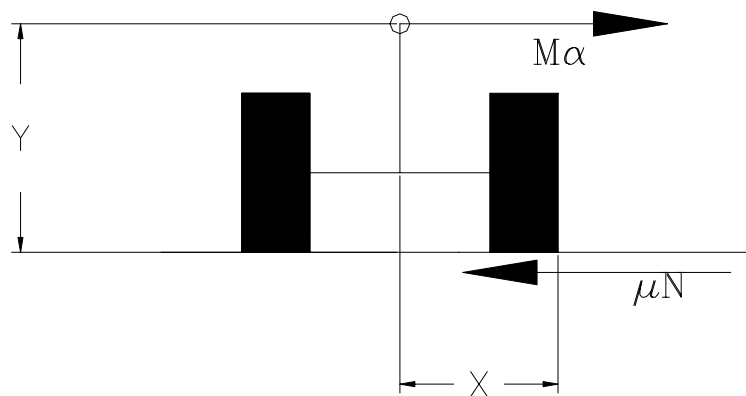


**The mathematics of rollover:** To understand rollover, it is necessary to present a few simple concepts.

From a theoretical analysis on rollover the following equations are easily developed. The non-mathematical reader should not be intimidated. The “ $M\alpha$ ” is the centrifugal force trying to tip the ATV over. The “ $\mu N$ ” term is the frictional force of the ground. The weight pushes downward at the “Y”, which is the location of the center of gravity. The first step is to find out how much centrifugal acceleration,  $\alpha$ , is needed to make it slide and then to make it tip over. The velocity of the ATV is in the equation for the centrifugal acceleration  $\alpha$ . Assume that the ATV tips over at 10 mph and it slides at 5 mph. The obvious conclusion is the ATV will not tip over because it slides before it reached the 10 mph tip-over. If it tips over at 5 mph, then it tips before it slides. That is about all the following equations are going to prove. There will be a certain coefficient of friction,  $\mu$ , which is critical. Since nothing can be done about the coefficient of friction, the driver must do one of two things. The turning radius,  $\rho$ , must be increased or the driver must lower the velocity,  $V$ . This is obvious without all the mathematics. However, if the jury can see that the coefficient of friction,  $\mu$ , dictates the speed and the turn radius of the ATV, they will have the potential of seeing why the ATV is unreasonably dangerous without a rear differential because this makes the turn radius a function of the coefficient of friction. The coefficient of friction is beyond the control of the ATV driver. If the driver has to over-steer the ATV because the manufacturer failed to put in a rear differential, the turn radius now is a variable. Back to the red and yellow paths in Figure 24, one setting of the turning radius that is safe on grass will end up in a tight turn without the driver doing anything. The ATV will go from being safe on grass to being dangerous on asphalt.

Also, do not let anyone tell you that this stuff has to be peer reviewed. It is old science and has been peer reviewed since the 1700’s.



## Figure 25. Sketch of Rollover Analysis

Referring to Figure 25:

*Slides?*

$$\mu \times N \leq M \times \alpha$$

$$\mu \times N \leq \frac{N}{g} \times \alpha$$

$$\mu \leq \frac{\alpha}{g} = \frac{V^2}{\rho \times g}$$

Where  $\mu$ ,  $\alpha$ ,  $N$  and  $M$  are the coefficient of friction between the ground and tire, the centripetal acceleration, the normal weight downward of the ATV and the mass of the ATV respectively. "V" is the velocity of the ATV, "g" is the gravitational constant of 32.2 feet per second squared and  $\rho$  is the turning radius. If the value of the coefficient of friction is less than  $\frac{V^2}{\rho \times g}$ , then the ATV slides and does not roll over. At larger coefficients of friction, the governing equation becomes:

$$M \times \alpha \times Y = N \times X$$

$$M \times \alpha \times Y = M \times g \times X$$

$$\alpha = \frac{g \times X}{Y}$$

$$\frac{V^2}{\rho} = \frac{g \times X}{Y}$$

$$V \geq \sqrt{\frac{\rho \times g \times X}{Y}} = \text{Tip - Over}$$

If the velocity is equal to or greater than the equation above, the ATV will roll over. A low center of gravity, "Y" or a wider wheelbase, twice "X", the larger the velocity needed to roll the ATV over, which is logical. The important point is the fact that X and Y are a constant. Nothing can be done about these values after it leaves the factory. The gravitational constant, "g", cannot be changed. Therefore the velocity, "V", that can cause tip-over is a function of the turning radius " $\rho$ ". The driver will adjust the velocity accordingly to prevent rollover. Since the value of the coefficient of friction determines whether the ATV will rollover or slide, any changes in the coefficient of friction will directly affect handling, which is not under the control of the driver.

*Slides?*

$$\mu \times N \leq M \times \alpha$$

$$\mu \times N \leq \frac{N}{g} \times \alpha$$

$$\mu \leq \frac{\alpha}{g} = \frac{V^2}{\rho \times g}$$

Again, assume the driver sets the turning radius and adjusts the velocity so the ATV is stable in a turn. The coefficient of friction goes from ice at  $\mu=0.1$  to  $\mu=0.8$ . According to the equation above the coefficient of friction goes from 0.1 to 0.8 and the velocity must be lowered or the turning radius increased to make this happen. Any changes in the turning radius will affect handling. The lack of a differential on the rear axle of an ATV causes the ATV to under-steer. Any change in the ground coefficient of friction can quickly change the safe turning radius,  $\rho$ . The greater the amount of under-steering in ATV's without a differentials increases the potential that the safe turning radius will change quickly and cause the ATV to roll over.

Since the jury may not understand the mathematics involved in this simplified analysis, further testing is required to demonstrate this problem. Testing is not needed for peer review or scientific proof since the equations used are old scientific tools and these equations are sufficient. Logically, the jury can wonder why all other ground vehicles use differentials except ATV's, but demonstrative proof will help the jury separate fact from fiction in the courtroom if the person is not comfortable with mathematical proofs.

Show the jury an exemplar ATV circling in grass. With the same handlebar and throttle setting go from grass to some other higher coefficient of friction surface such as imbedded gravel or asphalt. Video the ATV going up on two wheels with the same speed and handle bar setting, which was safe on grass.

The tests should be run with a professional driver with a helmet. The exemplar ATV should be modified with a couple of bars fastened to the luggage rack that will limit or prevent a complete rollover. The attorney must create tests or animation to show the jury the problem. Assume the jury cannot understand all the mathematics. The authors have found over the years that courtrooms fill with technical noise. Technical noise is composed of bloviating "bull-shooters". To be successful, the jury must see something that proves that the ATV is unreasonably dangerous and defectively designed without a rear differential.