SAE International™

# SURFACE VEHICLE RECOMMENDED PRACTICE

SAE J2188

REV. OCT2003

Issued 1996-03
Revised 2003-10

Superseding J2188 MAR96

## Commercial Truck and Bus SAE Recommended Procedure for Vehicle Performance Prediction and Charting

***Foreword***—This Document has not changed other than to put it into the new SAE Technical Standards Board Format.

This procedure is the recommended replacement for SAE J688 Truck Ability Procedure. It includes recommended graphic representations of vehicle steady-state performance, with mathematical equations and recommended constants for various configurations of commercial vehicle components, systems, and vocational environments. It may also be used instead of SAE J688, as a standardized form for summarizing and presenting comparative vehicle steady-state performance in bids and tenders. A proposed worksheet for bids and tenders is included (see Appendix A).

***1. Scope***—This SAE Recommended Practice takes into account modern standardized methods for collecting and summarizing data that has an effect on vehicle steady-state performance, such as engine output (gross and net), transmission losses, drivetrain efficiency, vehicle aerodynamic devices for various vehicle and body configurations, as well as road surface variations and air density variations resulting from altitude and barometric effects. The procedure does not address vehicle transient performance (acceleration, braking, and cornering), because of the considerable amount of additional data required such as moment of inertia of all the rotating parts. Nor does it address vehicles with torque converters and automatic transmissions. This document is, therefore, intended for vehicles having fixed-ratio type transmissions and positive engagement clutches. Metric and ISO unit conversions are provided in the metric conversion tables at the end of this procedure (see Appendix B).

Some modern vehicles with electronic engine controls have the ability to vary the maximum engine revolutions for each gear, as well as permitting the power or rpm to increase if more time is spent in the lower gears, as when climbing a grade. These special cases can be handled by this procedure, just by customizing the data for each transmission ratio and superimposing the long-term data on top of the instantaneous data.

All of the equations are written in a form suitable for programming into a mainframe or desk-top computer, using a spreadsheet/database or a higher level language, such as Basic, Fortran, Pascal, C or Unix, etc. However, they are simple enough, to be performed on a hand-held calculator.

## *2. References*

**2.1 Applicable Publications—**The following publications form part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATIONS——Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J688—Truck Ability Prediction Procedure
SAE J1489—Heavy Truck and Bus Retarder Downhill Performance Mapping Procedure

**2.2 Other Publications**

Tables and Formulas for the Automotive Engineer (reference 6-67 - BCR 10M), Clark Equipment Company

***3. Technical Data***—The following diagrams represent a recommended standard format for illustrating vehicle performance with tables and graphs. They also represent a recommended standardized form for presenting vehicle performance in a general manner. It should be recognized that there are special vehicles, powertrains, and operating conditions that may require a different form of presentation, such as those presented in SAE J1489 Vehicle Downhill Performance Mapping Procedure.

***4. Engine Speed Versus Road Speed***—(See Figure 1.)

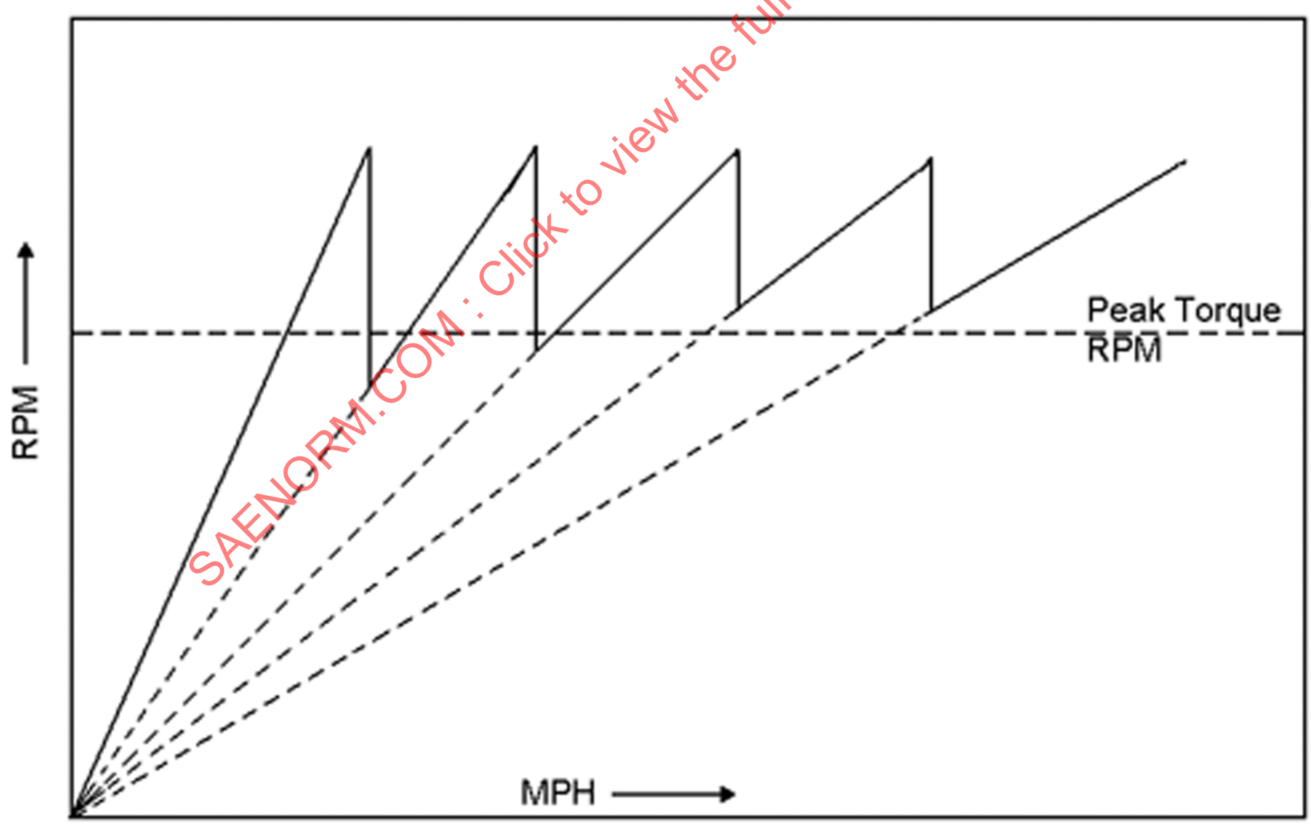


FIGURE 1—ENGINE SPEED VERSUS ROAD SPEED

For vehicles having stepped transmissions with positive engagement friction clutches, the co-ordinate of the point of rated engine speed (or full power governed engine speed) versus the maximum vehicle speed for each gear ratio is defined by Equation 1:

$$V_{GN}(max) = \frac{N_{RA} \times 60}{M \times R_G} \quad \text{(Eq. 1)}$$

The co-ordinates of the interception point or downshift engine speed are defined as follows in Equation 2:

$$V_{(G-1)N}(max) = \frac{N_{RA} \times 60}{MxR_{(G-1)}} \quad \text{(Eq. 2)}$$

$$N_S = N_{RA} \times \frac{R_G}{R_{(G-1)}}$$

## 5. *Percent Gradeability Versus Vehicle Speed*—(See Figure 2 and Equations 3 and 4.)



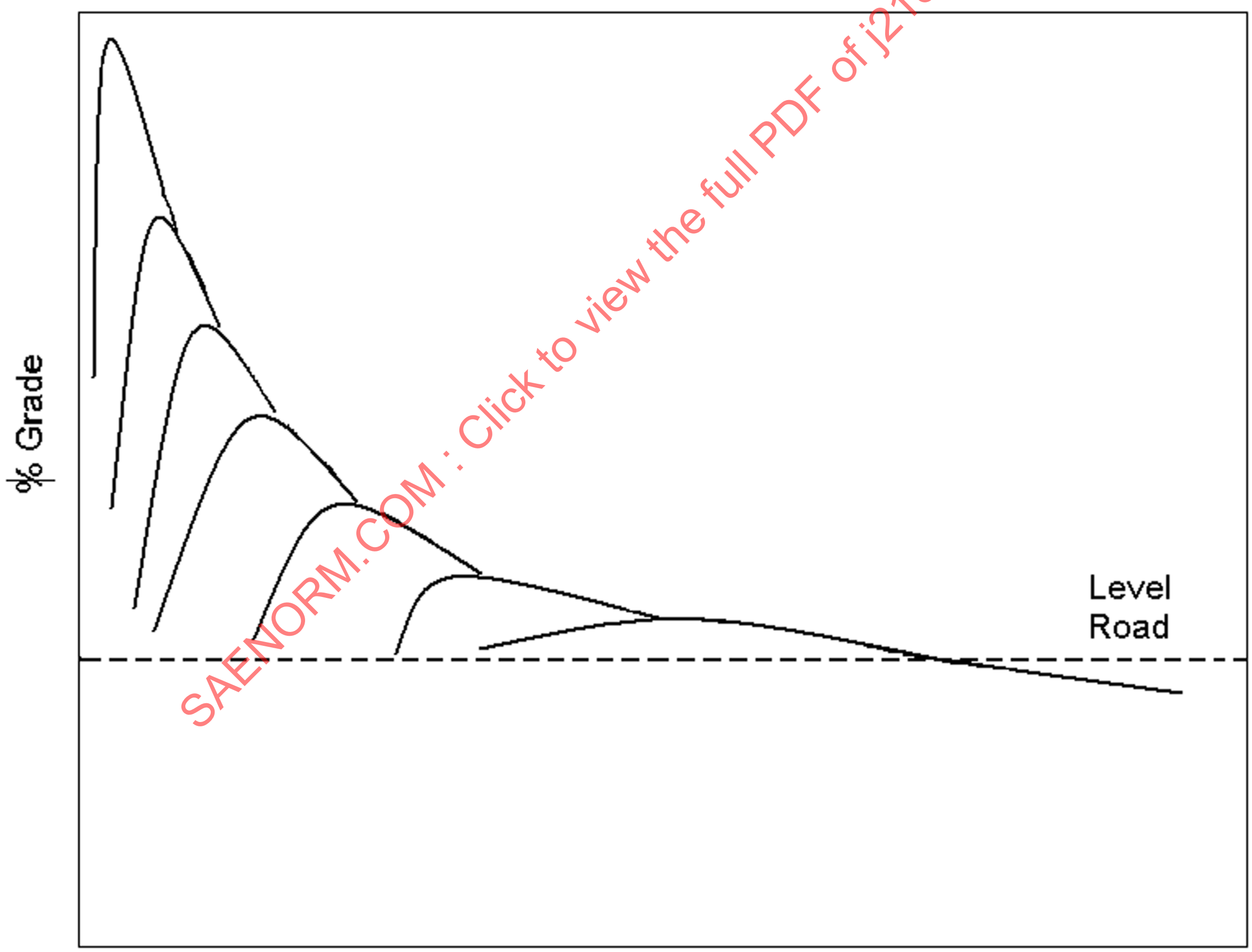


FIGURE 2—PERCENT GRADEABILITY VERSUS VEHICLE SPEED

$$V_{GN} = \frac{N \times 60}{M \times R_G} \qquad \text{(Eq. 3)}$$

$$P_{GN} = 100 \times \tan\left[\left(\mathrm{Sin}^{-1}\left[\left(\frac{375 \times HP_N \times E_G - (WP_R + WP_A)}{W \times V_{GN}}\right)\right]\right)\right] \qquad \text{(Eq. 4)}$$

where:

$$WP_R = \frac{W \times (RC_1 + RC_2 \times V) \times SC \times V}{375 \times 1000}$$

$$WP_A = \frac{C_D \times C_A \times FA \times V^3 \times 0.0024}{375}$$

6. ***Limiting Grade for Wheel Slip***—(See Figure 3.)

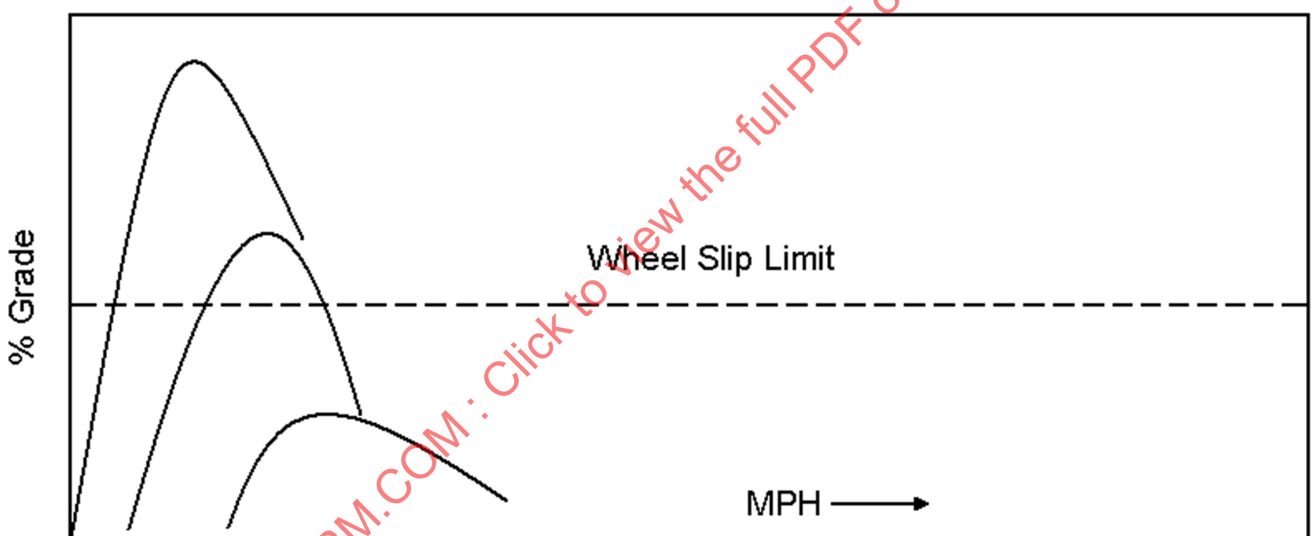


FIGURE 3—LIMITING GRADE FOR WHEEL SLIP

Figure 3 represents the maximum steady-state gradeability that can be achieved for a given vehicle combination and road surface. It can be represented by Equation 5:

$$P_S = \frac{W_{DA} \times C_T \times 100}{W} \qquad \text{(Eq. 5)}$$

7. ***Wheel Power Versus Vehicle Speed***—(See Figure 4.)

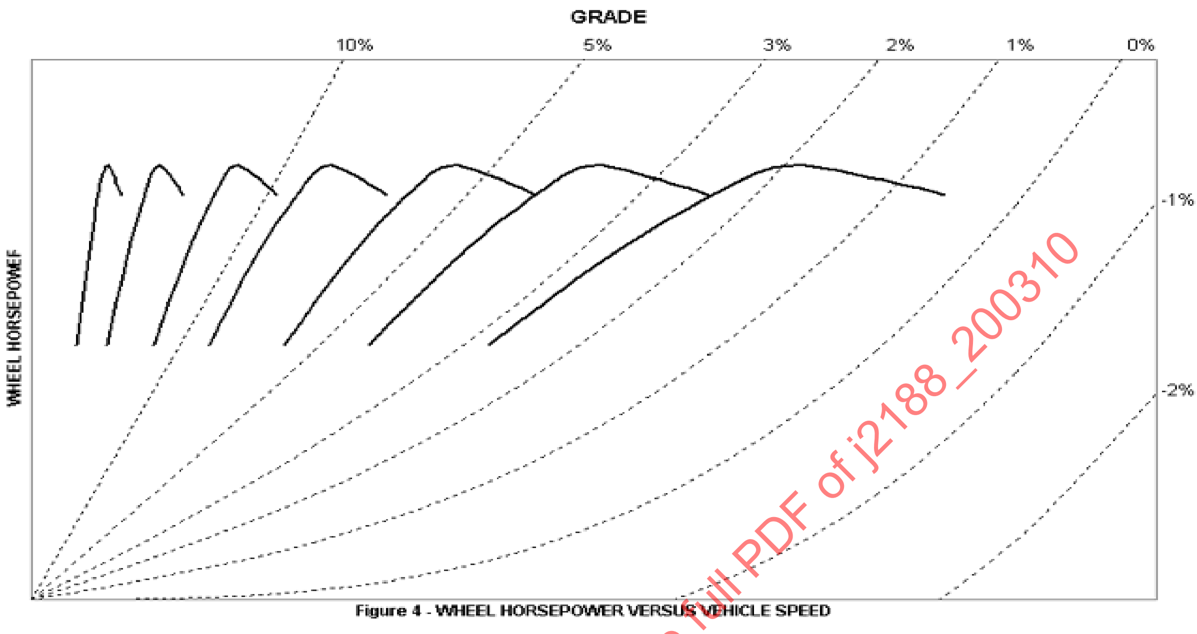


FIGURE 4—WHEEL POWER VERSUS VEHICLE SPEED



Figure 4 represents the wheel power exchange on the vehicle. It can be broken down into two major components, as follows:

a. Wheel Power available from the vehicle drivetrain in various gears and at specified engine speed.
b. Wheel Power required for given speed, tire/road surface interaction, vehicle weight, aerodynamic drag, and grade conditions.

The Wheel Power available is defined in Equation 6:

$$WP_{GN} = \frac{HP_N \times E_G}{100} \quad \text{(Eq. 6)}$$

The vehicle speed component is the same as for the previous chart, as follows in Equation 7:

$$V_{GN} = \frac{N \times 60}{M \times R_G} \quad \text{(Eq. 7)}$$

It is sometimes useful to define the engine rpm point where engine peak torque occurs with a distinctive mark on the power available curves. The same equation can be used, substituting the engine peak torque rpm ($N_{PT}$) for N.

The Wheel Power required can be plotted for both positive and negative grades. The values of the positive grades plotted should increase in approximately logarithmic order. For trucks under 15 HP per ton GCW on the USA highway system, the following percent grade values are of most interest:

**TABLE 1—GRADE VALUE PERCENTAGES**

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Uphill Grades | 0.0 | 0.5 | 1.0 | 2.0 | 3.0 | 5.0 | 8.0 | 15.0 | 25.0 |
| Downhill Grades | -0.5 | -1.0 | -1.5 | -2.0 | -2.5 | -3.0 | | | |

The Wheel Power (WP) required is the sum of the following three functions:

a. Power required to overcome wheel rolling resistance (WPR).
b. Power required to overcome air drag (WPA).
c. Power required to overcome the gradient (WPP).

This can be represented by Equations 8 to 11.

$$WP = WP_R + WP_A + W_P \quad \text{(Eq. 8)}$$

where:

$$WP_R = \frac{W \times (RC_1 + RC_2 \times V) \times SC \times V}{375 \times 1000} \quad \text{(Eq. 9)}$$

$$WP_A = \frac{C_D \times C_A \times FA \times V^3 \times 0.0024}{375} \quad \text{(Eq. 10)}$$

$$WP_P = \frac{W \times V}{375} \times \sin\left[\left(\tan^{-1}\left[\left(\frac{P}{100}\right)\right]\right)\right] \quad \text{(Eq. 11)}$$

The difference between Wheel Power Available and Wheel Power Required for a given grade is the Wheel Power available for acceleration or deceleration of the vehicle on this grade.

## 8. *Tractive Effort Versus Vehicle Speed*—(See Figure 5.)

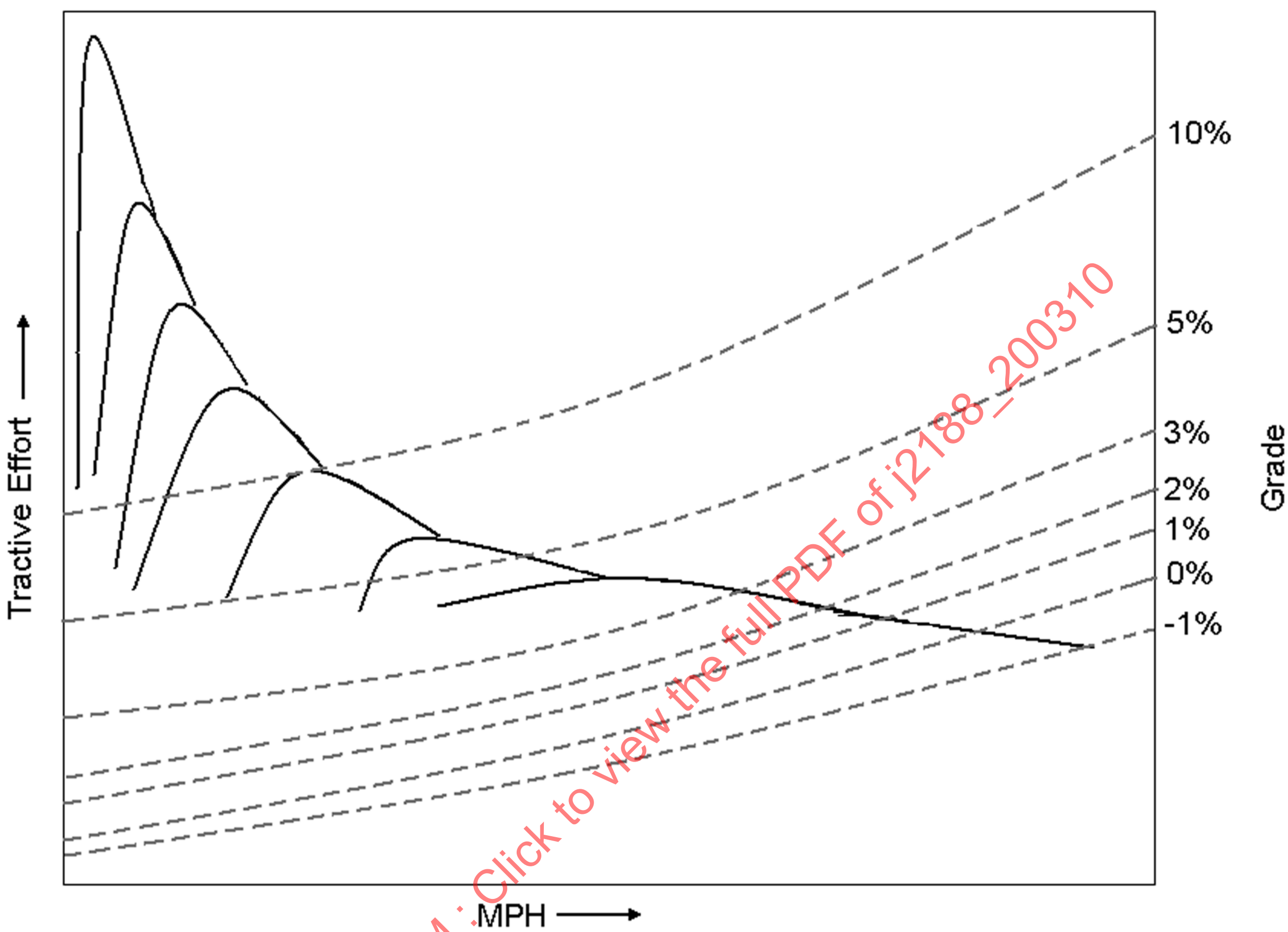




FIGURE 5—TRACTIVE EFFORT VERSUS VEHICLE SPEED

Tractive effort is the "drawbar pull" available after all other parasitic loads have been taken into account. It can be plotted alone for each vehicle gear ratio, or in combination with gradeability lines. As with the Wheel Power chart, the difference between Tractive Effort Available and Tractive Effort Required for a given grade is the Tractive Effort available for acceleration or deceleration of the vehicle on this grade.

The Tractive Effort (lb) Available ($TE_{GN}$) for each gear (G) and engine RPM (N), can be defined by Equations 12 and 13.

$$TE_{GN} = \frac{HP_N \times 5252}{N} \times \frac{E_G}{100} \times R_G \times \frac{2 \times \pi \times M}{5280} \qquad \text{(Eq. 12)}$$

or

$$TE_{GN} = \frac{HP_N \times E_G}{100} \times \frac{375}{V_{GN}} \qquad \text{(Eq. 13)}$$

The vehicle speed component is the same as for previous charts, as follows in Equation 14:

$$V_{GN} = \frac{N \times 60}{M \times R_G} \quad \text{(Eq. 14)}$$

The Tractive Effort Required can be defined by Equation 15:

$$TE = TE_R + TE_A + TE_P \quad \text{(Eq. 15)}$$

where:

$$TE_R = \frac{W \times (RC_1 + RC_2 \times V) \times SC}{1000} \quad \text{(Eq. 16)}$$

$$TE_A = FA \times V^2 \times C_D \times C_A \times 0.0024 \quad \text{(Eq. 17)}$$

$$TE_\rho = W \times \sin\left[\left(\tan^{-1}\left[\left(\frac{P}{100}\right)\right]\right)\right] \quad \text{(Eq. 18)}$$

### 9. *Description of Variables Used and Units*

M = Tire revolutions per mile at 45 mph (see Table 2)

$R_G$ = Total reduction ($R_A$ x $R_I$ x $R_T$)

$R_{(G-1)}$ = Previous Gear total reduction

$R_A$ = The axle ratio

$R_I$ = The intermediate or auxiliary transmission ratio

$R_T$ = The main transmission ratio

$E_G$ = Powertrain efficiency (%), for gear G (see Table 3)

N = Engine speed (RPM)

$N_{RA}$ = Engine speed (RPM) at rated power (or the full power governed engine speed if greater)

$N_{PT}$ = Engine speed (RPM) at peak torque

$N_S$ = Maximum theoretical instantaneous engine speed (RPM) before downshift or after upshift

$HP_N$ = Net Engine power available at “N” RPM

W = Vehicle actual Total Gross Combination Weight (lb)

$W_{DA}$ = Gross actual Load on drive axle(s) (lb)

$C_T$ = Traction coefficient between tire and road (see road surface Table 4)

$RC_1$ & $RC_2$ are rolling constants for the tires (see Table 5)

SC is a constant for the road surface (see Table 4)

P = Gradient (%) (vertical climb/travel distance horizontal projection)

$P_{GN}$ = Vehicle gradeability (%) for gear G at engine speed N

$P_S$ = Limiting gradeability (%) at which wheel slip occurs

$C_D$ = The air drag coefficient, calculated from total vehicle air drag, divided by the full frontal area (height x width) ignoring ground clearance (see examples on Table 6)

$C_A$ = Air Density Correction for altitude (see Table 7)

FA = Frontal Area of vehicle ($ft^2$), based on height x width, ignoring ground clearance (see Table 8)

V = Vehicle speed (mph)

$V_{GN}$ = Vehicle forward speed (mph) for selected gear G at engine speed N

$V_{GN}$(max) = Vehicle forward speed (mph) at rated engine speed (RPM) in gear G

$V_{(G-1)N}$(max) = Same as previous except for the previous gear

TE = Tractive Effort (lb)

$TE_R$ = Tractive Effort to overcome rolling resistance (lb)

$TE_A$ = Tractive Effort to overcome air resistance (lb)

$TE_P$ = Tractive Effort to overcome P% Grade (lb)

$TE_{GN}$ = The Tractive Effort Available (lb) for each gear ratio (G) and engine speed (N)

WP = Wheel Power (HP)

$WP_R$ = Wheel Power to overcome rolling resistance (HP)

$WP_A$ = Wheel Power to overcome air resistance (HP)

$WP_P$ = Wheel Power to overcome P% Grade (HP)

$WP_{GN}$ = Wheel Power Available (HP) for each gear ratio (G) and engine speed (N)

## TABLE 2—TYPICAL VALUES FOR TIRE REVOLUTIONS PER MILE AT 45 mph (M)

| Revs/Mile Rib | Revs/Mile Lug | Tire Type/Size Tube Type | Tire Type/Size Bias Tubless | Tire Type/Size Tube Type | Tire Type/Size Radial Tubeless | Tire Type/Size Tube Type | Tire Type/Size Low Profile Tubleless |
|---|---|---|---|---|---|---|---|
| 651 | 647 | | | | | | 225/70R19.5 |
| 629 | 624 | | | | | | 245/70R19.5 |
| 626 | 626 | | 8-19.5 | | 8R19.5 | | |
| 571 | 564 | | | | | | 255/70R22.5 |
| 561 | 557 | | | | | | 245/70R22.5 |
| 558 | 551 | 7.50-20 | 8-22.5 | 7.50R20 | 8R22.5 | | |
| 558 | 554 | | | | | | 235/80R22.5 |
| 542 | 538 | 8.25-20 | 8-22.5 | 8.25R20 | 9R22.5 | | |
| 541 | 540 | | | | | | 255/80R22.5 |
| 537 | 537 | | | | | | 265/75R22.5 |
| 519 | 513 | 9.00-20 | 10-22.5 | 9.00R20 | 10R22.5 | | |
| 515 | 513 | | | | | | 275/80R22.5 |
| 514 | 512 | | | | | | 275/75R22.5 |
| 503 | — | | | | | 13/80R20 | 13/75R22.5 |
| 503 | 496 | | | | | | 285/75R24.5 |
| 501 | 500 | | | | | | 275/80R24.5 |
| 501 | 497 | 10.00-20 | 11-22.5 | 10.00R20 | 11R22.5 | | |
| 491 | — | | | | | | 315/80R22.5 |
| 491 | — | | | | 15R22.5 | | 385/65R22.5 |
| 485 | — | | 18-19.5 | | | 14/80R20 | |
| 486 | 483 | 11.00-20 | 12-22.5 | 11.00R20 | 12R22.5 | | |
| 480 | — | | 15-22.5 | | | | |
| 478 | 473 | 10.00-22 | 11-24.5 | 10.00R22 | 11R24.5 | | |
| 471 | — | 12.00-20 | | 12.00R20 | 16R22.5 | | 425/65R22.5 |
| 462 | 459 | 11.00-22 | 12-24.5 | 11.00R22 | 12R24.5 | | |
| 464 | — | | 16.5-22.5 | | | | |
| 457 | 451 | | | | | | 445/65R22.5 |
| 448 | — | | 18-22.5 | | | | |
| 442 | 439 | 11.00-24 | | 11.00R24 | | | |
| 426 | 417 | 12.00-24 | | 12.00R24 | | | |
| 421 | 415 | 14.00-20 | | 14.00R20 | | | |

Tire type/size underlined are wide base.

**TABLE 3—TYPICAL VALUES FOR DRIVETRAIN EFFICIENCY ($E_G$)**

| | G - DIRECT (through trans.) | G - INDIRECT (single trans.) | G = DOUBLE INDIRECT (auxiliary trans.) |
|---|---|---|---|
| Single Drive | 0.94 | 0.92 | 0.90 |
| Tandem Drive | 0.93 | 0.91 | 0.89 |

**TABLE 4—TYPICAL VALUES FOR HIGHWAY SURFACE COEFFICIENTS (RC)**

| Road Type | Rolling Resistance lb per 1000 lb GCW | SC | Friction Coeff. $C_T$ |
|---|---|---|---|
| Concrete, excellent | 10 | 1 | 0.8 |
| Concrete, good | 15 | 1.5 | 0.7 |
| Concrete, poor | 20 | 2 | 0.6 |
| Asphalt, good | 12 | 1.2 | 0.6 |
| Asphalt, fair | 17 | 1.7 | 0.5 |
| Asphalt, poor | 22 | 2.2 | 0.4 |
| Macadam, good | 15 | 1.5 | 0.55 |
| Macadam, fair | 22 | 2.2 | 0.45 |
| Macadam, poor | 37 | 3.7 | 0.35 |
| Cobbles, ordinary | 55 | 5.5 | 0.5 |
| Cobbles, poor | 85 | 8.5 | 0.4 |
| Snow, 2 in | 25 | 2.5 | 0.2 |
| Snow, 4 in | 37 | 3.7 | 0.15 |
| Dirt, smooth | 25 | 2.5 | 0.3 |
| Dirt, sandy | 37 | 3.7 | 0.2 |
| Mud | 37 to 150 | 3.7 to 15 | 0.15 |
| Sand, level and soft | 60 to 150 | 6 to 15 | 0.15 |
| Sand, dunes | 160 to 300 | 16 to 30 | 0.1 |

NOTE—Source is from booklet titled: "Tables and Formulas for the Automotive Engineer," published by: Clark Equipment Company (reference 6-67 - BCR 10M).

## TABLE 5—TYPICAL VALUES FOR THE ROLLING RESISTANCE CONSTANTS ($RC_1$ AND $RC_2$)

| | Static $RC_1$ | Additional Increment for Each mph (lb (resistance)/1000 lb GCW) $RC_2$ | Additional Increment for Each mph (lb (resitancy)/1000 lb GCW) Source |
|---|---|---|---|
| Bias Ply Tires | 7.6 | 0.090 | SAE J688 |
| | 6.6 | 0.046 | SAE J1489 |
| Radial Ply Tires | 6.8 | 0.074 | |
| | 4.6 | 0.032 | |
| | 4.1 | 0.041 | SAE J1489 |
| Low Profile Tires | 4.2 | 0.029 | |

## TABLE 6—TYPICAL VALUES FOR VEHICLE WIND AVERAGED AIR DRAG COEFFICIENTS ($C_D$) (Based on full frontal area, ignoring ground clearance)

| Vehicle Type | $C_D$ |
|---|---|
| Vehicle not equipped with aerodynamic aids | 0.78 |
| Vehicle with minimal aerodynamic aids (roof fairing) | 0.64 |
| Vehicle with full aerodynamic treatment | 0.58 |
| Intercity or city/suburban bus | 0.45 |
| School bus or motor home conversion | 0.55 |
| Streamlined motor home | 0.48 |
| Car Hauler - Cattle Hauler | 0.96 - 1.10 |
| Garbage Truck, With Vertical External Ribs on Body | 0.95 - 1.05 |
| Van Body With Open Top or Vertical External Ribs | add 0.12 |