Tuning of BR V2 Locomotive

For Open Rails

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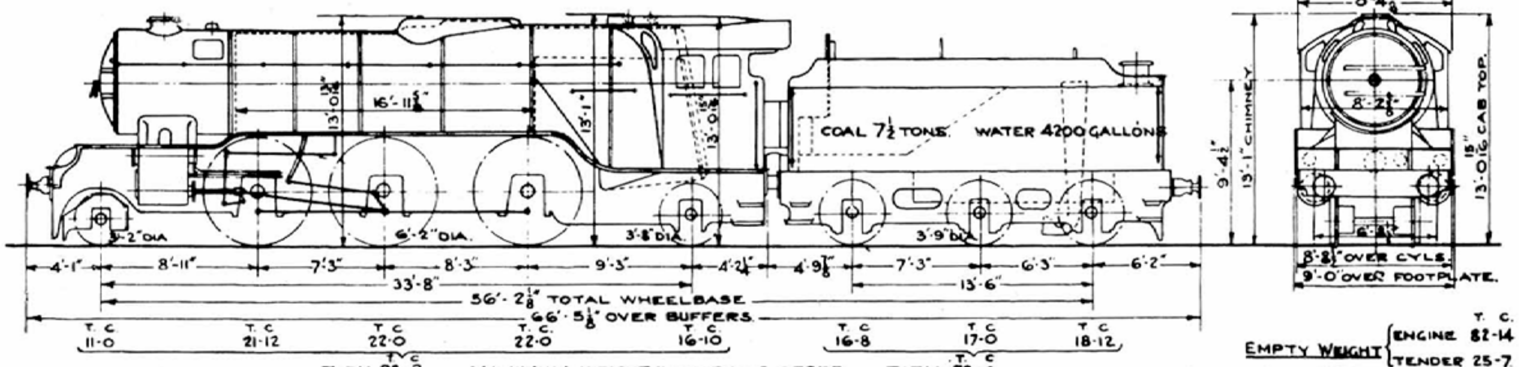
TYPE V2.



EMPTY WEIGHT { ENGINE 82-14 T. C.; TENDER 25-7

BUILT FROM 1936

LEADING DIMENSIONS & RATIOS.

BOILER:- MAX. DIA. OF BARREL. 6'-5"
OVERALL LENGTH OF FIREBOX. 9'-5¾"
" " " " AT BOTTOM. 6'-8"
" WIDTH " " " 7'-9"
THICKNESS OF BARREL PLATES. 23/32" & 21/32"
" " OUTSIDE WRAPPER. 9/16"
" " COPPER FIREBOX PLATES.
WRAPPER & BACKPLATE. 9/16"
TUBEPLATE. 9/16" & 1⅛"

TUBES. SMALL. NUMBER 121.
DIA. OUTSIDE 2¼"
SUPERHEATER FLUE. NUMBER 43
DIA. OUTSIDE 5¼"
SUPERHEATER ELEMENTS. NUMBER 43.
DIA. OUTSIDE 1·244"

GRATE:- AREA 41·25 SQ. FT.
HEATING SURFACE
FIREBOX. 218. SQ. FT.
TUBES. 1211·87. " "
FLUES 1004·8 " "
TOTAL EVAPORATIVE 2431 " "
SUPERHEATER 679·67 " "
TOTAL. 3110·74 " "

WORKING PRESSURE. 220 LBS/SQ. IN.
SAFETY VALVES.
TYPE & DIAMETER. TWO ROSS POP 3½" DIA.

AXLES — DIA. LENGTH
JOURNALS PONY 6½" x 9"
COUPLED WHEELS 9½" x 11"
TRAILING " 6" x 11"
CRANK PINS. OUTSIDE 5½" x 6"
INSIDE. 8¼" x 6"
COUPLING PINS. LEADING 4¾" x 3½"
DRIVING. 6" x 4¼"
TRAILING 4" x 4½"

CYLINDERS:- NUMBER 3.
DIAMETER & STROKE 18½" x 26
MOTION:- TYPE: OUTSIDE. WALSCHAERT
INSIDE. GRESLEY.
TYPE OF VALVE. PISTON.
DIA. " " 9"
MAX. VALVE TRAVEL 5⅝"
STEAM LAP INSIDE CYLS. 1 5/16"
" " OUTSIDE " 1⅝"
CUT OFF IN FULL GEAR. 65%
TRACTIVE EFFORT AT 85% BOILER PRESS.
33730 LBS.
TOTAL ADHESIVE WEIGHT. 146944 LBS
ADHESIVE WEIGHT ÷ TRACTIVE EFFORT 4·3
BRAKE - VACUUM; OR STEAM & VACUUM EJECTOR

LNER V2 LOCOMOTIVE GENERAL BACKGROUND INFORMATION

The V2 2-6-2 locomotive was designed by Sir Nigel Gresley in 1935, the LNER V2 went on to become a highly successful design, working both freight and passenger services throughout the region until withdrawal in 1960 184 in total were built, the first, Green Arrow, was presented to the National Railway Museum and has, until recently, run on the main line. Coming nearly ten years after the first A3s, the V2s had the same three cylinders and conjugated valve gear layout of the Pacifics and similar lines.

The V2 was an adaptable locomotive, capable of hauling fast fitted freights and express passenger trains. Their relatively heavy 22 ton axle load meant their use was restricted to around 40% of the LNER's route miles. For example, they were barred from all of the former Great Eastern Railway main lines. Gresley recognised that a lighter mixed-traffic locomotive was required, and the V4 class was designed to this end. However, it was to be the versatile LNER Thompson Class B1 4-6-0 which succeeded the V2 as the LNER's standard mixed traffic locomotive, although the B1 never matched the V2's power output.

First of the initial batch for five Doncaster-built V2s was number 4771, which emerged in June 1936 and was promptly named "Green Arrow", after the express freight service for which the locomotives had been built. Successful trials with this quintet led to both Doncaster and Darlington works producing further batches. The final locomotive, number 3695, was delivered from Darlington in July 1944.

The V2 had the free steaming qualities that the LNER's operating department required. Not only were they capable of working vacuum braked freights at up to 60 mph (97 km/h), they could deputise for Pacifics on express passenger schedules. In peak condition a V2 could almost match the Pacifics high speed for sustained running. One locomotive was reliably timed at 93 mph (150 km/h) on the Yorkshire Pullman while another attained 101.5 mph (163 km/h) on a test train.

The V2s were recognised as versatile and powerful locomotives by 1939, but their reputation was more firmly established by their remarkable feats of haulage during World War II. Trains of over 20 carriages loaded to 700 long tons (710 t) proved within their abilities. On at least one occasion a single V2 hauled 26 coaches from Peterborough to London. Given this capacity for work it was not surprising that construction was allowed to continue through the war years. The V2s performed equally competently for British Railways, leaving their mark on the East Coast Main Line, the Waverley Route between Carlisle and Edinburgh and on the ex-Great Central main line between London Marylebone and Sheffield.

Significant modifications were made to the V2 class during its service life. In 1946 a series of derailments was traced to the design of the leading pony truck, which was unduly sensitive to the often poor track conditions, a legacy of heavy wartime use and lack of maintenance. Modifications to the suspension cured the problem. During the 1950s cracked monoblocs became increasingly frequent, but replacement was expensive and in 1956 the decision was taken to replace the monobloc with separate cylinder castings. Seventy-one engines were thus modified: they can be identified by the presence of external steam pipes from smokebox to cylinders. Finally, around 1960 experiments were made with fitting double chimneys to two V2s. This yielded no significant performance gain, but eight engines were subsequently fitted with Kylchap exhausts. These so-called 'Super V2s' were reckoned to be fully equal in performance to the larger Pacifics. However, plans to fit Kylchap chimneys to the remainder of the class were abandoned once it became clear that replacement with diesel locomotives was imminent.

The V2s' swansong came on the Edinburgh—Aberdeen run, working alongside the last LNER A2s and A4s. The entire class was withdrawn from service between 1962 and 1966.

The V2 was classified as BR Class 6MT and later as 7P6F. Tractive Effort at 85% Boiler Pressure – 33730 lb.

LNER/BR V2 LOCOMOTIVE AND TENDER TUNING

The Advanced version of the V2 has been set up with advanced steam parameters and the latest vacuum braking parameters. A Basic version is also provided where there are no advanced steam parameters. However, both versions have ORTSDavis Resistance derived from the BR Std 8P Test Report. This gives accurate correlation to real world performance in terms of resistance, somewhat better than the traditional Davis Formula results. If there is no information available on likely resistances of stock then Davis Numbers calculated with Fcalc2 will provide a reasonable input.

General Method for Resistance Calculation

A formula was derived that reproduces exactly the test report curves for the 8P. This is a modified version of the Davis Formula and I have named it the Clarke-Davis Formula. The 8P report gives resistance for the locomotive and tender combined. This can be reproduced in OR by either putting all the resistance with the locomotive and having none for the tender or by making a split of the combined resistance between the locomotive and tender. The decision on how to make the split is entirely arbitrary. As long as the sum of the Loco and Tender A, B and C values equals the combined values the resistance produced in OR will be exactly the same no matter how the split is made. If the Loco is given all the resistance and the tender none, anomalies can appear in the various OR HUD readouts, so it was decided to make a split based on the Clarke-Davis formula.

The ORTS A B and C values required to meet the 8P Loco + Tender report resistance in metric units are; A = 7200, B = 65, C= 7.8

The Clarke-Davis formula in US units for a Locomotive is;

A = 0.425 x Loco Weight (US tons) + 18 x Number of Axles + 18.695 x Driver Wt. (US Tons)

B = 0.0374 x Loco Weight (US tons)

C = 0.00285 x Loco Frontal Area (Square feet), for Loco with a Tender

C = 0.00315 x Loco Frontal Area (Square feet), for Loco with no Tender, or old style open cab
Note: streamlining will reduce the frontal resistance.

And a Tender is;

A = 0.425 x Tender Weight (US tons) + 18 x Number of Axles

B = 0.0374 x Tender Weight (US tons)

C = 0.0029 x Tender Frontal Area (Square feet), for a Tender with Corridor connection
C = 0.0032 x Tender Frontal Area (Square feet), for a Tender with no Corridor connection.

The 6 Axle Standard 8P Locomotive weighs 101.25t-uk, Driver Weight is 66t-uk and the area is 112 sq. feet. The 3 Axle Tender weighs 55.5t-uk with an area of 98 sq. feet.

This will give metric ORTS Davis numbers as follows;
Locomotive, A = 6842, B = 42.2, C = 7.1

Tender, A = 358, B = 23.1, C = 0.7

Combined A = 7200, B = 65.3, C= 7.8, which matches the report curve.

V2 ORTS Resistance

The 5 Axle V2 Locomotive weighs 93.1t-uk, Driver Weight is 65.6t-UK and the frontal area is 113 sq. feet. The 3 Axle V2 Tender weighs 51.6t-uk and the frontal area is 91 sq. feet.

This will give metric ORTS Davis numbers as follows;

Locomotive, A = 6707, B = 38.8, C = 7.17

Tender, A = 349, B = 21.5, C = 0.65

Combined A = 7056, B = 60.3, C= 7.82, which gives resistances in OR that enable the V2 Road Test speeds to be matched.

Steam Era Carriage Resistance

To enable accurate testing the resistance of the carriage load needs to meet real-world figures. The Standard 8P Report contains a resistance graph for an unspecified 32t, 4 Axle coach.

The Clarke-Davis formula for a steam era carriage is,

A = 0.425 x Carriage Weight (US tons) + 18 x Number of Axles

B = 0.065 x Carriage Weight (US tons)

C = 0.0029 x Carriage Frontal Area (Square feet), for a Carriage with Corridor connection
C = 0.0032 x Carriage Frontal Area (Square feet), for a Carriage with no Corridor connection.

For a 4 Axle, 32t, corridor connected carriage with an assumed area of 105 sq. feet the ORTS numbers are,

32t-uk Carriage, A = 388, B = 23.2, C = 0.68, which exactly matches the report curve.

Resistance for Carriages of different weights can easily be calculated from the Clarke-Davis formula using the Clarke-Davis Calculator provided separately.

With the correct resistance in place for the stock it is now possible to fine tune the V2 Locomotive to match the results from the V2 Test report.

OR ADVANCED STEAM PARAMETERS

The following Parameters are available in Open Rails to allow fine tuning of a Locomotive. Default Parameters will normally give a reasonable performance, but the Advanced Parameters give an opportunity to closely match real world performance where this may be known from a Test Report or other verifiable data.

ORTSMaxIndicatedHorsepower

Sets the maximum Indicated Horse Power that the locomotive can achieve.

V2 setting (1980hp)

This figure is taken from Graph 23 of the V2 Test Report. An estimate can be determined by calculation as detailed below. For the V2 the calculated result is 2225hp which is 12% higher than that given in the report.

Maximum HP can be estimated by calculating the evaporation rate of the tubes where certain boiler parameters are known. The Evaporation Rate is then divided by a calculated steam consumption rate (lb/ihp/hr). Note the evaporation rate of the tubes can be increased by percentage factors relating to whether such items as Feed Water Heating (15%), Kylchap Exhaust (10%), Exhaust Injector (7%), or good firebox and grate conditions (3%) are present.

The calculated Evaporation Rate is derived from the Firebox Evaporation Rate + the Tube Evaporation Rate.
Firebox Evaporation = Firebox Heating Surface x 68
Tube Evaporation = Tube Heating Surface x (42/Square Root of the tube length)

The calculated Steam Consumption is derived from K x A x B,
where K is a cylinder valve factor which generally ranges from 17 to 20,
A is 5.47 x Boiler Pressure to the power of -0.335,
B is 0.192 x Natural log of (es/ss) + 0.781, where
es/ss = (Firebox Heating Surface + Tube Heating Surface)/Superheater Heating Surface).
For all Saturated Locomotives es/ss is taken as 1.4.

No percentage evaporation increases were considered for the V2. The following input was used,

Firebox Evaporation = 16660,	245 x 68
Tube Evaporation = 22268,	2186 x 42/17^0.5
K = 19,	Normal superheated Loco
A = 0.898,	5.47 x 220^-0.335
es/ss = 3.575	(245 +2186)/680
B = 1.03,	0.192 x Logn[3.575] + 0.781

Firebox heating surface	245 sq. ft.
Tube heating surface	2186 sq. ft.
Tube Length	17 ft.
Superheater heating surface	680 sq. ft.
Boiler Pressure	220 psi

ORTSBoilerEvaporationRate
Sets the steam generation rate of the locomotive in lb/hr

V2 setting (13.2)

This is the setting required to produce a maximum steam generation rate in OR for the V2 of 31000lb/hr as taken from the report, Graph 8.

ORTSSuperheatCutoffPressureFactor
Sets the factor for change of cut off pressure due to superheating.

V2 setting (35.0)

The setting was determined by checking performance against the steam, water and coal rates for various cut offs from the report Graph 8 using a light engine consist, and ensuring the steam rates against the superheat temperature were met in accordance with Graph 19.

<u>**ORTSMaxSuperheatTemperature**</u>
Sets the maximum superheat temperature the boiler can achieve.

V2 setting (350.0)

Taken from the report Graph 19.

<u>**ORTSBoilerEfficiency**</u>
Sets the efficiency at which the boiler will operate.

V2 setting (0.0 0.91 190.0 0.455)

Taken from the report Graph 28. The left hand pair of numbers indicate the efficiency at zero combustion and the right hand pair of numbers indicate the efficiency at the grate limit combustion. The Grate Limit efficiency is always half the zero combustion efficiency. Grate Limit Efficiency was found by extrapolation of the straight line curve to the right where efficiency is 0.455.

<u>**ORTSBurnRate**</u>
Sets the steam evaporation rate in lb/hr against Dry Coal fired rate in lb/hr

V2 setting (0.0 10.0   12000.0 1430.0   14000.0 1725.0   18000.0 2350.0   22000.0 3110.0   26000.0 4030.0   30000.0 5270.0   31000.0 5760.0   46500 8640)

The pairs of numbers are taken directly from the report Graph 8. Graph 21 shows a better visualisation of the relationship between Steam, Water and Coal rates. In the burn rate parameter, the left number is the steam rate and the right number is the associated coal rate. The first pair of numbers are just arbitrary for a zero steam rate. The last pair of numbers have been added to flatten the predicted curve as would be expected to happen at high firing rates.

<u>**ORTSCylinderInitialPressureDrop**</u>
Sets the cylinder pressure drop factor against wheel revolutions per minute.
V2 setting (0.0 0.99 350 0.98)

This was set as a result of stress testing the locomotive with a load of 320t-uk up a slope of 2%. The load is taken from the expected limit for run from Inverness to Slochdt summit for a BR Class 7 locomotive. The train should reach a speed of approximately 20 mph and ideally be able to start from a stand on the slope. The locomotive could not meet the target without increasing the Initial pressure drop which increases the force generated. The settings were found by empirical testing on the slope to meet the target.

ORTSCylinderBackPressure

Sets the cylinder back pressure against the Indicated HP

V2 setting: Not used

ORTSCylinderPortOpening

For Saturated Locomotives only. Sets the factor for the size of the port opening on the the cylinder.

V2 setting: Not Applicable

BoilerVolume

Not strictly an advanced feature the OR BoilerVolume parameter is not critical. However, an accurate value can be set if known. More generally a reasonable estimate can be made by dividing the total heating area by 8.

V2 setting (453*ft^3)

Calculated from the Boiler Diagram. Estimate gives (389*ft^3).

ADDITIONAL EFFECTS

Various additional effects have been added to the Locomotive, Tender and Mk1 Coaches.

Steam Heating and Hose Leaks

The Locomotive has steam heating for the comfort of passengers. This is enabled by the following parameter included in the eng section of the eng file,

MaxSteamHeatingPressure (100psi)

Steam heating was facilitated by hose connections from the loco to the carriages. Often there were steam leaks from these connections or even in the hoses themselves. A visual impression of hose leaks can be enabled in OR with the following type of parameter. The example given is for the Mk1 carriages,

Effects(
SpecialEffects(
Comment(Steam Heating Leak)
HeatingHoseFX(
0.0 0.6 -10.45
0 1 0

0.13
)))
Hose leaks have also added to the V2 Tender in a similar way.

Locomotive Effects

In addition to the normal effects found in MSTS a visual impression of the injector operation is available in OR. There are normally two injectors in the cab, one operated by the driver and most frequently one operated by the fireman. Two separate parameters are available for insertion in the effects section of the eng file to represent this. For the V2 these have been set as,

```
Injectors1FX
(
    1.36 0.98 -4.4
    0 1.4 -0.4
    0.15
        )
Injectors2FX
(
    -1.36 0.98 -4.4
    0 -1.4 -0.4
    0.15
)
```

A final enhancement has been included in the effects section of the locomotive eng file. The V2 is a three cylinder locomotive so an addition cylinder effects parameter has been added to represent the steam blow out of condensate from the cylinders.

```
CylindersFX
(
    -1.074 0.505 5.939
    0 0 1
    0.17
)
CylindersFX
(
    0 0.505 5.939
    0 0 1
    0.17
)
CylindersFX
(
    1.074 0.505 5.939
    0 0 1
    0.17
)
```

V2 LOCOMOTIVE PERFORMANCE

Graph 11 from the V2 report indicates the results from a road test between Winterbourne and Pangbourne on the Great Western Railway route towards Reading. The test route is 68 miles long and the test took 68 minutes, indicating an average speed of 60mph. The terrain consists of 1 in 300 rise then 1 in 300 fall followed by a short rise to Swindon roughly 1 in 500 average then a long fall of roughly 1 in 800 to Didcot. The final part of the test is on a more or less flat run with a very slight fall. The results show the train reached approximately 62mph on this final section. It can be considered that the test run is roughly equivalent to a run on the flat as the gradients are not very large and roughly equal out in terms of the up and down over the length of the run. The train had a load of 761.7 tons and was steamed at a steady rate of 23950 lb/hr to the cylinders.

V2 OR Testing

The OR tests were carried out on completely level track on the CTN Test Route with a 760 ton load. The train was run for approximately 30 minutes to allow the boiler to settle down and the train to reach very near its maximum speed. The steam to the cylinders was held constantly at around 24000 lb/hr when the train approached its maximum speed. This required a cut off of 26% with full Throttle. A test was then carried out over a 10 minute period, where the distance covered, coal and water in the tender used, and the steam used were noted from the HUD readout.

Typical results were as follows;

Coal used	582 tons,
Water used	408 gallons,
Steam used	3974 lb,
Distance	10.3 miles,
Max Speed	61.7 mph,
Max IHP	1850 hp.

Coal Rates	56.5 lb per mile, 3492 lb/hr,
Water Rates	39.6 gal per mile, 24480 lb/hr
Steam Rate	23844 lb/hr

These results indicate a good correlation to the Road Test Report which shows a mean coal rate of 3750 lb/hr and Water/Steam rate of 24350 lb/hr. The maximum speed is very close to that expected.

Theoretical Maximum Speed
The maximum speed can be calculated using a cubic equation for any given IHP, Train Weight and Train Resistance. Maximum speed is reached when the Driving Force produced by the locomotive exactly matches the total Resistance Force of the train.

Train Resistance is given by

$A + B \times S + C \times S^2$,
where A, B and C are the totals of the stock ORTS metric constants, and S is the speed in meters per second.
Power divided by Speed equals Force. Therefore, at maximum speed,

$A + B \times S + C \times S^2 = P/S$,
where P is Power in Watts, thus,

$A \times S + B \times S^2 + C \times S^3 - P = 0$,
This is a cubic equation which can be solved using a browser calculator such as that provided by Wolfram Widgets.

The formula can be modified to calculate maximum speed on a gradient by adding or subtracting Grade Resistance (G Newtons) multiplied by speed to the left hand side of the equation. G can be approximated to Weight in metric tonnes times Grade as a decimal fraction for grades less than 5%. This needs to be converted to Newtons so for a grade of 1% or 1 in a 100,

Grade Resistance = Weight (tonnes) x 0.01 x 9806.65002864,
and the formula for climbing becomes,

$G \times S + A \times S + B \times S^2 + C \times S^3 - P = 0$

The test consist was set up with,

2 x BTO coaches with a mass of 36t-uk	A=391, B=24.3, C=0.68
4 x RMB coaches with a mass of 38t-uk	A=401, B=27.5, C=0.68
16xTSO coaches with a mass of 33.5t-uk	A=396, B=26.1, C=0.68

Total for train including Loco and Tender	A=15708, B=611, C=22.78

Power is 1850 hp = 1380100 Watts

$22.78 \times S^3 + 611 \times S^2 + 15708 \times S - 1380100 = 0$

For this train on level track solving the cubic equation gives a speed of 27.6 meter per second which is 61.7 mph. This exactly matches the OR test result and very closely matches the V2 Test report result. This confirms that the Loco and Stock have the correct Power and Resistance.

Mick Clarke
23/4/18