

Why Did BR Give Up On Steam ?

– And Could It Have Been Avoided

Part 5 – Multiple Units

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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 5 focusses on multiple units
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Contents – Part 5

1. Requirements Recap
 - Perceived Steam Shortcomings
 - What Did BR DMUs replace ?
2. Previously Proposed Solutions
 - LNER SMUs
 - BR 1st gen DMUs
 - BR 2nd gen DMUs
 - Comparative Costings
3. New Solutions
 - Target Specifications
 - Technologies
 - Design
4. Assessment & Conclusions

R.E. Light-Weight Trains Comm. Report 1952

- ▶ Considered French, Belgian, German & NI experience with railcars
- ▶ DMU advantages
 - Operational
 - Better acceleration
 - Better hill climbing
 - Bi-directional – shorter turn-rounds
 - 1 man operation
 - Higher availability
 - Better passenger appeal
 - Clean, pleasant, modern
 - Faster and more frequent services
 - Increased pass. numbers and new services
 - Economy
 - Principal advantage – OPEX approx. 1 / 3 of steam push-pull (assuming One-Man operation)
- ▶ DMU Disadvantages
 - Limited capacity & power cf. trad. Steam – problem @ traffic peaks
 - Cannot undertake shunting/freight traffic
- ▶ Recommended DMU trials undertaken in 3 representative areas

Multiple Units on BR

New Pass. Tanks Built After 1948					
	BR Std	LMS	LNER	GWR	Totals
2-6-4T	155	147	99		401
2-6-2T	75	120		20	215
	230	257	99	20	616

	1948	1972
Steam Locos	20,023	3
Diesel Locos	53	3,633
Electric Locos	16	317
DMUs	40	3,467
EMUs	4184	6,747
Loco Hauled Coaches	36,033	6,791
Wagons	1,223,634	268,552

- ▶ A Lot of Steam Locomotives were replaced by DMUs & EMUs
- ▶ More Than Twice as Many DMU Power Cars built as BR Standard Steam Locos

1 st Gen Railcars	No.Built	Formations		
MC	2349	2 Car	MC/TC	750
TC	1461	3 Car	MC/TC/MC	500
Total	3810	4 Car	MC/TC/TC/MC	250

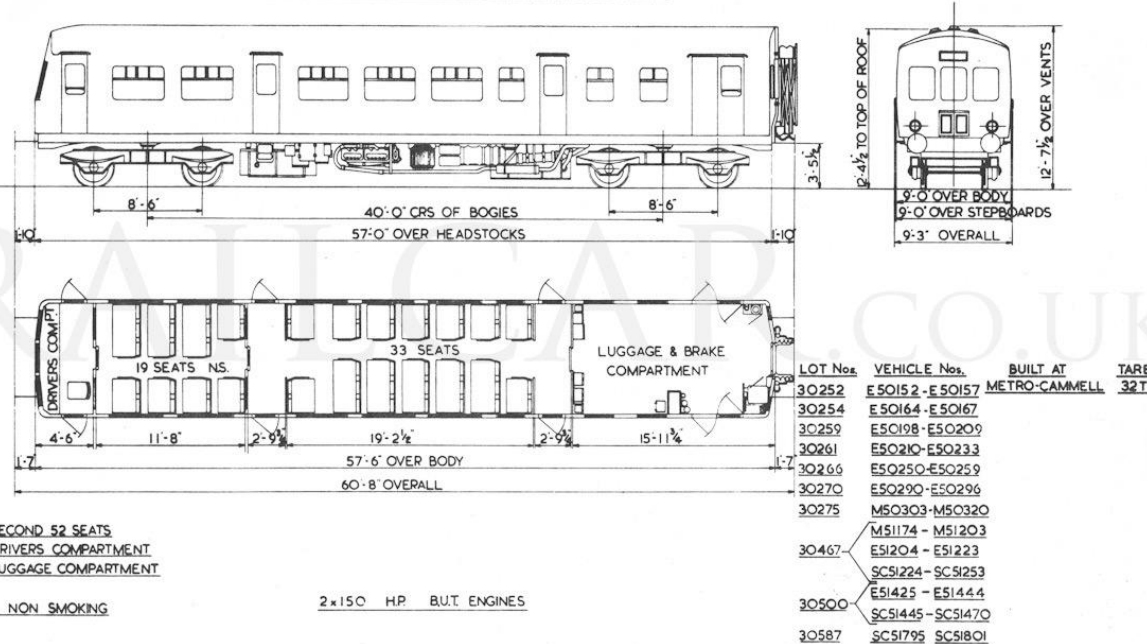
Previous Solutions

BR Class 101 DMU

introduced 1956

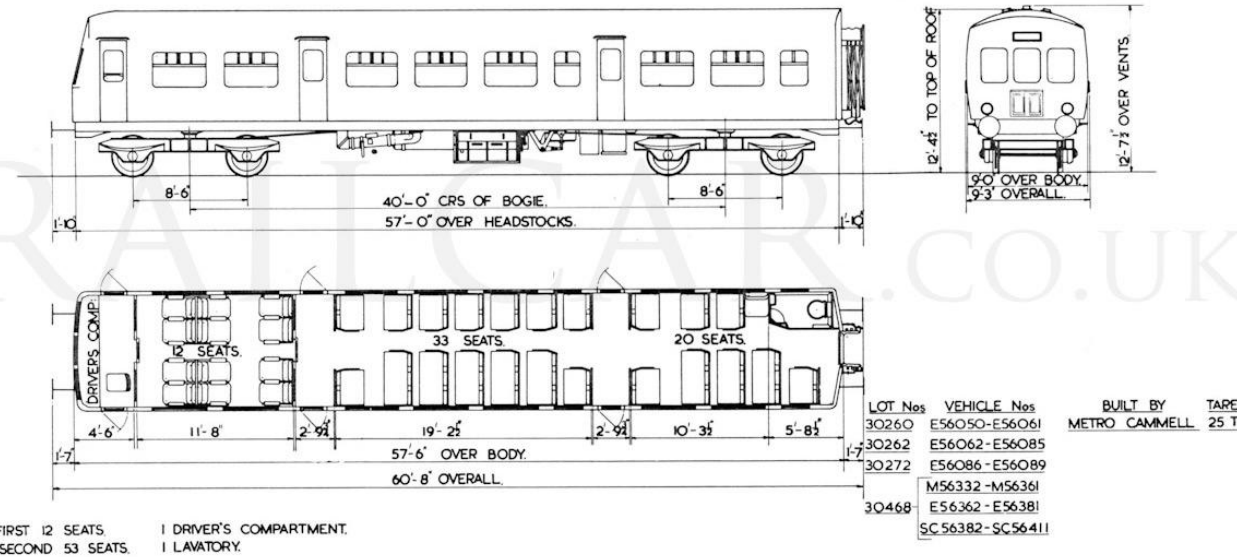
GANGWAYED MOTOR OPEN SECOND BRAKE

BR. 523.



GANGWAYED DRIVING TRAILER OPEN COMPOSITE LAVATORY

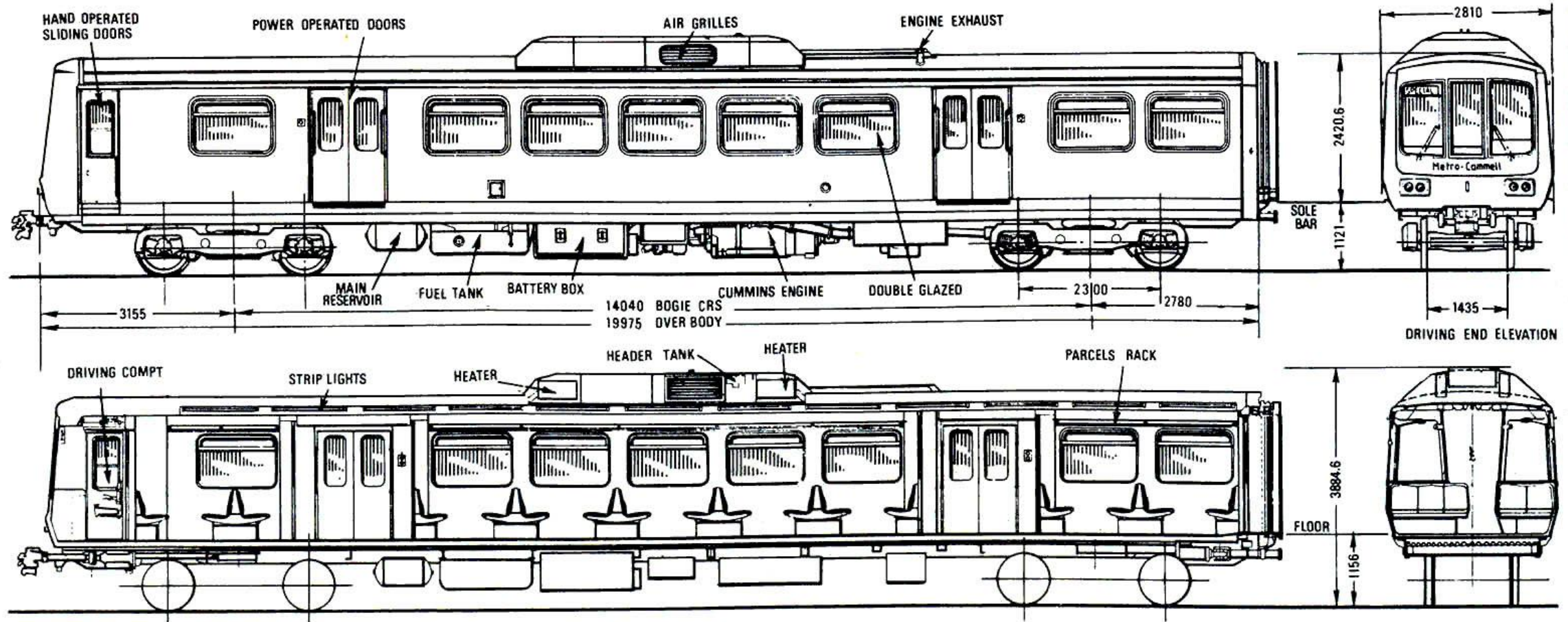
B.R. 630



- ▶ 2x150 hp - DMBS+DTC
- ▶ Each engine drives inner axle of bogie via 4 speed gearbox and axle-mounted final drive
- ▶ 12 1st Class seats, 105 2nd Class seats

BR Class 151 DMU

Class 150 introduced 1984



- ▶ Met Cam competitor to BREL class 150
- ▶ Production versions 2 car – DMSL+DMS
- ▶ 1 x 286hp Cummins diesel engine per car, driving both axles of inner bogie via torque converter and axle-mounted final drives
- ▶ 138 2nd Class seats (2 car)

GNR Steam Railcar

- ▶ Introduced 1906
- ▶ Gresley's 1st elliptical roof coach
- ▶ Other railways had similar designs
- ▶ None lasted very long
 - Inflexible in traffic
 - Couldn't cope with additional coaches/wagons

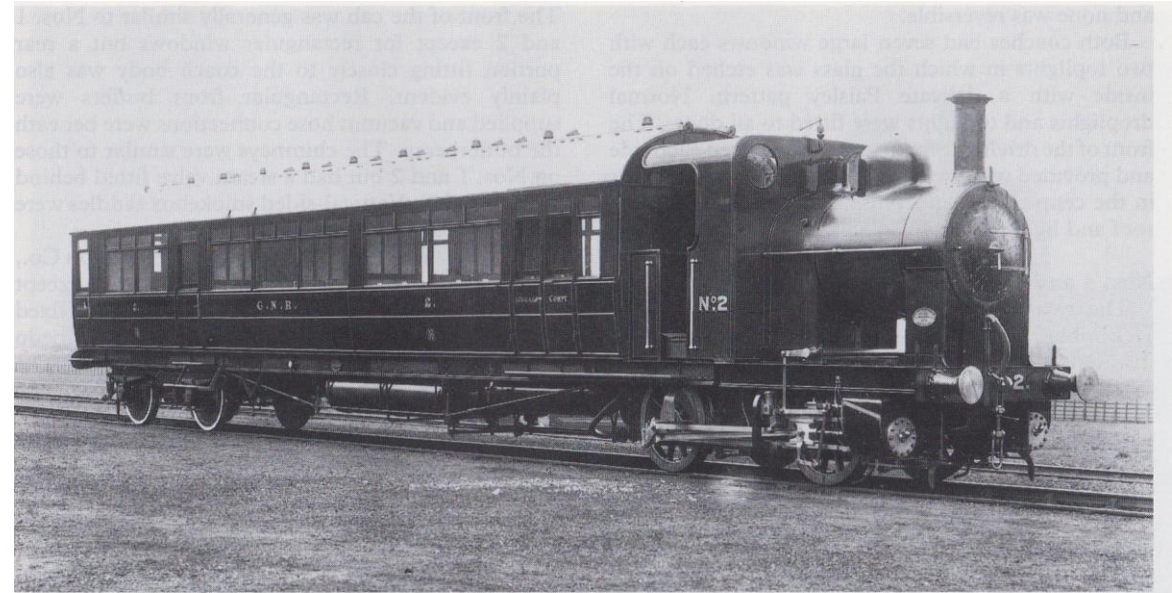
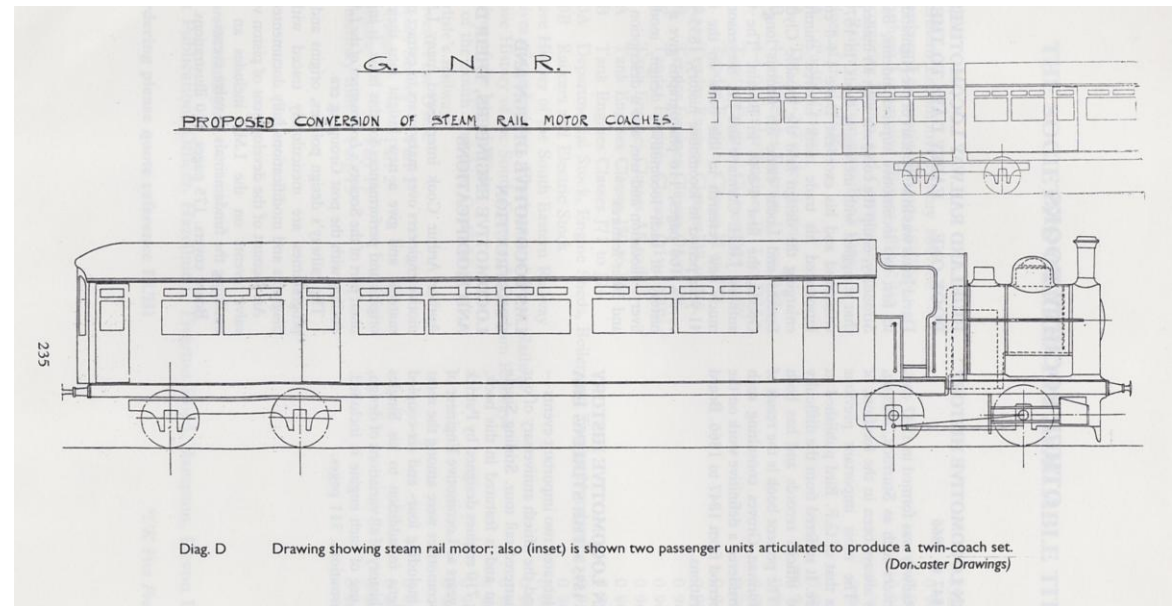
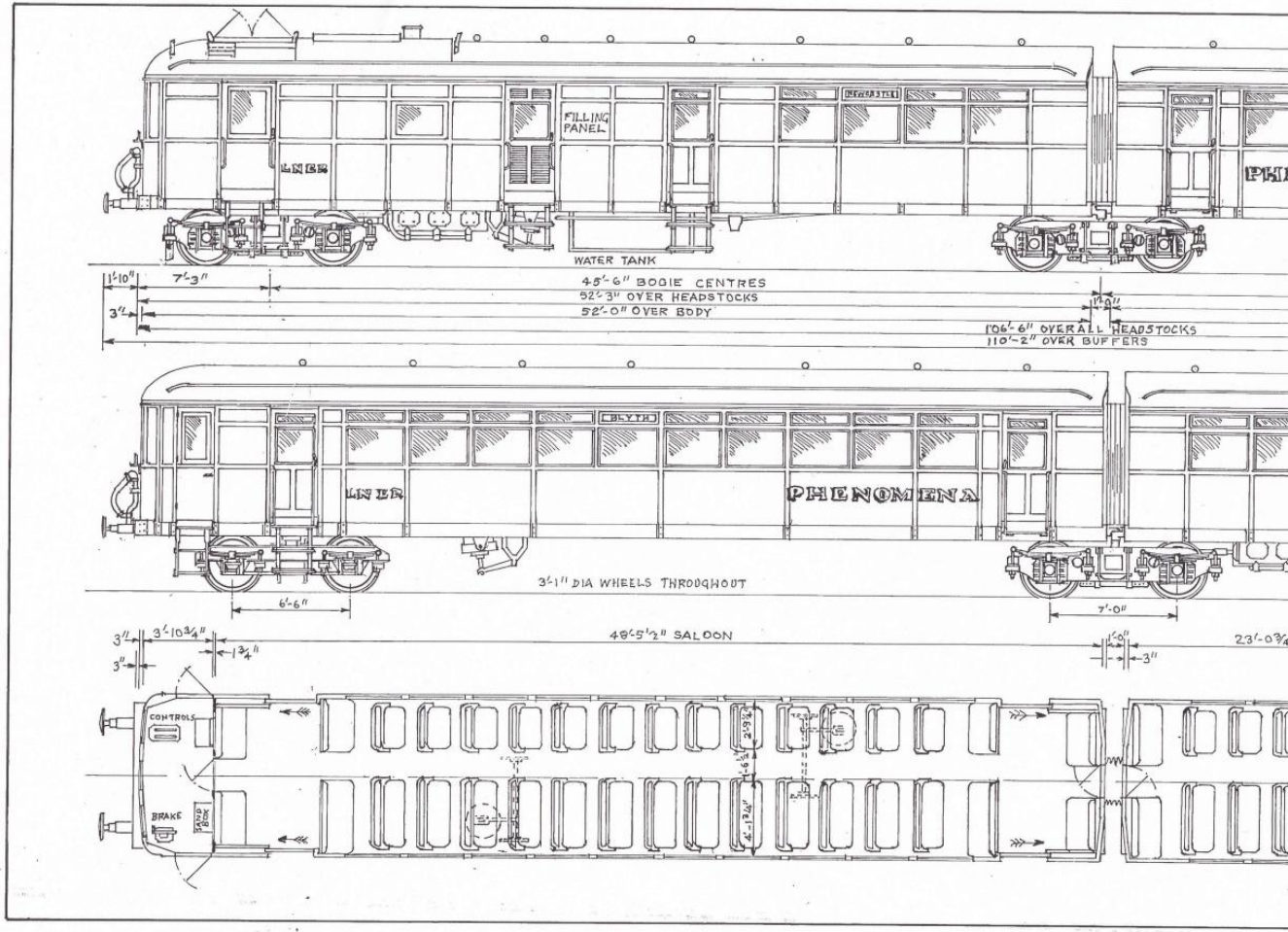


Fig. 86 Steam Motor Car No. 2, built Doncaster Works October 1905. Round-top firebox, straight-sided smokebox saddle. Parallel-sided chimney with flared top. Round head buffers. (Courtesy: N.R.M., York)



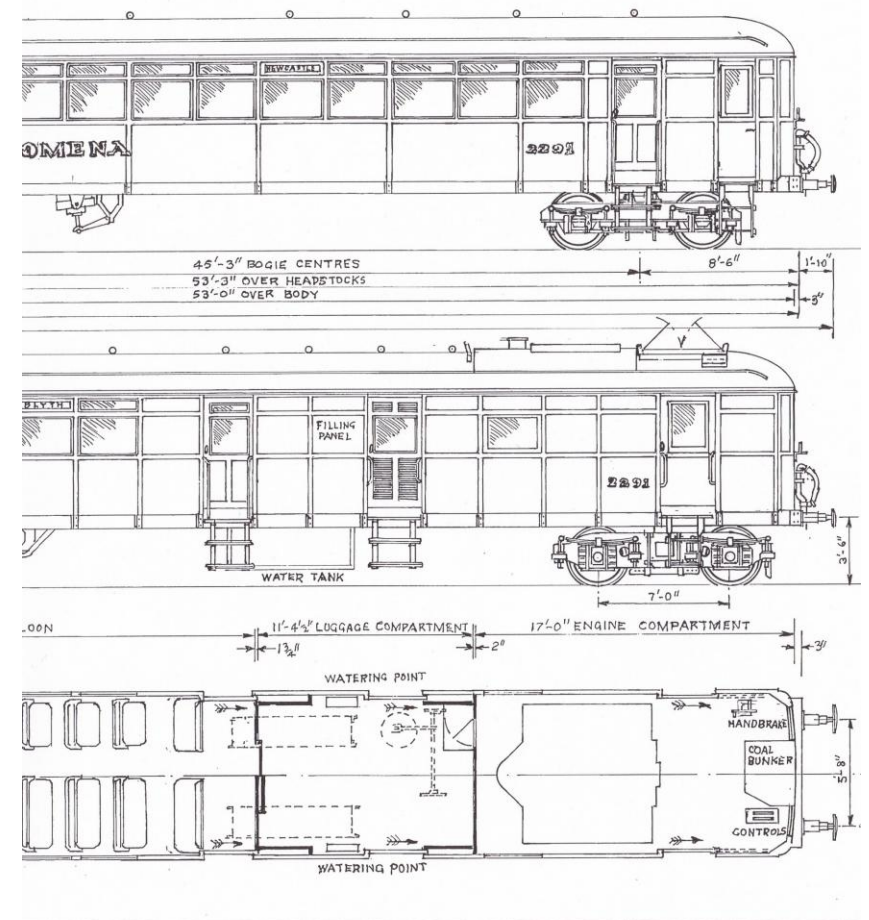
Diag. D Drawing showing steam rail motor; also (inset) is shown two passenger units articulated to produce a twin-coach set. (Doncaster Drawings)

LNER Class 99_100 SMU



- ▶ 2x100 hp
- ▶ 122 x 3rd Class

introduced 1930

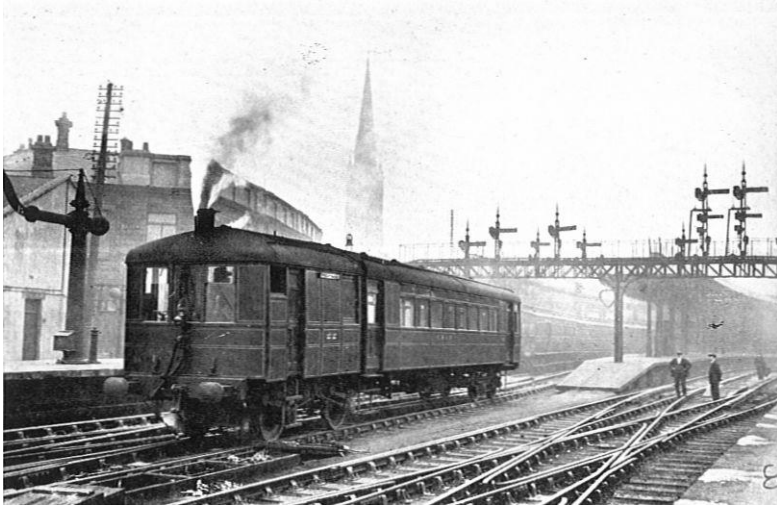


- ▶ cf. single car:
- ▶ 25% increase in empty weight
- ▶ 125% increase in seating capacity

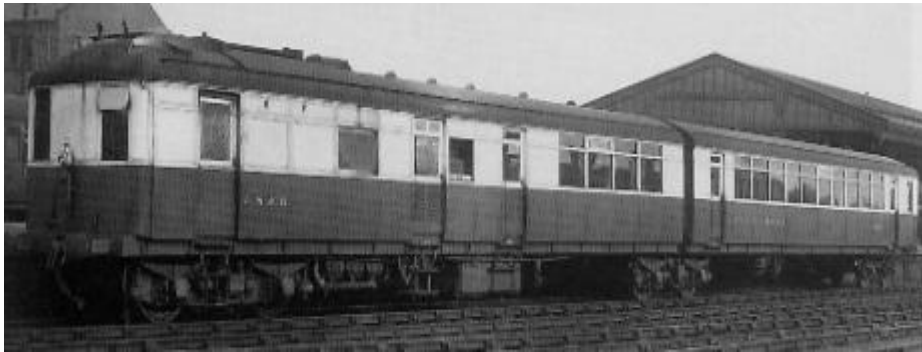
Sentinel SMU Development for LNER

Class	Date Introduced	NCyl	HP	Body	Transmission	Boiler	Seats	No.Built
153	1925	2	100	Artic	Chain	Cyl	52	2
88/89	1927	2	100	Artic	Chain	Cyl	59	22
90	1928	2	100	Rigid	Gear	Cyl	59	1
93/96/97	1930	6	100	Rigid	Gear & Cardan Shaft	Cyl	59	49
209	1930	6	100	Rigid	Gear & Cardan Shaft	Cyl	64	1
98	1930	12	200	Rigid	Gear & Cardan Shaft	Woolnough	54	2
100_99	1930	12	200	Rigid	Gear & Cardan Shaft	Woolnough	121	1
159	1932	12	200	Rigid	Gear & Cardan Shaft	Woolnough	48	3

Sentinel SMU Development (2)



- ▶ 2 Cyl, Chain Driven, Articulated Body



- ▶ Double Engine, Gear Driven, Rigid Body, Twin Car



- ▶ 6 Cyl, Gear Driven, Rigid Body



- ▶ Egypt 1950s
- ▶ Double Engine, Gear Driven, Rigid Body, Twin & Triple Car

LNER 1930 Comparative Sentinel Railcar Costs

Cost per Coach Mile	d/mile		d/mile
<u>Loco Expenses</u>		Carriage Expenses	
Superintendence	0.24	Maintenance of Carriage unit	0.85
Wages	4.74	Lighting, Cleaning & Lubricating	0.34
Fuel	1.32	Total Carriage Expenses	1.19
Water	0.10		
Lubricants	0.08	Total Working Expenses	10.07
Other Stores	0.17	Interest on Capital @ 5%	1.24
Total Loco Running Expenses	6.65	Total Cost/mile	11.31
Maintenance of Power Units	2.23	Annual Miles Run	2,173,087
Total Loco Expenses	8.88	Annual Cost	£102,407
		AutoTrain Annual Cost	£205,538
		Saving	50%

- ▶ SMU costs 50% Steam Push Pull
- ▶ Wages > Fuel

LNER – Sentinel Car Unreliability Feb 1936

- ▶ Gresley held meeting to discuss “unreliability of Sentinel railcars”
- ▶ 2 Cyl Chain Driven Cars (Sentinel vertical boilers) issues:
 - Boiler capacity – *capacity marginal to give required performance*
 - Injector & feed pump feed unreliability – *replace with Weir pump*
 - Water in crank case & sediment in boiler – *minimise with Weir pump*
 - Chains stretching – *incorrect maintenance @ Hull (no cases at Gateshead)*
 - Alignment of engine in frames – *variation in chain length*
- ▶ 6 Cyl Gear Driven Cars (Sentinel Vertical Boilers) issues:
 - Same as 2 Cyl (except chains)
- ▶ 6 Cyl Gear Driven Cars (Woolnough Horizontal Boilers)
 - No issues
- ▶ Gresley did observe that operators would appear to prefer going back to trad. Push-pull
 - Nobody likes change

1951 Forms of Motive Power Report Railcar Costs

- DMU d/mile 80% Steam
- DMU staff costs approx. half trad.steam
– driver only ?
- DMU fuel costs approx. quarter trad.steam
- *Driver-only Sentinel @50% trad.steam fuel cost would be cheaper*

d/train mile	AEC 210 hp Diesel Railcar		Steam + 1 Trailer	
	Max	128/day	Max	128/day
Interest on R.S. Replacement	2.58	4.51	1.92	2.88
Rolling Stock Renewals	2.14	3.73	0.47	0.71
Rolling Stock Repairs	9.52	9.52	6.63	7.84
Loco Running Costs				
Staff	3.95	6.91	8.55	12.82
Fuel	3.28	3.28	10.29	13.69
Water + Lubr.	0.83	0.96	0.87	1.17
Guard	2.63	4.61	3.07	4.61
Cleaning etc.	0.37	0.62	0.43	0.62
	25.30	34.14	32.23	44.34

Comparative Costings DMUs vs. Steam

	DMU	d/mile	Steam	d/mile	%
Sentinel	Single Car SMU	11.3	Push Pull +2T	22.6	50%
FoMP Rpt	Single Car	25.3	Push pull+1T	32.2	79%
1951	Single+1T	28.5	Push pull+2T	35.1	81%
LWT Rpt	2 car	24.3	<i>Loco+2C</i>	83.1	29%
1952	3 car	41.3		72.3	57%
	4 car	41.6		66.2	63%

- ▶ LNER costings based on LNER experience
- ▶ FoMP Rpt costings based on GWR experience
- ▶ LWT Rpt costings based on accounting assessment

New Solutions

Target Specifications

1st Gen DMU Spec

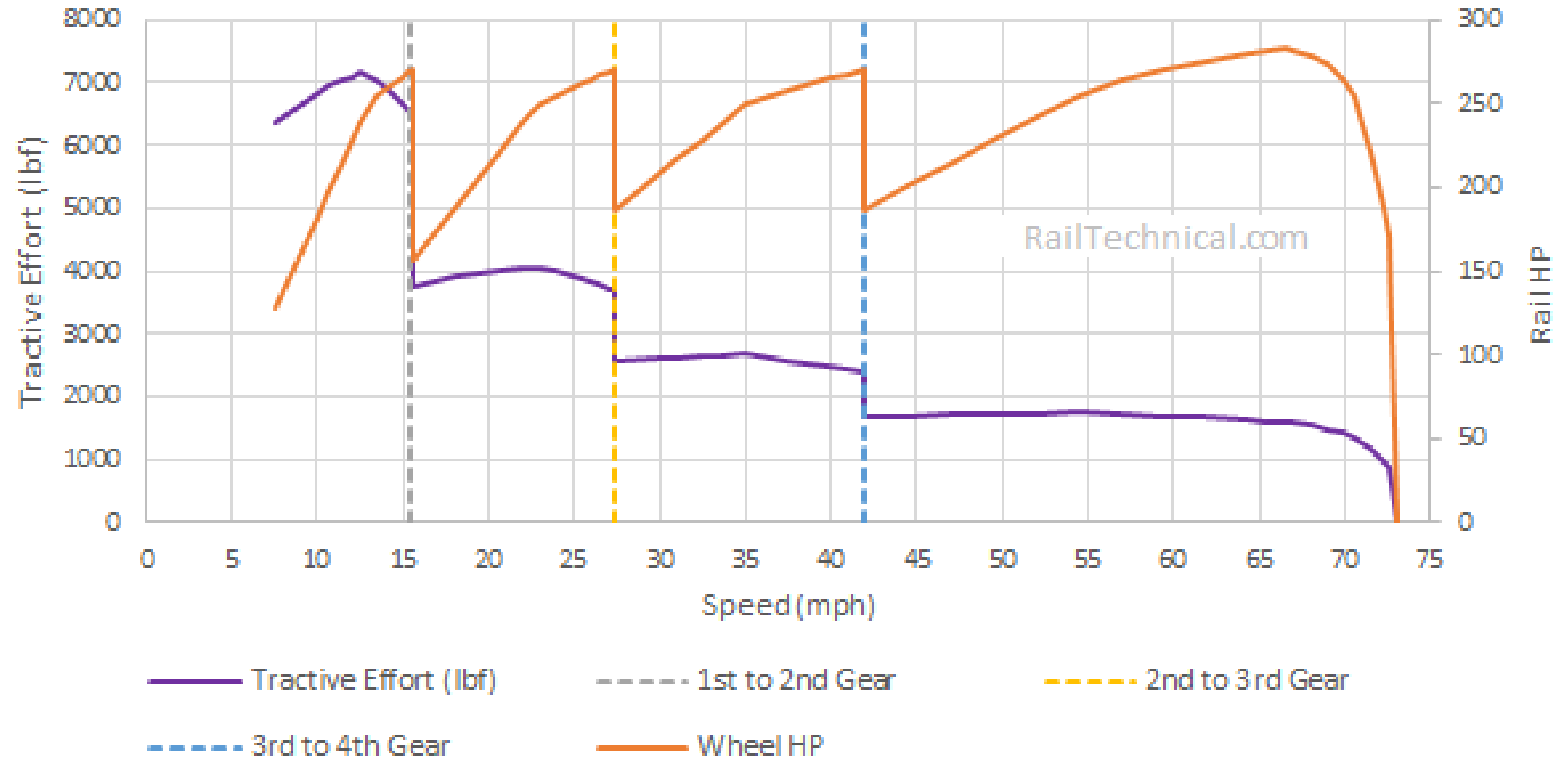
1. vehicles 57 ft long, C1 loading gauge
2. power weight ratio 10:1 (motor cars) 6:1 (MC+T)
3. 65mph max speed
4. underfloor fuel for 500 miles
5. open seating
6. automatic oil fired heating
7. capacity to MU up to 8 vehicles

2nd Gen DMU Spec

1. vehicles 65 ft long
2. power weight ratio 7:1 (all vehicles)
3. 75mph max speed
4. underfloor fuel for 1000 miles

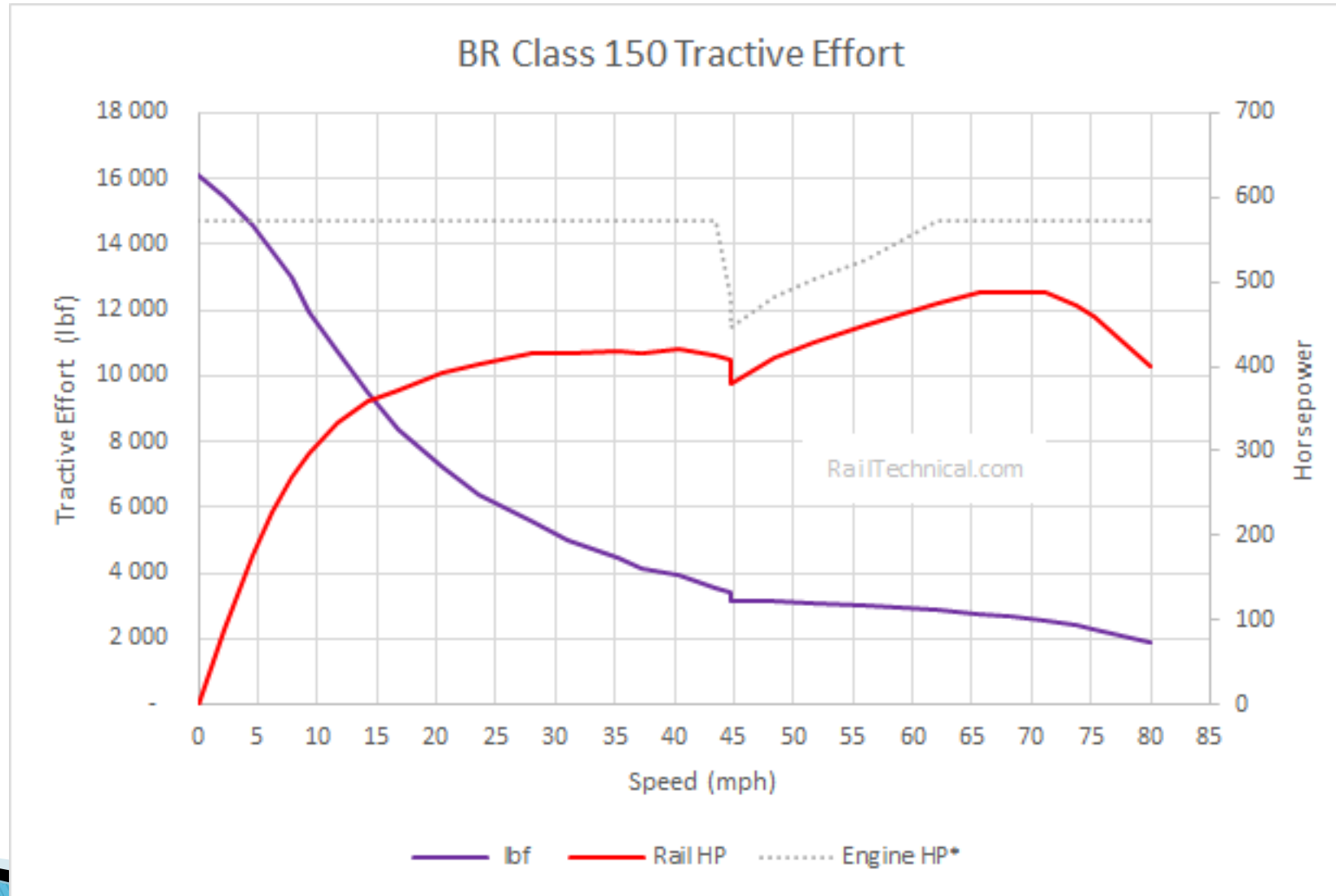
1st Gen DMU Power Curve

1st Generation DMU Tractive Effort vs Speed (1 Power Car: 2 x 150hp)

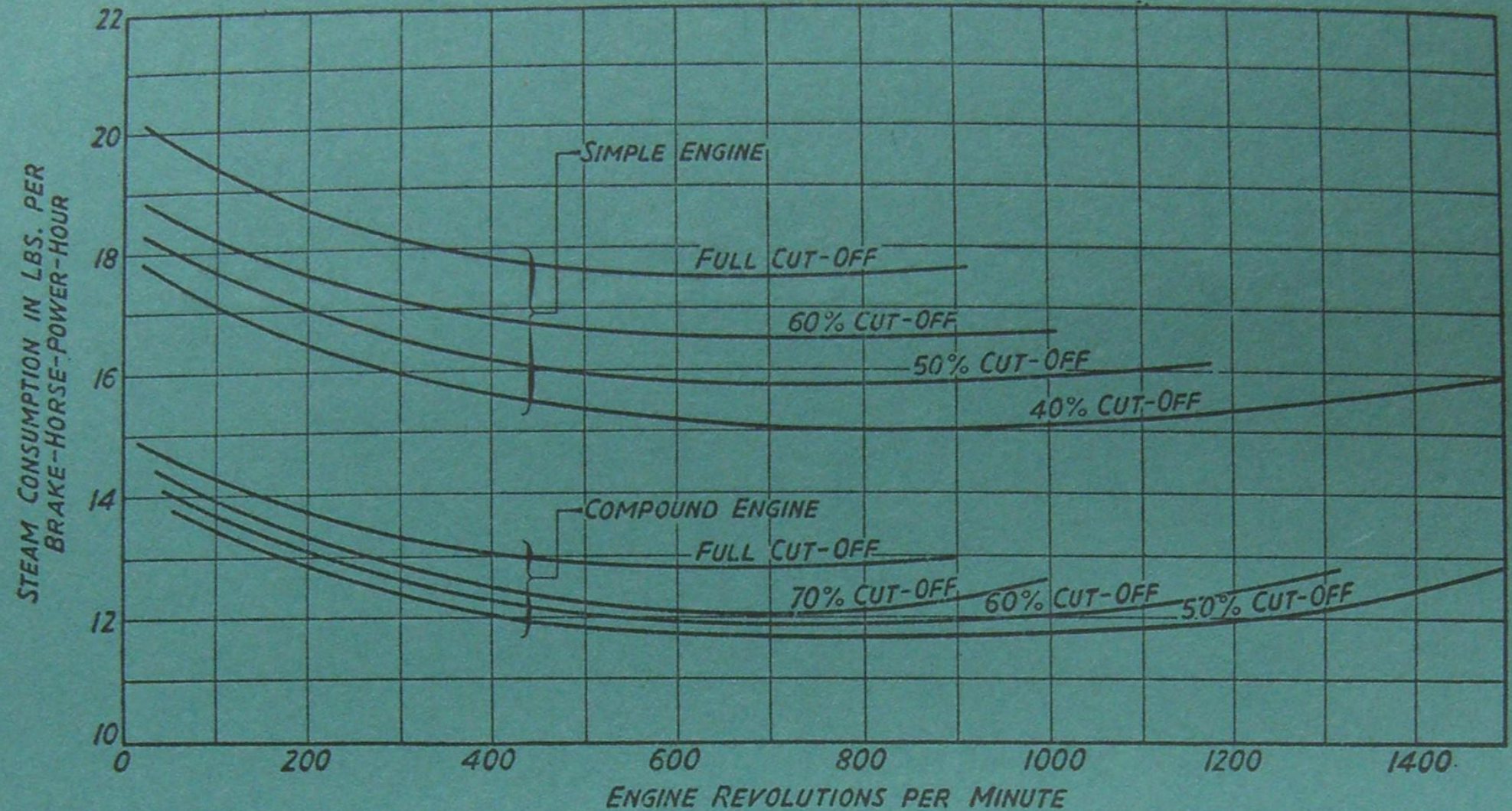


New 36" wheels

2nd Gen DMU Power Curve



Sentinel Steam Consumption Curves



STEAM CONSUMPTION CURVES—SIMPLE AND COMPOUND ENGINES

Sentinel BHP/Speed Curves

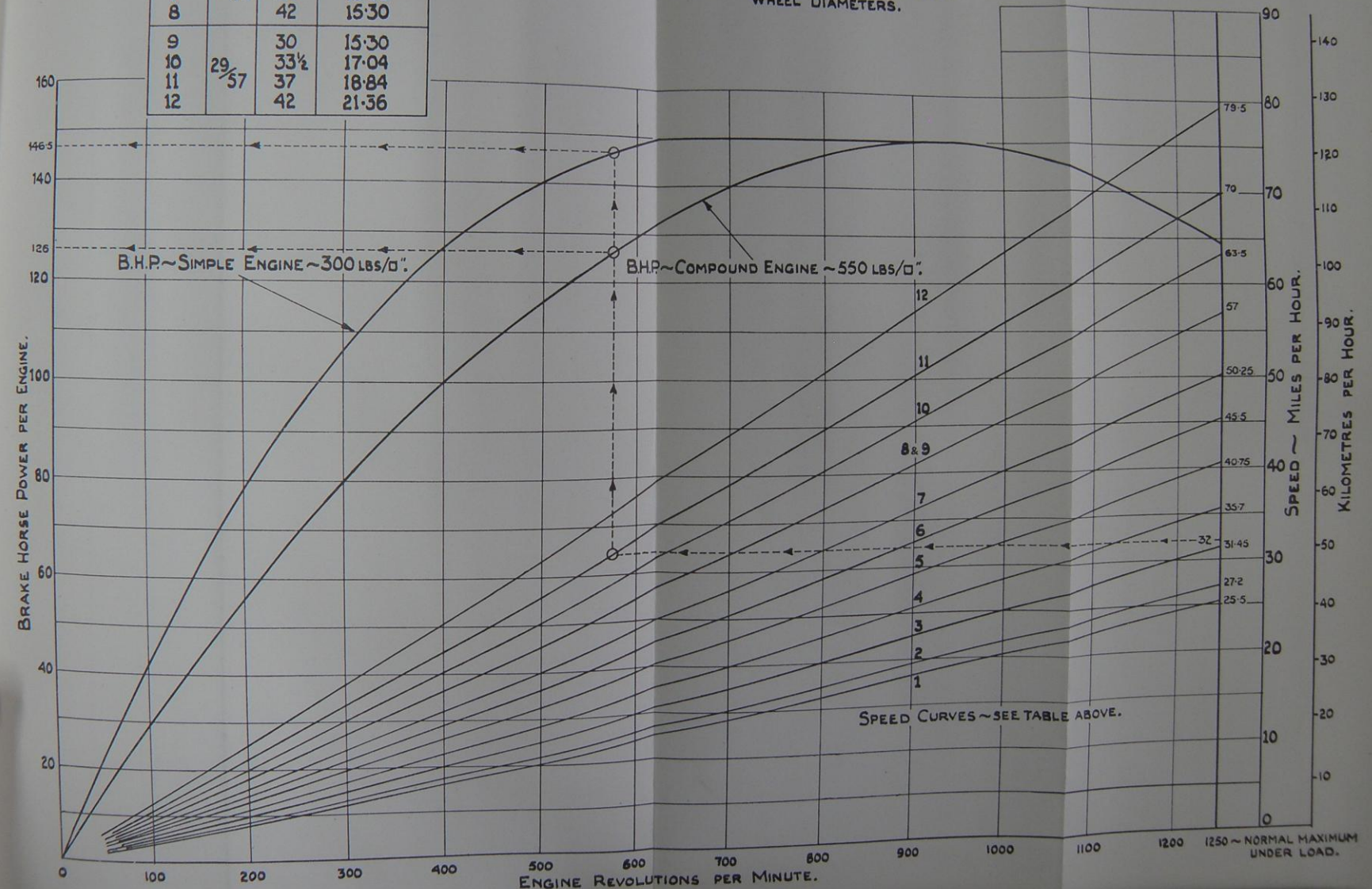
SPEED CURVE Nº	GEAR RATIO	WHEEL DIAM. (INCHES)	EQUIVALENT WHEEL DIAM. (INCHES)
1	16/70	30	6.86
2		32	7.31
3		37	8.46
4		42	9.60
5	23/63	30	10.96
6		33½	12.24
7		37	13.50
8		42	15.30
9	29/57	30	15.30
10		33½	17.04
11		37	18.84
12		42	21.36

The dotted lines give an example of how to use the graph, showing that at 32 m.p.h. with "equivalent wheel diameter" 18.84" (Speed Curve 11), the B.H.P. per engine is 126 (compound) or 146.5 simple.
Obviously these powers are also developed at 36.3 m.p.h. with equivalent wheel diameter 21.36" (Speed Curve 12); or at 29 m.p.h. with equivalent wheel diameter 17.04" (Speed Curve 10), etc.

B.H.P. AND SPEED CURVES.

4¼" & 7¼" x 6" COMPOUND ENGINE.
6" x 6" SIMPLE ENGINE.
STANDARD RANGE OF EQUIVALENT
WHEEL DIAMETERS.

GRAPH NO. 1



Technologies Assumed

- ▶ Woolnough water tube boiler
 - Sentinel claimed that c.f. trad steam:
 - ▶ “50% saving in fuel burnt”
 - ▶ “steam raised in half time”
- ▶ Less advanced steam cycle than 5AT
 - 305psi, 400 deg C (750 deg F) simple
 - Or 550 psi, 400 deg C compound
 - 14 psi cylinder back pressure (Sentinel claimed 5 psi)
- ▶ Automatic Coal Firing, same efficiency as hand firing
- ▶ Multiple cylinder single acting engines
- ▶ Gear & Cardan shaft drive
- ▶ Rotary Cam poppet valve gear, fully variable cutoff
- ▶ Atmospheric Condensing to improve Availability

All Proven Technology

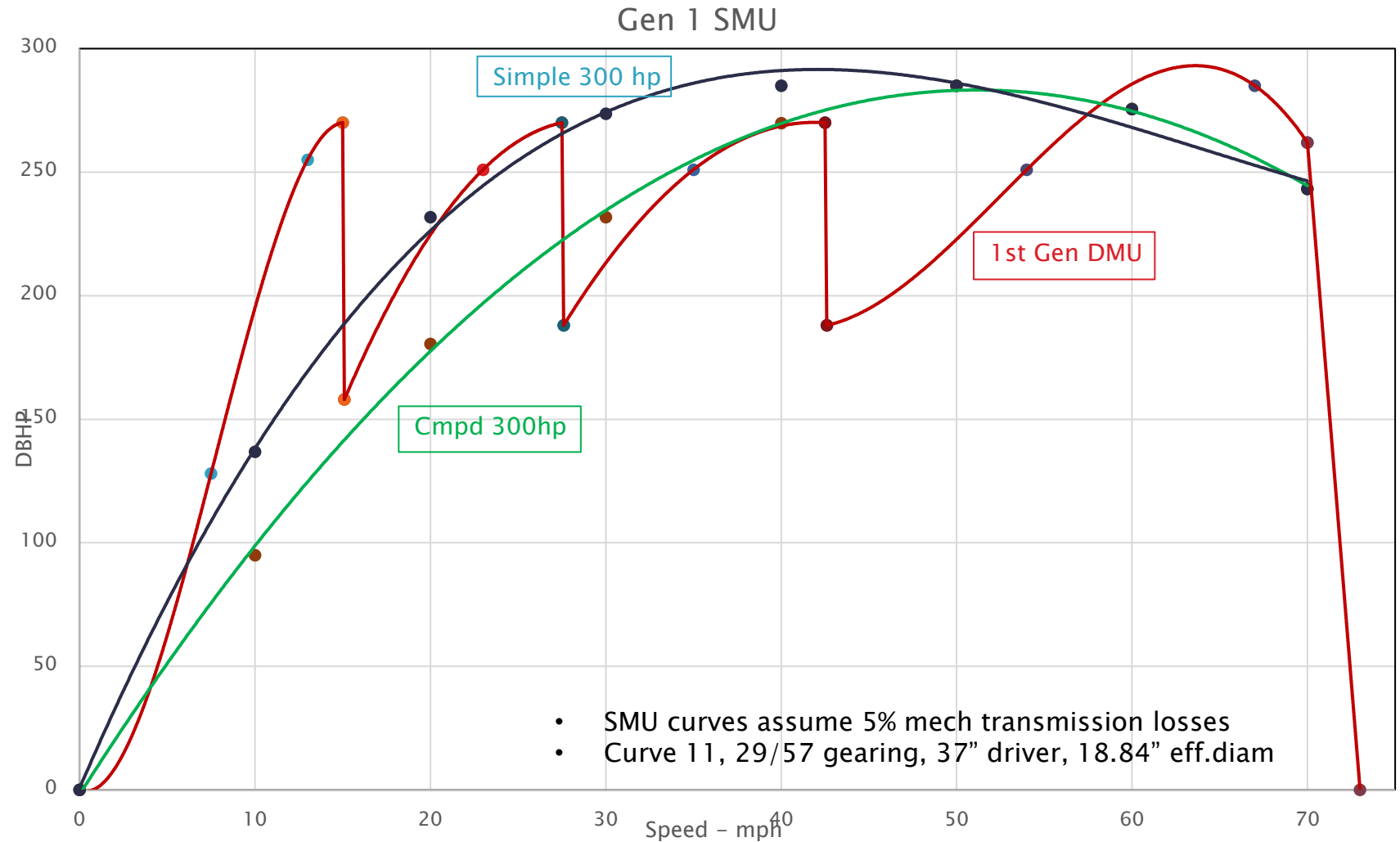
Design

Parametric Design

- ▶ Power curves from Sentinel brochure
- ▶ Thermodynamic Performance estimated from 1st principles
- ▶ Roosen for Condenser
- ▶ Auxilliary Power demands based on Roosen & X32
- ▶ Weight Estimates derived from Sentinel SMUs
- ▶ *Deviate as little as possible from traditional Stephenson form to minimise risk*
 - Traditional Steam had lost to D.M.U.s – need to do something different, but credible

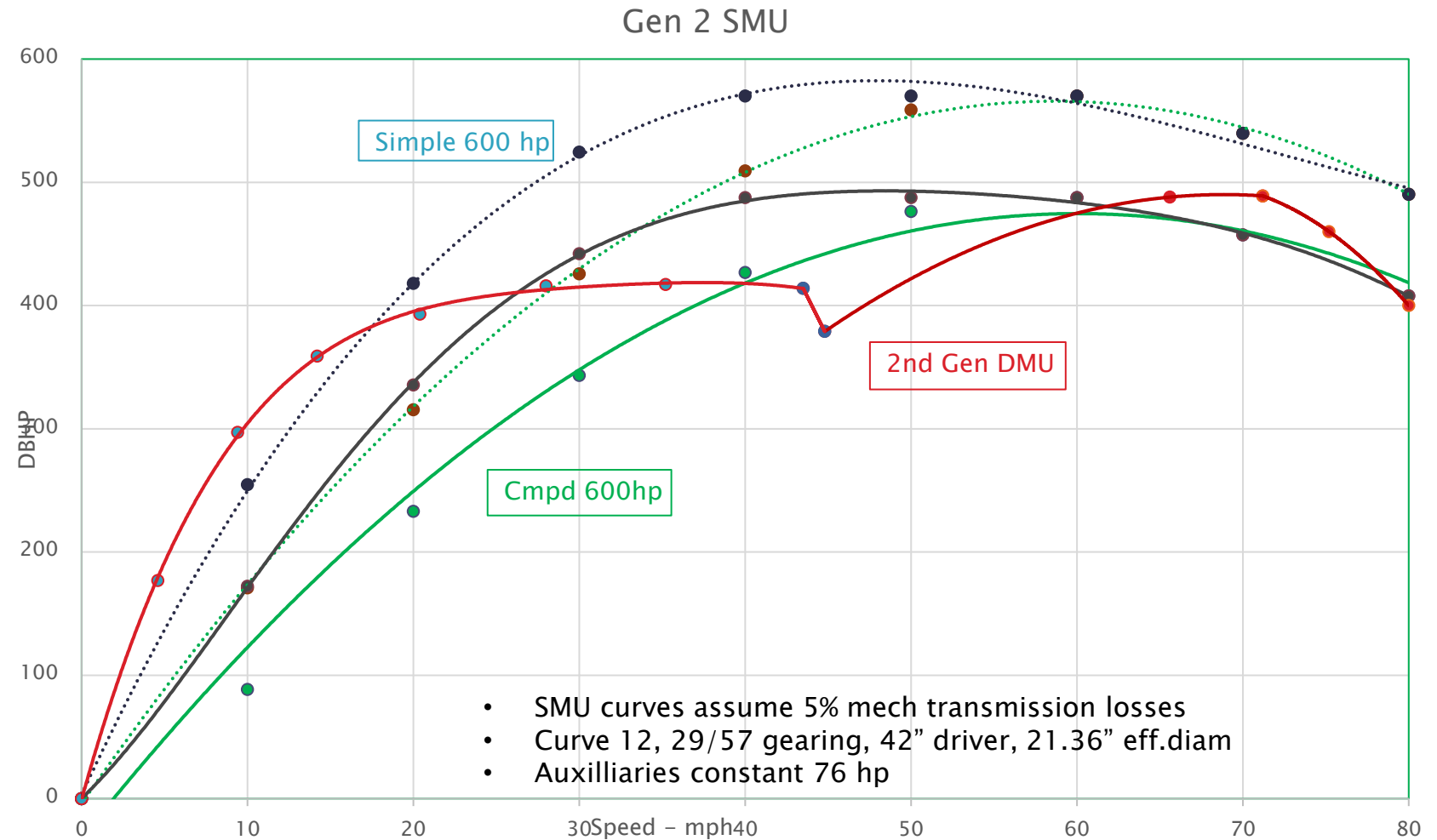
1st Gen SMU Power Curves

- Standard Sentinel configuration matches 1st Gen DMU power curve



2nd Gen SMUc Power Curves

- ▶ Standard Sentinel configuration matches 2nd Gen DMU power curve



Thermodynamics

Woolnough Open Cycle		Pressure	Temp	h	isen eff
Coal MJ/kg	30	psig	deg C	KJ/kg	%
SH Exit		305	399	3243	
HP Steam chest		290	399	3245	
Cyl exit	isen.	15	120	2706	75%
	adiab.	15	210	2841	
Total Cyls Adiabatic				404	
Total Cyls				384	

Woolnough Condensing		Pressure	Temp	h	isen eff
Coal MJ/kg	30	psig	deg C	KJ/kg	%
SH Exit		550	399	2798	
HP Steam chest		500	399	3219	
LP steam chest		140			
LP exit	isen.	15	120	2706	87%
	adiab.	15	150	2770	
Turbo In		15	150	2770	
Turbo exit	isen.	0	98	2640	85%
	adiab.	0	100	2660	
Total Cyls Adiabatic				449	
Total Cyls				427	
Turbo				111	

Type	Power		Coal	Evap	Cyl Feed	SSC		DB Effy	Range	Coal	Water
	BHP	DBHP	lb/hr	lb/hr	lb/hr	Lb/bhp-hr	Lb/dbhp-hr	%	miles	t	gall
SMU simple	300	285	686	5486	5240	17.5	18.4	8.2	500	1.8	3234
SMUc cmpd	600	488	975	8788	8400	14.0	14.7	11.5	1000	5.1	1035

Auxilliaries Design

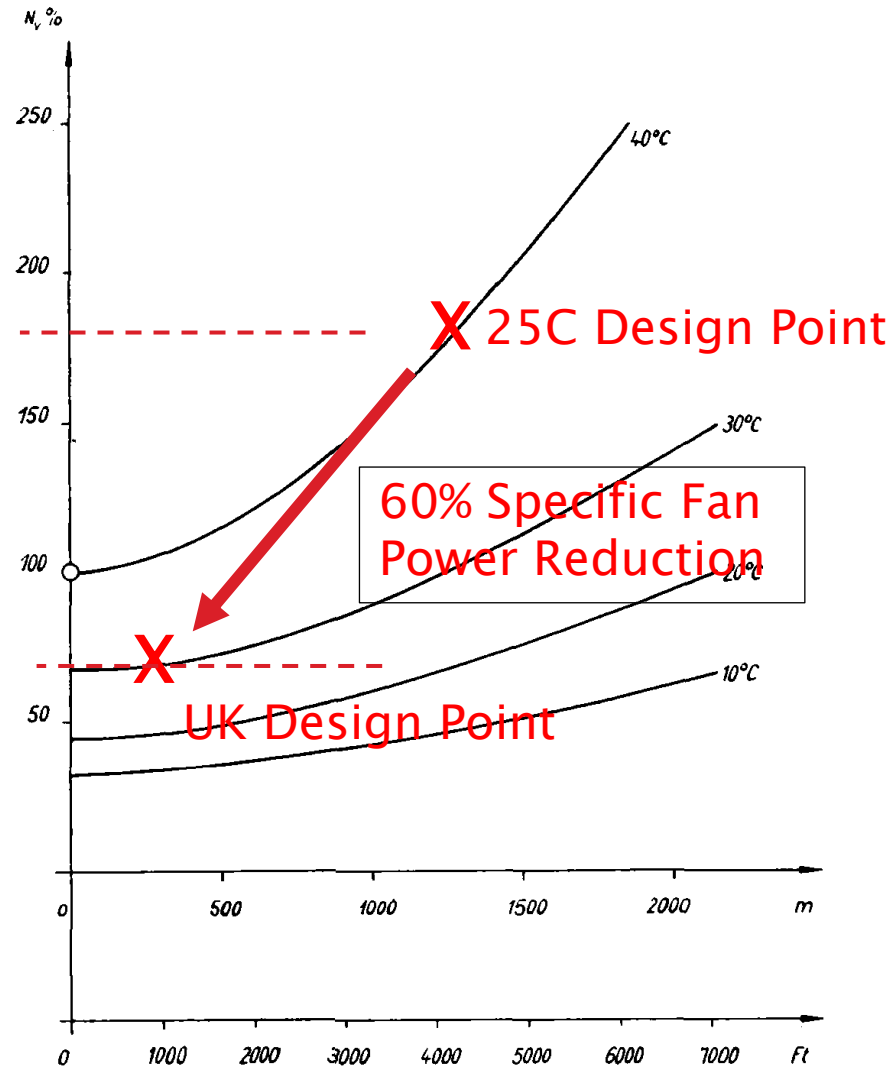


FIG. 8

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

Radiator Design Conditions				
	Steam Mass Flow	Heat Transfer	Design Altitude	Design Amb Temp
			Alt	Temp
	t/h	KW	ft	deg C
25C	25	7913	4500	40
SMUc	4.9	1551	1000	30

	Heat Transfer Factor	Alt & Temp Factor	Reqd Rad Area	Rad Fan Power	I.D. Fans	Feed Pumps	STUG	Total Aux Power
			ft2	hp	hp	hp	hp	hp
25C	1	1	490	550	150	9	24	733
SMUc	0.2	0.36	35	39	29	7	7	82

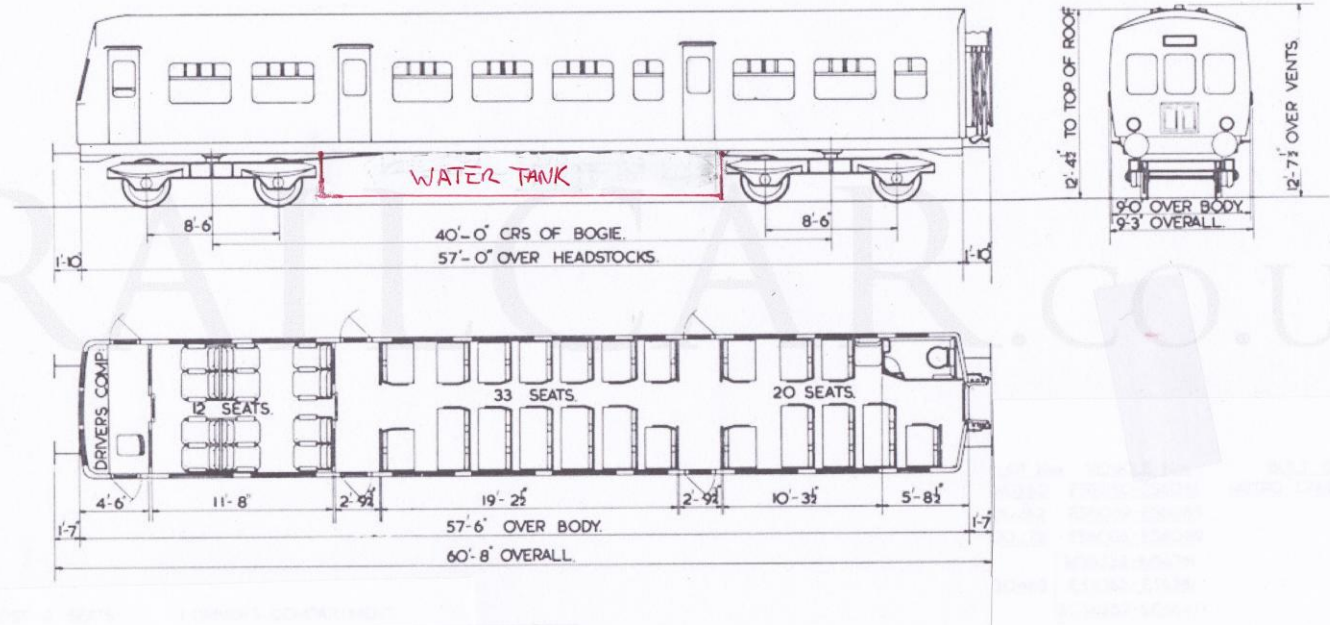
1st Gen DMU Equivalent

GANGWAYED MOTOR OPEN SECOND BRAKE



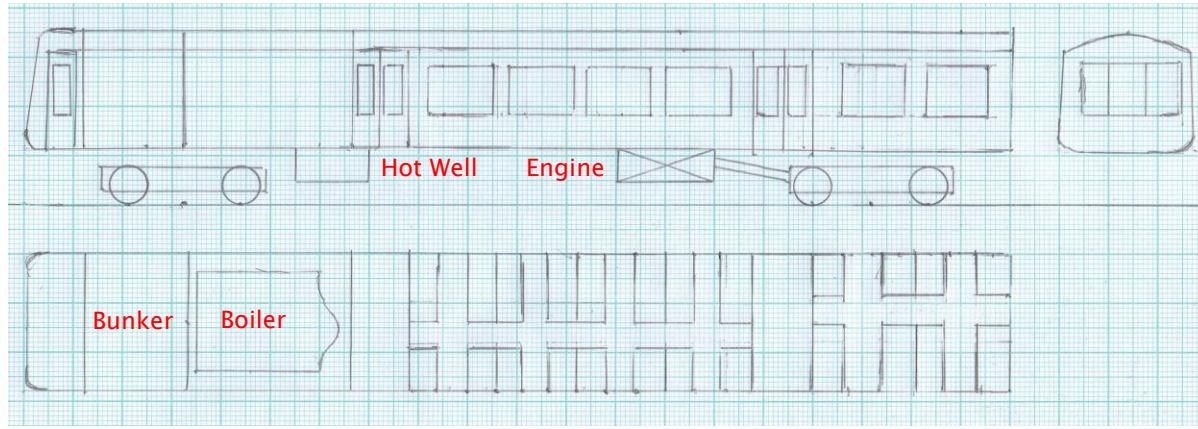
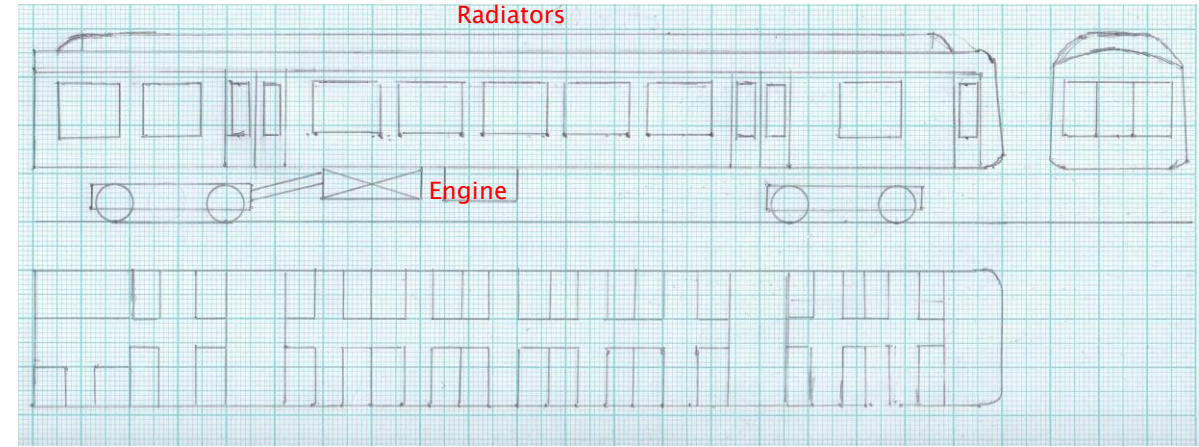
GANGWAYED DRIVING TRAILER OPEN COMPOSITE LAVATORY

B.R. 630



SMU	Max BHP	Max RPM	Cyls			Empty Weight	Pax	Coal	Water	Max Weight	Max Speed	Power/Weight
			n	dia	stroke							
				in	in	T		t	gall	t	mph	Hp/t
101	300	1800	12	5.12	5.58	57.0	117	0.3		66.1	65	4.5
Simple	450	1250	12	6	6	65.5	115	2.7	4851	98.5	70	4.5
Cmpd	450	1250	12	4.25/7.25	6	70.2	115	1.9	3881	98.0	70	4.5

2nd Gen DMU Equivalent



SMU	Max BHP	Max RPM	Cyls			Empty Weight	Pax	Coal	Water	Max Weight	Max Speed	Power/Weight
			n	dia	stroke							
				in	in	T		t	gall	t	mph	Hp/t
150	572	1900	12	5.5	6	72.8	138	0.8		84.0	75	6.8
Simple	900	1250	24	6	6	96.6	113	10.8	1940	133.4	80	6.8
Cmpd	900	1250	24	4.25/7.25	6	102.6	113	7.7	1552	132.7	80	6.8

Assessment & Conclusions



Assessment

Configuration

- SMU and DMU very similar
- DMU requires torque converter
- SMU requires large coal bunker & boiler compartment – loss of seating

Performance

- Speed & acceleration SMU can match DMU (1st Gen & 2nd Gen)
 - SMU requires 50% more hp to match DMU power/weight ratio
- Range
 - Fuel & Water calculated on equal full power running time
 - Assume → equal range

Economics

- SMU requires single man operation to compete with DMU
 - Implies automatic boiler operation
 - Multiple Unit working also requires automatic boiler operation
- SMU requires equal fuel costs to compete
 - £/MJ x thermal efficiency

Conclusions

- ▶ Yes, BR could have done something different
- ▶ Proven technologies were available
- ▶ SMU very similar to DMU, but less space efficient
- ▶ Performance is the easiest issue to address
- ▶ Economic competitiveness of steam dependent on :
 - Price ratio of coal/oil
 - Single manning
 - Automatic boiler operation
- ▶ Availability & Utilisation constraints of steam may be limiting factors, not performance
 - *Design to match diesel 6 day operating cycle*
- ▶ Still To Come:
 - British Superpower
 - Unconventional Solutions
 - What Does it All Mean ?

End of Part 5 Presentation

Main References

- ▶ Railcars
 - “Sentinel Locomotives & Sentinel–Cammell Railcars”, Hutchings, IRS, 2020
 - The British Railcar, Tufnell, David & Charles 1984
 - British Steam Railcars, Rush, Oakwood Press, Locomotion Papers No.53
 - National Archives RAIL 394_101 & 394_250 & ZLIB 5_150
- ▶ Performance
 - Sentinel General Service Locos”, Sentinel brochure 1930s, N.A. ZLIB 29_596
- ▶ Condensing
 - “Camels & Cadillacs”. Phil Girdlestone, Stenvalls 2014
 - “Class 25 Condensing Locomotives on SAR – Design & Operating Experiences”, Roosen, IMechE paper 1960

1951 Forms of Motive Power Report – Key Findings Railcar Costs (1)

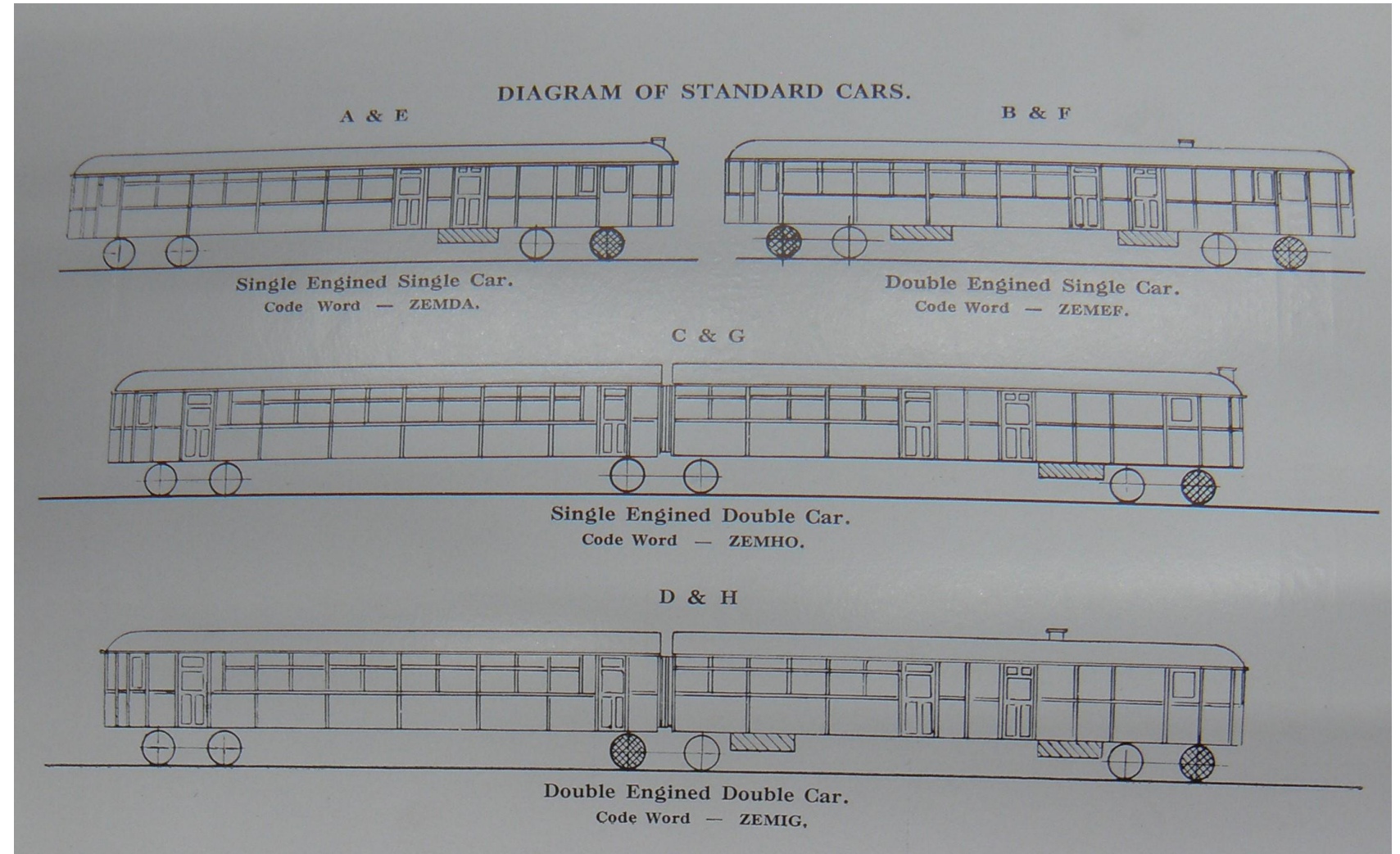
		Max Daily Mileage			128 miles/day	
	Seats	Miles	d/train mile	d/seat mile	d/train mile	d/seat mile
AEC 210 hp Diesel railcar	48	224	25.30	0.53	34.14	0.71
AEC 210 hp railcar + 1 trailer	124	224	28.52	0.23	38.25	0.31
2 x AEC 210 hp railcar + 1 trailer	180	224	47.86	0.27	61.99	0.34
Push-Pull Steam + 1 trailer	76	192	32.23	0.42	44.04	0.59
Push-Pull Steam + 2 trailers	152	192	35.17	0.23	47.67	0.31
Push-Pull Steam + 3 trailers	228	192	39.11	0.17	51.30	0.23
Steam + 4 coaches	312	208	42.47	0.14	60.46	0.19

1951 Capex	£
AEC 210 hp Diesel Railcar	15,000
Standard Class 2 Tank Loco	9,400

Sentinel SMU Development (2)

LNER Class	Diagram
93/96/97	A&E
98/159	B&F
100_99	D&H

- Very Similar to DMU layout
- Boiler Compartment Req'd
- Gresley Articulation



Comparative Costs Light Weight Trains Comm. Rpt

ANALYSIS AND COMPARISON OF COSTS FOR SCHEMES RECOMMENDED FOR ADOPTION - STEAM v DIESEL CARS

	SCHEME No.1		SCHEME No.2		SCHEME No.3					
	Lincolnshire		Harrogate, Leeds, Bradford, Halifax		(a) West Cumberland		(b) Edinburgh- Carlisle		(c) Newcastle- Carlisle	
	Diesel Two-car sets (13)	Steam	Diesel Two-car sets (8)	Steam	Diesel Two-car sets (13)	Steam	Diesel Three car sets (2)	Steam	Diesel Four car sets (10)	Steam
	d.	d.	d.	d.	d.	d.	d.	d.	d.	d.
Cost per train mile Operating (including servicing):										
Wages, etc.	6.26	19.32	5.76	17.80	6.71	14.73	6.56	11.08	5.99	11.27
Fuel and lubricants	4.61	25.95	4.41	25.42	4.65	23.92	8.30	24.25	8.82	17.40
Maintenance	8.86	24.66	8.47	24.72	8.93	20.82	15.87	22.08	16.94	22.14
Interest & Renewals	6.47	16.84	5.63	15.15	7.81	14.44	10.54	14.93	9.85	15.42
Total	26.20	86.77	24.27	83.09	28.10	73.91	41.27	72.34	41.60	66.23
Average miles per day per unit	274	-	301	-	216	-	300	-	340	-
		Miles to be withdrawn		Miles to be withdrawn		Miles to be withdrawn		Miles to be withdrawn		Miles to be withdrawn
Total train miles per annum (000's)	819	581	565	236	676	483	186	123	745	555
Net increase in train miles per annum (000's)	238		329		193		63		190	
Estimated Financial Results:										
Steam costs per annum	£ 210,000		£ 82,000		£ 149,000		£ 37,000		£ 153,000	
Diesel costs per annum	89,000		57,000		79,000		32,000		129,000	
	£121,000		£25,000		£ 70,000		£ 5,000		£ 24,000	

This scheme is designed primarily to test the economies of diesel car working. No attempt has therefore been made to assess the additional revenue likely to be secured although it is anticipated this will be sufficient to justify the additional mileage

There are no data on which to base a reliable estimate of the additional traffic likely to be secured but the following figures give a broad indication of the minimum increase which appears likely:-

Scheme No.2

£
31,000 per annum

Scheme No.3

£
34,000 per annum

BR Class 150 DMU

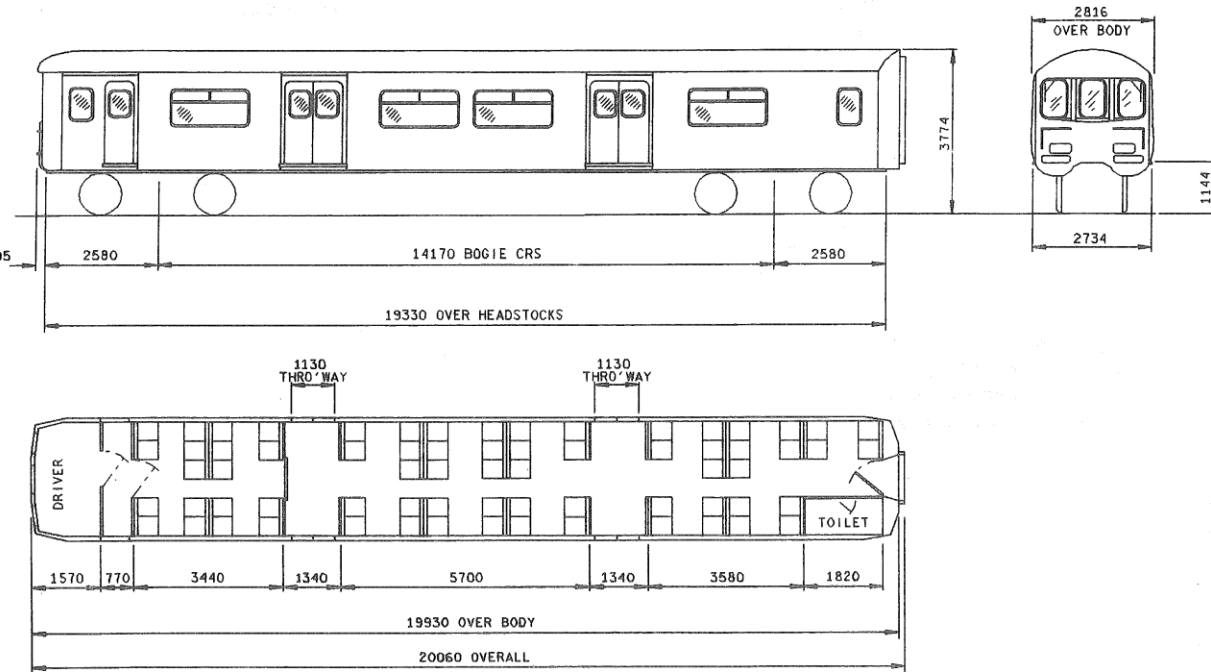
introduced 1984

DRIVING MOTOR SECOND

CLASS 150/1

DMS (A)

DP 238



SEATS	68
TOILETS	1
COMPARTMENTS	-
GUARDS COMPARTMENTS	CAB WHEN TRAILING
VENTILATION	-
CATERING EQUIPMENT	-

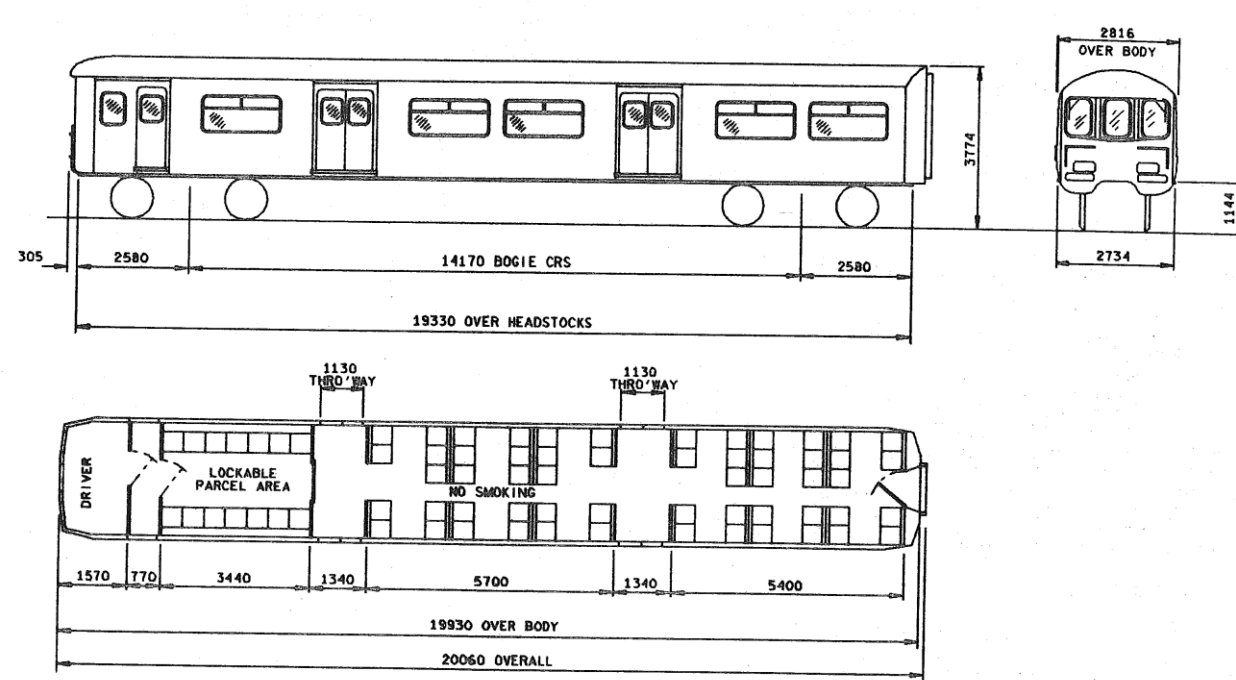
ISSUE 1 DATE MAY 85

DRIVING MOTOR STANDARD

CLASS 150/1

DMS (B)

DP 239



SEATS	70
TOILETS	-
COMPARTMENTS	-
GUARDS COMPARTMENTS	CAB WHEN TRAILING
VENTILATION	-
CATERING EQUIPMENT	-

ISSUE 2 DATE MAR 88

- ▶ 2 car version - DMSL+DMS
- ▶ 2x 286 hp
- ▶ 138 2nd Class seats (2 car)