Why Did BR Give Up On Steam ?
– And Could It Have Been Avoided

Part 3 – Freight Locomotives

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Objective

- This presentation seeks to answer two questions:

1. What were the reasons given at the time for the perceived superiority of diesel over steam traction ?
2. Would it have been possible for different designs of steam locomotive to the BR Standards actually built to have addressed these perceived weaknesses ?

3. Part 3 focusses on freight locomotives, building on previous work done by Chris Newman and Jamie Keyte on 8AT proposals

Contents – Part 3

Requirements For Steam to Compete With Diesel

- Less Old Fashioned
- Cleaner
  - ➔ Less Pollution
  - ➔ Better combustion (with lower quality coal)
- Less Manual Labour
  - Cleaning/Servicing
  - Firing
  - ➔ machine washing, stoker firing & reduced service reqmts
- Higher Low Speed Performance
    - ➔ Better Acceleration & Hill Climbing
    - ➔ consistent higher power outputs (Kiefer Rule) ➔ mech. firing
    - ➔ better use of locomotive weight for adhesion
- Reduced OPEX
  - Reduce Fuel costs to Diesel levels ➔ Higher Efficiency
- Higher Availability/Utilisation ➔ match diesels
  - Increased Operating Range w/o refuelling/water/ash removal
  - Reduced terminal time (turn, water, coal, ash)
  - Reduced servicing
  - Increased major repair intervals

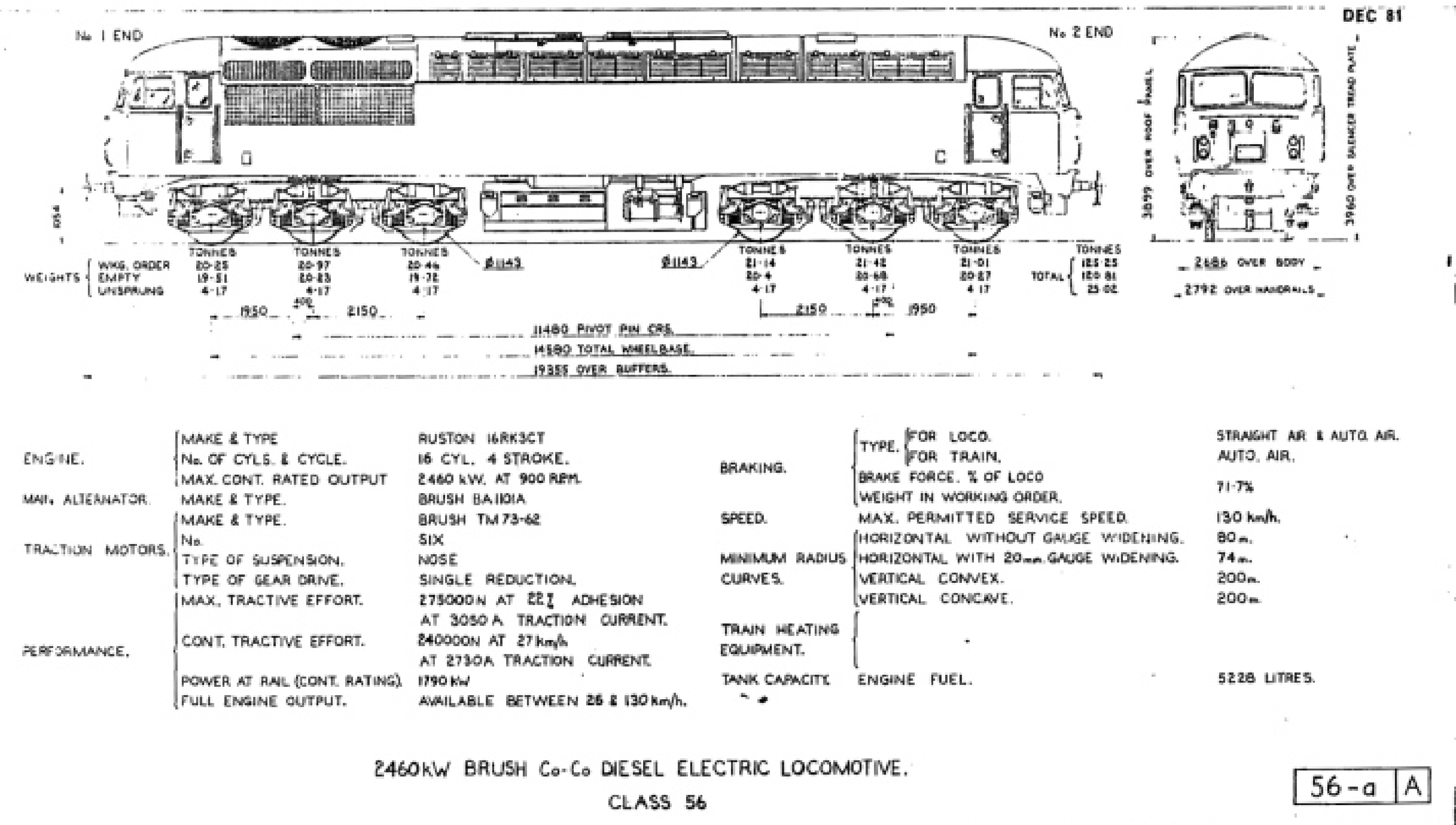
Freight vs. Passenger Loco Design

- Overall Requirements for Steam vs. Diesel the same
  - "Modern Looking" less important" ?
- Lower max speeds ➔ less max power required
- Matching diesel low speed performance critical
    - ➔ tractive effort
    - ➔ adhesive weight
- Matching diesel availability (& hence utilisation) equally important
    - ➔ maximise operational range between refuel/water stops
    - ➔ minimise routine maintenance requirements

Previous Solutions

Class 56

Class 56		
In Service	1976	
Loco Max power	3250	shp
Loco Max Weight	125	T
Adhesive Weight	125	T
Starting T.E.	61,000	Lbf
Starting Mu	0.22	



	Fuel Capacity	Energy Density	Energy Input	Thermal Efficiency	Energy Output
	litres or t	MJ/L or MJ/t	GJ	%	GJ
Class 56	5226	38	199	24	48
Steam	17.7	30	530	9	48

Diesel Power Curve Characteristics

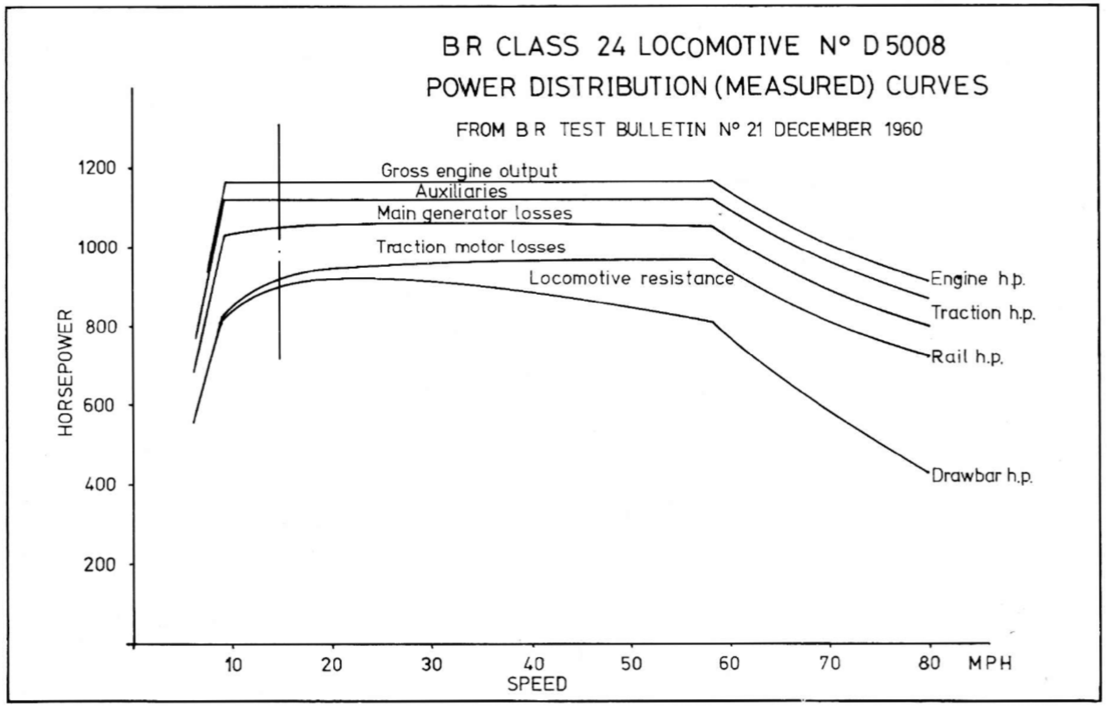
- Quoted HP is Engine SHP
- RHP is SHP – Aux & Transmission Losses
- RHP is approx. 80% of shaft hp

For the Class 56 the losses are:

- Ancillaries 3.2% (104hp)
- Generator Efficiency 93.3% (211 hp)
- TM Efficiency 92% (235hp)
- i.e. 17% loss from SHP to RHP

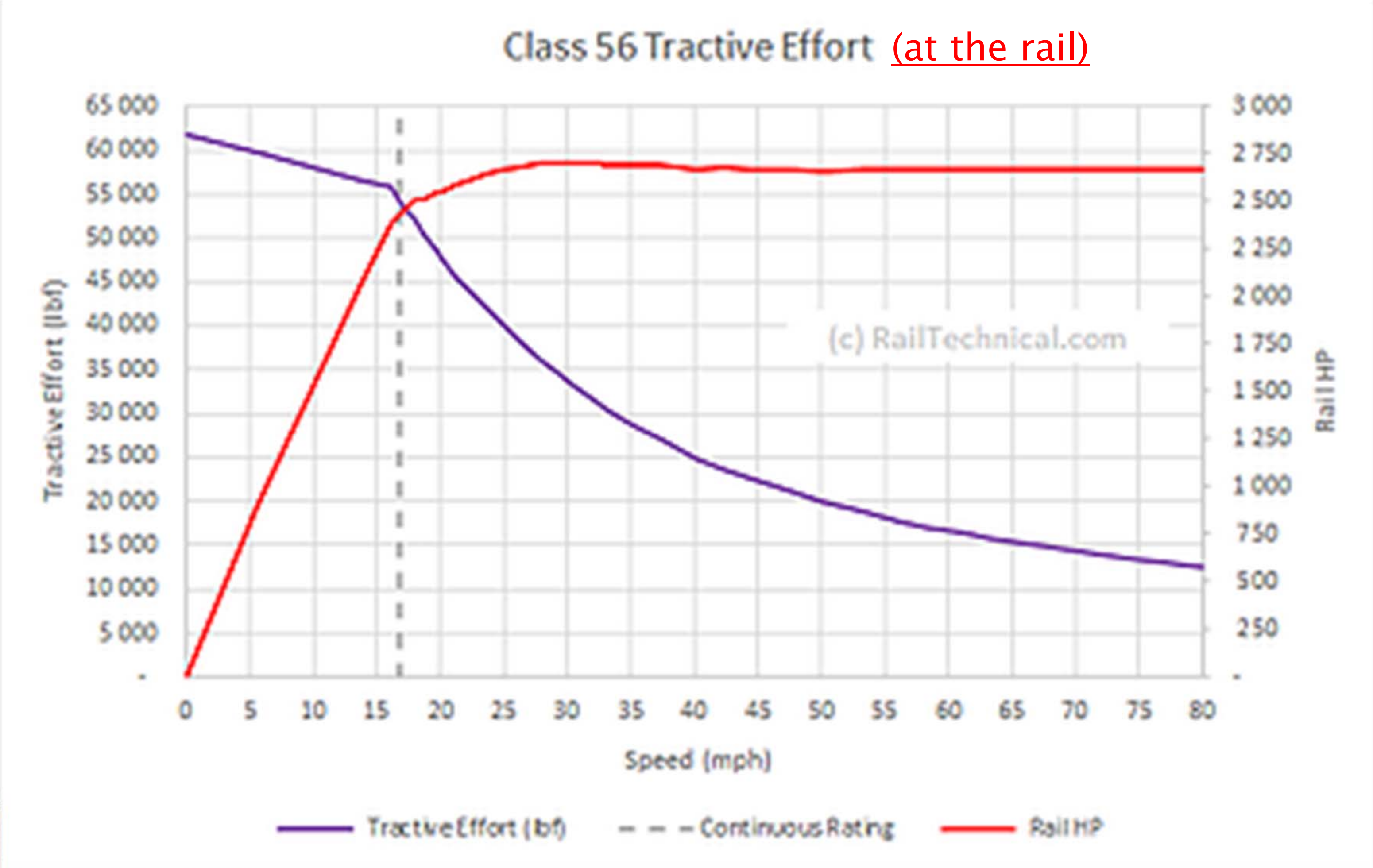
- Diesel Loco resistance curve similar to Steam

- RHP is therefore most analagous to Steam IHP
    - Wardale used 4% difference IHP to RHP in 5AT FDCs

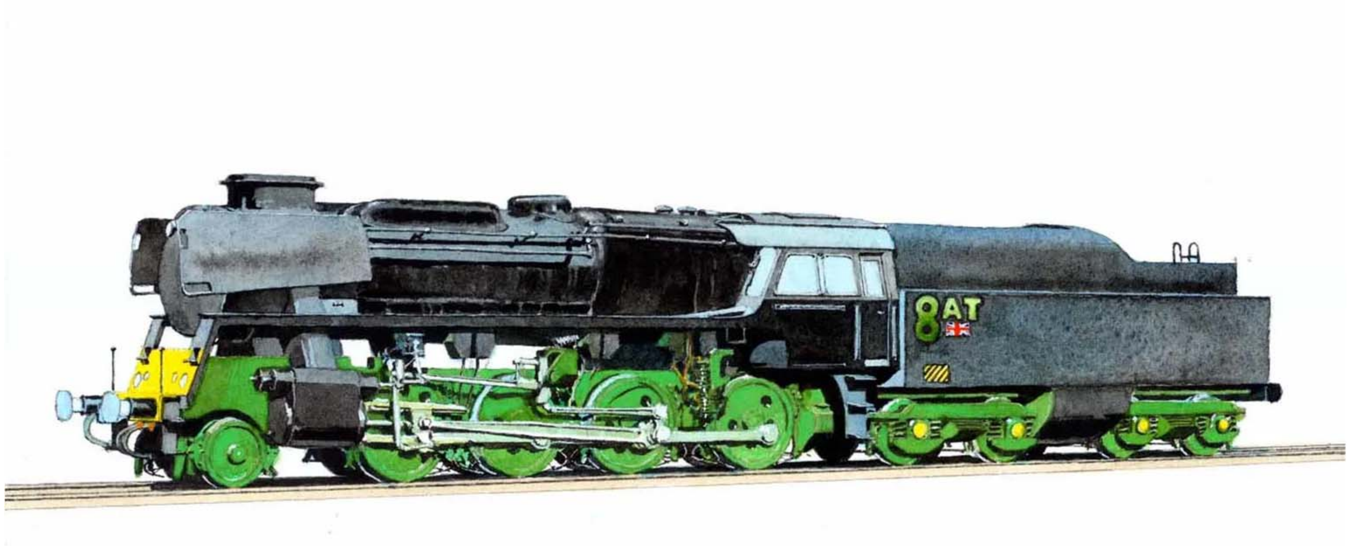


Thanks to steve@railtechnical.com for the diesel info

Class 56 Power Curve



8AT



			(Wardale Version)
Loco Wt	100	tonne	80 t
Adhesion Wt	88	tonne	74 t
D	1.435	m	1.425m
Pressure	21	bar	21 bar
Tractive Effort	46,400	lbf	44,019 lbf
Cyls	No.	Dia (mm)	Stroke (mm)
	2	450	800

Chapelon 2-12-0 Freight Loco

Loco Wt	137.5	tonne	
Adhesion Wt	120	tonne	
Cyls	No.	Dia	Stroke
HP	2	520	540
LP	2	520	540
LP	2	640	650
D	1.4	m	
HP	18	bar	
LP	10	bar	
Tractive Effort	40	t	

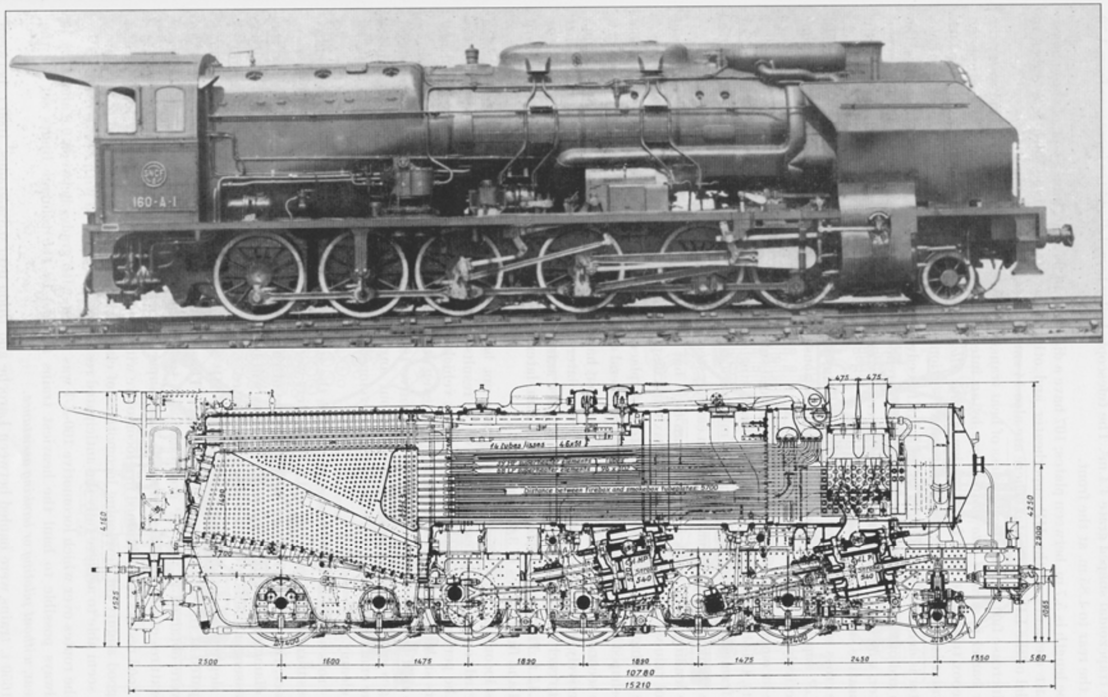


PHOTO & DRAWING: S.N.C.F.

FIG. 334. – SIX CYLINDER SUPERHEATED COMPOUND 2-12-0 LOCOMOTIVE WITH RESUPERHEAT AND STEAM JACKETED CYLINDERS, S.N.C.F.

Adhesion & Tactive Effort

Class	Weight				Starting		N Cyl
	Adhesion	Loco	Est. Ballast	Loco + Tender	Tractive Effort	Mu	
	t	t	t	t	lbf		
Class 56	125	125	0	125	61,000	0.215	16
9F	80	88.5	0	140.9	39,667	0.219	2
8AT	88	100	13	180	46,400	0.239	2
PO 2-10-0	78	85	0				
Chapelon 2-12-0	120	138	38	218	88,000*	0.33*	6 (=3)
					78,400	0.294	=3

* Based on claimed 40t corrected starting drawbar pull

- High levels of starting & low-speed T.E. require lots of adhesion weight

New Solutions

Target Specifications

Service	Wgn Type	Gross Wt	N Wagons	Train Weight	Max Speed	Route	Min Range Reqd	Time	Av DBHP Reqd	Class 56 Load Factor
		tons			mph		miles	hr	Level	%
MGR	HAA	50	40	2000	45	Toton-Didcot return	242	4.9	1244	25
Speedlink	VAB	40	25	1000	60	STJ-Glasgow	417	6.3	1131	50
Freightliner	FTA	80	20	1600	60	Soton-Glasgow	471	7.1	1809	70
Freightliner	FTA	80	20	1600	75	Soton-Glasgow	471	5.7	2946	70

- Av DBHP calculated @ av.speed from Serbian train resistance formula
- Min range includes 10% margin
- Time calculated @ max train speed
- Class 56 Load Factors from steve@railtechnical.com

Technologies

Technologies Assumed

- 5AT Steam Cycle & Boiler – 305psi, 450 deg C steam Temp
- Pulverised Coal Firing, same efficiency as hand firing
- Atmospheric Condensing to improve Availability
- 3 Cylinder drive to maximise useable adhesion
- Rotary Cam poppet valve gear

All proven technology (apart from 450 deg C steam temp ?)

3 Cylinders

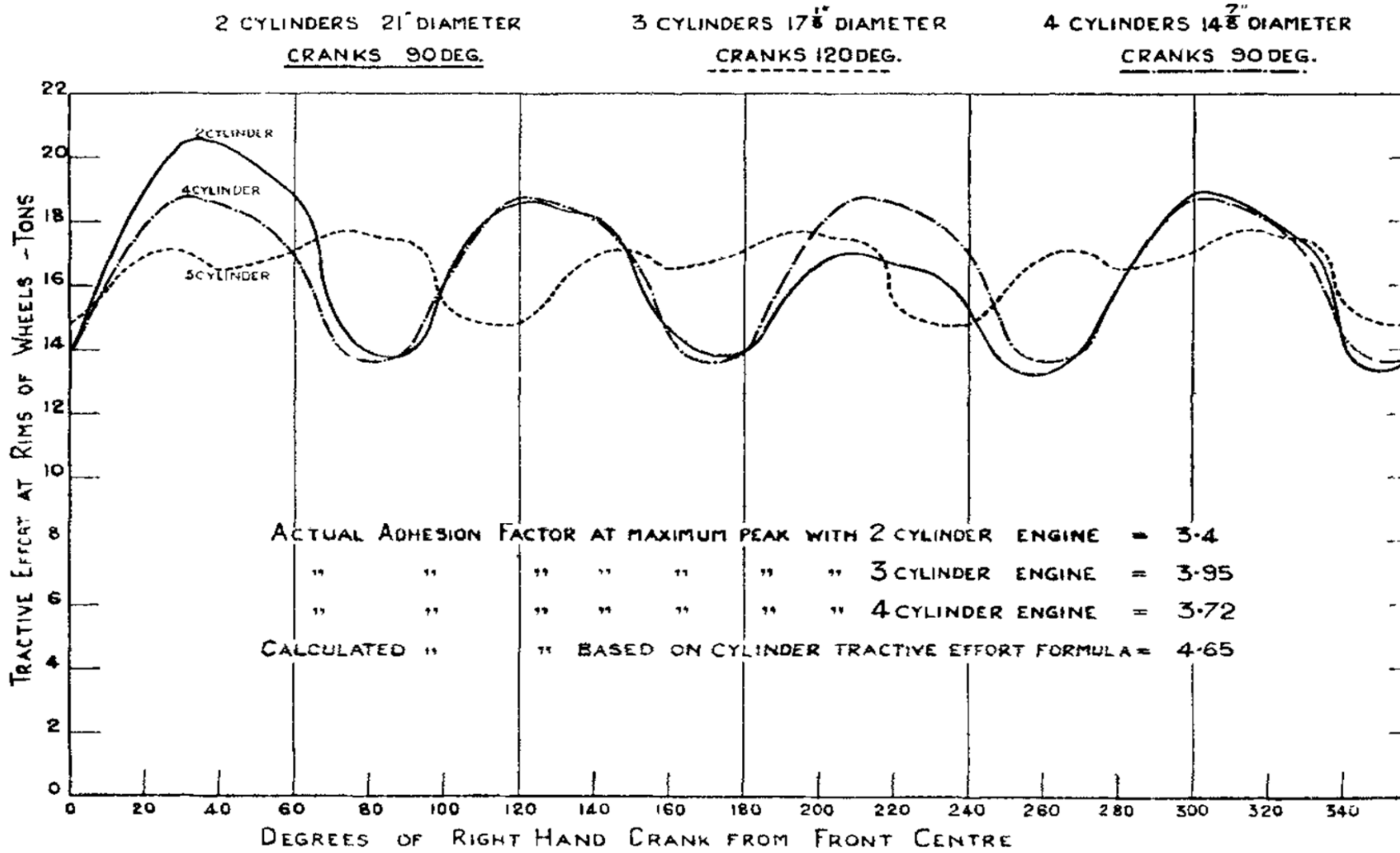
- Constant calculated coefficient friction (= 0.215) for 2,3,4 cyl designs of equal cyl volume

- 3 Cylinders give a more even turning moment than either 2 or 4 Cylinders and hence a 14% higher useable coefficient of friction than 2 cyl designs

N Cyl	Peak Mu
2	0.294
3	0.253
4	0.269
Calc	0.215

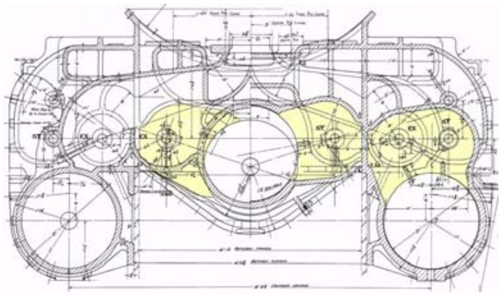
Fig. 2. *Variation in Tractive Effort at Rims of Wheels for one Revolution with 2, 3 and 4 Cylinder Engines of Equal Cylinder Volume.*

Boiler Pressure 180 lb. per sq. inch. Stroke 28 inches. Wheel Diameter 56 inches.
Cut-off 75 per cent. Connecting Rod 8 times crank radius. Adhesive Weight 70 tons.

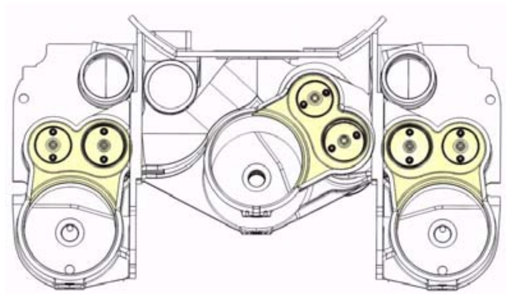


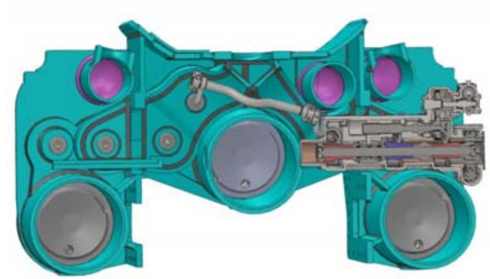
Valve Gear

- “All valve gears give practically the same diagram”
  – Porta, Fundamentals of the Porta Compound System
- Personal preference is for rotary cam poppet valve gear
  - Technically most elegant
  - Enclosed, therefore lower maintenance (Bond)
  - Lighter, therefore more suited to high speed (Chapelon 5kg poppet valve cf. 100kg piston valve)
  - ➔ RC Lenz, Franklin B or British Caprotti



2001 original Gresley P2
Large centre cyl clearance vol





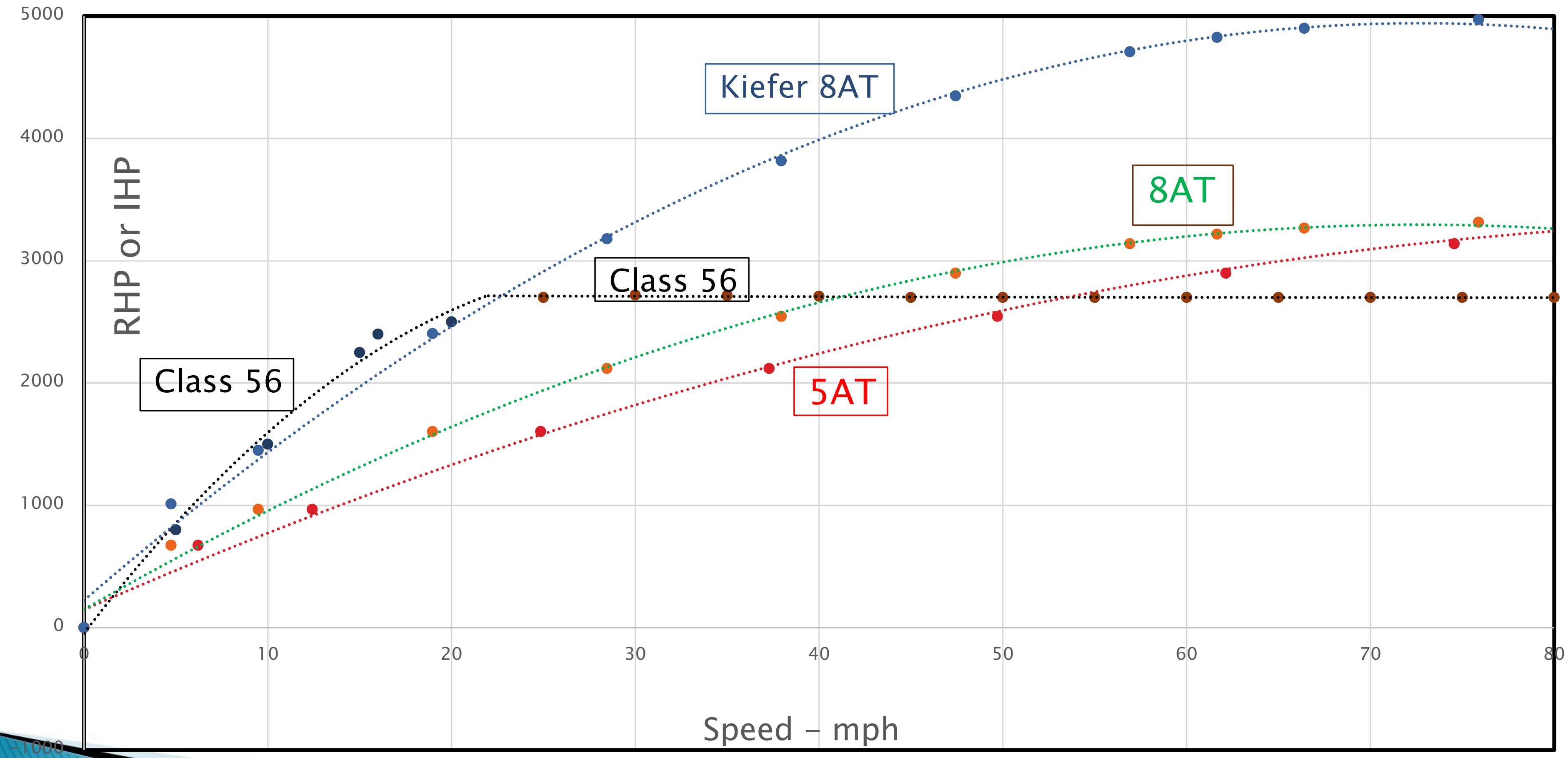
2007 P2 redesign
Reduced clearance vols, rocking shaft
Drive to centre cyl inlet valve

Design

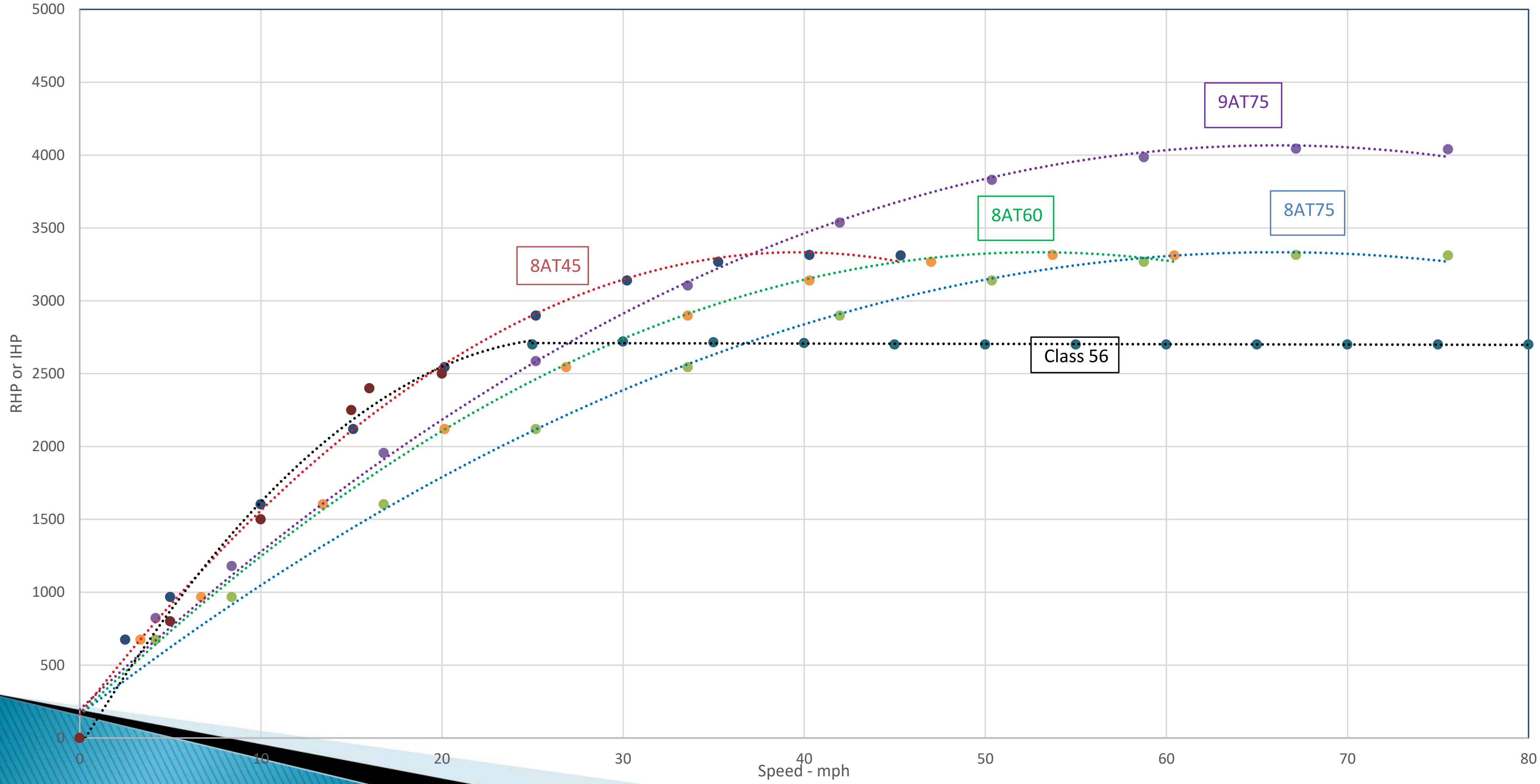
Parametric Design

- Performance estimates largely scaled from 5AT FDC + Roosen for Condensers
  - Major Exception LR
    - N/ton approach not valid for Aerodynamic Drag
    - ➔ David Pawson formula used for LR
- Weight Estimates derived from 5AT/ Girdlestone/ Durrant
- Deviate as little as possible from traditional Stephenson form to minimise risk
- Introduce new technologies only when absolutely necessary to address shortfalls in traditional Stephenson designs cf. diesels

Class 56 Equiv – 8AT Options 1



Class 56 Equiv – 8AT Options 2



Thermodynamics – 5AT 1B Open Cycle

5AT Cycle		Pressure		Temp	h	s	isen eff	dryness
Coal MJ/kg	30	psig	bars (abs)	deg C	KJ/kg	KJ/kg K	%	%
SH Exit		305	22.0	462	3384			
HP Steam chest		290	20.9	450	3356	7.265		
HP exit	isen.	7	1.5	119	2709	7.265	85%	
	adiab.	7	1.5	167	2806	7.500		
Total Cyls Adiabatic					550			
Total Cyls					523			

5AT FDCs		
Design IHP	3192	hp
Cyl Heat Drop		
Adiabatic	551	KJ/kg
Actual	525	KJ/kg

		Speed	Power				Coal	Evap	Cyl Feed	DB Effy
		mph	IHP	IKW	LR (hp)	DBHP	lb/hr	lb/hr	lb/hr	%
8ATB45		45	1852	1381	608	1244	3,000	21,926	20,982	8.2%
	max	45	3208	2393	608	2600	5,170	37,789	36,146	9.9%
8ATB60	VAB	60	1891	1410	760	1131	3,063	22,387	21,423	7.3%
	FTA	60	2569	1916	760	1809	4,162	30,420	29,110	8.6%
	max	60	3208	2393	760	2448	5,170	37,789	36,146	9.3%
9ATB75 max		75	3903	2912	957	2946	6,323	46,217	44,227	9.2%

Thermodynamics – 5AT 1B Condensing Cycle

5AT Condensing Cycle		Pressure		Temp	h	s	dryness	isen eff
30	MJ/kg	psig	bars (abs)	deg C	KJ/kg	KJ/kg K	%	%
SH Exit		305	22.0	463	3384	7.279		
HP Steam chest		290	20.9	450	3357	7.265		
HP exit	isen.	7	1.5	119	2709	7.265		85
	adiab.	7	1.5	167	2806	7.500		
Turbo In	isen.	7	1.5	167	2806	7.500		
Turbo exit	isen.	0	1	120	2717	7.500		85
	adiab.	0	1	131	2730	7.523		
Total Cyls Adiabatic					551			
Total Cyls					523			
Turbo					76			
Condenser In		0	1	131	2730	7.523		
Condenser Out	sat liq	0	1	100	417	1.303	0	
Feed Pumps		305	22.0	100	421	1.305	0	
Economiser Out		305	22	217	931	2.492	0	
Evaporator out		305	22	217	2800	6.304	100	
Superheater out		305	22	463	3384	7.279	100	

	8ATKM	9ATKM
	KW	KW
Radiator Fans	143	225
Induced Draft Fans	77	94
STUG	19	23
Boiler Feed Pumps	19	23
Total Addtl Aux	258	365
Turbo Available	345	415
Reqd Turbo Efficiency	75%	88%

	Speed	Power				Coal	Evap	Cyl Feed	DB Effy
1b condenser	mph	IHP	KW	LR	DBHP	lb/hr	lb/hr	lb/hr	%
8ATC45	45	1817	1356	573	1244	2,923	21,368	20,439	8.4%
max	45	3208	2393	573	2635	5,170	37,789	36,146	10.1%
8ATC60	60	1851	1381	721	1131	2,978	21,766	20,820	7.5%
	60	2529	1887	721	1809	4,069	29,742	28,449	8.8%
max	60	3208	2393	721	2487	5,170	37,789	36,146	9.5%
9ATC75	75	3868	2885	922	2946	6,222	45,477	43,500	9.3%

Roosen Radiator Design Curves

CLASS "25" CONDENSING LOCOMOTIVES ON THE S.A.R. 249

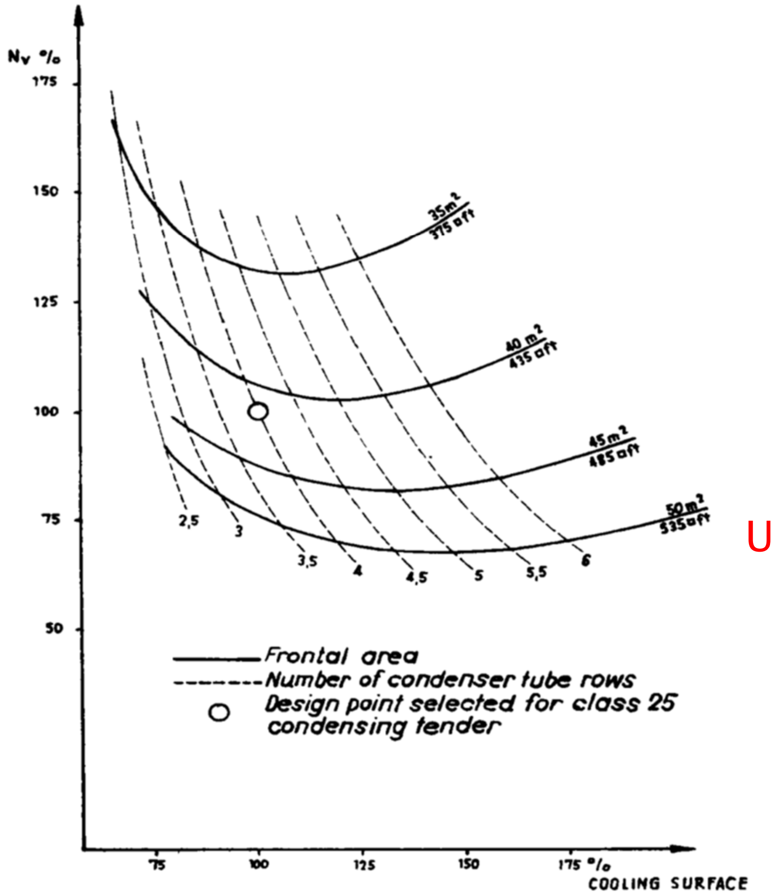


FIG. 7

POWER REQUIRED N_v TO OVERCOME CONDENSER RESISTANCE ON THE BASIS OF GIVEN AMOUNT OF STEAM AND AMBIENT TEMPERATURE, PERCENTAGEWISE.

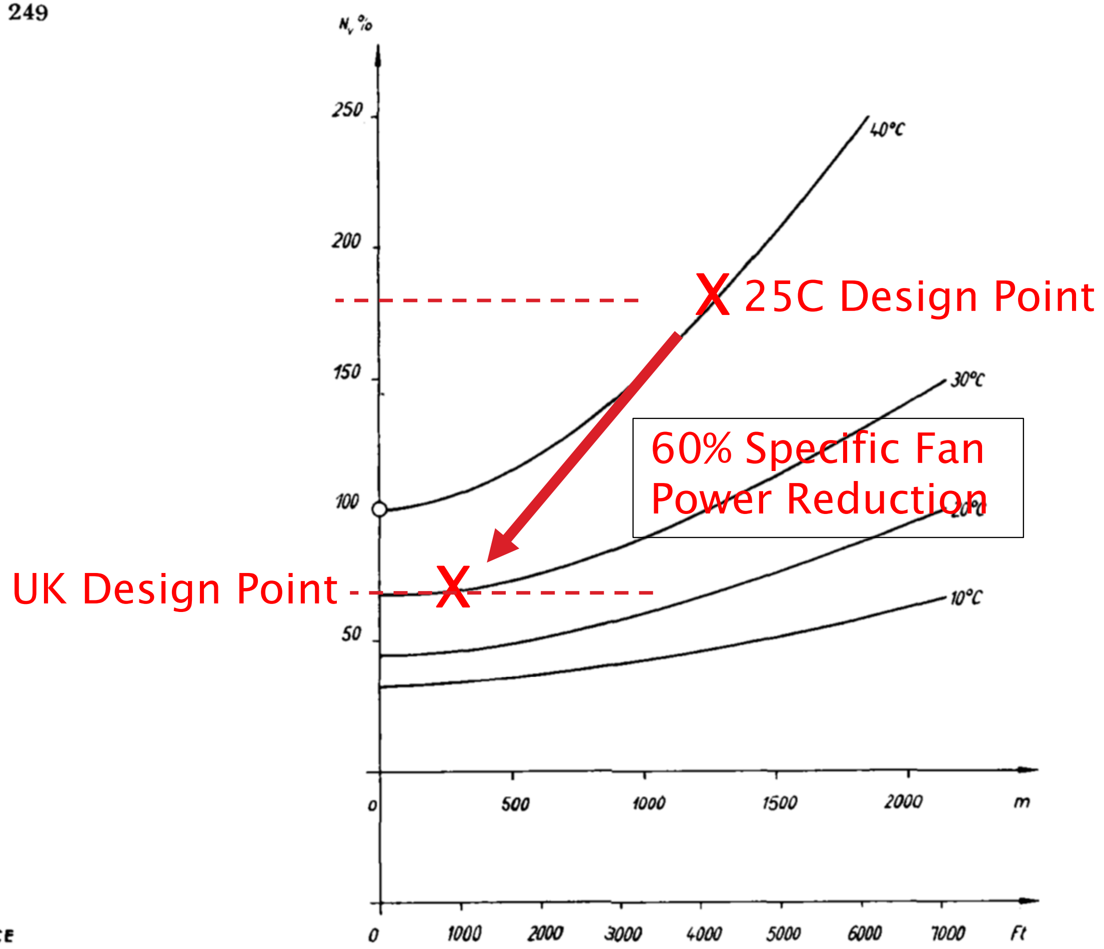


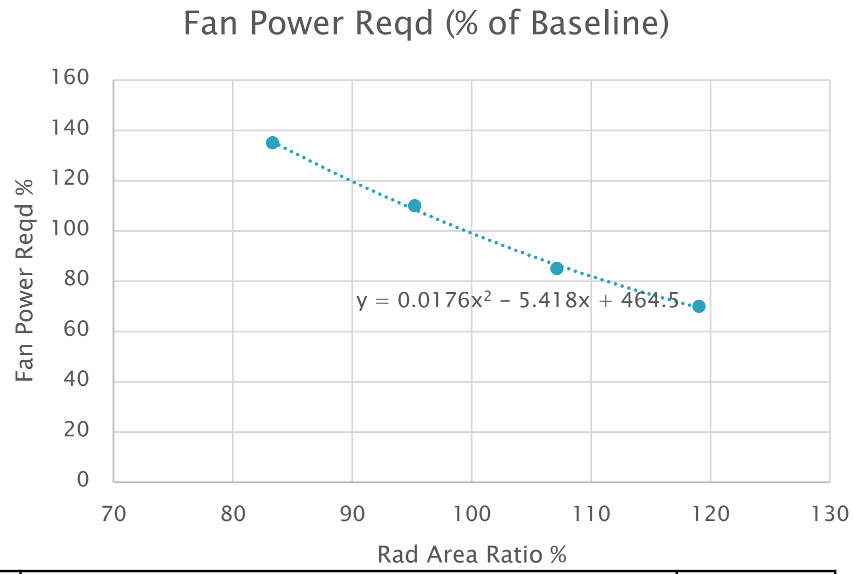
FIG. 8

EFFECT OF ALTITUDE AND AMBIENT AIR TEMPERATURE ON POWER DEMAND N_v, RELATED TO SEA LEVEL AND 40°C = 104°F.

Radiator Sizing

Hot Well	25C	8ATKM	9ATKM	
Max Evap	55,000	37,789	45,477	lb/hr
Capacity	500	344	413	gall

- Both 8ATKM & 9ATKM only need 1 radiator



Design Conditions					Roosen				
	Steam Mass Flow	Heat Transfer	Design Altitude	Design Amb Temp	Alt & Temp Factor	N fans	Rad Area Ratio	Fan Power Factor	Fan Power
			Alt	Temp					
	t/h	KW	ft	deg C					hp
25C	25	17,132	4500	40	1	5	1	1	550
8ATKM	17	11,746	1000	30	0.36	1.2	1	1	136
	17	11,746	1000	30	0.36	1	0.8	1.41	191
	17	11,746	1000	30	0.36	2	1.6	0.49	93
9ATKM	20.9	14,331	1000	30	0.36	1.5	1	0.99	163
	21	14,331	1000	30	0.36	1	0.7	1.82	302
	21	14,331	1000	30	0.36	2	1.3	0.55	92

Weight Estimate

			Loco											Tender					
		Config	Baseline	Bunker	Radiator	Coal	Water	No Ballast Gross Weight	Reqd Adhesion	No Ballast Adhesion	Ballast	Loco Gross Weight	Ballasted Axle Load	Coal	Water	Tare	Gross	N axles @ 20T	Total Gross Weight
			ton	ton	ton	ton	gall	ton	ton		ton	ton	ton	ton	gall	ton	ton		ton
8AT		2-8-0	80			0	0	80	84	71	13	93	21	11.25	9,250	26.7	80	4	160
9F		2-10-0	89			0	0	89	80	80	0	89	16	7	5,000	23	53	3	141
Chap 2-12-0		2-12-0	100			0	0	100	120	82	38	138	20	10	8,512	32	80	4	218
8ATB	120T adhesion	2-12-4B	80	7.3		14.6	0	102	120	74	46	148	20.0	0	23,869	53.3	160	8	308
8ATB_3Cyl	61,0000 lbf TE	2-10-2B	80	7.3		14.6	0	102	95	73	22	124	19.0	0	11,935	26.6	80	4	204
		2-10-4B	80	7.3		14.6	0	102	95	73	22	124	19.0	0	8,960	20.0	60	3	184
8ATB_2Cyl	61,0000 lbf TE	2-12-4B	80	7.3		14.6	0	102	111	74	37	139	18.4	0	11,935	26.6	80	4	199
9ATB	3900 ihp	2-10-4B	98	8.9		17.8		124	95	89	6	131	19.0	0	11,935	26.6	80	4	211
Condensing																			
Garratt	120T adhesion	2-6-0+ 0-6-2	111		12	14.6	425	139	120	119	1	140	20.0						140
6 Cyl	61,0000 lbf TE	2-6-0+ 0-6-2	111		12	14.6	425	139	95	119	-24	139	15.9						139
4 Cyl	61,0000 lbf TE	2-6-0+ 0-6-2	111		12	14.6	425	139	111	119	-9	139	18.4						139
Kitson Meyer																			
6 Cyl	61,0000 lbf TE	0-6-0+ 0-6-0	96		6	14.6	425	118	95	118	-23	118	19.7						118
4 Cyl	61,0000 lbf TE	0-6-0+ 0-6-0	96		6	14.6	425	118	111	118	-8	118	19.7						118
9ATC	3900 ihp	0-6-0+ 0-6-0	117		6	17.8	425	143	111	143	-32	143	23.8						143

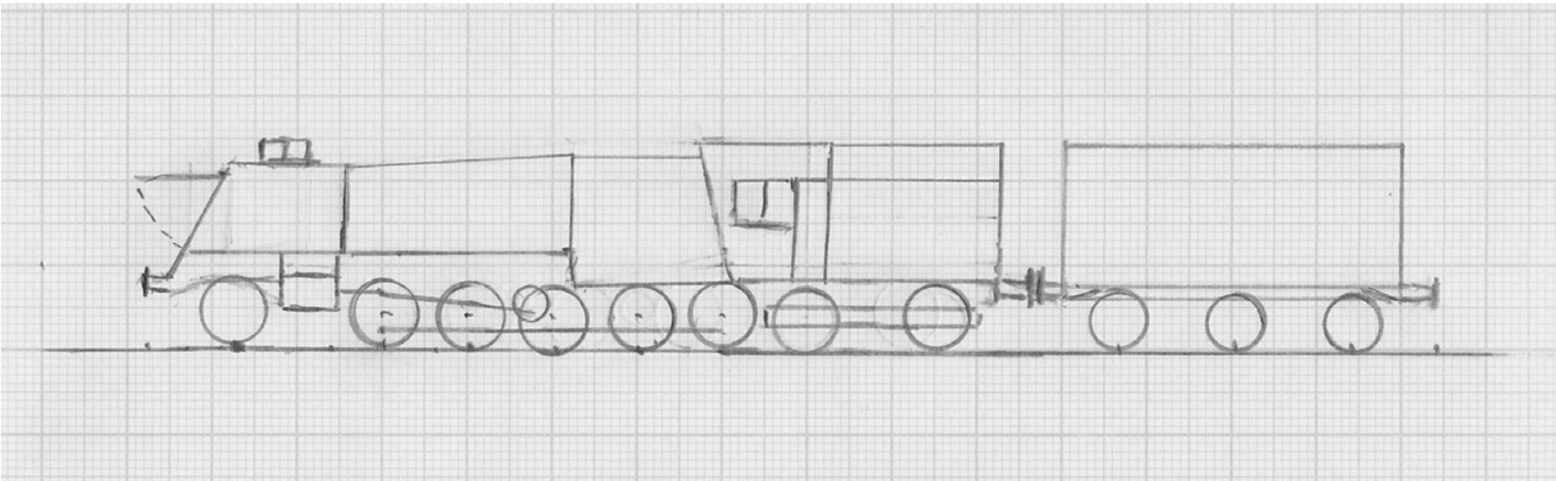
	Straight	KM	Garratt
Loco Only Empty Weight Ratio	1.0	1.2	1.4

	2 Cyl	3 Cyl
T.E. (lbf)	61,000	61,000
Usable Mu	0.25	0.291
Reqd Adhesion (t)	110.6	95.2

Ballast	Steel	8m x 2m
tons	m3	t (m)
6	0.8	0.05
22	2.9	0.18
46	5.9	0.37

8ATB Class 56 Equivalent

(3250 SHP)

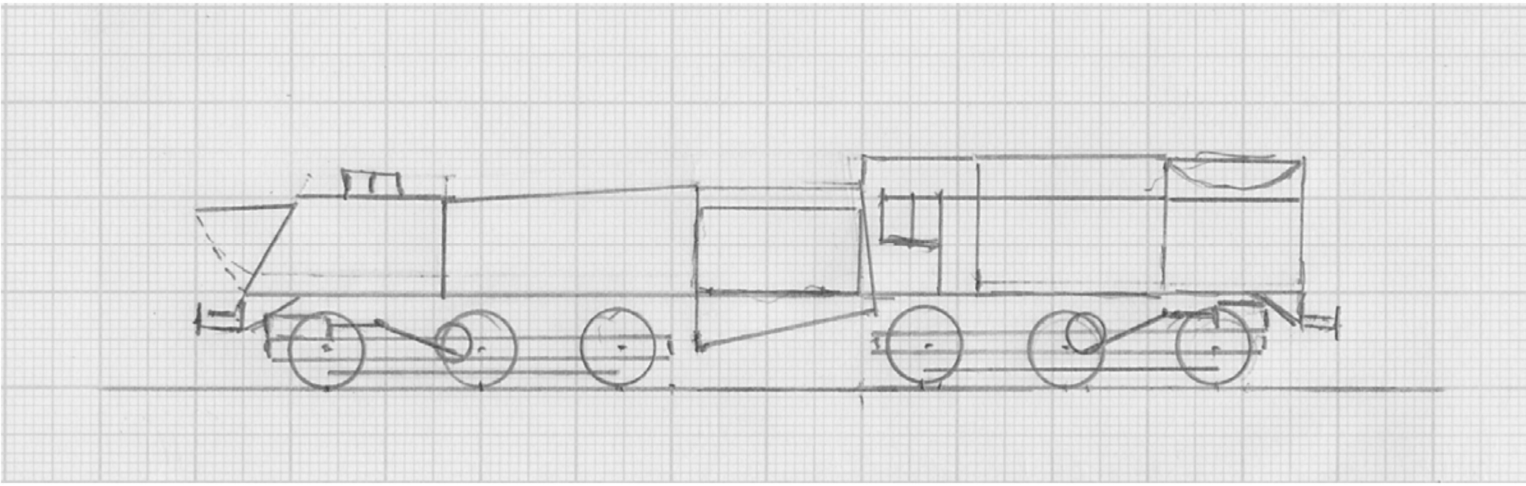


Config.	Max IHP	Max Speed	Cyls			Equiv Driver Dia	Act. Driver Dia	Starting T.E.	Boiler Max Diam	Grate Area	Max DB Effy
2-10-4B		mph	n	dia	stroke						
				in	in	m	m	Lbf	ft in	ft2	%
8ATB45	3200	45	3	12.2	31.5	0.76	1.14	61,000	5’6”	28.7	9.9
8ATB60	3200	60	3	14.2	31.5	1.02	1.14	61,000	5’6”	28.7	9.3
9ATB75	3903	75	3	15.8	31.5	1.27	1.14	61,000	6’2”	35.0	9.2

Fuel & Water						
Svc	Route	Speed	Dist	Time	Coal	Water
		mph	miles	hr	t	gall
MGR	Toton-Didcot	45	110	2.4	3.6	5,896
SL	STJ-Glasgow	60	379	6.3	9.5	15,555
FL	Soton-Glasgow	60	428	7.1	14.6	23,869

	Weights								Lengths		
	Loco Full	Tender Full	Total	Ballast	Max Axle Load	Adhesion	Coal	Water	Loco Only	+ 3 Axle Tender	+ 4 Axle Tender
	ton	ton	ton	Ton	ton	ton	ton	gall	ft	ft	ft
8ATB	124	60	184	22	19	95	14.6	8,960	51	75	85
9ATB	131	80	211	6	19	95	17.8	11.935	55	79	89

8ATKM Class 56 Equivalent (3250 SHP)



Config.	Max IHP	Max Speed	Cyls			Equiv Driver Dia	Act. Driver Dia	Boiler Max Diam	Grate Area	Starting T.E.	Max DB Effy
0-6-0 + 0-6-0		mph	n	dia	stroke						
				in	in	m	m	ft in	ft2	Lbf	%
8ATKM45	3200	45	4	13.6	19.5	0.76	1.14	5’6”	28.7	61,000	10.1
8ATKM60	3200	60	4	15.6	19.5	1.02	1.14	5’6”	28.7	61,000	9.5
9ATKM75	3900	75	4	17.8	24.0	1.27	1.14	6’2”	35.0	78,750	9.3

Fuel & Water						
Svc	Route	Speed	Dist	Time	Coal	Water
		mph	miles	hr	t	gall
MGR	Toton-Didcot	45	110	2.4	3.5	0
SL	STJ-Glasgow	60	379	6.3	9.2	0
FL	Soton-Glasgow	60	428	7.1	14.3	0

	Weights						Lengths
	Loco	Ballast	Max Axle Load	Adhesion	Coal	Water	Loco
	ton	Ton	ton	ton	ton	gall	ft
8ATKM	118	0	19.7	118	14.6	425	58
9ATKM	143	0	23.8	143	17.8	425	62

Assesment & Conclusions

Assessment

Diesel Equiv.	Assessment
Class 56	Technology to match Class 56 performance with steam available in 1950s
	Steam individual CAPEX much lower, offset by larger fleet size due to lower utilisation
	Steam and Diesel individual OPEX essentially equal (NYC trials)
	Steam much lower risk

Requirements Steam vs. Diesel	8ATB	8ATKM
Cleaner	X	X
Less Manual Labour	X	X
Low Speed Performance	X	X
Reduced OPEX	X	X
Increased Operating Range		X
Reduced terminal time	X	X
Reduced servicing		X
Increased major repair intervals		

Uncomfortable Questions

- Is the boiler the achilles heel of the steam locomotive ?
  - Inspection requirements – safety
  - Maintenance costs
  - ➔ Low Availability ?

  - Frequent Servicing Required
    - Water, Ash, Fuel
    - ➔ Low Utilisation ?

- Does direct side-rod drive inevitably mean low annual mileages ?
  - Fluctuating, asymmetric loads imposed on frames, axleboxes etc.
  - Mitigations – Tandem coupling rods, Franklin Wedges etc.

Conclusions

- Yes, BR could have done something different
- Proven technologies were available
- Performance is the easiest issue to address once manual firing limit removed
- Competitiveness of steam dependent on price ratio of coal/oil (and environmental acceptability)
- Availability & Utilisation constraints of steam may be limiting factors, not performance

- Still To Come:
  - Shunters
  - Multiple Units

End of Part 3
Presentation

Main References

- Performance
  - 5AT FDCs, Wardale & Newman, ASTT, 2015
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  - Bulleid IMechE Presidential Address,1947
- Pulverised Coal Burning
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- Other
  - “Sentinel Locomotives & Sentinel-Cammell Railcars”, Hutchings, IRS, 2020
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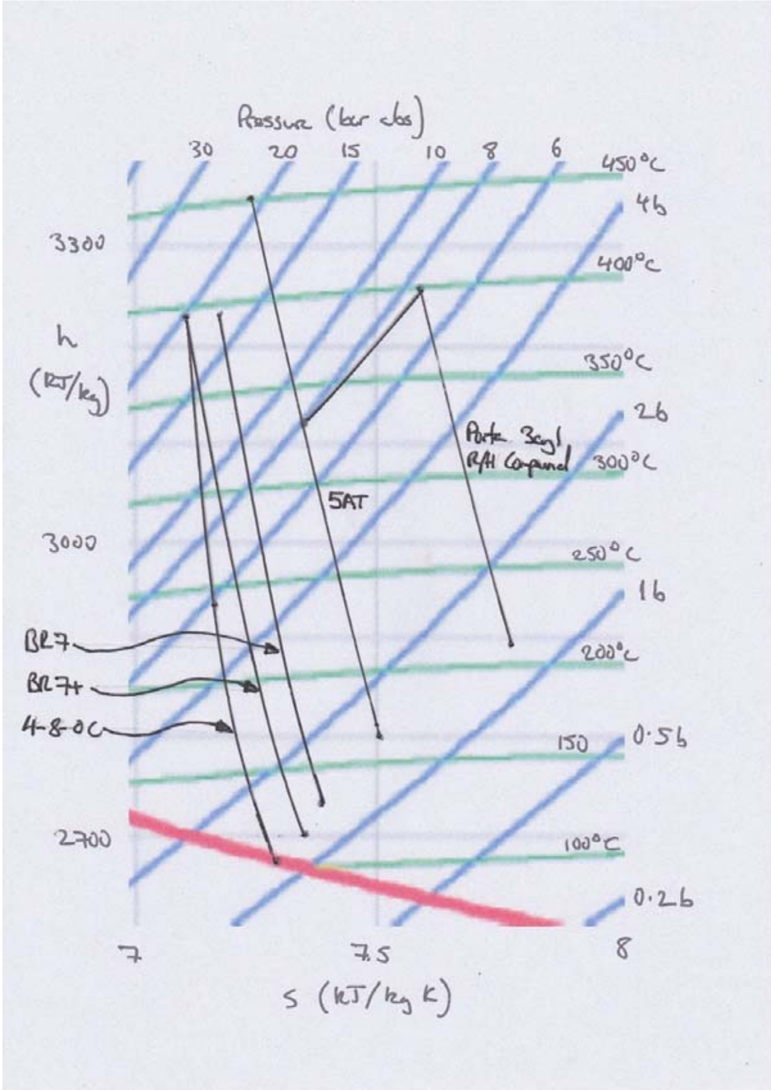
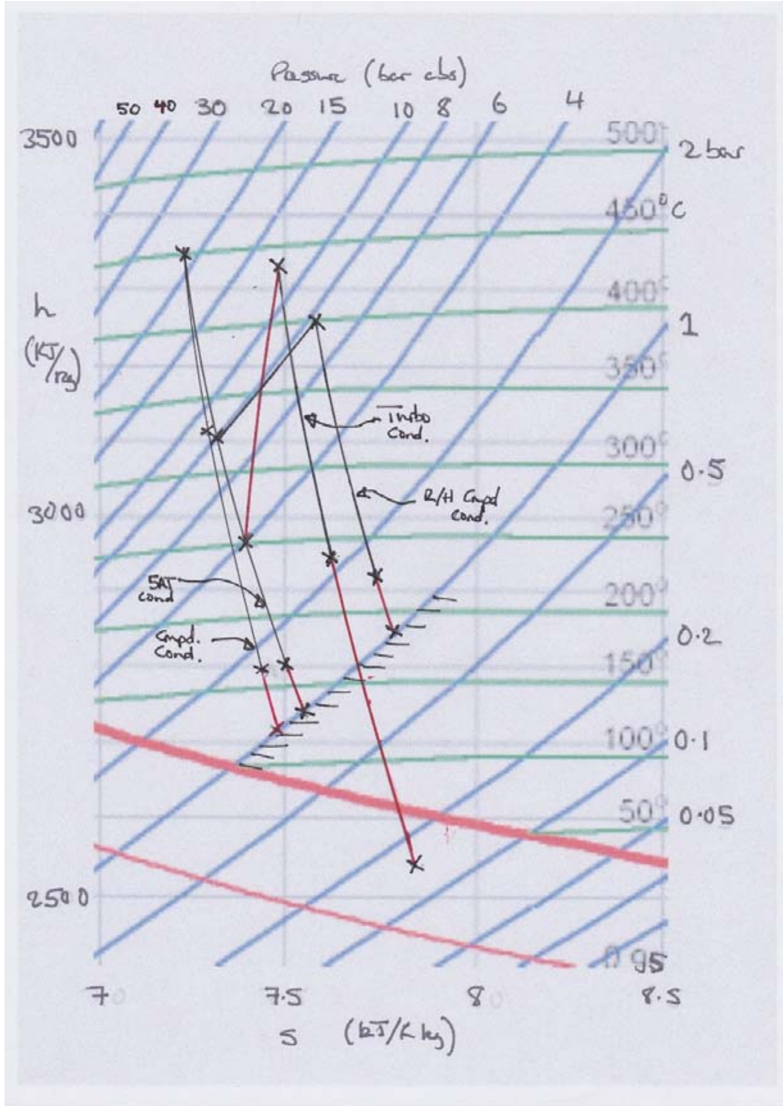
hs Diagram
– 1GS & 2GS

@ 70 mph	Evap. (lb/hr)	Pressure (psig)	Temp (deg C)	Delta h (KJ/kg)	Isen. Effy (%)
1GS					
BR7	24,000	250	393	496	86.9
	32,000	250	402	458	86.0
BR7+	24,000	290	393	527	85.0
	40,000	290	410	481	82.8
Chapelon 4-8-0	24,000	290	393	549	91.0
	40,000	290	410	524	89.5
2GS					
5AT	37.789	290	450	550	81.0
Porta 3 cyl compound		290	450	609	83.0

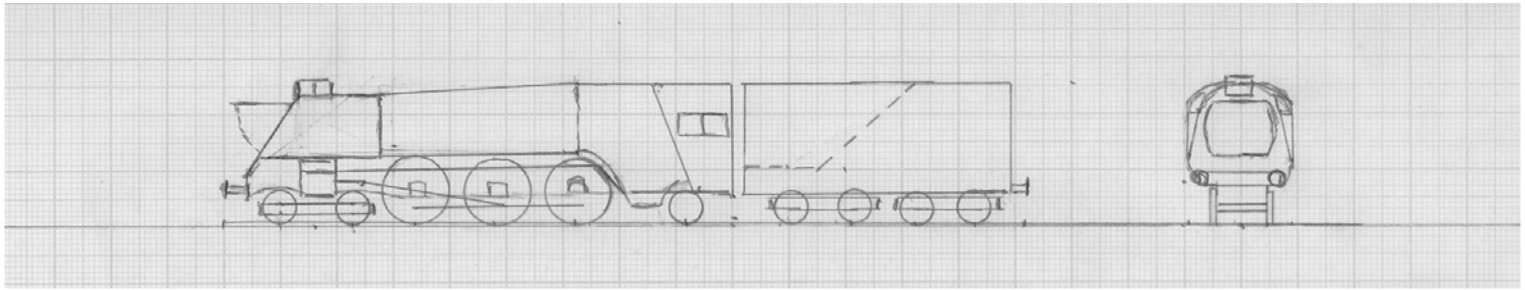


hs Diagram – Condensing Cycles

			Delta h (KJ/kg)		
	Pressure (psig)	Temp (deg C)	Cyls	Turbo	Isen. Effy (%)
3GS					
5AT 1b Cond	290	450	551	73	85
Porta 1b Cond.	290	450	562	75	88
Porta R/H 1b Cond.	290	450	595	74	83
4GS					
Turbo Cond.	290	450	766	403	85



1GS – 2000hp DE Equivalent



1GS			KX_Edinburgh			
Config.	4-6-2	Steam	Time	Av.Speed	Max Speed	DB Effy
DE Equiv	hp	ihp	hr	mph	mph	%
Class 40	2000	3000	6	67	90	5.6

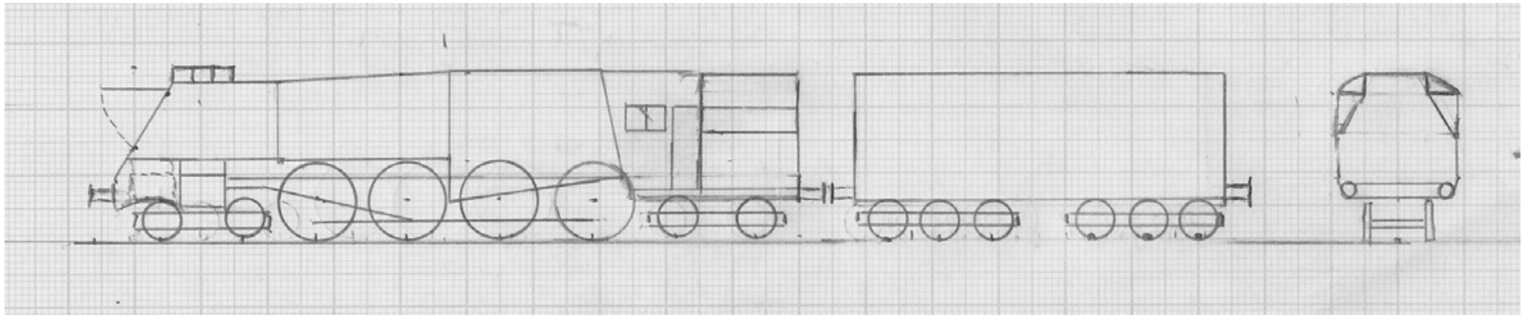
Cylinders		HP	LP
number		2	0
dia	in.	20	
stroke	in.	28	

Weights	Full	Coal	Water
	ton	ton	gall
Loco	98	0	0
Tender	62	10	5,000
Total	160	10	5,000
Max Axle Load	21.5		
Adhesion	64		

Thermodynamics	BR7+	
Max Boiler Pressure	psig	290
Cyl Steam Temp	deg C	410
Max Evap	lb/hr	41,030
Max Coal	lb/hr	6,969
Grate Area	ft2	41.9
N Large Tubes		90
N small tubes		66
Tot. delta h	KJ/kg	433

Starting T.E.	lbf	39,173
Driver Diam.	ft	6.2
Max Boiler Diam.	ft	6.45
Length Overall	ft	71.1

2GS – 3300hp Deltic Equivalent



2GS			KX_Edinburgh				
Config.	4-8-4B	Steam	Time	Av. Speed	Max Speed	DB Effy (%) @ Max Pwr&Speed	
DE Equiv	hp	ihp	hr	mph	mph	Cmpd	Simple
Deltic	3300	4950	6	73	105	9.2	8.6

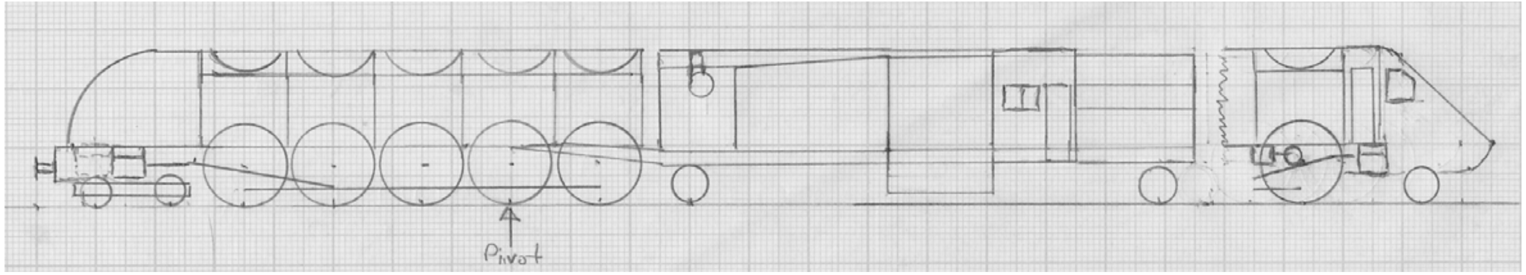
Cyls		HP	LP	S
no.		1	2	3
dia	in.	20.1	24.8	17.0
str	in.	31.5	31.5	31.5

Weights	Full	Coal	Water
	ton	ton	gall
Loco	119	9	
Tender	88		13,200
Total	207	9	13,200
Max Axle Load	20		
Adhesion	80		

Thermodynamics	Porta R/H Cmpd	
Max Boiler Pressure	psig	305
Cyl Steam Temp	deg C	450
Max Evap	lb/hr	52,630
Max Coal	lb/hr	6,465
Grate Area	ft2	40.2
N Large Tubes		134
N small tubes		102
Tot. delta h	KJ/kg	582

Starting T.E.	lbf	50,252
Driver Diam.	ft	5.84
Max Boiler Diam.	ft	6.55
Length Overall	ft	82.5

3GS – 4500hp HST Equivalent



3GS			KX_Edinburgh				
Config.	4-10-2+ 2-10-4	Steam	Time	Av. Speed	Max Speed	DB Effy (%) @ Max Pwr&Speed	
DE Equiv	hp	ihp	hr	mph	mph	Cond	NC
HST	4500	6750	5	89	125	7.3	7.3

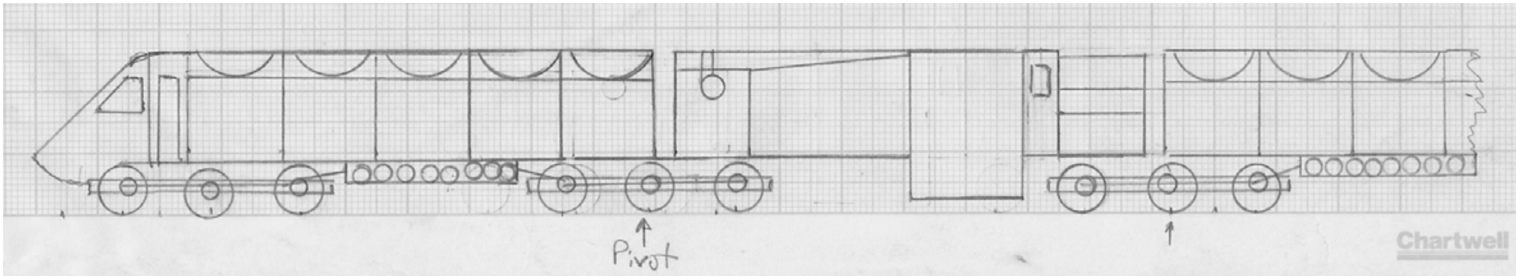
Thermodynamics	5AT Cond.	
Max Boiler Pressure	psig	305
Cyl Steam Temp	deg C	450
Max Evap	lb/hr	79,784
Max Coal	lb/hr	10,915
Grate Area	ft2	60.6
N Large Tubes		203
N small tubes		148
Tot. delta h	KJ/kg	523

Cylinders		Trad.	Encl.
number		6	20
dia	in.	21.0	15.0
stroke	in.	31.5	18.0

Weights	Full	Coal	Water
	ton	ton	gall
Loco (Cond.)	280	15	1,500
Loco + Tender (NC)	373	15	24,000
Max Axle Load	20		
Adhesion	200		

Starting T.E.	lbf	129,135
Driver Diam.	ft	6.95
Max Boiler Diam.	ft	7.78
Length Overall	ft	148.2

4GS – 6000hp Electric Equivalent



4GS			KX_Edinburgh			
Config.	Co-Co+ Co-Co	Steam	Time	Av. Speed	Max Speed	DB Effy @ Max Pwr&Speed
DE Equiv	hp	ihp	hr	mph	mph	%
Class 91	6300	9450	4	100	140	10.9

Thermodynamics	Turbo Single Act.	
Max Boiler Pressure	psig	305
Cyl Steam Temp	deg C	450
Max Evap	lb/hr	80,311
Max Coal	lb/hr	7,889
Grate Area	ft2	61.0
N Large Tubes		204
N small tubes		149
Tot. delta h	KJ/kg	728

Cylinders		HP	LP
number		16	16
dia	in.	13.8	18.1
stroke	in.	19.7	19.7

Weights	Full	Coal	Water
	ton	ton	gall
Loco	227	10	1,000
Tender			
Total	227	10	1000
Max Axle Load	19		
Adhesion	227		

Starting T.E.	lbf	131,766
Driver Diam.	ft	3.93
Max Boiler Diam.	ft	7.81
Length Overall	ft	142.0