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Airline Tow Tractor - Baggage/Cargo Factors for Design Consideration

FOREWORD

Changes in this revision are format/editorial only.

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1. SCOPE:

This document outlines the functional and design requirements for baggage/cargo tow tractors used for airline services.

2. DRAWBAR CALCULATION CLARIFICATION:

The following methods for the determination of Tractive Effort (TE), Drawbar Pull (DBP), Gross Vehicle Weight (GVW), Engine Torque (T), Engine Brake Horsepower (BHP), and Braking Capacity are presented for the purpose of assisting potential buyers and users of airline baggage/cargo tow tractors in the evaluation of their towing requirements and the capabilities of the various vehicles as offered by the equipment manufacturers.

In this analysis, exception is taken to the more prevalent tractor DBP/GVW formulas (generally used by ATA, SAE, equipment manufacturers, etc.) which were developed primarily for application to aircraft tow tractors. These tractors differ from the smaller baggage/cargo tow tractors in that the former utilizes a four-wheel drive traction system and the latter uses only a two-wheel (rear) traction system. In the case of the four-wheel drive system, all of the tractor GVW can be applied for traction purposes (with a consideration for friction and slippage). This is not the case of the two-wheel drive tractor where, for the most part, only the portion of the tractor GVW supported by the rear drive wheels can be utilized for traction. This generalization is modified by weight transfer and hitch height as developed in detail in this document. Other factors are also relevant to towing performance and will be discussed in this analysis.

3. DESIGN FACTORS:

In order to match or size a tractor to a particular application, the following design factors should be considered and evaluated in establishing baggage/cargo tow tractor performance requirements.

3.1 Towed Load Characteristics:

- Number of units being towed.
- Gross weight of each towed unit.
- Towbar and coupler configuration of each unit.
- Turn radius of towed train.
- Breakaway resistance of the train as a percentage of the total gross weight of the train for initial motion directed:

  1. straight ahead
  2. in a turn.

- Rolling resistance of the train as a percentage of the total gross weight of the train for constant velocity on various surfaces on:

  1. a horizontal plane.
  2. a grade.

- Maximum safe speed of the train.
- Maximum desirable acceleration of the train.
- Maximum frontal area of the train (wind resistance).
- Maximum length, width, and height of the train.

3.2 Airport Environment:

- Maximum grades to be negotiated.
- Maximum allowable speeds.
- Road and building clearance (width and height) limitations.
- Anticipated towing distances and routes between various airport areas.
- Maximum approach and breakover angles to be negotiated on ramps, inclined building entrances and exits, and access roads.
- Type and condition of the various driving surfaces encountered.
- Other towing equipment limitations, natural physical, or regulatory unique to the local station.

3.3 Tow Vehicle - General Characteristics and Requirements:

- Vehicle power and power train.
- Vehicle weight and traction.
- Tractive effort and drawbar pull.
- Braking capability.
- Wheel and tire type (s) and size (s)
- Method, type, location, and operation of coupler device.
- Maximum speed (no load and full load)
- Minimum and maximum required acceleration under full load.
- Dimensional limitations.
- Visibility requirements.
- Operator and passenger accommodations (environmental protection).

3.3 (Continued):

- Engine instrumentation requirements.
- Vehicle propulsion and steering controls.
- Operational lighting requirements.
- Steering characteristics.
- Ground control communications requirements.
- Special requirements imposed by airport authorities or other regulatory groups.
- Special requirements imposed by the tractor owner.

4. DESIGN DATA, EXPLANATIONS AND EXAMPLES:

Limiting this report paper in scope, the performance aspects of the tractor will be discussed. It is recommended that the specification or design engineer verify any data that he uses for a specific situation, since the multiple and interrelated factors affecting the towing forces preclude the use of general formulas that account for all variables. The following items should only be considered as general guidance.

4.1 Tow Vehicle - Power Train Requirements:

4.1.1 Engine Power: The tow vehicle engine must be capable of developing enough torque and horsepower to move both the tow vehicle and the towed load under the design considerations of weight, speed, direction, surface conditions and resistance to motion.

4.1.2 Torque (T): This is the ability of an engine to produce work and is measured in lb-feet, (Newton metres) or lb-inches (Newton metres).

4.1.3 Horsepower (BHP): This is the ability of an engine to produce power, which is a measure of work being done within a unit of time. The units of measurement are lb-feet per minute (joules) or lb-feet per second (joules). The value for horsepower may be determined by dividing this by 33,000 lb-foot per minute (44,741J) or 550 lb-feet per second (746J) respectively.

4.1.4 Rim Pull (RP): The is the total force, in pounds (Newtons), which is available at the outer (rolling) radius of the tractor drive tires for the transmission of engine torque to the surface on which the tires rotate. Rim pull (RP) can be expressed as:

$$RP = \frac{T \times R \times e \times C \times 12}{r}$$

Where:

T = Gross engine torque, lb-ft (Newton metres)
C = Correction factor for engine torque to determine net torque available at engine flywheel
R = Overall gear reduction ratio of tractor drivetrain
e = Mechanical efficiency of drivetrain, generally = 0.85
r = Drive tire rolling radius, in. (metres)
12 = A constant converting lb-ft to lb-in.

4.2 Tow Vehicle - Weight and Traction:

4.2.1 Weight: The ability of a tow vehicle with sufficient horsepower to impart motion to a given load without slipping its wheels is dependent upon the weight of the tow vehicle supported by the driving wheels. When the resistance to motion has been defined for the specific design situation, the weight required to allow the tow vehicle to develop the drawbar pull necessary to accomplish the desired motion with a given coefficient of friction can be determined.

4.2.2 Traction: Traction capabilities can be modified to match changing friction coefficients by the addition (or subtraction) of ballast to the tow vehicle. Consideration must be made for additional (less) available horsepower at a later date if the ballast of the tractor is to be increased (decreased) and it is desired to maintain the same performance. Wheel slippage may also be alleviated by the specification of "limited slip" differentials to transfer the available torque to the wheel that is not slipping.

4.3 Tractive Effort (TE):

Assuming adequate rim pull is available, TE is the maximum force in pounds (Newtons) which can be exerted by the tractor at the coupler to produce towing motion without slipping the drive wheels. It is a function of the portion of the tractor weight supported by the rear drive wheels, the tractor wheel base dimension, the effective height, above ground level, of the tow coupler, and the coefficient of traction between the tractor tires and the driving surface and may be expressed as:

$$TE = u\left[\frac{GVW_R \times WB}{WB - u\,(h)}\right] = (X)\,(u)\left[\frac{GVW \times WB}{WB - u\,(h)}\right]$$

Where:

GVW = Gross vehicle weight of tractor - pounds (kilograms)
GVW_R = Portion of tractor gross vehicle weight supported by rear drive wheels, pounds (kilograms)
WB = Tractor wheel base, inches (metres)
h = Coupler installation height above ground, inches (metres)
X = Quotient of $\frac{GVW_R}{GVW}$
u = Coefficient of traction for various road surface conditions and are tabulated as follows:

4.3 (Continued):

Surface Condition	u (ATA)	u (SAE)
Average	0.45	-
Glace Ice	0.10	-
Wet Asphalt	0.40-0.60	0.40
Dry Asphalt	-	0.80
Wet Concrete	-	0.50
Dry Concrete	0.80	0.80
Hard Snow	-	0.20
Oily Concrete	-	0.40

The effective value of "u" can be increased by equipping the tractor drive wheels with chains and/or studded tires. Therefore, for economic reasons, an average traction coefficient of 0.45 may be assumed. The derivation of TE is attached for informational purposes. (See Paragraph 5.).

4.4 Resistance to Motion:

The various resistances of the tractor/load that should be considered are as follows:

4.4.1 Acceleration Resistance (AR): This is the inertial resistance of a mass to a change in velocity either from and standstill or from one velocity to another greater velocity. The factor for this is 0.518 percent of the load weight for each 10 ft/min/sec (3.048 m/min/sec) of acceleration. A value of 0.5 percent of gross weight is generally applied in this case. The derivation of the A value of 0.5 percent of gross weight is generally applied in this case. The derivation of the factor is shown below. Thus, if the desired acceleration is 50 ft/min/sec (15.24 m/min/sec), then

$$AR = 0.5\% \times \frac{50 \text{ ft. } (15.24\text{m})/\text{min./sec.}}{10 \text{ ft. } (3.048\text{m})/\text{min./sec.}} \times \text{Load}$$

$$AR = 2.5\% \text{ of gross weight of the load}$$

(a) Derivation

Using the equation $F = m \times a = \frac{W}{g} \times a$

Where:

F = Force or AR - pounds (Newtons)
m = Mass of load - pounds (kilograms)
W = Weight of load - pounds (kilograms)
g = Gravity constant - = 32.2 ft/sec^2 (9.815 m/sec^2)
a = Acceleration - ft/sec^2 (m/sec^2)

4.4.1 (Continued):

At an acceleration of 10 ft/min/sec (3.048 m/min/sec).

$$a = 10 \text{ ft } (3.048 \text{ m})/\text{min./sec. x min./60 sec.} = 1/6 \text{ ft/sec}^2 \ (.05 \text{ m/sec}^2)$$

$$\therefore \ AR = \frac{W \text{ (lb.) (kg)}}{32.2 \text{ ft. } (9.815 \text{ m})/\text{sec./sec.}} \times 1/6 \text{ ft/sec}^2 \ (.051 \text{ m/sec}^2)$$

$$= .00518 \times W \times 100\%$$

$$\therefore \ AR = .518\% \times W \ @ \ \text{"a"} = 10 \text{ ft/min/sec } (3.048 \text{ m/min/sec})$$

4.4.2 Rolling Resistance (RR): This is a dynamic resistance to motion which is composed of friction and adhesion between the tires and the surface on which they move and the friction developed in the wheel bearings. The force required to overcome this composite resistance can be expressed as a percent of the gross weight to be towed. It is the force, in pound (Newtons), needed to keep the load moving over a level surface at a constant speed. Based on empirical tests, various factors of rolling resistance have been developed and are tabulated[1] as follows:

Surface Type	RR (% Gross Weight) Dry Surface	RR (% Gross Weight) Wet Surface
Hard Asphalt	1.4%	1.8%
Concrete	1.8%	2.2%
Snow and Ice	2.0%	2.5%
Snow (Hard Packed)	2.5%	3.1%
Snow (Soft)	3.3%	4.1%

Under normal conditions, RR is usually approximated at 2 percent of gross towed weight in a straight pull and 2 percent to 4 percent in a turn.

4.4.3 Grade Resistance (GR): This is the resistance to motion of a load moving uphill at constant speed and is a function of the percent of the grade. Percent of grade is the number of feet (metres) of vertical rise for every 100 feet (30.48 m) in the horizontal plane. A factor of 1% of the gross load per 1% of grade is used. Generally, for airports, an average grade of 2% is considered reasonable, although for baggage/cargo tow tractors, local entrance and exit grades for terminal baggage handling areas must be considered for a more meaningful application of this factor. Therefore,

$$GR = 1\% \text{ of the towed load x the \% of grade}$$

1. Source - ATA and SAE

4.4.4 Breakaway Resistance (BR): This is the total frictional and inertial resistance of the towed load which must be overcome in order to produce motion. The greatest value of static resistance to motion occurs at the point at which motion is impending. Once motion is initiated, the static or breakaway resistance reverts to the dynamic values of the inertial (acceleration) and frictional resistances. An average value of static breakaway resistance of 4% of the gross load may be used. Therefore,

$$BR = 4\% \text{ of the towed load}$$

4.4.5 Wind Resistance (WR): This is the resistance to motion that a vehicle experiences which is due to the composite effects of vehicle and wind speed, in this case the headwind component of the wind. The value may be negligible at slow speeds, but may be significant in tractor applications where fast road speeds and high winds may be encountered. The value is expressed as a function of the total headwind velocity and the frontal area of the train. Therefore,

$$WR = .0025\ (MPH)^2 \times FA = .613\ (m/s)^2 \times FA$$

Where:

WR = Wind resistance in pounds force (Newtons)
MPH = (m/s) = Total of vehicle and headwind speeds - miles/hour (metres/second)
FA = Frontal area of the train (width x height) - square feet (square metres)
.0025 (.613) = Constant conversion factor

4.5 Drawbar Pull (DBP):

4.5.1 Drawbar Pull Available (DBPa): This is the net force, in pounds (Newtons) that the tractor is capable of producing at the tow coupler device. It is the tractive effort, (TE), minus the force required to move the tractor on the driving surface. Assuming that the same types of resistance to motion that apply to the towed load also apply to the tractor, then:

DBPa (at breakaway) = TE - [BR + GR] of the tractor on a slope, and,
DBPa (after breakaway) = TE - [AR + RR + GR] of the tractor on a slope.

4.5.2 Drawbar Pull Required (DBP_R): This is the force required to move the load to be towed.

DBP_R (at breakaway) on a slope = [BR + GR + WR] of the towed load.

(If WR is negligible, it may be excluded from the calculation.)

DBP_R (to accelerate the load on a slope) = [AR + RR + GR + WR] of the towed load.

DBR_R (to maintain the load at a constant speed on a slope) = [RR + GR + WR] of the towed load.

To ensure that the tow tractor is sized for the worst condition, it may be assumed that the train is being towed up a grade into a headwind.

4.6 Example Calculations:

It is desired to specify a tractor to move a four (4) igloo trailer train from a standstill up a grade and then on to level ground:

4.6.1 Assumed Design and Performance Parameters:

4.6.1.1 Coefficient of traction (u) = 0.45 average.

4.6.1.2 Maximum towing speed on level surface = 15 miles/hour (6.706 m/s).

4.6.1.3 Maximum towing speed on grade - 8 miles/hour (3.576 m/s).

4.6.1.4 Maximum desired acceleration = 50 feet/minute/second (15.240 m/minute/second).

4.6.1.5 Tow coupler height (h) = 13 inches (.330 m).

4.6.1.6 Rolling resistance (RR) = 2 percent of the load.

4.6.1.7 Breakaway resistance (BR) - 4 percent of the load.

4.6.1.8 Maximum surface grade = 5 percent.

4.6.1.9 Weight of loaded igloo trailer = 12,000 pounds (5,443.2 kg).

4.6.1.10 Tractor wheel base (WB) = 57 inches (1.448 m).

4.6.1.11 Frontal area of load (FA) - 60 square feet (5.574 m^2).

4.6.1.12 Headwind speed = 20 miles/hour (8.941 m/s).

4.6.1.13 Tractor weight at drive wheels (GVW_R) = 0.7 X tractor GVW.

4.6.2 Determine the required drawbar pull (DBP_R) for breakaway on a 5 percent grade.

4.6.2.1 Using U.S. Units:

$$DBP_R = [\text{BR Load} + \text{GR Load} + \text{WR Load}]$$
$$= (4 \text{ trailers} \times 12{,}000 \text{ pounds/trailer}) (.04 + .05) + .0025 (\text{MPH})^2 \times \text{FA}$$
$$= (48{,}000 \text{ pounds}) (.09) + .0025 (20 \text{ MPH})^2 \times 60 \text{ square feet.}$$
$$= 4320 + .0025 (400) (60)$$
$$= 4320 + 60$$

Therefore: DBP_R = 4380 pounds

4.6.2.2 Using SI Units:

$$\begin{aligned} DBP_R &= [\text{BR Load} + \text{GR Load} + \text{WR Load}] \\ &= (4 \text{ trailers x } 5443.2 \text{ kg/trailer})\ (.04 + .05) + .613\ (\text{m/s})^2 \text{ x FA} \\ &= (21{,}772.8 \text{ kg})\ (.09) + .613\ (8.940 \text{ m/s})^2\ (5.574 \text{ sq m}) \\ &= 1{,}959.55 \text{ kg} + .613\ (79.924)\ (5.574) \\ &= (1{,}959.55 \text{ kg})\ (9.81 \text{ N/kg}_f) + 273.08 \text{ N} = 19.496.26 \text{ N} \end{aligned}$$

Therefore: $DBP_R = 19{,}496$ N

4.6.3 Determine the tractive effort (TE) of the tractor at breakaway on a grade.

TE - [BR + GR] tractor = DBPa (neglecting WR)
TE = DBPa + [BR + GR] tractor
Equating DBPa to DBP_R

Then: TE = 4380 lb (19,496 N) + (.04 + .05) x GVW tractor

Since 0.7 GVW tractor = GVW_R, then GVW tractor = $\frac{GVW_R}{0.7}$

$$TE = 4380 \text{ lb } (19{,}496 \text{ N}) + \frac{.09}{.7}\ (GVW_R) = 4380 \text{ lb } (19{,}496 \text{ N}) + .129\ GVW_R$$

Also,

$$TE = u \left[\frac{GVW_R \times WB}{WB - u(h)} \right]$$

4.6.3.1 Then in U.S. Units:

$$4380 + .129\ GVW_R = 0.45 \left[\frac{GVW_R \text{ X } 57''}{57 - 0.45(13'')} \right]$$

$$\begin{aligned} 4380 + .129\ GVW_R &= \frac{0.45 \text{ x } (57'')}{57 - 0.45\ (13'')} \text{ x } [GVW_R] \\ &= \frac{0.45\ (57'')}{51.15''} \text{ x } [GVW_R] \\ &= .502\ GVW_R \end{aligned}$$

$$\therefore 4380 = (.502 - .129)\ GVW_R = .373\ GVW_R$$

and $\underline{GVW_R} = \frac{4380}{.373} = \underline{11{,}743 \text{ pounds}}$

4.6.3.1 (Continued):

and $\underline{\text{GVW tractor}} = \frac{11,743}{.7} = \underline{16,775 \text{ pounds}}$

Solving for TE,

$TE = 4380 + .129\ GVW_R$

$= 4380 + .129\ (11,743) - 4380 + 1515$

$TE = 5895$ pounds

4.6.3.2 and in SI units:

$$19,496N + .129\ (9.81\ GVW_R) = \frac{0.45 \times 1.448\ m}{1.448 - 0.45\ (.330\ m)} \times (9.81\ GVW_R)$$

$$= \frac{.652\ m}{1.299\ m} \times (9.81\ GVW_R)$$

$$= .502\ (9.81\ GVW_R)$$

$$\therefore 19,496 = (.502 - .129)(9.81\ GVW_R)$$

and $\underline{GVW_R} = \frac{19,496}{9.81 \times .373} = \underline{5328 \text{ kg}}$

and $\underline{\text{GVW tractor}} = \frac{5328}{.7} = \underline{7611 \text{ kg}}$

Solving for TE:

$TE = 19,496 + .129\ (9.81\ GVW_R)$

$= 19,496 + .129\ (52,268)$

$\underline{TE} \ \underline{= 26,239N}$

4.6.4 Determine the drawbar pull required to accelerate the tractor and load from zero (after breakaway motion begun) to a speed of 8 miles per hour (3.576 m/s) on a 5 percent grade.

$DBP_R = AR_{Load} + GR_{Load} + RR_{Load} + WR_{Load}$

Similarly, for the tractor:

$TE = AR_{Tractor} + GR_{Tractor} + RR_{Tractor} = DBP_a$ tractor
(neglecting $WR_{Tractor}$)

Equating, $DBP_{a\ (Tractor)} = DBP_{R\ (Load)}$

4.6.4 (Continued):

$$TE = [AR_{Tractor} + GR_{Tractor} + RR_{Tractor}] = DBP_a \text{ tractor}$$
(neglecting $WR_{Tractor}$)

Equating, $DBP_{a\ (Tractor)} = DBP_{R\ (Load)}$

$$TE = [AR_{Tractor} + GR_{Tractor} + RR_{Tractor}] = AR_{Load} + GR_{Load} + RR_{Load} + WR_{Load}$$

4.6.4.1 Therefore substituting in U.S. Units:

$$.7\ (u)\left[\frac{GVW \times WB}{WB - u\ (h)}\right] - [.025\ GVW_{Tractor} + .05\ GVW_{Tractor} + .02\ GVW_{Tractor}]$$

$$= [.025\ (48{,}000) + .05\ (48{,}000) + .02\ (48{,}000) + .0025\left(20 + \frac{8}{2}\right)^2 (60)]$$

$$\left[\frac{.7\ (.45)\ (57'')}{57'' - .45(13'')}\right] GVW - [.095\ GVW] = [.095\ (48{,}000) + .0025\ (576)\ 60]$$

$$\left[\frac{17.96}{51.15} - .095\right] GVW = [4560 + 86.4]$$

$$[.351 - .095]\ \ GVW = 4646.4$$

$$GVW = \frac{4646.4}{.256} =$$

$\underline{GVW}$ $\underline{= 18{,}150 \text{ lb}}$

$\underline{DBP_R}$ = $\underline{4560 + 86.4 = 4646.4 \text{ lb}}$

$\underline{GVW_R}$ = .$\underline{7\ (18{,}150) - 12{,}705 \text{ lb}}$

$\underline{TE}$ = .351 (GVW) - .351 (18,150) = $\underline{6371 \text{ lb}}$

4.6.4.2 and in SI Units:

$$\left[\frac{.7\ (.45)\ (1.448\ m)}{1.448\ m - .45\ (.330\ m)}\right] GVW - [\ .095GVW\ ] = \left[.095\ (21{,}772.8\ kg) + \frac{.613\ (8.940 + \frac{3.576}{2})^2\ (5.574)}{9.81}\right],$$

$$\left[\frac{.45612}{1.299}\right] GVW - [.095\ GVW] = \left[2068.4 + \frac{.613\ (115.1)\ (5.574)}{9.81}\right]$$

$$.351\ GVW - .095\ GVW = 2068.4 + \frac{393.2}{9.81}$$

$$.256\ GVW - 2108.4$$

$$GVW = \frac{2108.4}{.256} = 8234\ kg$$

$\underline{DBP_R}$ = [(2068.4 x 9.81) + 393.2] = $\underline{20{,}684N}$

$\underline{GVW_R}$ = .$\underline{7\ (8234) - 5763.8\ kg.}$

$\underline{TE}$ = .351 (GVW) - .351 (8234) = 2890 kg = $\underline{28{,}352N}$

4.6.5 Determine the tractor TE and GVW required to maintain a four igloo trailer train at a constant speed of 15 miles per hour in a headwind on level ground.

4.6.5.1 In U.S. Units:

DBP_R = [RR + WR] = [.02 (48,000) + .0025 $(15 + 20)^2$ (60)]

= [960 + 184]

$\underline{\therefore\ DBP_R = 1144\ pounds}$

For the tractor:

TE - RR = DBPa

Equating DBPa to DBP_R

4.6.5.1 (Continued):

$TE - RR = 1144$ pounds

$.351\ GVW_{Tractor} - .02\ GVW_{Tractor} = 1144$ lbs (since $TE = .351\ GVW_{Tractor}$)

then, $GVW = \frac{1144}{.331}$

$\underline{GVW = 3456 \text{ pounds}}$

$TE = .351\ (3456)$

$\therefore\ \underline{TE = 1213 \text{ pounds}}$

4.6.5.2 In SI Units:

$DBP_R = [RR + WR] = .02\ (21{,}772.8\ kg) + .613\ (6.706\ m/s + 8.940)^2\ (5.574)$

$= 435.46 + 85.26$

$\therefore\ \underline{DBP_R = 520.7\ kg = 5108N}$

For the tractor

$TE - RR = DBPa$

Equating DBPa to DBP_R

$TE - RR = 520.7$ kg

$.351$ GVW tractor $- .02$ GVW tractor $= 520.7$ kg

then, $GVW = \frac{520.7}{.331}$

$\underline{GVW = 1573\ kg}$

$TE = .351\ (1573)$

$\therefore\ \underline{TE = 552\ kg = 5420N}$

4.6.6 Engine Torque Required to Slip the Tractor Drive Wheels: Since the tractor maximum TE was previously determined to be 6371 pounds, (28,352N), we can assume TE = 6370 pounds (28,350N) and from it determine the minimum engine torque required to slip the drive wheels.

$$T = \frac{TE \times r}{R \times e}$$

In U.S. Units:

$$T = \frac{6370 \times 14.0}{34.42 \times 0.85}$$

T = 3048 inch-pounds

In SI Units:

$$T = \frac{28,350 \times .356 \text{ m}}{34.42 \times 0.85}$$

T = 345 N·m

Where:

T = Net engine torque, pound-inches (N·m)
TE = Tractive effort, 6370 pounds (28,350N)
r = Rolling radius of drive tire, assume 14.0 inches (.356 m)
R = Total power train reduction ratio
Transmission (1st gear) = 2.4
Converter (at stall) = 2.0
Rear axle = 7.17
Total Ration = 2.4 x 2.0 x 7.17 = 34.42
e = Mechanical efficiency of drive train - assume 0.85

4.6.7 Engine Horsepower Requirement (Net): Since the tractor transmission is equipped with a torque converter, it will allow the engine to develop sufficient torque to overcome the breakaway requirements of the loaded train, that is, if the tractor is adequately powered. Since the torque (net) requirement has been previously calculated, it can now be used to determine the required net horsepower of the engine. Most diesel engines develop their maximum net torque in the 1600 RPM range, while most gasoline-powered engines develop this torque in the 2000 - 3000 RPM range. For the sake of this calculation, a gasoline engine will be assumed with a net torque rating being developed at 2500 RPM. Apply the following formula:

$$BHP_{net} = \frac{T \times RPM}{5250}$$

4.6.7 (Continued):

Where T = Net Engine Torque required - pounds-feet

RPM = Engine Speed at Net Torque - revolutions per minute

5250 = Conversion Constant

Since Torque has been calculated in pounds-inches,

$$T = 3048 \text{ lb-in} \times \frac{\text{ft}}{12 \text{ inches}} = \underline{254 \text{ pounds-feet}}$$

Substituting,

$$BHP_{net} = \frac{254 \times 2500}{5250}$$

$\underline{BHP_{net} = 121 \text{ HP @ } 2500 \text{ RPM}}$

Various engine horsepower/torque/RPM curves can then be consulted to determine the required engine size. Generally internal combustion engines have maximum net torque ratings at one RPM and maximum net BHP ratings at some higher RPM. The RPM at which maximum BHP can be developed is generally 1.5 to 2.0 times the RPM at which maximum net engine torque is developed. Therefore while the engine selected may have a maximum net torque rating at 2500 RPM, and develop 121 BHP at this speed, it may not develop its maximum rated BHP (possibly 200 BHP) until engine speed reaches approximately 4000 RPM.

Therefore, the minimum required design parameters for a tow tractor under the aforementioned operating conditions of breadaway at full load on a grade are as follows:

Tractor GVW = 18,150 pounds (8234 kg)
GVW_R = 12,705 pounds (5764 kg)
TE = 6,371 pounds (28,352N)

Engine - Minimum Net Torque = 2823 pounds-inches

= 254 pounds-feet (345 N·m)

- Minimum Net BHP at Minimum Torque RPM = 121 HP.

4.7 Braking:

The braking capability of a tow tractor should be designed for the safe, controlled, deceleration to a full stop of the entire train (tractor and towed load). From the point of view of actual brake performance, Federal and SAE Standards and various airport regulations offer some criteria for performance. The parameters involve test speed, minimum deceleration rate and/or maximum stopping distance.

The following arbitrary parameters will be utilized to calculate the average deceleration rate for a tractor and its towed load.

- initial speed = 15 mph (6.70 m/s)
- required maximum stopping distance = 50 feet (15.240 m)
- reaction time = 3/4 second (from first application of the brakes to the point where braking is effective).

Converting MPH to ft/sec:

$$\frac{\text{miles}}{\text{hr.}} \times \frac{\text{hr.}}{3600\text{ sec}} \times \frac{5280\text{ ft}}{\text{mile}} = 1.466\text{ ft/sec (.447 m/s)}$$

Therefore: $$\frac{15\text{ miles}}{\text{hr}} \times \frac{1.466\text{ ft/sec}}{\text{mph}} = 21.99\text{ ft/sec (6.70 m/s)}$$

For the calculation 22 ft/sec (6.70 m/s) will be used.

Applying the equation:

$$\frac{V^2}{2d} + Vt - S = 0$$

Where:

V = initial speed, ft/sec. (m/s)
d = deceleration rate, ft/sec.^{2} (m/s^2)
t = reaction time, sec.
s = stopping distance, ft (m)