Friction Calculator
for Open Rails

The Open Rails software calculates rolling resistance (other than starting from rest) by using the parameters ORTSDavis_A, ORTSDavis_B and ORTSDavis_C from eng and wag files. These correspond to the coefficients in a quadratic equation of the form:

$$\text{Resistance} = A + B.V + C.V^2$$

Equations of this type have been used by railway engineers to calculate friction since the early 20th century. In English speaking countries the equation is commonly called the Davis equation, after W.L. Davis of USA, who derived an equation in this format in 1926, together with some rules for determining the parameters A, B and C. The calculation of these parameters was later revised in the USA and more recently by Canadian National in 1992. The 'standard' values in use in North America today can be found in the AREMA Manual for Railway Engineering[1].

These values formed the basis of the "FCalc" utility by Joseph T. Realmuto, which has been widely used to calculate the friction parameters for Microsoft Train Simulator. However the values obtained from this do not correspond well to the measured values for rolling stock in other parts of the world. For example they tend to give larger than expected values for smaller rolling stock in Western Europe. A review of railway literature shows a variety of methods of calculation are used in different countries. A summary of these has been put together by Profillidis[2]. Many of these are only directly valid for a limited range of rolling stock as they estimate the value of C based only on the mass of the vehicle regardless of its size and shape. The comparison spreadsheet allows graphs of the results of some of these different calculations to be compared.

A quick review of the graphs in the comparison spreadsheet, or an examination of real life data, such as the measurements of freight train resistance in Serbia[3] will show that any calculation of train resistance data is more of a crude estimate than an exact science. With that in mind any results from the friction calculator should not be considered to have any greater accuracy than 10% or two significant figures!

Passenger Carriages, Diesel and Electric Locomotives, and Multiple Units

For passenger carriages, diesel and electric locomotives, multiple units and high speed trains the equations used are those employed by SNCF[2]. These seem to be the most flexible in being able to cover a wide range of vehicles. Rather than using cross sectional area to estimate the C factor for trailing vehicles the French equation uses the longitudinal surface area (perimeter x length). In addition there are three constants that can be changed to represent the characteristics of different types of stock. These are:
λ – representing the resistance of different types of bearing or bogie.
k_1 - representing the degree of streamlining due to the shape of the nose or tail of the train.
k_2 - representing the degree of streamlining of the surface, roof and underframe of the train.
The general equations being:

$$R = \lambda \sqrt{(10\ M\ n)} + 0.1\ M\ V + (k_1\ C + k_2\ S)\ V^2 \text{ for the leading vehicle;}$$
$$\text{and } R = \lambda \sqrt{(10\ M\ n)} + 0.1\ M\ V + k_2\ S\ V^2 \text{ for the following vehicles;}$$

1 AREMA (1999)
2 Profilidis (2006)
3 Radosavljevic (2006)

Where R is resistance (N), M mass (tonnes), n number of axles, V velocity in m/s, C cross sectional area (m^2) and S surface area (m^2) calculated as perimeter x length.

Goods Wagons

The Canadian National revision of the Davis Equation[4] produced a comprehensive set of resistance calculations for different types of freight wagons. The values obtained from these are well suited to the large bogie wagons currently used in North America, but they seem to overestimate the resistance of smaller wagons. To calculate resistance for smaller 4-wheel wagons the SNCF equation is used. (For smaller bogie wagons on narrow gauge railways it will probably be better to use the calculations for passenger carriages.) The Canadian National formula estimates that the air resistance of an empty ‘open’ wagon is almost three times that of a loaded wagon. This has been called into question by Szanto[5], who from measurements of iron ore trains in Australia found that the air resistance of the empty wagons was approximately 1.5 times that of the loaded wagons. Earlier measurements made with smaller open wagons in the United Kingdom[6] suggest an increase of 1.5 to 2 times. The suggested values for ORTSDavis_C for empty wagons are therefore taken as being 1.5 times those of the loaded wagon for bogie wagons and 2.0 times those of the loaded wagon for 4 wheeled wagons. (The original CN figures are available from the comparison spreadsheet if required.) It seems likely that the air resistance figures for empty Bulkhead Wagons and Open Auto-Rack wagons should also be proportionately lower, however at present I have been unable to find any data to support this assumption.

Steam Locomotives

There have been relatively few attempts to provide a generic equation for steam locomotive resistance. Two equations are presented in this section as possible alternatives for use in ORTS, the original Davis equation for steam locomotives and the Sanzin formula as modified by André Chapelon[7]. Both of these give broadly similar estimates, with the more complex Sanzin formula generally giving smaller values of resistance at lower speeds, which may be more appropriate for smaller locomotives. An estimate for the reduction of air resistance of 24% as a result of streamlining is also included, this is based on Johansen’s report[8]. Tender and tank locomotives are treated separately so that values can be entered for into ORTS for when the full supply of coal and water is carried and for when there is none.

High Speed Trains

A review of available data from China, Germany, Japan, Korea, Spain, Sweden and the United Kingdom shows considerable variation in the equations used to describe the resistance of high speed trains. For example data published by Kim *et al*[9], these include the general equation for the KTX TGV given by Alstom as:

$$R = 0.77 \sqrt{(10 M n)} + 0.008 M V + (0.02225 + 0.0035 T) V^2 \text{ (kg force)}$$

Where T is the number of trailer cars. The form of the calculation, not suprisingly follows that used by SNCF. From their results the authors are able to show how resistance can be reduced by

4 AREMA (1999)
5 Szanto (2016)
6 The Railway Executive (1950)
7 Lamalle (1951)
8 Johansen (1936)
9 Kim, Kwon, Kim and Park (2016)

redesigning the shape of the train nose. Much of the air resistance of longer trains is made up of drag caused by the sides, roof, underframe and bogies. Much has been done to reduce the effect of these in the N700 Shinkansen train.

To allow users maximum freedom to try to model either empirical measurements or manufacturers predictions for different high speed trains the spreadsheet allows the adjustment of all four input constants by the user. Suggested values for each are given based on published data.

A Note on Multiple Units, High Speed Trains and Fixed Formation Train Sets.

Although the SNCF equations calculate for either a leading vehicle or a trailing vehicle, it does not matter in Open Rails, where in the train the "leading" unit is positioned as the total resistance of the train will be the sum of resistance of all the vehicles. With that in mind rather than have different ORTSDavis_C figures for the front and rear vehicle of a set, it may be preferable to take the average of the two and use this for both. As an example for a TGV-PSE set the calculator would give:

Leading Power Car: ORTSDavis_C (2.62) / Trailing Power Car: ORTSDavis_C (0.56)

The same result would be given by using a value of ORTSDavis_C (1.59) for both Power cars.

Where possible resistances for all the vehicles in a train should be added together and compared to published data for the full train set.

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Darwin Smith, August 2017.

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