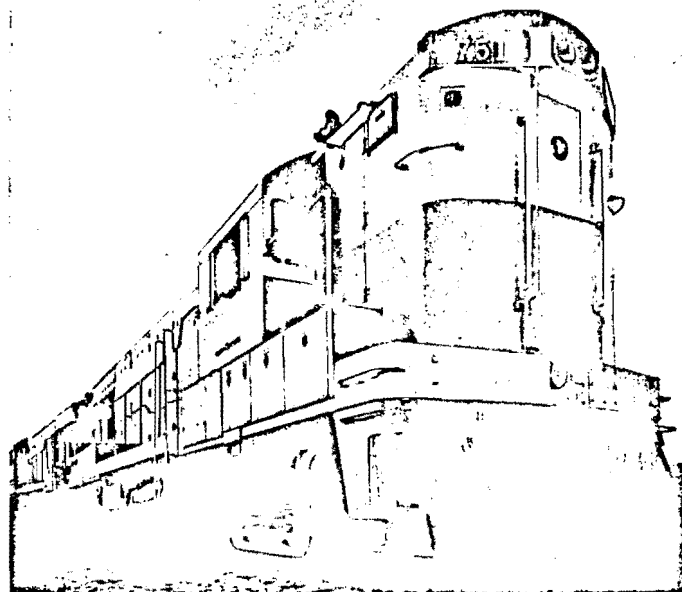# OF
DIESEL-ELECTRIC LOCOMOTIVES

TRANSPORTATION FORMULAE

LOCOMOTIVE AND CAR EQUIPMENT DEPARTMENT

GENERAL ⊕ ELECTRIC

ERIE, PA.

TRANSPORTATION
USEFUL FACTS & FORMULAE

General:

To accelerate a train, forces must be applied to balance those forces which oppose train movement and to provide additional force to accelerate the train. These opposing forces are:

1. Train resistance—friction, air, rail bending.
2. Grade resistance—due to lifting the train weight in ascending a grade.
3. Curve resistance—friction between wheel flanges and rails on curves.

Train Resistance:

A great many formulae have been devised to permit calculation of the resistance values of different types and weights of trains. The most satisfactory of these are the Davis formulae:

		JOURNAL	FLANGE	WIND
LOCOMOTIVE RESISTANCE lbs./ton	=	$1.3+\frac{29}{W}$ +	.03V +	$\frac{.0024AV^2}{WN}$
PASSENGER CAR RESISTANCE lbs./ton	=	$1.3+\frac{29}{W}$ +	.03V +	$\frac{.0034AV^2}{WN}$
FREIGHT CAR RESISTANCE lbs./ton	=	$1.3+\frac{29}{W}$ +	.045V +	$\frac{.0005AV^2}{WN}$

W=Average Tons Per Axle V=Speed in Miles Per Hour
N=Number of Axles   A=Frontal Area in Sq. Ft.
 (A=100 for Box Cars and 120 for Piggy-Back Cars)

Grade Resistance:

The percent grade is the number of feet rise per 100 feet length of track. On a 1 per cent grade a ton (2000 lbs.) must be raised *one* foot for each hundred feet the train advances. The resultant grade resistance will equal

$$\frac{2000 \text{ lbs. x 1 ft.}}{100 \text{ ft.}}=20 \text{ pounds/ton}$$

1

Curve Resistance:

A one degree curve is one in which a hundred feet of track is 1/360 of a complete circle. The radius of a *one* degree curve is 5730 feet or

$$\text{Radius of Curvature in feet}=\frac{5730}{\text{Degree of Curve}}$$

$$\text{Degree of Curve}=\frac{5730}{\text{Radius in Feet}}$$

Curve Resistance=.8 lbs. per ton per degree of Curve

Acceleration:

The force required to accelerate a *ton* of train weight at a rate of *one* mile per hour each second is 100 pounds.

$$F=MA \text{ or } \frac{W}{g} A$$

$$F=\frac{W \times 2000 \times A \times 5280}{32.2 \quad 3600}$$

$$F=91.1 \text{ WA}$$

The rotational acceleration of the wheels, motors, gears, requires approximately 8.9 pounds, which therefore produces a

$$\text{Force}=100 \text{ WA}$$

Thus, if the net tractive force available for accelerating a 2000-ton train were 50,000 pounds, after accounting for all resistances, the acceleration would be

$$\frac{50,000}{2,000}=25 \text{ pounds/ton}=\frac{25}{100}\text{MPH/S}$$

Balancing Speed:

The train speed at which all of the available tractive force is used to overcome the various resistances to train movement, leaving no net tractive force for acceleration, is called balancing speed.

Adhesion:

Is the ratio of a *horizontal* force to a *vertical* force, or in railroad terms is the equivalent to

$$\frac{\text{available tractive force (lbs.)}}{\text{total weight on drivers (lbs.)}}$$

2

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and is expressed in a per cent ratio. Experience has indicated that a starting adhesion of 25—30 per cent can be attained, while running adhesions above 20 per cent are almost impossible to hold unless under extreme good rail conditions.

TRANSPORTATION FORMULAE

$$\text{Rail Horsepower (RHP)}=\frac{\text{Tractive Effort x MPH}}{375}$$

$$\text{Horsepower (Input For Traction)}=\frac{\text{Rail Horsepower}}{\% \text{ Transmission EFF.}}$$

$$\text{Gross Horsepower (Brake)}=\text{Input HP}+\text{HP for Auxiliaries}$$

$$\text{Drawbar Pull (lbs.)}=\text{Trailing tons x Total Train Resistance (lbs/ton)}$$

$$\text{Trailing Tons}=\frac{\text{Tractive Effort Available (lbs)}}{\text{Total Train Resistance (lbs/ton)}}-\text{Loco. Wt.}$$

$$\text{Acceleration (MPH/Sec)}=\frac{\text{Net Tractive Effort (lbs)}}{100 \times \text{Weight of Train (tons)}}$$

$$\text{Time (Seconds)}=\frac{\text{Change Speed (MPH)}}{\text{Acceleration (MPH/Sec.)}}$$

$$\text{Time (Minutes)}=\frac{\text{Distance (Miles)}}{\text{Average Speed (MPH)}}\times 60$$

Distance (Feet)=1.467 x Average MPH x Time (Sec.)

$$\text{Gear Ratio (G.R.)}=\frac{\text{Teeth on Gear}}{\text{Teeth on Pinion}}$$

$$\text{Motor R.P.M.}=\frac{336 \times \text{MPH}}{\text{Wheel Diam. (Inches)}}\times \text{G.R.}$$

Tractive Effort varies directly with Gear Ratio

Tractive Effort varies inversely with Wheel Diameter

Speed (MPH) varies directly with Wheel Diameter

Speed (MPH) varies inversely with Tractive Effort

3

ЕXAMPLE

TRAILING TONS AND RUNNING TIME CALCULATIONS

Freight train ascending a grade: (using a U25B-130 ton loco)

How many 50-ton freight cars (4 axle) can one U25B locomotive haul at 20 miles per hour up a 15-mile 1% grade with a series of 1.5° curves equivalent to a train length?

Grade resistance=20 lbs/ton x 1%	=20.0 lbs/ton
Curve resistance=0.8 lbs/ton x 1.5°	= 1.2 lbs/ton
Train resistance at 20 MPH—50 ton cars	= 4.9 lbs/ton
TOTAL Resistance	26.1 lbs/ton

Tractive effort of one U25B locomotive unit at 20 MPH=38,700 lbs
(from Specification 3030, assuming locomotive has 74/18 gear ratio)

$$\text{Trailing tons} = \frac{\text{Tractive Effort}}{\text{Total Resistance}} - \text{Loco. Wgt.} =$$

$$\frac{38,700}{26.1} - 130 = 1350 \text{ tons or } 27 \text{ cars}$$

2. What is the running time up the grade?

$$\text{Time (in minutes)} = \frac{\text{Distance}}{\text{Avg. Speed}} \times 60 = \frac{15}{20} \times 60 = 45 \text{ min.}$$

DYNAMIC BRAKING CALCULATION

Same freight train descending same grade as above:

Forces retarding train:—Train & Locomotive Friction +Curves

Forces aiding train:—Gravity or % grade

Braking Effort required=Total train resistance x train weight

Total resistance=Algebraic sum of grade, curve and train friction or T.R.= −20+1.2+ 6.8= 12.0

Braking Effort=12.0 (1350+130)=17,800 lbs.

From the dynamic braking curve this would be at a max. speed up to 42.0 MPH.

How many cars could one U25B hold with dynamic brakes on this same 1% grade?

(Maximum braking effort from braking curve= 42,500 lbs at 20 MPH)

42,500=13.8* (train wgt.+130) *(−20+1.2+5.0=13.8 lbs/ton)

Train wgt.=2950 tons or 60 cars (could be held without air brakes at 20 MPH)

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ACCELERATION

1350-ton—27 car train on a 0.75% grade
Balancing speed is 26 MPH

To find *time* and *distance* required to move this train from standstill to 26 MPH would require detailed calculations of 5 MPH increments for accurate results. However, for approximate values for estimating purposes *two* steps could be calculated for quick reference i.e. 0-20 MPH and 20-26 MPH.

From 0 to 20 MPH (Avg. speed during this step is 10 MPH)

Available tractive effort limited by 25% of driver wgt.= 65,000 lbs.

Train resis=15 lbs/ton (grade)+4.5 lbs/ton (friction)+ 10 lbs/ton (starting res.)

(Note—*in starting* only 10 lbs/ton used to overcome friction inertia)

Lbs. of tractive effort required to overcome total train resistance=(15+4.5+10)(130+1350)=43,750 lbs.

Net tractive effort available for accelerating 0-20 MPH
Net T.E.=65,000 lbs.−43,750 lbs.=21,250 lbs.

$$\text{Acceleration} = \frac{21,250}{100 \times 1480} = .144 \text{ MPH/SEC}$$

$$\text{Time to reach 20 MPH} = \frac{20}{.144} = 139 \text{ seconds}$$

From 20 to 26 MPH (Avg. speed=23 MPH)

Available T.E.=34,000 lbs. (from T.E. curve at 23 MPH)
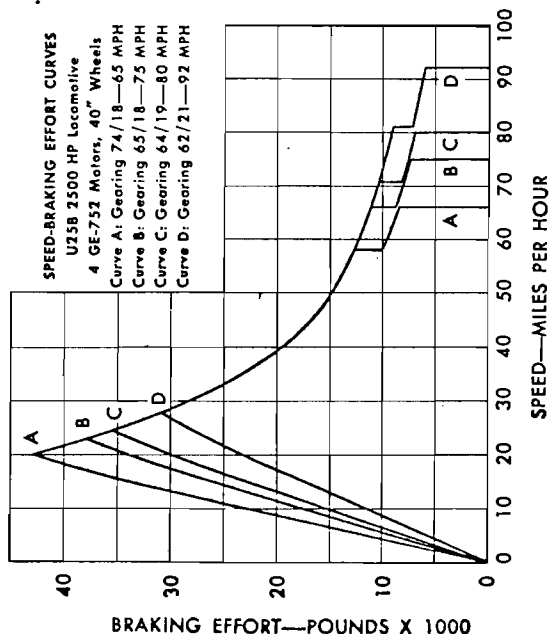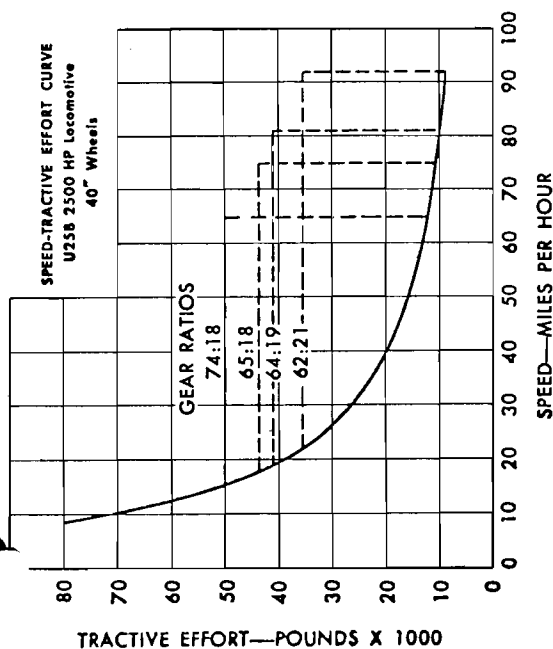Total train resis=30,000=(15+5.3)(130+1350)
Net T.E.=34,000−30,000=4,000 lbs.

$$\text{Acceleration} = \frac{4,000}{100 \times 1480} = .027 \text{ MPH/SEC}$$

Time required to accelerate train from 20 to 26 MPH=
$$\frac{6}{.027} = 222 \text{ seconds}$$

Total time to accelerate from standstill to 26 MPH=139 +222=361 seconds

Distance train moved in this time=1.467 x Avg. speed x time=1.467 x 13 x 361=6900 feet (1.3 miles)
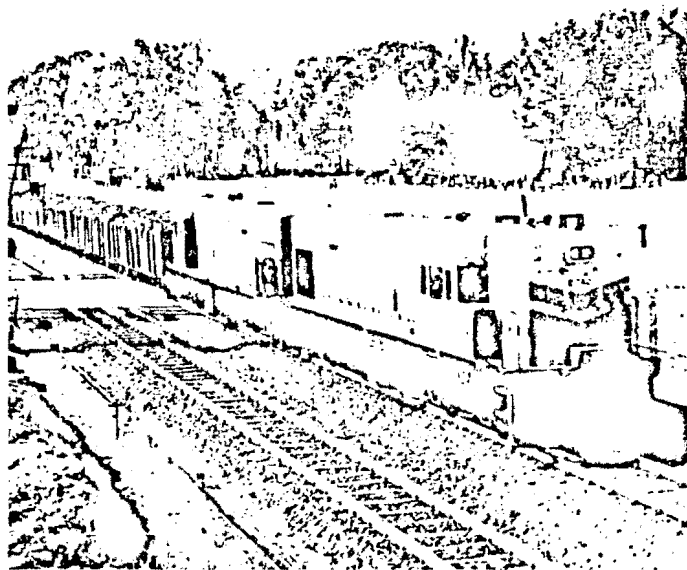
5

SPEED-TRACTIVE EFFORT CURVE
U25B 2500 HP Locomotive
40″ Wheels

GEAR RATIOS
74:18
65:18
64:19
62:21

SPEED—MILES PER HOUR

TRACTIVE EFFORT—POUNDS X 1000

6

SPEED-BRAKING EFFORT CURVES
U25B 2500 HP Locomotive
4 GE-752 Motors, 40″ Wheels
Curve A: Gearing 74/18—65 MPH
Curve B: Gearing 65/18—75 MPH
Curve C: Gearing 64/19—80 MPH
Curve D: Gearing 62/21—92 MPH

SPEED—MILES PER HOUR

BRAKING EFFORT—POUNDS X 1000

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APPLICATION OF DIESEL-ELECTRIC LOCOMOTIVES

TRANSPORTATION FORMULAE

LOCOMOTIVE AND CAR EQUIPMENT DEPARTMENT

GENERAL ⚙ ELECTRIC

ERIE, PA.

TRANSPORTATION FACTS & FORMULAE

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Train Resistance:

A great many formulae have been devised to permit calculation of the resistance values of different types and weights of trains. The most generally used are the Davis formulae:

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LOCOMOTIVE RESISTANCE lb/ton	$= \dfrac{1.3+29}{W}$	$+ .03V$	$+ \dfrac{.0024AV^2}{WN}$
PASSENGER CAR RESISTANCE lb/ton	$= \dfrac{1.3+29}{W}$	$+ .03V$	$+ \dfrac{.00034AV^2}{WN}$
FREIGHT CAR RESISTANCE lb/ton	$= \dfrac{1.3+29}{W}$	$+ .045V$	$+ \dfrac{.0005AV^2}{WN}$

W = Average Tons/Axle   V = Speed in Miles/Hour
N = Number of Axles   A = Frontal Area in Sq. Ft.

1

Grade Resistance:

The percent grade is the number of feet rise per 100 feet length of track. On a 1 per cent grade a ton (2000 lb) must be raised *one* foot for each hundred feet the train advances. The resultant grade resistance will equal

$$\frac{2000 \text{ lb} \times 1 \text{ ft}}{100 \text{ ft}} = 20 \text{ pounds/ton}$$

Curve Resistance:

A one degree curve is one in which a hundred feet of track is 1/360 of a complete circle. The radius of a *one* degree curve is 5730 feet.

$$\text{Degree of Curve} = \frac{5730}{\text{Radius in Feet}}$$

Curve Resistance = .8 lb per ton per degree of Curve

Acceleration:

The force required to overcome the inertia of a body for acceleration is expressed:

$$F = Ma, \text{ or } F = \frac{Wa}{g}$$

If F is force in pounds, W becomes the weight in pounds, g is the acceleration due to gravity (32.2 ft/sec/sec), and a the linear acceleration of the mass in ft/sec/sec. In railroad problems, forces are generally expressed in pounds, weights in tons and acceleration in miles per hour per second. To find the force required to impart a linear acceleration of one mile per hour per second to a weight of one ton,

$$F = \frac{2000 \times 5280}{32.2 \quad 3600} = 91.1 \text{ (lb)}$$

Thus, the force in pounds to impart a linear acceleration of A mphps to a weight of T tons is

$$F = 91.1 \text{ AT (lb)}$$

The rotational acceleration of the wheels, motors and gears requires approximately 8.9 pounds, which therefore produces:

$$F = (91.1 + 8.9) \text{ AT} = 100 \text{ AT (lb)}$$

2

Balancing Speed:

The train speed at which all of the available tractive force is used to overcome the various resistances to train movement, leaving no net tractive force for acceleration, is called balancing speed.

Adhesion:

The ratio of a *horizontal* force to a *vertical* force:

$$\% \text{ Adhesion} = \frac{\text{available tractive force (lb)}}{\text{total weight on drivers (lb)}} \times 100\%$$

Experience has shown that a starting adhesion of 25—30 per cent can be attained, while running adhesions of 18—18.5 per cent are normally possible under average rail conditions.

TRANSPORTATION FORMULAE

$$\text{Rail HP} = \frac{\text{Tractive Effort (lb)} \times \text{mph}}{375}$$

$$\text{Rail CV} = \frac{\text{Tractive Effort (kg)} \times \text{kph}}{270}$$

$$\text{HP (Input to Generator)} = \frac{\text{T.E. (lb)} \times \text{mph}}{375 \times \text{Eff. (\%)}}$$

$$\text{CV (Input to Generator)} = \frac{\text{T.E. (kg)} \times \text{kph}}{270 \times \text{Eff. (\%)}}$$

$$\text{Trailing Tons} ^* = \frac{\text{T.E. (lb)}}{\text{Tot. Resis. (lb/ton}^*)} - \text{Loco. wt (tons}^*)$$

$$\text{Trailing Tons} ^{**} = \frac{\text{T.E. (kg)}}{\text{Tot. Resis. (kg/ton}^{**})} - \text{Loco. wt (tons}^{**})$$

$$\text{Adhesion Factor} = \frac{\text{Required T.E. (lb)}}{\text{Weight on Drivers (lb)}}$$

*Short Ton (2,000 lb)
**Metric Ton (2,204.6 lb)

3

$$\text{Adhesion Factor} = \frac{\text{Required T.E. (kg)}}{\text{Weight on Drivers (kg)}}$$

$$\text{Acceleration (mph/sec)} = \frac{\text{Net Tractive Effort (lb)}}{100 \times \text{wt of Train (tons*)}}$$

$$\text{Acceleration (kph/sec)} = \frac{\text{Net Tractive Effort (kg)}}{31.1 \times \text{wt of Train (tons**)}}$$

$$\text{Time (seconds)} = \frac{\text{Change in Speed (mph)}}{\text{Acceleration (mph/sec)}}$$

$$\text{Time (seconds)} = \frac{\text{Change in Speed (kph)}}{\text{Acceleration (kph/sec)}}$$

$$\text{Time (minutes)} = \frac{\text{Distance (miles)}}{\text{Avg Speed (mph)}} \times 60$$

$$\text{Time (minutes)} = \frac{\text{Distance (km)}}{\text{Avg Speed (kph)}} \times 60$$

Distance (feet) = 1.467 x Avg mph x Time (sec)

Distance (meters) = 0.278 x Avg kph x Time (sec)

Distance (miles) = .000278 x Avg mph x Time (sec)

Distance (km) = .000278 x Avg kph x Time (sec)

$$\text{Gear Ratio (G.R.)} = \frac{\text{Teeth on Gear}}{\text{Teeth on Pinion}}$$

$$\text{Motor rpm} = \frac{336 \times \text{mph}}{\text{Wheel Diameter (in.)}} \times \text{G.R.}$$

$$\text{Motor rpm} = \frac{530 \times \text{kph}}{\text{Wheel Diameter (cm)}} \times \text{G.R.}$$

4

HAULAGE

1. How many 50-ton 4-axle freight cars can a U18C locomotive haul at 15 miles per hour up a 20 mile 1% grade with a 1.5° curve?

$$\text{Trailing Tons} = \frac{\text{Tractive Effort}}{\text{Total Train Resistance}} - \text{Loco. wt}$$

Tractive Effort of U18C at 15 mph = 36,150 lb
(from U18C T.E. Curve on page 7)

Grade resistance = 20 lb/ton x 1%	= 20 lb/ton
Curve resistance = .8 lb/ton x 1.5%	= 1.2 lb/ton
Train resistance at 15 mph—50 ton cars	= 4.6 lb/ton
TOTAL Resistance	25.8 lb/ton

Locomotive Weight = 100 tons

$$\text{Trailing Tons} = \frac{36.150}{25.8} - 100 = 1300 \text{ tons or 26 cars}$$

2. What is the running time up this grade?

$$\text{Running Time on Grade} = \frac{\text{Distance}}{\text{Avg Speed}} \times 60$$
$$= \frac{20}{15} \times 60 = 80 \text{ min}$$

DYNAMIC BRAKING—Going Downhill

Forces retarding train: Friction and curves

Forces aiding or helping train: Gravity or percent of grade

Thus, one U18C could hold the above trailing tonnage of 1300 tons on a 1% down grade at the following speeds:
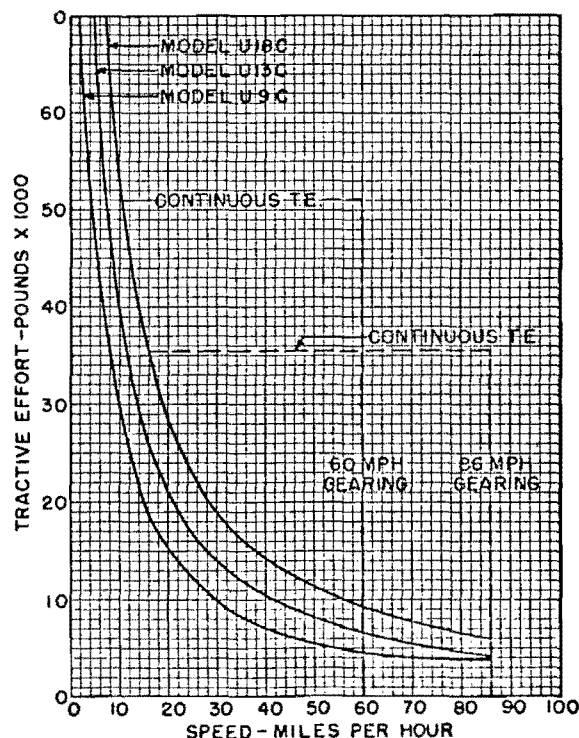
Total Resistance = Algebraic sum of grade, curve and train friction

TR (lb/ton) =
$$-20 \text{ (grade)} + 1.2 \text{ (curve)} + 4.6 \text{ (train)} = 14.2 \text{ lb/ton}$$
Braking T.E. = Total Resistance (train wt + loco. wt)
$$= 14.2 \text{ (1300} + 100) = 19880 \text{ lb}$$

From speed-dynamic braking curve on Page 8, one U18C provides 19880 lb B.E. at 6 mph and 31 mph, and will therefore hold 1300 tons trailing load at these speeds.

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ACCELERATION at starting on 1% grade

$$A \text{ or Acceleration (mphps)} = \frac{F}{100 \times T} = \frac{\text{Net T.E. (lb)}}{100 \times \text{Train Weight (tons)}}$$

Net T.E. = Starting T.E. − Total Resistance

Starting T.E. = 30% adhesion x locomotive wt on drivers
$$= 30\% \times 200,000 \text{ lb} = 60,000 \text{ lb}$$

Total Resistance =
(grade+curve+train in lb/ton) x train wt in tons
$$= [20(\text{grade}) + 1.2(\text{curve}) + 4.6(\text{train})] \times [1300 + 100]$$
$$= 25.8 \times 1400 = 36,100 \text{ lb}$$

Net T.E. = 60,000 − 36,100 = 23,900 lb

$$A = \frac{23,900}{100 \times 1400} = 0.17 \text{ miles/hour/second}$$

EFFECT OF HIGHER SPEED GEARING

Example: U18C—100 tons on drivers

GEARING

	94/17	92/19	90/21
Top Speed (mph)	60	68	77
Starting T. E. (lb)	60,000	60,000	60,000
Continuous T.E. (lb)	51,000	44,700	39,600
18.5% ADH—T.E. (lb)	37,000	37,000	37,000
% utilization of cont. T. E. rating	72.5%	82.8%	93.5%
% increase in top speed	----	13.3%	28.3%
Max. dynamic braking effort (lb)	44,700 @ 13.9 mph	41,000 @ 15.7 mph	35,000 @ 17.8 mph

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U9C, U13C, U18C
SPEED—TRACTIVE EFFORT CURVES

7

U9C, U13C, U18C
SPEED—DYNAMIC BRAKING CURVES

MODELS
U9C, U13C, U18C

50 MPH GEARING

86 MPH GEARING

BRAKING EFFORT – POUNDS X1000

SPEED—MILES PER HOUR

8
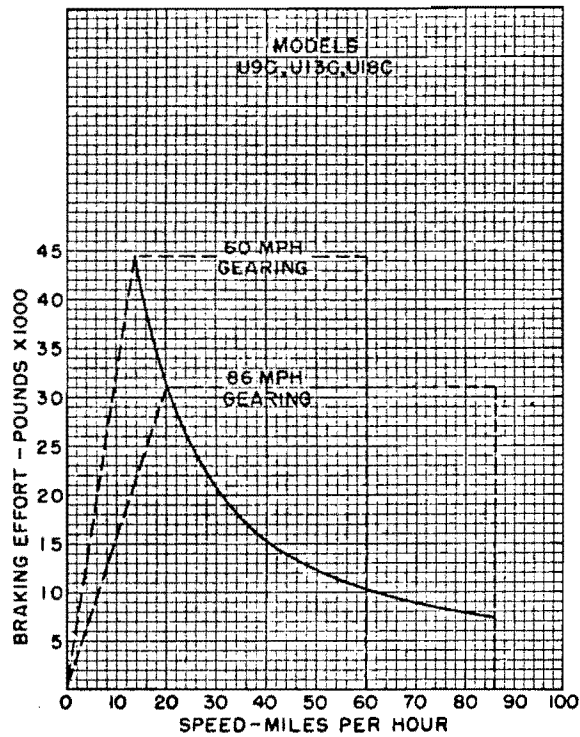
	U6B	U8B	U9B	U9C	U13B	U13C	U18C
Gross hp	700	900	990	990	1420	1420	1980
Cont. hp for Traction	640	810	900	900	1300	1300	1800
Cont. Tractive Effort (lb)	34,000	34,000	34,000	51,000	34,000	51,000	51,000
Min. wt Loaded (tons)	52.8	54.6	73	83.2	77.2	88.2	98.0
Min. wt/axle (tons)	13.2	13.6	18.2	13.9	19.3	14.7	16.3
Length	33'6"	33'6"	46'4½"	46'4½"	46'4½"	46'4½"	52'0"
Height	12'	12'	12'	12'	12'	12'	12'
Width	9'	9'	9'	9'	9'	9'	9'
Min. Radius Curvature	75'	75'	145'	186'	145'	186'	186'
Fuel (gal)	400	400	800	800	800	800	1200
Sand (cu ft)	12	12	18	18	18	18	18
Air Reservoir (cu in)	45,000	45,000	51,800	51,800	51,800	51,800	51,800