UNDERSTANDING COACH / RV PERFORMANCE

CATERPILLAR®

This document is written for educational purposes only. The coach, powertrain, and accessories performance and fuel economy depicted are for illustrative purposes only and are not intended to reflect the actual performance level of any particular coach, powertrain, and accessories.

Understanding vehicle performance and fuel economy requires a basic knowledge of the many variables that may impact the operation of a heavy vehicle such as a coach.

The following discussion will review some of the most significant factors affecting fuel economy and performance. The topics under scrutiny are:

- Driver / operator
- Route Selection
- Vehicle speed
- Grade
- Frontal area, and aerodynamic properties
- Climate
- Fuel
- Idle Time
- Auxiliary Power Unit (APU)
- GVW (Gross Vehicle Weight) or GCW (Gross Combination Weight / Towing)
- Tires

The references to fuel mileage penalties percentages are based on a coach averaging 6.5 MPG (Miles Per Gallon).

DRIVER / OPERATOR
The most significant fuel economy variable is the driver. It is the driver who controls the vehicle speed, acceleration rate, brake usage, tire inflation pressure, cruise control usage, automatic transmission shifting override, and more. It is not uncommon, with identically spec'ed coaches, to observe as much as 20% (6.0 Vs 7.5 mpg) in fuel consumption penalty between the worst and the best drivers.

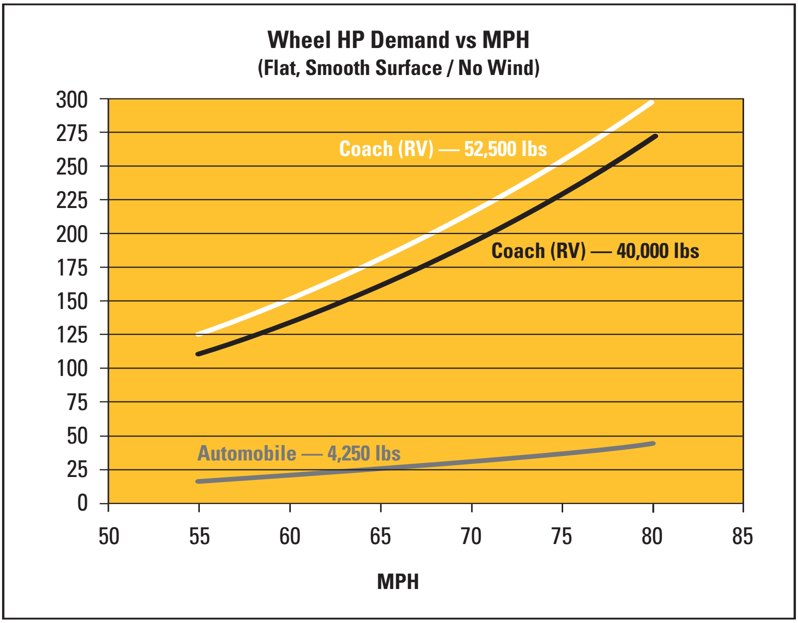
INTERSTATE VS CONGESTED ROAD
Avoid operating in congested areas whenever possible. Anticipate your stops; a heavy vehicle like a coach can coast a long distance without throttle application and, as a side benefit, a diesel engine does not consume fuel while coasting. Minimize vehicle speed fluctuation; utilize the cruise control as much as possible and whenever it is safe to do so, maintain a steady vehicle speed. 15% of the miles traveled on congested roads can translate into an 8% fuel economy penalty. 25% of the miles traveled on congested roads can represent a 15% fuel economy penalty.

VEHICLE SPEED
Vehicle speed is another very important factor affecting fuel economy. Increasing vehicle speed (and/or gross vehicle weight) translates into a higher horsepower demand placed on the engine. When horsepower demand increases, RESERVE horsepower decreases and fuel consumption increases.

RESERVE horsepower is the difference between the available horsepower and the demand horsepower at the drive wheels at any given speed. Reserve horsepower can be used to accelerate the coach or climb a steeper grade at the same speed or the same grade at a faster speed. When reserve horsepower has been exhausted, the coach can no longer accelerate and will begin losing speed as the grade becomes progressively steeper.

Graph 1 provides a visual comparison between an automobile and two coaches of different weights (52,500 and 40,000 pounds) depicting the Wheel Horsepower Demand at various speeds, on a flat smooth surface and on a calm day (no wind).

Graph 1. Wheel HP Demand Vs Vehicle Speed - Flat Smooth Surface / No Wind



Graph 1 depicts the wheel horsepower demand of a coach without a trailer. Coaches frequently have a vehicle or trailer in tow. Trailer weight, travel speed, and towed vehicle aerodynamic properties can substantially increase the coach wheel horsepower demand. Bear in mind that fuel consumption varies proportionately with wheel horsepower demand.

Table 1 provides a comparison between an automobile and a 52,500-pound coach related to the Wheel Horsepower Demand at various speeds, on a flat smooth surface and on a calm day (no wind). The combination of Air Resistance and Rolling Resistance constitute the Wheel Horsepower Demand that varies according to the vehicle speed. Note that above 55 MPH, the coach air resistance horsepower demand becomes more significant than the rolling resistance horsepower demand.

Table 1. Wheel HP Demand Vs Vehicle Speed - Flat Smooth Surface / No Wind

	Automobile						**Coach / RV (C13)**					
GVW / GCW (lbs)	4,250						52,500					
Frontal Area (ft²)	30						90					
Coefficient of Drag (Cd)	0.32						0.60					
MPH	**55**	**60**	**65**	**70**	**75**	**80**	**55**	**60**	**65**	**70**	**75**	**80**
Aerodynamic / Air Resistance HP	11	14	18	23	28	34	62	80	102	127	156	190
Rolling Resistance HP	5	5.7	6.4	7	7.9	9	63	71	79	88	97	107
Wheel HP Demand	**16**	**20**	**25**	**30**	**36**	**43**	**125**	**151**	**181**	**215**	**253**	**297**

When the coach speed increases from 65 to 70 MPH, the engine must develop an additional 34 (215 – 181) horsepower to overcome the air and rolling resistance. The air resistance accounts for 25 (127 – 102) horsepower and represents the larger share (approximately 75%) of the increase. Increasing vehicle speed from 65 to 70 MPH represents an approximate 20% (34 HP / 181 HP) increase in wheel horsepower demand.

The rule of thumb to remember is that fuel economy will change approximately 0.08 mpg for every 1 mph speed change above 55 mph. In other words, decreasing vehicle speed from 70 mph to 65 mph can improve fuel mileage by 0.4 mile per gallon.

GRADE

The amount of force (pounds) required to move a vehicle up a steep grade becomes very significant as the gross vehicle weight (GVW) increases.

Coach / RV — C13 525 HP / 1650 lb-ft

Table 2. Force (lbs) required to move a vehicle up a 6% Grade

	Automobile	Coach / RV (C13)
Gross Vehicle Weight (GVW), lbs:	4,250	52,500
Aerodynamic / Air Resistance Force (lbs):	0	0
Rolling Resistance Force (lbs):	40	500
Grade Resistance Force (lbs):	255	3,150
Total Force Required (lbs):	**295**	**3,650**

The 52,500 lbs coach requires 3,650 pounds of force to move up a 6% grade compared to 295 pounds of force for a full size automobile.

A force exerted over a distance in a given period of time represents the horsepower demand to move an object (vehicle). When the force required to do work and vehicle speed increases, horsepower demand also increases.

Table 3. Vehicle Description

	Automobile	Coach / RV (C13)
Gross Vehicle Weight (GVW), lbs:	4,250	52.500
Advertised Horsepower:	250	525
GVW (lbs) / Horsepower:	17	100
Highway Fuel Economy (MPG):	25	6.5

Graph 4 provides a visual comparison between an automobile and two coaches of different weights (52,500 and 40,000 pounds) regarding the Wheel Horsepower Demand at various speeds, on a 6% grade and on a calm day (no wind). Note that on a grade the wheel horsepower demand increases significantly as vehicle weight increases.

Graph 4. Wheel HP Demand Vs Vehicle Speed – 6% Grade / No Wind

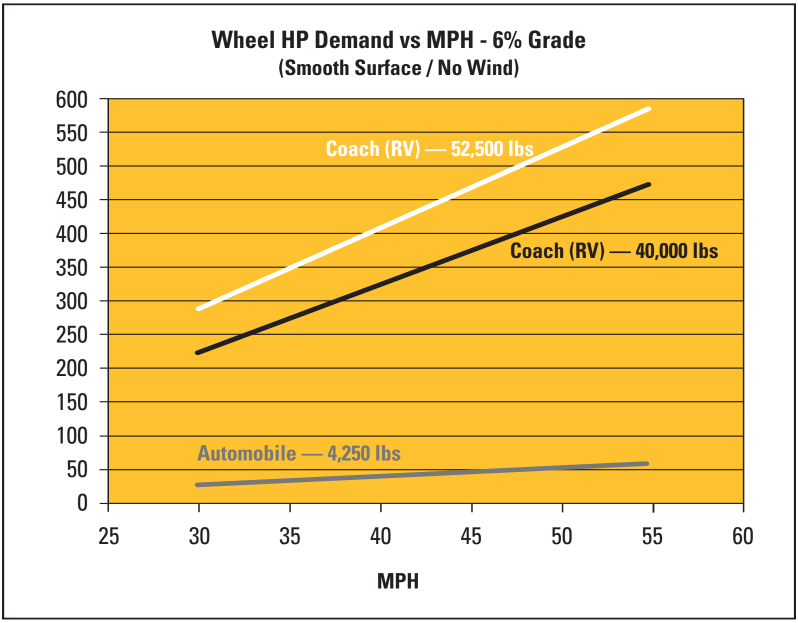


Table 4 compares the horsepower required (wheel horsepower demand) to operate the automobile and the 52,500-pound coach described above on a 6% grade at various speeds. On a grade, the combination of Air Resistance, Rolling Resistance, and Grade Resistance horsepower constitute the Wheel Horsepower Demand that varies according to the vehicle speed. Note that the Grade Resistance Horsepower is by far the most significant contributor to the Wheel Horsepower Demand.

Table 4. Wheel Horsepower Demand on 6% Grade

MPH	Vehicle	Aerodynamic / Air Resistance HP	Rolling Resistance HP	Grade Resistance HP	Total Wheel Demand HP
30	Auto	2	2.5	20	24.5
	Coach	10	28	252	**290**
35	Auto	3	3	24	30
	Coach	16	34	294	**344**
40	Auto	4.5	3.5	27	35
	Coach	24	41	336	**401**
45	Auto	6	4	31	41
	Coach	34	48	378	**460**
50	Auto	8.5	4.5	34	47
	Coach	46	55	420	**521**
55	Auto	11	5	37	53
	Coach	62	63	462	**587**

The coach is powered by a C13 Caterpillar® diesel engine rated at 525 horsepower and 1650 lb-ft of torque. Note that the maximum horsepower is available at 1800 rpm, while the maximum torque is available from 1600 all the way down to 1200 rpm.

While the engine delivers 525 horsepower at 1800 rpm, the available wheel horsepower is reduced to 462 horsepower (engine cooling fan OFF) due to the total powertrain parasitic losses. Approximately 88% of the engine horsepower is available to do work at the drive tires (Table 5, Fan “OFF”). Based on the Table 4 calculations, the coach can be expected to climb a 6% grade at 45 MPH while the engine is turning at 1800 rpm. The wheel horsepower demand at 45 MPH (460 HP) is for all practical purposes equivalent to the available wheel horsepower calculated in Table 5 (462 HP).

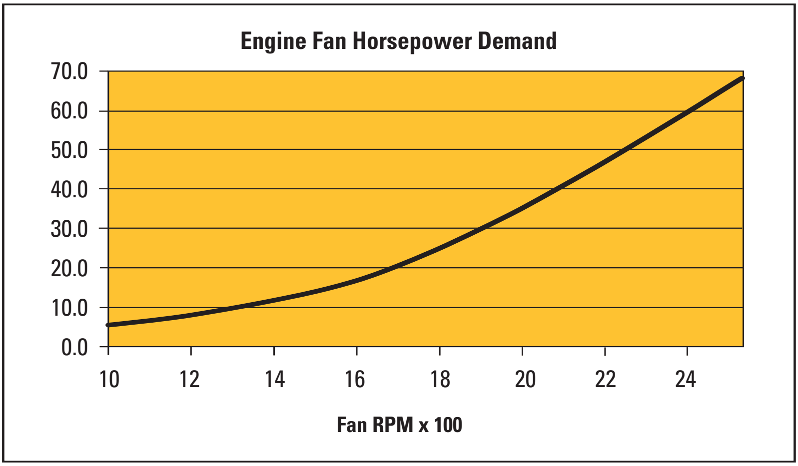
It is IMPORTANT to note that the coach engine cooling fan, when operational, can reduce the engine horsepower available at the drive wheels by 50 horsepower or more. In other words, the total wheel horsepower demand has just increased by a proportional amount required to operate the engine cooling fan. With the engine cooling fan “ON,” the coach is expected to climb the same 6% grade at 40 MPH since the available engine horsepower is reduced to 412 HP at 1800 RPM (Table 5) when the engine cooling fan is “ON.” Table 4 indicates that 401 HP is required at the wheels to climb a 6% grade at 40 MPH.

Table 5. Coach – Available Wheel Horsepower Vs Engine RPM

Engine RPM	Engine HP	Engine T (lb-ft)	Fan RPM	Available Wheel HP C13 525 / 1650	
				Fan OFF	Fan ON
1900	517	1429	2375	**455**	**393**
1800	525	1532	2250	**462**	**412**
1700	520	1607	2125	**458**	**416**
1600	503	1650	2000	**443**	**408**
1500	471	1650	1875	**414**	**385**
1400	440	1650	1750	**387**	**364**
1300	408	1650	1625	**359**	**341**
1200	377	1650	1500	**332**	**318**

In this example, the variable speed engine cooling fan drive ratio can be 25% faster than the engine to provide the necessary cooling requirements. This means that while the engine is running at 1800 RPM, the fan can be operating at 2250 RPM. Under these conditions, the fan demands 50 HP (462 HP – 412 HP) from the engine and reduces the reserve horsepower at the drive wheels by a proportionate amount. It is counterproductive to operate the engine above 1800 RPM since the fan horsepower demand becomes a major contributor in the reduction of available wheel horsepower.

Graph 6. Engine Cooling Fan Horsepower Demand



The coach horsepower demand on level ground (Table 1) is approximately 7.3 times greater than the full size automobile. If the automobile gasoline engine were as efficient as the coach diesel engine, the automobile fuel economy would be 45-50 MPG (7.3 X 6.5 MPG = 47.5 MPG), not 25 MPG.

The coach horsepower demand on a 6% grade (Table 4) is approximately 11.4 times greater than the full size automobile. For this reason, the coach speed is expected to drop-off at a faster rate and climb grades at a much slower pace than the automobile.

Coach / RV — C9 400 HP / 1100 lb-ft

A 40,000 lbs coach powered by a C9 engine rated at 400 horsepower would exhibit similar performance characteristics as the more powerful and larger coach mentioned above primarily due to its lower GVW.

With the engine cooling fan "OFF," approximately 352 horsepower (400 X 88% = 352 HP) is available at the drive wheels at 1800 RPM. The lighter coach is expected to climb a 6% grade at just under 45 MPH (Table 7). With the engine cooling fan "ON," 40 MPH is a reasonable expectation.

Table 7. Wheel Horsepower Demand on 6% Grade

MPH	Aerodynamic / Air Resistance HP	Rolling Resistance HP	Grade Resistance HP	Total Wheel Demand HP
35	16	26	224	**266**
40	24	31	256	**311**
45	34	36	288	**358**

The above comparison between the C13 and C9 powered coaches shows that for every 1000 lbs GVW reduction, the wheel horsepower demand is reduced by 8 horsepower at 45 MPH. Due to the lower GVW, the C9 powered coach performance is very similar to the heavier and more powerful C13 powered coach.

A similar comparison can be made between a 60,000 lbs coach powered by a C15 600 HP 1850 lb-ft engine and the above 52,500 lbs coach powered by the C13 525 HP 1650 lb-ft engine. The C15 powered coach weighs an additional 7,500 lbs. The heavier weight requires an additional 60 RESERVE horsepower (8 HP / 1000 lbs @ 45 MPH) for comparable performance on a grade. It is now apparent that these two coaches would exhibit similar performance characteristics while climbing a grade.

Another comparison can be made between the above 40,000 lbs coach powered by a C9 rated at 400 HP 1100 lb-ft of torque and a lighter 34,000 lbs coach powered by a C7 rated at 350 HP 860 lb-ft of torque. A 6,000 lbs reduction in gross weight is equivalent to a 48HP increase at the drive wheels (8 HP / 1000 lbs @ 45 MPH) and allows the C7 powered coach performance to emulate that of the more powerful but heavier C9 powered coach.

NOTE: 8 HP per 1,000 lbs @ 45 MPH increases to 12 HP per 1,000 lbs @ 65 MPH

One additional comment regarding performance; a full size automobile is expected to accelerate from Zero to 60 MPH in approximately seven (7) to nine (9) seconds. For the coach, a reasonable expectation is thirty-five (35) to forty (40) seconds.

AERODYNAMICS

The coach aerodynamic properties (Coefficient of drag — Cd), are similar to some of the most aerodynamic tractor-trailers but considerably higher than the modern automobile.

The coach higher Coefficient of drag, along with a much larger frontal area compared to the automobile, generates a much higher air resistance horsepower demand on the engine (Table 1 and 4). The air resistance horsepower increases as a cubic function of vehicle speed meaning that when vehicle speed doubles, horsepower requirement is eight (8) times greater.

CLIMATE / AMBIENT CONDITIONS

During the summer months, nighttime travel in the desert or excursions at high elevation, the coach can encounter some chilly temperatures. Cold air is denser and increases the aerodynamic drag on the coach. An ambient temperature of 50°F represents a 5% fuel mileage penalty (0.3 MPG) compared to summer time conditions of 70°F or higher. At 30°F, the penalty increases to 9% (0.6 MPG).

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

FUEL

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

(50°F = 0.3 MPG) + (API 38 = 0.15 MPG) = 0.45 MPG penalty (7% worse than summer)

(30°F = 0.6 MPG) + (API 38 = 0.15 MPG) = 0.75 MPG penalty (12% worse than summer)

IDLE TIME

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 to maintain a comfortable habitat environment, is unnecessary.

A perspective on idling can be gained with the following example: A coach engine consumes 9.5 gallons of fuel per hour while driving and 1.0 gallon per hour while idling to keep the occupants comfortable. Table 8 illustrates the propulsion engine fuel consumption comparison between 20% and 10% idle time.

Table 8. Propulsion Engine Fuel Consumption at Idle

20% Idle Time			
Driving Fuel	**Idling Fuel**	**Idling Fuel % of Total**	**Idling Fuel MPG Penalty**
8 hrs X 9.5 gal / hr = 76 gal	2 hrs X 1.0 gal / hr = 2 gal	2.6%	**0.17 mpg**
10% Idle Time			
8 hrs X 9.5 gal / hr = 76 gal	0.9 hr X 1.0 gal / hr = 0.9 gal	1.2%	**0.08 mpg**

The above example shows that a very significant 50% reduction in idle time (20% down to 10%) contributes to improving fuel economy by 0.09 mpg (0.17 mpg – 0.08 mpg). With much less effort, reducing vehicle speed by 1 mph (1.5% change) can improve fuel economy by nearly the same amount.

AUXILIARY POWER UNIT (APU)

The Auxiliary Power Unit (Generator) consumes approximately 0.4 to 0.5 gallon of diesel fuel per hour when operating at 50% load factor. When calculating the coach fuel economy (tank mileage), fill the tank on a level surface before departing and fill it to the same level upon arrival. Do not include the initial fill in the fuel mileage calculations.

Use the following formula:
MPG = Miles Traveled / [*Gallons Purchased – (APU Hrs X 0.5 Gal / Hr)]
* Don't forget to subtract the initial fill.

Example: The coach traveled 7,500 miles and 1225 gallons of diesel fuel were purchased. During that period, the APU operated 154 hours.

7,500 Miles Traveled / [1225 Gallons Purchased – (154 Hrs X 0.5 Gal / Hr)] =
7,500 Miles Traveled / 1148 Gallons (Adjusted for APU usage) = 6.53 MPG

If the fuel consumed by the Auxiliary Power Unit is not subtracted from the total fuel purchased, the fuel economy is incorrectly calculated as 6.12 MPG (7,500 Miles / 1225 Gallons) equivalent to a 6% error.

ENGINE ECM (ELECTRONIC CONTROL MODULE)
The engine ECM (Electronic Control Module) also calculates fuel economy. Make sure the PPM (Pulses Per Mile) is programmed correctly into the ECM.

Programming PPM (Pulses per Mile)
The PPM 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.

A) PPM is Too 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 coach speed is Higher
- PENALTY ➤ Lower MPG due to Higher vehicle speed

B) PPM is Too 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 coach speed is Lower
- BONUS ➤ Better MPG due to Lower vehicle speed

PPM = Drive Tires Revolutions / Mile X Drive Axle Ratio X * Number of Teeth (Chopper Wheel)

* The number of teeth on the transmission output shaft chopper wheel is normally **16**, sometimes 11, and can be any number of teeth.

Example: 500 Tire Revs Per Mile X 4.30 axle ratio X 16 = 34,400 PPM

TIRES

Coaches are normally equipped with low profile and low rolling resistance tires to optimize ride comfort and fuel economy. The 295/80R22.5 tire size frequently used rotates at approximately 500 Revolutions per Mile.

Some facts to consider:

- Proper tire inflation pressure is important for your safety and that of others. Maintaining correct inflation pressure for the 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 load, fuel economy will degrade 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.
- The majority of the fuel economy advantage is obtained when the tread is 50% worn.
- Regular radial tires and fuel economy labeled tires provide nearly the same fuel economy as they approach wear out.
- Above 55 mph, air resistance / aerodynamics is a more important consideration than tire rolling resistance.
- Fuel-efficient tires lose half of their fuel efficiency benefit when vehicle speed increases from 60 to 75 mph.
- Retreads are nearly equal to new tires in rolling resistance.

LOAD / GCW

During the last decade, the coach weight has increased substantially to satisfy the owners' appetite for a greater abundance of amenities. The coaches went from no slide to four (4) slide-outs, heavier granite counter tops and ceramic tiles replaced laminate counter tops and linoleum floor coverings, longer coaches with larger storage compartments, two (2) instead of one (1) air conditioner, larger APU's to satisfy the increased electrical demand, and larger powertrain and driveline are commonly specified.

Increasing the GVW or the Gross Combination Weight (GCW / Towing) increases the engine horsepower demand and negatively impacts fuel economy. The corollary is also true, decreasing the GVW or GCW reduces fuel consumption and improves performance. A 10,000-pound increase in payload or GCW will decrease fuel savings by about 8.5% (0.55 MPG) and is equivalent to a 120 engine horsepower (12 HP / 1,000 lbs @ 65 MPH) reduction at 65 MPH.

GEARING

The gearing of a coach (drive axle ratio selection) is based on several factors including the drive tires revolutions per mile, transmission top gear ratio, engine torque rating, GCW (gross combination weight), gradeability requirement, and vehicle speed. Gearing is a compromise between vehicle performance and fuel economy.

For optimum performance and fuel economy, Caterpillar recommends the following spec'ing guideline:

C7	350 HP	860 lb-ft	40,000 lbs GCW	1750 RPM @ 65 MPH
C9	400 HP	1100 lb-ft	45,000 lbs GCW	1625 RPM @ 65 MPH
C13	525 HP	1600 lb-ft	60,000 lbs GCW	1425 RPM @ 65 MPH
C15	600 HP	1850 lb-ft	60,000 lbs GCW	1350 RPM @ 65 MPH

OTHER FACTORS

There are several other variables that can negatively affect the coach fuel economy. Road congestion (Stop and Go), rough road surface, tire air pressure too low, axle and front end misalignment, etc… Even small things like roof-mounted conveniences (air conditioners, cargo carrier, and satellite dish) or driving with the side window(s) opened can have an adverse affect on fuel economy. The cumulative effect of small changes becomes significant.

Most fuel economy complaints can be explained with a basic understanding of some of the variables that affect fuel efficiency. All new vehicle components (engine, transmission, drive axle, drive line U-joints, wheel bearings) require a "wear-in" period. During the initial 30,000-mile "break-in" period, fuel economy continues to improve.

CUSTOMER FACTORS

The Driver influence alone can be a significant factor in the fuel economy results.

SUMMARY OF SIGNIFICANT FACTORS INFLUENCING TANK MILEAGE

COACH / RV	(% Penalty)
DRIVERS:	
Worst to Best drivers – (6.0 – 7.5 mpg)	20%
ROUTE:	
Interstate Vs Congested Road – (up to 1.3 mpg)	20%
VEHICLE SPEED:	
60 Vs 70 MPH – (0.8 mpg / Aero dependent)	12%
CLIMATE:	
Summer (70°F or higher) Vs Winter (30°F) – (0.75 mpg)	12%
Wind / Terrain (On any given trip) – (0.75 mpg)	12%
FUEL:	
#2D (API 35) Vs Winter Blend (API 38) – (0.15 mpg)	2.5%
#2D (API 35) Vs Kerosene (API 48) – (0.9 mpg)	14%
GCW:	
55,000 lbs Vs 45,000 lbs @ 65 MPH – (0.55 mpg)	8.5%
TIRES:	
New Vs Worn low profile radial tires – (0.15 mpg)	2.5%
IDLE TIME:	
20% Vs 10% idle time – (0.09 mpg)	1.5%

NOTE: 10% = $350 / Year (Assuming 7,500 miles / 6.5 mpg / $3.00 per gallon)

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