# UNDERSTANDING TRACTOR-TRAILER PERFORMANCE

CATERPILLAR®

*This document is written for educational purposes only. The tractor-trailer, power train, accessories, performance and fuel economy depicted are for illustration only and do not reflect the actual performance of any particular tractor-trailer.*

Understanding vehicle performance and fuel economy requires a basic knowledge of the many variables that affect the operation of a Class 8 tractor-trailer. Some of the most significant factors affecting fuel economy and performance are:

- Driver (Operator)
- Route selection
- Vehicle speed
- Frontal area and Aerodynamic properties
- Grade (Hill)
- Engine Cooling requirements (Fan Horsepower Demand)
- Climate (Ambient Conditions)
- Fuel API Gravity
- GCW (Gross Combination Weight)
- Idle time
- Auxiliary Power Unit (APU)
- Tires
- Gearing (Spec'ing)
- Transmission
- Other Factors
- Customer Factors
- Compression Brake (C11, C13, and C15 Engines with ACERT Technology)

## DRIVER (OPERATOR)

The most significant variable affecting fuel economy is the driver. The driver controls the vehicle speed, acceleration rate, brake usage (service, compression, or exhaust), cruise control usage, shifting technique, trailer gap setting, idle time, tire inflation pressure, and more. It is not uncommon for fleets with identically spec'ed trucks to experience as much as 25% (5.0 vs. 6.7 MPG) difference in fuel consumption between the best and the worst drivers.

## ROUTE SELECTION

Driving in congested areas increases fuel consumption. Traveling 15% of the total miles on congested roads results in approximately an 8% increase in fuel consumption. Traveling 25% of the total miles on congested roads results in approximately a 15% increase in fuel consumption.

Fuel economy can improve while driving on 2-lane highways providing that the trip distance is shorter and that the driver has the discipline to drive at a slower speed to maintain a steady speed. Slower speed and steady speed will reduce fuel consumption due to the lower horsepower demand on the engine.

**Anticipate stops.** A heavy vehicle like a tractor-trailer can coast a long distance without throttle application. A diesel engine, mechanically or electronically controlled, does not consume fuel when coasting since fuel is not injected into the cylinders. Minimize vehicle speed fluctuation. Use the cruise control, when safe to do so, to maintain a steady vehicle speed.

In the following discussion, four (4) different vehicles mentioned in *Figure 1* are compared.

**Figure 1. Vehicle Description Type**

| Vehicle GCW (lb) | Type | Engine | HP / Torque (lb-ft) | Frontal Area (ft$^2$) | Coefficient of Drag (Cd) |
|---|---|---|---|---|---|
| | | | | | |
| Automobile 4,250 | | Gas | 250 / 250 | 30 | 0.32 |
| | | | | | |
| Tractor-Trailer 80,000 | Van | C15 | 550 / 1850 | 108 (8.5' × 13.5') | 0.60 |
| | Flat-bed | | | 87 (8.5' × 11.0') | 0.80 |
| | | | | | |
| Tractor-Trailer 140,000 | Lowboy | C15 | 550 / 1850 | 108 (8.5' × 13.5') | 1.00 |

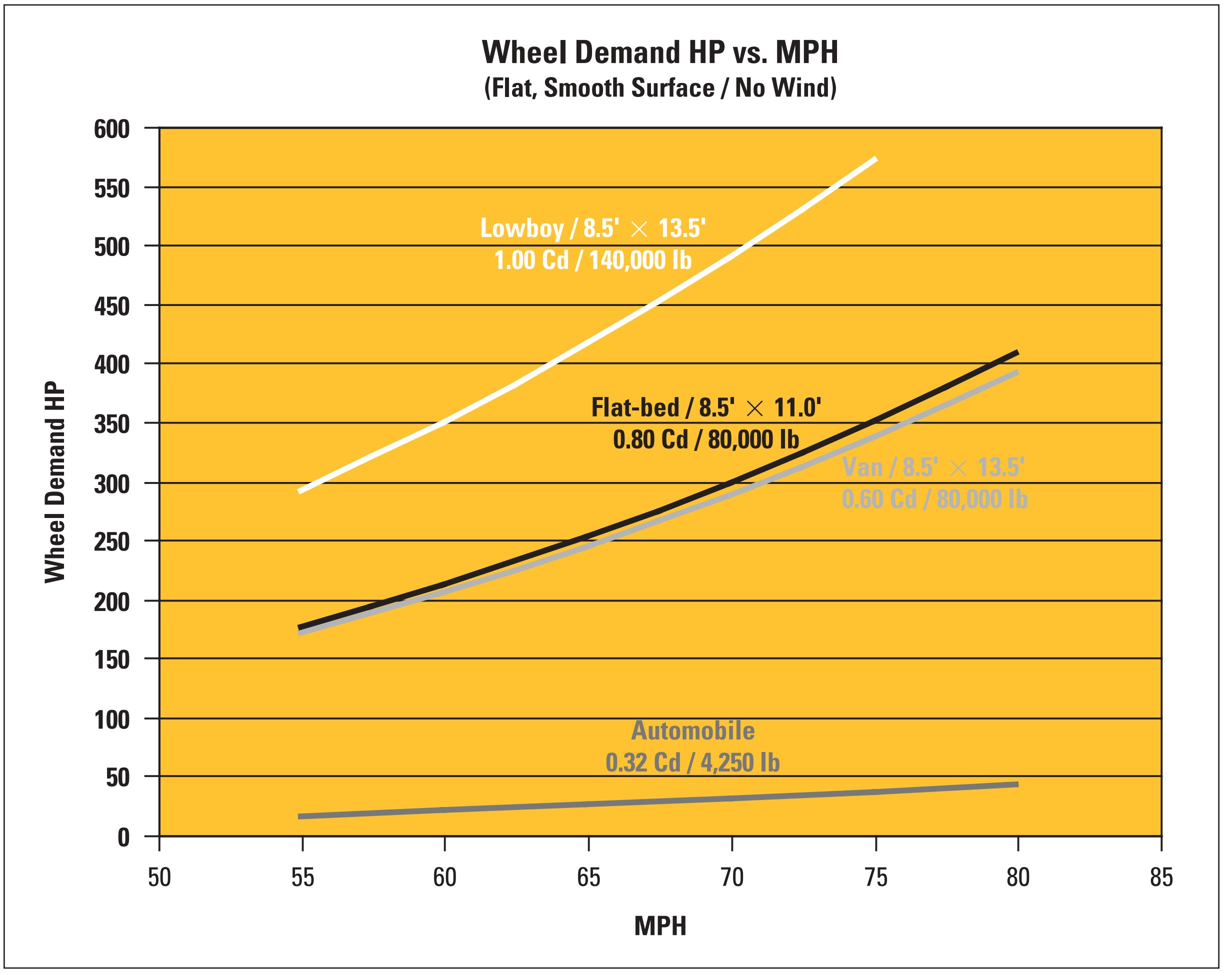
## VEHICLE SPEED

Vehicle speed is a very important factor affecting fuel economy. A general rule of thumb to remember is that fuel economy will change approximately 0.1 MPG for every 1 MPH above 55 MPH. Decreasing the vehicle speed from 70 MPH to 65 MPH can improve fuel mileage by approximately 0.5 mile per gallon.

Increasing vehicle speed places a higher horsepower demand on the engine. When horsepower demand increases, fuel consumption increases.

*Figure 2* shows Wheel Demand Horsepower vs. Speed, on a flat, smooth surface and on a calm day (no wind) for an automobile and three tractor-trailers described in *Figure 1*.

**Figure 2. Wheel Demand HP vs. MPH – Flat, Smooth Surface, No Wind**




## FRONTAL AREA AND AERODYNAMIC PROPERTIES

The tractor-trailer aerodynamic package is a very large contributor to a vehicle fuel economy performance. The industry trend is toward more aerodynamic tractors while the widely used Van / Refer trailers are undergoing aerodynamic scrutiny.

*Figure 3* provides a breakdown of Aerodynamic Resistance horsepower and Rolling Resistance horsepower. Combined, they represent the Wheel Demand horsepower needed to move a vehicle at a given speed, on a flat, smooth surface on a calm day (no wind). Data is given for the automobile and the three tractor-trailers described in *Figure 1*.

**Figure 3. Wheel Demand HP vs. MPH – Flat, Smooth Surface, No Wind**

| MPH | Vehicle Description GVW (lb) | Aerodynamic / Air Resistance HP | Rolling Resistance HP | Total Wheel Demand HP |
|---|---|---|---|---|
| | | | | |
| **55** | Automobile – 4,250 | 11 | 5 | 16 |
| | Van – 80,000 | 74 | 96 | 170 |
| | Flat-bed – 80,000 | 80 | 96 | 176 |
| | Lowboy – 140,000 | 124 | 167 | 291 |
| | | | | |
| **60** | Automobile – 4,250 | 14 | 5.7 | 20 |
| | Van – 80,000 | 96 | 108 | 204 |
| | Flat-bed – 80,000 | 103 | 108 | 211 |
| | Lowboy – 140,000 | 160 | 188 | 348 |
| | | | | |
| **65** | Automobile – 4,250 | 18 | 6.4 | 25 |
| | Van – 80,000 | 122 | 121 | 243 |
| | Flat-bed – 80,000 | 131 | 121 | 252 |
| | Lowboy – 140,000 | 204 | 211 | 415 |
| | | | | |
| **70** | Automobile – 4,250 | 23 | 7 | 30 |
| | Van – 80,000 | 153 | 134 | 287 |
| | Flat-bed – 80,000 | 164 | 134 | 298 |
| | Lowboy – 140,000 | 254 | 234 | 488 |
| | | | | |
| **75** | Automobile – 4,250 | 28 | 7.9 | 36 |
| | Van – 80,000 | 188 | 148 | 336 |
| | Flat-bed – 80,000 | 202 | 148 | 350 |
| | Lowboy – 140,000 | 313 | 259 | 572 |
| | | | | |
| **80** | Automobile – 4,250 | 34 | 9 | 43 |
| | Van – 80,000 | 228 | 163 | 391 |
| | Flat-bed – 80,000 | 245 | 163 | 408 |
| | Lowboy – 140,000 | 379 | 284 | 663 |

The 80,000-pound tractor-trailer Rolling Resistance demand horsepower is approximately nineteen (19) times greater than that of the automobile.

The tractor-trailer has a frontal area that is approximately three and one-half (3.5) times larger than an automobile. The larger frontal area combined with a greater Coefficient of drag (0.60 Cd) creates an aerodynamic drag that is approximately seven (7) times greater than that of an automobile, and places a much higher horsepower demand on the engine to overcome air resistance.

A Coefficient of drag (Cd) with a range of 0.55 to 0.60, that is the aerodynamic properties of some of the most aerodynamic tractor-trailers, is considerably higher than that of the modern automobile with a 0.25 to 0.35 Coefficient of drag.

Above 55 MPH, the Aerodynamic Resistance horsepower of a typical tractor-trailer becomes more significant than the Rolling Resistance horsepower.



The horsepower needed to overcome Air Resistance increases as a cubic function of vehicle speed. This means that when vehicle speed doubles, horsepower requirement is eight (8) times greater.

Looking at the 80,000-pound tractor-trailer, when speed increases from 65 to 70 MPH, the engine must develop an additional 45 horsepower to meet the Total Wheel Demand horsepower. This is a significant 18% increase! Aerodynamic Resistance horsepower accounts for 32 horsepower and represents 71% of the increase.

As a rule of thumb, fuel consumption increases approximately 0.1 MPG for every 1 MPH above 55 MPH, assuming that the vehicle is properly spec'ed and the transmission is in top gear. In other words, increasing vehicle speed from 65 MPH to 70 MPH increases fuel consumption and reduces the fuel mileage by 0.5 MPG.

The aerodynamic differences between two tractors, one equipped with all the fairings and the other without fairings, coupled to a Dry Van can amount to 0.55 MPG or a 9% penalty.

The tractor-trailer gap for a high cube trailer (Dry Van, Reefer) is another factor affecting aerodynamics. A 6-foot gap can represent a 7.5% penalty or 0.45 MPG. Testing by a major OEM has shown that for every 12 inches of trailer gap, the fuel mileage changes approximately 1%.

The tractor-trailer configuration can represent up to 1.8 MPG or a 30% difference in fuel mileage penalty. This is based on a comparison between an aerodynamic tractor-trailer (Dry Van) with an 18" gap and a Car Hauler, both with 80,000 lb GCW.

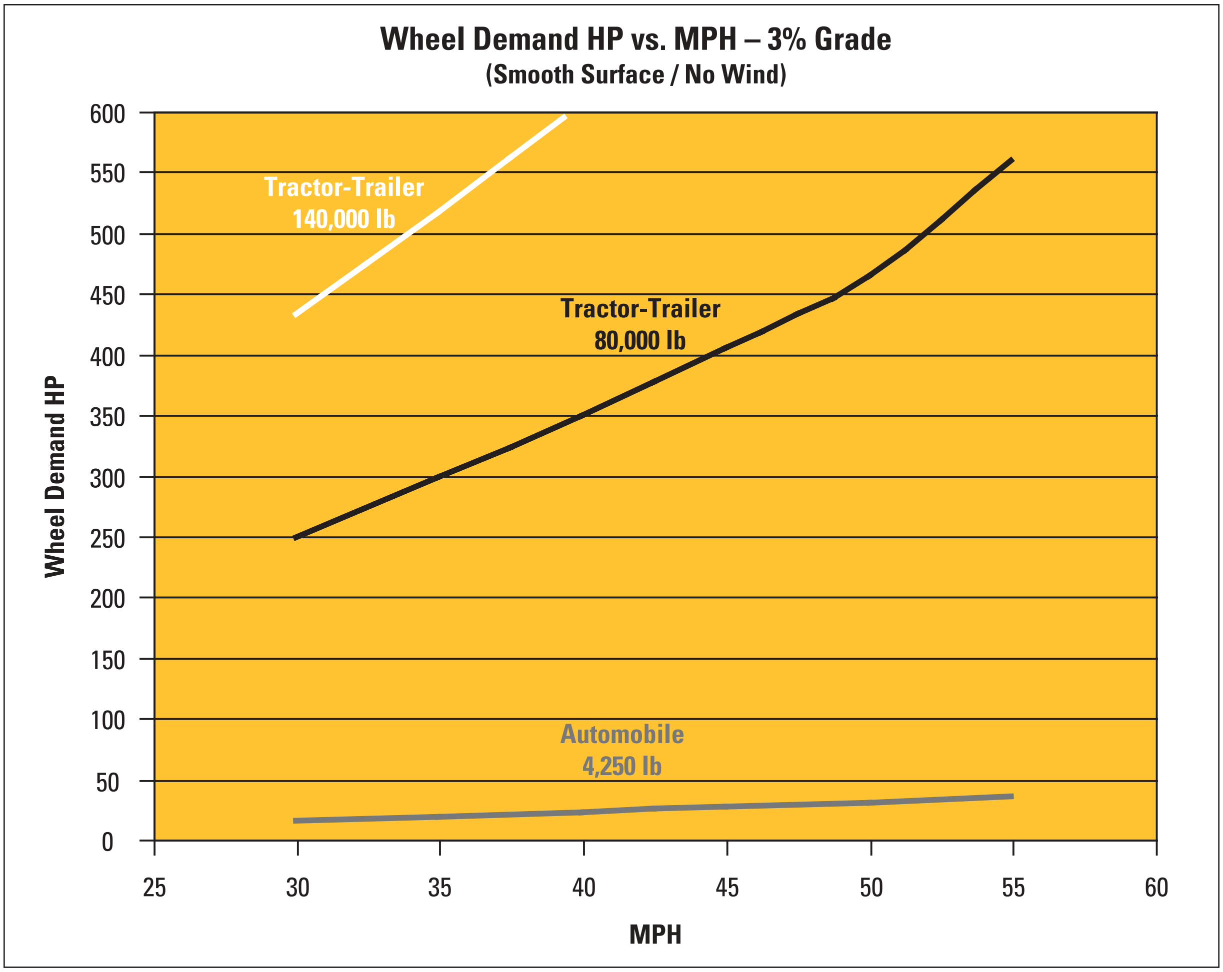
As speed increases, tractor-trailers with lower aerodynamic drag will experience a smaller fuel mileage penalty than vehicles with poorer aerodynamic properties.

## GRADE (HILL)

On a grade, the Wheel Demand horsepower increases significantly as vehicle weight increases.

*Figure 4* shows Wheel Demand Horsepower vs. MPH, on a 3% grade and on a calm day (no wind) for the automobile and the three (3) tractor-trailer combinations described in *Figure 1*.

**Figure 4. Wheel Demand HP vs. MPH – 3% Grade, Smooth Surface, No Wind**




On a grade, the total of the horsepower required to overcome Air Resistance, Rolling Resistance, and Grade Resistance constitute the Wheel Demand horsepower. This horsepower demand increases dramatically with vehicle weight and speed.

*Figure 5* provides a breakdown of Aerodynamic Resistance horsepower, Rolling Resistance horsepower and Grade Resistance horsepower. Combined, they represent the Wheel Demand horsepower needed to move a vehicle at a given speed, on a 3% grade on a calm day (no wind). Data is given for the automobile and the three (3) tractor-trailer combinations described in *Figure 1*.

Note that Grade Resistance horsepower is by far the highest contributor to the Wheel Demand horsepower.

Figure 5. Wheel Demand HP vs. MPH – 3% Grade, Smooth Surface, No Wind

| MPH | Vehicle Description | Aerodynamic / Air Resistance HP | Rolling Resistance HP | Grade Resistance HP | Total Wheel Demand HP |
|---|---|---|---|---|---|
| | | | | | |
| 30 | Automobile | 2 | 2.5 | 10.2 | 15 |
| | Van | 12 | 43 | 192 | 247 |
| | Flat-bed | 13 | 43 | 192 | 248 |
| | Lowboy | 20 | 76 | 336 | 432 |
| | | | | | |
| 35 | Automobile | 3 | 3 | 11.9 | 18 |
| | Van | 19 | 53 | 224 | 296 |
| | Flat-bed | 20.5 | 53 | 224 | 298 |
| | Lowboy | 32 | 92 | 392 | 516 |
| | | | | | |
| 40 | Automobile | 4.5 | 3.5 | 13.6 | 22 |
| | Van | 28.5 | 62 | 256 | 347 |
| | Flat-bed | 30.5 | 62 | 256 | 349 |
| | Lowboy | 48 | 109 | 448 | 605 |
| | | | | | |
| 45 | Automobile | 6 | 4 | 15.3 | 26 |
| | Van | 40.5 | 73 | 288 | 402 |
| | Flat-bed | 43.5 | 73 | 288 | 405 |
| | | | | | |
| 50 | Automobile | 8.5 | 4.5 | 17 | 30 |
| | Van | 55.5 | 84 | 320 | 460 |
| | Flat-bed | 59.5 | 84 | 320 | 464 |
| | | | | | |
| 55 | Automobile | 11 | 5 | 18.7 | 35 |
| | Van | 74 | 127 | 352 | 553 |
| | Flat-bed | 79.5 | 127 | 352 | 559 |

## ENGINE COOLING REQUIREMENTS (FAN HORSEPOWER DEMAND)

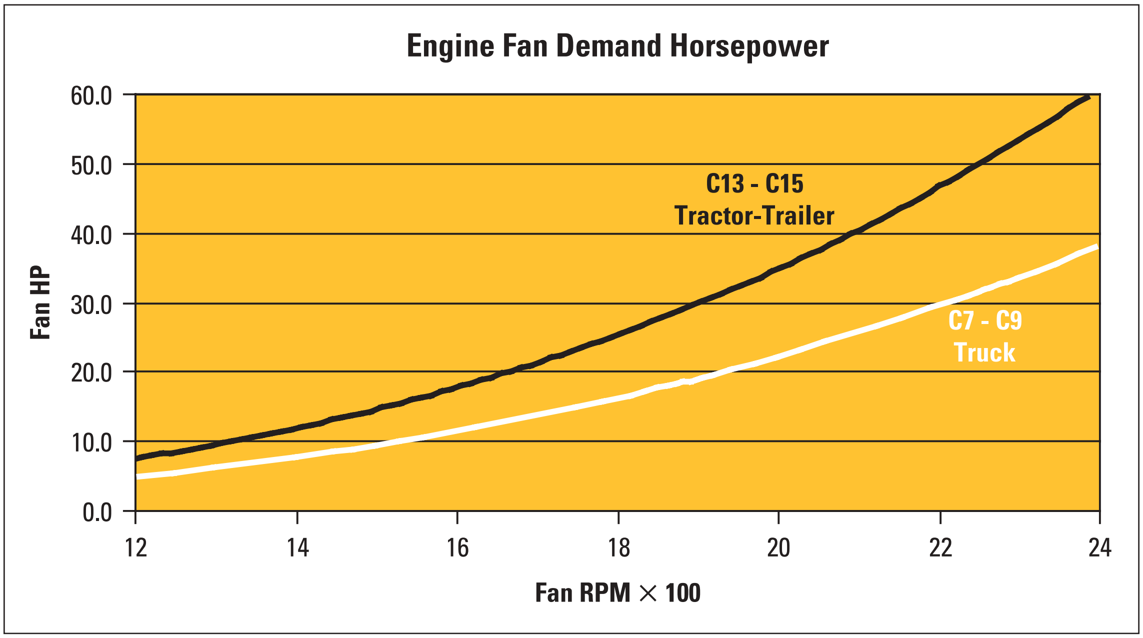
Tractor-trailers and trucks powered by Caterpillar diesel engines are generally equipped with an ON / OFF fan. Ram air through the various heat exchangers is normally sufficient to handle the cooling requirements and the fan is usually operating less than 5% of the time. These larger cooling fans, when operational, require more horsepower from the engine to handle the greater cooling requirements. When the fan is not running, it requires a minimum amount of horsepower from the engine.

The smaller units at the low end of the horsepower spectrum can be equipped with a viscous fan. The viscous fan rotates whenever the engine is running. The faster the engine runs, the faster the fan turns, increasing the horsepower demand on the engine.

The cooling fan parasitic horsepower not only consumes fuel, it also reduces the reserve horsepower available at the drive wheels to accelerate the tractor-trailer or maintain cruise speed on an uphill climb.

*Figure 6* shows a typical engine cooling fan demand horsepower for a C7 or C9 powered truck and a C13 or C15 powered truck or tractor-trailer with the radiator cooling fan "ON".

**Figure 6. Engine Cooling Fan Demand Horsepower vs. Fan RPM**




**NOTE:** Fan RPM and Engine RPM are often different. The Original Equipment Manufacturer (OEM) designs the cooling system configuration. *Figures 6* and *7* depict an engine cooling fan turning at engine speed (1.00:1 Ratio).

*Figure 7* shows the horsepower and torque at different RPM for the C15 Caterpillar diesel engine rated at 550 horsepower and 1850 lb-ft of torque. The table also provides the horsepower demand of a typical cooling fan and the available wheel horsepower at different RPM.

**Figure 7. Available Wheel Horsepower vs. Engine RPM**

| Engine RPM | Engine HP | Engine Torque (lb-ft) | Fan Demand HP | Available Wheel HP C15 550 / 1850 | |
|---|---|---|---|---|---|
| | | | | Fan OFF | Fan ON |
| 2100 | 531 | 1328 | 41 | 470 | 429 |
| 2000 | 539 | 1415 | 34 | 477 | 443 |
| 1900 | 550 | 1520 | 28.5 | 486 | 457 |
| 1800 | 550 | 1604 | 24 | 486 | 462 |
| 1700 | 550 | 1699 | 20.5 | 486 | 465 |
| 1600 | 550 | 1805 | 17 | 486 | 469 |
| 1500 | 528 | 1850 | 14 | 467 | 453 |
| 1400 | 493 | 1850 | 11.5 | 436 | 424 |
| 1300 | 458 | 1850 | 9 | 405 | 396 |
| 1200 | 423 | 1850 | 7 | 374 | 367 |

The engine delivers 550 horsepower at 1800 RPM and the available wheel horsepower is reduced to 486 horsepower (engine cooling fan OFF) due to the total power train parasitic losses. Therefore, approximately 88.5% of the engine horsepower is available to the drive wheels (*Figure 7*, cooling fan OFF).

At 1600 engine RPM, either with the engine cooling fan "ON" or "OFF", the maximum engine and drive wheels horsepower is obtained. Nothing is gained by operating the engine above 1600 RPM since engine horsepower has reached a maximum plateau and engine torque available declines substantially as engine RPM increases above 1600 RPM. Fan demand horsepower is a major factor in the reduction of available wheel horsepower above 1600 RPM.

Based on the data from *Figure 5*, the 80,000-pound tractor-trailer requires 462 horsepower at the drive wheels to climb a 3% grade at 50 MPH. This is roughly equivalent to the 469-486 horsepower that is available at the drive wheels at 1600 RPM with the engine cooling fan "ON" and "OFF" respectively. The 140,000-pound tractor-trailer is limited to 30-32 MPH on the same 3% grade.

The horsepower requirement of the 80,000-pound tractor-trailer on a 3% grade is approximately 16 times greater than that of the full size automobile. For this reason, the tractor-trailer speed drops-off at a faster rate and climbs grades at a much slower pace than the automobile.

One additional comment regarding performance: a full size automobile accelerates from zero to 60 MPH in 7-9 seconds. For the 80,000-pound tractor-trailer, a reasonable expectation is approximately 60 seconds.

## CLIMATE (AMBIENT CONDITIONS)

Cold air is denser than warm air and increases the aerodynamic drag on the tractor-trailer. Compared to 70° F ambient temperature, the increased drag caused by denser air at 50° F ambient temperature represents a 5% (0.3 MPG) fuel mileage penalty. At 30° F, the penalty increases to 10% (0.6 MPG).

Have you ever wondered why, each and every year and in late winter, drivers who operate non-aerodynamic tractors at high speed complain about poor fuel economy? The answer is that you have just uncovered the three most common and significant factors influencing fuel economy. Vehicle speed, tractor-trailer aerodynamics, and ambient temperature are nearly equal in importance during the winter months and converge to bring the fuel economy penalty to the forefront.

The average Mid-West winter months daily temperature of 25° F is responsible for an approximate 0.7 MPG fuel mileage penalty compared to summer time conditions of 70° F or higher. Cold air is denser and increases the aerodynamic drag on the tractor-trailer. To maintain the same cruise speed, the engine must develop more horsepower to overcome the higher air resistance and therefore consumes more fuel.

Wind is a very important variable affecting fuel economy (MPG). *Figure 8* shows the effect of wind condition on the Wheel Demand horsepower of the automobile, the Dry Van, and the Lowboy mentioned in *Figure 1*.

**Figure 8. Wind Condition vs. Wheel Demand HP – Flat, Smooth Surface at 65 MPH**

| Wind Condition | Vehicle | Aerodynamic / Air Resistance HP | Rolling Resistance HP | Total Wheel Demand HP |
|---|---|---|---|---|
| | | | | |
| No Wind | Auto | 18 | 6.4 | 25 |
| | 80,000 | 127 | 121 | 248 |
| | 140,000 | 204 | 211 | 415 |
| | | | | |
| Head Wind 15 MPH | Auto | 34 | 6.4 | 41 |
| | 80,000 | 237 | 121 | 358 |
| | 140,000 | 379 | 211 | 590 |
| | | | | |
| Tail Wind 15 MPH | Auto | 8.3 | 6.4 | 15 |
| | 80,000 | 58 | 121 | 179 |
| | 140,000 | 93 | 211 | 304 |

*Figure 8* shows that the 80,000 pound tractor-trailer requires 248 horsepower at the drive wheels to maintain 65 MPH on a flat, smooth surface on a calm day (no wind). When faced with a 15 MPH head wind, 358 wheel horsepower are required to maintain 65 MPH, a 44.4% increase (110 HP) all attributable to the greater air resistance. A 15 MPH tail wind does not directly offset the 15 MPH head wind penalty. With a 15 MPH tail wind, the 80,000-pound tractor-trailer requires 179 wheel horsepower to maintain 65 MPH, representing a 27.8% (69 HP) reduction in wheel demand horsepower.

The 140,000-pound tractor-trailer, with a 15 MPH head wind, requires 421 and 501 wheel horsepower to maintain a cruise speed of 55 and 60 MPH respectively on a level road. Since a maximum 486 horsepower is available at the drive wheels with the engine cooling fan "OFF", the tractor-trailer can only be expected to reach a maximum cruise speed of 57-58 MPH on level ground.

Rough roads, rain, slough and snow increase the vehicle rolling resistance and contribute to lower fuel economy. On a cool rainy day, observe the steam (water vapor) surrounding the tires shortly after coming to a stop. Tires act as a pump to displace water from the roadbed. Pumping water requires horsepower and the energy turns to heat contributing to water evaporation and lower fuel economy.

High winds, terrain, and snow-covered roads can change fuel economy by an additional 13% compared to a calm day and well-maintained roads.

## FUEL API GRAVITY

Summer blend #2 diesel fuel (API 35 gravity) has a higher BTU (higher heat value) content than #1 winter blend (API 38) and contributes to better fuel economy. Depending on the geographic location, winter blend fuel can make its appearance during the later part of August. Winter blend is responsible for a 2.5% penalty (0.15 MPG).

Winter fuel with higher API gravity will generate a higher fuel mileage penalty. In the southern region of Canada, API 41 fuel translates into a 5% fuel mileage penalty (0.3 MPG). Further north, kerosene with 48 API gravity results in a 15% fuel mileage penalty (0.9 MPG).

Combined effects of Cooler Ambient Temperature and Winter Blend Fuel on fuel economy:

(50° F = 0.3 MPG) + (API 38 = 0.15 MPG) = 0.45 MPG penalty (8% worse than summer)

(30° F = 0.6 MPG) + (API 38 = 0.15 MPG) = 0.75 MPG penalty (13% worse than summer)

The total AVERAGE Mid-West WINTER TIME (25° F) penalty on fuel economy amounts to 15.5% (13% ambient temperature + 2.5% winter fuel) or approximately 0.9 MPG. At 0° F, the fuel mileage penalty approaches 1.1 MPG.

## GCW (GROSS COMBINATION WEIGHT)

Increasing the GCW (Gross Combination Weight) increases the engine demand horsepower and increases fuel consumption. The corollary is also true, decreasing the GVW or GCW reduces fuel consumption and improves performance.

A 10,000-pound reduction in payload will increase fuel savings by about 4.4%. A reduction in gross weight from 80,000 lb to 60,000 lb will generate an 8.8% improvement in fuel savings. Pulling an empty trailer will only increase fuel savings by 21%.

A freight company has the option of delivering 90,000 pounds of building materials using two tractor-trailers weighing 77,000 pounds GCW each or one double tractor-trailer weighing 137,000 pounds GCW with fuel economy being the primary concern. Which transport method should be used? It is more fuel efficient to transport 90,000 pounds of goods with one tractor-trailer than to split the load between two tractor-trailers. The heavier tractor-trailer engine will consume substantially more fuel than either of the lighter tractor-trailer engine but the total fuel consumption is reduced by approximately 1/3 (33 1/3%) compared to using two tractor-trailers to move the same amount of freight. A substantial portion of the fuel savings is attributable to the 17,000-pound lower deadweight of the double tractor-trailer configuration and the lower aerodynamic drag horsepower of one frontal area compared to that of two tractor-trailers.

## IDLE TIME

A diesel engine consumes approximately 1 gallon of fuel per hour at a fast idle (900-1000 RPM). Idling consumes valuable resources (fuel) and for the most part is unnecessary. Excessive idling can contribute to carbon build-up and / or engine slobber and is detrimental to the engine.

The fuel consumed by an idling diesel engine is not as significant as many people believe. In terms of impact on fuel mileage, it ranks near the bottom of the list of factors affecting fuel economy. This is not to say that idle time should be ignored. The cumulative effect of small improvements can be very significant. Idling, unless it is necessary for security, driver comfort, and equipment need (PTO), is unnecessary.

A perspective on idling can be gained with the following example: A tractor-trailer engine consumes 11 gallons of fuel per hour while driving and 1.0 gallon per hour while idling to keep the driver comfortable. *Figure 9* compares the idle fuel consumption between 50%, 33 1/3%, and 20% idle time.

**Figure 9. Idling Fuel Consumption at Various Percent (%) Idle Time**

| Driving Fuel | Idling Fuel | | |
|---|---|---|---|
| **Gallons** | **Gallons** | **% of Total** | **MPG Penalty** |
| | | | |
| 50% Idle Time | | | |
| 10 hrs × 11 gal / hr = 110 gal | 10 hrs × 1.0 gal / hr = 10.0 gal | 8.3% | 0.50 MPG |
| | | | |
| 33 1/3% Idle Time | | | |
| 10 hrs × 11 gal / hr = 110 gal | 5 hrs × 1.0 gal / hr = 5 gal | 4.3% | 0.26 MPG |
| | | | |
| 20% Idle Time | | | |
| 10 hrs × 11 gal / hr = 110 gal | 2.5 hrs × 1.0 gal / hr = 2.5 gal | 2.2% | 0.13 MPG |

The above examples show that a 50% reduction in idle time (50% down to 33 1/3% / 10 hours down to 5 hours) contributes to improving fuel economy by 0.24 MPG.

A second attempt to again reduce idle time by 50% (33 1/3% down to 20% / 5 hours down to 2.5 hours) improves fuel mileage by 0.13 MPG. With much less management time commitment and training effort, reducing vehicle speed by 2 MPH (3% change) can improve fuel economy by nearly 0.2 MPG.

**Engine "Warm-up"** – The best and fastest way to warm-up an engine is to begin driving at part load (part throttle) shortly after start-up, following a brief inspection of the tractor-trailer.

**Engine "Shut-down"** – Before exiting the highway, take your foot off the throttle and coast long enough to decelerate the tractor-trailer to the point where a minimum amount of braking is required to exit the main roadway. A tractor-trailer can coast a long distance with the driver's foot off the throttle. During the coasting period the engine is not consuming any fuel. With a light load on the engine for a period of two to three minutes, the engine has cooled sufficiently and can be shutdown.

## AUXILIARY POWER UNIT (APU)

To eliminate unnecessary idling, an Auxiliary Power Unit (APU) can be installed on a tractor-trailer. These devices provide climate control (cab heat and air conditioning), engine preheating, tractor batteries charging, electrical power for the truck cab (12 VDC to 120 VAC), and auto start-stop for maximum fuel efficiency.

A typical fleet sleeper tractor idles 45% of the time or approximately 150 hours per month. Based on an estimated idling cost of $3.00 per hour, savings of $5,400 can be realized per tractor per year. Consider the fuel savings alone. The APU consumes approximately 0.25 gallon of diesel fuel per hour when the tractor engine is shutdown and contributes to an approximate net 7% fuel saving. With diesel fuel at $2.50 per gallon (US) and a tractor averaging 120,000 miles per year and 6.0 MPG, the fuel savings alone amount to $3,500 per tractor per year.

Less elaborate units are available for cab heat only (0.1 Gal / hr), or cab and engine coolant heat, and / or cab air conditioning only. The bunk air conditioner media is chilled with the engine 12-volt DC alternator during the normal tractor operation and provide bunk comfort for approximately 8 hours while the engine is shutdown.

In very cold environment, the fuel flowing through small diameter fuel lines tends to gel and cause the heating device to shutdown. For these conditions, the fuel lines should be insulated and / or electrically heated.

## CALCULATING FUEL MILEAGE (MPG)

When calculating fuel economy, fill the tank on a level surface before departing. Fill it to the same level upon arrival. Do not include the initial fill in the fuel mileage calculations. In the real world, because the pavement at most fuel islands is not level, calculating fuel mileage based on only one tank can be misleading as a few degrees difference in slope at the fuel island can make several gallons difference in amount of fuel pumped to achieve the same level in the tank.

Use the following formula:

**MPG = Miles Traveled / [*Gallons Purchased – (APU Hrs × 0.25 Gal / Hr)]**

* Do not include the initial fill.

**Example:** A tractor-trailer traveled 9,500 miles and 1,567 gallons of diesel fuel were purchased. During that period, the APU operated 150 hours.

9,500 Miles Traveled / [1,567 Gallons Purchased – (150 Hrs × 0.25 Gal / Hr)] =
9,500 Miles Traveled / 1,529.5 Gallons (Adjusted for APU usage) = 6.21 MPG

If the fuel consumed by the APU is not subtracted from the total fuel purchased, the fuel economy is incorrectly calculated as 6.06 MPG (9,500 Miles / 1,567 Gallons) equivalent to a 2.5% error.

## ENGINE ELECTRONIC CONTROL MODULE (ECM)

The engine ECM (Electronic Control Module) also calculates fuel economy (MPG). When comparing the ECM calculated fuel mileage to the actual fuel mileage (tank mileage), make sure the vehicle odometer and speedometer displays are accurate. If the mileage recorded is inaccurate, the fuel mileage (MPG) calculations will also be incorrect.

The speedometer accuracy can be verified using the interstate mile markers as a reference. At a constant 60 MPH, it takes 60 seconds to travel one mile. For every second less than 60 seconds required to travel one mile, the actual tractor-trailer speed is approximately one MPH faster. For every second exceeding 60 seconds required to travel one mile, the actual vehicle speed is approximately one MPH slower.

**Example:** The cruise speed is set at 60 MPH and the tractor-trailer travels one mile between mile markers in 58 seconds. The actual vehicle speed is approximately 62 MPH.

Speedometer accuracy can also be confirmed with a Global Positioning System (GPS).

If the speedometer is inaccurate, the odometer may require calibration. A dealer authorized to service Caterpillar engines can verify that the Vehicle Speed Calibration is correct. In addition, make sure that the Fuel Correction Factor is set to 0.0% or, if the Fuel Correction Factor was changed, that the calculations were performed correctly.

Refer to: “Programming Cat Electronic Truck Engines”, May 2005, media number LEXT0023-01. Consult the following chapters entitled:

- Vehicle Speed Parameters, Vehicle Speed Calibration
- Trip Parameters / Cat ID / Cat Messenger Access, Fuel Correction Factor

### Vehicle Speed Calibration

The Vehicle Speed Calibration number programmed in the ECM may be incorrect. Make sure that the Drive Tires Revolutions per Mile is correct. Verify both, the tire size and specific tire model to obtain the correct drive tires revolutions per mile.

If the Vehicle Speed Calibration Number is,

A) HIGH:
- ECM displays Lower MPG number
- MPG calculations based on actual fuel purchases also show Lower MPG number due to the speedometer error (actual distance traveled is Longer)
- Speedometer reads Low
- Actual truck speed is Higher
- PENALTY → Lower MPG due to Higher vehicle speed

B) LOW:
- ECM displays Higher MPG number
- MPG calculations based on actual fuel purchases also shows Higher MPG number due to the speedometer error (actual distance traveled is Shorter)
- Speedometer reads High
- Actual truck speed is Lower
- BONUS → Better MPG due to Lower vehicle speed

## TIRES

Tires are available with different types of tread design suitable for various applications.

Deep Lug, improve traction at the expense of higher rolling resistance. Shallow Lug, reduce the tread depth to decrease the rolling resistance. Rib, sacrifice traction but offer lower rolling resistance and better fuel economy.

In addition, there are tall tires (11R24.5), low profile tires (285/75R24.5), and wide base (singles) tires (445/50R22.5). The tall tires exhibit a little more rolling resistance because of the increased flex of the taller sidewall. Low profile tires have a weight advantage and less rolling resistance. The wide base (singles) tires can provide up to a 600-pound advantage over duals on the tractor alone. A similar weight saving can be realized on the trailer. The wide base (singles) tires offer the least rolling resistance. In the real world, do not expect more than a 3-4% improvement in fuel economy with wide base (singles) installed on both the tractor and the trailer.

Some facts to consider:

- Proper tire inflation pressure is important for your safety and that of others. Maintaining correct inflation pressure based on the actual tire load will also optimize tire life, vehicle ride quality, and fuel economy. With a tire pressure 10 psi lower than the manufacturer's recommendation for the weight, fuel economy will drop 0.5%.
- All tires are at their least fuel-efficient point when new. As the new tire wears, the rolling resistance decreases and fuel economy improves. Most of the fuel economy advantage (6%) is obtained when the tread is 50% worn.
- Regular radial tires and "fuel economy" tires provide nearly the same fuel economy as they approach wear out.
- Fuel-efficient tires loose half of their fuel efficiency benefit when vehicle speed increases from 60 to 75 MPH.
- Tire treads wear faster at higher speeds. Tire removal mileage point can be reached with 1/3 fewer miles.
- The trailer tires of a single tractor-trailer configuration account for 50% of the fuel economy. The trailer tires of a double tractor-trailer configuration account for 75% of the fuel economy.
- Retreads are nearly equal to new tires in rolling resistance.
- Above 55 MPH, air resistance / aerodynamics is a more important consideration than tire rolling resistance.

## GEARING (SPEC'ING)

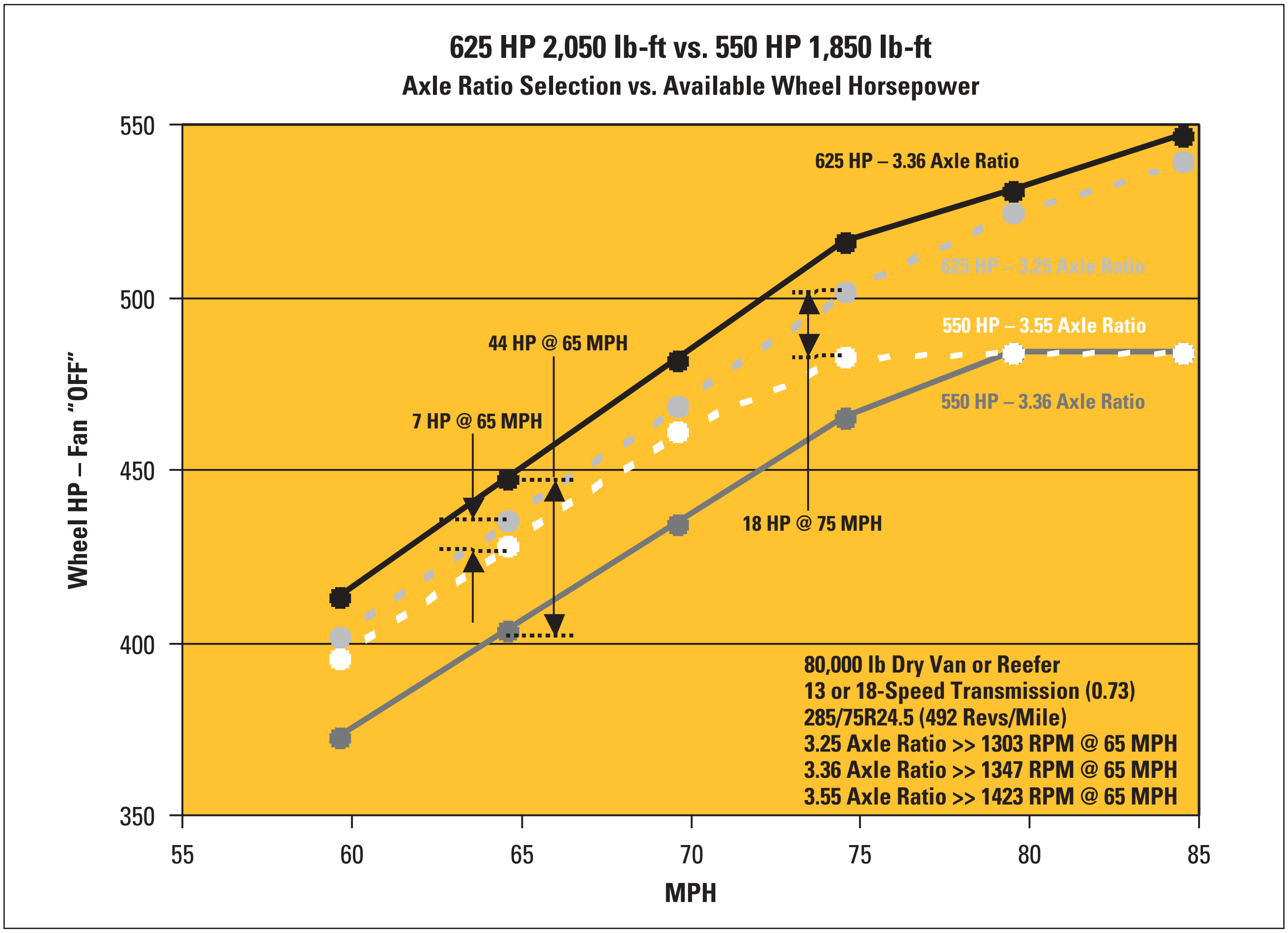
The gearing of a tractor (drive axle ratio selection) is based on several factors: the drive tires revolutions per mile, transmission top gear ratio, engine torque rating, GCW (gross combination weight), gradeability and startability requirements, tractor-trailer aerodynamics, application, and vehicle speed. Gearing is a compromise between truck performance and fuel economy. Fuel cost is a substantial part of the total owning and operating cost (top 2 in importance with driver's pay) and therefore optimum gearing leans toward the fuel economy side of the equation.

Some operators of trucks geared for best fuel economy can compensate for any reduced performance by down shifting prematurely and more often to keep the engine RPM in the peak horsepower range. Driving this way defeats the purpose of "Gear Fast – Run Slow" and can lead to poor fuel economy complaints.

*Figure 10* shows two properly spec'ed tractor-trailers with the same 3.36 axle ratio. The only difference between the two tractors is the engine rating; one is a 625 HP 2050 lb-ft and the other a 550 HP 1850 lb-ft engine. The 625 HP tractor provides 44 more RESERVE wheel horsepower at 65 MPH compared to the 550 HP tractor, not the 75 engine horsepower difference between the two engines rating.

A dealer may have spec'ed the 625 HP tractor with a 3.25 axle ratio to maintain lower engine RPM a high Cruise Speed. If the same customer previously operated a 550 HP tractor with a 3.55 axle ratio, the new 625 HP tractor provides only a 7 reserve horsepower advantage at the drive wheels at 65 MPH. The customer is likely to voice dissatisfaction with the new 625 HP tractor and a performance complaint will certainly follow.

**Figure 10. Axle Ratio Selection Impact on Wheel Horsepower**




Gearing

For more specific spec'ing information, refer to: "Pure Power Spec", media number LEDT3408-01. Design Pro 2.0, media number LERT2702 is a valuable software tool to assist with your spec'ing needs. LERT2703 is a Design Pro 2.0 customer-spec'ing tool without the routing feature.

## TRANSMISSION

A direct drive transmission, one with a top gear ratio of 1.00:1, can be 2% more fuel efficient than an overdrive transmission. Depending on the engine horsepower and torque rating, an overdrive transmission may be required to reduce driveline torque to an acceptable value.

## OTHER FACTORS

There are several other factors that negatively affect the tractor-trailer fuel economy. Rough road surface, axle and front end misalignment, vertical-rib and / or open-top trailers, etc… Even small things like adding a bug deflector or driving with the side window(s) down adversely affect the aerodynamic drag and negatively impact fuel economy.

All new vehicle components (engine, transmission, drive axle, driveline U-joints, wheel bearings) require a "break-in" period. During the initial 50,000-mile "break-in" period, fuel economy continues to improve. The cumulative effect of small factors becomes significant.

## CUSTOMER FACTORS

One of the first steps in investigating a fuel economy complaint is to inspect the tractor-trailer and interview the driver. Consider the engine horsepower and torque, cruise speed, look at the aerodynamics of the tractor-trailer, the type of trailer and load pulled, the type of tires on the drive axles and check the gearing of the truck. Compare the tractor gearing with Caterpillar's gearing recommendations. Ask the customer about their driving techniques.

Find out what the customer thinks the fuel mileage should be and why they think that. Many times they are comparing their truck to another truck with different aerodynamics and gearing. The engine might be the same but the chassis' could be completely different. The customer may also be referring to the worst conditions encountered during the winter months. Occasionally, they will mention that the selling dealer told them what fuel mileage they should expect out of the truck. "Estimating" the fuel mileage of any given truck can be difficult and time consuming. The driver influence alone can be a significant factor in the fuel economy results.

The next step is to download the engine ECM information and compare the results with the estimate provided by Design Pro 2.0 software.

Pay attention to the cruise speed, the months of the year the tractor-trailer fuel mileage represents, the engine RPM at cruise speed and the percent idle time. Compare the ECM fuel mileage with the actual tank mileage obtained from the customer records. The customer records MUST be available.

## CAT® COMPRESSION BRAKE (C11, C13, and C15 with ACERT Technology)

Brakes have one purpose in life, to convert kinetic energy – that is the energy of a moving vehicle into HEAT. Heavier vehicles, particularly at high speed, have a large amount of kinetic energy. For this reason, service brakes of large vehicles are more susceptible to overheating and fade on a long downgrade. A compression brake can be used to assist with the tractor-trailer deceleration and to control speed on a steep grade.

Compression brakes provide greater braking performance (retarding HP) at higher engine RPM. Generally speaking, descend a steep grade in the next lower gear than would be required to climb the same grade. Compression brakes provide a significant amount of retarding horsepower (*Figures 11* and *12*) to minimize service brakes usage. The compression brake has a three-position (LOW, MED, HIGH) switch to modulate braking under a wide variety of road conditions.

DO NOT use the compression brake, or cruise control on a slippery road.

A compression brake does not lower the fuel mileage (MPG) when used for controlling vehicle speed on steep grades or to assist in stopping the tractor-trailer. Keep in mind that best fuel mileage is achieved when "coasting" as much as possible before using any type of brake to bring the vehicle to a stop.

In moderate rolling hills, brake usage can materially reduce fuel economy (MPG). In rolling hills, best fuel economy is achieved by turning the compression brake "OFF". The vehicle accelerates on descent and decelerates on the climb. On a downhill, let the mass of the heavy vehicle provide most of the acceleration horsepower and crest the next hill with minimum throttle. Most drivers can achieve better fuel economy by using the cruise control rather than taking over the throttle position management task.

*Figure 11* shows the retarding horsepower of the Caterpillar Compression Brake for the C11, C13, and C15 at various engine RPM.

**Figure 11. Cat Compression Brake Performance for Heavy-Duty ACERT Engines**

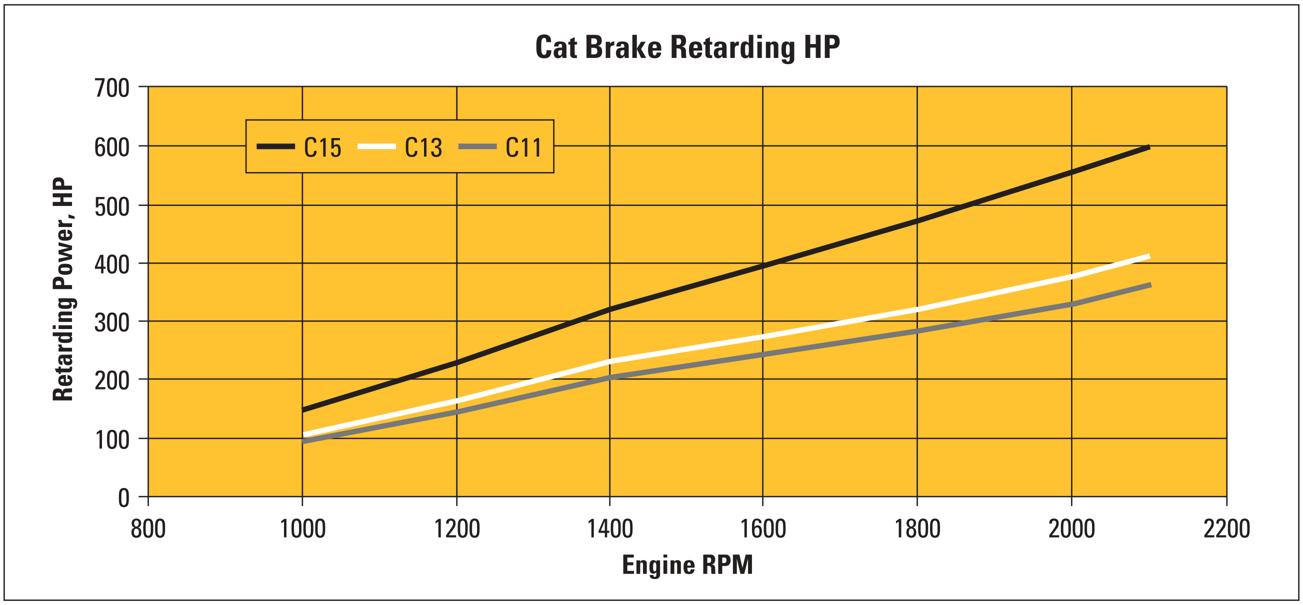


*Figure 12* shows the retarding horsepower required for an 80,000-pound tractor-trailer on various slopes to provide a desired vehicle speed without using the service brakes.

**Figure 12. Cat Compression Brake Grade Performance**

**Retarding HP Required**

| Grade (%) | Speed (MPH) | Power Needed (HP) | |
|---|---|---|---|
| 7 | 30 | 370 | Downshift |
| 6 | 35 | 350 | Downshift |
| 5 | 40 | 320 | Downshift |
| 4 | 60 | 320 | No Downshift |
| 3 | 60 | 200 | No Downshift |
| 2 | 60 | 80 | No Downshift |

**Capable of maintaining road speed without using service brakes.**

To improve fuel mileage, follow these recommendations

Slow Down – Do not exceed 60 MPH. This can be implemented immediately and does not require up front capital investment. It is likely to be your largest cost saving item.

Spec Smart – For your next purchase, consider a Tractor-Trailer with good aerodynamic characteristics and low rolling resistance tires. “Gear Fast / Run Slow” is also recommended for most 80,000 pounds GCW (Gross Combination Weight) applications.

Don’t Idle – Do not run the engine at idle anymore than absolutely necessary.

Driver Training – Learn proper operating habits that will save money on fuel, tires, brakes, and tractor-trailer maintenance. A safe driver is also rewarded with a more enjoyable driving experience.

## SUMMARY OF SIGNIFICANT FACTORS INFLUENCING TANK MILEAGE (TRACTOR-TRAILER)

| FACTORS | % PENALTY |
|---|---|
| | |
| **DRIVER (OPERATOR)**<br>• Worst to Best Drivers – (5.0-6.7 MPG) | 25% |
| | |
| **ROUTE SELECTION**<br>• Interstate vs. Congested Road – (up to 1.2 MPG) | 20% |
| | |
| **VEHICLE SPEED**<br>• 60 vs. 70 MPH – (0.8 MPG or more / Aero dependent) | 13% |
| | |
| **AERODYNAMICS**<br>• Worst to Best Class 8 tractors at 65 MPH – (0.55 MPG)<br>• Dry Van / Refer vs. Livestock trailer at 65 MPH – (0.9 MPG) | 9%<br>15% |
| | |
| **CLIMATE (AMBIENT CONDITIONS)**<br>• Summer (70° F or higher) vs. Winter (25° F) – (0.75 MPG)<br>• Wind / Terrain (On any given trip) – (0.75 MPG) | 13%<br>13% |
| | |
| **FUEL API GRAVITY**<br>• #2D (API 35) vs. Winter Blend (API 38) – (0.15 MPG)<br>• #2D (API 35) vs. Kerosene (API 48) – (0.9 MPG) | 2.5%<br>15% |
| | |
| **TIRES**<br>• Radial vs. Wide Base Singles – (0.25 MPG for tractor and trailer) | 4% |
| | |
| **IDLE TIME**<br>• 10% vs. 40% idle time – (0.25 MPG) | 4% |

**NOTE:** 10% = $5,000 / Year / Tractor (Assuming 120,000 miles / 6.0 MPG / $2.50 per gallon)

## Fuel Economy Comparison between Tractor-Trailers

When comparing Fuel Economy between tractor-trailers, AVOID making comparisons between apples and oranges. This sounds easy and obvious but it is done all the time. Below, you will find some recommendations to avoid common mistakes.

### Engine Displacement

When comparing the fuel mileage of engines with different displacement such as a 12 L and a 15 L engine, the lower displacement engine usually has an unfair advantage. For a similar horsepower rating, the engine with the lower displacement has the advantage with higher cylinder pressure (BMEP) and lower pumping losses that translate into slightly better fuel economy. When a customer talks about fuel economy, he is interested in operating costs. Fuel economy is only part of the life-cycle cost. The tractor residual value at trade-in time is also an important part of the consideration when spec'ing a 12 L or a 15 L engine. How much can I sacrifice in fuel economy in exchange for higher resale value?

### Engine Emission Certification Level

Compare engines of the same model year and / or of the same emissions certification level.

### ECM Data Accuracy

When downloading the ECM data, make sure the information obtained represents the same calendar period of operation for all tractors. The ambient temperature is a very significant factor affecting fuel economy. The winter-blend fuel with a higher API gravity (lower BTU content) provides an additional fuel mileage penalty.

### Distance Traveled

Is the tractor Odometer Reading accurate? How does it compare to the Hub-O-meter reading or the ECM Mileage?

Is the Vehicle Speed Calibration number correct? Is the Fuel Correction Factor correct? Refer to: "Programming Cat Electronic Truck Engines", media number LEXT0023-01.

### Fuel Consumption

Is the fuel consumption measured at a calibrated fuel pump or with the ECM?

### How Do They Compare?

Some engine manufacturers make sure that the ECM calculated fuel economy is better than the actual fuel mileage recorded at the pump. Make sure you compare the ECM Data with the actual fuel purchased by the customer. The ECM may not be programmed or calibrated properly and may not record distance and fuel consumption accurately.

Fuel economy tests must be repeatable within ± 1.0%.

## Road Test – HOW TO COMPARE TWO OR MORE TRACTOR-TRAILERS

References SAE Type 2, J1321 / Type 3, J1526 / Type 4, ATA procedure

### Same Fuel Island

Fill up at the same fuel pump, park in the same spot (chalk mark), before and after the trip. The fuel temperature must be the same when measuring fuel consumption in gallons. A smaller fuel tank may contain hotter fuel, causing the engine to consume a larger volume of fuel to obtain the same BTU content.

### 200-Mile Round Trip

Plan at least a 200-mile round trip to maintain a reasonable level of data accuracy.

### Spec'ed the Same Way

The tractors and trailers should be spec'ed identically except for the component (engine) to be evaluated for fuel economy performance.

- The engine ...................same model year and emissions certification level
- Tractor .......................same configuration, aerodynamics, fifth-wheel height
- Transmission .................Overdrive or Direct Drive, NOT both
- Axle ratio ....................same or based on the manufacturer gearing recommendations
- Tires ........................same size and model, same tire wear and inflation pressure
- Trailer and trailer gap .........same height and configuration
- GCW ........................within 1,000 lb (80,000 lb GCW) or 1.25%
- Other variables ...............same

### New Tractors and Trailers (50,000 Miles)

The comparison should take place after the break-in period – 50,000 miles minimum.

### 1/4-Mile Apart

Maintain visual contact during the road test, 1/4 mile apart. This minimizes differences between important variables affecting fuel economy (ambient temperature, wind, vehicle speed, road congestion, and idle time).

### Mimic Each Other

Mimic each other. Drive at the same legal and safe speed. All should idle the same amount. Use the transmission top gear and cruise control whenever possible.

### Switch Trailer

Switch trailer at the halfway point. The driver stays with the trailer.

## Performance and Fuel Economy Complaint Resolution

"Understanding Tractor-Trailer Performance" – LEGT6380

**Engine:**
- Serial Number
- Rating
- Software Version?

**Tractor / Truck:**
- Model Year
- Odometer Reading

**Maximum Intake Manifold Boost Observed?** **Ask the Driver**
- Within the Specification "Min/Max" values?
- Unchanged / Same as Before?
- Same Speed on Hill with Same Trailer and Load / No Wind?

**NOT OK**

**Boost is Lower, Changed**
**Speed is Lower on Same Hill, Changed**

**Check / Repair:**
- Fuel Pressure Ask the Driver
- Boost Gauge Accuracy / Defective
- High Ambient and/or Fuel Temperature
  - Low Fuel Level / Small Tank / Fuel Cooler
  - Large Engine Cooling Fan "ON" or "OFF"
- Air Cleaner / Intake Piping Restriction
- High Pressure Air Lines and ATAAC Leaks
- Fuel Filters, 10-micron Primary (Not 2-micron)
- Fuel Line Restriction / Fuel Aeration
- Fuel API Gravity
- Valves and Brake Lash Setting
- ATAAC Restriction / Plugging
- Exhaust Restriction
- Turbo Damage

**OK**

**Continue**

**Tractor-Trailer / Truck Description:**

- Tractor Model
- Aerodynamics – Full Roof Fairing and Cab Extender – YES / NO
- Transmission Model and Top Gear Ratio
- Axle Ratio
- Drive Tires – Size / Model (Revs / Mile)
- Trailer Gap
- Type of Trailer(s) – Van / Refer, Flat-bed, Dump, Lowboy, etc
- Duty – Linehaul, P&D, Vocational......Mixer, Wrecker, etc
- GCW / GVW
- Load Height
- Flat, Rolling Hills, or Mountains
- Normal Cruise Speed (MPH)
- % Idle Time / °F Ambient Temperature / Fuel API Gravity

**ECM – Parameters Programming: LEXT0023-01**

- Vehicle Speed Calibration
- VSL and Engine RPM @ VSL
- Gear Down Protection
- Progressive Shifting
- Fuel Correction Factor OK
- Gear Ratios

**OK**

**NOT OK**

**Make proper ECM Programming recommendations**

**ECM – Download / Evaluate:**

- Cruise Speed and Engine RPM
- Percent (%) Idle Time
- Driving and Overall MPG
- Tank Mileage vs. ECM Mileage

Is MPG and/or Gradeability explained?

**NOT OK**

**Model in Design Pro 2.0 – LERT2702 or LERT2703**

Explain Spec'ing Recommendations and results to customer

**OK**

**Discuss Recommended Tractor-Trailer Operating Technique with Customer**

**OK**

**NOT OK**

**PAR Chassis Dynamometer**

Explain results to customer

## Notes

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