The Application of the Davis Formula to set Default Train Resistance in Open Rails

Coals to Newcastle
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Resistance

Introduction

The understanding and measurement of train resistance values is an important aspect of train performance (both in real railways, and also in Open Rails). All locomotives generated a defined "pulling force" determined by their relevant design features. The speed, load and gradients that a train is able to pull will be determined by the locomotive pulling power and the amount of train resistance that it needs to overcome.

Train resistance, the combination of forces which must be overcome to set a train in motion, continue it in motion at a constant speed, or to accelerate it to a higher speed, is customarily divided into two main divisions; first, those resistances inherent to all train operation, and are typically developed on level tangential track; and second, those encountered only on grades, curves, during the acceleration cycle, or when operating in adverse winds, called incidental resistances.

They may be segregated as follows:
A. Inherent Resistances developed on level tangential track
- Track or flange resistance
- Rolling resistance
- Oscillatory and miscellaneous frictional resistance
- Journal or Roller Bearing friction
- Air resistance in still air

B. Incidental Resistances
- Grade resistance
- Curve resistance
- Acceleration resistance
- Wind resistance

In addition to the above, there is to be considered the machinery friction of the steam locomotive and the motor gearing, bearing, and other transmission losses of electric or Diesel-electric power units, active between the power source and the rails, but this resistance does not enter into practical consideration of power requirements inasmuch as power ratings are usually referred to tractive effort at the rail.

This paper will currently focus on the Inherent resistances developed by the train.

Inherent (Level Tangent Track)

A railway vehicle moving upon level, tangent track, in still air and at a constant speed encounters certain resistances that must be overcome by the tractive effort of the locomotive.

The predominant but not exclusive contributors to the various coefficients are as follows:

<u>Track or Flange Resistance</u> - As the car truck moves along the rails, it generally oscillates laterally, the wheel flanges bearing first upon one rail then the other, at each impact introducing a force tending to change its direction. Further, frictional resistance results from the rubbing action between wheel flanges and rail heads. Light equipment exhibits this oscillating or nosing tendency to a greater degree than do the heavier, conventional cars with their greater inertia combined with six-wheel trucks resisting the development of resonant oscillation. Moreover, a wheel flange throat, worn to a shorter radius than that of the rail head, superimposes a wedging action between the flange and rail head, materially increasing the rubbing friction between the two surfaces.

Rolling Resistance - Low track joints and track in poor surface from any cause aggravate the condition, since the impact at speed of a car wheel upon any track irregularity initiates or intensifies the oscillatory motion and increases flange pressure. A resilient track structure constantly presents an uneven surface to the rolling wheel, introducing an equivalent adverse grade, the extent of the tendency varying directly with the yielding properties of the track. Rolling resistance is so closely associated with track and lateral oscillatory resistances that it is impossible to segregate and measure the effect of any one component. The deformation of the wheel and rail surfaces extends further into a bending and depression of rails, thus providing an uneven track, indirectly augmenting flange pressure.

Oscillatory and Miscellaneous Frictional Resistance - Oscillatory or miscellaneous frictional resistance as here defined is intended to include all undirected but unavoidable motions which are incidental to train operation; the swaying and interaction of car bodies with consequent energy absorption, spring compression and recoil, recurrent surges throughout the train, friction at coupler faces, journal box pedestals, bolsters, and center plates, along with many other miscellaneous unproductive motions, combine to form an important fraction of total train resistance.

Journal Friction - Journal friction arises from contact between the rotating axle journal and its relatively stationary bearing. This resistance component varies over a wide range of values depending directly upon journal box temperature, viscosity and other characteristics of the lubricant employed, and its proper distribution between journal and bearing. Indirectly, atmospheric temperature and length of period of rest or motion are important in so far as they influence bearing temperatures. Much of the lubricant is squeezed from the journal bearing of a car at rest, draining into the journal box, leaving a partially and poorly lubricated surface. The viscosity of the oil may be increased due to lower temperature, increasing its shearing resistance.

Air Resistance in Still Air - Head-end resistance, the most important of these components when rail motor cars and very short trains are operated, is a function of frontal area, shape and nature of the surface, and vehicle speed. It is due to displacement of the air by a vehicle and the production of a high pressure zone through which the vehicle endeavours to press. Rear-end suction is closely associated with head-end resistance but is negative in its effect, retarding forward motion of the vehicle. Air resistance of a locomotive is reported by Goss to be approximately four times the corresponding resistance of the last car of a train, based upon laboratory tests conducted in still air Rear-end suction is dependent upon tail fairing, cross-sectional area at the rear, and train speed. Mathematically, it combines readily with head-end resistance, responding to similar factors, and generally is so treated. Skin friction is caused by the dragging action created by the relative motion of air with respect to the sides of car bodies and the formation of eddies and pressure strata. As train length increases, skin friction dominates in air resistance effects. It can be controlled by provision of smooth car sides and roofs, which carry less depth of air in the high pressure stratum adjacent to the exposed areas, reducing eddy and shearing resistances. Ground effects, truck resistances, and the obstruction to free air flow created by attachments beneath car floors combine all the effects of head-end, rear-end suction, and skin friction in a complex and still indeterminable manner.

This component of the resistance formula can increase quite dramatically as it is related to the square of the speed. Wind tunnel tests suggest that at speeds of less than 40mph little is gained by streamlining rolling stock. Definite gains can be achieved if streamlining is used at speeds in excess of this speed. Modern tests have also shown that gaps between containers, etc can have a large impact upon the efficiency of operation of the train due to increased resistance.

Various tests made over the years have shown that the resistance to train movement can be determined using an empirical expression of the following form:

$$\mathbf{R = A + BV + CDV^2}$$

where:
R= train resistance in lbs
A = rolling resistance component independent of train speed
B = coefficient used to define train resistance dependent on train speed
C= streamlining coefficient used to define train resistance dependent on the square of the train speed
D = aerodynamic coefficient or polynomial function used to further define train resistance, often combined with C
V = train speed in mph

Thus in summary the ABC values equate to the following types of friction.

A	B	C & D
Journal / Roller Bearing Resistance	Flange friction	Head-end wind pressure
Rolling resistance	Flange impact	Skin friction on the side of the train
Track resistance	Rolling resistance wheel/rail	Rear drag
	Wave action of the rail	Turbulence between cars
		Yaw angle of wind tunnels

Impact of the respective Davis coefficients on resistance is shown in the graph below.

From the graph it can be seen that the A value and the frictional elements that contribute to it (see table above) remain static regardless of the speed of the train. The B value can be seen to slowly increase with speed, whilst increases at significant rate as the speed increases. This predominately represents the wind resistance of the stock. This also explains why so much attention is paid to high speed trains, and the need to streamline them.

Development of Train Resistance Formula

Train resistance formulas were developed empirically by running a series of test on various train consists, and then fitting a quadratic formula (Davis format) to the test results.

American engineers did quite extensive testing and development of formulas. Professor Edward C. Schmidt was the first of a series of engineers who developed a set of formulas that were accepted by the railway community for use in calculating train resistance. His formulas were for freight wagons operating at speeds of up to 40mph by running a series of tests in 1910. In these days this speed range was considered satisfactory as the speed of freight trains rarely exceeded 40mph. In 1937, Professor J. K. Tuthill repeated the tests of Schmidt, and extended the tests up to speeds of 70mph.

Schmidt and Dunn ran a series of tests on passenger trains in the 1908-1916 period to determine the resistance formulas for speeds up to 70mph.

Davis Formula

In 1926, W. J. Davis proposed an empirical formula for computing "Tractive Resistance of Electric Locomotives and Cars" moving on straight and level track. His formulas were primarily based upon the formulas of Schmidt (as Tuthill hadn't undertaken his tests until 1937), and his proposed values for the coefficients A, B and CD shown above were as follows:

A = $1.3 + \frac{29}{W}$

B = 0.03for locomotives, 0.045 for freight wagons,

CD = $\frac{Ca}{WN}$

NB: Weight is in US tons (2000lbs)

For vehicles with light axles weights, ie less than 5 tons, then use A = $\frac{9.4}{\sqrt{W}} + \frac{12.5}{W}$

Where:
R = Train resistance in lb/ton
W = Axle weight in tons per axle of locomotive or car
N = Number of axles
a = cross-sectional area of the locomotive or car in square feet
C = streamlining coefficient

Davis recommended the following values for the formula

Where Used	B	C	a
Locomotives	0.03	0.0024 (0.0017 – Streamlined)	50 ton = 105 sq ft, 70 tons = 110 sq ft, 100+ tons = 120 sq ft
Freight Cars	0.045	0.0005	85-95 sq ft
Passenger Cars (Vestibuled)	0.03	0.00034	120 sq ft
Multiple Units - Leading	0.045	0.0024	100-110 sq ft
Multiple Units - Trailing	0.045	0.00034	"
Motor Cars	0.09	0.0024	2 trucks – 80-100 sq ft 1 truck – 70-75 sq ft

The equation which Davis proposed thus became (for freight cars):

Normal weight

$$\boldsymbol{R = 1.3 + \frac{29}{W} + 0.045V + \frac{0.0005aV^2}{WN}}$$

Low weight (axle weight < 5 tons (US))

$$\boldsymbol{R = 9.\frac{4}{\sqrt{W}} + \frac{12.5}{W} + 0.045V + \frac{0.0005aV^2}{WN}}$$

Explanatory Notes -

1. The first two terms of the equations represent journal friction almost entirely. They have been derived from dynamometer and coasting tests on standard freight and passenger cars and electric locomotives and are based on oil lubrication with average temperature conditions. Journal friction may be increased 20 to 40 per cent at temperatures below freezing.

2. The third term comprises resistances due to flange friction, concussion, swaying, and miscellaneous frictions proportional to the speed. The factor for this element is decreased by increase in length of truck wheel base and increased .by poor road bed conditions and inferior riding qualities of motor cars.

3. The last term gives air resistance for average weight of car or locomotive in pounds per ton for standard types of equipment. No allowance is made for head winds or strong side winds.

4. Locomotive resistance represents tractive effort delivered to driving axles and does not include friction losses in gears, motor bearings or other parts o£ the driving equipment, as there are usually covered in the motive power efficiency.

5. The formulas are based on tests taken under mild weather conditions. Values obtained from them may be used as found in calculations relating to electric distributing systems, substations, energy consumption, and power demand. In the determination of electric motor characteristics and gear reductions to meet particular speed requirements, however, it may be desirable to add a small percentage to the required speed as a protection against unusual conditions.

6. Locomotive resistance represents tractive effort delivered to driving axles and does not include friction losses in gears, motor bearings or other parts of the driving equipment, as these are usually covered in the motive power efficiency, and *also applies to the driver tractive effort of steam locomotives. The mechanical resistance of steam locomotives equals 20 lb. per ton weight on drivers, hence should be added to locomotive resistance when applied to cylinder or indicated tractive effort. [This last note was added as a recommendation by AREA in 1943, and required the addition of 20 x Weight on Drivers to the Davis formula]*

Passenger Train Contour (New York University Wind Tunnel Test Results)

In 1934, a comprehensive series of wind tunnel tests was jointly sponsored by The American Locomotive Company, the American Car and Foundry Company, and the Brill Company. These experiments were conducted in the laboratories of New York University under the direction of Professor Alexander Klemin and data have been released by the sponsors. Models of standard railway motive power and rolling stock were examined along with models of streamlined equipment with various nose, tail fairing and enclosure shroud forms. These variations are noted below in connection with the presentation of equations applicable to the several test models.

AIR RESISTANCE FORMULAS FOR TRAINS OPERATING IN STILL AIR

POWER CAR TRAINS

Open skirts (18 in. from skirt to top of rail):

$$\boldsymbol{Air\ drag = 0.00224\ Pc\ (\frac{L}{100})^{0.88} V^{2 + \sum KV^2}}$$

Closed skirts (completely under car):

$$\boldsymbol{Air\ drag = 0.0020\ Pc\ (\frac{L}{100})^{0.88} V^{2 + \sum KV^2}}$$

Where:
P_c = Perimeter of car, in feet, from plane of top of rails over car to plane of top of rails
L = Overall length of train in feet
V= Speed of train in m.p.h.

$\sum K$ = Summation of factors (K_1 + K_2 + etc.) of the various items whose drag depends on other dimensions than perimeter and length

K_1= Factor for power car nose shape:

For nose bluntly streamlined, K_1 = +0.000036 X cross-sectional area of nose at full section, including trucks, in square feet

For nose well streamlined, K1 = 0

K_2 = Factor for tail shape:

For tail bluntly streamlined, K_2 = +0.000061 X cross-sectional area of tail at fu11 section, including trucks, in square feet

For tail well streamlined, K_2 = 0

K_3 = Factor for power car trucks:

For two faired trucks, K_3 = 0

For two unfaired trucks, K_3 = +0.0099 (This factor is large, because as tested, the truck fairings formed part of the nose and skirt fairing, and when the truck fairings were removed the nose and skirt shape was damaged. On designs in which the truck fairings do not interfere with the nose or skirt contours, K_3 = +0.00026)

K_4 = Factor for fairing trailing car trucks on streamlined trains (as tested, neither the trucks nor the fairings interfered with the continuity of the open skirts):

For faired trucks, K_4 = +0.00013 X number of trailing car trucks

For unfaired trucks, K_4 = 0

K_5 = Factor for diaphragm shape:

For smooth diaphragms, K_5 = 0

For cowled diaphragms, K_5 = +0.000037 X P_c X number of diaphragms

K_6= Factor for bulge of power car:

For no bulge (as tested), K_6 = 0

For a bulge of good streamline shape, *K-6* = +0.00032 X cross-sectional area of bulge in square feet (in order for this coefficient to apply, the bulge must be of such a character that it has a streamline shape as good as, or better than, the power car itself). Under this heading may be classed bulges that are merely expansions of the general power car contours, as well as local bulges having well streamlined noses and tails.

For a bulge of relatively poor streamline shape, K_6 = +0.00051 X cross-sectional area of bulge in square feet (this coefficient applies where the bulge has relatively poor shape, such as sharp edges or corners, blunt tail, a blunt nose, etc.)

STREAMLINE LOCOMOTIVE TRAINS

With open skirts on cars (18 in. from skirt to top of rail)

$$\boldsymbol{Air\ drag} = \mathbf{0.023}\ \mathrm{L_L}^{1/3} + \sum \mathrm{K_L} + \mathbf{0.001735}\ \mathrm{Pc}\ \left(\frac{\mathbf{Lc}}{\mathbf{100}}\right)^{\mathbf{0.88}} \boldsymbol{V}^{\mathbf{2}} + \sum \boldsymbol{KV}^{\mathbf{2}}$$

With closed skirts on cars (completely under cars)

$$\boldsymbol{Air\ drag} = \mathbf{0.023}\ \mathrm{L_L}^{1/3} + \sum \mathrm{K_L} + \mathbf{0.001535}\ \mathrm{Pc}\ \left(\frac{\mathbf{Lc}}{\mathbf{100}}\right)^{\mathbf{0.88}} \boldsymbol{V}^{\mathbf{2}} + \sum \boldsymbol{KV}^{\mathbf{2}}$$

Where:
V= Train speed in miles per hour
L_L =Length of locomotive and tender in feet
L_c = Length of car consist, in feet, rear of tender to rear of train
P_c = Perimeter of cars, in feet, from plane of top of rails over car to plane of top of rails
$\sum K_L$ = Summation of factors of the various items affecting the locomotive and tender, whose drag depends on other dimensions than those given above:
K_7 = Factor for wheel shrouds on streamline locomotives:
For closed shrouds (ail wheels completely enclosed), $K_7 = 0$
For open shrouds (2-ft. by 2-ft. 6-in. inspection openings over the driving wheel journals),
K_7 = +0.0005 X total number of openings
For short shrouds (driving wheels and tender trucks completely exposed), K_7 = +0.0182

K_8 = Factor for nose shape on streamline locomotive:
For helmet nose, $K_8 = 0$
For straight nose, K_8 = +0.0021
For round nose, K_8 = +0.0026

K_9 = Factor for boiler shape on streamline locomotive:
For round top, $K_9 = 0$
For cowled top (domes and fittings enclosed in longitudinal cowl above boiler shroud), K_9 = +01.0035

K_c = Summation of factors of the various items affecting the cars, whose drag depends on other dimensions than those given above. These factors are K_2, the factor for tail shape; K_4, the factor for fairing trailing car trucks on streamlined trains; and K_5, the factor for diaphragm shape. Their values are the same as given under the formulas for power car trains.

The first two terms in the brackets of the drag equations for streamlined locomotive trains are functions of the locomotive and tender only, while the last two terms are functions of the car consist only.

STANDARD LOCOMOTIVE TRAINS - NEW YORK CENTRAL 4-6-4 TYPE

$$\boldsymbol{Air\ drag} = \mathbf{0.083}\ L_L^{1/4} + \mathbf{0.0031}\ Pc\ (\frac{\mathbf{Lc}}{\mathbf{100}})^{\mathbf{0.7}} \boldsymbol{V^2}$$

Where:
V= Train speed in miles per hour
L_L= Length of locomotive and tender in feet
L_c = Length of car consist, in feet, rear of tender to rear of train
P_c = Perimeter of cars, in feet, from plane of top of rails over car to plane of top of rails

The first term in the brackets of this formula is a function of the locomotive and tender only, while the second term is a function of the car consist only.

Davis Formula (1970 Variation)

The original Davis formula gave satisfactory results for older freight equipment with journal bearings within a speed range between 5 and 40 mph. However, roller bearings, increased dimensions and heavier loading of freight cars, the much higher operating speeds of freight trains, and changes in the track structure made it desirable to modify the constants in the Davis equation.

Tests showed improved results when using the following modified Davis Formula:

$$R = 0.6 + \frac{20}{W} + 0.01V + \frac{KV^2}{WN}$$

where:
R= resistance in pounds per ton
W= weight per axle in tons
N= number of axles
V= speed in miles per hour
K= combined air resistance coefficient:
- 0.076 for conventional equipment
- 0.16 for piggyback
- 0.0935 for containers

Davis Formula (1992 Canadian National variation)

The original train resistance formula has been retained as to form, but over the years different coefficients have been developed to reflect changes such as higher speeds, more modem equipment, and today's track and truck designs.

The 1990 Canadian National version of the train resistance formula (6) is presented below. When used with the coefficients shown (many of which have been developed in dynamometer car tests), the formula has given reliable results in train performance calculator programs or similar applications.

$$Rr = 1.5 + \frac{18N}{W} + 0.03 + \frac{CaV^2}{10000W}$$

where:
Rr = the rolling resistance of vehicle in lb/ton
N = Number of axles
W = Total weight in tons of locomotive or car
V = Velocity of train in miles per hour
C = Canadian National streamlining coefficient
A = cross-sectional area of the locomotive or car in square feet

The following table shows the range of values for the C coefficient for various kinds of equipment. Note that these values for C are scaled for use with the Canadian National formula only.

Table of Values of C Coefficient (7)
For use with Canadian National Train Resistance Formula Only

Degree of Streamlining	Example Equipment	C Coefficient	
		Leading Eqpt.	Trailing Eqpt.
Nil 1	Open auto transporter	-	12.3
Nil 2	Freight locomotive	24.0	*5.5*
	Mixed consist of freight cars	-	5.0
Low 3	RDC	19.0	4.0
Low4	Conventional passenger incl. loco.	19.0	3.5
Med 5		14.0	3.0
Med 6		10.0	2.6

High 7	High speed passenger	7.6	2.3
High 8	Maximum possible streamlining	7.0	2.0

When certain types of cars predominate in a train more accurate resistance values for such a train can be obtained by using C coefficients from the following table. The table shows in more detail recommended Canadian National values for C and cross-sectional areas for the various equipment types.

Table of Values of C Coefficient and Areas for Freight and Passenger Equipment
For Use with Canadian National Train Resistance Formula Only (8)

Type of Equipment	C	Coefficient Area (sq ft)
Box Car	4.9	140
Bulkhead Flat (loaded)	5.3	140
Bulkhead Flat (empty)	12.0	140
Coal Gondola (loaded)	4.2	105
Coal Gondola (empty)	12.0	105
Covered Hopper	7.1	125
Tank Car	5.5	95
Standard Flat Car (without trailers)	5.0	25
Standard Flat Car (with trailers)	5.0	125
Caboose	5.5	145
Conventiona1 Passenger Coach	3.5	130
Modem Lightweight Passenger Equipment	2.0	110
Leading Freight Locomotive	24.0	160
Multi-level Auto Transporter (open)	12.3	150
Multi-level Auto Transporter (closed)	7.1	170

It will be noted that the C coefficients for empty gondolas and empty bulkhead flats are much larger than those for loaded gondolas and loaded bulkhead flats. This is due to the air swirling inside the empty car and the resulting turbulence.

Through 1988, the Association of American Railroads produced a series of reports as part of its continuing Energy program. These reports developed train resistances based upon the original Davis equation, but with a number of changes in the coefficients. Some of these changes include:

- AAR tests on Class 3 or better track indicated a negligible value for the "B" term, which was dropped.
- Modem roller bearings have a resistance of 16 - 18 lbs/axle, which is consistent with the 20 lbs/axle used in the modified Davis Formula. These factors change the original Davis formula to:

$$\boldsymbol{R = 1.3 + \frac{18}{W} + \frac{CaV^2}{WN}}$$

- The speed-independent rolling resistance term (I. 3) can vary from 2. 13 lbs/ton (loaded car) and 1.77 lbs/ton (empty car) without whee/rail lubrication, down to 0.8 lbs/ton to 0.7 lbs/ton with

lubrication for three-piece trucks, and from 1.35 lbs/ton (loaded car) to 0.91 lbs/ton (empty car) for radial, frame braced, and primary aligned truck designs.
- Attributing the third term to aerodynamic resistance, the "C" term can be defined as follows:
R aero = cv2 = 0.5 p (CDa) y2
p is air density, which is dependent on air pressure and temperature. The (CDa) term is the drag area of the train (drag coefficient), which is determined by summing the drag areas for all cars in the consist. The Aerodynamic Subroutine of the AAR Train Energy Model version 2.0 expresses the "C" term as a seventh order polynomial function of crosswind yaw angle for each car, and then sums over all cars. Thus the drag areas of different trains will vary considerably, depending on car design, car spacing, wind yaw angle, and train make-up. Test data used to develop this model are available in AAR Report R-685 (9).

Version 2.0 of the AAR Train Energy Model (TEM) incorporates this train resistance subroutine and data. This model permits simulation of train handling and includes fuel consumption, travel time, and speed profile as model output. To run the AAR TEM, the user does not need to gather resistance information.

Suggested Implementation of Level Track Tangent Resistance in Open Rails

The correct application of resistance in Open Rails (OR) is critical to ensure a high degree of accuracy in the performance of the train being modelled.

If test values are available from the relevant railway company in regard to the stock being configured, then they should always be used in preference to the default values suggested below.

When relevant values are not readily available, then the table below can be used to get the best approximation. It should be noted that the categorises identified in the table below are indicative only, and should be used as a guide only.

Operating Speed Range	Track Type (Condition)	Vehicle Type	Era of operation	Suggested Formula	Comments
		Freight Wagons			
40mph to 50mph	Track flexible (wooden sleepers), light weight track, numerous track joints	Journal bearing, older style design	Pre 1950s	Original Davis Formula	
50 to 75mph	Track semi-rigid, heavier weight track, longer rail sections	Roller bearing, older design	Post 1950s	Davis Formula - 1970	
>75mph	Track rigid (concrete sleepers), welded rail	Roller bearing, modern design	Post 1990s	Davis Formula – 1992 Canadian National	
		Passenger Stock			
< 60mph	Track flexible (wooden sleepers), numerous	Journal bearing, older style design, light weight,	Pre 1960s	Original Davis Formula	

	track joints	minimal streamlining			
60 to 125mph	Track rigid (concrete sleepers), welded rail	Roller bearing, modern design, significant streamlining	Post 1960s	Davis Formula – 1992 Canadian National	
>125mph	High Speed Design	Streamlined	All eras	As per manufacturers figures	
			Locomotives		
Steam (Journal Bearings)	Track flexible (wooden sleepers), light weight track, numerous track joints	Standard Design	All eras.	Original Davis Formula (plus mechanical resistance)	NB: The locomotive and tender should be considered a single unit for the calculation of resistance.
Diesel/Electric (Early)	Track semi-rigid, heavier weight track, longer rail sections	Standard Design	Pre 1970	Original Davis Formula	
Diesel/Electric (Modern)	Track rigid (concrete sleepers), welded rail	Standard Design	Post 1970	Davis Formula – 1992 Canadian National	

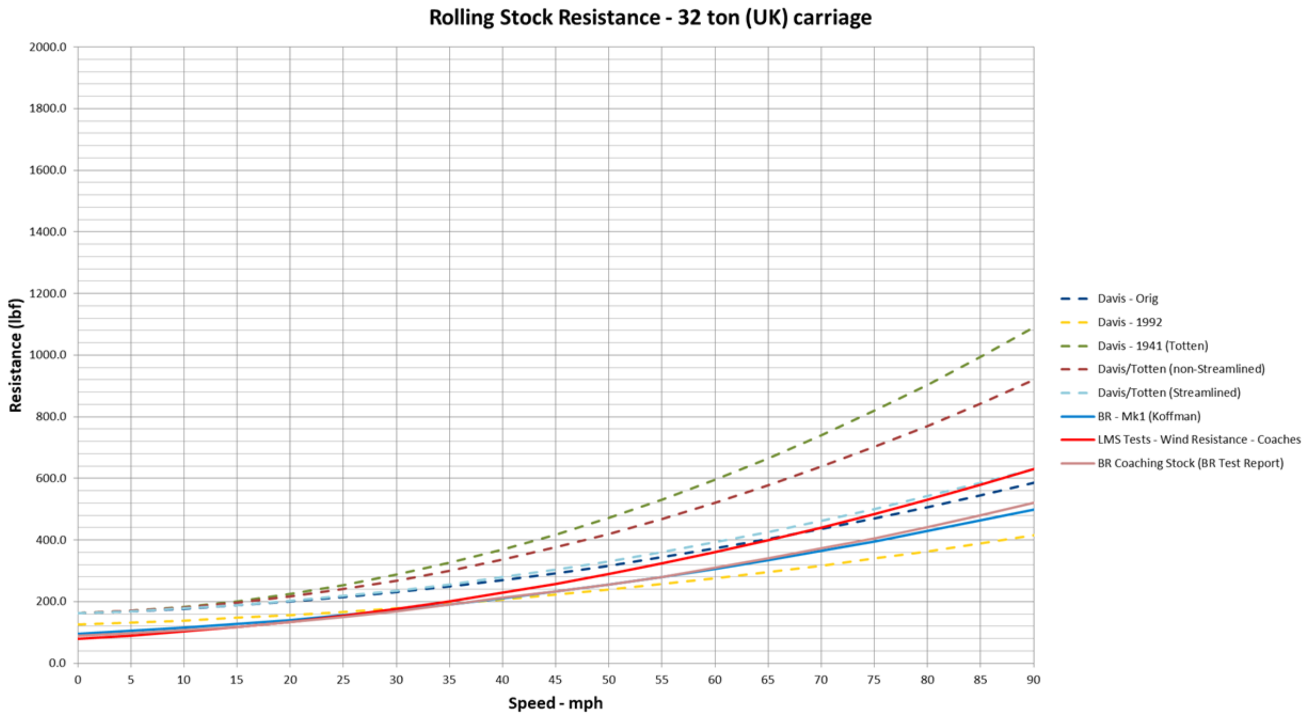
Examples of Resistance Curves

The following curves for different types of stock show the variety of resistance values that can be obtained.

Passenger Stock

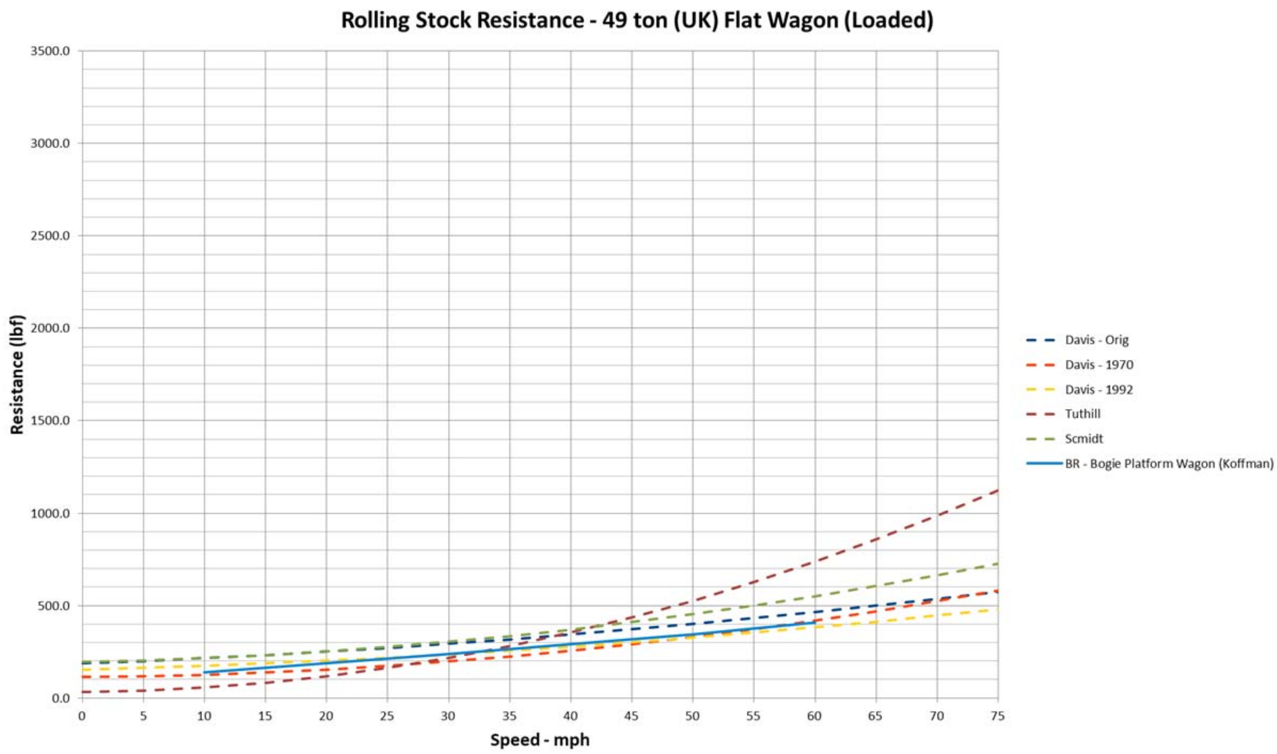
The first curve represents Passenger Stock and shows the various Davis variations (shown with dotted curves) against three curves (shown in solid curves) provided by UK railway companies.

The LMS curve were used for testing in the 1933, whereas the BR Coaching stock curve was measured during testing of the Duke of Gloucester locomotive, and the Mark1 (Mk1) passenger stock curve was taken from a report by Koffman, which were introduced from the early 1950s.. Some of the differences between these curves can possibly be attributed to the change in design of the vehicles between the 1930s and 1950s, as well as differences in streamlining, etc. Possible differences between the Davis curves and the curves taken from BR literature could be more to do with the A and B parameter, which impacts the curve more towards lower speeds. Thus there could be differences in the type of journal bearings used in these cars, as well as track designs and standards could be different between the UK and US.



Freight Wagons

The BR flat wagon curve was taken from a 1964 publication by Koffman.

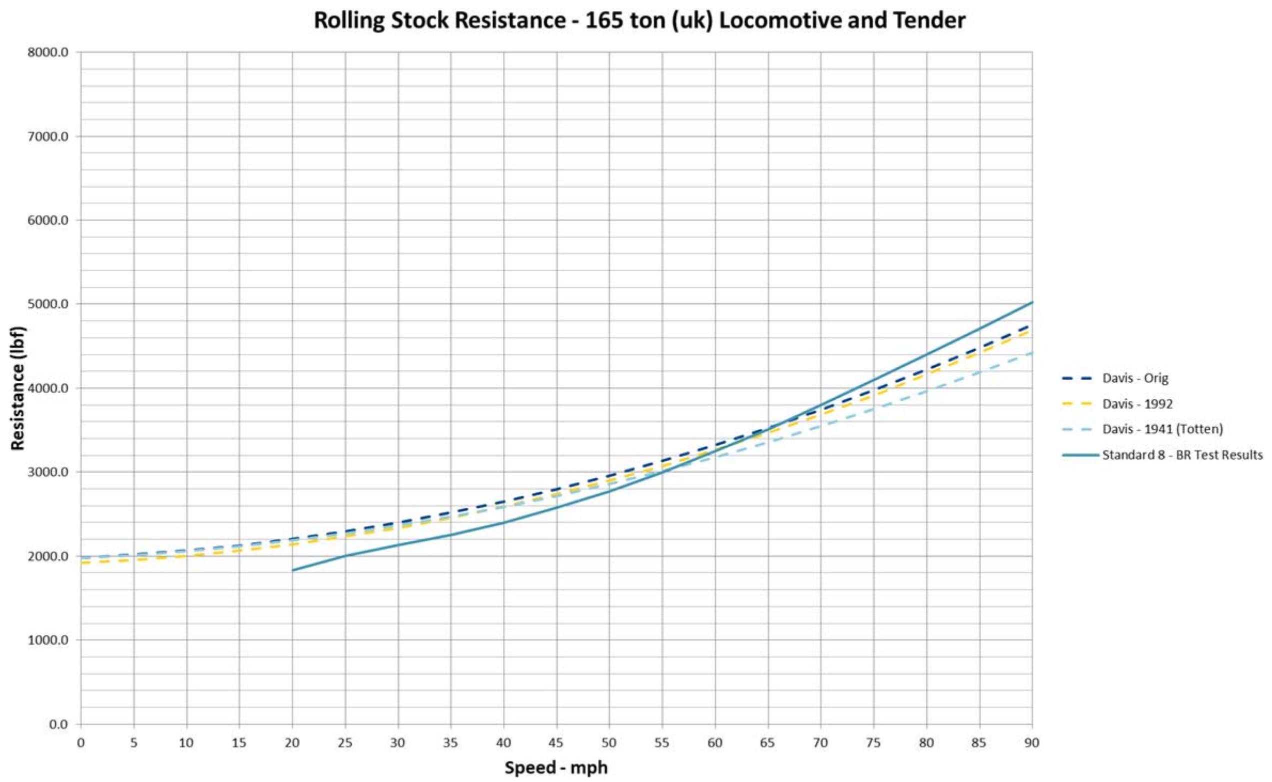


Locomotives

The graph for the locomotive shows the combined resistance of the locomotive and the tender. It shows the curve taken from a BR Test report for the Duke of Gloucester locomotive, and the curves predicted using the Davis variation formulas.

It should be noted that strictly speaking the 1992 variation of the Davis equation was probably not pertinent to the steam locomotive as most, if not all steam locomotives were no longer operated by the Canadian National Railway at the time the formula was adjusted. It would apply to diesel and electric locomotives.

Once the combined resistance is found for the locomotive and tender, it will be necessary to separate it into two elements for configuration into OR.



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