How To Determine The

Center of Gravity
and
Roll Over Angles
of
Your Jeep

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Any who would like a soft copy of the write up in MS Word format and the spreadsheet in MS Excel format should contact the author via email at:

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Table of Contents

Introduction

So often in our trail side conversations we talk about the CG (Center of Gravity) of one Jeep being higher or lower than the CG of another Jeep, and we relate this not only to the ability to get up or down a slope, but also to the dreaded thought of rolling over.

Yet most of us have never really figured out where the Center of Gravity is actually located on our own Jeep and similarly what the Rollover Angles are.

Why haven't we done this? Well to be honest, probably because it isn't so easy to do.

This write-up is an effort to provide a process that most folks can follow to determine, with a reasonable degree of accuracy, the Center of Gravity and Rollover Angles for their own Jeep.

There is some mathematics involved here, Algebra, Geometry and Trigonometry.

However, if you are like me and not a math wiz kid, don't let that scare you away. I have automated all the math via an Excel spreadsheet.

All that is really required is that you follow some simple directions, take some accurate weight and distance measurements, and then just plug the numbers into the spreadsheet.

If you hang in here with me and follow this process through you will be rewarded with the locations of the following values for your Jeep.

- The 3-Dimensional Single Point Center of Gravity of your Jeep as well as the:
  - Wheelbase Center of Gravity
  - Wheel Track Center of Gravity
  - Height of the Center of Gravity

- Roll Over Angles in four directions:
  - Driver Side
  - Passenger Side
  - Front
  - Rear

If you can use a tape measure, get a few minutes access to a truck "weighing scale" and you can type some numbers into a spreadsheet you can do this.

Capturing Weights and Measures

In this section you will take some specific measurements of your Jeep following these three process steps.

- Preparing your Jeep for off-road use
- Measuring lengths and heights in your driveway
- Measuring weights at a truck stop scale

Tools Needed

You will need the following tools.

- Tape Measure
- Access to a truck weighing scale for approximately 5 minutes
- A means to elevate the front tires of your Jeep at least 24 inches off the ground (Ramps, blocks, a trailer with car ramps on it, etc.)
- A Helper

Measured Values

During this process you will measure and record the values shown in the table below. Each will be explained in detail within this document.

Please note I have put fictitious numbers in this table to use in the examples throughout this document. You will need to record your own Jeep's data in this table for use in the formulas and spreadsheet. I have provided a blank table at the end of this document for you to use for this.

Label	Value	Description of Measured Values
Lengths		
LWB	95 in.	Length of the Wheelbase *(Axle center to axle center)*
LTB	65 in.	Width of the Track. *(Outer tire edge to outer tire edge)*
Heights		
HF1	17.4 in.	Height of Front Axle Hub *(center)* from the level ground.
HF2	42.7 in.	Height of Front Axle Hub *(center)* from ground while Front is Elevated.

Weights		
WF	2,600	Weight on Front Axle with Jeep Level
WP	2,100	Weight on Passenger side
WR1	2,200	Weight on Rear Axle with Jeep Level
WR2	2,415	Weight on Rear Axle when Front is Elevated

Convert any fractions to decimal values. For example, a wheelbase measurement of 92 and 5/16-inchs would be converted to 92.3125 inches. LWB = 92.3125

Here is a table to assist you in converting fractions to decimal format.

Fractions to Decimal Conversion Chart

* Fractions of an Inch *				Decimal
			1/16	0.0625
		1/8	2/16	0.1250
			3/16	0.1875
	1/4	2/8	4/16	0.2500
			5/16	0.3125
		3/8	6/16	0.3750
			7/16	0.4375
1/2	2/4	4/8	8/16	0.5000
			9/16	0.5625
		5/8	10/16	0.6250
			11/16	0.6875
	3/4	6/8	12/16	0.7500
			13/16	0.8125
		7/8	14/16	0.8750
			15/16	0.9375

Calculated Values

Using the data values you recorded above, the following values will be calculated and used in your efforts to determine the Center of Gravity and Rollover angles.

Label	Value	Description of Calculated Values
Calculated Values		
HFd	25.3 in	Difference between Front Hub Elevated and Front Hub when Level. *(HFd = HF2-HF1)*
LWBn	91.57 in	Length of wheelbase when front is elevated. *(LWBn=SQRT (LWB^2-HFd^2)*
WRd	215 lbs	Weight added to rear axle when front axle was elevated. *(WRd = WR2 – WR1)*
Wt	4,800	Total Weight of your Jeep. *(Wt = WF + WR1)*

If you would like, you can calculate these values yourself. I have provided a blank table for you to record these values in at the end of this document. However the Excel spreadsheet will perform this for you automagically!

Jeep Setup

Before you begin to make any measurements you will need to set your Jeep up just as if you were ready to take it off road. This setup vital to accurately determine the Off-Road Center of Gravity and Roll Over Angles of your Jeep.

Please do not skip this step.

Whatever you do to prepare your Jeep for an off road trip, do the same now.

Pack that toolbox, spare parts, Hi-Lift Jack and anything else that you would normally bring. Make sure everything is safely anchored down.

If you have two sets of tires, one for the street and another set for off road, put the off road tires on and air them down to the level you would use off road.

Fill your gas tank.

If you would normally off road with someone in the passenger seat, or any other seats for that matter, make sure this folks are available to keep these seats warm when you are taking the weight measurements.

I cannot overemphasize the importance of weight and weight distribution in and on your Jeep to accurately determine the Center of Gravity. Your efforts in setting your Jeep up now will be rewarded in accuracy later.

Off-Scale Measurements

These measurements should be taken away from the weight scale so the scale is not tied up when it isn't necessary.

With a friend, measure and record the following values.

Length of Wheelbase - LWB

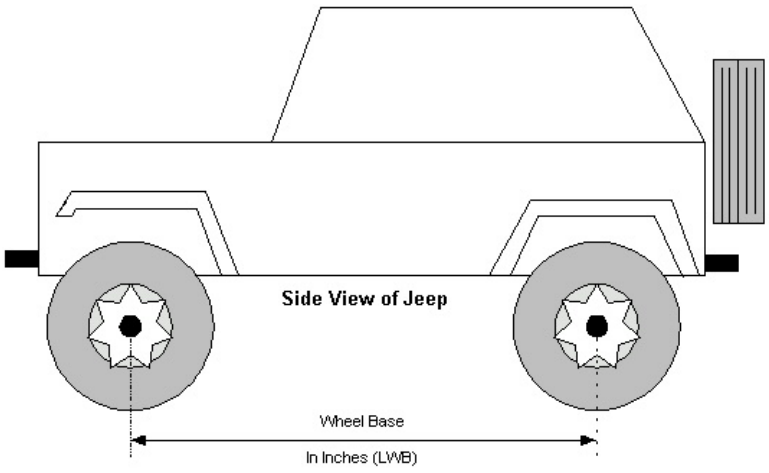
Measure your Jeep's wheelbase length while it is sitting on level ground and fully prepared for an off road trip.

Your Jeep's wheelbase is the distance between the centers of the front tire footprint on the ground and the rear tire footprint on the ground. This is a bit difficult to measure accurately, however we can get it by measuring the distance between the axle hubs.

With a friend, measure the distance between the center of the front axle hub and the center of the rear axle hub. This will be equal to the length of your Jeep's wheelbase.

Make all measurements accurate to a 1/16 of an inch.

Here is a drawing of what you will need to measure to capture the wheelbase length.



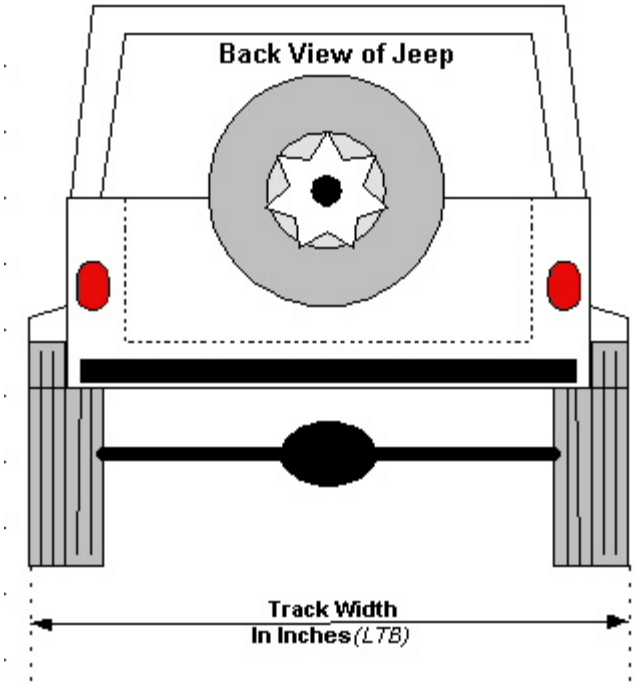
Measure your Jeep Wheel Base *(Center of Hub to Center of Hub)* **with the Jeep on Level Ground** *(LWB)*

Remember to convert fractions to decimal values.

Width of Wheel Track Base - LTB

Measure the distance between the outer edges of your rear tires. This is the Track Width of your Jeep. Convert any fractions to decimal values and record this measurement in inches as LTB.

Here is a drawing of the measurement you need to take.

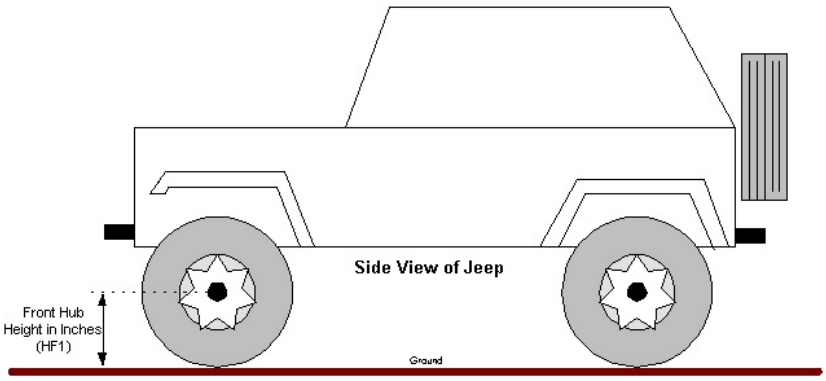


Measure the Width of the Rear Track
(Outer Tire Edge to Outer Tire Edge -LTB)

Front Axle Height – HF1

Measure the distance from the center of your front hub to the ground and record this as HF1.

Be sure your Jeep is sitting on level ground when you do this.



Measure the Height of the Front Hub *(Center of the Hub)* **from the Level Ground**. *(HF1)*

Weighing Your Jeep

Drive your Jeep over to the local friendly neighborhood weigh station.

Be sure to bring whatever means you will use to elevate the front axle with you, and remember to take whatever this is out of your Jeep before you weigh your Jeep.

Also remember to put those other warm bodies in their seats before you take any weight measurement. This includes you too!

Potential Scale Locations

- Major Truck Stops
- Highway Roadside Weigh Stations
- Agricultural Centers (Bulk Grain Sales)
- Salvage Yards
- Recycling Centers

The scale you choose should be accurate to at least 5 lbs. (1 lb would be better.)

Once you have identified the scale you would like to use, I have found it helpful to pay a visit to the friendly scale operator ahead of time. Explain what you want to do and how you will do it. Be nice and, be friendly! Maybe even entice the operator with a seat in your Jeep for next weekends trail ride.

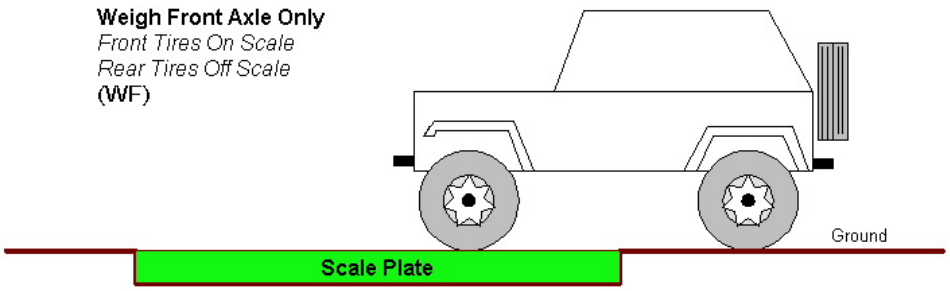
If all else fails try $10!

<u>Your objective is to get five to ten minutes on that scale!!!</u>

OK, now that you have the politics out of the way here's what you need to do.

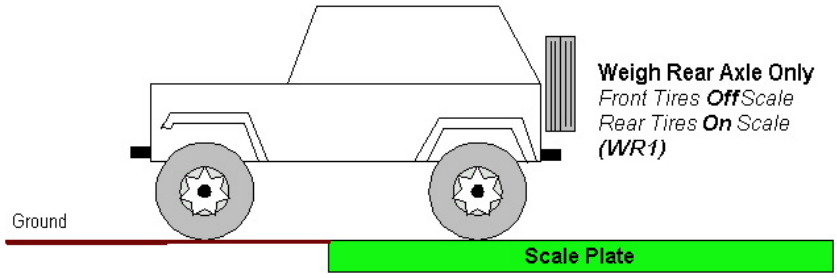
Front Axle Weight - WF

Weigh the front axles of your Jeep and record this weight as WF. To do this pull only your front tires onto the scale plate.



Rear Axle Weight – WR1

Weigh the rear axle of your Jeep by pulling the front tires off the scale plate and record this weight as WR1.



Rear Axle Weight Modified – WR2

You must come up with a means to lift the front axle of your Jeep, **by the tire patches**, at least 24-inches higher than on level ground.

DO NOT USE A JACK to do this. You MUST elevate your front axle **BY THE TIRE PATCHES** or the geometry will be thrown off and your calculation will be flawed. This is truly vital to the success of this process.

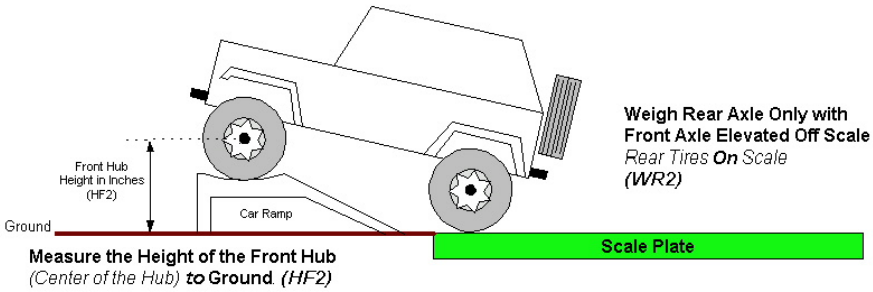
The first time I did this I used a set of 13-inch tall car ramps bolted to 12-inch square railroad ties. Yes this was a pain to carry there and back but it allowed me to lift the front, by the tire patches, a little more than 24 inches.

The second time I did this a friend volunteered the use of a flat bed trailer.

With the trailer parked in front of the scale plate, I put the trailer ramps down and my car ramps on top of the trailer bed. I drove my Jeep up and managed to get more than 30 inches of lift above level this way.

OK, have you figured out how you're going to elevate the front of your Jeep **BY THE TIRE PATCHES** yet?

Good, now weigh the rear axle with the front elevated (at least 24 inches) and record this weight as WR2.

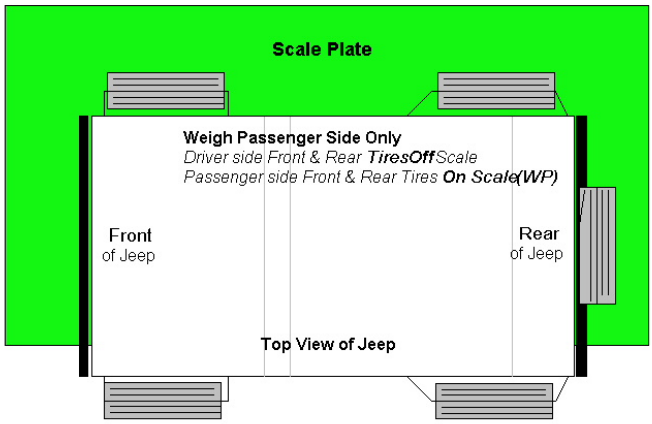


Front Axle Elevated – HF2

Measure the distance from the ground to the center of the elevated front hub and record this distance as HF2.

Passenger Side Weight – WP

Weigh the passenger side of your Jeep by pulling only the passenger side tires on the scale plate. Record this weight as WP.



You have now finished collecting all the data you will need to determine your Jeep's Center of Gravity and Rollover Angles. All that is left is to do is calculate a few formulas.

Calculating the Centers of Gravity

"X" The Wheelbase Center of Gravity (WBCG)

The easiest Center of Gravity coordinate to find is where the Center of Gravity lies relative to your Jeep's wheelbase.

The weight on your Jeep's front and rear axles is directly proportional to the location of the Center of Gravity along your Jeep's wheelbase. In fact, it is a direct inverse ratio.

Think about it.

If 100% of the weight of your Jeep was located on the front axle, the Center of Gravity would be located ZERO inches, or 0% of the wheelbase distance from the front axle.

If the weight were distributed 60% on the front axle, then the Center of Gravity would be located 40% of the wheelbase distance from the front axle.

To calculate your Jeep's **WBCG** (Wheelbase Center of Gravity) you will use the data values you measured and recorded earlier.

Once again, please remember I am using fictitious data in these examples. You will need to substitute your measurements, or type them into the spreadsheet.

LWB = 95 inches = Wheelbase in Inches
WF = 2,600 lbs = Weight on Front Axle
Wt = 4,800 lbs = Total weight of Jeep

The following formula will enable you to determine in inches where the **WBCG** is located behind your Jeep's front axle.

(1 - (WF / Wt)) * LWB = WBCG location, in inches, behind the front axle.

(1 - (2,600 / 4,800)) * 95 =

(1 - 0.541667) * 95 =

0.46 * 95 = **43.54 Inches behind the front axle**

"Y" The Wheel Track Center of Gravity (WTCG)

The location of your Jeep's **WTCG** (Wheel Track Center of Gravity) is calculated in much the same way as you just calculated the WBCG.

The WTCG coordinate location is a direct inverse ratio of the weight on each side of your Jeep to the wheel track.

Here are the data elements you will need to use for this formula.

LTB = 65 inches - Width of your wheel track
WP = 2,100 lbs – Weight on passenger side of your Jeep
Wt = 4,800 lbs – Total weight of your Jeep

The following formula will enable you to determine in inches where the **WTCG** is located from the outer tire edge on the passenger side of your Jeep.

Substitute the data values you measured and recorded and then simplify and solve the formula as in this example.

(1 - (WP / Wt)) * LTB = WTCG in inches, from the passenger side tire edge

(1 - (2,100 / 4,800)) * 65 =

(1 - 0.4375) * 65 =

0.5625 * 65 = **36.56 Inches from the passenger side outer tire edge**

"Z" The Center of Gravity Height (HTCG)

The Height of your Jeep's Center of Gravity (**HTCG**) is not quite as easy to determine.

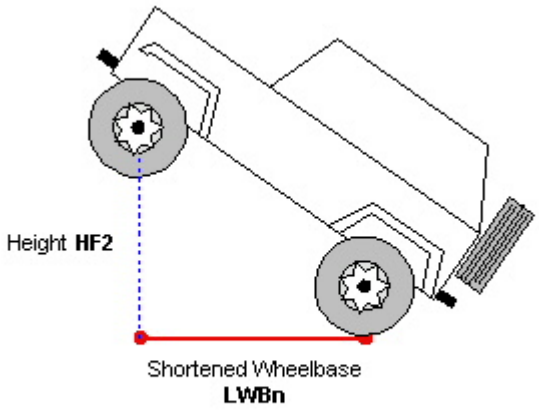
Calculating the HTCG is a bit more difficult to accomplish. It's difficult for some people to even visualize, and difficult for me to explain.

Let me give it a shot.

When you went about measuring and weighing your Jeep, one of the things you did was lift the front axle (at least 24 inches higher than it would be on level ground) and then you weighed the rear axle.

When you lifted the front, you in effect shortened the wheelbase as it relates to gravity. In other words, the horizontal distance between the front and rear tire patches became shorter than what it is on level ground.

Here is a drawing that might help in understanding this.



When the front axle is elevated the horizontal distance between the front and rear tire patches becomes shorter.
We will calculate this shortened wheelbase (LWBn) with a formula.

Now, if we can measure how high we lifted the front axle, calculate the length of this shortened wheelbase, and determine how much weight was added to the rear axle when we lifted the front, we will be able to calculate the Height of your Jeep's Center of Gravity (HTCG).

Here are three formulas you must solve before you can get to the HTCG.

HFd = HF2 - HF1 = Height difference between front axle level and elevated

HFd = 42.7 – 17.4

HFd = 25.3 inches

LWBn=SQRT (LWB^2 - HFd^2) = Length of the shortened wheelbase when elevated

LWBn=SQRT (95^2 – 25.3^2)

LWBn=SQRT ((95 * 95) – (25.3 * 25.3))

LWBn=SQRT (9025 – 640.09)

LWBn=SQRT (8384.91)

LWBn=91.57 inches

WRd = WR2 – WR1 = Weight added to rear axle

WRd = 2,415 – 2,200

WRd = 215 lbs.

OK, now you have all the data needed to find the Height of your Jeep's Center of Gravity (HTCG).

Here's the formula.

HTCG = HF1 + ((WRd * LWB * LWBn) / (Wt * HFd)) = Your Jeep's CG Height

HTCG = 17.4 + ((215 * 95 * 91.57) / (4,800 * 25.3))

HTCG = 17.4 + (1,870,317.2 / 121,440)

HTCG = 17.4 + 15.40

HTCG = 32.80 Inches above the tire patches

Roll Over Angles

So where are we?

We now know the X, Y, and Z coordinates that define the 3D Center of Gravity of your Jeep.

In the example I've been using. the Center of Gravity is located at a point,

43.54 Inches behind the front axle,
36.56 Inches from the passenger side outer tire edge, and
32.80 Inches above the Jeep's tire patches.

Can you see it?

If you can find the single point represented by these three coordinates, you can find the Center of Gravity of your Jeep!

Some people can visualize this; others like myself have a harder time of it.

For the sake of this discussion, let's just say these three coordinates define the Center of Gravity as the Radio Volume Control Knob!

What's that? You don't have a radio in your Jeep?

Borrow one in your mind's eye!

The CG "Balancing Point"

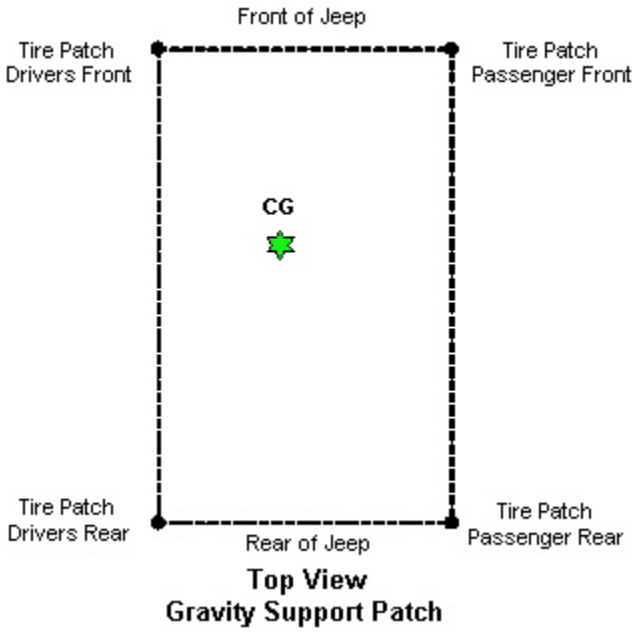
The Center of Gravity represents the single point where the average weight of the Jeep is located. You can think of this as the "Balancing Point".

If you could somehow reach the Center of Gravity with a long pole you could support the Jeep from that pole and rotate the Jeep in any direction, 360 degrees, in 3D and the Jeep would not fall.

Fortunately for us, we do not have to support our Jeep's Center of Gravity from a pole, nor do we want to balance it in a 360-degree sphere. We do however balance it; we do this under normal conditions by balancing the Center of Gravity on our tire patches.

If you were to look at the location of your Jeep's Center of Gravity from the top, you would see that it falls within the rectangular support structure formed by your tires on the ground.

Here's a drawing that might help you visualize this.



Top View
Gravity Support Patch

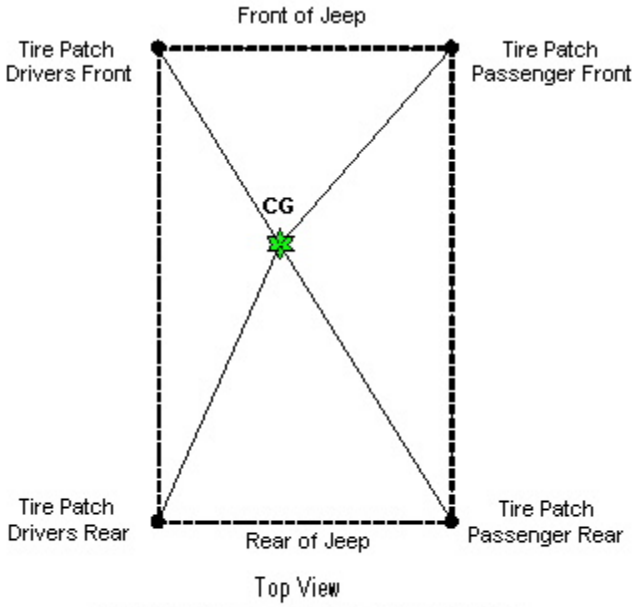
This is goodness! This is a stable condition!

Notice that the Center of Gravity is located within the "Physical Geometry" of all four tires even though it is not centered. It is located at the X and Y coordinates which you calculated.

(In all likelihood your Jeep's Center of Gravity will not be centered either.)

Another way to look at this is that the Center of Gravity (under normal conditions) is being balanced on top of a pyramid (instead of a pole) with the Center of Gravity at the apex of four unequal sides.

Take a look at this top-view drawing. Perhaps it will help you to visualize this.



CG Balanced on Top of A Pyramid.
Tires Form Four Base Corners

As long as your Jeep's Center of Gravity is contained within the gravity support structure (Gravitational Geometry) formed by the tires, your Jeep will not roll.

If your Jeep's Center of Gravity is allowed to move outside the gravity support structure formed by your tires, your Jeep will roll!

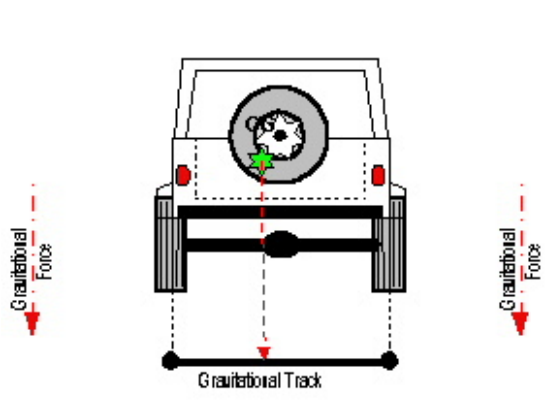
This is a basic law of physics.

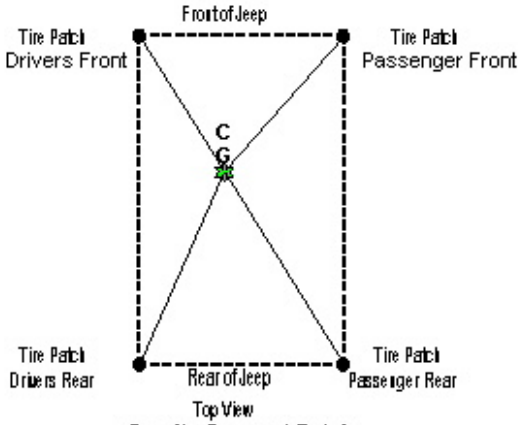
Anatomy of a Roll Over

If you position your Jeep in such a way that the Center of Gravity is moved outside the gravity support structure of your tires, your Jeep will become unstable and will roll.

Lets look at this from another view, from the rear.

When your Jeep is on level ground looking from the back the Center of Gravity is contained between the driver and passenger side tires, or in other words, within the gravitational support structure.

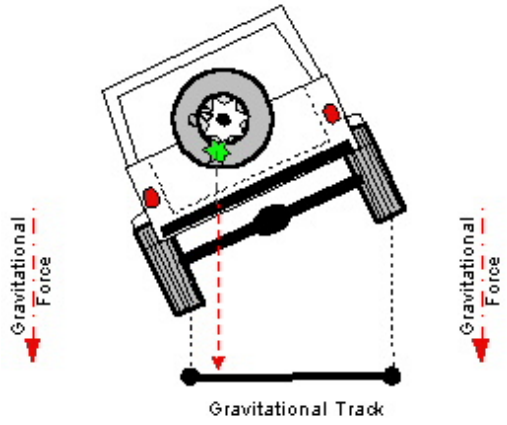


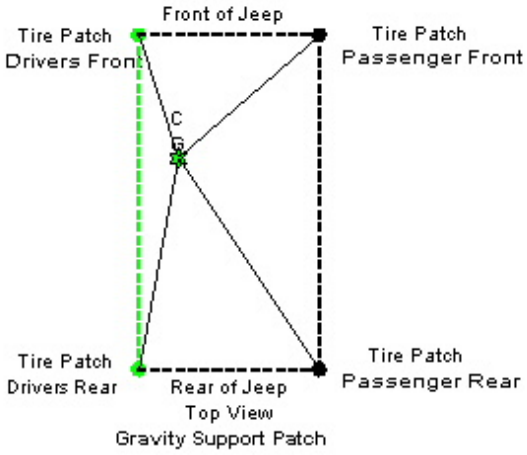


Jeep on level surface. Center of Gravity is well within the Gravitational Track of the Jeep. There is no chance of a roll over .

As your Jeep is positioned somewhat off-camber to the driver's side, the Center of Gravity (CG) will move closer to the edge of the gravitational support structure (green line).

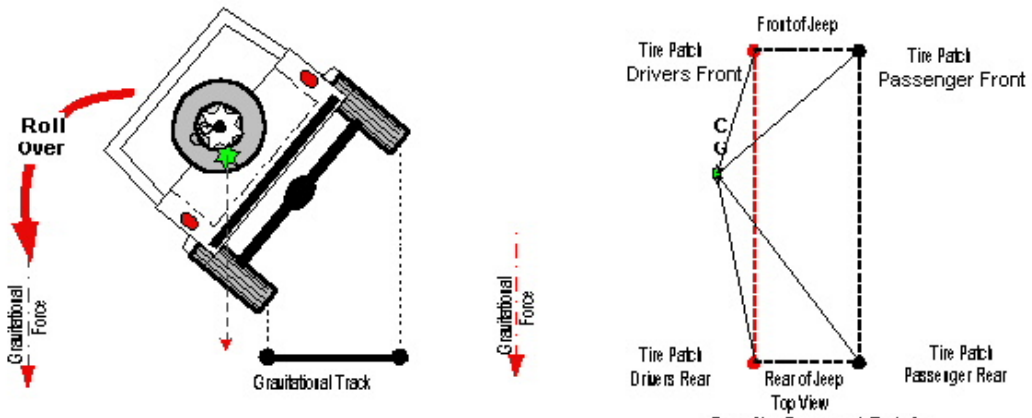
Note that the Center of Gravity did NOT MOVE in relation to the Jeep itself. (It is still the Radio Volume Control Knob.)





Jeep is off-camber, yet Center of Gravity is will within the Gravitational Track.

If you position your Jeep too far off-camber, the Center of Gravity will move outside the gravitational support structure (red line) created by your tires and your Jeep will roll.



Camber Angle is Too Steep! Gravitational Track is very small AND Center of Gravity is outside the Gravitational Track. This Jeep is going to Roll Over !!!

Why do we roll?

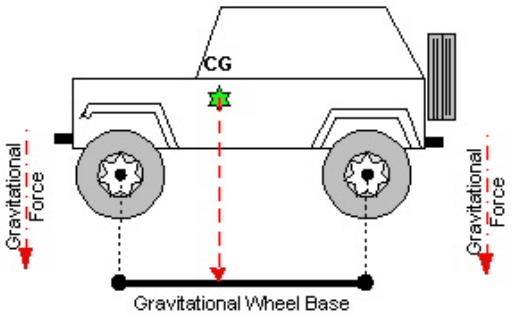
We roll because the Center of Gravity is no longer balanced under our “preferred gravity support structure” formed by our tires!

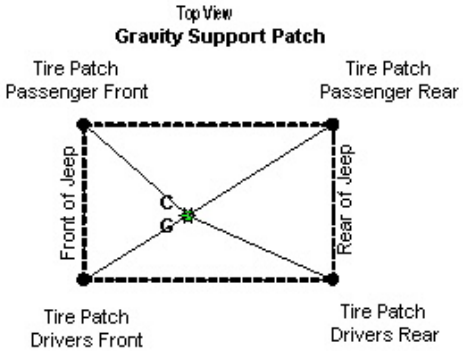
This is a basic law of Physics.

The Center of Gravity is always balanced (contained) within the gravitational geometry of some support structure.

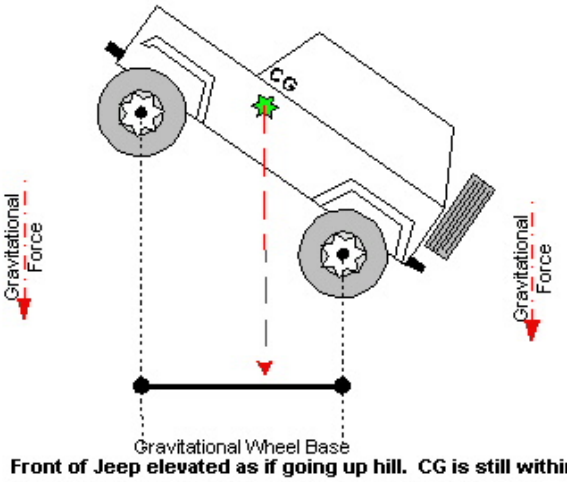
If the Center of Gravity is moved outside one structure (your tires), the Center of Gravity will be supported by another support structure. (Like the side of your Jeep!)

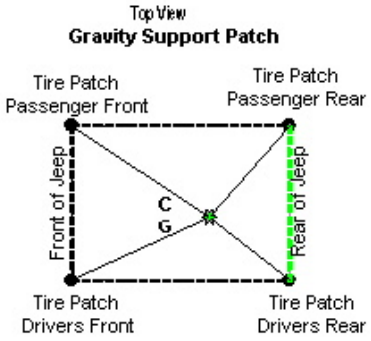
Here is what this looks like for a rearward roll over.



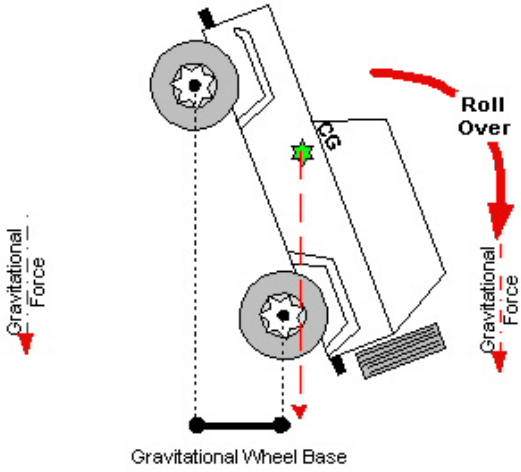


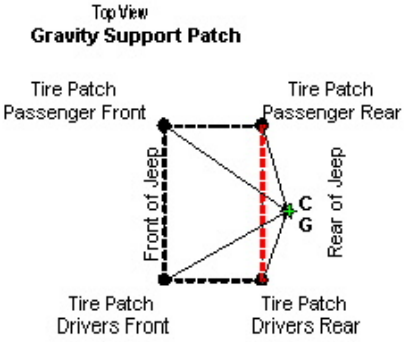
Jeep on level surface. Center of Gravity is well within the Gravitational Wheel Base. No chance of a roll over.





Front of Jeep elevated as if going up hill. CG is still within the Gravitational Wheel Base, however, Gravitational Wheel Base is much smaller, increasing risk of a roll over.





Incline is Too Steep! Gravitational Wheel Base is very small AND Center of Gravity*Falls*outside the Gravitational Wheel Base. This Jeep is going to*Roll Over*!!!

Similar drawings for a passenger side roll over and a forward direction roll over could be drawn but I'm tired. I'm sure you get it visualize these as well.

As you now know, the Center of Gravity can be moved outside the gravitational geometry of the support structure formed by the tires. When this happens the Jeep will roll.

But when will this happen?

This will happen at a certain angle in each of four directions, based on the location of your Jeep's Center of Gravity.

Here's how to calculate these angles for your Jeep.

Calculating Roll Over Angles

If you have done the work to determine where the Center of Gravity is located for your Jeep you have all the information you need to calculate your four roll over angles.

Here are the data elements you will be using.

Required Data Elements to Determine Roll Over Angles

Label	Value	Description of Data Element for Roll Over Angles
LWB	95 in.	Length of the Wheelbase *(Axle center to axle center)*
LTB	65 in.	Width of the Track. *(Outer tire edge to outer tire edge)*
WBCG	43.54.	Wheel Base Center of Gravity behind Front Axle = (1 - (WF / Wt)) * LWB = WBCG
WTCG	36.56	Wheel Track Center of Gravity from the passenger side outer tire edge = (1 - (WP / Wt)) * LTB = WTCG
HTCG	32.80	Your Jeep's CG Height = HF1 + ((WRd * LWB * LWBn) / (Wt * HFd)) = HTCG

Please note the formulas that follow contain the trigonometry function of Arc Tangent, which presents a solution in "Radians". (Yes radians are totally useless in the Jeep'n world, unless you're a rocket scientist.)

Radians are then converted into "Degrees" (I understand degrees!) through the use of a published standard mathematics table.

Both Arc Tangents and Radian to Degree Conversions are outside my ability to explain in this document.

This is the only time I will ask for your faith without an adequate explanation. Newton, Galileo and Einstein have all proved this functions out. That's good enough for me. I hope it is good enough for you as well.

You can perform these calculations on most good scientific calculators, or you can use the Excel spreadsheet I will provide to do this math automagically for you.

Side Roll Over Angle - WARNING!!!

As stated at the top of this write-up, this process will help you determine the Center of Gravity and Roll Over Angles for your Jeep "with a reasonable degree of accuracy".

That is true, however I need to make you aware of a particular off-road condition and it's potential effects on Side Roll Over Angles.

This is important because it is NOT ADDDRESSED in these formulas.

In truth I do not know how to calculate these variables.

I do know it is prudent to make you aware of any potential that could DECREASE your Side Roll Over Angles and present you with a rather unpleasant surprise.

PLEASE READ THIS!

The formulas for Driver and Passenger Side Roll Over Angles DO NOT take into consideration or calculate the potential effect of the down-slope tires "rolling, sliding or tucking" under the wheels.

How much your tires may "tuck" under the wheels will depend on tire size, profile, air pressure, sidewall strength and slope of the angle.

When tires "tuck" under the wheels two physical events occur.

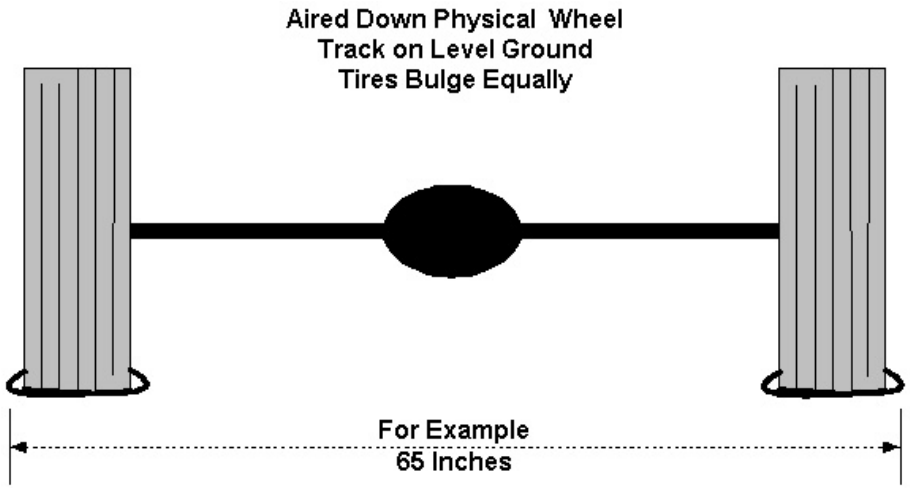
1. The Physical Width of your Jeep's Wheel Track is shortened.

   This, in combination with the angle your Jeep is on, will result in an UNKNOWN DECREASE in Roll Over Angle! (This is NOT Goodness.)

2. The Vertical Height of your Jeep's Center of Gravity will be lowered.

   This will result in an UNKNOWN INCREASE in Side Roll Over Angle. (This is Goodness.)

Here are two drawing in which I believe you will get a clearer picture of what is going on when a tire tucks under your wheels. Please look closely at the down slope tires.

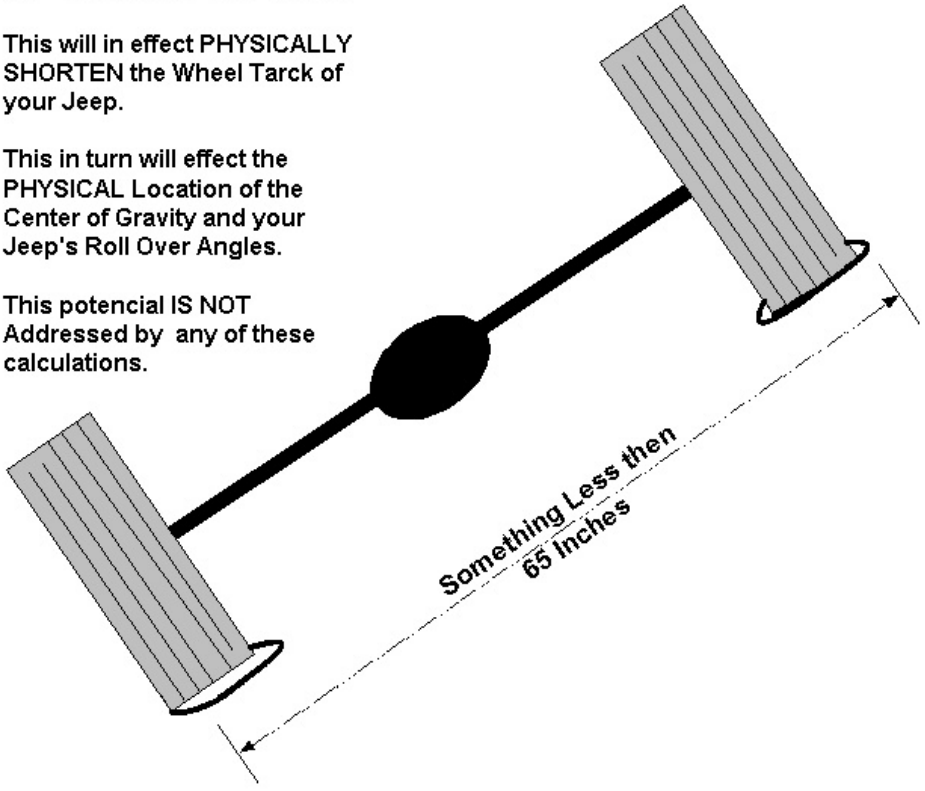


When aired down and your Jeep is on a slope THERE IS A POSSIBILITY the down hill tires will "Tuck Under" the wheels.

This will in effect PHYSICALLY SHORTEN the Wheel Tarck of your Jeep.

This in turn will effect the PHYSICAL Location of the Center of Gravity and your Jeep's Roll Over Angles.

This potencial IS NOT Addressed by any of these calculations.



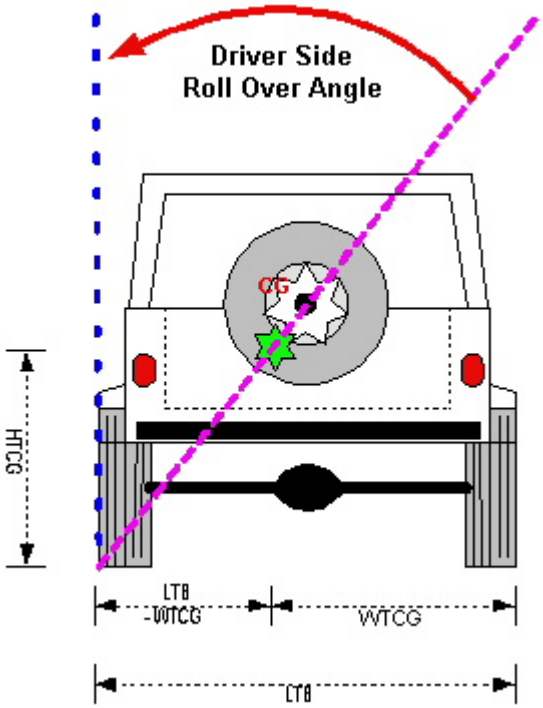
Please note I do not know of any means of calculating these effects at this time.

Perhaps in the near future we will.

Driver Side Roll Over Angle "DSROA"

What we will be determining is how many degrees to the left you can take your Jeep before the Center of Gravity pierces the vertical plan of gravity and extends outside the gravitational support structure formed by the tires.

Here is a drawing of what we are going to solve.



The vertical blue line represents the vertical pull of gravity on your Jeep. It intersects the angled pink line, which runs between the outer edge of the driver side tire and the Center of Gravity of your Jeep.

The angle that is formed between these two lines is the Driver Side Roll Over Angle.

Here is the formula we will use to calculate the **DSROA**.

DSROA = DEGREES (ATAN ((LTB–WTCG)/HTCG))

DSROA = DEGREES (ATAN ((65–36.56)/32.80))

DSROA = DEGREES (ATAN (28.44/32.80))

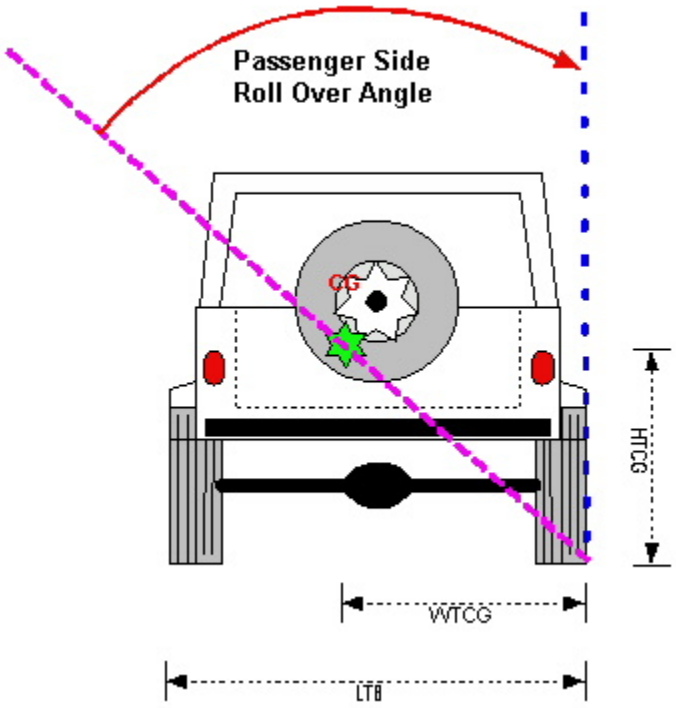
DSROA = DEGREES (ATAN (0.8670731))

DSROA = **40.92 Degrees Left = Driver Side Roll Over Angle**

Passenger Side Roll Over Angle "PSROA"

What we will be determining is how many degrees to the right you can take your Jeep before the center of gravity pierces the vertical plan of gravity and extends outside the gravitational support structure of your tires.

Here is a drawing of what we are going to solve.



The vertical blue line represents the vertical pull of gravity on your Jeep. It intersects the angled pink line, which runs between the outer edge of the passenger side tire and the Center of Gravity of your Jeep.

The angle that is formed between these two lines is the Passenger Side Roll Over Angle.

And here is the formula we will use to calculate the **PSROA**.

PSROA = DEGREES (ATAN (WTCG/HTCG))

PSROA = DEGREES (ATAN (36.56/32.80)

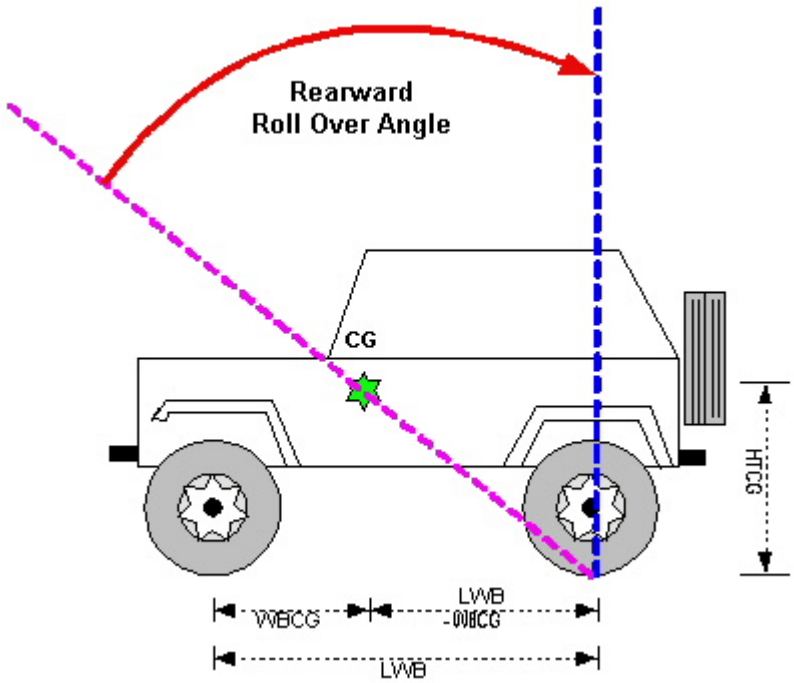
PSROA = DEGREES (ATAN (1.1146341)

PSROA = **48.10 Degrees Right = Passenger Side Roll Over Angle**

Rearward Roll Over Angle "RWROA"

What we will be determining is how many degrees to the rear you can take your Jeep before the center of gravity pierces the vertical plan of gravity and extends outside the gravitational support structure formed by the tires.

Here is a drawing of what we are going to solve.



The vertical blue line represents the vertical pull of gravity on your Jeep. It intersects the angled pink line, which runs between the centerline of the rear tire patch and the Center of Gravity of your Jeep.

The angle that is formed between these two lines is the Rearward Roll Over Angle.

And here is the formula we will use to calculate the **RWROA**.

RWROA = DEGREES (ATAN ((LWB–WBCG)/HTCG))

RWROA = DEGREES (ATAN ((95–43.54)/32.80))

RWROA = DEGREES (ATAN (51.46/32.80))

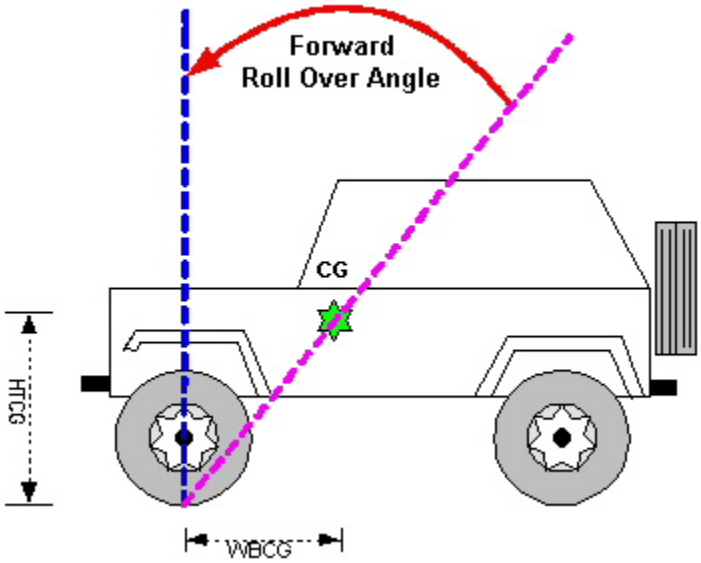
RWROA = DEGREES (ATAN (1.5689024))

RWROA = **57.49 Degrees Backward = Rearward Roll Over Angle**

Forward Roll Over Angle "FWROA"

What we will be determining is how many degrees to the front you can take your Jeep before the center of gravity pierces the vertical plan of gravity and extends outside the gravitational support structure formed by the tires.

Here is a drawing of what we are going to solve.



The vertical blue line represents the vertical pull of gravity on your Jeep. It intersects the angled pink line, which runs between the centerline of the front tire patch and the Center of Gravity of your Jeep.

The angle that is formed between these two lines is the Forward Roll Over Angle.

And here is the formula we will use to calculate the **FWROA**.

FWROA = DEGREES (ATAN (WBCG/HTCG))

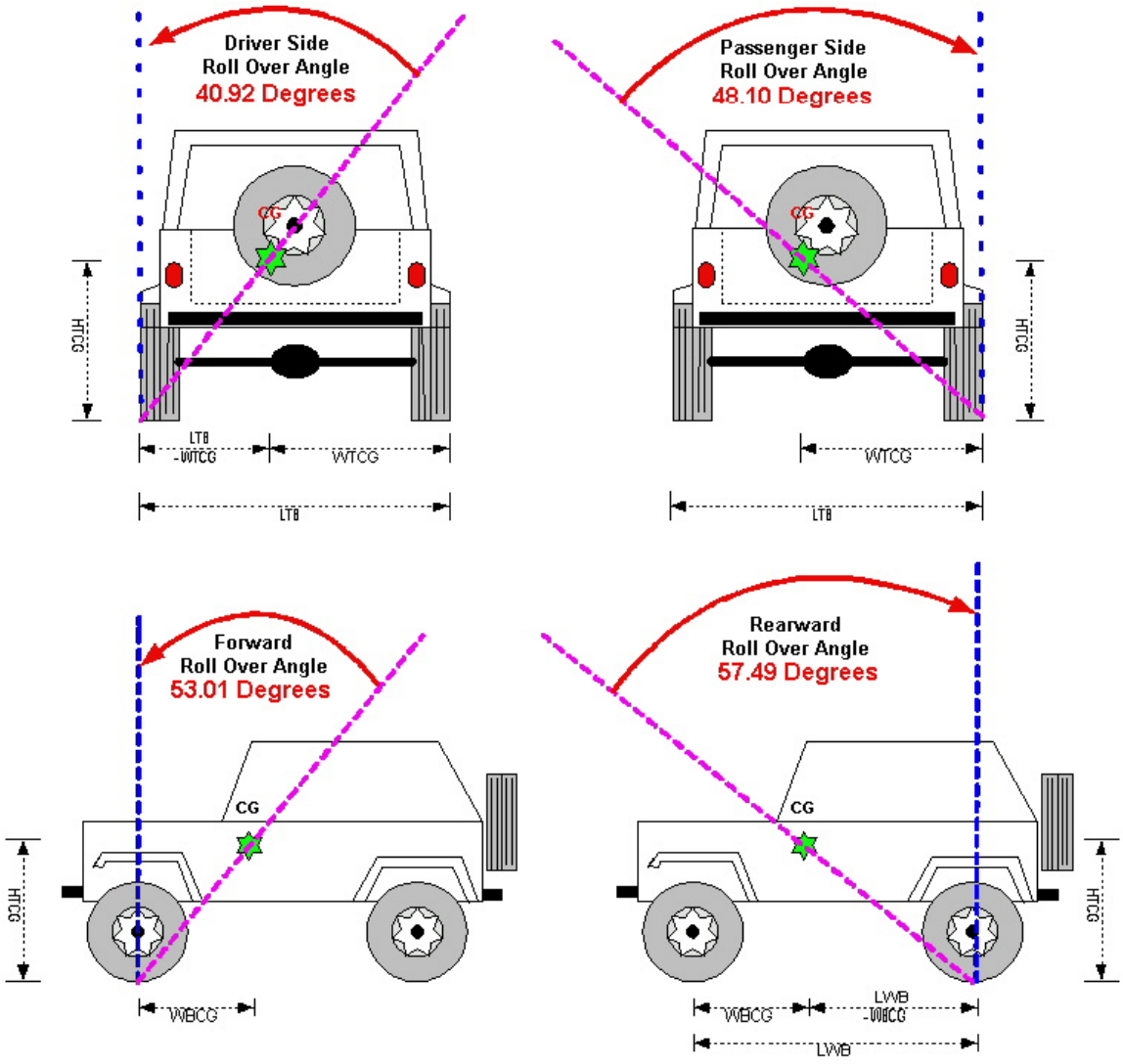
FWROA = DEGREES (ATAN (43.54/32.80))

FWROA = DEGREES (ATAN (1.327439))

FWROA = **53.01 Degrees Forward = Forward Roll Over Angle**

Summary of Roll Over Angles

The Roll Over Angles we just calculated for our fictional Jeep will look like this.



The Higher the Roll Over Angle the Better!

Think of the Roll Over Angle as a buffer, the defined operating range in all four directions where your Jeep will remain stable and unlikely to roll over.

The greater this range (angle), the more you will be able to "safely conquer" in your Jeep.

Can you see the relationship between the physical location of the Jeep's Center of Gravity and the Jeep's gravitational support structure (tire patches)?

> **The greater the horizontal distance between your Jeep's Center of Gravity and the tire patch, the greater the Roll Over angle will be.**

Check it out in the drawing above.

Can you see the relationship between the Height of the Center of Gravity and each Roll Over Angle?

> **The lower you can get your Jeep's Center of Gravity to the ground, the greater all of your Jeep's Roll Over Angles will be.**

Conversely, if you raise your Jeep's Center of Gravity you will decrease all of your Jeep's Roll Over Angles.

Tuning your Jeep's Roll Over Angles

Now that you know how to calculate the Center of Gravity and the Roll Over Angles for your Jeep the question becomes "What to do with this information?"

Well one thing you can do is "tune" your Jeep to get the Center of Gravity and Roll Over Angles more to your liking.

Here are a few of the many actions you can take to "tune" your Jeep's Center of Gravity and Roll Over Angles.

- Lengthen wheelbase and/or wheel track
- Redistribute Physical Weight
- Lower Location of Physical Weight
- Remove Unneeded Weight
- Apply or Remove Cantilevered Weight

Gravity Support Structure

Lengthen the Wheel Base or Widen the Wheel Track

This action will increase the size of the gravitational support structure on which the Center of Gravity is balanced and increase your Jeep's Roll Over Angles. (Goodness)

Lengthening the wheelbase or widening the wheel track is something akin to putting outriggers on a canoe. They help keep it from turning over.

Weight Tuning

The next four examples all deal with weight. To best understand these it would be helpful to have a general understanding of the effects of "weight placement" on your Jeep.

Where weight is placed along the wheelbase of your Jeep, or even outside the wheelbase of your Jeep, will have significant effects on the weight carried by each axle. This will affect the location of the Center of Gravity and your Jeep's Roll Over Angles.

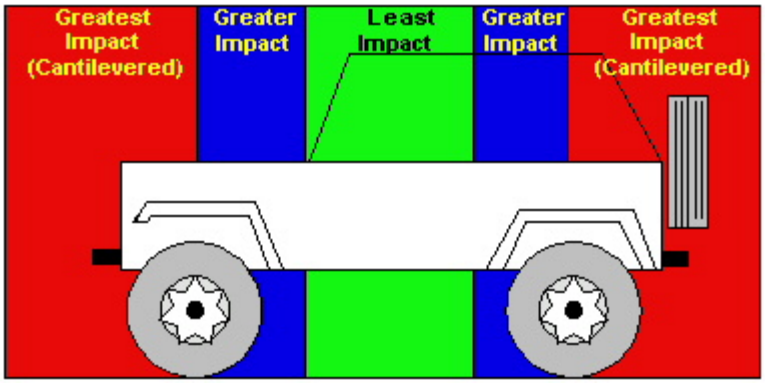
The closer weight is located to the center of your Jeep's wheelbase the more equally that weight will be distributed on both axles. (See Green Zone in drawing below.)

As the weight is moved closer to one of the axles, a higher percentage of weight will be placed on that axle and a smaller percentage of weight will fall over the axle farthest away. (See Blue Zones)

Things get real interesting when we hang, or cantilever weight beyond your Jeep's wheelbase.

Cantilevered weight has the most dramatic effect on the weight distribution. (See Red Zones.)

Weight Placement and Weight Effects on Axles



Redistribute Physical Weight

Redistribute physical weight from one part of your Jeep to another part.

This will move the Center of Gravity in the direction you are moving the weight and away from the location where the weight came from.

This will alter Roll Over Angles. (Could be good, or not so good.)

Lower the Physical Location of Weight

Any time existing weight can be lowered you will lower the Center of Gravity of your Jeep.

A lower Center of Gravity will create greater Roll Over Angles. (Goodness.)

Remove Unneeded Weight

Removing unneeded weight will affect the height of your Jeep's Center of Gravity.

However, be aware! Removing weight can either raise or lower the height of your Jeeps Center of Gravity.

- Weight you remove that was BELOW the original Height of the Center of Gravity will cause the new Center of Gravity to rise. (Think removing your skid plates)

  If the Center of gravity goes up, the Roll Over Angles will Decreases (Not goodness).

- Weight that you remove that was ABOVE the originally Height of the Center of Gravity will result in a new lower Center of Gravity. (Think removing a hard top.)

  If the Center of Gravity goes down, the Roll Over Angles will increase. (Goodness!).

Apply or Remove Cantilevered Weight

Yes, this is the real interesting weight placement.

Any weight hanging in front of the front axle or behind the rear axle is called cantilevered weight.

Cantilevered weight has a "force multiplying" effect on the weight distribution over your axles and on the location of your Jeep's Center of Gravity.

There are two unique physical effects of cantilevered weight.

1. Cantilevered weight will increase the weight on the nearest axle by an amount GREATER than the actual weight being added.

2. Cantilevered weight will cause a fractional DECREASE in the weight on the axle farthest away.

The effects of cantilevered weight on your Jeep can be calculated prior to actually adding the weight.

Here are the data elements you will need and the formulas to calculate the effects of cantilevered weight.

Date Elements Required to Calculate Effects of Cantilevered Weight	
AddW	Weight of the object you are going to place in a cantilevered position
CantD	The distance from the axle center to the weight you are adding
LWB	The length of your Jeep's Wheelbase

In this example we will add a winch and mounting plate to the front of a Jeep.

AddW = 150 lbs = Weight of winch and mounting plate

CantD = 26 inches = Distance to front axle center from center of the winch plate

LWB = 95 inches = Length of the Jeep's Wheelbase

Here is a formula that can be used to determine the weight that will be added to the front axle as a result of mounting a 150 lbs winch on the front bumper.

(AddW * CantD) / LWB + AddW = Weight added to front axle

(150 * 26) / 95 + 150 =

(3900 / 95) + 150 =

41.05 + 150 = **191.05 lbs added to front axle**

And here is the formula to determine the how much weight will be removed from the rear axle as a result of mounting this winch on the front bumper.

(AddW * CantD) / LWB = (Weight removed from Rear Axle)

(150 * 26) / 95 =

(3900 / 95) = **41.05 lbs of weight removed from rear axle**

In summary, the winch and mounting plate added a total of 150 lbs of new weight to the Jeep. However, because of this weight's cantilevered placement the effects on the front and rear axle weights are far greater than 150 lbs.

- Front axle weight goes up by 191 lbs. That is 27% more weight then the winch and mounting plate actually weigh.

- The rear axle received a weight reduction of 41.05 lbs because of the leverage effect of the cantilevered weight.

- The Jeep's Wheelbase Center of Gravity was also changed. It was shifted forward toward the front axle by a multiple of the weight added.

If you care to you can go back and recalculate the new WBCG by adding and subtracting these weights from the front, back and total of our example Jeep. You will see that the Wheelbase Center of Gravity has indeed been moved forward as a result of mounting the winch on the front bumper.

ROA Alarm System

I am in the process of developing a two-axis (X and Y) Roll Over Angle Alarm System for my Jeep. This system will monitor the dynamic angles on my Jeep and provide a warning when I am approaching predefined Roll Over Angles.

This effort is currently incomplete.

This ROA Alarm System will incorporate the following design functions and attributes.

- Provide the ability to monitor my Jeep's dynamic angles.
- Enable the setting of individual roll over angle "trigger points", in degrees, in four directions. (Left, Right, Forward, Backward.)
- Provide an audible alarm when trigger points have been reached.
- All "trigger points' will have a built in design error of 2 to 3 degrees to provide a margin of safety.
- System must be small (Jeep real estate is valuable) and easily mounted and removed from the inside of my cab.
- System must be relatively inexpensive ($100 Max) and be within the capabilities of a reasonably skilled person to build.

Wilson Instruments

Recently I have become aware of a patent pending product called ClinoExtreme, which is made by the folks at Wilson Instruments in Sacramento, CA.

While I am still trying to get my hands on one of these units, my first and second glace tells me this may be exactly what I am looking for. If it is and the cost is reasonable I will drop my efforts to develop my own Roll Over Angle Alarm System.

If you have an interest in learning more about this Wilson Instruments product here is their web address:

http://www.wilsoninstrumentsmfg.com/clinoextreme.htm

Here are the highlights of the ClinoExtreme unit, as I understand them.

- Dual Electronic Clinometers (Front/Back Pitch and Side to Side Roll)
- No moving parts (accept for the gauge needles)
- Warning Angle Alarms programmable by the end user via a RS232 computer interface
- Cost is unknown at this time

When I get my hands on one of these units I will let you know how it works out for me.

C of G / ROA Spreadsheet

I have a complete Excel spreadsheet titled “CoG_ROA.xls” which will accompany this write-up.

There are two pages to this spreadsheet titled “COG-ROA” and “Data Collection”.

Use the COG-ROA page to enter your Jeep’s weights and measurement and obtain your Jeep’s Center of Gravity and Roll Over Angles.

The “Data Collect” page is optional. I am trying to collect data pertaining to this topic.

I am requesting that you complete this page and sent the entire spreadsheet to Daless2@Yahoo.com

I plan to build an online database that will let you compare your Jeep’s CG and ROA to other Jeeps in your class.

All data will be added to the database anonymously.

Sending this spreadsheet in is certainly optional, but I would appreciate receiving the data and I believe it will be helpful to all. Once enough data is in.

Here are the two spreadsheet pages.

Enter Your Jeep's Data in the Green Value Fields Below.		
Label	**Value**	**Description**
LWB	**95.0** Ins.	Length of your Jeep's the wheelbase (axle center to axle center)
LTB	**65.0** Ins.	Width of the wheel track. (outer tire edge to outer tire edge)
HF1	**17.4** Ins.	Height of front axle hub (center) from the level ground
HF2	**42.7** Ins.	Height of front axle hub (center) from ground while front is elevated
WF	**2,600** Lbs.	Weight on front axle with your Jeep level
WP	**2,100** Lbs.	Weight on passenger side of your Jeep
WR1	**2,200** Lbs.	Weight on rear axle with your Jeep level
WR2	**2,415** Lbs.	Weight on rear axle when front is "elevated"

These values will be calculated for you.		
Label	**Value**	**Description**
HFd	**25.3** Ins.	Difference between front hub elevated and front hub when level
LWBn	**91.6** Ins.	Length of wheelbase when front is elevated
WRd	**215** Lbs.	Weight added to rear axle when front axle was elevated
Wt	**4,800** Lbs.	Total weight of your Jeep

Center of Gravity Locations for Your Jeep

Wheel Base Center of Gravity

43.54 Ins. Behind the front axle

Wheel Track Center of Gravity

36.56 Ins. From the outer edge of the passenger side tires

Height of your Jeep's Center of Gravity

32.80 Ins. From the bottom of the tires

Roll Over Angles for Your Jeep

Drivers Side Roll Over Angle

40.92 Degrees Left

Passenger Side Roll Over Angle

48.10 Degrees Right

Rearward Roll Over Angle

57.49 Degrees Back

Forward Roll Over Angle

53.01 Degrees Forward

Daless2@Yahoo.com

A Request for your Assistance.

I am planning to create an online database containing data related to Center of Gravity and Roll Over Angles for as many Jeeps as I can get.

If you find this spreadsheet and write-up helpful I would appreciate if you would complete this page as well as the COG-ROA page of this spreadsheet and email the spreadsheet to me. Your data will be anonymously added to the online database I plan to build.

Once built you will be able to compare your Jeep's C of G and ROA against other Jeeps in the database.

Please send your complete spreadsheet to **Daless2@Yahoo.com**

	Model (TJ, YJ, CJ5, CJ7, XJ, ZJ etc,)	**Please enter the appropriate answers that reflects your Jeep's configuration in the green fields to the left.**
	Year (19xx or 20xx)	
	Engine Cylinders (4/ 6/ 8)	
	Full Door, Half Doors, No Doors (F/H/N)	
	Lift Height in Inches (2/3/4/5/6/8)	
	Tire Height in Inches (29 through 44)	
	Tire Width in Inches (9.50, 10.50, 11.50 etc)	
	Auto Transmission (Y/N)	**Please indicate if these items are on your Jeep.** Enter **Y** for Yes, or Enter **N** for NO, **in the green fields to the left**.
	Hard Top (Y/N)	
	Winch (Y/N)	
	Heavy Duty Front Bumper (Y/N)	
	Heavy Duty Rear Bumper (Y/N)	
	Swing Out Tire Carrier (Y/N)	

43.54	**WBCG**	**This is are your Jeep's Center of Gravity and Roll Over Angles data. I pulled it from the COG-ROA page for you.**
36.56	**WTCG**	
32.80	**HTCG**	
40.92	**DSROA**	
48.10	**PSROA**	
57.49	**RWROA**	
53.01	**FWROA**	

Worksheets

I have a complete Excel spreadsheet titled “CoG_ROA.xls” which will accompany this write-up.

Measured Values

Label	Value	Description of Measured Values
Lengths		
LWB	in.	Length of the Wheelbase *(Axle center to axle center)*
LTB	in.	Width of the Track. *(Outer tire edge to outer tire edge)*
Heights		
HF1	in.	Height of Front Axle Hub *(center)* from the level ground.
HF2	in.	Height of Front Axle Hub *(center)* from ground while Front is Elevated.
Weights		
WF	lbs	Weight on Front Axle with Jeep Level
WP	lbs	Weight on Passenger side
WR1	lbs	Weight on Rear Axle with Jeep Level
WR2	lbs	Weight on Rear Axle when Front is Elevated

Calculated Values

Label	Value	Description of Calculated Values
Calculated Values		
HFd	in	Difference between Front Hub Elevated and Front Hub when Level. *(HFd = HF2-HF1)*
LWBn	in	Length of wheelbase when front is elevated. *(LWBn=SQRT (LWB^2-HFd^2)*
WRd	lbs	Weight added to rear axle when front axle was elevated. *(WRd = WR2 – WR1)*
Wt	lbs	Total weight of Jeep

Roll Over Angles

Label	Value	Description of Data Element for Roll Over Angles
LWB	in.	Length of the Wheelbase *(Axle center to axle center)*
LTB	in.	Width of the Track. *(Outer tire edge to outer tire edge)*
WBCG	in.	Wheel Base Center of Gravity behind Front Axle = (1 - (WF / Wt)) * LWB = WBCG
WTCG	in	Wheel Track Center of Gravity from the passenger side outer tire edge = (1 - (WP / Wt)) * LTB = WTCG
HTCG	in	Your Jeep's CG Height = HF1 + ((WRd * LWB * LWBn) / (Wt * HFd)) = HTCG

Document Ownership

This process was developed and documented by Frank D. (Daless2 on the Jeeps Unlimited, Jeepaholics Anonymous, and JeepBBS forums) and is being place in the public domain for unrestricted non-commercial use.

Commercial and non-commercial organizations are encouraged to distribute, post or host this write up and accompanying spreadsheet on their web sites. All I ask is that no "fee" be charged for this information.

Any who would like a soft copy of the write up in MS Word format and the spreadsheet in MS Excel format can get it from me. Just drop me an email.

Daless2@Yahoo.com

Addendum: Second Edition

Force and its effects on our Jeeps

There will be a "Second Edition" of this write-up that will focus more on exploring the dynamic effects of force on our Jeeps roll over angles as they may occur in the off road environment.

I thought it might be helpful here to provide a baseline understanding of the forces of physics so we could begin to give some thought to which forces might apply in what circumstances.

Please note that I am not a physicist, but rather an interested Jeep'r just like you. This is my attempt to take a complex subject and simplify so we may better understand the forces our Jeeps are interacting with and against.

What is a force?

Our Jeeps are constantly interacting with many forces in the off road environment. But what is a force?

A force is a push or pull on our Jeeps as a result of an interaction with some other object, say your Jeep's front tire against a rock, or your entire Jeep against a significant climb.

Whenever there is an interaction between your Jeep and another object there is force acting on both.

When the interaction stops (you make it to the top of that steep hill climb) your Jeep is no longer experiencing the force of the climb.

In Physics a force only exists as a result of an interaction between two (or more) objects. In the Jeeping world a force exists as a result of an interaction between our Jeep and anything else we encounter on the trail.

Force interactions between your jeep and everything you encounter on the trail can be put in one of two categories:

- Contact Forces
- Action-at-a-Distance Forces

Contact Forces

These are the types of interaction forces that come into play when your Jeep is physically in contact with another object.

Contact Forces include:

- Frictional Force
- Tensional Force
- Normal Force
- Air Resistance Forces
- Applied Force.

Action-at-a-Distance Forces

Forces of this type occur when our Jeeps interact with another object while not in physical contact with it but are still able to exert a push or pull despite the physical separation.

Examples of Action-at-a-Distance Forces include:

- Gravitational Forces
- Electrical Forces
- Magnetic Forces

Describing Force

Force is measured using a standard metric unit known as the Newton.

Newton (the one who had the apple fall on his head while sitting under a tree) developed a set of formulas that are used to convert any of these nine defined forces into a common unit of measurement. That unit of measurement is called a Newton.

This means Gravitational Pull can be expressed in Newtons, and Frictional Force can also be expressed in Newtons. As can the rest of the field.

Don't worry; we're not going to go here. I don't have anything against Newtons. (Heck I eat them with figs inside quite often.) But Newtons aren't exactly a part of my every day vocabulary, let alone my Jeeping experiences.

We will use more normal words like Pounds or PSI or Ft/Lbs. Measures that I readily understand without having to calculate an incredible formula for Newtons for 15 minutes and forgetting why I wanted to know the information in the first place!

Vector Quantity for Force

There is something we must understand that applies to all forces and that is the "vector quantity for force".

Forces acting on your Jeep have a vector quantity having both **magnitude** (size) and **direction**.

In order to convey how a force is acting on your Jeep you must be able to describe both its magnitude (size) and its direction and it is best to do this in a drawing.

You cannot say 10 Newtons (We will use anything but Newtons) is a full description of the force acting on your Jeep or a part of your Jeep.

You can say 10 Newtons, downwards and you would be giving a full and complete description of a force. See what I am getting at?

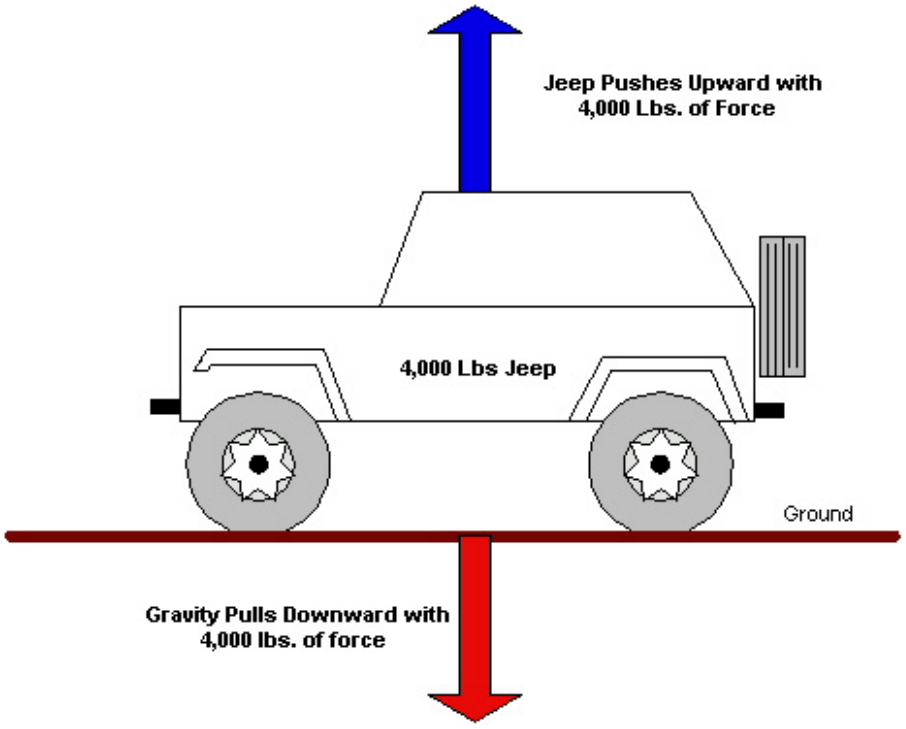
Both the magnitude (10 Newtons) and the direction (downwards) are described.

Because force is a vector and it has a magnitude (size) and a direction we have to agree on a way to represent force in future drawings. I would like to suggest this approach. It is loosely based on standard called "free-body diagrams" commonly used in Physics.

- In our vector diagrams we will use the size of the arrow to reflect the magnitude or size of a force, even if we don't know exactly what that size is.

- The direction of the arrows will give the direction in which the force is acting.

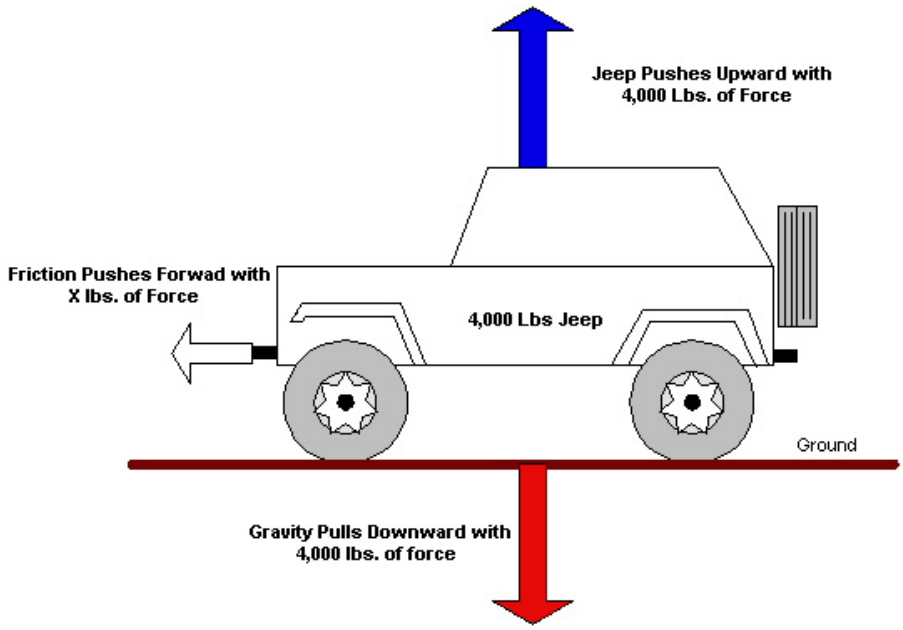
Here is an example of what this will look like in the second edition.



Often one force on your Jeep is canceled out by another force acting on your Jeep.

In the above drawing, 4,000 lbs of gravitational pull is canceled out by 4,000 lbs of push from the tires. In this case two forces "balance each other".

But force can also go unbalanced. If we add a third force to the above drawing you will better be able to visualize this.



The same two “Balancing Forces” are acting on your Jeep and canceling each other out.

When a third force is now applied, in this case, an unbalanced friction force, a state of forward motion exists.

Your Jeep moves forward because there is no counter-balancing force to stop it!

Want a counter-balancing force? Apply your brakes! (Any idea what type of force your brakes would be applying? Yes you’re right! Frictional!)

Why all the emphasis on this?

Well, you don’t have to have a Ph.D. in Physics, but you do have to fully understand two points in order to understand what forces are acting on your Jeep.

- More than one force can be acting on your Jeep at any moment in time.
- All force has two dimensions, Magnitude (size) and Direction.

If you understand these two points you have all the tools you need to begin to figure out what is happening with your Jeep in many off road situations.

Force Descriptions

Here is a short explanation of seven of the nine forces, which are most likely to come into play in the Jeeping world. Please note I pulled this right out of the book.

Applied Force:

An applied force is a force that is applied to an object by another object or by a person.

If a person is pushing a desk across the room, then there is an applied force acting upon the desk. The applied force is the force exerted on the desk by the person.

Gravitational Force:

The force of gravity is the force with which the earth, moon, or other massive body attracts an object towards itself.

By definition, this is the weight of the object.

All objects upon earth experience a force of gravity that is directed "downward" towards the center of the earth. The force of gravity on an object on earth is always equal to the weight of the object.

Normal Force:

The normal force is the support force exerted on an object that is in contact with another stable object.

For example, if a book is resting upon a surface, then the surface is exerting an upward force upon the book in order to support the weight of the book.

On occasion, a normal force is exerted horizontally between two objects that are in contact with each other.

Frictional Force:

The friction force is the force exerted by a surface as an object moves across it or makes an effort to move across it.

The friction force opposes the motion of the object. For example, if a book moves across the surface of a desk, the desk exerts a friction force in the direction opposite to the motion of the book.

Friction results when two surfaces are pressed together closely, causing attractive intermolecular forces between the molecules of the two different surfaces. As such, friction depends upon the nature of the two surfaces and upon the degree to which they are pressed together.

Air Resistance Force:

Air resistance is a special type of frictional force that acts upon objects as they travel through the air.

Like all frictional forces, the force of air resistance always opposes the motion of the object.

This force will frequently be ignored due to its negligible magnitude. It is most noticeable for objects that travel at high speeds (e.g., a skydiver or a downhill skier) or for objects with large surface areas.

(Yea like a Jeep, the functional equivalent of drive a brick with a tent on top down the highway.) (Couldn't help myself, I had to add that.)

Tensional Forces:

Tension is the force that is transmitted through a string, rope, or wire when it is pulled tight by forces acting at each end.

The tensional force is directed along the wire and pulls equally on the objects on either end of the wire.

Spring Force

The spring force is the force exerted by a compressed or stretched spring upon any object that is attached to it.

This force acts to restores the object, which compresses or stretches a spring, to its rest or equilibrium position.

For most springs the magnitude of the force is directly proportional to the amount of stretch or compression.

The End

OK Folks, I put this info in here because I wanted to provide a baseline for those who might be interested in participating or contributing to the "Second Edition" of this write up. There are many here reading this who are far more knowledgeable then I when it comes to Jeeps, and handling, and off road situations.

Give it some thought, and see if you would like to do a short write up on a particular topic dealing with Center of Gravity, or Roll Over Angles or something related to the two.

Thanks for your time in reading this. I hope you have found some value in it.

A special thanks to those how have questioned and probed me in this effort, especially Kerry (MostlyYJ) and Brad (Hellbender). Your contributions have clearly made this a better write up. Thank You.

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