1 Introduction

This article provides additional guidance on Train Physical Data, supplementing section 8.2 of the SES Users' Manual.

2 Acceleration Resistance of Rotating Parts

The Acceleration Resistance of Rotating Parts is a factor which is used to increase the effective mass of the train to allow for the rotational inertia of the wheels, motors, axles, etc. The train effective mass consists of two parts: the empty car mass, which is modified by a factor to account for the acceleration resistance of rotating parts, and the mass of the passengers.

The modified empty car mass is

$$m_{\mathrm{v,mod}} = m_{\mathrm{v}} \left(1 + f_{\mathrm{acc}}\right) \tag{1}$$

where f_{acc} is a coefficient representing the effective mass of rotating parts relative to the car mass. SES is coded in such a way that f_{acc} cannot be set directly. The corresponding user input is the Acceleration Resistance of Rotating Parts, R_{acc}, with units lbf/(ton-mph/sec). The two parameters are related by a unit conversion factor, f_{c},

$$f_{\mathrm{acc}} = \frac{R_{\mathrm{acc}}}{f_{\mathrm{c}}} \tag{2}$$

$$\begin{aligned} f_{\mathrm{c}} &= \frac{2000\,\frac{\mathrm{lb}}{\mathrm{ton}} \times 5280\frac{\mathrm{ft}}{\mathrm{mil}}}{32.174\,\frac{\mathrm{ft}}{\mathrm{s}^2} \times 3600\,\frac{\mathrm{s}}{\mathrm{hr}}} \\ &= 91.2\,\frac{\mathrm{lb}}{\mathrm{ton}}\frac{\mathrm{s\,hr}}{\mathrm{mil}} \end{aligned} \tag{3}$$

If the acceleration resistance of rotating parts is to be estimated as a fraction of the vehicle mass, then it can be converted to the appropriate SES input using equation 2. The default value of 8.8 lbs per ton/(mph/sec) corresponds to 9.6% of the car mass.

The implementation of equation 1 in the SES source code is as follows. The train acceleration is calculated in the `TRAIN` subroutine (line 198),

```
C*****FIND ACCELERATION TRAIN IS CAPABLE OF
      DUDTV(NUMV)=(TEV(NUMV)*MOTORV(ITYP)-RSISTV(NUMV))/(WV(ITYP)*RRACC(
     1ITYP)+WPATV(NUMV)/GRACC)
```

where the modified empty car mass (equation 1) appears as the term `WV(ITYP)*RRACC(ITYP)`. Note that the variable `RRACC(ITYP)` is redefined when initially read by the `GARAGE` subroutine (line 307):

```
       RRACC(I) = ( 91.2 + RRACC(I) ) / ( 91.2 * GRACC )
```

Equation 1 can be recovered from the above source code as follows,

$$
\begin{aligned}
R_{\mathrm{racc}} &= \frac{91.2 + R_{\mathrm{acc,input}}}{91.2g} = \frac{f_{\mathrm{c}} + R_{\mathrm{acc,input}}}{f_{\mathrm{c}}g} \\
m_{\mathrm{v,mod}} &= w_{\mathrm{v}} R_{\mathrm{acc}} = \frac{w_{\mathrm{v}}(f_{\mathrm{c}} + R_{\mathrm{acc,input}})}{f_{\mathrm{c}}g} \\
&= \frac{w_{\mathrm{v}}}{g} + \frac{w_{\mathrm{v}} R_{\mathrm{acc,input}}}{f_{\mathrm{c}}g} \\
&= m_{\mathrm{v}} + \frac{R_{\mathrm{acc,input}}}{f_{\mathrm{c}}} m_{\mathrm{v}} \\
&= m_{\mathrm{v}} \left(1 + f_{\mathrm{acc}}\right)
\end{aligned}
$$

where w_{v} is car weight, g is gravitational acceleration and the subscript 'input' indicates the original R_{acc} defined by the user.

3 Rolling Resistance Coefficients

The Train Rolling Resistance Coefficients are used to compute the mechanical friction created by train movement, and suggested values for rubber-tired and steel wheels are provided on the instructions for Input Form 9E.

The mechanical rolling resistance is calculated in the subroutine `GARAGE.FOR` (line 297) and `TRAIN.FOR` (line 493) as

```
CORMV(I,2) = CORMV(I,2) * NCARV(I)
RM=CORMV(ITYP,2)+(CORMV(ITYP,1)+CORMV(ITYP,3)*UV(NUMV))*WTRN
```

which is equivalent to

$$
R_{\mathrm{m}} = C_1 w_{\mathrm{t}} + C_2 n_{\mathrm{car}} + C_3 w_{\mathrm{t}} u_{\mathrm{v}} \tag{4}
$$

where w_{t} is the train weight (force in tons), n_{car} is the number of cars in a train and u_{v} is the train speed.

The default resistance coefficients for trains with steel wheels appear to be based on the original equation by Davis [1] (also see Szanto [2]), who defined the specific resistance as

$$
r_{\mathrm{Davis}} = \frac{R_{\mathrm{Davis}}}{w_{\mathrm{t}}} = 1.3 + \frac{29}{w_{\mathrm{ax}}} + 0.045 u_{\mathrm{v}} + 0.0005 \frac{A u^2}{n_{\mathrm{ax}} w_{\mathrm{ax}}} \tag{5}
$$

where w_{ax} is the axle load and n_{ax} is the number of axles per car. Note that the axles are assumed to have journal bearings [2]. The default SES coefficients of $C_1 = 1.3$ lbf/ton, $C_2 = 116$ lbf and $C_3 = 0.045$ lbf/ton-mph can be recovered by assuming $n_{\mathrm{ax}} = 4$ and noting that $n_{\mathrm{ax}} w_{\mathrm{ax}} = w_{\mathrm{car}}$ and $w_{\mathrm{t}}/w_{\mathrm{car}} = n_{\mathrm{car}}$.

$$
\begin{aligned}
R_{\mathrm{Davis}} &= 1.3 w_{\mathrm{t}} + \frac{116 w_{\mathrm{t}}}{n_{\mathrm{ax}} w_{\mathrm{ax}}} + 0.045 w_{\mathrm{t}} u_{\mathrm{v}} + 0.0005 \frac{w_{\mathrm{t}} A u^2}{n_{\mathrm{ax}} w_{\mathrm{ax}}} \\
&= 1.3 w_{\mathrm{t}} + 116 n_{\mathrm{car}} + 0.045 w_{\mathrm{t}} u_{\mathrm{v}} + 0.0005 n_{\mathrm{car}} A u^2
\end{aligned} \tag{6}
$$

Note that the final term in the Davis equation accounts for aerodynamic resistance, and is not used in SES.

Szanto [2] provides a useful discussion on the impact of roller bearings versus journal bearings as well as dynamic effects.

References

[1] W.J. Davis jr. The tractive resistance of electric locomotives and cars. *General Electric Review*, 29, 1926.

[2] F. Szanto. Rolling resistance revisited. `https://railknowledgebank.com/Presto/content/Detail.aspx?ctID=MTk4MTRjNDUtNWQ0My00OTBmLTllYWUtZWFjM2U2OTE0ZDY3&rID=NDQwMA==&qrs=RmFsc2U=&ph=VHJ1ZQ==&bckToL=VHJ1ZQ==&rrtc=VHJ1ZQ==`, 2016. Proc. Conf. Railway Excellence, Melbourne, Australia.