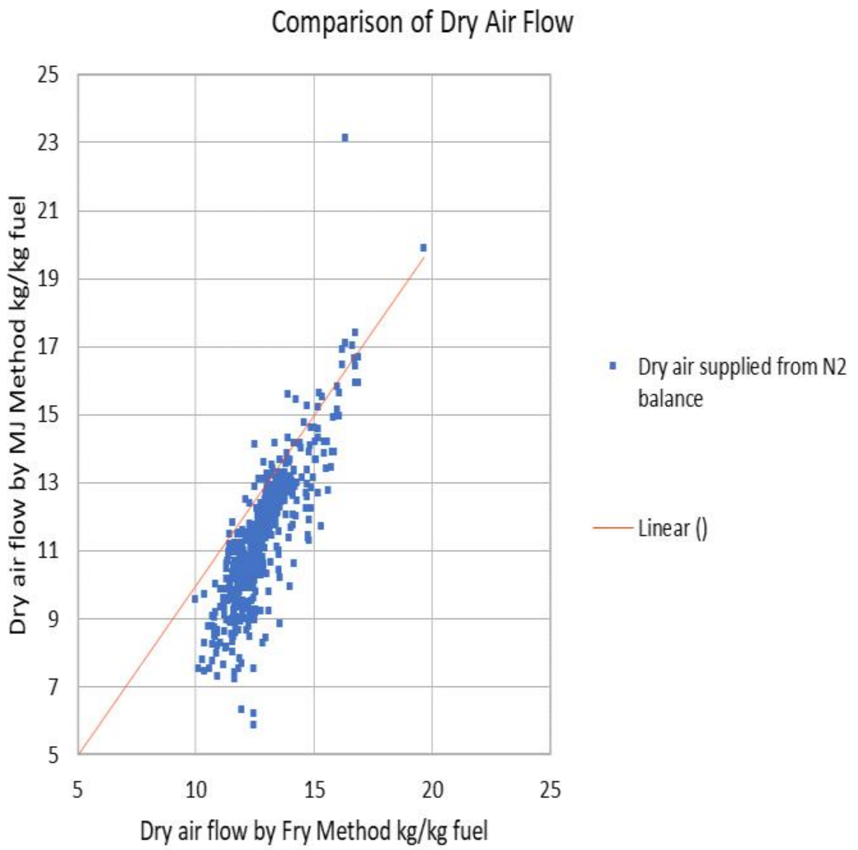


Figure 3: Comparison of dry air flow by proposed method and Fry's Method

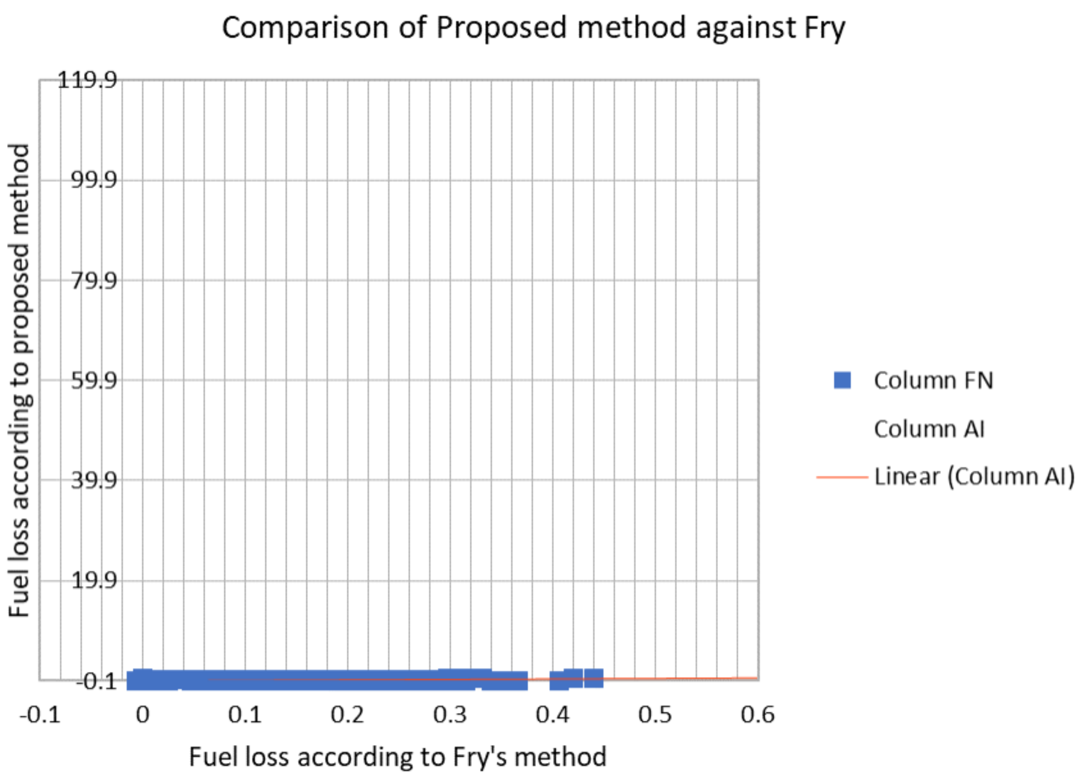


Figure 4: Comparison of fuel loss according to proposed method and Fry

Figure 4 shows a comparison of ratio of dry coal lost according to both methods, and as before the straight line would represent perfect agreement between methods. The proposed method shows a slightly lower loss of fuel. This is a rather surprising result which requires some explanation. The Fry method assumes the calorific value of the coal lost is as the complete sample including ash whereas my method assumes pure carbon is lost which has a higher calorific value than the coals used for the Rugby tests. It would seem that this difference in calorific value more than offsets the reduction in stack losses due to the lower gas flow.

So while the quantity of fuel lost may not be significantly different between Fry's and my method, the quantity of combustion gas does change significantly at higher grate loadings. This has implications for our understanding of front end performance - we are actually pumping less combustion gas than previously thought.

3. CONSTRUCTING A COMBUSTION MODEL

My principal reason for following this line of research has been to provide more reliable combustion data for boiler modelling software. As others have pointed out, the absorption efficiency of boilers covers a relatively narrow band but combustion efficiency including fuel losses is more difficult to quantify. This development should also account for fuel of the future that may not perform in the same way as good quality coal of the past.

3.1. What is the Independent Variable?

Past practice dictates that just about everything is correlated against grate loading or fuel flow. Fuel flow and grate loading are easy to measure to good accuracy. However, a significant mass of carbon is stored on the grate. Therefore instantaneous combustion rate may vary significantly from firing rate.

The key feature of the Stephenson locomotive is to make the air flow roughly proportional to the work done so that steam production stays in step with demand. Therefore, it seems logical to me that the independent variable should be air flow. The fireman's task is to feed fuel at a rate which maintains a suitable thickness of granular carbon on the grate in a manner that maintains maximum combustion efficiency. The locomotive does the rest (which I acknowledge is an over-simplification of the reality).

Therefore, I choose to correlate against air flow.

3.2. A General View

A conventional (non GPCS) locomotive fire generally consists of two parts:

- A granular bed of mainly carbon, through which air is forced by the locomotive front end. Some of the carbon will burn, reducing the available oxygen to the area above the fire.
- A volume above the bed where volatile hydrocarbons and particulate carbon are burnt.

Following the argument through, I reasoned that combustion rate would be a function of air flow. As a first step, I considered only the combustible content of the coal (eliminating ash, nitrogen and moisture). However, the amount of coal burnt would still not be precisely related to air flow as coals of differing chemical analyses, and particularly oxygen content will require differing theoretical (stoichiometric) quantities of air for combustion (See Ref. 5.2). A further complication is that the stoichiometric air demand must apply to the fuel net of carbon lost. So I chose to plot the stoichiometric air demand of the combustible fuel burnt (net of carbon losses) against air supply.

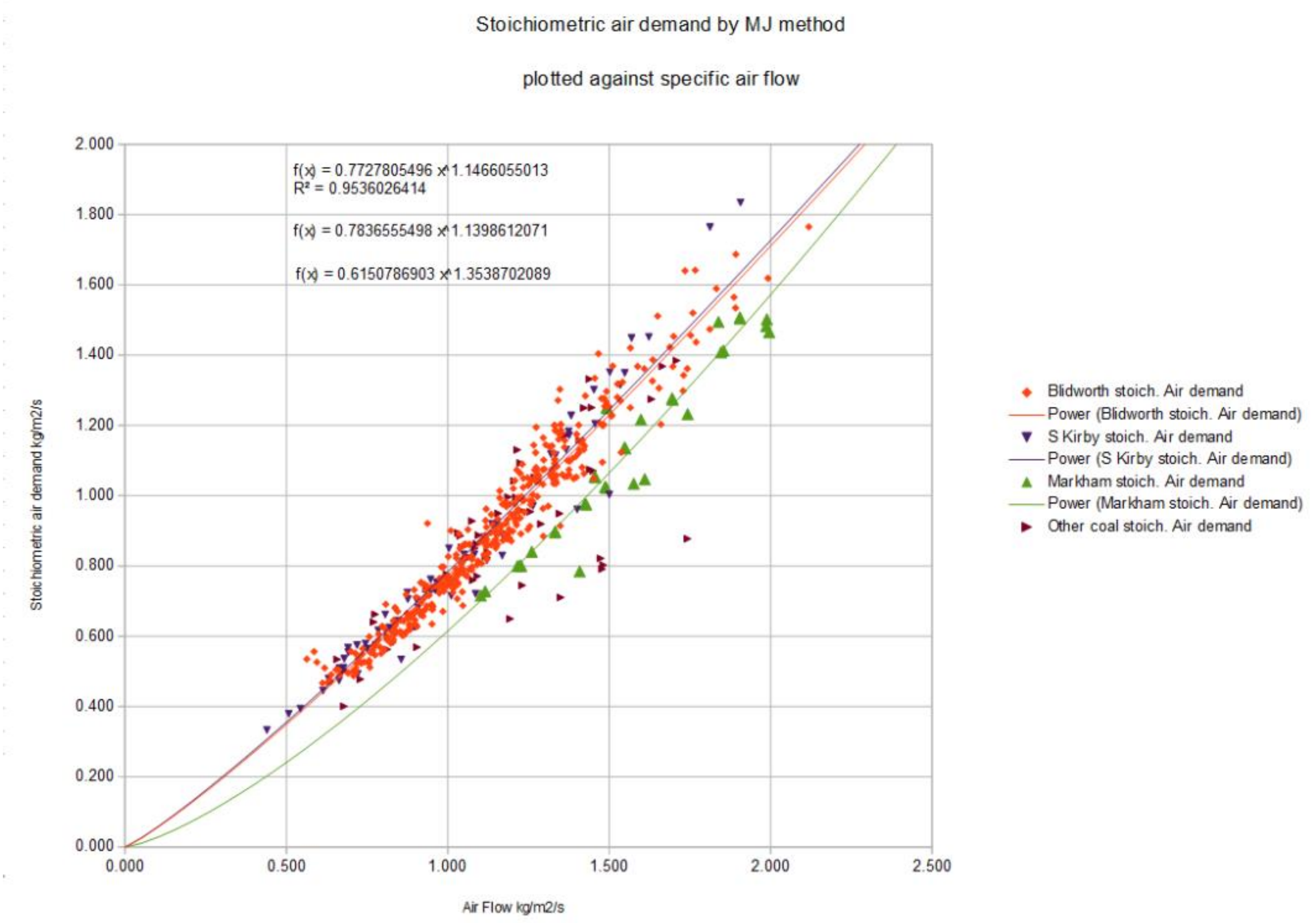


Figure 5: Correlation of stoichiometric air demand of combustible fuel burnt (net of fuel loss) against specific air flow

Figure 5 shows a good correlation using a power law curve fit. The Blidworth and South Kirby coals give very similar curve fits with a good degree of correlation ($R^2 > 0.95$ for Blidworth coal).

However, Markham coal shows a stoichiometric air demand some 80% of the Blidworth & South Kirby data, meaning for a given air flow some 20% less Markham coal is burnt and the discrepancy is not due to the chemical content of the coal. There is also a small grouping of data relating to tests on Merchant Navy class 35022 at the lowest edge of the data between air flows of 1.2 to 1.7 kg/m^3/s. There is insufficient data to determine why some data follows a different pattern, but the following factors might be involved:

- Particle size of the coal - a coarser coal would offer less surface area for reaction with oxygen meaning that within a given fire bed not so much air could be consumed. Note that particle size distribution of a coal in a firebox is not the same as a particle size distribution determined on an unburnt sample.
- The fire bed might be run thinner for Markham coal. All the data for Markham coal was determined on King class 6001, and might represent Western Region firing practice.
- The hardness of the coal may prevent the air getting to the carbon so easily, giving a similar effect as coarser particle size.
- There may be some effect due to the design details of King class locomotives such as a particularly long sloping grate.
- Experimental error.

3.3 Generation of Carbon Monoxide

Carbon monoxide is the result of insufficient oxygen in the reaction between carbon and oxygen. The lack of oxygen may be due to insufficient air or inefficient mixing meaning that oxygen may be present, but not sufficiently mixed to react with all the carbon.

Porta (Ref. 5.1) associates the presence of CO with free hydrogen in the exhaust, which suggests some influence due to the water gas shift reaction where CO oxidises to CO_2 taking oxygen from H_2O, to leave CO_2 and H_2. My analysis does not consider this mechanism.

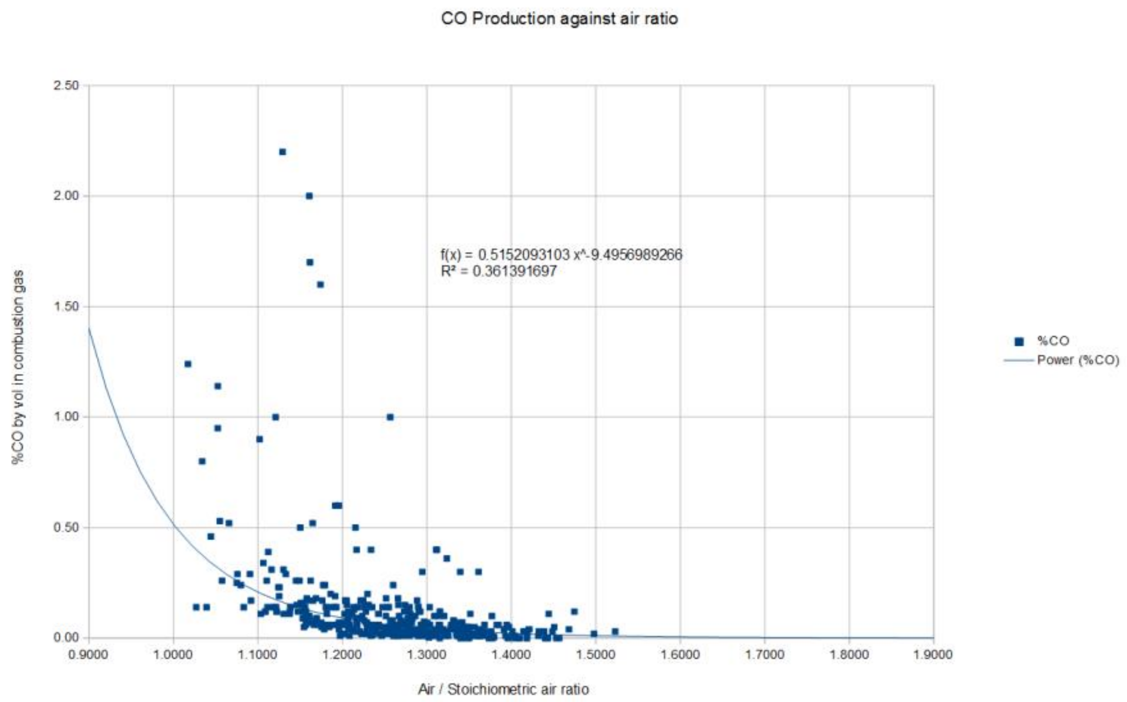


Figure 6: Carbon monoxide volume plotted against stoichiometric air ratio

The data for CO in the Rugby tests is scattered which is to be expected since most readings are less than 1% by volume, so experimental error is large. I tried a number of possible correlations, but the most reliable was found by plotting amount of CO against air flow/stoichiometric air flow which is shown in Figure 6. A power law model fits the data reasonably well.

3.4 Fuel Loss

Fuel loss has been shown to comprise principally carbon which may be lost as:

- Unburnt material in the ashpan
- Unburnt particles ejected as soot
- Unburnt large particles ejected (or filling the smokebox) as char

Other studies have shown that ashpan carbon comprises roughly 5% of the lost material. The present study has no means of determining exactly where the carbon is lost.

Relatively large amounts of carbon can be lost as large particles, particularly at higher steaming rates when air flow through the grate becomes sufficient to lift particles off the fire bed. Once lifted a particle may continue to burn, but only in full size practice is it likely to have sufficient time to burn completely before being taken into the tube bank and extinguished. I hope to consider some of the mechanisms behind fuel loss in more detail in another article.

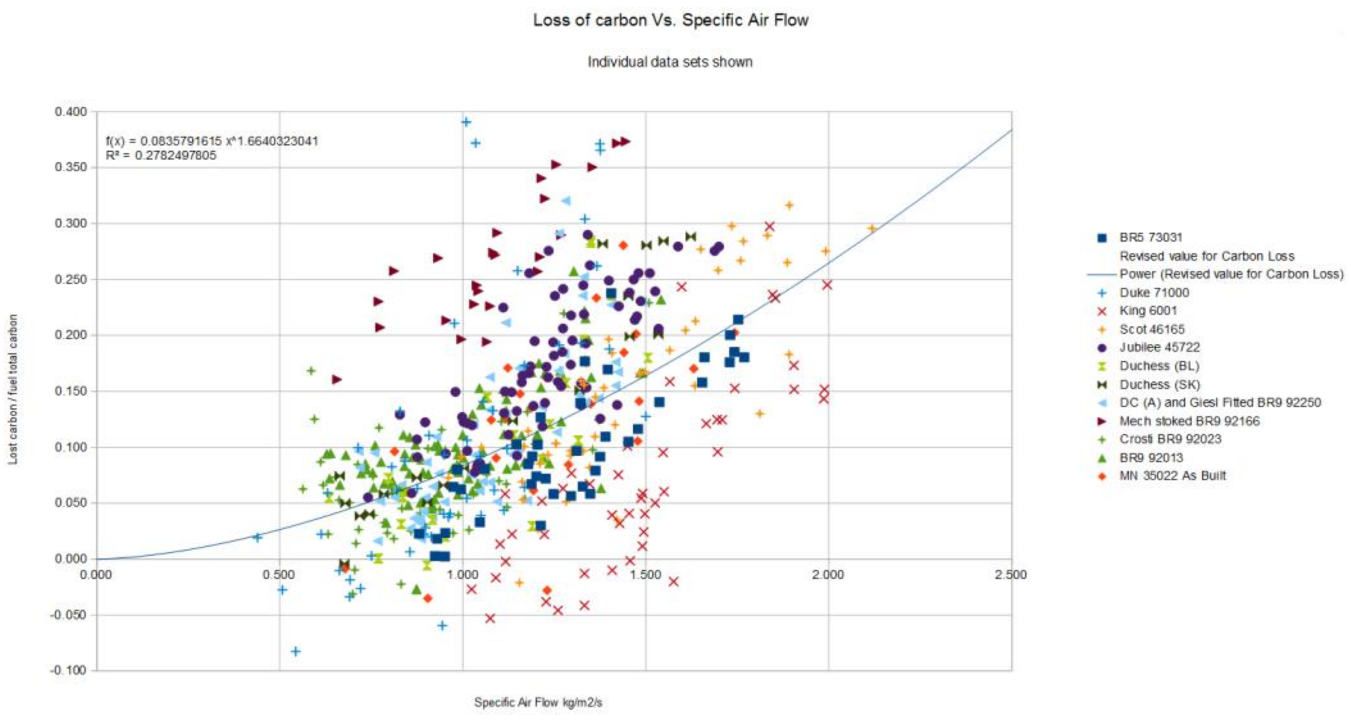


Figure 7: Carbon loss as a ratio of carbon in fuel as a function of specific air flow through the grate.

Figure 7 shows a summary of the carbon loss derived using my method of energy balance, plotted against specific air flow. As expected, carbon loss is modest at low air flows, but rises rapidly at higher air flows and a power law model fits the scattered data reasonably well.

Looking at the data in more detail, the tests on King 6001 show remarkably low carbon losses while the mechanically stoked 92166 show very high losses. The high loss due to mechanical stoking is largely expected for several reasons:

- The coal is likely to be finer, so losses of a given particle size would represent a larger proportion of the whole.
- The coal is "sprayed" round the grate by steam jets, so some coal may never reach the fire bed, being carried away by the gas flow.
- The steam jets cool the furnace gases and the heat energy of the steam is then lost to the chimney losses.

The low losses on the King are unusual and having already noted that the combustion rate for a given air flow is significantly lower on those tests, it is likely the two effects are linked.

Looking at some of the other locomotive classes tested, it appeared that wide firebox designs tended to give increased carbon loss at air flows above approximately 1.2 kg/m^2/s, so I replotted Figure 7 but with the data sorted into wide and narrow firebox designs.

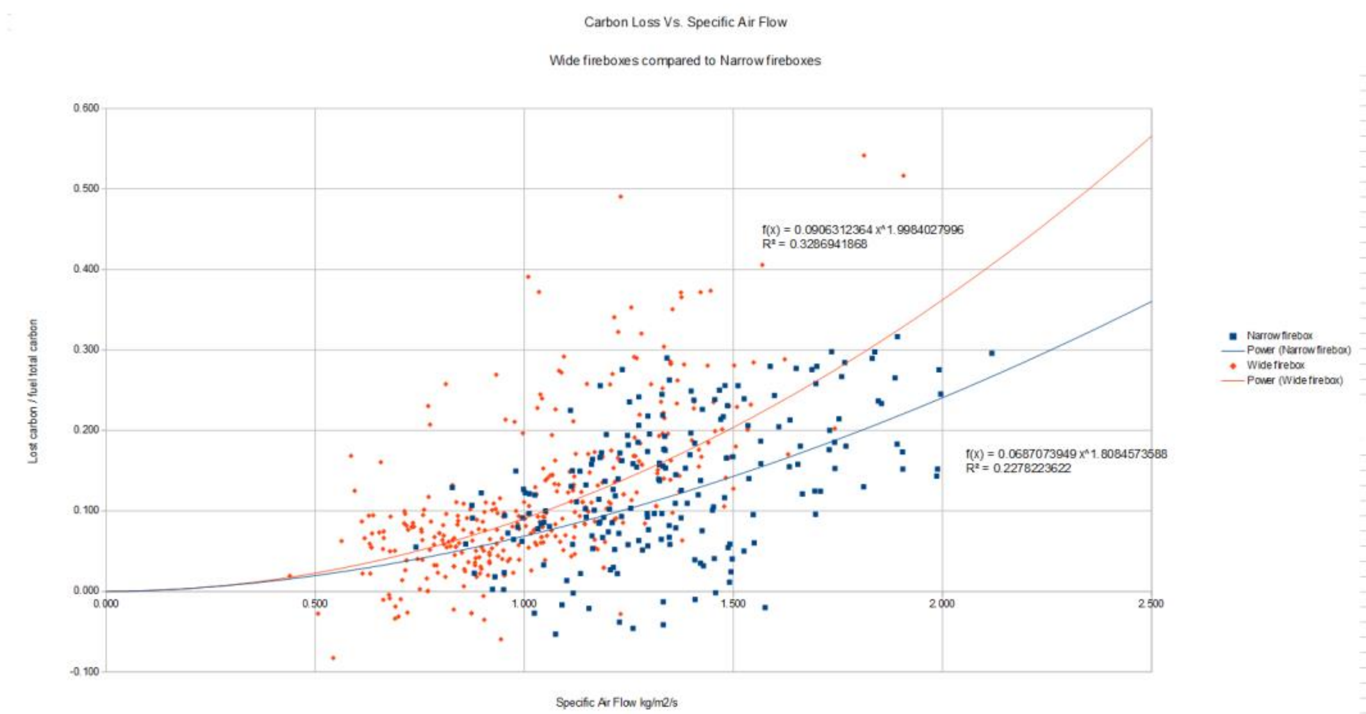


Figure 8: Carbon loss Vs. air flow for wide and narrow firebox designs.

As before, I fitted power law curves through each set of data, and there is a marked increase in carbon loss for wide fireboxes over narrow. At modest firing rates, the fuel loss in a wide firebox is some 30% higher than for narrow and the gap widens at higher firing rates.

4. CONCLUSIONS

Fuel loss has been shown to be mainly carbon as demonstrated by improved mass balances, and improved agreement between back calculated and experimental flue gas analyses using the proposed methods.

The proposed method of analysing locomotive tests gives an energy balance in which the air flow is significantly less than that derived by the Fry method. The quantity of unburnt fuel is broadly similar, but is defined here as carbon loss rather than coal loss.

Three parameters have been correlated against air flow through the grate:

- Stoichiometric air demand yields a good correlation against air flow.
- Carbon monoxide generation gives a poor correlation, reflecting scattered data of poor accuracy. Nevertheless, the correlation is probably adequate for numerical modelling of the combustion process.
- Fuel loss for both narrow and wide fireboxes give poor correlation, but sufficient to be confident of a difference in performance between the two. The poor correlation is probably due to scattered data derived from multiple experimental readings.

4.1. Further Work

I intend to check whether the above three correlations will give better agreement with original data when used to back calculate that data. On the assumption that can be achieved, I shall be implementing the correlations into my boiler analysis program.

Work needs to be done to consider how widely the results which are based on main line practice on good quality coal (by 21st century standards) can be applied to smaller locomotives and working miniatures potentially burning replacement eco fuels. Limited data to hand suggests that miniature locomotives show a lower stochiometric air demand at a given air flow and higher carbon losses at a given air flow.

The iterative methods used in deriving the energy balance here can equally well be used to determine combustion conditions in the same way that Porta proposed. While the data can be expected to show widely scattered results, it will be interesting to see if the same general trends can be confirmed by relying only on combustion gas analysis to determine air ratio and fuel loss.

4.2. A Plea for Help

If anyone can help with details of firebox dimensions for the following classes, I would be very grateful:

- 9F
- Duke 71000
- Duchess
- Merchant Navy (as built)
- Royal Scot

5. REFERENCES

5.1. Porta, L.D. "*Locomotive Boiler Combustion Calculations - The Heat Balance, A criticism of the Lawford Fry Method*" in Selection of Papers by L.D. Porta, Vol. 3 Ed. by C. Newman, Publ. ASTT 2021

5.2. Anon - "*Steam, Its Generation And Use*" Publ. Babcock & Wilcox Company – Chapters "*Combustion*" and "*Analysis of Flue Gases*". Can be found at : http://www.gutenberg.org/files/22657/22657-h/22657-h.htm

CAPROTTI - POPPET SIZE VALVE DESIGN SPECIFICATION

Graham Shirley, CEng

An advanced steam engine should consider poppet valves. The specification of the Poppet valves sizes for a locomotive cylinder application was a procedure regularly exercised in the 1950 by the ALE steam traction department. The design proposal calculations exist for the following dreams, and some were implemented.

Valve Size Specifications Calculations				
Item HMRS C12	**No Pages**	**Description**	**Date**	**Author**
7	3	New Zealand Government Railway JA Class	22 Oct 1952	LTD
8	5	New Zealand Government Railway K Class	16 Feb 1952	LTD
9	2	BR Class 8 Duke of Gloucester with extended steam capacity	31 Mar 1953	LTD
13	2	Argentine Railways (BAP) Mikado	28 May 1951	LTD
14	1	Argentine Railways San Martin Mikado	27 July 1951	LTD
17	1	South African Railway 25 NC Class 4-8-4	N/A	JCM
21	2	Indian Government Railway WG Class loco	3 Jul 1952	LTD
24	2	FNG Roca Class 8E Loco Argentine	5 Oct 1954	LTD
25	2	Hawksworth County Class 1000 Weston Region BR	5 Oct 1954	LTD
26	2	BR Class 5 4-6-0	8 Aug 1955	LTD
27	2	BR Class 9F 2-10-0	11 Aug 1955	LTD

The calculation procedure is outlined in a document, the work of L T Daniels & FP. Caprotti valves operate with the valve stem in the vertical direction and the valve operates in a cage which includes the guide bearing for the valve seat as one modular assembly. See figures 1,2 and 3.

<u>Determination of Poppet Valve Size.</u>

1. 10% of piston area gives approximate Indication of inlet poppet valve size.

2. Comparison with analysis of steam and exhaust areas as shown on Sk.No.10.304/2 gives a guide as to the relative areas from regulator to blast pipe cap. This enables more particularly comparison with the Pennsylvania Railroad T.1 class locomotives which gave the lowest water rate ever recorded on the Altoona Test Plant.

3. Such bases for fixing valve sizes take no account of such important details as wheel diameter, maximum speed, boiler pressure, degree of superheat etc. which have an important bearing on the volume of steam to be handled and the speed at which it is required to flow. The following

method takes account of these factors.

Calculation for Inlet Poppet Valve.

1. Ascertain the specific volume in cu. ft. per lb. of the steam at the superheat temperature and pressure of the boiler.
2. Determine the volume of steam available per valve per rev. from the steam rate of the boiler and the r.p.m. of the wheels.
3. Determine the theoretical cut—off thus possible for $maximum\ output = (Consumption\ per\ rev.\ per\ valve)/(Volume\ of\ cylinder)$
4. Convert theoretical cut-off into time in minutes that the valve is open to steam and taking steam speed at 200 ft. per second (12,000 ft. per min.) obtain inlet valve area necessary to pass the volume of steam available.
5. Choose the nearest standard valve to give requisite area.

Calculation for Exhaust Poppet Valve.

1. Using theoretical cut—off lay down expansion curve. $Pv^{1.3} =$ C and establish the pressure at release point.
2. Connect release point to back pressure line at end of stroke with straight line to represent pressure drop.
3. So long as ratio of release pressure to back pressure is above 1.6 steam speed will be the critical (speed of sound) approximating to 1,300 ft. per sec.
4. When ratio drops below 1.6 the speed will drop from critical to nil at the end of the stroke.
5. From 3 and 4 the average steam speed over the whole release period is determined.
6. The volume of steam in the cylinder, the time the valve is open, and the average steam speed then enables the approximate valve area required to pass the steam to be determined.

BRITISH-CAPROTTI VALVE GEAR POPPET VALVE FLOW AREA 5.5 INCH TO 9.25 INCH DIAMETER.						
INLET						**EXHAUST**
VALVE SIZE DIA	MAX. AR-EA THRO’	AREA WITH LIFT	AREA WITH LIFT	AREA WITH LIFT	AREA WITH LIFT	AREA WITH LIFT
5.5	21.44	N/A	N/A	N/A	N/A	21.44
6.25	27.54	N/A	N/A	N/A	N/A	27.54
7	32.47	N/A	N/A	N/A	N/A	32.47
7.75	38.87	38.25	N/A	N/A	N/A	38.87
8.25	45.12	41.7	46.58	N/A	N/A	45.12
8.5	48.023	42.5	47.6	50.54	N/A	48.023
8.75	50.99	44.19	49.4	52	N/A	50.99
9	54.81	45.46	50.8	53.4	57.04	54.81
9.25	57.5	46.7	52.2	54.95	58.6	57.5

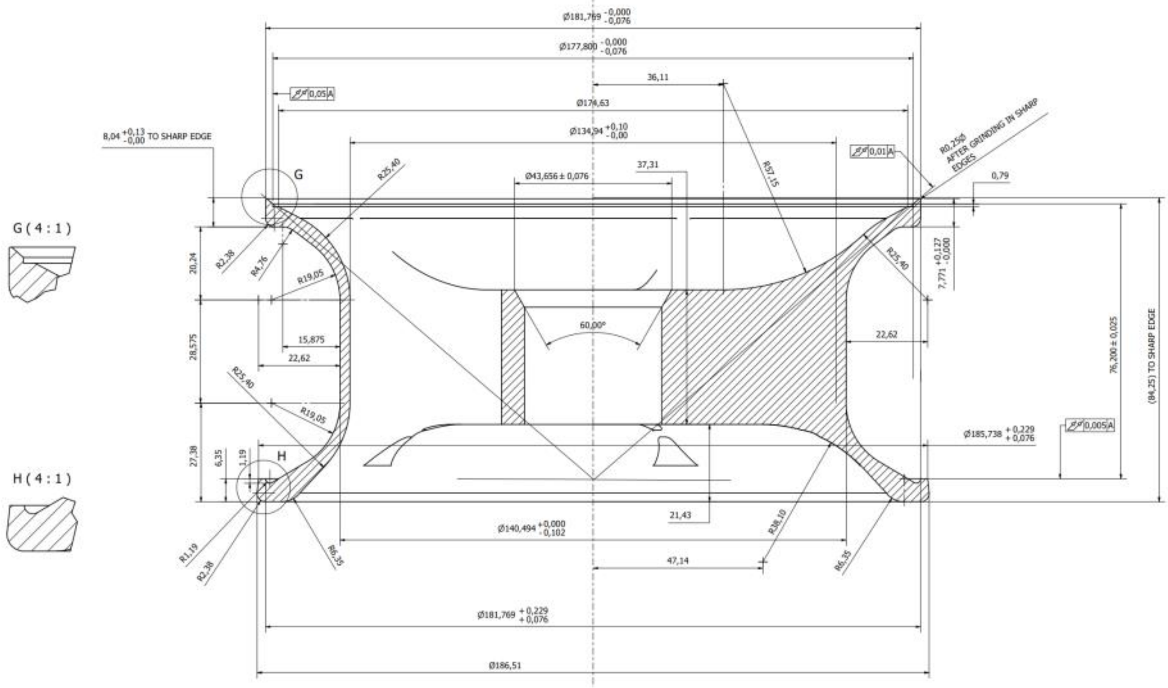


Figure 1 7" V.601 DIA EXH POPPET VALVE

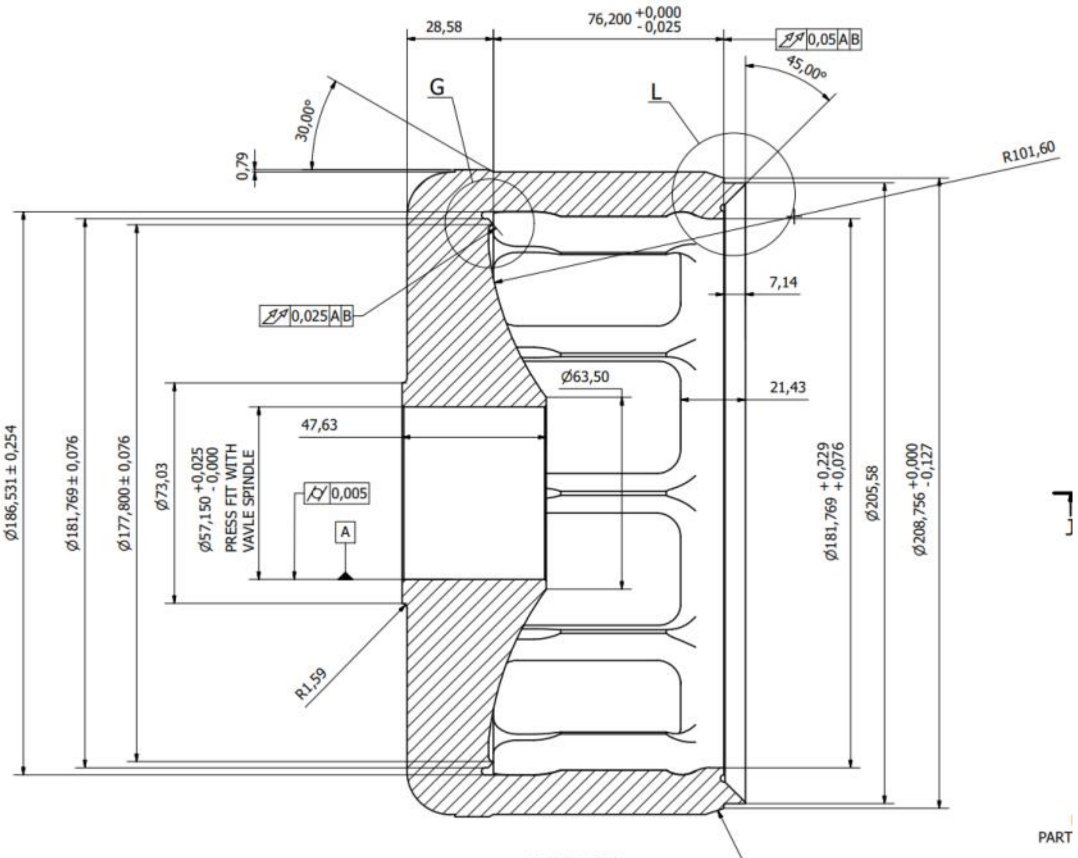


Figure 2 V.602 7" DIA POPPET EXHAUST CAGE

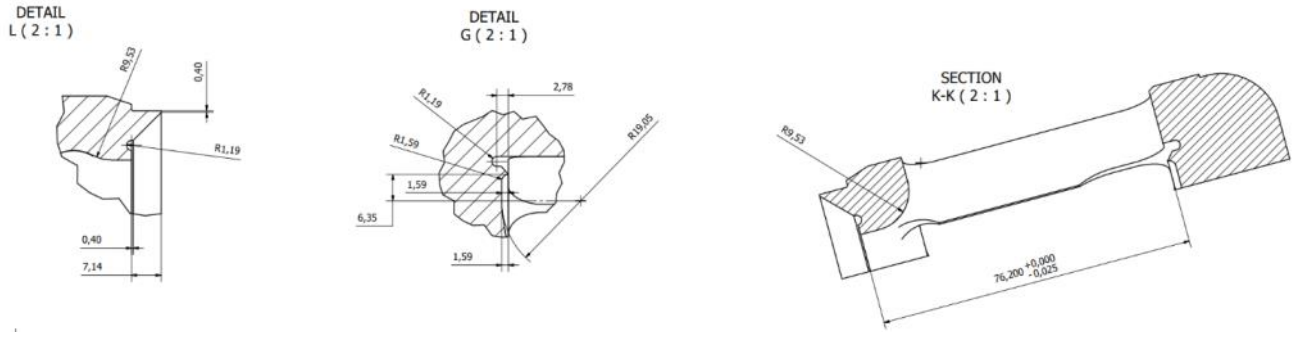


Figure 3 Caprotti valve seat faces

ASTT readers will be familiar with the South African Railway 25 NC Class 4-8-4 and the calculations are presented here as a worked example to illustrate the procedure. The original hand calculations are shown in figure 4 and 5 and have been dusted off and reproduced in a modern computer form for easier comprehension.

17/1

SOUTH AFRICAN RLY. 25 NC CLASS - 4-8-4.

VALUE SIZES.

By Cole's system.

Cylinder HP = ·0229 P.A. [Superheated and 2 cyl. locos.] Where P = Boiler Pressure

= ·0229 × 225 × ·7854 × 24². A = Area of one piston

= 2324 HP. Cyl. = 24 × 28″

∴ Maximum Steam Demand = 2324 HP × 20.8

= 48,400 lbs per hr.

From Henschel Formulae.

Steam Demand = Max. continuous IHP × Specific Steam Consumption

and IHP $= \frac{MEP \times L \times A \times N \times 2 \times 4}{33{,}000}$ MEP from Henschel curve = 57.5 with steaming rate of 57 kg/sq.m.

$= \frac{57.5 \times 2.33 \times 24^2 \times .7854 \times 8}{33{,}000}$ = 2200 HP.

Specific steam consumption by Henschel = 15.5 lb/HP say 16 to allow for difference in metric HP

Then Steam Demand = 2200 × 16 = 35200 lb/hr.

Also at same steaming rate = 57 k/□.m. = 11.81 lb./□ ft.

H = Heating surface (Tube) = $\frac{\text{Steam demand/hr.}}{\text{Steaming rate}}$ H = 3390 sq. ft. R.G. 15 sq. ft.

∴ Steam demand = 3390 × 11.81 = 40,000 lbs / hr.

Taking mean of the two IHP formulae. Steam = 42,000 lb/hr.

Data and Assumptions.

Boiler Pressure = 225 lb/□″. Steam Chest assumed 215 lb./□″.

Steaming Capacity = 42.000 lb/hr.

Superheat = 650° F assumed.

Working Speed = 55 m.p.h. max.

Wheel diameter = 5 ft.

R.P.M = 310 approx.

Inlet Valve Size.

With Steam at 650° and Steam chest pressure 215 lb/□″

Specific volume = 3 c. ft./lb.

Volume of cylinder = ·7854 × 2² × 2.33 = 7.33 cu. ft.

Figure 4 SAR 25NC - Hand Calculation Page 1.

17/2.

Inlet Valve Size cont.

Consumption of steam per rev. = $\frac{42000}{310 \times 60}$ =

& " " " " 4 valve = $\frac{42000}{310 \times 60 \times 4}$ = .565 lbs.

= $\cdot 565 \times 3$ = 1.695 cu.ft.

$\therefore$ Theoretical cut-off = $\frac{1.695}{7.33}$ = 23.15 %.

Allowing for gradual closing of valve make effective cut off . 20%.

20 % Cut off angle = 53° = ·1472 rev.

$\therefore$ Time valve is open = $\frac{\cdot 1472 \times 60}{310}$ = ·0285 secs.

$\therefore$ Area of valve required = $\frac{1.695 \times 144}{\cdot 0285 \times 200}$ [Steam speed assumed 200 ft/sec

= 42.8 sq. in.

Exhaust Valve size.

Taking mean steam speed from release to end of stroke = 866 ft/sec.
(From Albino's specimen calculation)

At 23.15 % cut-off. Release angle = 51°. (R.D. cams. Release at 5% C.O. 55%)
and release occurs at 82% of stroke.

Volume of steam at release = ·82 × 7.33 = 6 cu. ft.

Time valve is open = $\frac{51}{360} \times \frac{60}{310}$ = ·0274 secs.

$\therefore$ Area of valve required = $\frac{6 \times 144}{\cdot 0274 \times 866}$ = 36.5 sq.in.

Figure 5 Hand Calculation Page 2.

REF: C17 Historical Model Railway Society - ALE Technical Data Valve Sizes calculation pack Page 17 Author John Milton 1953.

REF
https://en.wikipedia.org/wiki/South_African_Class_25NC_4-8-4

Poppet Valve size specification

1. 0 General Data

$Boiler\_Pressure := 225\ psi$

$Steam\_chest\_pressure := 215\ psi$ Assumed

$Wheel\_Dia := 5\ ft$

$Speed := 55\ mph$ Assumed

$Cylinder\_Dia := 24\ in$

$Cylinder\_Stroke := 28\ in$

$Boiler\_Steam\_Capacity := 42000\ \frac{lb}{hr}$ Ref: See below

$Steam\_temp := 650\ °F$ Assumed

$No\_Cylinders := 2$

Calculated Data

$$Speed\_crank := \frac{Speed \cdot 2 \cdot \pi}{Wheel\_Dia \cdot \pi}$$

$Speed\_crank = 308\ rpm$ $Cylinder\_Stroke \cdot 2 \cdot Speed\_crank = 45.9\ \frac{m}{s}$

Estimate engine power by Alco system also reffered to as Coles system..

$$A := \left(\frac{Cylinder\_Dia}{2}\right)^2 \cdot \pi$$ Area of Piston

$A = 3.1416\ ft^2$

$$A \cdot \frac{Steam\_chest\_pressure}{2}$$

$$Cylinder\_HP := 0.0229\ \frac{hp}{psi\ in^2} \cdot Boiler\_Pressure \cdot A$$

$Cylinder\_HP = 1738\ kW$

REF: Locomotive Handbook, Page 67, 1917.
American Locomotive Company. Formula for 2 cylinders and super heaters.
Cylinder HP = 0.229.P.A
P = Boiler Pressure psi.
A = Area of one piston diameter

$$Cylinder\_HP := 0.1746 \cdot Cylinder\_Stroke \cdot 2 \cdot Speed\_crank \cdot A \cdot \frac{Steam\_chest\_pressure}{2}$$

$Cylinder\_HP = 2325\ hp$

From Henschel formula.

$Steam\_rate := 57.5\ \frac{kg}{m^2}$

$MEP := 57.5\ psi$ From Henschel curve with steaming rate 57 kg per m^2

$$Power\_Henschel := \frac{MEP \cdot Cylinder\_Stroke \cdot A \cdot Speed\_crank \cdot 2 \cdot 2}{2 \cdot \pi}$$

$Power\_Henschel = 1690\ kW$

$Power\_Henschel = 2267\ hp$

Where: $HP := \frac{PLAN}{33000}$

P=Mean Effective Pressure in Cylinder (MEP)
L=Length of Stroke in FEET (times 2 for Double acting engine)
A=Area of Piston in Inches
N=Revolutions per minute

Since 1 HP = 33,000 ft-lbf/min

Specific steam consumption by Henschel 15.5 lb per hp assume 16 to allow for differences in motion HP

$Specific\_steam\_per\_hp := 16\ \frac{lb}{hp}$

$Steam\_demand := Power\_Henschel \cdot Specific\_steam\_per\_hp$

$Steam\_demand = 36270\ lb$

$Steam\_rate = 11.78\ \frac{lb}{ft^2}$ See above

$Heating\_surface := \frac{Steam\_demand}{Steam\_rate}$

$Heating\_surface = 3080\ ft^2$

$Heating\_surface := 3390\ ft^2$ Override value selected by RG 15th May 1953

$Steam\_demand := Heating\_surface \cdot Steam\_rate$

$Steam\_demand = 39924\ lb$

1.0 Inlet Valve Sizes.

$Steam\_consumption\_per\_valve\_per\_hr := \frac{Boiler\_Steam\_Capacity}{No\_Cylinders \cdot 2}$

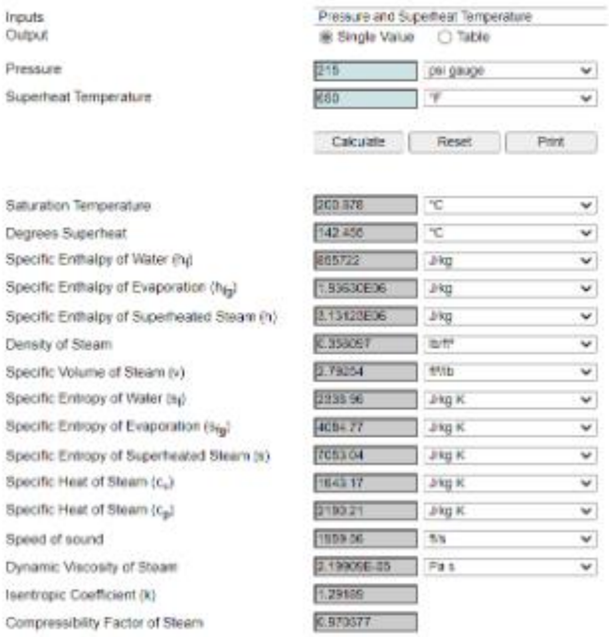
$Steam\_consumption\_per\_valve\_per\_hr = 10500\ \frac{lb}{hr}$

$Steam\_consumption\_per\_rev := \frac{Steam\_consumption\_per\_valve\_per\_hr \cdot 2 \cdot \pi}{Speed\_crank}$

$Steam\_consumption\_per\_rev = 0.568\ lb$

$Specific\_Volume := 2.56128\ \frac{ft^3}{lb}$

Superheated steam specific volume assuming steam chest at boiler
pressure gauge and 650 deg F superheating.
https://www.spiraxsarco.com/resources-and-design-tools/steam-tables/superheated-steam-region#article-top



$$Specific\_Volume := 3\ \frac{ft^3}{lb}$$

Figure used by ALE from Steam Table in 1953.

$$Steam\_consumption\_vol\_per\_rev := Steam\_consumption\_per\_rev \cdot Specific\_Volume$$

$$Steam\_consumption\_vol\_per\_rev = 1.704\ ft^3$$

$$Cylinder\_volume := \left(\frac{Cylinder\_Dia}{2}\right)^2 \cdot \pi \cdot Cylinder\_Stroke$$

$$Cylinder\_volume = 7.33\ ft^3$$

$$Theoretical\_cut\_off := \frac{Steam\_consumption\_vol\_per\_rev}{Cylinder\_volume}$$

$$Theoretical\_cut\_off = 23.24\ \%$$

Assuming 20% cut off as effective opening and steam at 200 ft per sec. ALE generally chose a figure short on the theoretical here.

$$Steam\_speed := 200\ \frac{ft}{s}$$

Steam speed is defined as the piston area divided by the valve area multiplied by the piston speed. 2000 ft/s is critical - sonic choking of flow. They assumed about 1 tenth for steam speed. The filling of the cylinder will be subsonic for most working cut offs. At full gear where the pressure ratio cylinder compression / stream chest is less than 0.55 flow may be choked but the engine speed low.

Calculate the cut off positions.

$Cut\_off\% := 20\ \%$

Neglecting the coupling rod definite length disturbance.

$\theta := acos(2 \cdot Cut\_off\% - 1)$ $\qquad \theta = 126.9\ deg$ $\qquad$ Angle at cut off from rear dead centre

$\alpha := 180\ deg - \theta$ $\qquad \alpha = 53.1\ deg$ $\qquad$ Angle at cut off from forward dead centre

$$Time\_Steam\_Admission := \frac{\alpha}{Speed\_crank}$$

$$Time\_Steam\_Admission = 0.0287\ s$$

$$Steam\_consumption := \frac{Steam\_consumption\_vol\_per\_rev}{Time\_Steam\_Admission}$$

$$Steam\_consumption = 59.29\ \frac{ft^3}{s}$$

$$Valve\_Area\_required := \frac{Steam\_consumption}{Steam\_speed}$$

$$Valve\_Area\_required = 42.7\ in^2$$

$$Poppet\_Area_{8.25} := 45.12\ in^2$$

Nearest standard poppet valve

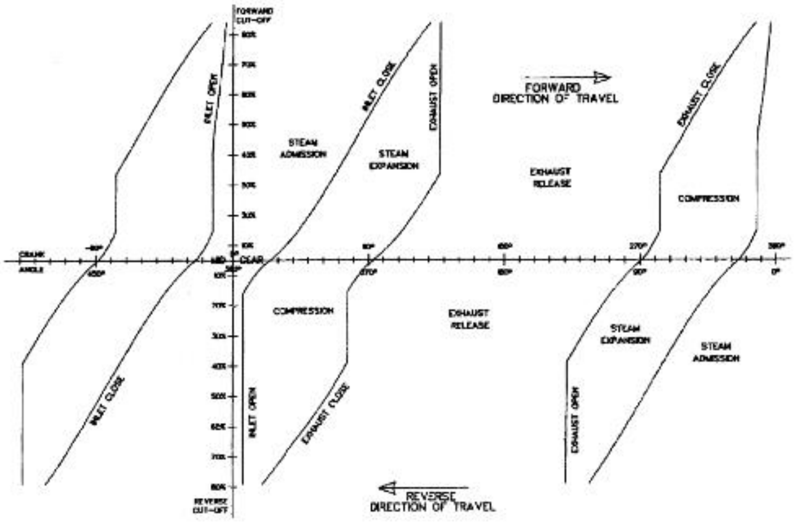
$$Inlet\_poppet\_Dia := 8.25\ in$$

BRITISH-CAPROTTI VALVE GEAR
VALVE AREAS.

5½" - 9¼" diameter.

	INLET					EXHAUST
Valve Size.	Max. Area through Valve. sq. ins.	Area 51/64" Lift. sq. ins	Area 57/64" Lift. sq. ins.	Area 15/16" Lift. sq. ins.	Area 1" Lift. sq. ins.	1.5/64" Lift. Area sq. ins.
5½"	21.44	-				21.44
6¼"	27.54	-				27.54
7"	32.47	-				32.47
7¾"	38.87	38.25				38.87
8¼"	45.12	41.7	46.58			45.12
8½"	48.023	42.5	47.6	50.54		48.023
8¾"	50.99	44.19	49.4	52.0		50.99
9"	54.81	45.46	50.8	53.4	57.04	54.81
9¼"	57.5	46.7	52.2	54.95	58.6	57.5

2.0 Exhaust Valve Sizes.



Valve events for Caprotti 2CO, 3CI. Last type of Caprotti with variable compression.

Calculate the release positions.

$$Release\_Crank\_angle := 130\ deg$$

$$Release\% := \frac{1 + \cos\left(Release\_Crank\_angle - 180\ deg\right)}{2}$$

$$Release\% = 82\ \%$$

$$Time\_Steam\_Release := \frac{180\ deg - Release\_Crank\_angle}{Speed\_crank}$$

$$Time\_Steam\_Release = 0.027\ s$$

Angle at release from forward dead centre for 20% cut off from graph above on the y axis read off the crank angle at which the exhaust valve opens.

Taking 20% Cut off
Using the assumed cut off lay down the Mariotte's Law expansion curve Pv^n = constant and establish the pressure at release point.
Then connect the release point to the back pressure line at the end of the stroke with a straight line representing the pressure drop.
So long as the ratio of release pressure to back pressure is above 1.6 the steam speed will be the critical (speed of sound) assuming 1300 ft/s. When the ratio drops below 1.6 the speed will drop from critical to nil at the end of the stroke.
On valve opening initial flow is at Critical 1300 ft per second (Speed of sound assumed but low figure used, choked flow as downstream pressure less than critical ratio 0.575 for saturated steam, the remaining is at half 650 ft per second on average (Flow subsonic so depends on pressure)

$$Release\_Pressure := (Steam\_chest\_pressure + 14.7\ psi) \cdot \left(\frac{Cut\_off\%}{Release\%}\right)^{1.24}$$

n ssumed to match ALE pressure in document.

$Release\_Pressure = 39.8\ psi$ — Release pressure absolute

$Release\_Pressure = 2.7\ bar$

$Cap\_pressure := 3\ psi$ — Pressure on entry of exhaust cap in smoke box.

$Back\_pressure := 14.7\ psi + Cap\_pressure$ — Pressure at entry to blast pipe cap 3 psi back pressure above atmosperic.

$Back\_pressure = 1.2\ bar$

$$Exhaust\_pressure\_ratio := \frac{Release\_Pressure}{Back\_pressure}$$

$Exhaust\_pressure\_ratio = 2.25$

No sure what is going on here !! From Allen's specimen calculator ?

ALE figures for straight line pressure once released at stoke end

$$Average\_Exhaust\_steam\_speed := 866\ \frac{ft}{s}$$

Exhaust Valve size

$Vol\_to\_release := Release\% \cdot Cylinder\_volume$

$Vol\_to\_release = 6\ ft^3$

$$Exhaust\_valve\_Area\_required := \frac{Vol\_to\_release}{Time\_Steam\_Release \cdot Average\_Exhaust\_steam\_speed}$$

$Exhaust\_valve\_Area\_required = 37.02\ in^2$

$Exhaust\_valve\_Dia := 8.24\ in$

Give some safety margin on a 8.25 in diameter valve.

BRITISH-CAPROTTI VALVE GEAR
VALVE AREAS.

5½" - 9½" diameter.

	INLET					EXHAUST
Valve Size.	Max. Area through Valve. sq. ins.	Area 51/64" Lift. sq. ins	Area 57/64" Lift. sq. ins.	Area 15/16" Lift. sq. ins.	Area 1" Lift. sq. ins.	1.5/64" Lift. Area sq. ins.
5½"	21.44	-				21.44
6¼"	27.54	-				27.54
7"	32.47	-				32.47
7¾"	38.87	38.25				38.87
8¼"	45.12	41.7	46.58			45.12
8½"	48.023	42.5	47.6	50.54		48.023
8¾"	50.99	44.19	49.4	52.0		50.99
9"	54.81	45.46	50.8	53.4	57.04	54.81
9½"	57.5	46.7	52.2	54.95	58.6	57.5

More in-depth study of the exhaust valve flow and timings which are not explained in the original document (Allen's Method). Calculation based on straight line interpolation between Release pressure and Back Pressure.

$$P\_choked := \frac{Release\_Pressure - \frac{1}{0.575} \cdot Back\_pressure}{Release\_Pressure - Back\_pressure} \cdot (1 - Release\%) + Release\%$$

$P\_choked = 89.4\ \%$ Stroke position where flow becomes subsonic

$$Expandsion\_curve(x) := \left| \begin{array}{l} \text{"Plot out expansion curve - Fill, Cut off, Expandsion Pv^1.2, Release with straight line approx"} \\ \text{if } x \le Cut\_off\% \\ \quad Cyl\_P := Steam\_chest\_pressure + 14.7\ psi \\ \text{if } (x > Cut\_off\%) \wedge (x \le Release\%) \\ \quad Cyl\_P := (Steam\_chest\_pressure + 14.7\ psi) \cdot \left(\frac{Cut\_off\%}{x} \right)^{1.2} \\ \text{if } x > Release\% \\ \quad Cyl\_P := \frac{(Steam\_chest\_pressure + 14.7\ psi) \cdot \left(\frac{Cut\_off\%}{Release\%} \right)^{1.2} - Back\_pressure}{(1 - Release\%)} \cdot (1 - x) + Back\_pressure \\ \frac{Cyl\_P}{1\ bar} \end{array} \right.$$

$Expandsion\_curve(P\_choked) = 2.2$

$$Choked\_Time := \frac{P\_choked - Release\%}{1 - Release\%}$$

$Choked\_Time = 40.9\ \%$ Flow time for choked sonic flow 1300 ft/s. Flow proportional to valve area only.

$$Average\_Exhaust\_steam\_speed := 1300\ \frac{ft}{s} \cdot Choked\_Time + 650\ \frac{ft}{s} \cdot (1 - Choked\_Time)$$

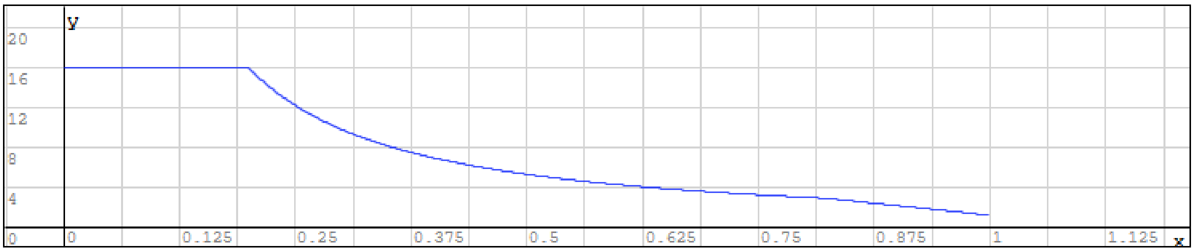
$Average\_Exhaust\_steam\_speed = 916\ \frac{ft}{s}$

$$Flow\_subsonic := \frac{Back\_pressure}{0.575}$$ Min sonic pressure for saturated steam

$Flow\_subsonic = 2.1\ bar$

$Back\_pressure = 1.2\ bar$

Expandsion Press Bar abs vs Stroke



$$\begin{cases} \text{if } (x \ge 0) \wedge (x \le 1) \\ \quad Expandsion\_curve(x) \end{cases}$$

SK10.304/2 Steam Flow Areas Typical Examples - 13 March 1951

ENGINE CLASS	4.6.2. K4		4.4.4.4 T1		4.6.0 CLASS 5		4.6.0. CLASS 5		4.6.2. PS11		0.4.2 XT1		4.6.2. YB		2.8.2. XD		4.6.2 XS1	
RAILWAY	PENNSYLVANIA RR		PENNSYLVANIA RR		LMSR		LMSR		CAR		MWREIR		O&T		MSMR		NWR (PAKISTAN)	
WHEEL SIZE	6ft 8 in		6ft 8 in		6ft		6ft		6ft 2.5 in		4ft 3in		4ft 9in		5ft 1.5in		6ft 2in	
MPH	85		100		85		85		85		45		50		50		65	
RPM	357		420		397		397		384		297		285		275		295	
TYPE OF VALVE GEAR	FRANKLIN POPPET		FRANKLIN POPPET		WALSCHAERT PISTON VALVE		BRITISH CAPROTTI POPPET		BRITISH CAPROTTI POPPET		BRITISH CAPROTTI POPPET		BRITISH CAPROTTI POPPET		BRITISH CAPROTTI POPPET		BRITISH CAPROTTI POPPET	
VALVE SIZE	2 OFF 6 IN DIA INLET 2 OFF 7 IN DIA EXHAUST		2 OFF 5 IN DIA INLET 2 OFF 6 IN DIA EXHAUST		10 IN DIA		2 OFF 6.25 IN DIA INLET 2 OFF 7 IN DIA EXHAUST		2 OFF 6.25 IN DIA INLET 2 OFF 7 IN DIA EXHAUST		4.385 IN DIA		5.5 IN DIA		7.75 IN DIA		140 MM DIA	
#CYLINDERS	2		4		2		2		3		2		2		2		4	
CYLINDER SIZE	27 IN DIA x 28 IN STROKE		19.75 IN DIA x 26 IN STROKE		18.5 IN DIA x 28 STROKE		18.5 IN DIA x 28 STROKE		19.5 IN DIA x 26 IN STROKE		12 IN DIA x 22 IN STROKE		16 IN DIA x 24 IN STROKE		22.5 IN DIA x 28 IN STROKE		16 IN DIA x 26 IN STROKE	
CLINDER AREA	572.56 SQ IN		306.35 SQ IN		268.8 SQ IN		268.8 SQ IN		298.65 SQ IN		113 SQ IN		201.1 SQ IN		397.6 SQ IN		201.1 SQ IN	
	STEAM FLOW AREA SQ. IN.	% OF AREA	STEAM FLOW AREA SQ. IN.	% OF AREA	STEAM FLOW AREA SQ. IN.	% OF AREA	STEAM FLOW AREA SQ. IN.	% OF AREA	STEAM FLOW AREA SQ. IN.	% OF AREA	STEAM FLOW AREA SQ. IN.	% OF AREA	STEAM FLOW AREA SQ. IN.	% OF AREA	STEAM FLOW AREA SQ. IN.	% OF AREA	STEAM FLOW AREA SQ. IN.	% OF AREA
REGULATOR	85.5	14.9	101.7	33.0 (4 CYLS) 16.5 (2 CYLS)	28.27	10.5	27.15	10.1	49.3	16.5			18	8.95	28.3	7.14		
DRY PIPE	70.9	12.4	78.9	25.8 (4 CYLS) 12.9 (2 CYLS)	28.27	10.5	28.27	10.5	38.6	12.9	11.1	9.77	15.9	7.9	28.3	7.13	28.3	14.1
SUPERHEATER(ELEMENTS)	91	15.9	137.6	45 (4 CYLS) 22.5 (2 ccCYLS)	45.58	17	DOWN 37.42 ELEMENT 45.5	13.9 16.9	67.3	22.5	15.9	14.1	17.9	8.9	25.8	6.5	25.2	12.5
HEADER	80	14	63.62	20.8	19.63	7.3	INLET 28.27 OUTLET 33.18	10.5 12.3	62.2	20.8	7.1	6.25	12.6	6.3	47.2	11.9	19.6	9.8
STEAM PIPE	50.2	8.8	38.49	12.5	15.9	5.9	28.27	10.5	30.68	10.3	6.6	5.86	19.6	9.8	47.2	11.9	19.6	9.8
INLET VALE	48.6	8.5	29.58	9.7	41.4	15.4	27.5	10.3	27.54	9.2	12.70	11.2	21.8	10.9	38.9	9.8	18.5	9.2
PORT	54	9.5	39.6	12.9	34.4	12.8	32	11.9	35	11.7	10.1	8.9	20.5	10.2	35.2	8.87	18.7	9.3
EXHAUST VALVE	68	11.9	45.34	14.8	41.4	15.4	32.6	12.1	32.5	10.9	12.7	11.2	21.8	10.9	39.1	9.87	21.6	10.7
EXH PIPE AT COMMENCEMENT OF PASSAGE	68 (*)	11.9	47.5	15.5	65.6	24.4	37.6	14			9.5	8.36	34.8	17.3	69	17.4	40.5	20.1
EXHAUST PIPE BEFORE					33.18	12.4	33.18	12.3			9.6	8.5	29.8	14.8	52	13.1	33.2	16.5
BLAST PIPE BASE	147	25.6	95.033	31	100	37.4	98	36.5			20	17.7	41.2	20.5	92.5	23.3		
BLAST PIPE CAP					20.63	7.7	20.63	7.7			6.7	5.95	17.4	8.65	30.2	7.52	14.2	7.1
REMARKS	TEST PLANT READINGS * MIN THROUGH ONE EXH																	

Revision 2 - 13th March 1952 - Chart extended to include wheel Dia and Speed.
Revision 1 - 13 September 1948 - LMS Class 5 Exh Valve from 7.75 and areas revised.

Figure 6 SK. No.10 304/2

CHAPELON ON 160A1 TESTING Letters from Joe Cliffe, Translation by Hendrik Kaptein

Translation from the French (by Hendrik Kaptein) of letters sent by Chapelon to Pierre Trentesaux-Vernier from 1947 to 1974, on 160A1 testing, transcripts of which were made available by Joe Cliffe:

Introduction

In *La Locomotive à Vapeur* (1938) Chapelon already extensively treated steam jacketing and of superheating as remedies against cylinder condensation and its adverse effects on engine efficiency (pp. 619 ff. & elsewhere in Part II). Among other things superheating was found to be less effective with lower engine speed. Steam jacketing is unaffected by speed, which was one of the motives behind trying out a combination of steam jacketing, superheat and re-superheat on a goods locomotive, in fact the rebuilt 160A1 (* 1940, † 1954). Vitry stationary test results got lost but then these letters offer some insight into postwar road testing data & conclusions drawn from them.

Summary

Steam jacketed engine efficiency is almost unaffected by (re-)superheat. Very good boiler efficiency is attained, thanks to the feedwater heater section between boiler and smokebox as well. Removal of (re-)superheaters still further improves boiler efficiency. Steam jackets improve power output and engine efficiency at low speeds as well. Saturated steam temperatures are conducive to good lubrication, to overall engine steam tightness (important for engine efficiency) and to engine life. Best arrangement may be HP steam jackets only, combined with re-superheat only, increasing fluidity of (LP) steam as well. Further research and testing is still in order, among other things as the 160A1 cannot be tested without steam jackets and is fitted with a boiler designed to contain superheaters.

Letter dated 16 October, 1947. The 160A1 entered service by early October. Preliminary road tests were done with 1,300-1,400 ton trains between Villeneuve St Jacques and Laroche. Hauling the fourth train and at around 20-30 km from Laroche HP driving rod overheating occurred, caused by big end failure and leading to driving rod damage for no apparent reason.

After stopping the train both wheels at the HP driving axle appeared to have inexplicably loosened as well. Early November and after repairs the engine was brought to Sotteville. Apart from this there were quite a number of poppet valve and cylinder safety valve ruptures, just as there was quite serious HP cylinder cover leakage at one side. Still everything was repaired when the wheel loosening occurred. But then remaining and rather limited road test were **most** encouraging, apparently so with minimal fuel consumption. Riding was excellent. 70 km/h was reached several times, notwithstanding a 60 km/h speed limit. Altogether everything went well. HP and LP superheat temperatures were as expected. Still constructional issues related to adverse present conditions have to be addressed.

25 May, 1948. First tests between Laroche and Dijon brought good results. Engine mechanics are sound, and the 6 cylinders do not really complicate things, diminishing as they do the forces applied to each axle. Superheating and re-superheating temperatures are almost exactly as expected, at 300-330° C HP and 270-350° C LP, depending on power output. Still the steam jackets appeared to be much more effective than already expected. This may well lead to less superheating and re-superheating.

Boiler efficiency appears to be better than that of similar engines. This may have to do with the long firebox and the 2 m long preheater between the boiler and the smokebox.

Up to now 1,670 t were hauled, on an 8‰ incline and up to the drawbar limit. Thus 52 min 50 secs were gained between Laroche and Dijon, at an average speed of 47.25 km/h and with an average drawbar power output of 1,702 hp[1] during 2 hours and 43 min. This is a train drawbar power output record.

Water consumption per drawbar hp was 8.54 kg, coal consumption was 1.23 kg, both very low for prolonged goods train service.

From Dijon no exact consumption data could be established, due to permanent way restrictions like advance and stop signals (due to electrification works). But then in a curved 8‰ incline at Beuchail starting drawbar tractive effort was 36 t, equivalent to 38 t on level track, corresponding to a 1/3 adhesion coefficient.

Drawbar power output relative to level track reached up to 2,625 hp at 58 km/h and 2,770 hp t at 46 km/h, with 14.6 t tractive effort on a 8‰ incline.

25 June, 1948. Again interesting results were obtained. Major power outputs were reached between Badan and St Etienne (14‰) and between Roanne and St Etienne (12‰).

Really outstanding was the handling of an express train from Lyon Perrache to Roanne, via Tarare. Time was kept and even recovered (5 mins 30 secs), climbing the 26‰ incline at the Sauvage tunnel without any helper engines and within a 70 km/h downhill and level track speed limit. This was a higher speed than the original 60 km/h limit, meeting with no objections from the accompanying permanent way officials.

Running light engine established perfect riding qualities at 90 km/h as well. This is like 128 km/h for a Pacific fitted with 2 m driving wheels. There is no sway at all. Curves are negotiated in a most gentle fashion, comparable in this respect to the 242A1 only.

Level track equivalent tractive efforts between 20 and 22 t at 20 to 30 km/h have been maintained for quite some time. 16.5 t was reached at 45 km/h and 12 t at 60 km/h, with corresponding power outputs between 2,650 and 2,750 hp. For express passenger train haulage this would come down to a sustained drawbar tractive effort of about 8.4 t.

Steep inclines notwithstanding fuel and water consumption remained satisfactory. Average tractive effort rose from 9.7 t at Dijon to 15.7 t between Badan and St Etienne. Water consumption rose from 8.54 l to 9.45 l per drawbar hp / hour, coal consumption went up from 1.23 kg to 1.51 kg. These are all low numbers, given prolonged goods train riding times and standstills.

6 hours, 39 minutes and 53 seconds were gained in heading 16 trains, or 25 minutes 33 seconds per train on average, notwithstanding a 60 km/h speed limit for 12 trains and 70 km/h for the last 4 trains.

The 6 cylinder engine did **remarkably** well, proving its value for a very high tractive effort engine.

Right now starting tractive effort reaches 30 t (38 t maximum). Trains are started without any shocks and without any reactive forces. This is due to the LP engines in particular, functioning as they do like a 3 cylinder engine with cranks at 120°. There are no intercepting valves. Re-superheating did not give any trouble. HP inlet temperatures ranged from 300° to 340° C, BP from 270° to 380° C, equivalent to single stage superheat of 400° to 475° C.

Still the steam jackets are so effective that superheat will be reduced, increasing already excellent boiler efficiency probably due to the feedwater heater at the front of the boiler.

So everything went quite well but then at the end of tests there was a derailment on a switch while entering the station of Givors Ville, at 30 km/h.

Happily enough this did not do any harm to the engine. It was returned to Paris by train nr. 52 *bis* and ran at 80 km/h without any problems. Still the engine will be back at Sotteville for superheating checks and modifications.

The derailment was caused by faulty switch construction in a 400 m radius curve, to be used in a 3,000 m radius curve only. Adding to this was the deviation radius being 105 m only, instead of the 150 m minimum. Another engine derailed there as well, at walking pace, just like a 141C made available for testing purposes.

Thus the tests went quite well. They will be resumed by September.

30 June, 1950. Next the 160A1 was tested at constant speed heading goods trains and a brake locomotive. These tests were quite complete, concerning numerous temperature measurements. They revealed lots of data on re-superheat, steam jackets and wall effects. Such measurements were done for the first time, so these results are to be considered with great care, susceptible as they are to further breakdown, collection and analysis. After first tests there will be another one with HP superheat reduced by about 1/3. Again there will be systematic study of

[1] 1 continental hp = 0.986 hp

cylinder phenomena. The engine is performing perfectly. 23 t of tender drawbar tractive effort at 20 km/h was sustained for a full hour, with excellent steaming, in fact hard to realise at such a high tractive effort at such a low speed.

Steaming limit at 40 km/h was 20.6 t, with 17.5 t of tractive effort. At such loads the engine may well be some 30 to 40% more economical than ordinary locomotives. Remarkable boiler efficiency is rather better than that of the Pacifics. With more certainty on all these issues, to be established by tests from September more information is to follow. Few engine tests are more informative. They may well lead to new possibilities and progress. It would be great to realise them.

7 September, 1950. First data breakdown, collection and analysis is now in progress, after staff absences of leave. This confirms first impressions. Lowering LP superheat temperature appears to have no effect at all on overall engine efficiency. So a normal compound engine may well be better fitted with receiver superheating instead of HP superheating. Re-superheating is the future, though this interesting issue is to be still further clarified. Lubrication and superheater lifespans are to greatly profit from this as long as overall efficiency may be maintained.

8 November, 1950. Good engine efficiency at lower superheat temperatures is confirmed. This generally neglected result must be due to the steam jackets. Thorough research is needed in order to draw telling conclusions here. High efficiency reached at HP and LP superheat temperatures of 250° C only is most interesting as well because lubrication oils remain remarkably unaffected, then. This is good for piston rings in particular and it ensures good steam tightness, a most important factor in securing efficiency gains in continuous service. In the end it may be still better to go for LP more than for HP superheat, even so without steam jackets. Given sufficient efficiency piston rings and cylinder walls will then do very much better in actual service. These are completely new perspectives, meriting greatest attention. Without the 160A1 this would have never come to light. Thus the consequences of this research may be quite important.

12 December, 1950. Next tests were conducted without any HP superheat. This led to slightly higher water consumption but did not make much difference for coal consumption. This really remarkable result may confirm what was already thought: LP superheat is much more important than HP superheat. Numerous pressure and temperature measurements may well lead to complete analysis and positive conclusions.

20 February, 1951. Test date breakdown, collection and analysis continues, but this takes some time as each test furnishes more than 50 separate readings. Still coal consumption appears to be about 0.85 (at 1,600 hp) to 0.9 (at 800 hp) per drawbar hp / hour, between 1,600 and 800 hp. Stationary test plant coal consumption of the high superheat 150X[2] was 1.3 kg of Aniche coal (the same as fired in the 160A1) at 800 hp and 1.5 kg at 1,600 hp.

5 May, 1951. The 160A1 was tested with LP superheat only. More tests may be done with slightly higher LP superheat, in order to clarify a couple of issues. Right now the engine is just as economical as with 2 superheaters, with slightly higher water consumption at the same coal consumption. Next runs will be done with saturated steam only. Uncoupling the HP and LP driving mechanisms did not really affect motion resistance, not even so in curves. Positive effects if any were quite small. On the other hand there appeared to be a slightly greater tendency to slipping at high power outputs and with HP cutoff at 62.5% and LP cutoff at 40%. Uncoupling appeared to have no advantages in the end. Still it made sense to verify this, as it is universally assumed to be the other way round. Above 45 km/h and in fact at approaching 65-70 km/h 2,750 drawbar hp were measured.

25 June, 1951. Prolonged silence on the 160A1 is due to hitherto incomplete test results. In the meantime and remarkably so the completely non-superheated engine performed like before. Power output went down no more than a bit, like from 2,500 hp to 2,350 hp at 62,5% HP and 40% LP cutoff at 40 km/h. This just relates to superheater calories no longer reaching the engine. Though subject to further analysis it appears that superheating does not make any real difference for the practical efficiency of a steam jacketed engine. This will lead to lower coal consumption with saturated steam, as this steam is generated more efficiently, compared to superheated steam production.

[2] Originally German 2-10-0 3-cylinder simple expansion heavy goods locomotives series (DR BR) 44, built as a standard type from 1926 and since World War II in French service as well.

Thus the steam jackets appear to be most efficient, as confirmed by dry exhaust steam. Counterpressure with saturated steam is the **same** as with superheated steam, which is not at all the case with saturated steam without steam jackets.

This opens new horizons, from which important conclusions may be drawn. So the 160A1 may lead to most important and hitherto unknown insights into the functioning of steam locomotives.

12 July, 1951. Most interesting results obtained with the 160A1 confirm earlier hypotheses on superheat as most important at high speeds in the first place, given its effect on exhaust throttling by doing away completely with water droplets obstructing steam flow. But then steam jackets will produce comparable results at low speeds, at which wall effects are predominant.

Thus a goods engine might well be fitted with steam jackets, while an express engine may be equipped with LP superheating only. High efficiency at high pressures cannot do without superheating of course. As noted by the author (in a recent conference) this may be interestingly combined with HP steam jackets.

22 October, 1952. Breakdown, collection and analysis of 160A1 test data goes on, confirming what was stated before, and to be included in the second volume of the author's upcoming book.

10 May, 1955. Complete test results of the 160A1 will be published in the second volume. Conclusions are as follows:

LP superheating only is better than HP superheating only
Thermally a re-superheater is more efficient than a superheater
Steam jackets are efficient

Thus the ideal engine is fitted with HP steam jackets and LP superheating. With 40 at (water tube firebox) boiler pressure, triple expansion (in 4 cylinders: 1 HP, 1 IP and 2 LP), steam jackets, IP superheating and LP re-superheating there may be an efficiency gain of 35%, compared to the best 4 cylinder compounds at 20 at boiler pressure and 400° C superheat (240P-141P). A Franco-Crosti boiler may increase this to 55%, or to 45% with a simpler version like in the 160A1 boiler. All this may be easily realised.

12 April, 1958. A newly constructed 160A1 would have 1 HP cylinder instead of 2, just like 1 inside LP cylinder instead of 2, as already envisaged since 1932. There would be LP superheating only.

19 September, 1958. Lowering 160A1 superheat until its elimination did not really change engine heat consumption per ihp both at 40 km/h and 60 km/h. Curiously enough the number of superheat calories contained in LP inlet steam regularly increased to the degree HP superheat was reduced. Thus LP superheater efficiency increased with reduction of HP superheat, reaching its maximum with no HP superheat at all. So LP superheat efficiency increases with less HP superheat. This suggests better heat conductivity of less dry steam in the LP superheater. This all did not affect power output any way. Steaming remained totally normal.

Steam jacket temperatures remained the same or almost the same as HP and LP inlet temperatures, as the steam fed into the jackets is the inlet steam itself. In fact the steam jackets are part of the steam chests. This was seldom if ever realised. Here it was done in full, including the cylinder covers. The good results obtained may well have to do with this. More or less the same power output was developed without superheat. Slightly lower power output may be explained by the absence of superheat calories. But this may be made up for by modifying the boiler tubing. This proves that the steam jackets have been most conducive to engine efficiency. Wall effects might be still further reduced by replacing the 2 HP cylinders and the 2 inside LP cylinders with a single cylinder each, thus slightly reducing condensation surfaces. This may also lead to slightly reduced leakage areas. Piston valves instead of poppet valves would have had the same effect, with no inertia issues, given relatively low goods engine speeds.

With express engines speed reduces leakage. Then poppet valves might still be advantageous, given their low inertia.

4 July, 1960. The 5th coupled axle of the 160A1 is fitted with "tandem" coupling rods. With no more than 4 cylinders and the 2 inside cylinders replaced by one steam distribution would be like that of the C3's[3]. This is derived from Young steam distribution, the expansion link being driven from the opposite side of the engine, at 90°.

[3] No clue yet what C3 engines might have been? Transcription issue here?

11 September, 1967. A newly constructed 160A1 frame might have been rather better, just like new axles and wheels, and a 4 cylinder engine with 1 HP and 3 LP cylinders. A better tubed boiler would have been fitted, with LP superheat only, thus being more efficient than the actual boiler tested with extremely shortened superheater elements, in order to limit superheat found to be excessive.

23 May, 1970. Given its construction the 160A1 could not have been tested without steam jackets. But then the efficiency of these steam jackets was established beyond doubt. Engine efficiency remained the same with and without HP superheat, with steam jackets and LP superheat. Thus HP superheating may be left out forthwith, given HP cylinder steam jacketing and LP re-superheating. LP cylinder steam jackets may be done away with, thus optimally simplifying a highly efficient engine.

Saturated HP steam engines without steam jackets would be no good for engine efficiency at all, as HP steam would then be much less dry, necessitating more re-superheat, at the expense of boiler efficiency.

5 October, 1970. Steam jackets are designed to reheat cylinder walls, in order to ensure re-vaporisation before exhaust. Superheated or saturated steam makes no difference in this respect. Moreover a part of the unused superheated steam calories is brought into contact with cylinder walls, thus working against condensation as well.

12 February, 1974. Higher powers persistently wanted these tests to be terminated once and for all. This became quite clear with the 160A1 and the 141E113. Important results were almost always obtained in a stealthy fashion. The "traction" spirit was always much more widespread than the "engineering" spirit.

THE FOUNDING OF THE INSTITUTION OF LOCOMOTIVE ENGINEERS

By Chris Newman

It came as a surprise to me to discover recently that Google could find very little information about the history, or even existence, of the Institution of Locomotive Engineers. Such information as it offered, boils down to the following:

- **The Science Museum** (sciencemuseumgroup.org.uk/) said that: "The Institution of Locomotive Engineers was founded in London in 1911 for the purpose of the 'dissemination of information concerning Locomotive Engineering and its allied sciences'. The organisation was active in this role until 1969 when it merged with the Institution of Mechanical Engineers as its Railway Division (one of the eight divisions the Institution of Mechanical Engineers has). The Institution of Mechanical Engineers was founded in 1847 and is still active today with a railway division."
- **The Institution of Mechanical Engineers** (archives.imeche.org) said only that: "The Institution of Locomotive Engineers (I.Loco.E.) was founded in 1911. The I.Loco.E. was formed for the '...dissemination of information concerning Locomotive Engineering and its allied sciences by the reading, discussion and publication of papers and otherwise'. I.Loco.E. merged to become the Railway Division of the Institution of Mechanical Engineers (IMechE) in 1969."
- **Gracesguide.co.uk** said: "1911. Founded as an independent engineering learned society and professional body. Its purpose was 'the dissemination of information concerning locomotive engineering and its allied sciences...' The organisation continued in this role until 1969, when it merged with the Institution of Mechanical Engineers."
- **Wikipedia** only mentioned it indirectly in its IMechE entry in which it said: "The Railway Division *[of IMechE]* was formed in 1969 when the Institution of Locomotive Engineers amalgamated with IMechE."

Beyond that, there are only links offering access to the Journals of the Institution.

However, a book written by one of our members throws some interesting light on the beginnings of the Institution which might be of interest to ASTT's members. Fred Rich's book "Yesterday, Once More" (published in 1996 by P.E. Waters & Assocs.) relates stories of steam from the Brighton Line as told to him by an engineman by the name of George Washington who joined the LBSCR in 1911, later becoming a driver on the Southern Railway and BR. Fred first met George in 1952 when he (Fred) was an apprentice at Brighton Locomotive Works.

Chapter 4 of Fred's book tells the story of a remarkable character by the name of Johnnie Maitland in which the beginnings of I.Loco.E., are revealed. The following paragraphs are copied from Fred's book (with some abbreviation):

THE WORLD OF JOHNNIE MAITLAND

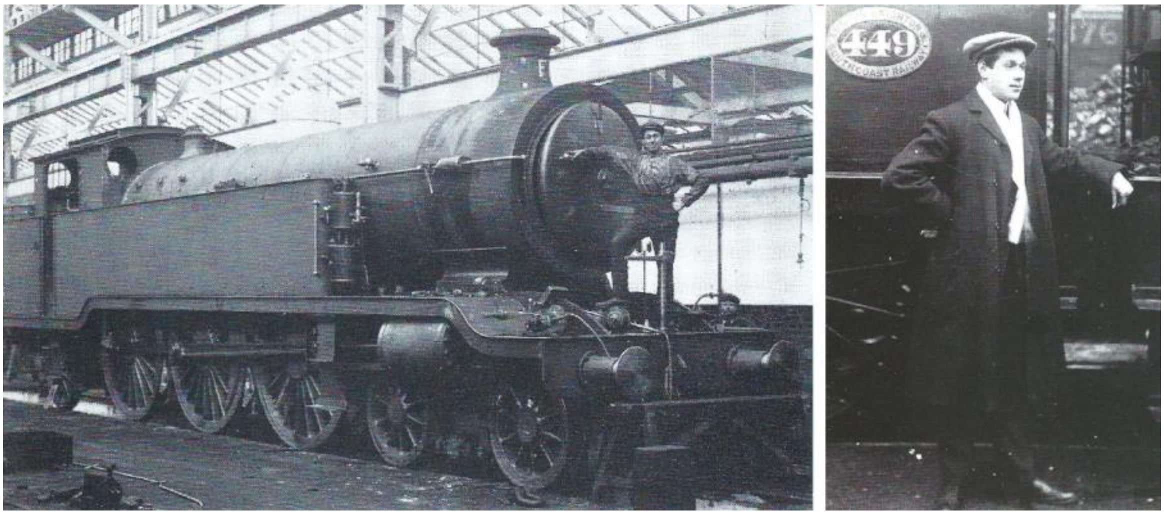
John Pelham Maitland was born on 31 March 1890. He was the son of wealthy parents, who lived in Croydon, and his father wanted him to follow in the family profession (I believe, but have not confirmed, that Maitland senior was a surgeon). However, the young man had set his heart on a career with steam locomotives and on 4 January 1907, at the age of sixteen and three quarters, he started at Brighton Works as a Fitter's Apprentice under D. Earle Marsh. It was a 5-year apprenticeship for which, no doubt, his father had to pay a premium at the outset. Another pre-requisite was, of course, to find some lodgings in Brighton: apart from any other consideration, the working hours were too long for a daily journey to be contemplated.

In due course some 'digs' were obtained and (as JPM told George) his father gave the landlady five years' rent in advance before declaring "That's it! I've done *my* part!" (or words to that effect).

We may assume, then, that JPM's earnings were entirely his own, to be spent as he wished; but they were not on a princely scale - the rate for a first-year apprentice was less than half that for an engine-cleaner. For the first twelve months, JPM was on tenpence a day, and I'm referring to *real* pennies: in 'funny money' the equivalent would be a trifle over 4 New Pence. This amount was increased to one shilling (5p) in the second year of his apprenticeship, 1/4d in the third, 1/6d in the fourth and two shillings per day (10p) in his final year, which ended in January 1912. In fact, however, he received a fireman's pay during part of that final year because it was the custom for all Pupils, and some favoured apprentices, to be given a spell on the footplate, not in the 'third man' role of later times but as firemen in their own right. In the Public Record Office at Kew, amongst the London, Brighton & South Coast Railway archive material, there is a foolscap-sized book (RAIL414/631) labelled *"List of cleaners passed as firemen and firemen passed as drivers"*; and under the letter 'M' it contains: *Maitland; John P; Fireman; Brighton; Aug 1911.*

[paragraphs omitted]

At the end of his apprenticeship, he joined the little group of 'Inspectors' in Richardson's general office and it was there, a year or so later, that George came to know him. His locomotive career went on from there for another 38 years and, with each successive appointment which he held, a bit more was added to the Maitland legend. But the ingredients of that legend were already there to begin with.



*Left: Brighton Works erecting shops with D. Earle Marsh's J Class 4-6-2T No.325 "*Abergavenny*" under construction. 20-year-old John Pelham Maitland is posing in front of the smokebox door. He was then in the final year of his apprenticeship, and only a few months later he presented Paper No 1 to the newly-formed Institution of Locomotive Engineers.*

Right: another early photograph of J.P. Maitland, taken beside a Vulcan 0-6-0.

In 1911, before his twenty-first birthday, he was among those who founded the Institution of Locomotive Engineers. This professional body grew from its origins in Brighton to become one of the world's most prestigious focal points for locomotive engineering. During well over half a century of existence (until it was absorbed by the Institution of Mechanical Engineers) the I.Loco.E. generated several hundreds of papers, touching every aspect of locomotive technology. The very first of these dissertations, Paper Number One, was entitled "French Locomotive Practice" and it was presented in London on 27 May 1911 by J.P. Maitland, the 21-year-old apprentice from Brighton Works. And what did he know about French locomotive practice? The answer is that he knew quite a lot; more than enough to produce a digest in about 4,500 words and to handle the discussion afterwards. In point of fact, JPM had a profound interest in locomotives and he travelled extensively in pursuit of this interest - not only in the UK but also abroad. His paper to the I.Loco.E. was a result of seeing the French railways at first hand, travelling on them and talking to French railwaymen.

There were no communication problems for him as he was an accomplished linguist and spoke several languages fluently.

Another abiding interest which took him to the continent was archaeology and he was no slouch at that either. On one occasion, while in his twenties, he took charge of a dig somewhere in France and the French authorities provided about thirty assistants to work under his direction. His life-long interest in archaeology led, naturally enough, to numerous connections in that field and he became a Fellow of the Society of Archaeologists.

As for his involvement with the Institution of Locomotive Engineers, he presented another contribution in 1912 (Paper No.13, "Coal as a factor in locomotive practice") and yet another in 1914 (Paper No.24, "The design and equipment of the running-shed").

[paragraphs omitted]

During the 1914-18 war, he served with the Royal Sussex Regiment and subsequently with the Royal Engineers. And then, in 1920, he moved on from his original appointment to become a so-called 'Platform Inspector' at Brighton. This rather misleading title denoted a Locomotive Inspector who operated partly on the station platforms and partly in the running shed yard. He worked from a little hut at the station end of the loco yard, and it was his job to 'help things along' in any way he could. We must remind ourselves that Brighton station was a large passenger terminus of the 'dead-end' type with lines coming in from East, West and North. It handled a large volume of traffic which was worked entirely by steam locomotives; and (except in the case of pull-and-push Motor' trains) each incoming engine was 'trapped' on the buffer-stops for some time after arrival. So, if (for example) an engine arrived with some kind of problem, and if the Platform Inspector was there to meet it, he could size up the situation and forewarn the appropriate running shed staff (or whoever else was involved). Perhaps a simple 'running repair' was needed, in which case he would alert the fitters; or maybe the engine would have to be 'stopped' and a substitute provided at short notice. It was never too early to start making arrangements. There were countless other circumstances in which the Platform Inspector earned his keep and, of course, he maintained a close working link with the station staff, signalmen etc. In George's recollection, some Platform Inspectors were conspicuous by their absence when needed but Maitland was almost invariably in the right place at the right time. His experience as a Platform Inspector provided some of the background to his fourth and final I.Loco.E. paper "Terminal Station Working" (Paper No. 172) was presented to the Institution in April 1924 and, inter alia, it touched on the subject of signalling.

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[Back to 2023] Copies of Fred's book appear to be scarce on the second-hand market, but it is we'll worth reading for those who can procure a copy, since it presents an illuminating description of a steamy world that disappeared over half-a-century ago, and of the sorts of characters that made up that world.

It may be of interest to members to know that whilst the very first paper presented to the fledgling institution was given by the young Johnnie Maitland, the very last paper (No.721) was given by none other than Livio Dante Porta in the form of his "Manchester paper", which he presented in March 1969 just before I.Loco.E. merged with I.Mech.E.

Help sought from ASTT Members

As for I.Loco.E. it would be nice to imagine that ASTT might one day feel justified in claiming to be a 21st Century incarnation of that once-hallowed institution. After all, we pursue much the same aims as I.Loco.E. did, namely: "the dissemination of information concerning locomotive engineering and its allied sciences by the reading, discussion and publication of papers and otherwise" (as quoted on I.Mech.E's website).

With that thought in mind, I believe that perhaps it behoves us to fill this gap in steam's story that Google's search has revealed. To that end, I have drafted a potted history of I.Loco.E. which I've uploaded to Wikipedia in draft form. This can be viewed at

https://en.wikipedia.org/wiki/Draft:Institution_of_Locomotive_Engineers[1]

Unfortunately it seems that Wikipedia has toughened up their standards in recent years because its reviewers have twice rejected my submission on the basis that it lacked sufficient references. (They did the same to an article on the Rio Turbio Railway that I uploaded at the same time, but which they accepted after my second attempt.) Anyway, since the last rejection notice, I've added several additional references and website links to the page and I am now waiting for their further response.

However, regardless of their response, I'd like to appeal to ASTT members who are more knowledgeable than myself to help to fill out my submission, either adding more facts or more references – or both. Those who are not familiar with Wikipedia's editing functions can send their edits to me so that I can upload them on their behalf.

Better still would be a more complete history of I.Loco.E. in the form of a book that ASTT might publish. Any offers?

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1. It is possible that by the time this article is published in ASTT's Newsletter, Wikipedia will have accepted my revised submission. If this happens, then the I.Loco.E. page should have been moved to https://en.wikipedia.org/wiki/Institution_of_Locomotive_Engineers.