WEIGHT DISTRIBUTION CONCEPTS

Weight Restrictions

The Gross Vehicle Weight Rating (GVWR) and the Gross Axle Weight Rating (GAWR) of each Incomplete Vehicle are specified on the cover of its Incomplete Vehicle Document in conformance to the requirements of Part 568.4 of the Federal Motor Vehicle Safety Regulations. The final stage manufacturer is responsible under Part 567.5 to place the GVWR and the GAWR of each axle on the Final Vehicle Certification Label. The regulation states that the appropriate rating “shall not be less than the sum of the unloaded vehicle weight, rated cargo load, and 150 pounds times the vehicle’s designated seating capacity.”

Unloaded vehicle weight means the weight of a vehicle with maximum capacity of all fluids necessary for operation of the vehicle, but without cargo or occupants.

During completion of this vehicle, GVWR and GAWR may be affected in various ways, including but not limited to the following:

1. The installation of a body or equipment that exceeds the rated capacities of this Incomplete Vehicle.

2. The addition of designated seating positions which exceeds the rated capacities of this Incomplete Vehicle.

3. Alterations or substitution of any components such as axles, springs, tires, wheels, frame, steering and brake systems that may affect the rated capacities of this Incomplete Vehicle.

Use the following chart to assure compliance with the regulations. Chassis curb weight and GVW rating is located on Page 2 in each vehicle section. Always verify the results by weighing the completed vehicle on a certified scale.

<table>
<thead>
<tr>
<th>Curb Weight of Chassis (lbs.)</th>
<th>PLUS weight of added body components, accessories or other permanently attached components.</th>
<th>PLUS total weight of passengers, air conditioning and all load or cargo.</th>
<th>EQUALS Gross Vehicle Weight (lbs.) (GVW) of completed vehicle.</th>
</tr>
</thead>
<tbody>
<tr>
<td>(From required vehicle section)</td>
<td>(Body, liftgate, reefer, etc.)</td>
<td>(Driver, passengers, accessories and load)</td>
<td>(Should equal GVWR from required vehicle section)</td>
</tr>
</tbody>
</table>
**Gross Axle Weight Rating**

The Gross Vehicle Weight is further restricted by the Gross Axle Weight Rating (GAWR). The maximum GAWR for both front and rear axles is listed in each Vehicle Section. Weight distribution calculations must be performed to ensure GAWR is not exceeded. Always verify the results by weighing the completed vehicle on a certified scale.

**NOTE:** Although the Front Gross Axle Weight Rating (FGAWR) plus the Rear Gross Axle Weight Rating (RGAWR) may exceed the Gross Vehicle Weight Rating (GVWR), the total GVW may not exceed the respective maximum GVWR.

The variation in the GAWRs allow the second stage manufacturer some flexibility in the design of the weight distribution of the attached unit.

**Weighing the Vehicle**

Front and rear GAWRs and total GVWR should be verified by weighing a completed loaded vehicle. Weigh the front and rear of the vehicle separately and combine the weights for the total GVWR. All three weights must be less than the respective maximum shown in the vehicle sections.

**Tire Inflation**

Tire inflation must be compatible with GAWR and GVWR as specified on the cover of the Incomplete Vehicle Document for each vehicle.

**Center of Gravity**

The design of the truck body should be such that the center of gravity of the added load does not exceed the guidelines as listed in each Vehicle Section. If the body is mounted in such a way that the center of gravity height exceeds the maximum height of the center of gravity designated for each model, the directional stability at braking and roll stability at cornering will be adversely affected. A vertical and/or horizontal center of gravity calculation must be performed if a question in stability arises to ensure the designed maximum height of the center of gravity is not violated.
Weight Distribution

A truck as a commercial vehicle has but one purpose. That purpose is to haul some commodity from one place to another. A short distance or a long distance, the weight to be hauled, more than any other factor, determines the size of the truck. A small weight requires only a small truck; a large weight requires a large truck. A simple principle, but it can easily be misapplied. In any case, selecting the right size truck for the load to be hauled will ensure that the job will be done and that it will be able to be done with some degree of reliability and within the legal limitations of total gross weight and axle gross weights.

Not only must a truck be selected that will handle the total load, but the weight must also be properly distributed between the axles. This is of extreme importance from both a functional and economic aspect. If a truck consistently hauls less than its capacity, the owner is not realizing full return on his investment and his operating costs will be higher than they should be. If the truck is improperly loaded or overloaded, profits will be reduced due to increased maintenance costs and potential fines resulting from overloading beyond legal limitations. Careful consideration must be given to distribution of the load weight in order to determine how much of the total, including chassis, cab, body and payload, will be carried on the front axle and how much will be carried on the rear axle, on the trailer axles and the total. Moving a load a few inches forward or backward on the chassis can mean the difference between acceptable weight distribution for the truck or an application that will not do the job satisfactorily.

Every truck has a specific capacity and should be loaded so that the load distribution is kept within Gross Axle Weight Ratings (GAWR) and the truck’s Gross Vehicle Weight Rating (GVWR) or Gross Combination Weight Rating (GCWR) for a tractor/trailer and the weight laws and regulations under which the truck will operate. Improper weight distribution will cause problems in many areas:

1. Excessive front end wear and failure
   a. Tie-rod and kingpin wear
   b. Front axle failure
   c. Overloading of front suspension
   d. Wheel bearing failure

2. Rapid tire wear
   a. When the weight on a tire exceeds its rating capacity, accelerated wear will result and could result in tire failure.
3. Rough, erratic ride
   a. If the center of the payload is directly over or slightly behind the rear axle, the lack of sufficient weight on the front axle will create a bobbing effect, very rough ride, and erratic steering. This condition will be magnified when the truck is going uphill.

4. Hard steering
   a. When loads beyond the capacity of the front axle are imposed upon it, the steering mechanism is also overloaded and hard steering will result.
   b. Excessive overloading could result in steering component damage or failure.

5. Unsafe operating and conditions
   a. Poor traction on the steering axle effects the safety of the driver and equipment, particularly on wet, icy and slippery surfaces. Experience indicates that approximately 30% of the total weight at the ground on a truck or tractor should be on the front axle with a low cab forward vehicle.
   b. When a truck is overloaded, a dangerous situation may exist because minimum speeds cannot always be maintained, directional control may not be precise and insufficient braking capacity can cause longer than normal braking distances.

6. High maintenance costs
   a. Improper weight distribution and overloading cause excessive wear and premature failure of parts. Additional stresses imposed on the frame by the misapplication of wheelbases may be instrumental in causing the frame to crack or break.

7. Noncompliance with weight laws and regulations
   a. When there is the possibility that axle loads will exceed existing weight laws and regulations, careful weight distribution is necessary to provide a correct balance between front and rear axle loads and total load within legal limitations.

In this way, maximum payloads may be carried without exceeding legal limits. If the body is too long for a wheelbase, the center of the body and payload is placed directly over the rear axle. This places all the payload on the rear axles, resulting in overloading the rear tires, rear axle springs and wheel bearings and potentially exceeding the rear axle legal weight limit. The front axle is then carrying no part of the payload and is easily lifted off the ground when going over rough terrain, creating a very rough ride and temporary loss of steering control. If the body is too short for the wheelbase used, frame stress may be increased and may result in excessive loads on the front axle. Excessive front axle loads increase wear on the kingpins and bushings, wheel bearings and steering gear. Excessive front axle loads also overstress the front axle, springs, tires and wheels. All of these contribute directly to higher maintenance costs and hard steering, both of which are undesirable.
Weight distribution analysis involves the application of basic mathematical principles to determine the proper positioning of the payload and body weight in relation to the wheelbase of the truck chassis.

It is much less expensive to work all of this out on paper, make mistakes on paper and correct them there than to set up the truck incorrectly and either have it fail to do the job or, much worse, fail completely.

It is important to become familiar with the dimensions of the truck, as these will be needed to perform the necessary calculations.

---

**Glossary of Dimensions**

- **BBC** – Bumper to back of cab
- **BA** – Bumper to axle
- **CA** – Cab to axle
- **AB** – Axle to back of cab
- **BOC** – Back of cab clearance
- **CG** – Center of gravity of body and payload from axle
- **WB** – Wheelbase
- **OAL** – Overall length
- **AF** – Axle to end of frame
- **FH** – Frame height
**Weight Distribution Formulas**

A – Front axle to back of cab  
B – Distance between cab and body or trailer  
C – Front of body to C.G. or front of trailer to kingpin  
D – Distance C.G. of body or fifth wheel is ahead of rear axle  
F – \((A + B + C)\) or distance C.G. of weight of fifth wheel is behind front axle  
WB – Wheelbase  
W – Weight of body plus payload, or kingpin load  
WF – Portion of W transferred to front axle  
Wr – Portion of W transferred to rear axle
**Basic Formulas**

(a) \( W \times D = W_f \times WB \)

(b) \( W \times F = W_r \times WB \)

(c) \( WB = (A + B + C + D) = (F + D) \)

(d) \( W = W_f \times W_r \)

1. \( W_f = \frac{W \times D}{WB} \)

2. \( D = \frac{W_f \times WB}{W} \)

3. \( WB = \frac{W \times D}{W_f} \)

4. \( W = \frac{W_f \times WB}{D} \)

5. \( W_r = \frac{W \times F}{WB} \)

6. \( F = \frac{W_r \times WB}{W} \)

7. \( WB = \frac{W \times F}{W_r} \)

8. \( W = \frac{W_r \times WB}{F} \)

---

**Weight Distribution Formulas in Words**

To find:

1. Weight transferred to front axle  =  \( \frac{(Total \ weight) \times (Distance \ C.G. \ is \ ahead \ of \ the \ rear \ axle)}{(Wheelbase)} \)

2. Distance C.G. must be placed ahead of rear axle  =  \( \frac{(Weight \ transferred \ to \ the \ front \ axle) \times (Wheelbase)}{(Total \ weight)} \)

3. Wheelbase  =  \( \frac{(Total \ weight) \times (Distance \ C.G. \ is \ ahead \ of \ the \ rear \ axle)}{(Weight \ to \ be \ transferred \ to \ the \ front \ axle)} \)

4. Total Weight  =  \( \frac{(Weight \ to \ be \ transferred \ to \ the \ front \ axle) \times (Wheelbase)}{(Distance \ C.G. \ is \ ahead \ of \ the \ rear \ axle)} \)
1. Weight transferred to rear axle = \frac{(\text{Total weight}) \times (\text{Distance C.G. is behind the front axle})}{(\text{Wheelbase})}

2. Distance C.G. must be placed behind the front axle = \frac{(\text{Weight transferred to the rear axle}) \times (\text{Wheelbase})}{(\text{Total weight})}

3. Wheelbase = \frac{(\text{Total weight}) \times (\text{Distance C.G. is behind the front axle})}{(\text{Weight to be transferred to the rear axle})}

4. Total Weight = \frac{(\text{Weight to be transferred to the rear axle}) \times (\text{Wheelbase})}{(\text{Distance C.G. is behind the front axle})}

9. Remember = \text{Total weight must always equal weight transferred to the rear axle plus the weight transferred to the front axle}

To find the value of “P”, the leverages must be equal for balance.

**Example:**

100 lbs. x 8 in. = “P” x 20 in.

or \[ “P” = \frac{100 \text{ lbs.} \times 8 \text{ in.}}{20 \text{ in.}} \]

Therefore: \[ “P” = 40 \text{ lbs.} \]

This same approach is used to determine axle loadings on a tractor or truck chassis. Assuming the rear axle serves as a pivot point, the front axle load can be determined by applying the lever principle.
Front Axle Load: \[ W_{f} = \frac{\text{Kingpin Load} \times 5\text{th Wheel Location}}{\text{Wheelbase}} \]

Rear Axle Load: \[ W_{r} = \text{Kingpin Load} - \text{Front Axle Load} \]

Example: (4) A tractor has a wheelbase of 150 inches. If the kingpin load is 20,000 lbs. and the fifth wheel location is 15 inches, find the total weight on the front and rear axles. The tare weight of the tractor is 7,000 lbs. on the front axle and 4,400 lbs. on the rear axle.

\[
\begin{align*}
\text{Front Axle} & \quad = \quad 20,000 \times \frac{15}{150} \\
& \quad = \quad 2,000 \text{ lbs.}
\end{align*}
\]

\[
\begin{align*}
\text{Rear Axle Load} & \quad = \quad 20,000 - 2,000 \text{ lbs.} = 18,000 \text{ lbs.}
\end{align*}
\]

Therefore:

\[
\begin{align*}
\text{Total Front Axle Weight} & \quad = \quad 2,000 + 9,000 \text{ lbs.} = 11,000 \text{ lbs.} \\
\text{Total Rear Axle Weight} & \quad = \quad 4,400 + 18,000 \text{ lbs.} = 22,400 \text{ lbs.}
\end{align*}
\]
In calculating the weight distribution for a truck, the same lever principle is applied; however, there is one change in the initial consideration of the method of loading the truck body. Instead of the trailer kingpin location ahead of the rear axle centerline, we must determine the position of the center of gravity of the payload and body weight in relation to the rear axle centerline.

For our calculations, we assume that the payload is distributed in the truck body so that the load is supported evenly over the truck body floor (water-level distribution). The weight of the body itself is also considered to be evenly distributed along the truck frame. In this manner, we can add the payload and body weights together and calculate the distribution on the vehicle chassis as an evenly distributed load on the truck frame rails.

So that we can make the necessary calculation in a simple manner, the total body and payload weight is considered to act at the center of gravity which will be at the center of the body length.

Example:

\[
\text{Front Axle Load} = (\text{Body Weight} + \text{Payload}) \times \frac{\text{C of G location}}{\text{Wheelbase}}
\]

\[
\text{Rear Axle Load} = (\text{Body Weight} + \text{Payload}) - \text{Front Axle Load}
\]

Therefore, Front Axle Load = \(15,000 \times 24 = 2,400\) lbs.

Rear Axle Load = 15,000 – 2,400 = 12,600 lbs.
If the truck tare weight without the body is 5,000 lbs. on the front axle and 2,400 lbs. on the rear axle, then
- Total Front Axle Weight = 5,000 + 2,400 = 7,400 lbs. and
- Total Rear Axle Weight = 2,400 + 12,600 = 15,000 lbs.

This same lever principle is applied in all calculations of weight distribution, whether we are dealing with concentrated loads as with a kingpin load acting on a fifth wheel or if it be with an evenly distributed load as with a truck body. The same approach is made in calculating an evenly distributed load on a trailer.

In the case of a tractor/trailer or a tractor with a set of double or triple trailers, each unit is handled as a separated unit and then combined to determine the total.

This simple example illustrates how the principles are applied. Using the formulas, find the weight distributed to each axle.

\[
\begin{align*}
\text{Front Weight} & \quad \text{Rear Weight} \\
A. \quad W_f &= \frac{W \times D}{WB} & A. \quad \text{Total Weight} - \\
B. \quad 300 \times 24 &= \frac{96}{96} & B. \quad 300 - 75 \\
C. \quad = 75 \text{ lbs.} & C. \quad = 225 \text{ lbs.}
\end{align*}
\]

The body manufacturer can provide the body length and weight, or actual measurements of the body may be taken with a tape. Generally, (D) is unknown. This you must find logically, or with a tape measure.
Find (D) and then solve for $W_f$ and $W_r$.

\[ D = 60 - 3 - 48 = 9 \text{ in.} \]
\[ W_f = 205 \]
\[ W_r = 2,795 \]

**Recommended Weight Distribution % of Gross Vehicle Weight by Axle**

**Conventional (2 Axle)**
- Front Axle: 25% Desired Permissible, 20-30%
- Rear Axle: 75% Desired, 70-80%

**COE (2 Axle)**
- Front Axle: 33 1/3% Desired Permissible, 30-35%
- Rear Axle: 66 2/3% Desired, 65-70%

*Weight Distribution Concepts Section – continued on next page*
Calculating tractor/trailer weight distribution can be thought of in the same terms as calculating full trucks.

The weight at the center of the body and the load when applied is the same as the single point load of the kingpin on the fifth wheel.
In the following example, a 50,000-pound payload at water-level loading. Calculate the payload (PL) weight transfer to kingpin and the rear axle.

**NOTE:** Apply the same principles used with truck chassis.

(Weight Distribution Concepts Section – continued on next page)
Payload at Kingpin

\[ PL_{kp} = \frac{W \times D}{WB} \]

Calculate the “D” dimension.

OAL/2 – AF = D
45 feet/2 – 48 inches – 36 inches = 186 inches

\[ PL_{kp} = \frac{50,000 \text{ lbs.} \times 186 \text{ in.}}{456 \text{ in.}} = 20,394 \text{ lbs.} \]

\[ PL_{kp} = 20,394 \text{ lbs.} \]

Payload at Rear Tandem

\[ PL_{rt} = W - PL_{kp} \]

\[ PL_{rt} = 50,000 \text{ lbs.} - 20,394 \text{ lbs.} = 29,606 \text{ lbs.} \]

\[ PL_{rt} = 29,606 \text{ lbs.} \]

Once the weight on the kingpin is determined, it can then be treated on the tractor the same as a weight on a straight truck.

Due to the variations in hauling and wheelbase requirements from one truck application to another, there is no one specific fifth wheel setting that will apply in all cases.

A “rule of thumb” which has proven satisfactory in many cases sets the fifth wheel one inch ahead of the rear axle for every 10 inches of wheelbase. In the case of tandem axles, the wheelbase is measured from the center line of the front axle to the midpoint between the tandem rear axles. The location of the fifth wheel fixes the load distribution between the front and rear axles. Too far forward and the front axle is overloaded. If too far back, the front axle may be too lightly loaded and cause an unsafe steering and braking control situation at the front axle.
A tractor on a hill with the fifth wheel set at the axle center line or too close to it will result in an unsafe handling situation by transferring too much weight to the rear axle and actually unloading the front axle.

**Performance Calculations**

The following calculations have been included to help you determine the performance characteristics required by your customers and to select the appropriate model vehicle:

1. **Speed Formula**

   This formula can be used to determine:
   1. Top speed of the vehicle.
   2. Speed in a given gear.
   3. Final ratio required for a given speed.

   \[
   \text{MPH @ Governed Speed} = \frac{(60) \times (\text{RPM})}{(\text{Rev/Mile}) \times (\text{Gear Ratio})}
   \]
2013 Isuzu Truck

(Weight Distribution Concepts Section – continued from previous page)

Definitions in formula:

- RPM = Revolutions per minute of the engine at Governed Speed
- Rev/Mile = Tire revolutions per mile
- Gear Ratio = The product of the axle ratio times the transmission ratio
- 60 = Time Constant

Example: NPR 12,000 GVWR automatic transmission.

\[
\text{RPM} = 3,000 \\
\text{Rev/Mile} = 674 \\
\text{Gear Ratio} = 0.703 \times 5.375 \\
\]

\[
\text{MPH @ Governed Speed} = \frac{(60) \times (3,000)}{(674) \times (0.703 \times 5.375)} \\
\]

\[
\text{MPH @ Governed Speed} = 70 \text{ MPH} \\
\]

2. Grade Horsepower Formula

This formula can be used to determine horsepower required for a given grade and speed.

\[
\text{Horsepower Req'd. for a given grade} = \frac{\text{GVWR} \times \text{Grade} \times \text{Speed}}{37,500 \times \text{Efficiency Factor}} + \text{AHP} \\
\]

Definitions in formula:

- GVWR = Gross Vehicle Weight Rating
- Grade = Grade anticipated in percent
- Speed = Speed in miles per hour
- 37,500 = Constant
- Efficiency Factor = Factor for losses in drivetrain due to friction (use 0.9 for a 90% efficient driveline)
- AHP Resistance = Horsepower required to overcome wind force

(Weight Distribution Concepts Section – continued on next page)
Example: NPR 11,050 GVWR automatic transmission with a van body.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>GVWR</td>
<td>12,000 lbs.</td>
</tr>
<tr>
<td>Grade</td>
<td>1 percent</td>
</tr>
<tr>
<td>Speed</td>
<td>55 MPH</td>
</tr>
<tr>
<td>37,500</td>
<td>Constant</td>
</tr>
<tr>
<td>Efficiency Factor</td>
<td>0.9</td>
</tr>
<tr>
<td>AHP Resistance</td>
<td>53.6 HP (see the following formula for calculation)</td>
</tr>
</tbody>
</table>

\[
\text{HP Required for Grade} = \frac{12,000 \times 1 \times 55}{37,500 \times 0.9} + 53.67
\]

HP Required for Grade = 73.22

3. Air Resistance Horsepower Formula

This formula is used to determine the horsepower required to overcome air resistance at a given speed.

\[
\text{Air Resistance Horsepower} = \frac{FA \times Cd \times (\text{MPH})^3}{156,000}
\]

Definitions in formula:

- FA = Frontal area of vehicle in square feet
- Cd = Aerodynamic Drag Coefficient
- MPH = Speed of vehicle in miles per hour
- 156,000 = Constant

Frontal area is calculated by multiplying the height of the vehicle by the width of the vehicle and subtracting the open area under the vehicle from the total.

Aerodynamic Drag Coefficients (Source Material: Motor Truck Engineering Handbook):

- 0.70 for most trucks, semitrailer combinations with tanks or van bodies
- 0.77 for double and triple trailers and flatbeds with loads
Example: NPR 12,000 GVWR van body with 96” wide, 115” high (84” body height + 31” frame height).

\[
FA = \frac{(96) \times (115)}{12 \times (12)} - 3.2
\]

\[
FA = 73.47 \text{ ft}^2
\]

\[
Cd = 0.70
\]

Speed = 55 mph

\[
\text{Air Resistance HP} = \frac{73.47 \times 0.70 \times (55)^3}{156,000}
\]

\[
\text{Air Resistance HP} = 54.85
\]

4. **Engine Horsepower Formula**

This formula can be used to derive the output at a given RPM and torque.

\[
\text{Horsepower} = \frac{\text{Torque} \times \text{RPM}}{5,252}
\]

Definitions in formula:

- Torque = Twisting output of engine given in lbs.-ft.
- RPM = Revolutions per minute of engine
- 5,252 = Constant

Example: NPR 12,000 GVWR automatic transmission.

\[
\text{Torque} = 347 \text{ lbs.-ft.}
\]

\[
\text{RPM} = 2,000
\]

\[
132 \text{ HP} = \frac{(347) \times (2,000)}{5,252}
\]
5. **Gradeability Formula**

This formula can be used to determine how large of a grade a vehicle can climb.

\[
\text{Percent Grade} = \frac{1,200 \times (T) \times (E) \times (C) \times (R)}{\text{GVWR} \times r} - \frac{\text{RR}}{}
\]

Definitions in formula:

- 1,200 = Constant
- T = Maximum Torque of Engine
- E = Engine Efficiency (0.9)
- C = Driveline Efficiency (0.9)
- R = Transmission Ration x Axle Ratio
- RR = Rolling Resistance (see following chart)
- GVWR = Gross Vehicle Weight Rating
- r = Loaded radius of tire

**Example:** NPR 12,000 GVWR automatic transmission on concrete highway.

\[
\begin{align*}
T &= 347 \text{ lbs.-ft.} \\
E &= 0.9 \\
C &= 0.9 \\
R &= 0.703 \times 5.375 \text{ (in overdrive)} \\
RR &= 1.0 \\
\text{GVWR} &= 12,000 \\
r &= 14.1 \text{ in.}
\end{align*}
\]

\[
\text{Percent Grade} = \frac{1,200 \times (347) \times (0.9) \times (0.9) \times (0.703) \times (5.375)}{12,000 \times 14.1} - 1.0
\]

\[
\text{Gradeability} = 6.53 - 1
\]

\[
\text{Gradeability} = 5.53\%
\]
<table>
<thead>
<tr>
<th>Road Surface</th>
<th>Grade Road</th>
<th>Surface</th>
<th>Grade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concrete, excellent</td>
<td>1.0</td>
<td>Cobbles, ordinary</td>
<td>5.5</td>
</tr>
<tr>
<td>Concrete, good</td>
<td>1.5</td>
<td>Cobbles, poor</td>
<td>8.5</td>
</tr>
<tr>
<td>Concrete, poor</td>
<td>2.0</td>
<td>Snow, 2 inches</td>
<td>2.5</td>
</tr>
<tr>
<td>Asphalt, good</td>
<td>1.25</td>
<td>Snow, 4 inches</td>
<td>3.75</td>
</tr>
<tr>
<td>Asphalt, fair</td>
<td>1.75</td>
<td>Dirt, smooth</td>
<td>2.5</td>
</tr>
<tr>
<td>Asphalt, poor</td>
<td>2.25</td>
<td>Dirt, sandy</td>
<td>3.75</td>
</tr>
<tr>
<td>Macadam, good</td>
<td>1.5</td>
<td>Mud</td>
<td>3.75  to 15.0</td>
</tr>
<tr>
<td>Macadam, fair</td>
<td>2.25</td>
<td>Sand, level soft</td>
<td>6.0  to 15.0</td>
</tr>
<tr>
<td>Macadam, poor</td>
<td>3.75</td>
<td>Sand, dune</td>
<td>16.0 to 30.0</td>
</tr>
</tbody>
</table>

6. Startability Formula

This formula is used to determine what type of a grade a vehicle can be started on.

\[
\text{Startability} = \frac{(1,200) \times (\text{CET}) \times (E) \times (C) \times (R)}{\text{(GVWR} \times r)} - 10\%
\]

Definitions in formula:

- 1,200 = Constant
- CET = Clutch Engagement Torque
- E = 0.9
- C = 0.9
- R = Transmission x Axle Ratio
- 10% = Average break away resistance and static inertia constant
- GVWR = Gross Vehicle Weight Rating
- r = Loaded radius of tire
Example: NPR 12,000 GVWR manual transmission.

\[
\text{CET} = 260 \text{ lbs.-ft.} \\
R = 6.02 \times 4.10 \\
\text{GVWR} = 12,000 \text{ lbs.} \\
r = 14.1 \text{ in.}
\]

\[
\text{Startability} = \frac{(1,200) \times (260) \times (0.9) \times (0.9) \times (6.02 \times 4.10)}{(12,000 \times 14.1)} - 10\%
\]

Startability = 26.86\%

7. Vertical Center of Gravity Formula

These formulas are used to estimate the vertical center of gravity of a completed vehicle in order to determine whether maximum allowable limits have been exceeded. This formula should be used when encountering high center of gravity loads.

\[
\begin{align*}
7.1 Wv \times (Vv) &= Mv \\
7.2 Wb \times (Vb) &= Mb \\
7.3 Wp \times (Vp) &= Mp \\
7.4 We \times (Ve) &= Me \\
7.5 V_{Cg} &= \frac{(Mv + Mb + Mp + Me)}{Wv + Wb + Wp + We}
\end{align*}
\]

Definitions in formula:

\[
\begin{align*}
V_{Cg} &= \text{The total average vertical center of gravity of the completed vehicle (vehicle, body, payload and equipment)} \\
Wv &= \text{Weight of vehicle} \\
Wb &= \text{Weight of body} \\
Wp &= \text{Weight of payload} \\
We &= \text{Weight of equipment}
\end{align*}
\]
Definitions in formula (continued):

\[ V_v = \text{Distance from ground to center of gravity of the vehicle} \]
\[ V_b = \text{Distance from ground to center of gravity of the body} \]
\[ V_p = \text{Distance from ground to center of gravity of the payload} \]
\[ V_e = \text{Distance from ground to center of gravity of the equipment} \]
\[ M_v = \text{Moment of vehicle} \]
\[ M_b = \text{Moment of body} \]
\[ M_p = \text{Moment of payload} \]
\[ M_e = \text{Moment of equipment} \]

Example: NPR 12,000 GVWR automatic transmission, 132” WB, 14’ body length, 84” high body, full payload of boxes stacked to a maximum height of 48” above the flooring.

\[ W_v = 5,291 \text{ lbs. (from vehicle specifications)} \]
\[ W_b = 2,100 \text{ lbs. (from body manufacturer)} \]
\[ W_p = 4,609 \text{ lbs. (GVWR – (W_v + W_b + W_e))} \]
\[ V_v = 24.9 \text{ in. (from Body Builder’s Guide, NPR Section)} \]
\[ V_b = 80 \text{ in. (from body manufacturer)} \]
\[ V_p = 62 \text{ in. (1/2 of payload height + frame height + height from frame to flooring)} \]
\[ M_v = 5,291 \times 24.9 = 131,746 \text{ lbs.-in. (from 7.1)} \]
\[ M_b = 2,100 \times 80 = 168,000 \text{ lbs.-in. (from 7.2)} \]
\[ M_p = 4,609 \times 62 = 285,758 \text{ lbs.-in. (from 7.3)} \]
\[ W_e, V_e, M_e = \text{None in this example} \]

\[ VC_g = \frac{(131,746 + 168,000 + 285,758)}{(5,291 + 2,100 + 4,609)} = 48.8 \text{ inches} \]

48.8 < 54.0 inches (54 inches is maximum allowable VCg per mfg. specifications from Body Builder’s Guide, NPR section)

Since maximum VCg for this truck is not exceeded, 48” stack height above flooring is acceptable.
8. **Horizontal Center of Gravity Formula**

These formulas are used to estimate the horizontal center of gravity of a completed vehicle in order to determine whether it exists between the centerlines of the front and rear axles. This formula should be used when a load and/or permanent equipment (liftgate, reefer unit, snowplow, etc.) is installed on either extreme along the completed vehicle’s overall length.

8.1 \( Wv \times (Hv) = Mv \)

8.2 \( Wb \times (Hb) = Mb \)

8.3 \( Wp \times (Hp) = Mp \)

8.4 \( We \times (He) = Me \)

8.5 \[
HCg = \frac{(Mv+Mb+Mp+Me)}{(Wv + Wb + Wp + We)}
\]

Definitions in formula:

- **HCg** = The total average horizontal center of gravity of the completed vehicle (vehicle, body, payload and equipment)
- **Wv** = Weight of vehicle
- **Wb** = Weight of body
- **Wp** = Weight of payload
- **We** = Weight of equipment
- **Hv** = Distance from front axle to center of gravity of the vehicle
- **Hb** = Distance from front axle to center of gravity of the body
- **Hp** = Distance from front axle to center of gravity of the payload
- **He** = Distance from front axle to center of gravity of the equipment
- **Mv** = Moment of vehicle
- **Mb** = Moment of body
- **Mp** = Moment of payload
- **Me** = Moment of equipment
Example: NPR Diesel 12,000 GVWR automatic transmission, 132” WB, 14’ body length, full payload of boxes stacked and distributed evenly throughout the flooring, 1,000 lb. reefer unit attached in front of body.

\[ W_v = 5,291 \text{ lbs. (from vehicle specifications)} \]
\[ W_b = 2,100 \text{ lbs. (from body manufacturer)} \]
\[ W_p = 3,609 \text{ lbs. (GVWR – (W_v + W_b + W_e))} \]
\[ W_e = 1,000 \text{ lbs. (from equipment manufacturer)} \]
\[ H_v = 42.4 \text{ in. (from Body Builder's Guide, NPR Section)} \]
\[ H_b = 107.5 \text{ in. (from body manufacturer)} \]
\[ H_p = 107.5 \text{ in. (1/2 of payload length + distance from front axle to front of body)} \]
\[ H_e = 17.5 \text{ in. (from equipment manufacturer)} \]

\[ M_v = 5,291 \times 42.4 = 224,338 \text{ lbs.-in. (from 8.1)} \]
\[ M_b = 2,100 \times 107.5 = 225,750 \text{ lbs.-in. (from 8.2)} \]
\[ M_p = 3,609 \times 107.5 = 387,967 \text{ lbs.-in. (from 8.3)} \]
\[ M_e = 1,000 \times 17.5 = 17,500 \text{ lbs.-in. (from 8.4)} \]

\[ H_{cg} = \frac{(224,338 + 225,750 + 387,967 + 17,500)}{(5,291 + 2,100 + 3,609 + 1,000)} = 71.3 \text{ inches (from 8.5)} \]

Since \( H_{cg} \) for this truck is not greater than the WB or negative (–) (denotes \( H_{cg} \) forward of front axle centerline), it exists between the centerlines of the front and rear axles.

NOTE: \( H_p \) and \( H_b \) dimensions are the same in this example because CG of body and payload happen to be at the same point.
The Federal Government established the Federal Bridge Gross Weight Formula to provide a standard to control the spacing of truck axles on trucks that use highway bridges. This is intended to space loads out over a distance to avoid too high a concentration in one area that could cause damage. The truck's gross weights, axle weight and axle spacings are set in order to keep axle loads and gross weight loads within the limits set by the Federal Government. The Bridge Formula Table is used to check trucks to make sure that Federal weight limit requirements are met and that the allowable gross and axle weights are in the correct relationship with the spacing of axles to prevent high load concentrations on highway bridges.

The Federal Government has established the following formula to be used to determine the allowable weight limits and axle spacings for trucks.

\[
W = 500 \left( LN + 12N = 36 \right) N-1
\]

Where:

- \( W \) = The total gross weight that may be carried on any group of two or more consecutive axles to the nearest 500 lbs.
- \( L \) = The distance (spacing) in feet between the outer axles of any group of two or more consecutive axles.
- \( N \) = The number of axles in the group under consideration; except that two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each provided the overall distance between the first and last axles of such consecutive sets of axles is 36 feet or more.

**Bridge Formula Definitions**

The following definitions are used for bridge formula calculations.

**Gross Weight**

The total weight of a truck (and/or trailer) combined with the weight of the load being hauled. The Federal gross weight limits on interstate highways and federal-aid highways and reasonable access is 80,000 lbs.
Single Axle Weight

The total weight at the ground by all wheels of an axle whose centers may be included between parallel transverse planes 40 inches apart, extending across the width of the truck. The Federal single axle weight limit on the interstate system and reasonable access is 20,000 lbs.

Tandem Axle Weight

The total weight at the ground of two or more consecutive axles whose centers may be included between parallel vertical planes spaced more than 40 inches but not more than 96 inches apart, extending across the full width of the truck. The Federal tandem axle weight limit on the interstate system and reasonable access is 34,000 lbs.

Consecutive Axle Weight

The Federal law states that any two or more consecutive axles may not exceed the weight as computed by the formula even though the single axles, tandem axles, and gross weights are within the legal requirements.

Exception to the Bridge Formula

There is one exception to the use of the Federal Bridge Formula: two consecutive sets of tandem axles may carry a gross load of 34,000 lbs. each, providing the overall distance between the first and last axles of such consecutive sets of tandem axles is 36 feet or more.

Other Federal Provisions

Maximum Width: 102 inches overall

Length: States cannot set overall length limits on tractor, semitrailer or tractor-semitrailer, trailer combinations. States must allow tractors with double trailers. States must allow semitrailers of up to 48 feet in length for doubles combinations. There is also not a limitation on overall length for semitrailer or doubles combinations.

These width and length dimensions apply to trucks operating on interstate highways and federal-aid highways designed by the Federal Highway Administration. This also provides for reasonable access to the interstate highways.
### Federal Bridge Formula Table

| Distance in feet between the extremes of any group of 2 or more consecutive axles | Maximum Load in Pounds on Any Group of 2 or More Consecutive Axles |
|---|---|---|---|---|---|---|---|
| 4  | 34,000* |       |       |       |       |       |       |
| 5  | 34,000* |       |       |       |       |       |       |
| 6  | 34,000* |       |       |       |       |       |       |
| 7  | 34,000* |       |       |       |       |       |       |
| 8 and less | 34,000* | 34,000 |       |       |       |       |       |
| 8 and more | 38,000 | 42,000 |       |       |       |       |       |
| 9  | 39,000  | 42,500 |       |       |       |       |       |
| 10 | 40,000  | 43,500 |       |       |       |       |       |
| 11 |        |       | 44,000 |       |       |       |       |
| 12 |        |       | 45,000 | 50,000 |       |       |       |
| 13 |        |       | 45,500 | 50,500 |       |       |       |
| 14 |        |       | 46,500 | 51,500 |       |       |       |
| 15 |        |       | 47,000 | 52,000 |       |       |       |
| 16 |        |       | 48,000 | 52,500 | 58,000 |       |       |
| 17 |        |       | 48,500 | 53,500 | 58,500 |       |       |
| 18 |        |       | 49,500 | 54,000 | 59,000 |       |       |
| 19 |        |       | 50,000 | 54,500 | 60,000 |       |       |
| 20 |        |       | 51,000 | 55,500 | 60,500 | 66,000 |       |
| 21 |        |       | 51,500 | 56,000 | 61,000 | 66,500 |       |
| 22 |        |       | 52,500 | 56,500 | 61,500 | 67,000 |       |

* Tandem Axle by Definition.

+ Exception to Federal Bridge Formula Table and Law. See Text for Explanation.

**NOTE:** All permissible load calculations are to the nearest 500 lbs. Maximum load on any single axle, 20,000 lbs. Weights over 80,000 lbs. are in excess of the Federal GVW on the National Highway Network.
### Federal Bridge Formula Table

| Distance in feet between the extremes of any group of 2 or more consecutive axles | Maximum Load in Pounds on Any Group of 2 or More Consecutive Axles |
|---|---|---|---|---|---|---|
| 23 | 53,000 | 57,500 | 62,500 | 68,000 |  |  |
| 24 | 54,000 | 58,000 | 63,000 | 68,500 | 74,000 |  |
| 25 | 54,500 | 58,500 | 63,500 | 69,000 | 74,500 |  |
| 26 | 55,500 | 59,500 | 64,000 | 69,500 | 75,000 |  |
| 27 | 56,000 | 60,000 | 65,000 | 70,000 | 75,500 |  |
| 28 | 57,000 | 60,500 | 65,500 | 71,000 | 76,500 | 82,000 |
| 29 | 57,500 | 61,500 | 66,000 | 71,500 | 77,000 | 82,500 |
| 30 | 58,500 | 62,000 | 66,500 | 72,000 | 77,500 | 83,000 |
| 31 | 59,000 | 62,500 | 67,500 | 72,500 | 78,000 | 83,500 | 90,000 |
| 32 | 60,000 | 63,500 | 68,000 | 73,000 | 78,500 | 84,500 | 90,500 |
| 33 | 64,000 | 68,500 | 74,000 | 79,000 | 85,000 | 91,000 |
| 34 | 64,500 | 69,000 | 74,500 | 80,000 | 85,500 | 91,500 |
| 35 | 65,500 | 70,000 | 75,000 | 80,500 | 86,000 | 92,000 |
| 36 | 66,000 | 70,500 | 75,500 | 81,000 | 86,500 | 93,000 |
| 37 | 66,500 | 71,000 | 76,000 | 81,500 | 87,000 | 93,500 |
| 38 | 67,500 | 72,000 | 77,000 | 82,000 | 87,500 | 94,000 |
| 39 | 68,000 | 72,500 | 77,500 | 82,500 | 88,500 | 94,500 |
| 40 | 68,500 | 73,000 | 78,000 | 83,500 | 89,000 | 94,500 |
| 41 | 69,500 | 73,500 | 78,500 | 84,000 | 89,500 | 95,000 |
| 42 | 70,000 | 74,000 | 79,000 | 84,500 | 90,000 | 95,500 |

* Tandem Axle by Definition.  
+ Exception to Federal Bridge Formula Table and Law. See Text for Explanation.  

**NOTE:** All permissible load calculations are to the nearest 500 lbs. Maximum load on any single axle, 20,000 lbs. Weights over 80,000 lbs. are in excess of the Federal GVW on the National Highway Network.
### Federal Bridge Formula Table (Continued)

| Distance in feet between the extremes of any group of 2 or more consecutive axles | Maximum Load in Pounds on Any Group of 2 or More Consecutive Axles |
|---|---|---|---|---|---|---|---|---|
| | 2 Axles | 3 Axles | 4 Axles | 5 Axles | 6 Axles | 7 Axles | 8 Axles | 9 Axles |
| 43 | 70,500 | 75,000 | 80,000 | 85,000 | 90,500 | 96,000 | 100,500 |
| 44 | 71,500 | 75,500 | 80,500 | 85,500 | 91,000 | 96,500 | 101,000 |
| 45 | 72,000 | 76,000 | 81,000 | 86,000 | 91,500 | 97,500 | 102,500 |
| 46 | 72,500 | 76,500 | 81,500 | 87,000 | 92,500 | 98,000 | 103,000 |
| 47 | 73,500 | 77,500 | 82,000 | 87,500 | 93,000 | 98,500 | 103,500 |
| 48 | 74,000 | 78,000 | 83,000 | 88,000 | 93,500 | 99,000 | 104,000 |
| 49 | 74,500 | 78,500 | 83,500 | 88,500 | 94,000 | 99,500 | 105,000 |
| 50 | 75,500 | 79,000 | 84,000 | 89,000 | 94,500 | 100,000 | 105,500 |
| 51 | 76,000 | 80,000 | 84,500 | 89,500 | 95,000 | 100,500 | 106,000 |
| 52 | 76,500 | 80,500 | 85,000 | 90,500 | 95,500 | 101,000 | 106,500 |
| 53 | 77,500 | 81,000 | 86,000 | 91,000 | 96,500 | 102,000 | 107,000 |
| 54 | 78,000 | 81,500 | 86,500 | 91,500 | 97,000 | 102,500 | 107,500 |
| 55 | 78,500 | 82,000 | 87,000 | 92,000 | 97,500 | 103,000 | 108,000 |
| 56 | 79,500 | 83,000 | 87,500 | 92,500 | 98,000 | 103,500 | 108,500 |
| 57 | 80,000 | 83,500 | 88,000 | 93,000 | 98,500 | 104,000 | 109,000 |
| 58 | 84,000 | 89,000 | 94,000 | 99,000 | 104,500 |
| 59 | 85,000 | 89,500 | 94,500 | 99,500 | 105,000 |
| 60 | 85,500 | 90,000 | 95,000 | 100,500 | 105,500 |

* Tandem Axle by Definition.
+ Exception to Federal Bridge Formula Table and Law. See Text for Explanation.

**NOTE:** All permissible load calculations are to the nearest 500 lbs. Maximum load on any single axle, 20,000 lbs. Weights over 80,000 lbs. are in excess of the Federal GVW on the National Highway Network.