# ATV Braking Data, Sign Recognition Analysis And Validation

## Final Report

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## 1.0 INTRODUCTION

The U.S. Forest Service San Dimas Technology and Development Center (SDTDC) was interested in conducting a study to develop signage guidelines for motorized trails with the end result being a table showing advance placement distances for warning signs based on speed and other relevant factors. The purpose of the study was to determine appropriate sign size, height, reflective sign material and how far away the sign should be placed from a hazard or event to warn and instruct the rider to take an appropriate action under various climatic and environmental conditions. This was done by determining stopping distances for OHVs under various physical conditions of the trail including different soils and trail conditions along with recognition of and reaction distances to signs.

One of the major purposes of this trail signage effort was to collect braking distance information for different types of Off-Highway Vehicles (OHVs) on a variety of trail surfaces. The literature search revealed no published braking test data for All-Terrain Vehicles (ATVs) and very little published braking data for snowmobiles. Most braking distance testing was done with cars and light or heavy trucks. The goal of the studies in the literature was to develop a consistent methodology for conducting the braking tests for cars and light trucks for the purpose of comparing braking distances of different types of vehicles on a consistent surface while minimizing other variables.

The braking tests for the sign study have an entirely different reason and goal than the braking tests described in most published braking test reports. The goal is to determine the average range of braking distances on various trail surfaces for the types of ATVs that are available. This not only involves a wide range of ATVs and utility terrain vehicles (UTVs), but also the range of driving abilities from novice to experienced on a variety of trail surfaces including a packed sandy loam, gravel, loose sand and packed snow. Variables such as the experience level of the rider, the rate of brake application and the surface condition cannot be minimized, as was done for the on-road vehicle tests described in most reports on braking. The ATV braking data was collected to be used with sign recognition and reaction distance data to develop guidelines for the placement of warning signs along U.S. Forest Service trails.

Also important, as mentioned above, are the sign recognition and reaction distances. This report discusses a sign recognition test that was conducted to determine how recognizable the various types and sizes of signs are by measuring time, distance and speed.

The braking distance and sign recognition data is used to develop a table for sign size and placement on the trail based on average trail speed. Data from this table was then validated in a final validation test.

## 2.0 ATV BRAKING

### *2.1 ATV Braking Testing*

#### 2.1.1 Test Vehicles

The selection of the test vehicles for the braking distance study was based on time available, cost, and expected reasonable differences in ATVs and rider habits. For this study it was determined that two types of ATVs and one UTV would be used for the braking tests. One of the most common types of ATVs on the market is the utility type that serves the purpose of general trail use and work use such as pulling trailers or hauling cargo on the racks. The second most common type was the sport type of ATV that generally accelerates much faster and is lighter than the utility type ATV. The UTV was selected to determine if there was a difference between either type of ATV and the UTV. The following vehicles were used for the braking study:

1) Utility ATV – 2008 Honda Rincon
2) Sport ATV – 2007 Yamaha YFZ
3) UTV – 2009 Polaris RZR

The UTV was not tested on all trail surfaces and grades. It was tested on a few select surfaces and grades for general comparison. Only two sensor and data acquisition systems had been planned for the testing, so the UTV was tested against the utility ATV separately from the utility and sport ATV testing. It was important to test at least two vehicles at the same time in order to obtain a fair comparison as surface conditions can vary significantly from day to day.

#### 2.1.2 Test Terrains

The types of trails available throughout the United States vary considerably. It would be impossible to test for all types of trail terrains and conditions unless an extraordinary amount of funding was available. Therefore, the number of different types of terrain was limited to the following as representative of most trails and range of braking coefficients:

1) Gravel – a road gravel such as the 22a specification used in the mid-west with 3/4” or smaller crushed rock with minimal clay, usually with a layer of three inches or more over a hard packed native soil. Gravel may be compacted but the top one inch is normally loose. Gravel is the baseline terrain for this study.
2) Sandy loam – a hard packed sand mix, sometimes found with a loose surface.
3) Loose sand – a soft and deep sand that has a weak shear strength on the upper 6 to 12 inches.
4) Packed snow – a groomed, hard packed snow with a loose surface of one to two inches thick, where riders can still drive the ATVs before having to use snowmobiles.

All trails are not flat so therefore it was determined to test for situations where the riders may have more difficulty in stopping. Three grade ranges were tested for braking distances and they were all flat or downhill. The following grade ranges were used:

1) 0 to 8% grade – generally a flat surface.
2) 8 to 15% grade – a mid-level downhill grade.
3) 15 to 25% grade – a steep downhill grade.

#### 2.1.3 Test Riders

A novice and experienced rider were used for all braking tests in an effort to cover the range of potential riders. Novice riders are those that have rarely driven an ATV or UTV, if at all. The novice can generally ride and handle the ATV to some degree but may not be comfortable in certain situations. An experienced rider is one that has driven several different ATVs/UTVs in a variety of situations and at a range of speeds such that he or she feels comfortable at near the top speed possible for a given trail condition. The experienced rider also knows how to control the vehicle in these situations, based on experience, and therefore brakes using that experience. A prudent rider may be either novice or experienced but rides on the public trails at their personal limits of handling capability, similar to a defensive driver on the road.

Test speeds were selected to be 15, 30 and 45 mph, if attainable, and the riders attempted 6 or more braking stops for each terrain, vehicle and speed.

### 2.1.4 Data Acquisition

Each vehicle was instrumented to monitor longitudinal and lateral acceleration using accelerometers, throttle position using the throttle position sensor on the vehicle, brake activation by measuring brake pressure and speed using a GPS. Special brake lines were ordered for each vehicle to accommodate the pressure transducers. These were installed and the brakes bled prior to testing and then replaced with the originals after testing was completed. Each vehicle had a box (cooler) that contained the data acquisition hardware and laptop for data acquisition. The data acquisition program was written in LABVIEW and the data was later processed using MATLAB. Final data analysis was done using Microsoft EXCEL for this report.

## *2.2 Braking Data Analysis*

The following sections contain the analysis of the braking data. The utility ATV was compared to the sport ATV and to the UTV. The novice rider was compared to the experienced rider. The data points were plotted and then curve fit for comparison to show general average trends using a parabolic curve fit because braking distance is physically defined by a parabolic equation. The spread of the data points show the bands that can be expected between vehicles and between novice and experienced riders.

This data can also be examined using the curve fit equations to determine the average coefficient of friction. This was done using the following equation found in the literature [1]:

$$D = \frac{(V_o^2)}{2g(\mu \pm grade)}$$

Where: D = Braking Distance (ft)
$V_o$= Original velocity at which brakes were applied (ft/sec)
g = acceleration due to gravity (32.2 ft/sec$^2$)
μ = Coefficient of friction
grade = grade of surface in percent/100 (subtract grade for downhill slopes)

### 2.2.1 ATV Braking on Flat Gravel

Braking data was collected for the two types of ATVs first. Both novice and experienced riders tested both ATVs. The data for flat gravel is shown in Figure 1. The data was curve fit for each vehicle and level of rider experience. Figure 1 shows a separate curve for each of the four combinations; experienced rider on the utility ATV, novice rider on the utility ATV, experienced rider on the sport ATV and novice rider on the sport ATV. Note that the novice rider had shorter stopping distances as compared to the experienced rider for each vehicle.

The data looks fairly consistent which indicates that the terrain conditions were fairly consistent and the riders applied the brakes in a consistent manner.

Figure 2 is a plot of the utility and sport ATV data for both rider types with no separation of rider experience. Note that the sport ATV curve indicates slightly shorter braking distances than the utility ATV.

Figure 3 is a plot of all the utility and sport ATV data combined for gravel on flat terrain with one curve fit through all of the data. This is a representation of braking data for ATVs in general on flat gravel. The flat gravel surface used for this test consisted of two to three inches of 22a gravel over a hard packed base material of sandy loam and rock mix. The top one inch of the surface was loose.

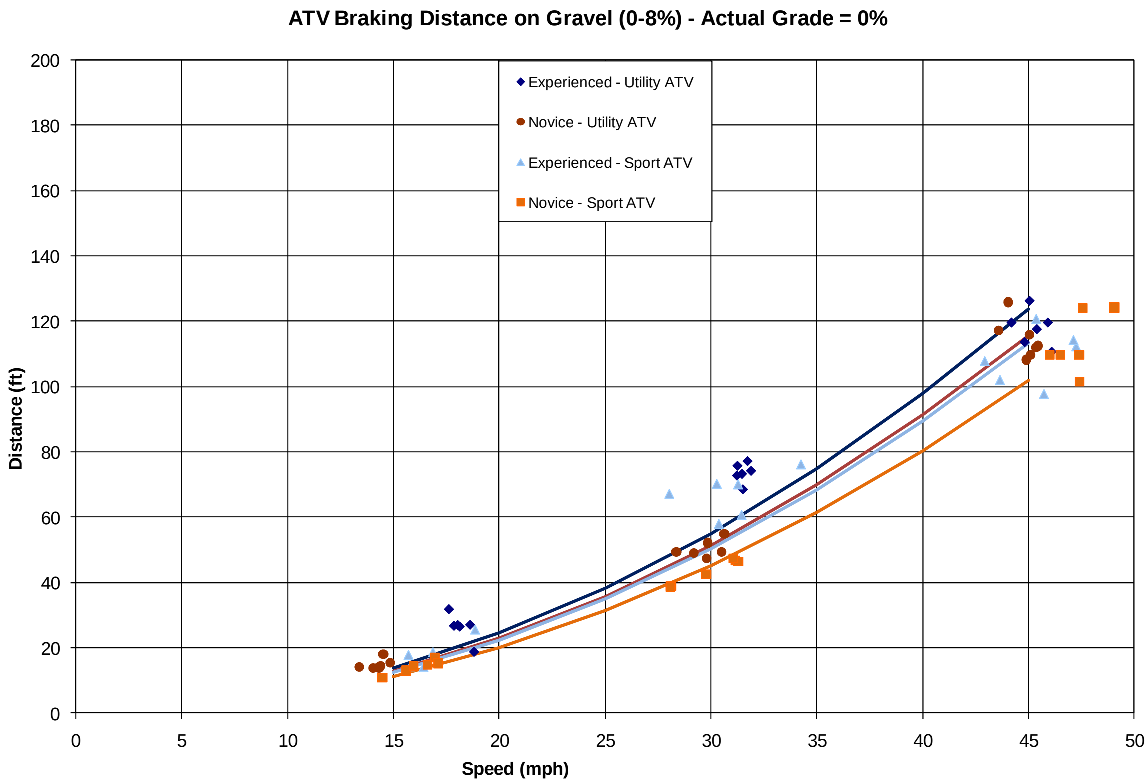



Figure 1 Plot of braking data and curve fits for both rider types and vehicles on flat gravel.

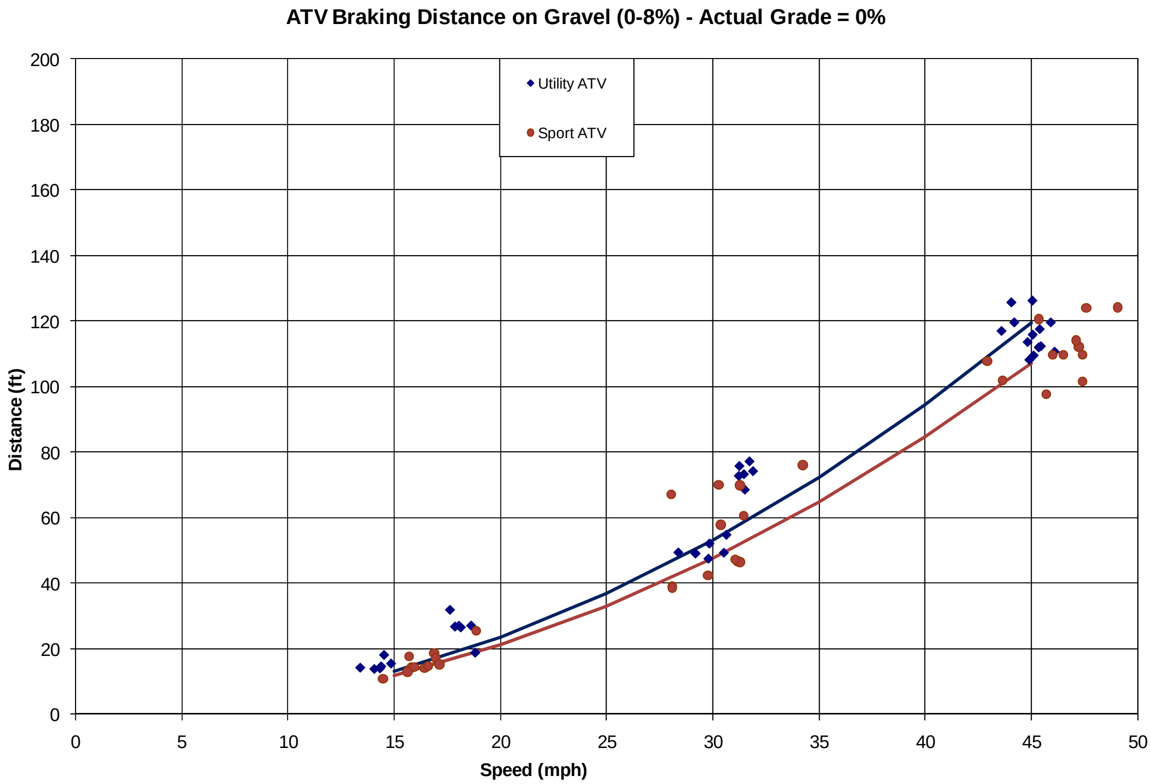



Figure 2 Plot comparing braking distances of the utility ATV and the sport ATV on gravel.

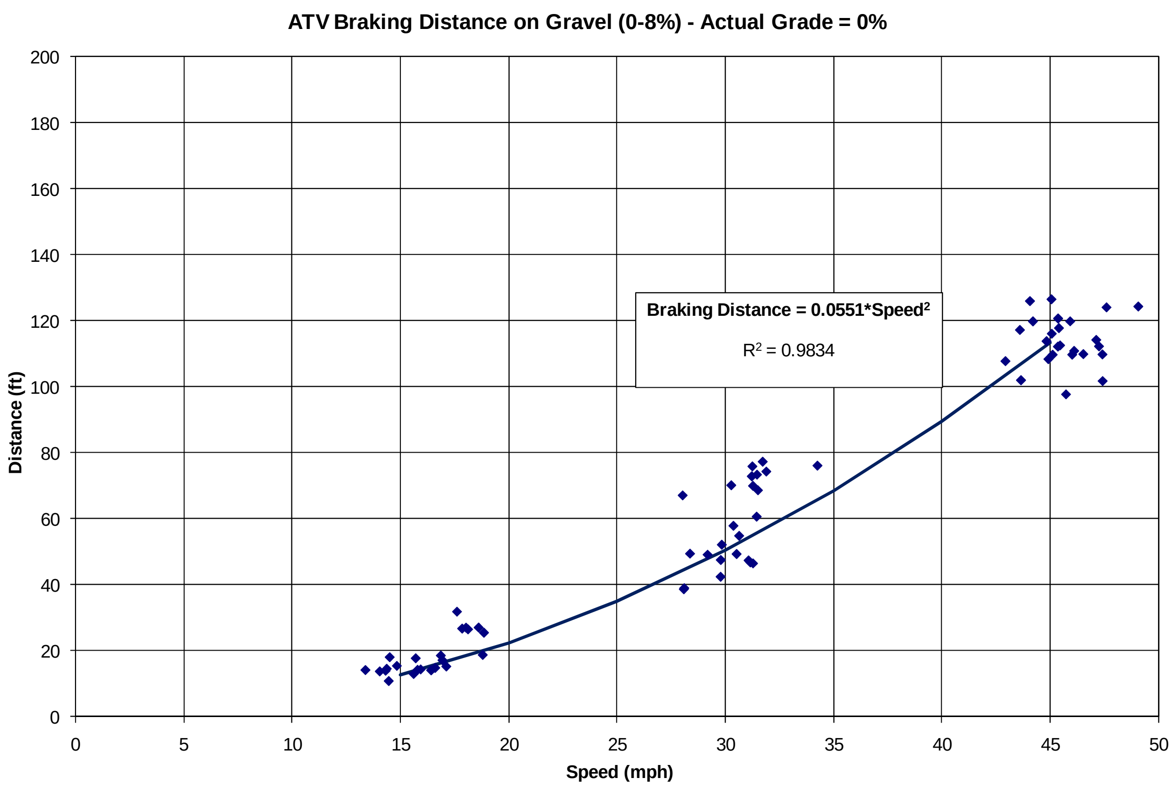



Figure 3 Plot showing all utility and sport ATV braking data on flat gravel with one curve fit.

There was interest in determining if a UTV would vary much from an ATV as far as braking performance. This was funded later in the project and only two sets of data acquisition were available. The UTV could not be tested by itself on the flat gravel because the condition of the gravel was most likely different from when the utility and sport ATVs were tested. Therefore, one of the two previously tested ATVs had to be tested at the same time as the UTV. The equipment was removed from the sport ATV and installed on the UTV. The UTV was tested in a separate set of tests with the utility ATV. Figure 4 is a plot of the utility ATV and UTV data taken on a different day than the utility and sport ATVs data. The data looks similar to the utility ATV – sport ATV data but it should be noted that the novice braking on the utility ATV had longer stopping distances than the experienced this time. The experienced rider had very similar braking distances with both the UTV and the utility ATV. The novice had the shortest braking distances in the UTV of all vehicles and riders. Figure 5 is a plot showing the utility ATV and UTV braking data independent of riders. Note that the relationship of the UTV curve to the utility ATV curve is similar to the relationship of the sport ATV curve to the utility ATV curve in Figure 2. Figure 6 is a plot of the average curve fit for all utility ATV and UTV data on flat gravel.

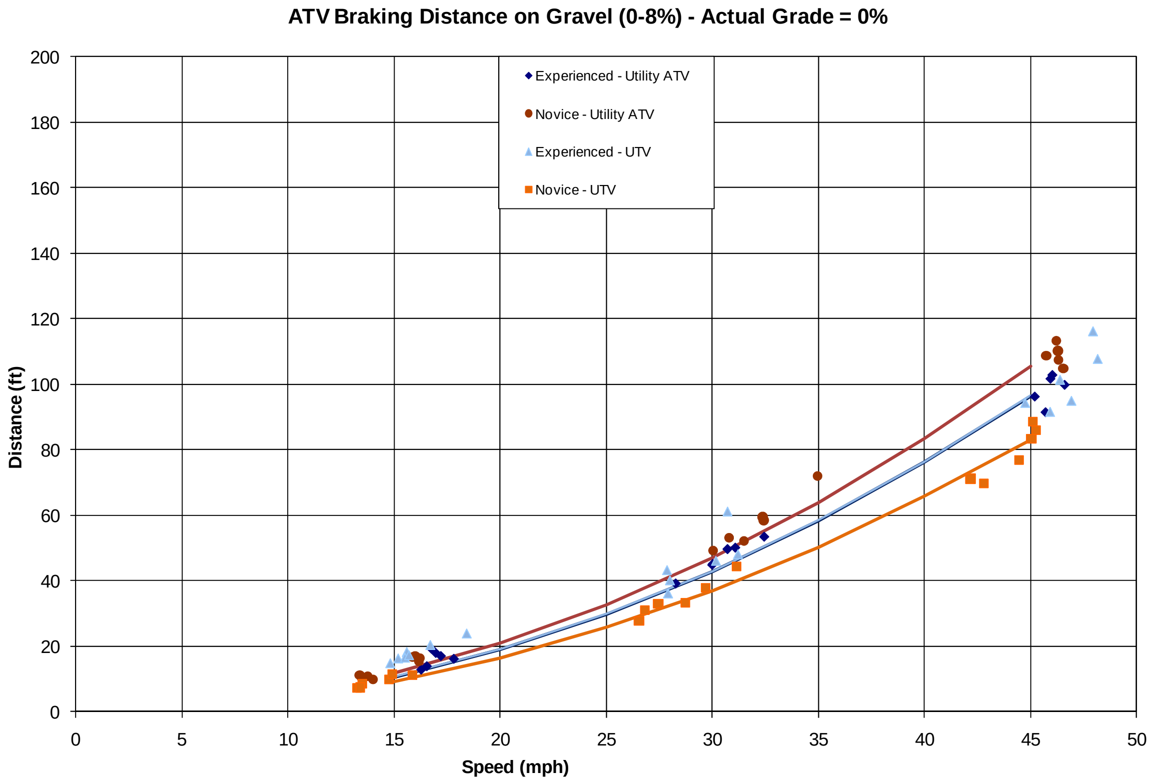



Figure 4 Plot of the utility ATV and UTV braking data for each rider type on flat gravel.

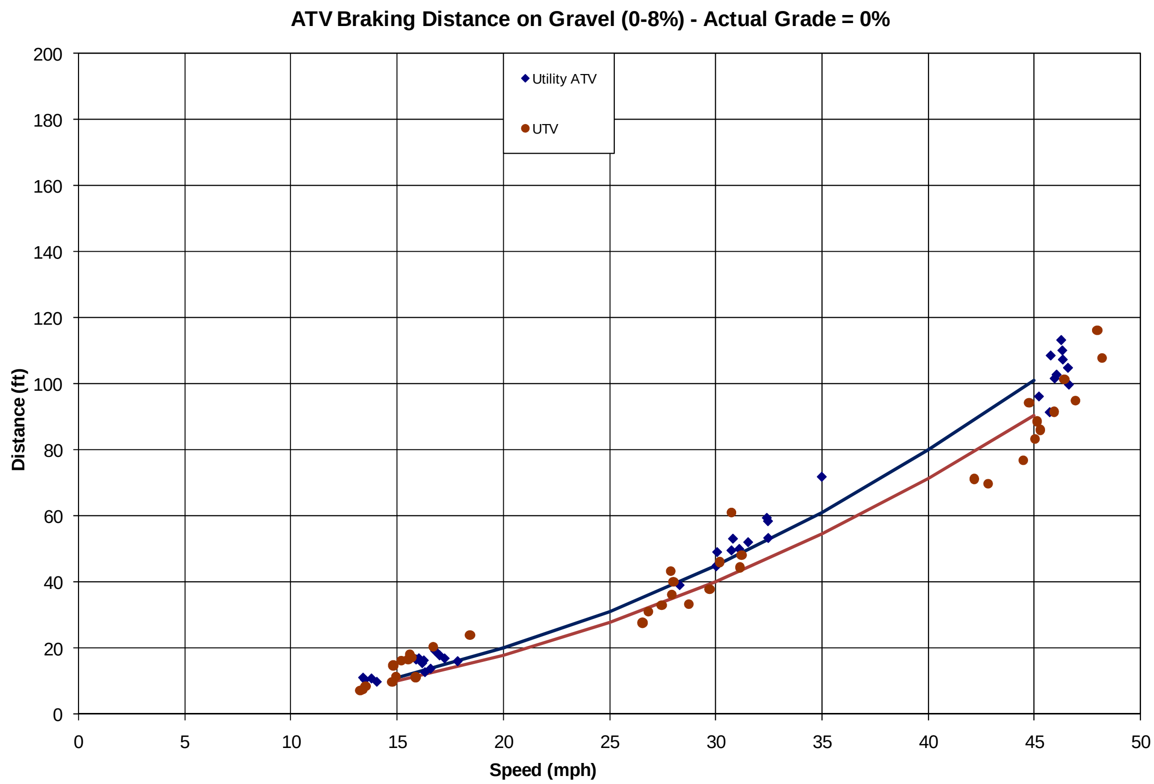



Figure 5 Plot of the utility ATV versus UTV data, independent of rider type, on flat gravel.

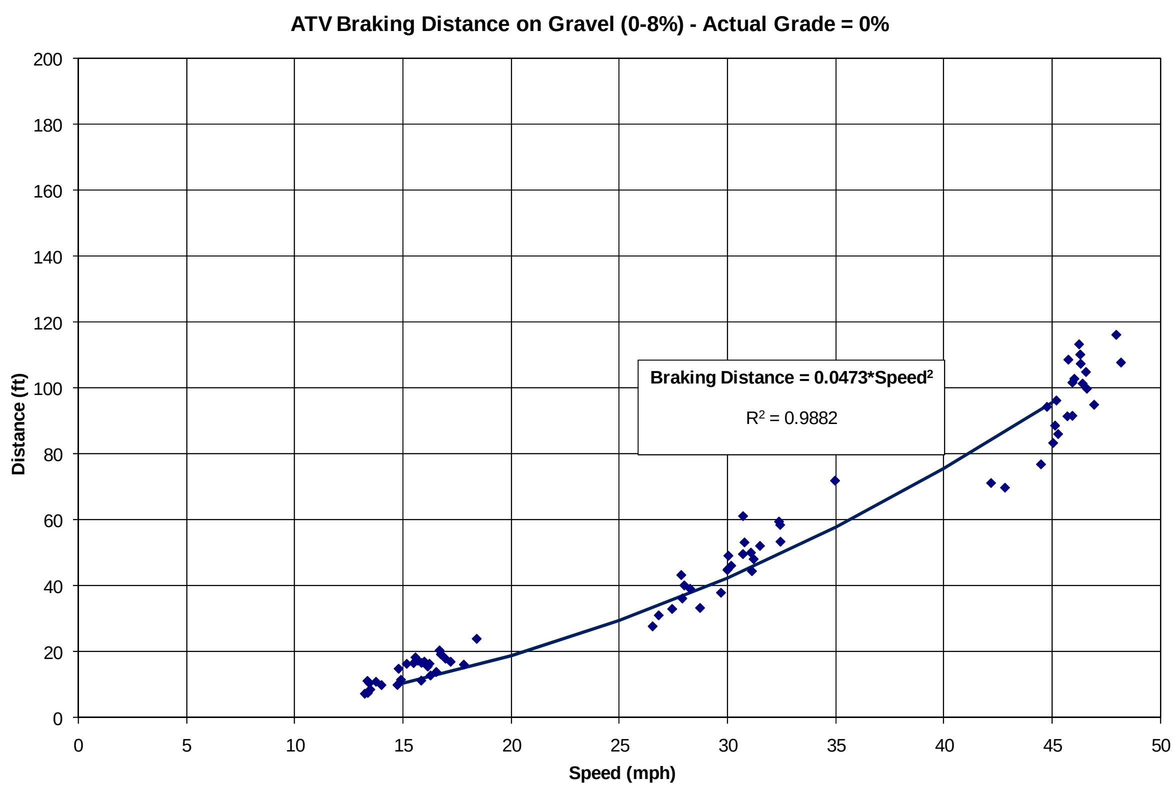



Figure 6 Plot showing the curve fit for all utility ATV+UTV braking data on flat gravel.

Figure 7 is a plot showing just the equation plotted for the utility ATV+sport ATV versus the utility ATV+UTV data equation on flat gravel. Note that the two curves represent average stopping distance for both riders and both vehicles in each set of data. The differences between the curves are due to the terrain conditions on the days tested where one day data was acquired with the utility and sport ATVs in one set of terrain conditions and on another day the data was acquired with the utility ATV and UTV in a different set of terrain condtions. The curves are very similar and lead one to believe that the main difference in the curves was the coefficient of friction for that particular day of testing.

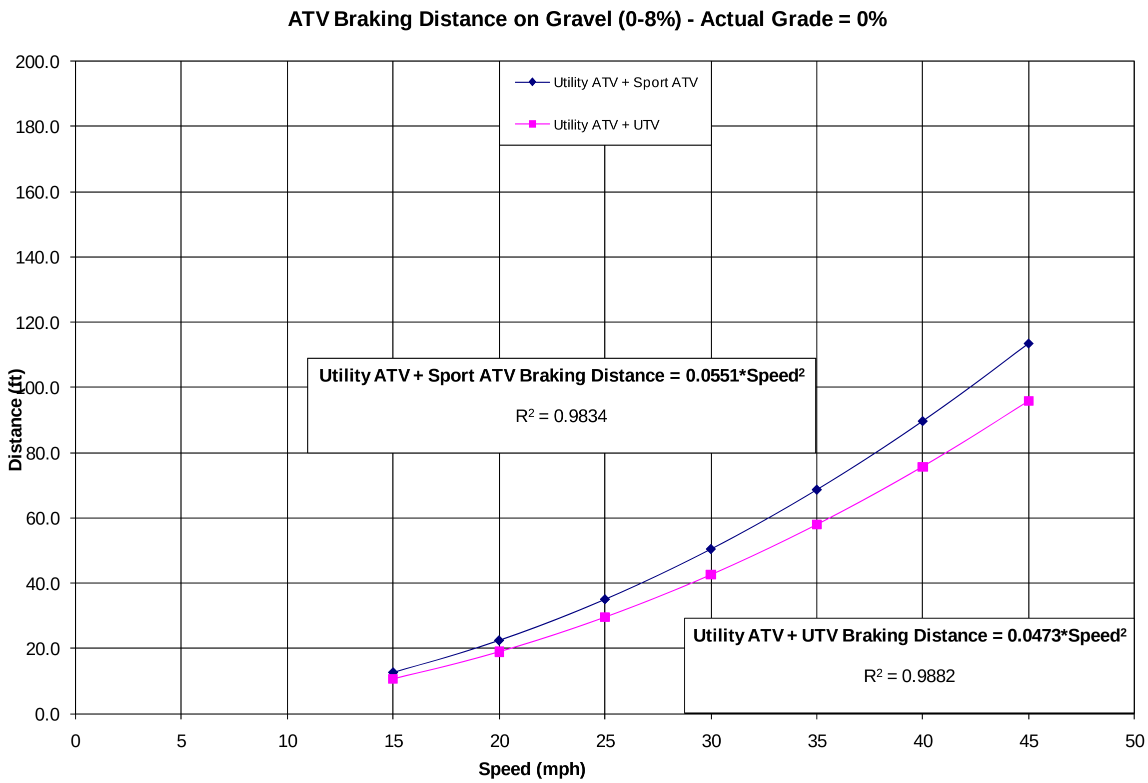



Figure 7 Plot comparing the utility+sport ATV to the utility ATV+UTV curve fit data.

### 2.2.2 ATV Braking on 10% Gravel Grade

Braking on a downhill gravel grade should require a longer stopping distance due to having to overcome the gravitational forces plus the coefficient of friction. Figure 8 is a photograph from the gravel grade testing. Figures 9 and 10 are the plots for utility and sport ATVs braking on a 10% gravel grade. Figure 9 separates out both vehicles and both rider types while Figure 10 separates only the utility ATV from the sport ATV. Figure 9 shows that the braking distances were greater, due in part to stopping on the grade and in part to the coefficient of friction of the gravel on the slope as compared to the coefficient of friction of the gravel on the flat. The 10% gravel grade used for this testing consisted of a hard packed base of sandy loam mixed with a small, coarse, stamp sand with two to three inches of a crushed, sharp edged rock about ¾ inch in diameter (typically called crushed mine rock in this area). The top one to two inches of this terrain was loose.

Note that the novice and experienced riders had very comparable braking distances. Figure 10 shows that the utility and sport ATVs were closer in braking distance at the lower speeds but spread out more as speeds increased with the sport ATV stopping in less distance than the utility ATV. Figure 11 is a plot of all the utility and sport ATV braking data with the general curve fit for braking on a 10% gravel grade.

Figure 8 Photograph of braking on a gravel grade.

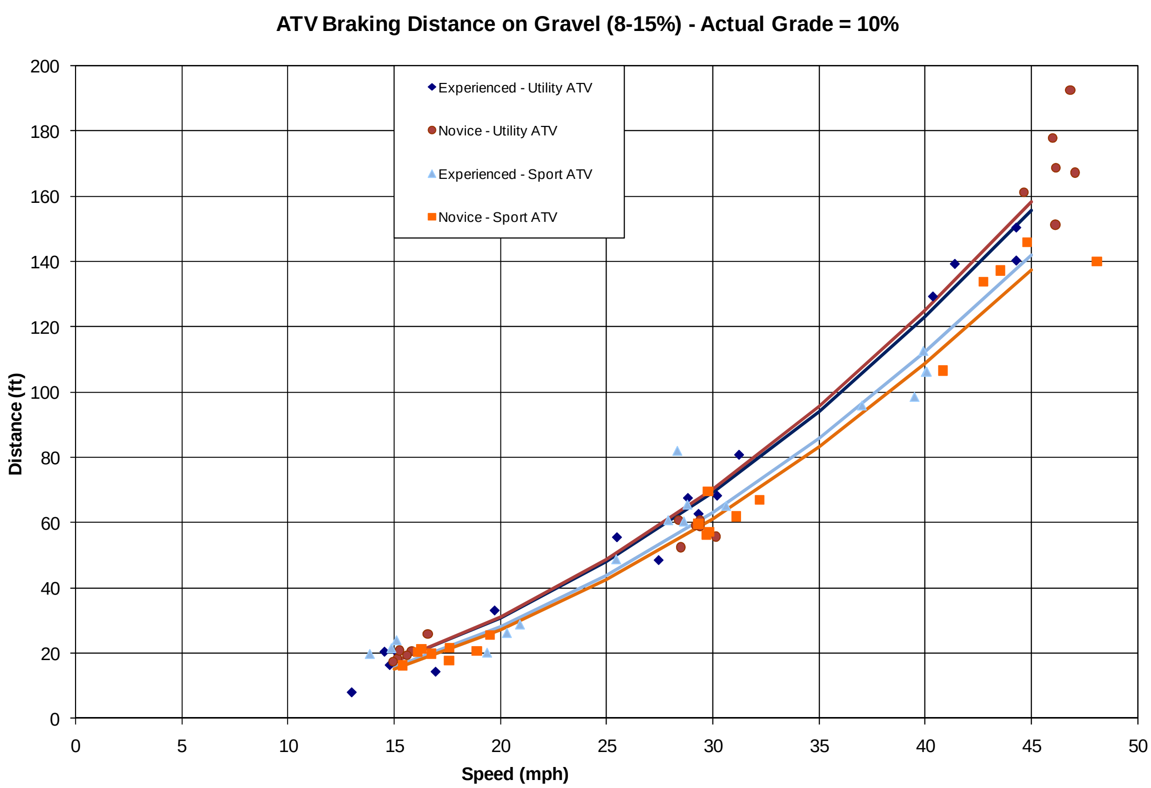



Figure 9 Plot of the utility and sport ATV braking data for both rider types on 10% gravel.

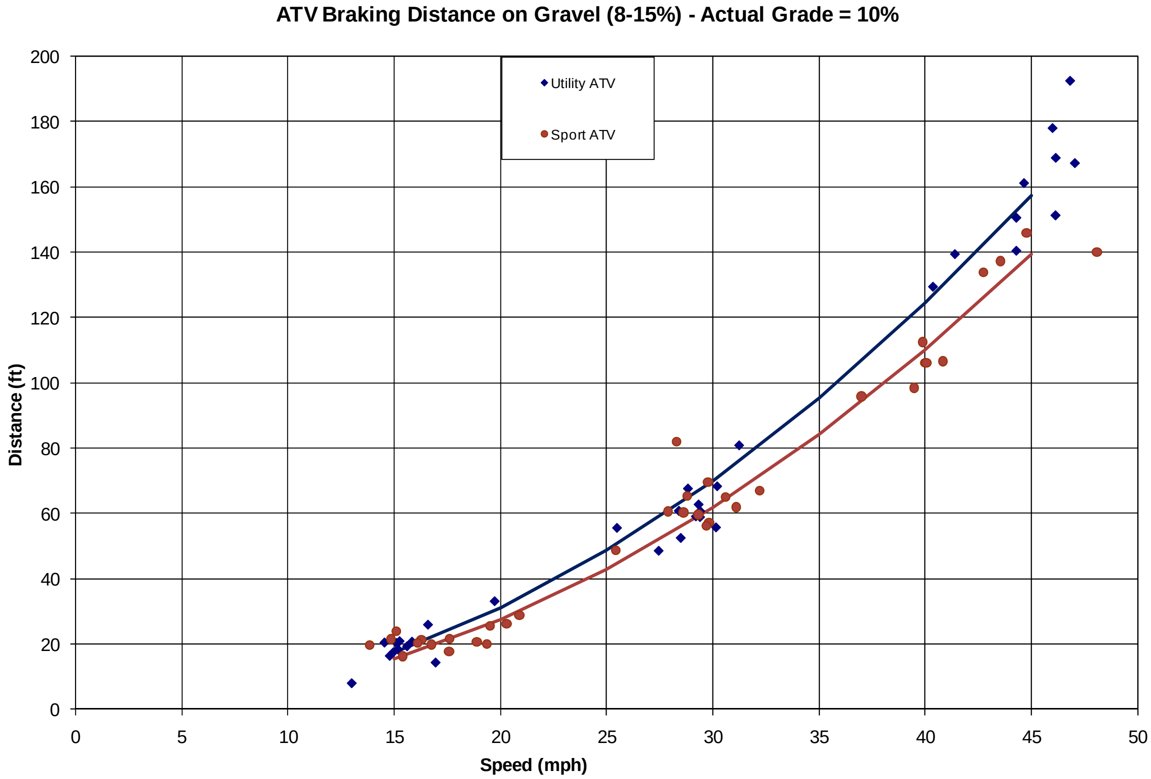



Figure 10 Plot showing utility and sport ATV braking data and curve fits on 10% gravel.

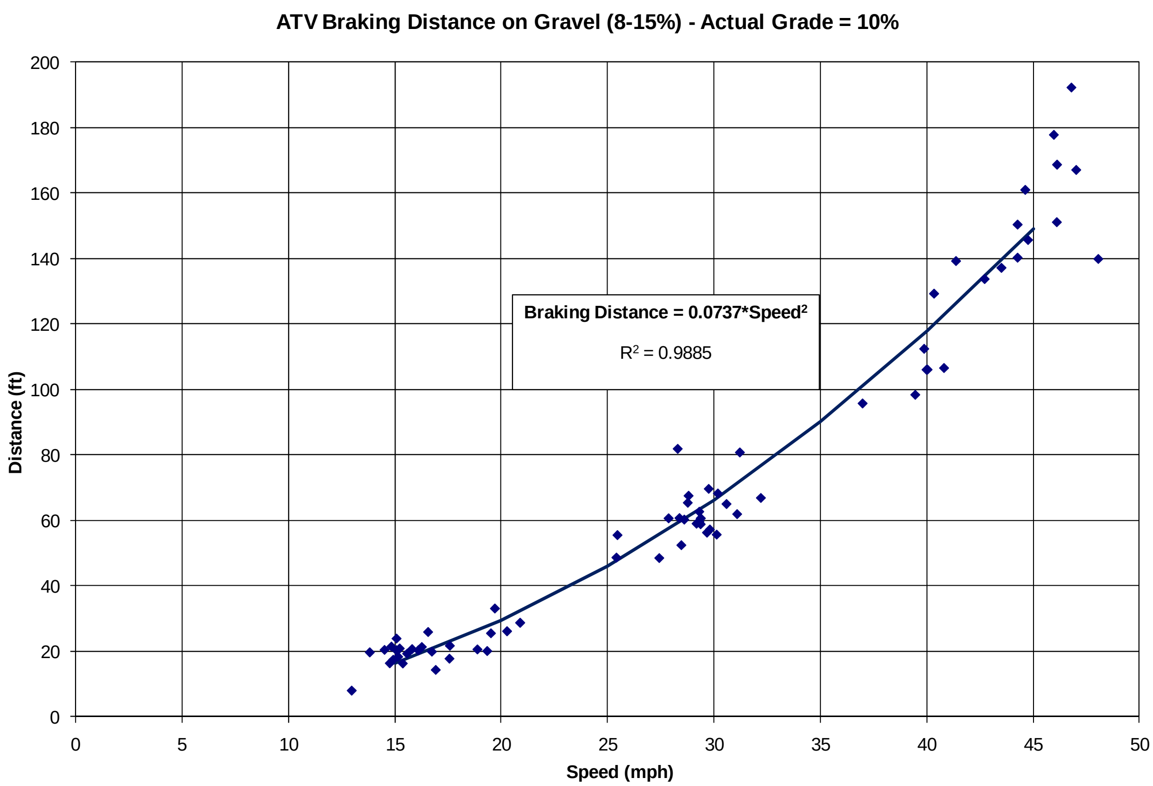



Figure 11 Plot showing the general curve fit for all utility and sport ATV data on 10% gravel.

The utility ATV and the UTV were also tested on the 10% gravel grade, on a different day than the utility and sport ATVs were tested. The braking data for both rider types on both vehicles are presented in Figure 12. Note that the novice stopped in shorter distances than the experienced rider for both vehicles (as compared to the utility ATV-UTV data for flat gravel where the novice did not stop in a shorter distance with the utility ATV than the experienced rider).

Figure 13 is a plot comparing the utility ATV and UTV braking data and the curve fits independent of rider types. Note that the stopping distances for the utility ATV-UTV test were not as great as for the utility -sport ATV test, possibly due to the coefficient of friction on the day tested. Also, because the novice rider stopped shorter with the utility ATV this time, the utility ATV-UTV curves are slightly different with the utility ATV having a slightly shorter stopping distance as compared to the UTV. In general, the utility ATV versus the UTV is similar to the utility ATV versus the sport ATV for the 10% gravel grade.

Figure 14 is a plot showing the general curve for the utility ATV and UTV braking data on the 10% gravel grade.

Figure 15 is a plot of the utility ATV+sport ATV and utility ATV+UTV curve fit data for the 10% gravel grade. Note that the curves are different than that for the flat gravel in that at the lower speeds they are very close and at the higher speeds the curves separate. This appears to be due to the novice rider stopping shorter with both the utility ATV and UTV in those tests and the tight grouping of the utility+sport ATV test data.

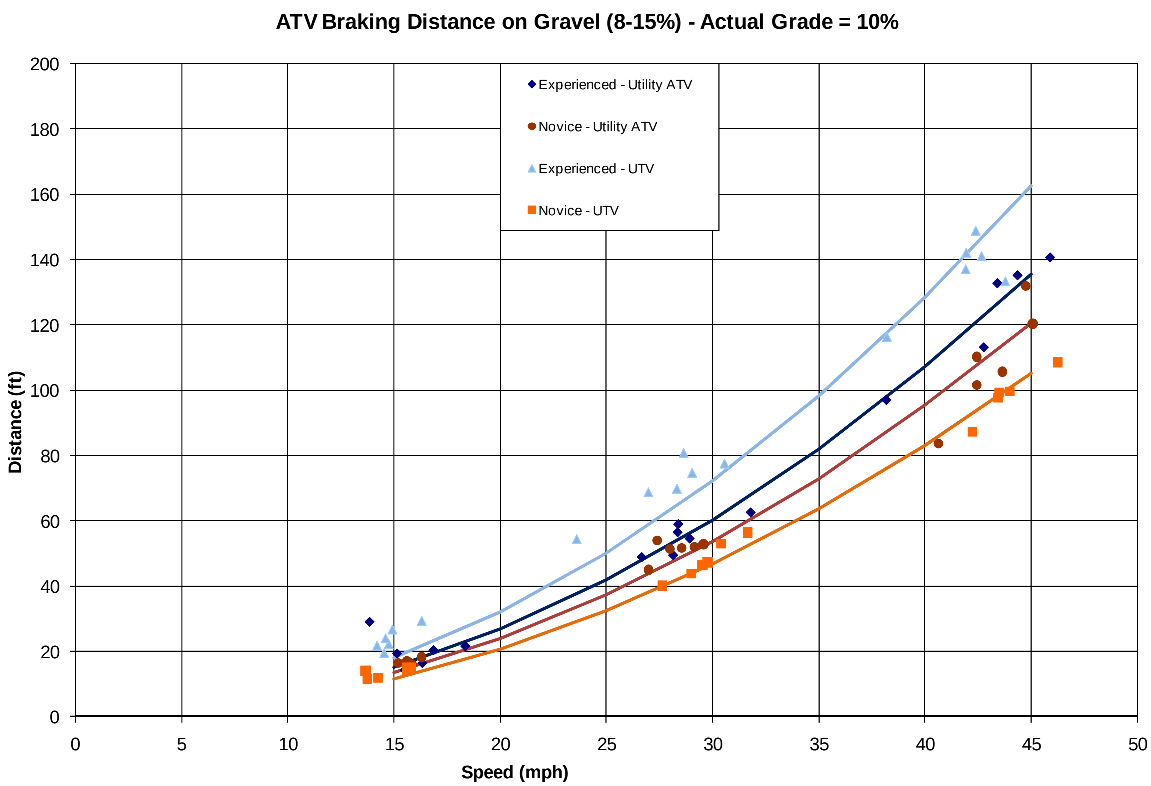



Figure 12 Plot of utility ATV and UTV braking data for both rider types on 10% gravel.

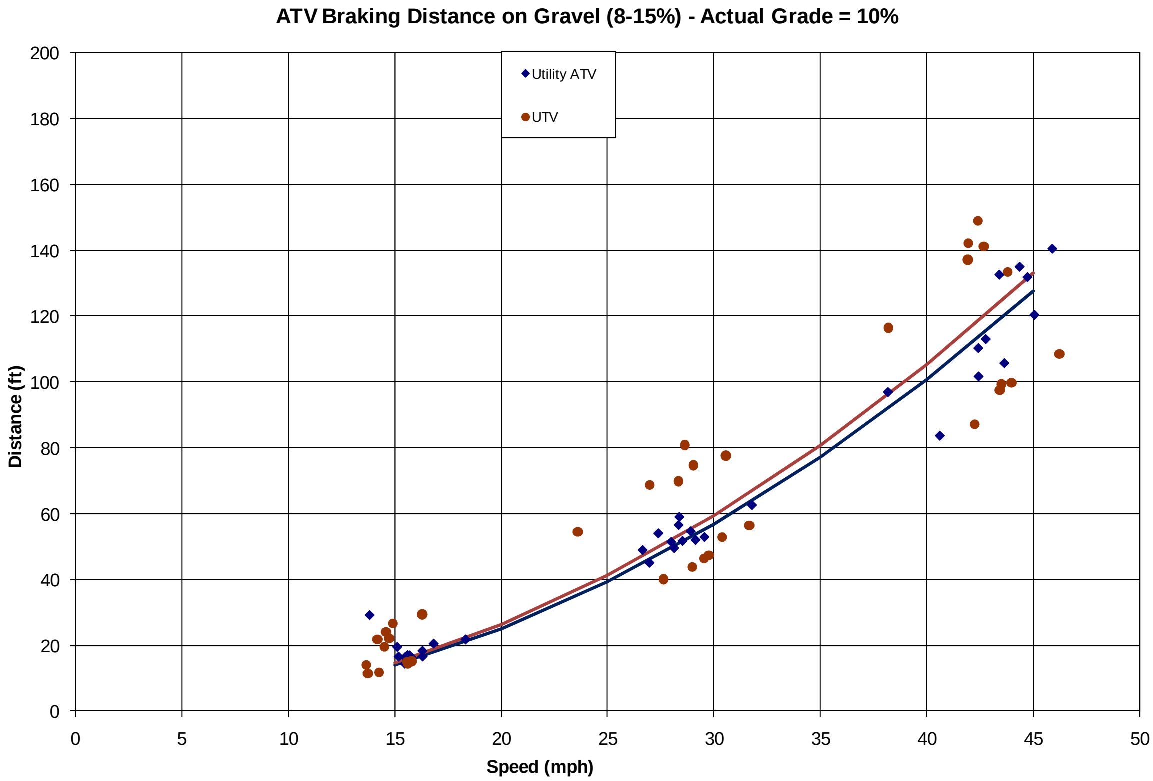



Figure 13 Plot of the utility ATV and UTV braking data for the 10% gravel grade.

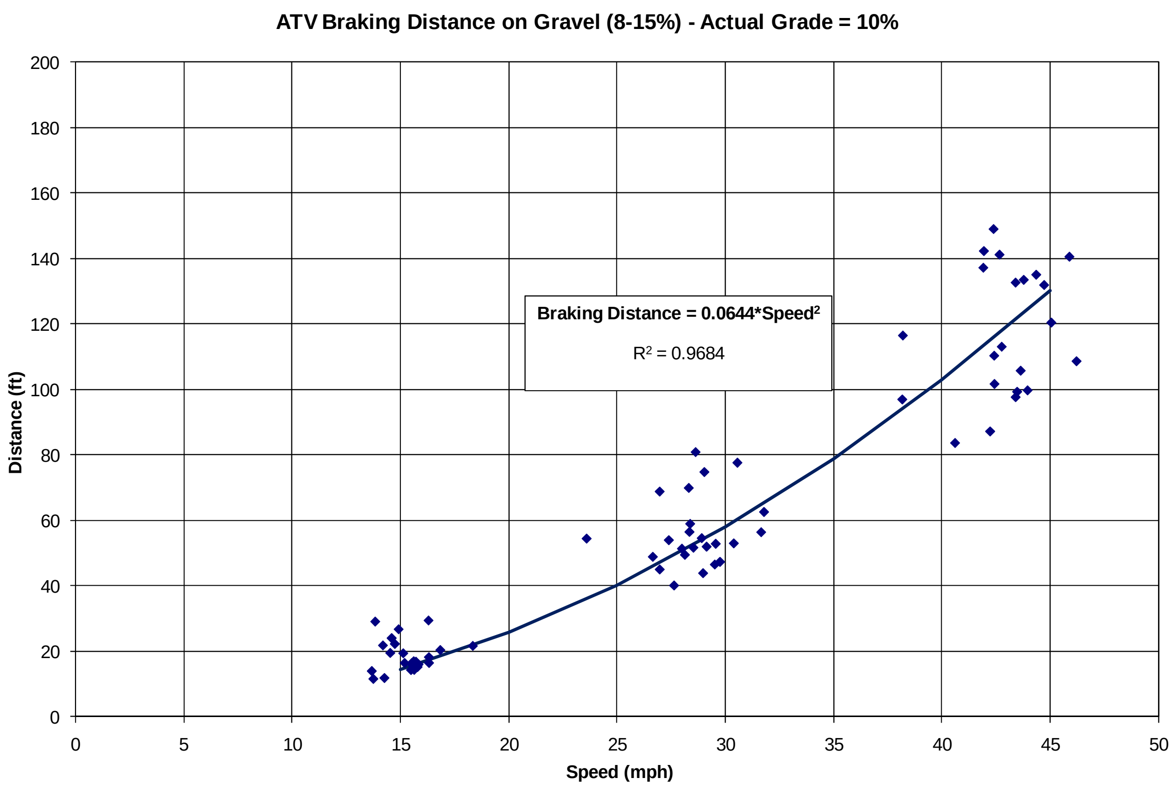



Figure 14 Plot of the general utility ATV+UTV braking data curve for 10% gravel grade.

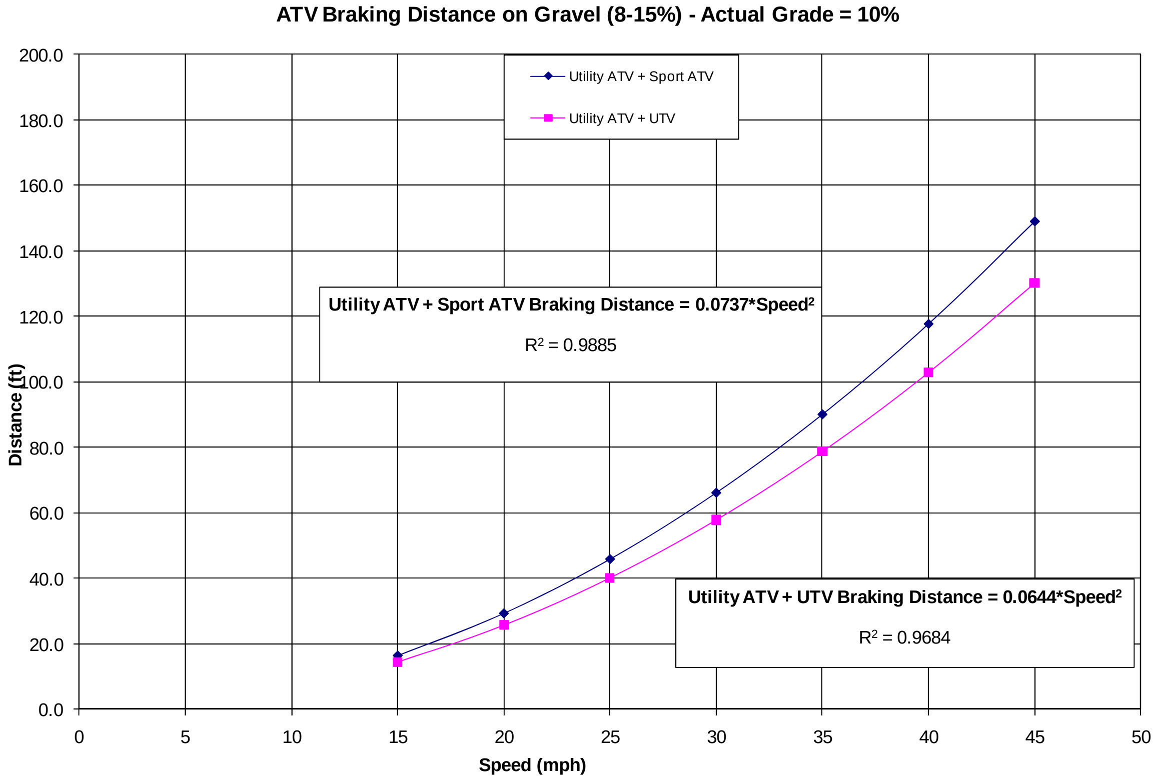



Figure 15 Plot of the utility+sport ATV versus utility ATV+UTV curve fit for 10% gravel.

### 2.2.3 ATV Braking on 16.6% Gravel Grade

The steepest gravel grade test was conducted on a 16.6% grade that had some tree cover which affected GPS speed readings. Only the utility and sport ATVs were tested on the 16.6% gravel grade. The 16.6% gravel grade consisted of a hard packed sandy loam and rock base with two to three inches of 22a road gravel on the top surface. The top one inch layer was loose.

Figure 16 is a plot showing the utility and sport ATVs braking data for both rider types. Note that the data is more scattered on the steeper slope. The novice rider had the longest stopping distance on the utility ATV but the shortest on the sport ATV while the experienced rider had nearly the same stopping distance for both vehicles. This shows that the experienced rider is more consistent from vehicle to vehicle as compared to the novice rider.

Figure 17 is a plot showing the utility and sport ATV braking data and the curve fits independent of rider types. The curves were significantly affected by the novice rider's inconsistency between vehicles as shown by the novice rider's short braking distances with the sport ATV and long braking distances with the utility ATV that were shown in Figure 16.

Figure 18 is a plot of all utility and sport ATV data with one curve fit for all data on the 16.6% gravel grade. Note also that it was more difficult for the riders to be consistent at attaining the highest speed on the steeper grade.

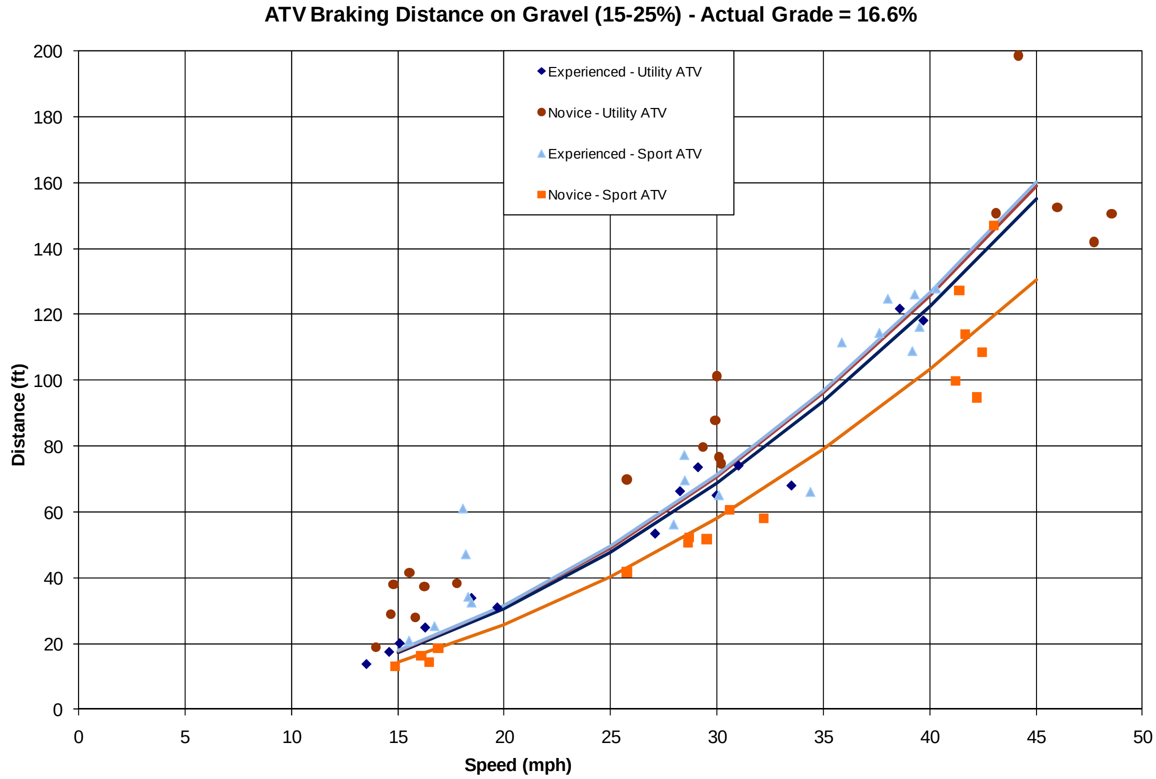



Figure 16 Plot of utility and sport ATV braking data for both rider types on 16.6% grade.

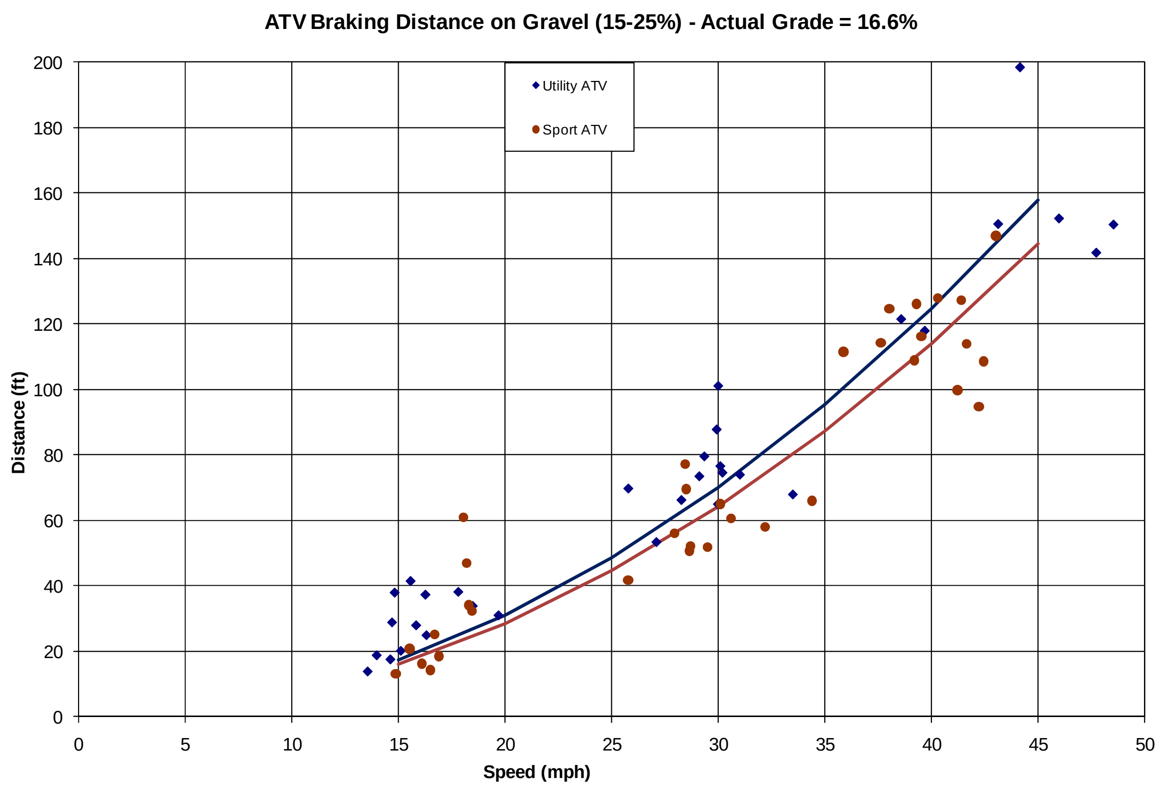



Figure 17 Plot of the utility and sport ATV braking data and curve fits for 16.6% grade.

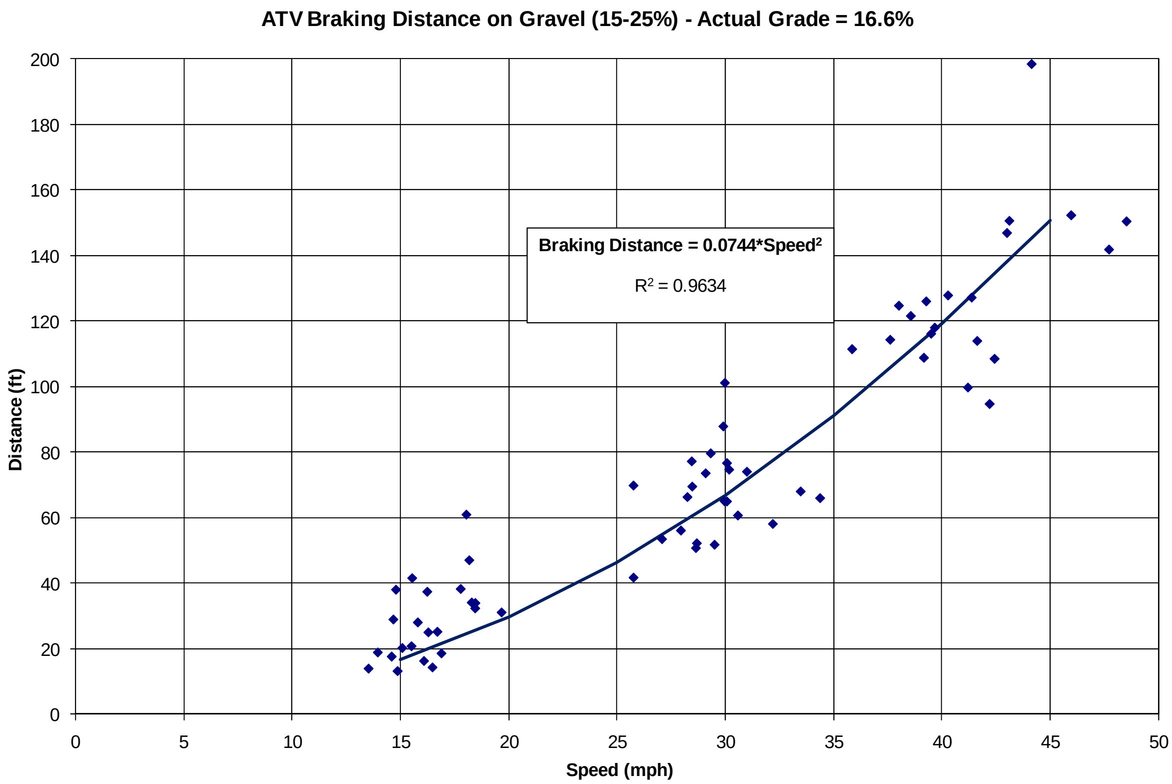



Figure 18 Plot of all utility and sport ATV braking data curve fit for 16.6% gravel grade.

In summary, the data shows that the gravel braking data is fairly consistent and that braking distance depends a lot on coefficient of friction. It is also obvious that the steeper the grade the more variable the stopping distances are and that on very steep grades the novice rider was less likely to go fast.

### 2.2.4 ATV Braking on Flat Sandy Loam

Braking tests were conducted on a sandy loam terrain that was hard packed with a slightly loose surface that was no deeper than one inch. There were a few scattered rocks, approximately one inch in diameter mixed in with the sandy loam. Conditions varied due to weather and light rain which may have helped to bind the surface in some areas. Both the utility and sport ATVs and at a later date the utility ATV and UTV vehicles were tested on flat and 10% grades. Only the utility and sport ATVs were tested on the 18.4% grade. Figure 19 is a photograph of the sport ATV braking on flat sandy loam.

Figure 20 is a plot showing the utility and sport ATVs braking data for both rider types on flat sandy loam. The data was very consistent at the lower speeds and then separated slightly at the higher speeds, indicating a consistent surface.

Figure 21 is a plot showing the utility and sport ATV braking data and the curve fits independent of rider types. Figure 22 shows a plot of all data with the overall general curve fit for the utility and sport ATVs data together.

Figure 19 Photograph of the sport ATV braking on flat sandy loam.

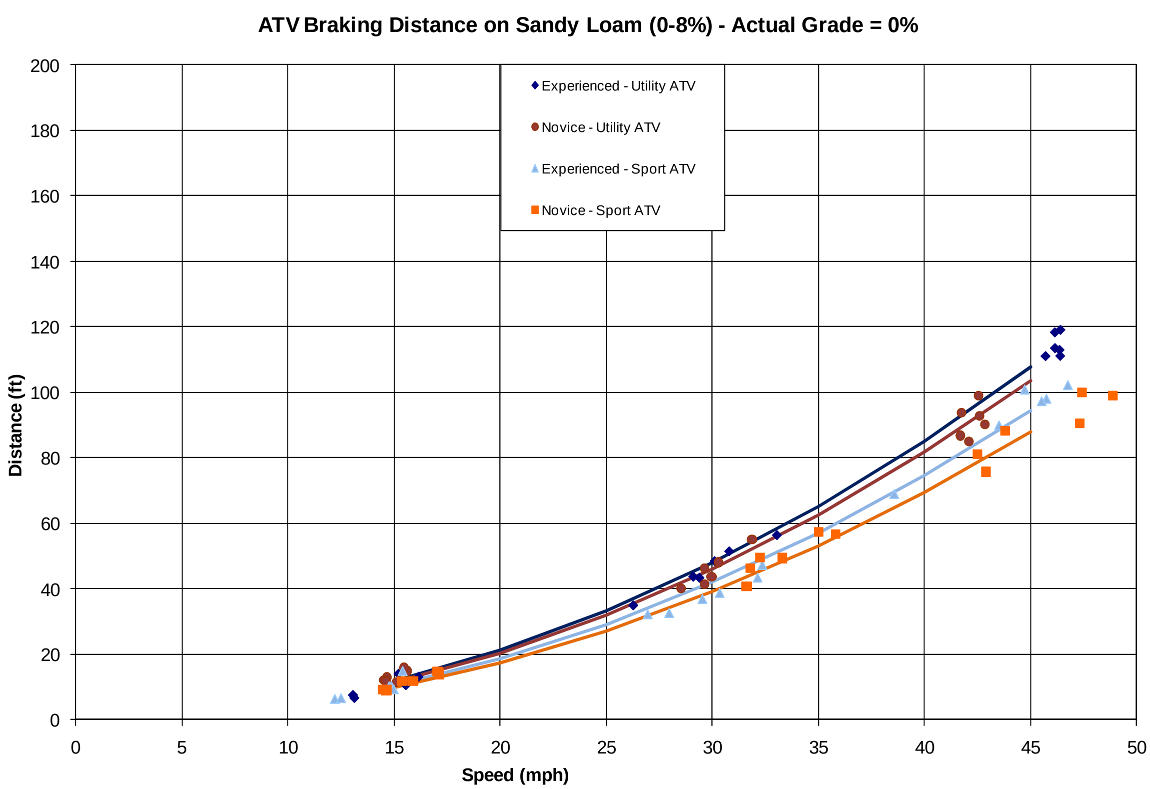



Figure 20 Plot of utility and sport ATV braking data for both rider types - flat sandy loam.

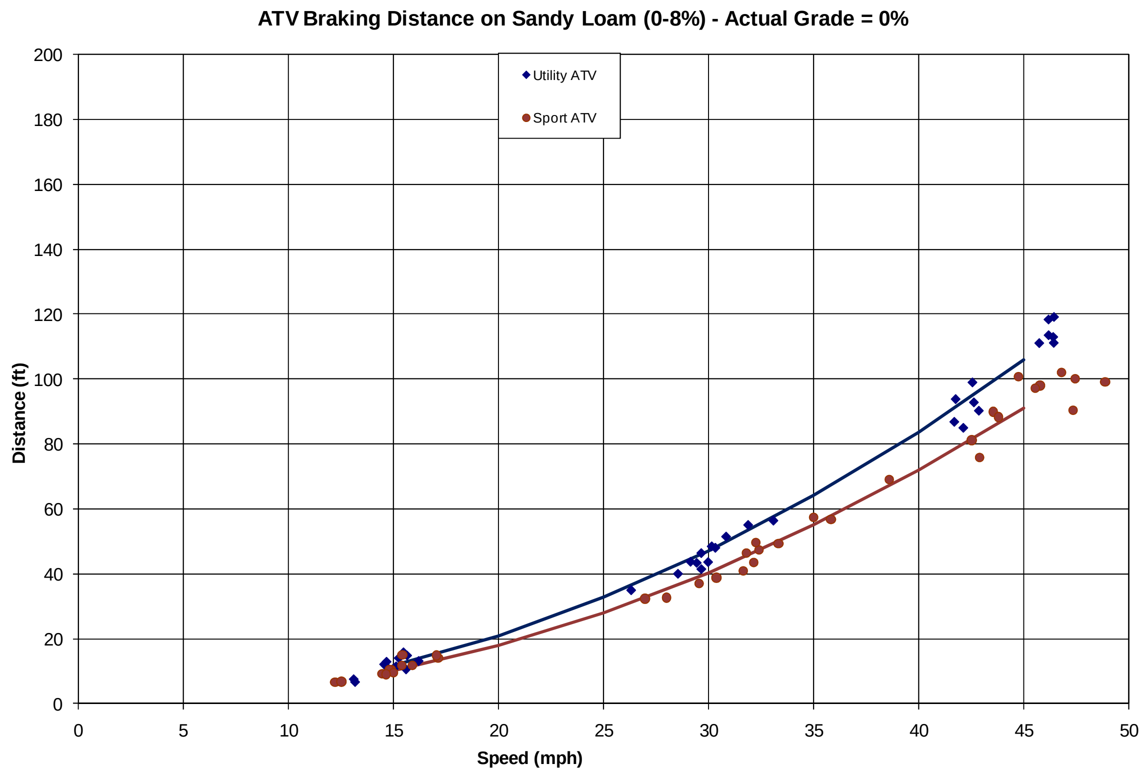



Figure 21 Plot of utility and sport ATV braking data and curve fits, independent of rider type, for flat sandy loam.

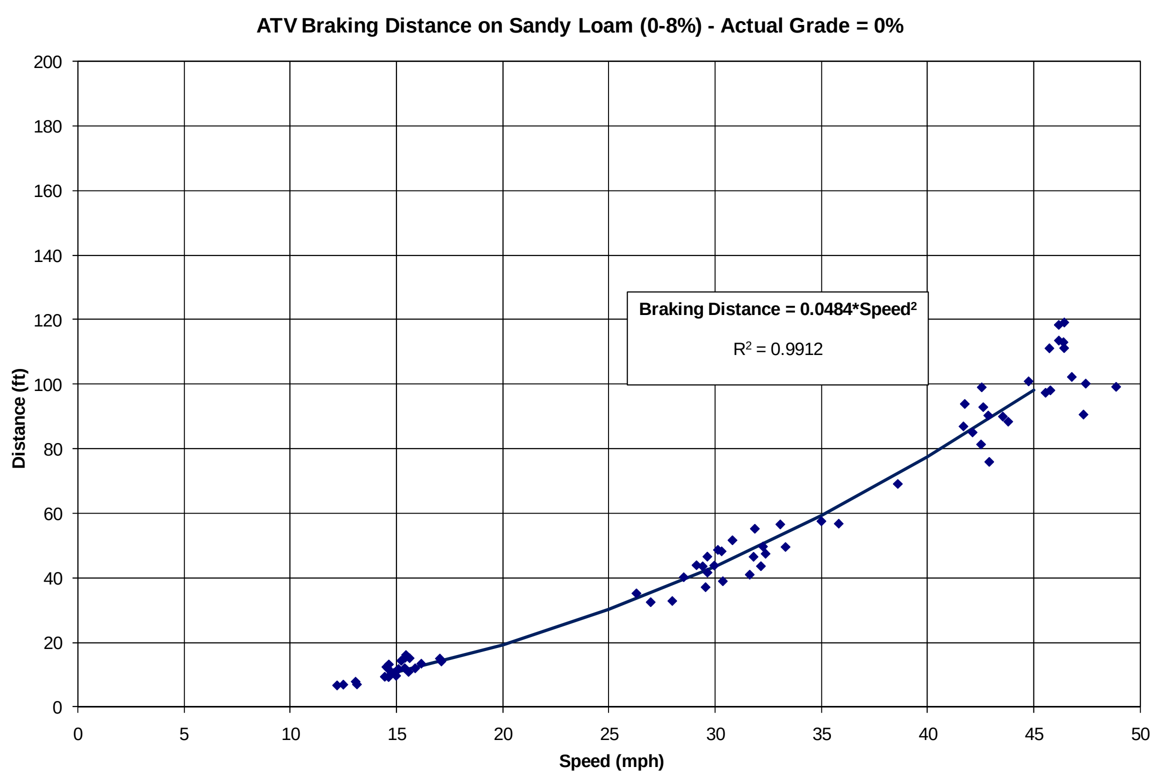



Figure 22 Plot of all utility and sport ATVs braking data and curve fit for flat sandy loam.

The utility ATV was also tested against the UTV on a different date, but on the same sandy loam surface. The data for these two vehicles and the two rider types was consistent like it was for the utility and sport ATVs. Figure 23 is a plot of the utility ATV and UTV braking data for both the novice and experienced riders. The novice rider in the UTV had the shortest braking distance. The other braking distances were similar.

Figure 24 is a plot of the utility ATV and UTV braking data and curve fits, independent of rider type, for flat sandy loam. The data is very similar to the utility and sport ATVs braking data for flat sandy loam.

Figure 25 is a plot of all the utility ATV and UTV braking data fit with one curve for flat sandy loam.

Figure 26 is a plot of the utility+sport ATV braking curve fit data and the utility ATV+UTV curve fit data showing that there was very little difference in braking distances.

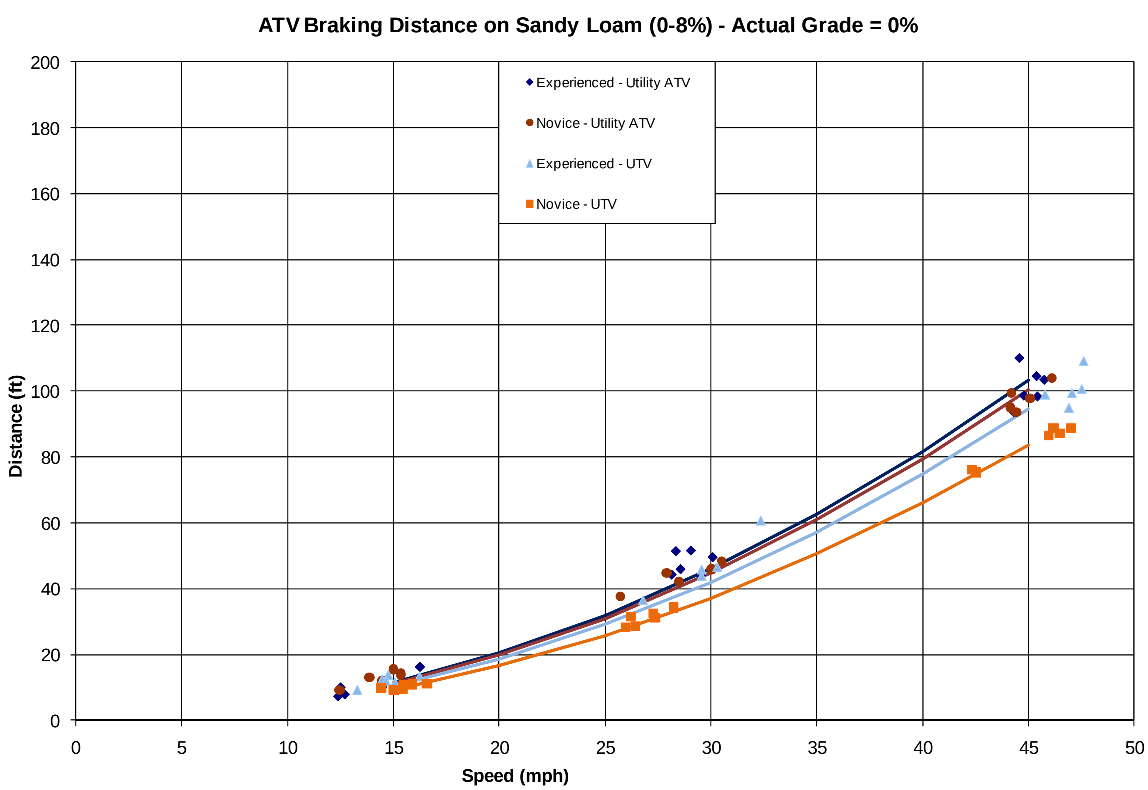



Figure 23 Plot of braking data for the utility ATV and UTV with both rider types on flat sandy loam.

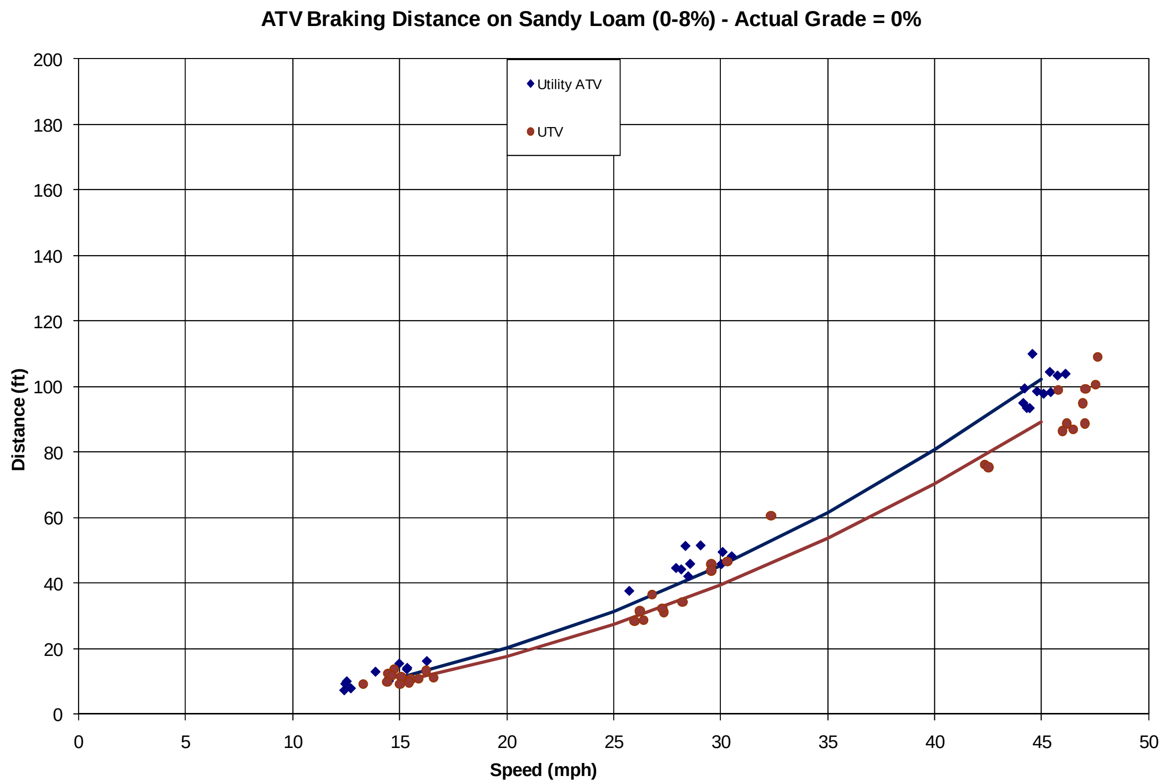



Figure 24 Plot of braking data for the utility ATV and UTV with curve fits - flat sandy loam.

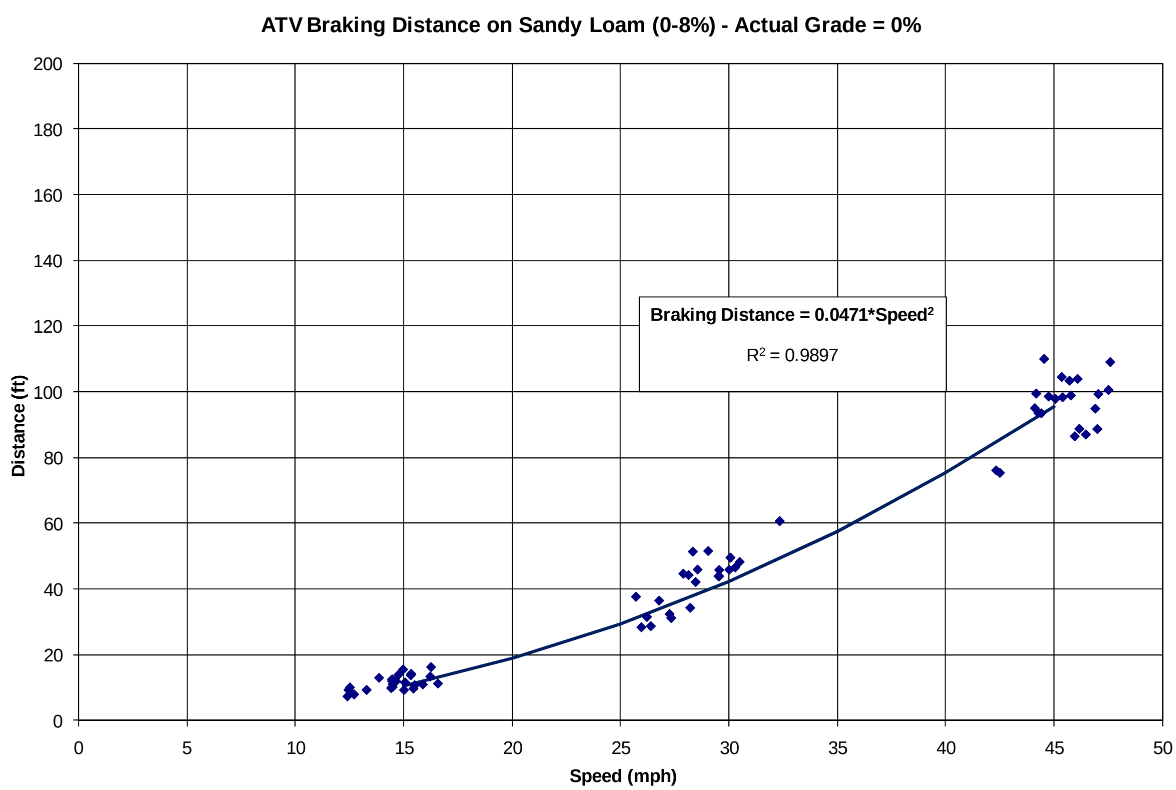



Figure 25 Plot of all utility ATV and UTV braking data curve fit for flat sandy loam.

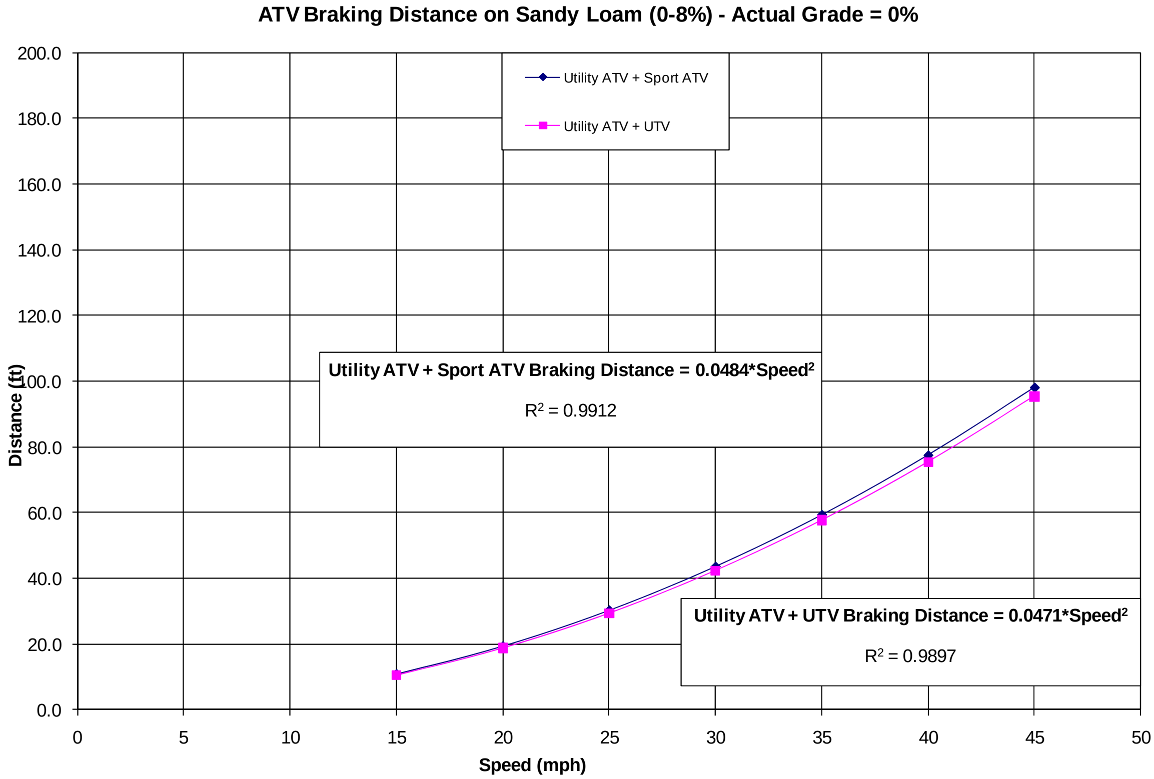



Figure 26 Plot of the utility ATV+sport ATV and utility ATV+UTV curve fit - flat sandy loam.

### 2.2.5 ATV Braking on 10.7% Sandy Loam Grade

Figure 27 is a plot showing the utility and sport ATVs and both rider types braking data for the 10.7% grade sandy loam. The data was very consistent starting out and separating a little at higher speeds, indicating a consistent surface and testing even for a grade at 10.7%.

Figure 28 is a plot showing the utility and sport ATVs braking data and the curve fits independent of rider types. Figure 29 shows a plot of all data with the overall general curve fit for the utility and sport ATVs data together.

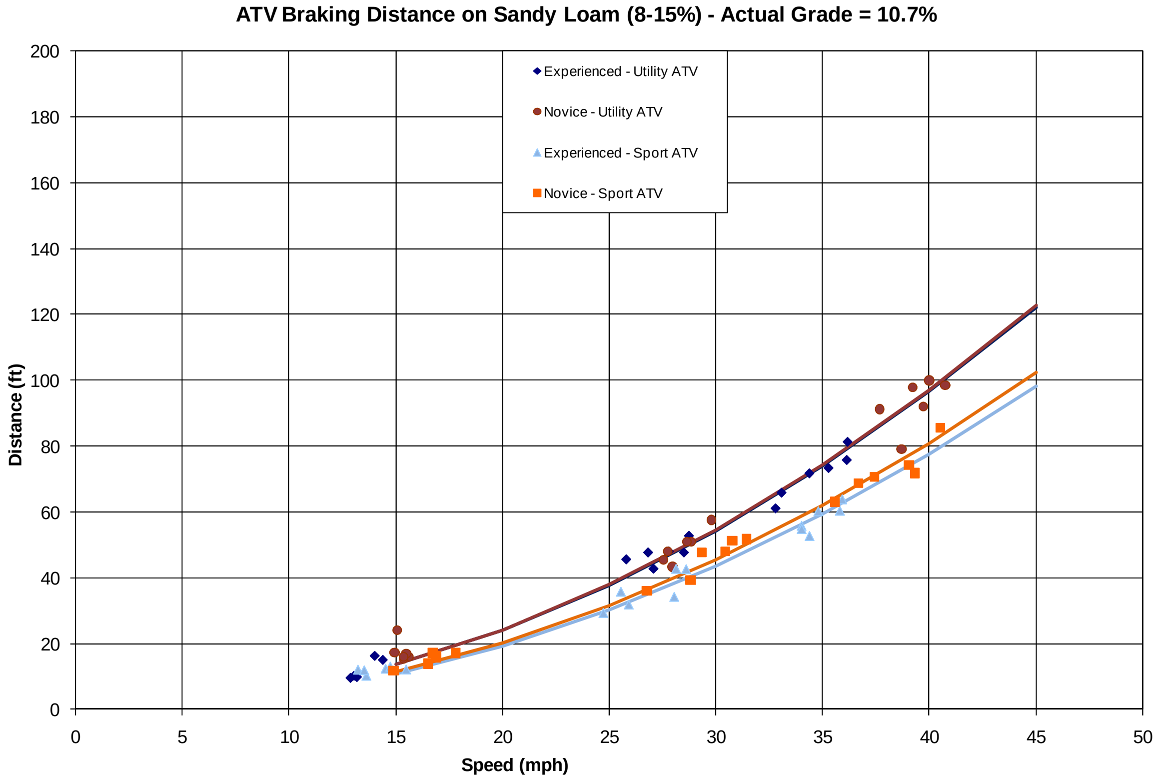



Figure 27 Plot of utility and sport ATVs braking data for both rider types-10.7% sandy loam.

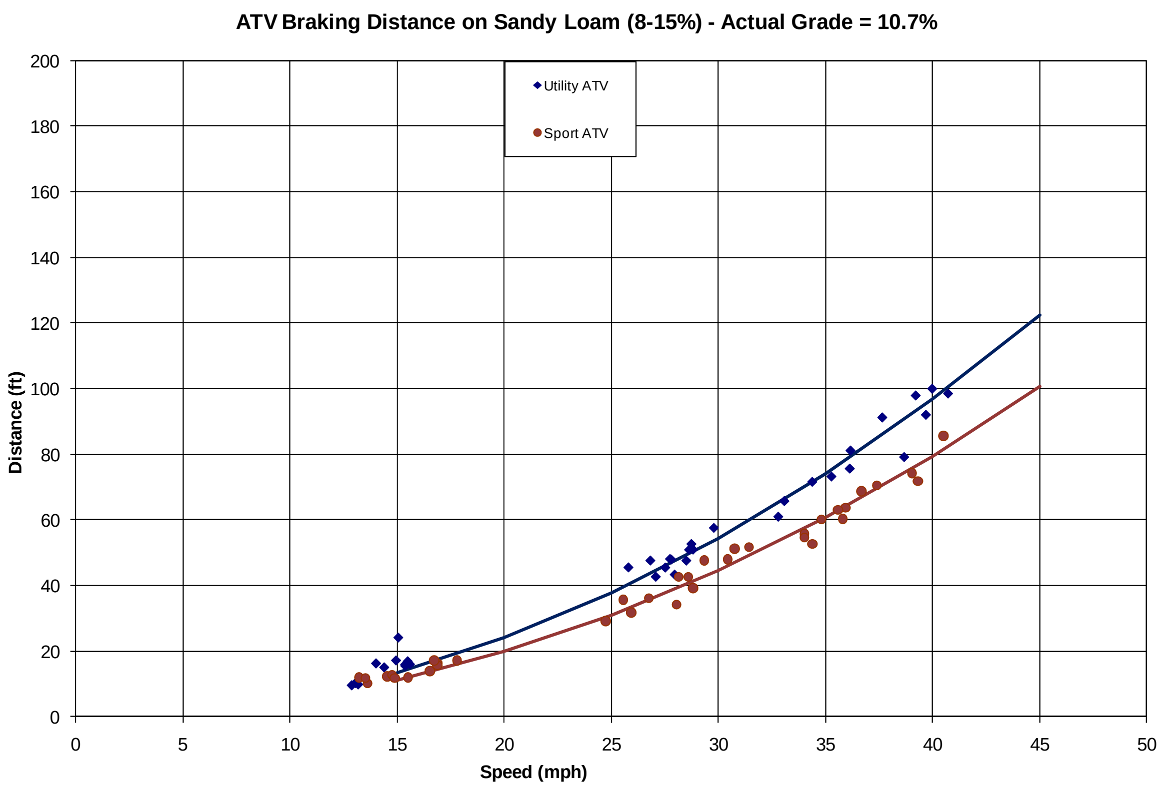



Figure 28 Plot of utility and sport ATVs braking data and curve fits for 10.7% sandy loam.

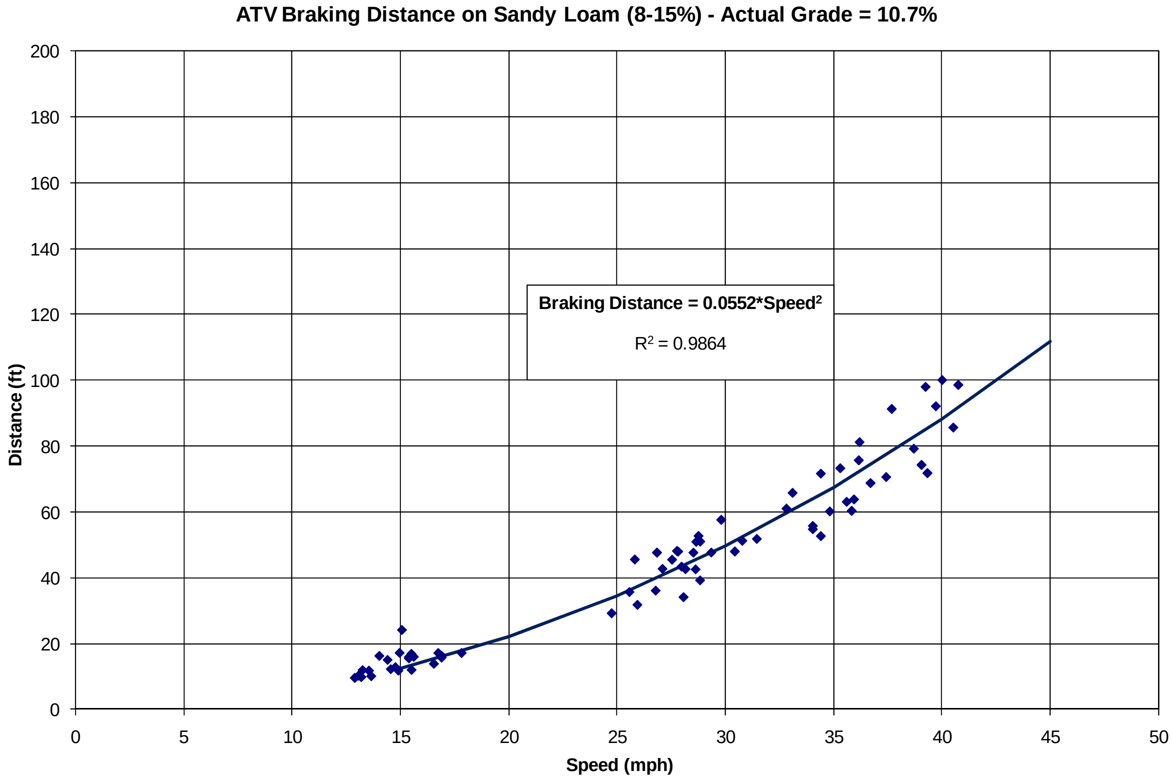



Figure 29 Plot of all utility and sport ATVs braking data and curve fit for 10.7% sandy loam.

The utility ATV was also tested against the UTV on a different date, but on the same surface. The data for these two vehicles and the two rider types was again consistent as it was for the utility and sport ATVs. Figure 30 is a plot of the utility ATV and UTV braking data for both the novice and experienced riders on a 10.7% sandy loam grade. The novice rider in the UTV had the shortest braking distance.

Figure 31 is a plot of the utility ATV and UTV braking data and curve fits, independent of rider type, for 10.7% sandy loam. The data is very similar to the utility and sport ATVs braking data for 10.7% sandy loam.

Figure 32 is a plot of all the utility ATV and UTV braking data fit with one curve for 10.7% sandy loam.

Figure 33 is a plot of the utility+sport ATV braking curve fit data compared to the utility ATV+UTV curve fit data showing that the utility ATV+UTV took longer to stop than the utility+sport ATV. Note that the curve is almost exactly the same shape, indicating that the main difference was the coefficient of friction of the surfaces at the time of testing.

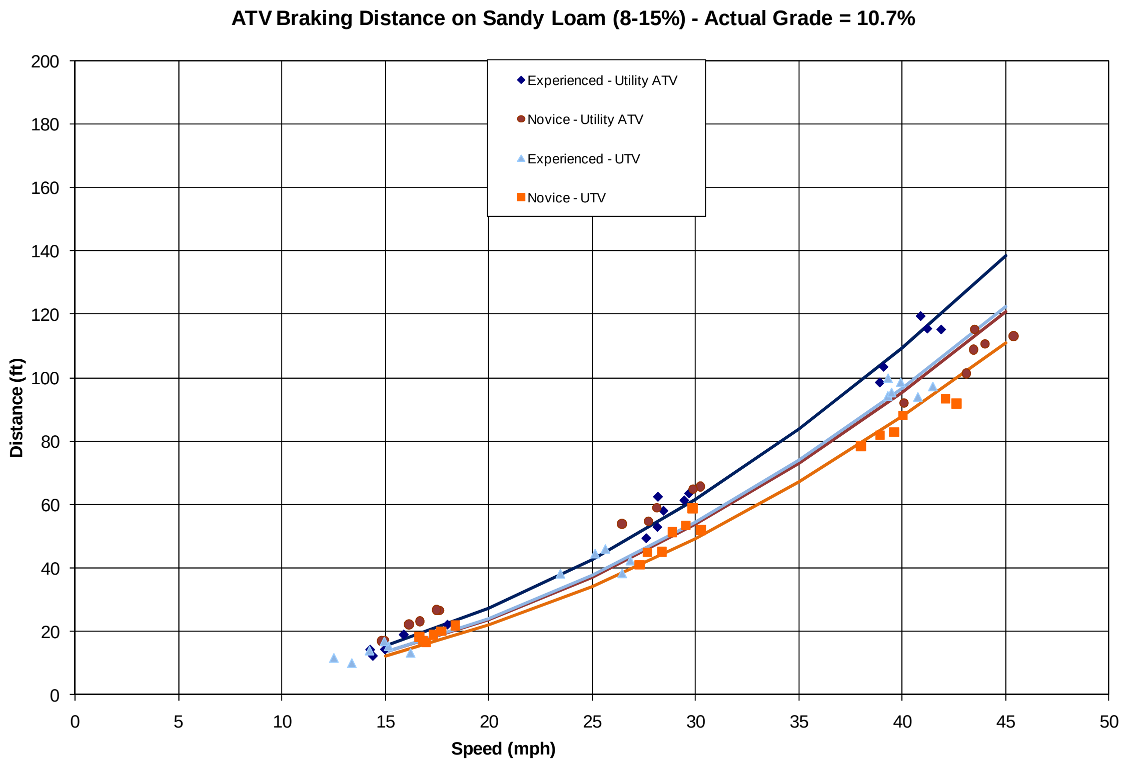



Figure 30 Plot of braking data for utility ATV and UTV, for both rider types, on 10.7% sandy loam.

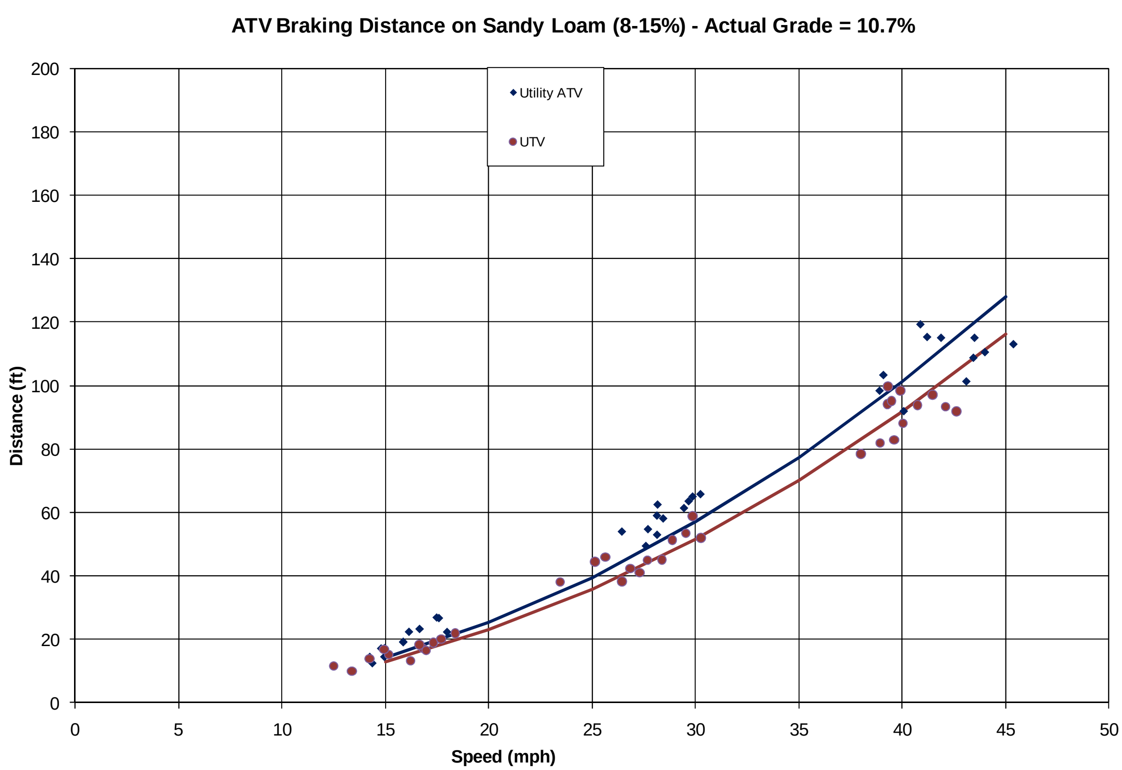



Figure 31 Plot of braking data for utility ATV and UTV with curve fits - 10.7% sandy loam.

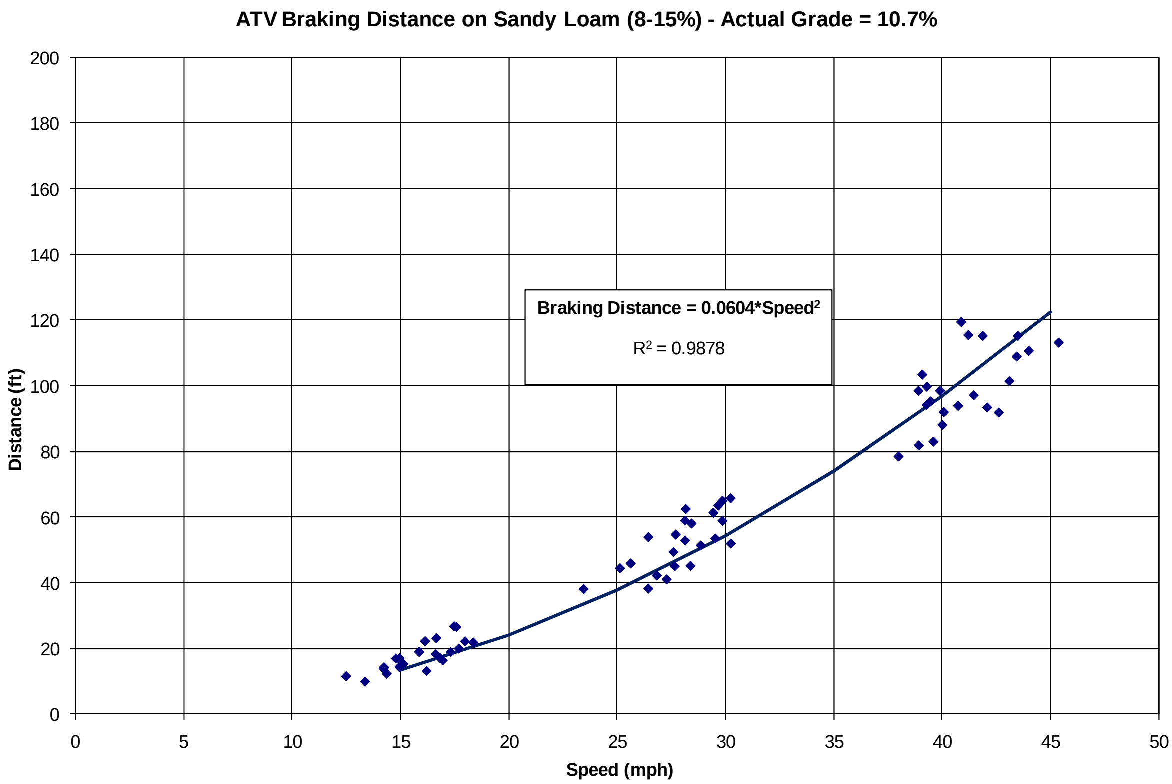



Figure 32 Plot of all utility ATV and UTV braking data curve fit for 10.7% sandy loam.

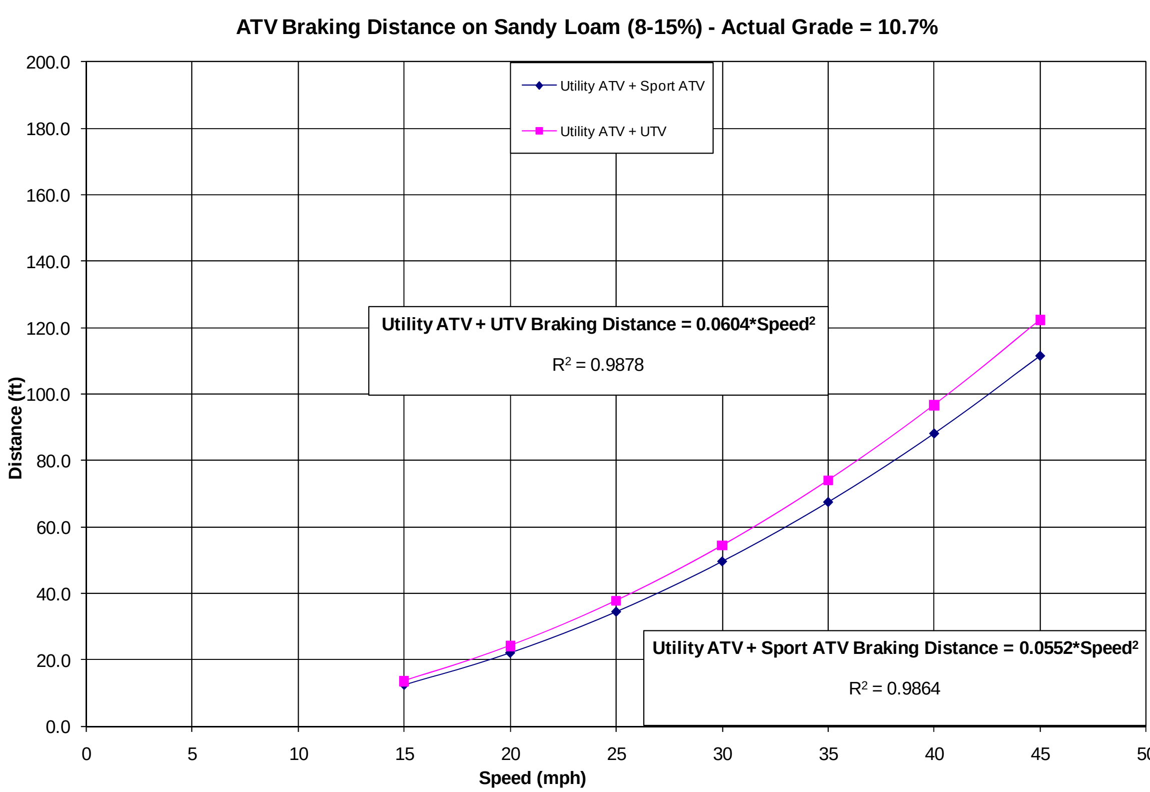



Figure 33 Plot of utility+sport ATV and utility ATV+UTV curve fit - 10.7% sandy loam.

### 2.2.6 ATV Braking on 18.4% Sandy Loam Grade

The steepest grade braking test on sandy loam was conducted on an 18.4% hill that was shorter in length than desired for high speed braking. The road leading up to this grade had a gradual turn just before going down the grade. This turn and the short length of the grade made it difficult for the riders to safely attain the highest speed desired for these braking tests. Only the utility and sport ATVs were tested on the 18.4% sandy loam grade. Figure 34 is a photograph of an ATV braking test on the steepest sandy loam grade.

Figure 35 is a plot showing the utility and sport ATVs braking data for both rider types. Note that the riders only ran at speeds of 15 and 30 mph and at times they did not quite make the 30 mph speed. The data was fairly consistent without much scatter although from shortest to longest stopping distance curves there was a 15 foot difference at 30 mph.

Figure 36 is a plot showing the utility and sport ATVs braking distances and curves fits independent of the rider types. The curves were pretty close together, but spread further apart as the speed increased.

Figure 37 is a plot of all utility and sport ATVs data and one curve fit for all vehicles and rider types on the 18.4% sandy loam grade.

The results show that braking distances in sandy loam were shorter than on the gravel surfaces. On gravel the vehicle tended to slide a lot due to the loose stones. On sandy loam the surface was loose but the tires were able to bite and grip into the hard packed layer of sandy loam.

Figure 34 Photograph of the utility ATV during a braking test on 18.4% sandy loam grade.

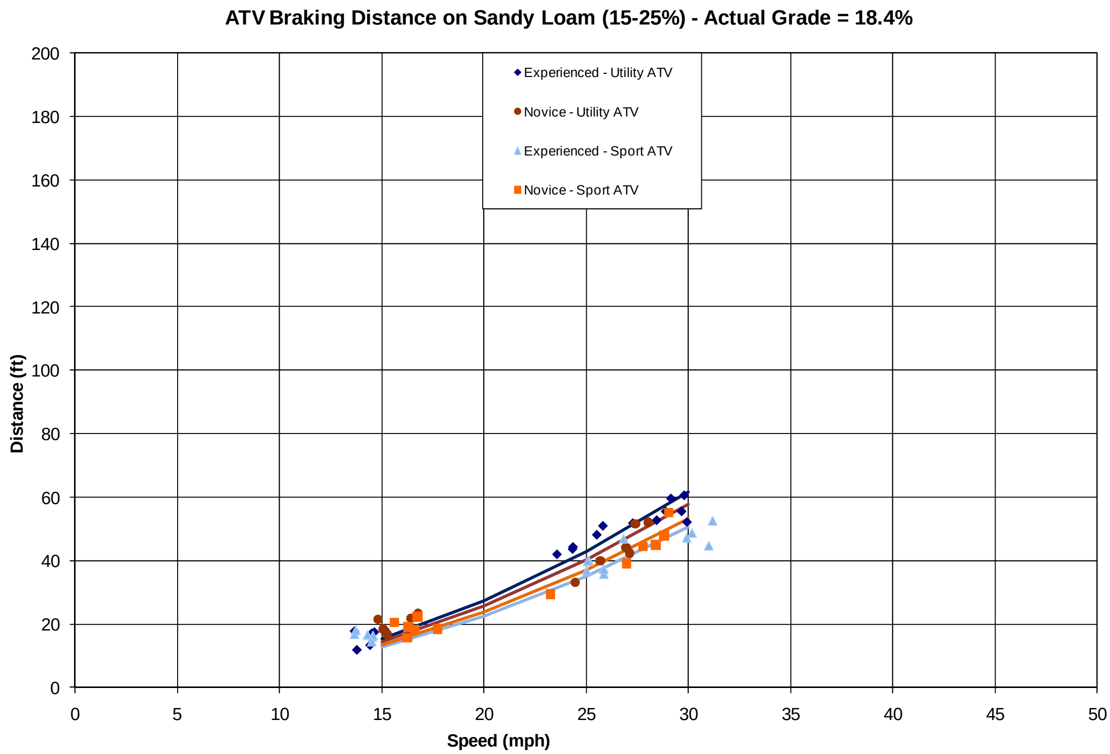
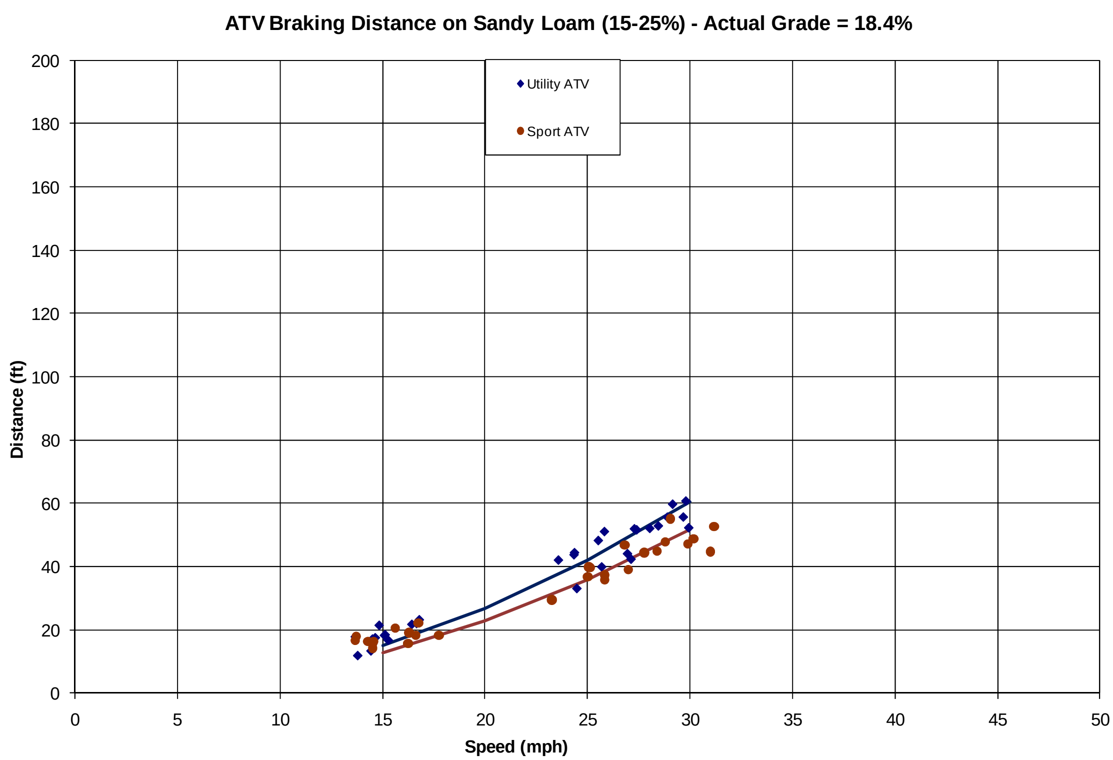



Figure 35 Plot of utility and sport ATV braking data for both rider types on 18.4% sandy




loam grade.

Figure 36 Plot of the utility and sport ATV braking data and curve fits for 18.4% sandy loam grade.

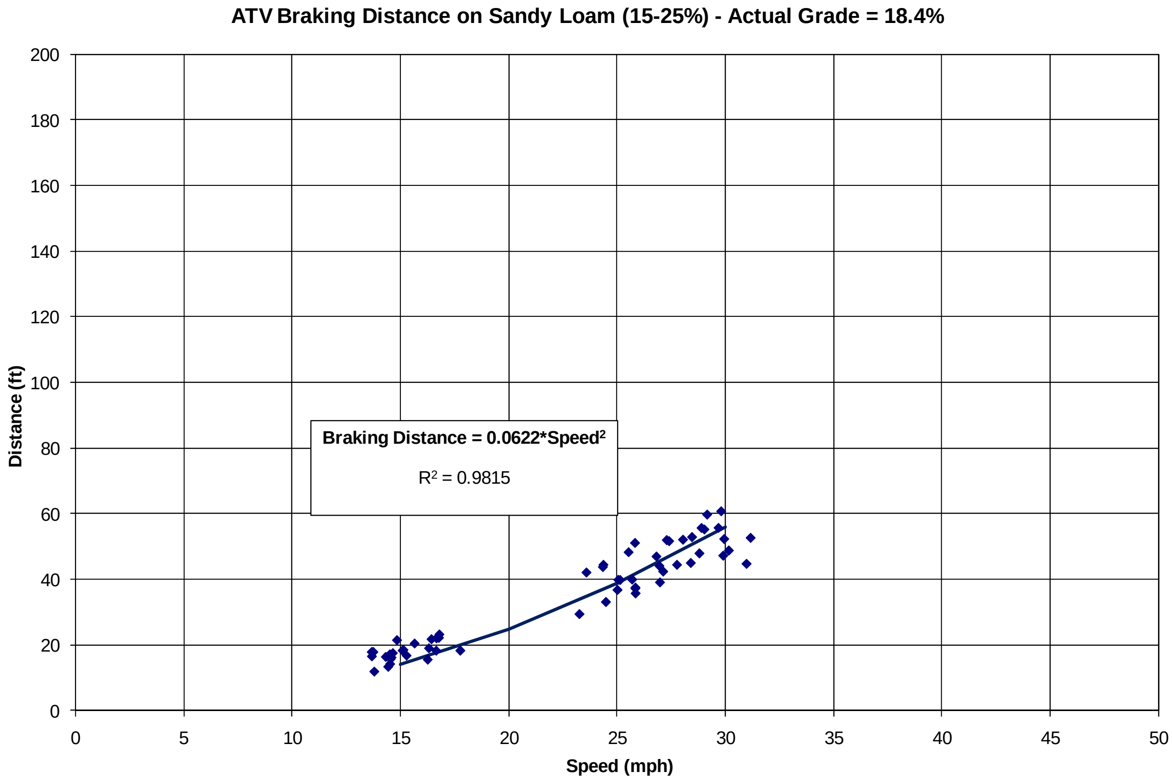



Figure 37 Plot of all utility and sport ATV braking data curve fit - 18.4% sandy loam grade.

### 2.2.7 ATV Braking on Flat Loose Sand

Braking tests were conducted on a loose sand terrain which was soft and at least six inches deep. Only the utility and sport ATVs were tested on the loose sand surface. The "flat" loose sand surface was about a 5% downhill grade. Tests were also conducted on a 24% downhill grade. A loose sand grade in the 8 to 15% range was not available. A much steeper grade was found but only limited testing could be done on it because the grade was too short and to attain speed it would have been dangerous even for the experienced rider. The loose sand didn't allow the vehicles to accelerate to very high speeds due to the resistance of the deep sand on the vehicle tires. Braking distances were short and consistent. Figure 38 is a photograph of an ATV during the flat loose sand braking test.

Figure 39 is a plot showing the braking data for both the utility and sport ATVs and both rider types for flat loose sand. The data was very consistent starting out and then separated a little at the higher speeds. The top speed was only slightly above 30 mph.

Figure 40 is a plot showing the utility and sport ATVs braking data independent of rider types and the curve fits. Figure 41 shows a plot of all data with the overall general curve fit for the utility and sport ATVs data together on the flat loose sand terrain.

Figure 38 Photograph of the utility ATV during flat, loose sand braking testing.

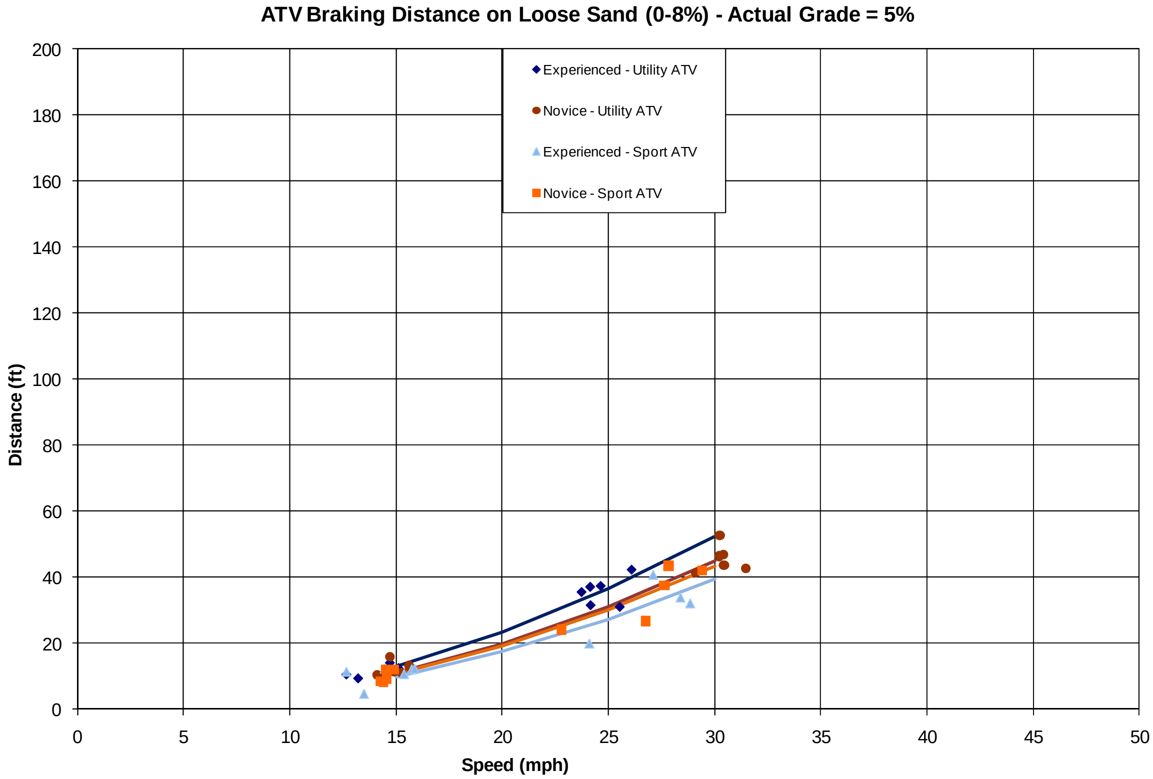



Figure 39 Plot of utility and sport ATV braking data for both rider types on 5% sand grade.

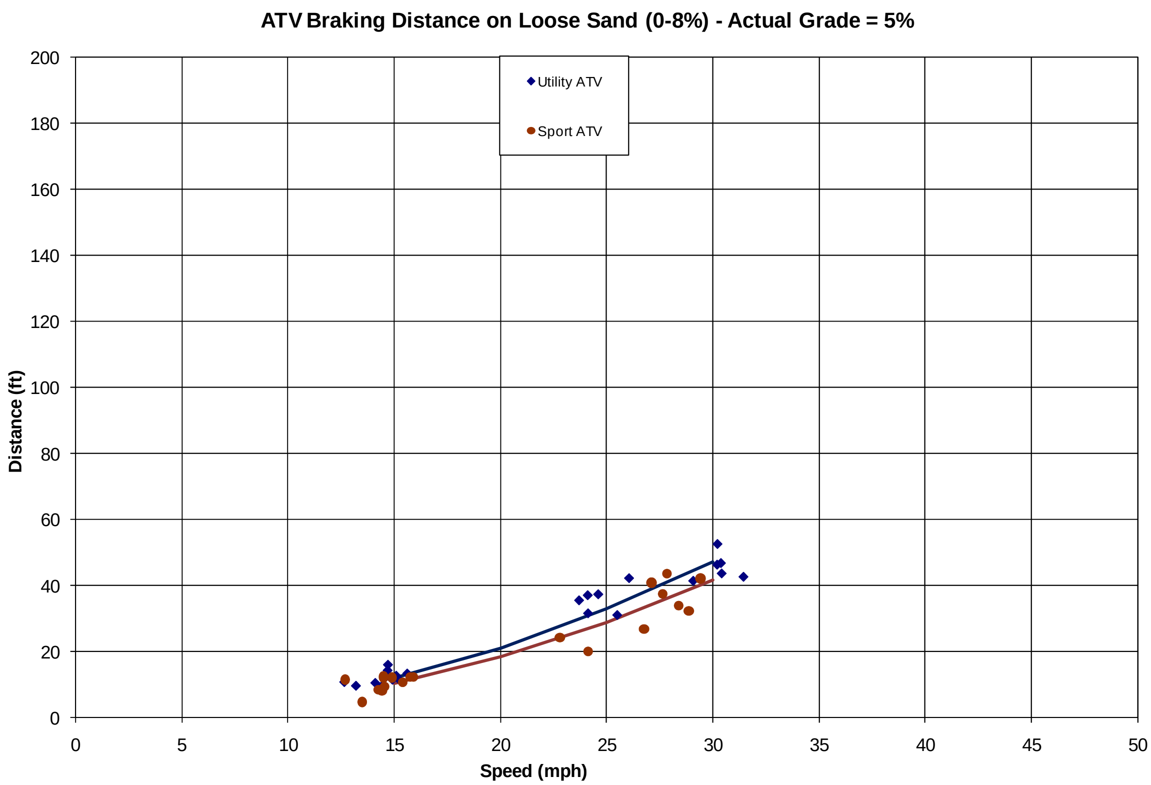



Figure 40 Plot of the utility and sport ATV braking data and curve fits for 5% sand grade.

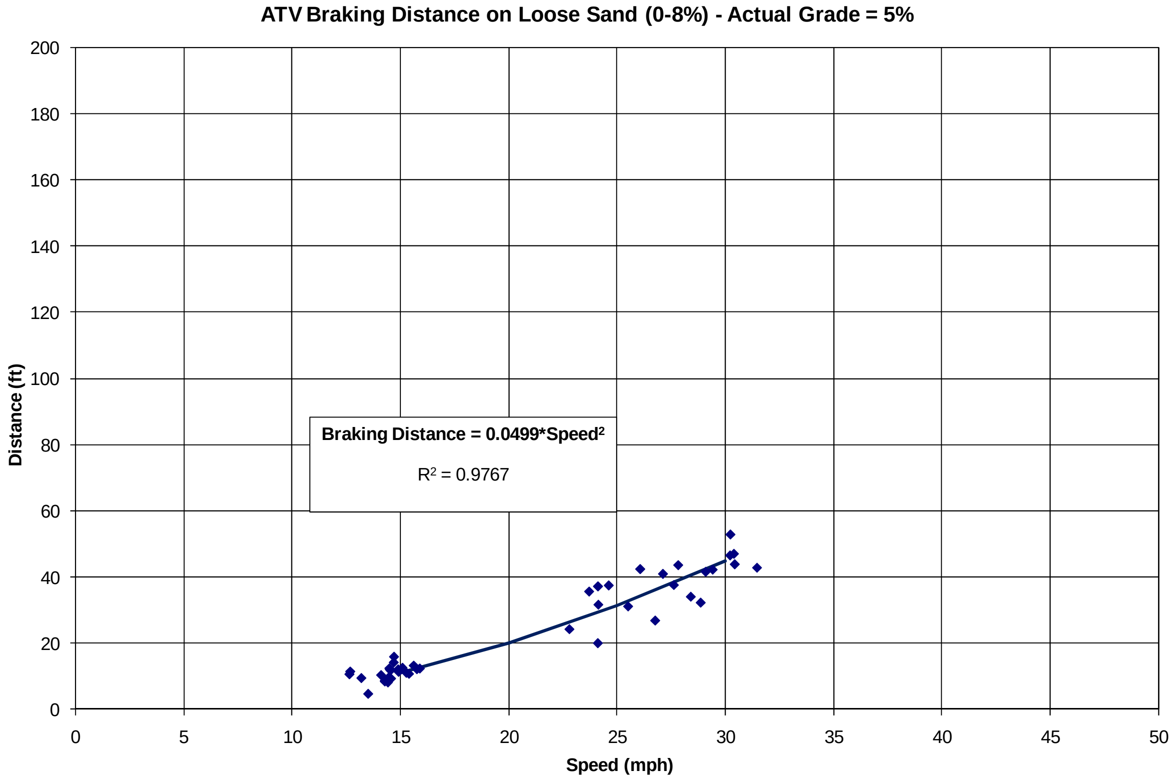



Figure 41 Plot of all utility and sport ATV braking data curve fit for 5% loose sand grade.

### 2.2.8 ATV Braking on 24% Loose Sand Grade

The data for the 24% grade in loose sand was very similar to the 5% flat loose sand data. The top speed, attainable due to the limited approach to the 24% grade and the resistance of the sand, was slightly greater than 25 mph. Braking distances were slightly greater than for the 5% grade.

Figure 42 is a plot showing the data for both the utility and sport ATVs and both rider types for the 24% grade on loose sand. The data was very consistent at the lower speeds and then separated a little at the higher speeds. The top speed was only slightly above 25 mph.

Figure 43 is a plot showing the utility and sport ATVs braking data, independent of rider type, and the curve fits. Figure 44 shows a plot of all data with the overall general curve fit for the utility and sport ATVs data together on the 24% grade loose sand terrain.

The two main factors concerning loose sand is that an average ATV is not going to be able to attain high speeds in loose sand and the braking distance on different steepness of grades is not going to vary significantly as indicated by the variation in braking distances shown between the 0-8% and the 15-25% results. The "bulldozing" affect is one of the major factors in the braking distance results for loose sand. Braking distances on loose sand were shorter than on gravel.

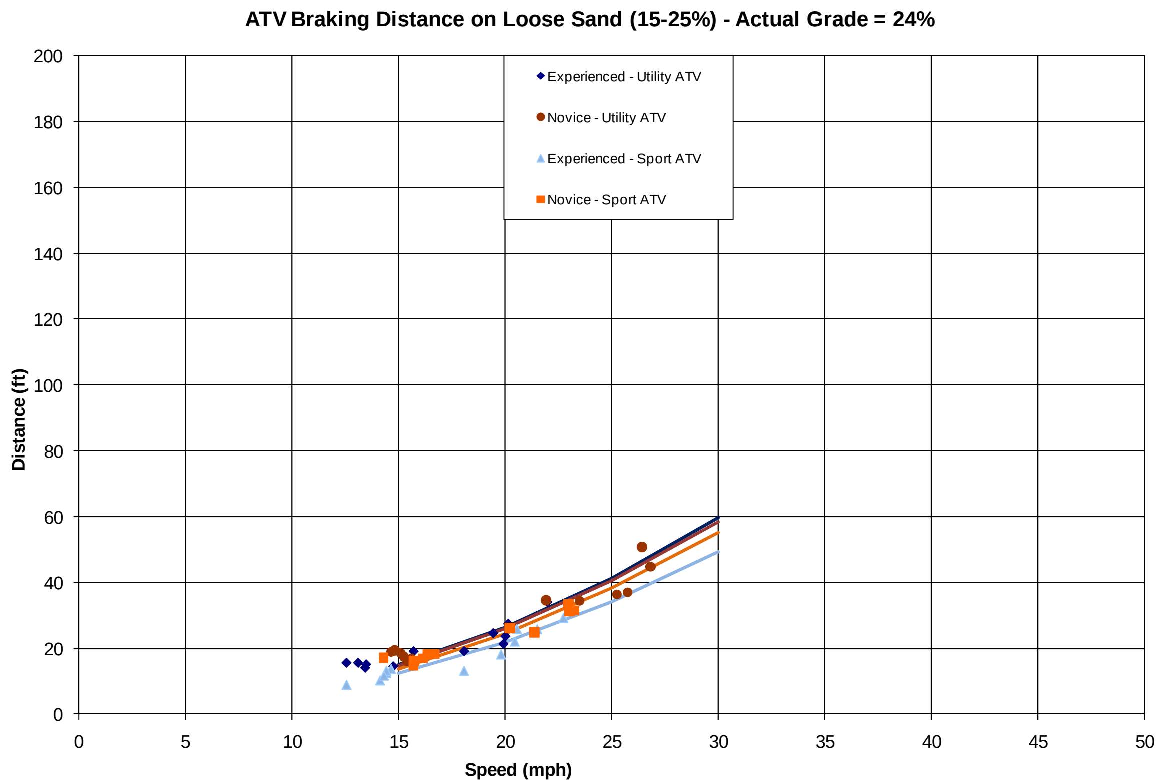



Figure 42 Plot showing utility and sport ATV braking data for both rider types on 24% loose sand grade.

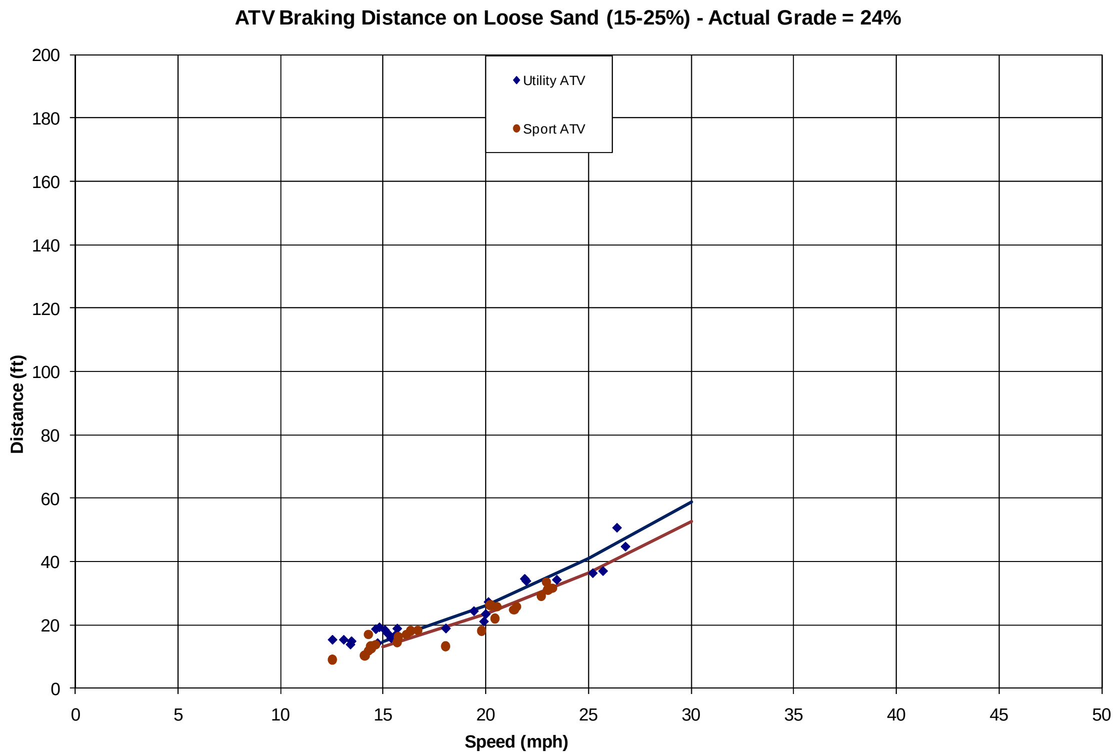



Figure 43 Plot of the utility and sport ATV braking data and curve fits for 24% loose sand grade.

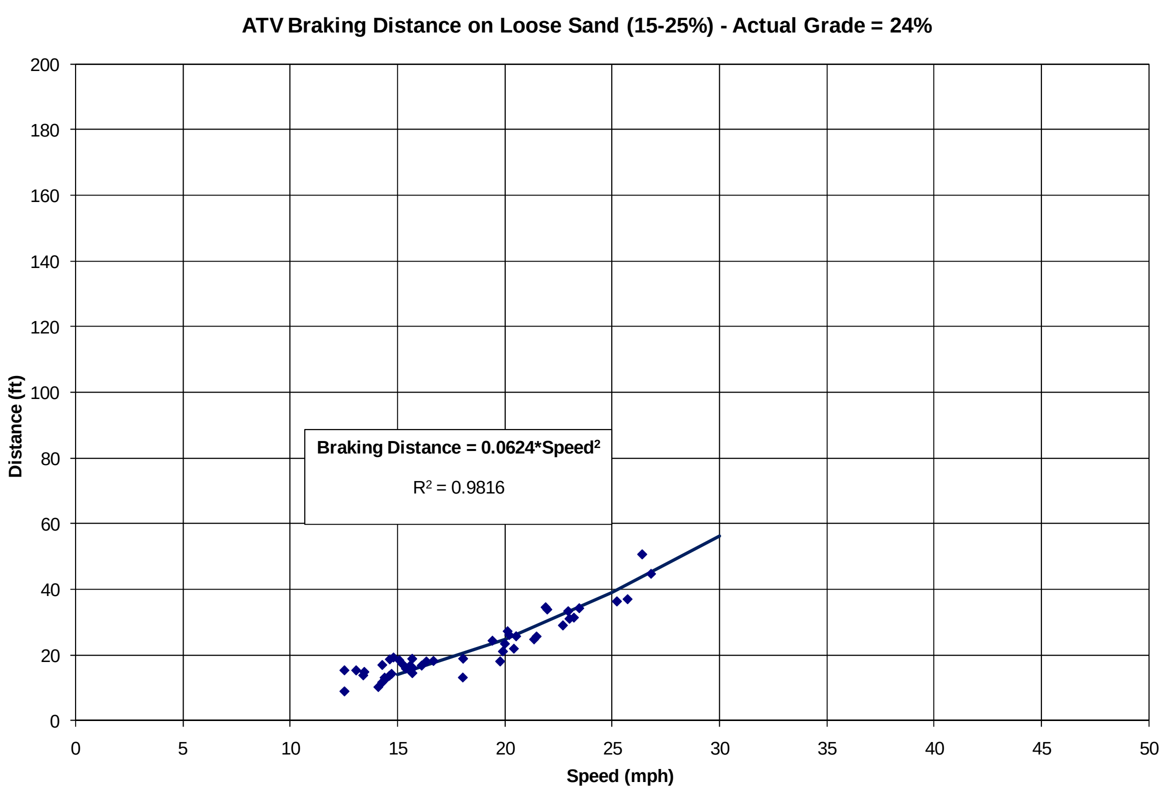



Figure 44 Plot of all utility and sport ATV braking data curve fit for 24% loose sand grade.

### 2.2.8 ATV Braking on Flat Packed Snow

In many areas of the United States ATV riders may end up driving on trails covered in snow, mainly in snow that has been packed down by other drivers. Therefore, it was decided to conduct braking tests on a packed snow covered terrain which was groomed medium to hard-packed with a slightly loose surface no deeper than one inch, similar to ATV trails. Conditions varied due to solar loading and temperature. Both the utility and sport ATVs and, on a separate day, the utility ATV and UTV vehicles were tested on flat and 10.7% grades. Only the utility and sport ATVs were tested on the 18.4% grade.

Figure 45 is a plot showing data for both the utility and sport ATVs and both rider types for flat packed snow. The data was very consistent starting out and then separated a little at the higher speeds.

Figure 46 is a plot showing the utility and sport ATVs braking data and the curve fits independent of rider type. Figure 47 shows a plot of all data with the overall general curve fit for the utility and sport ATVs data together.

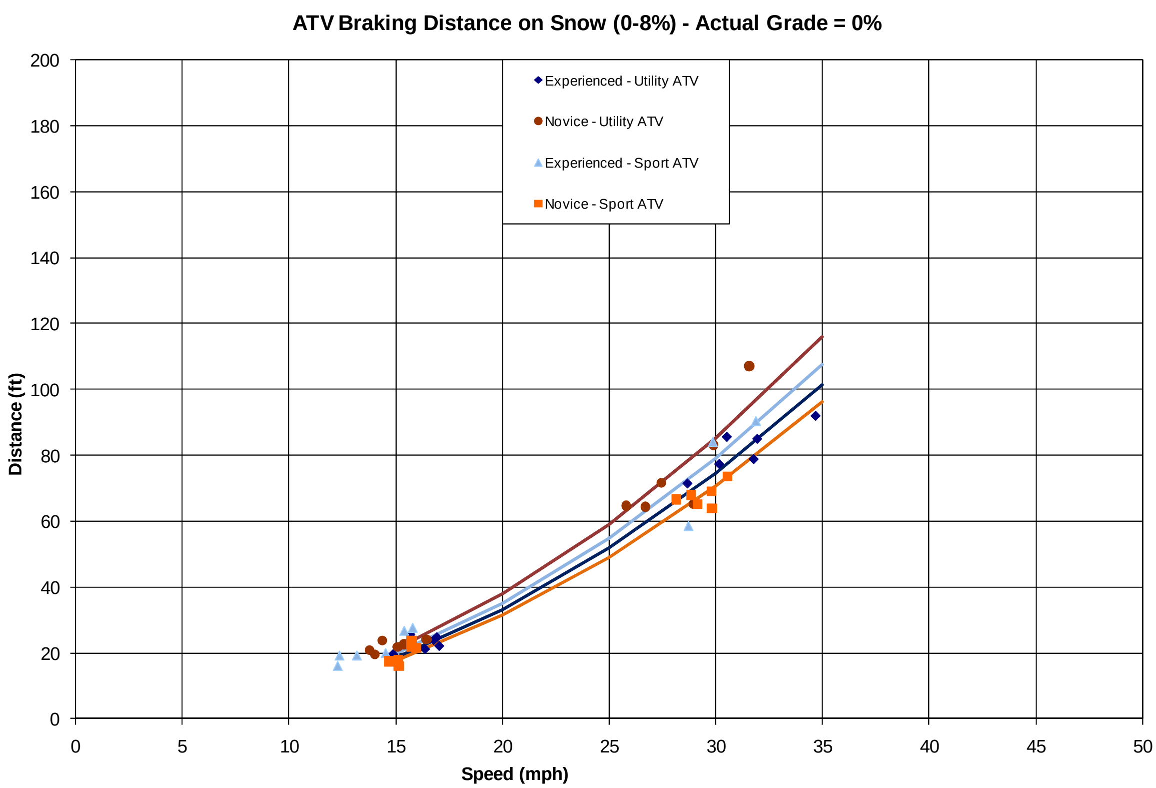



Figure 45 Plot of utility and sport ATV braking data, for both rider types, on flat packed snow.

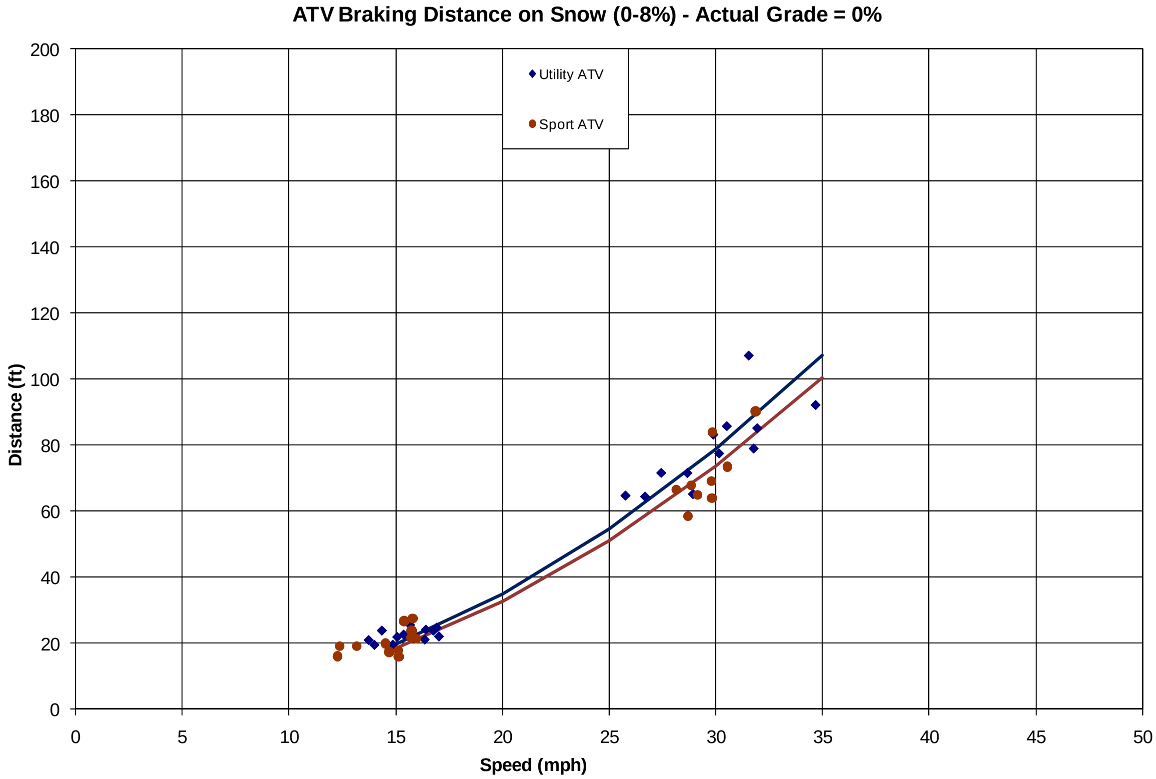



Figure 46 Plot of the utility and sport ATV braking data and curve fits for flat packed snow.

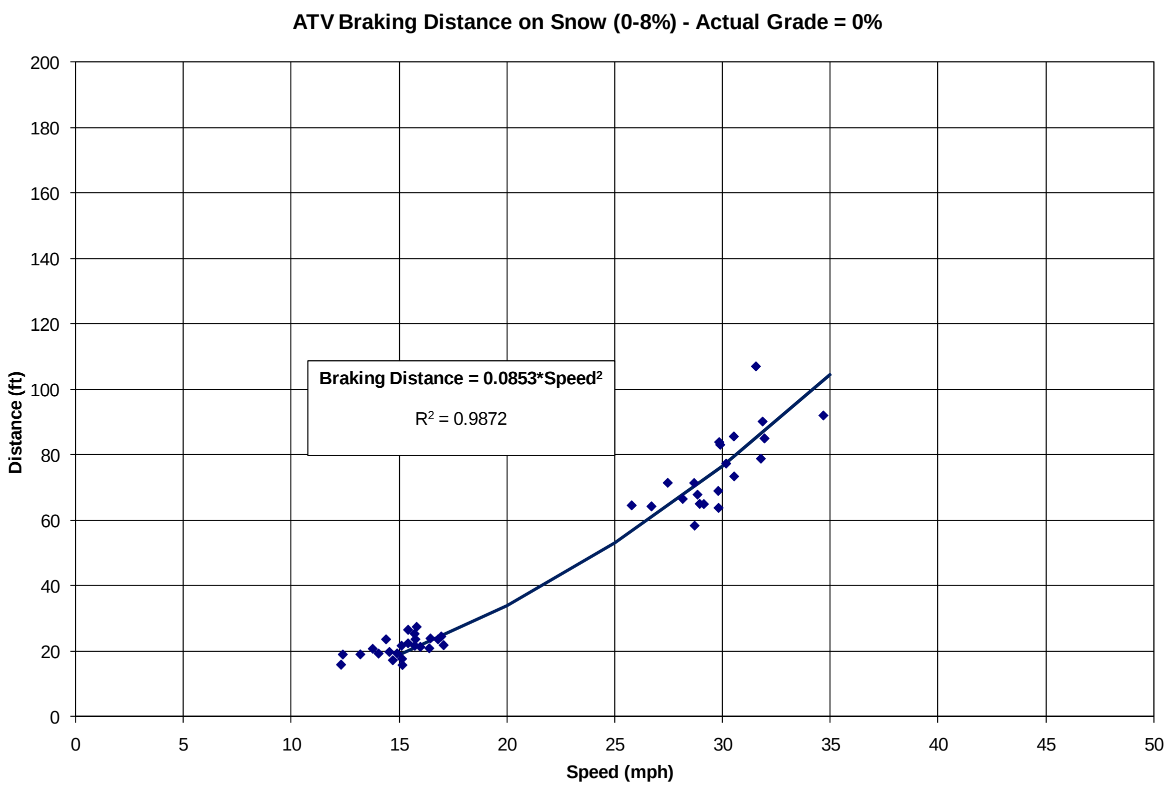



Figure 47 Plot showing all utility and sport ATVs braking data curve fit for flat packed snow.

The utility ATV was also tested against the UTV on a different day but on the same type of packed snow surface in the same location.  The data for these two vehicles and the two riders was again consistent as it was for the utility and sport ATVs.  Figure 48 is a photograph of the UTV during testing on flat packed snow.

Figure 49 is a plot of the utility ATV and UTV braking data for both the novice and experienced riders.  The novice rider in the utility ATV had the shortest braking distance at the higher speeds.  The other braking distances were similar.

Figure 50 is a plot of the utility ATV and UTV braking data and curve fits, independent of rider type, for flat packed snow.  The data is very similar to the utility and sport ATVs braking data for flat packed snow although the data was slightly more variable at the higher speeds.

Figure 51 is a plot of all the utility ATV and UTV braking data fit with one curve for flat packed snow.

Figure 52 is a plot of the utility+sport ATV braking curve fit data to the utility ATV+UTV curve fit data showing that there was very little difference in braking at the lower speeds but as the speeds increased the braking distances varied more.  It was noted that on the day that the utility ATV and UTV were tested the snow was more hard-packed and slippery with less penetration of the tire lugs.  The surface therefore had a lower coefficient of friction on the day of the utility ATV and UTV testing resulting in longer braking distances.


Figure 48 Photograph of the UTV during braking tests on flat packed snow.

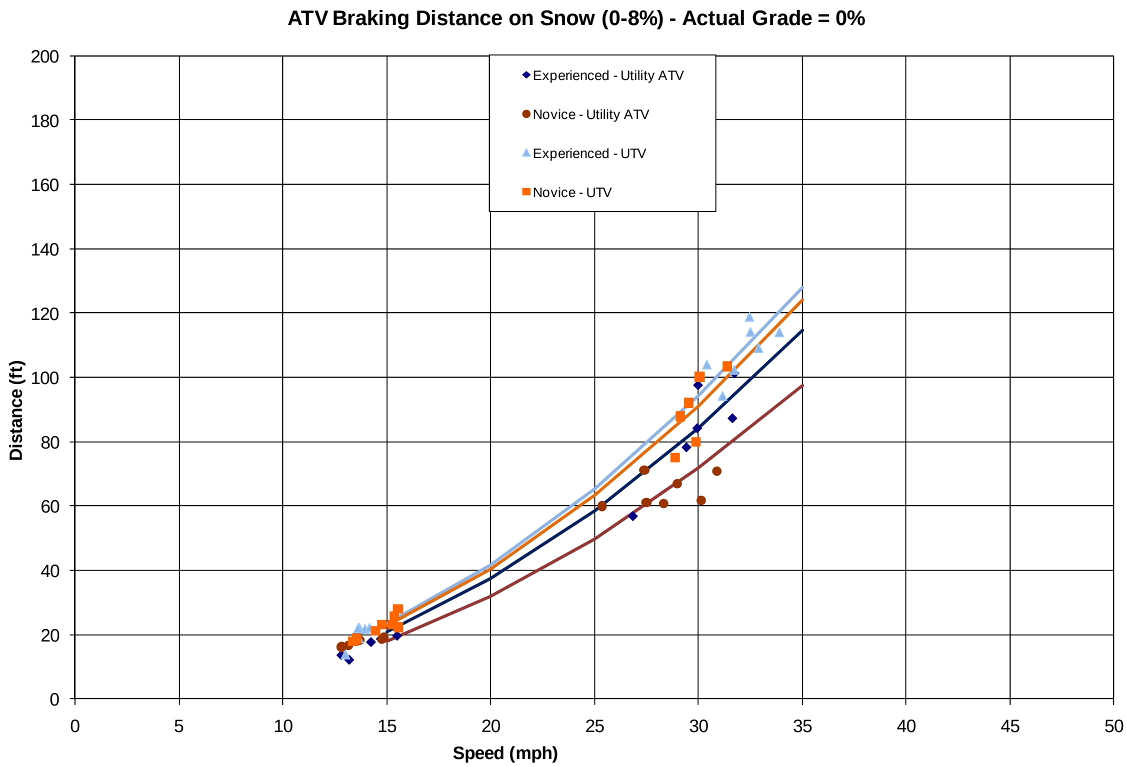



Figure 49 Plot of braking data for utility ATV and UTV for both rider types on flat packed snow.

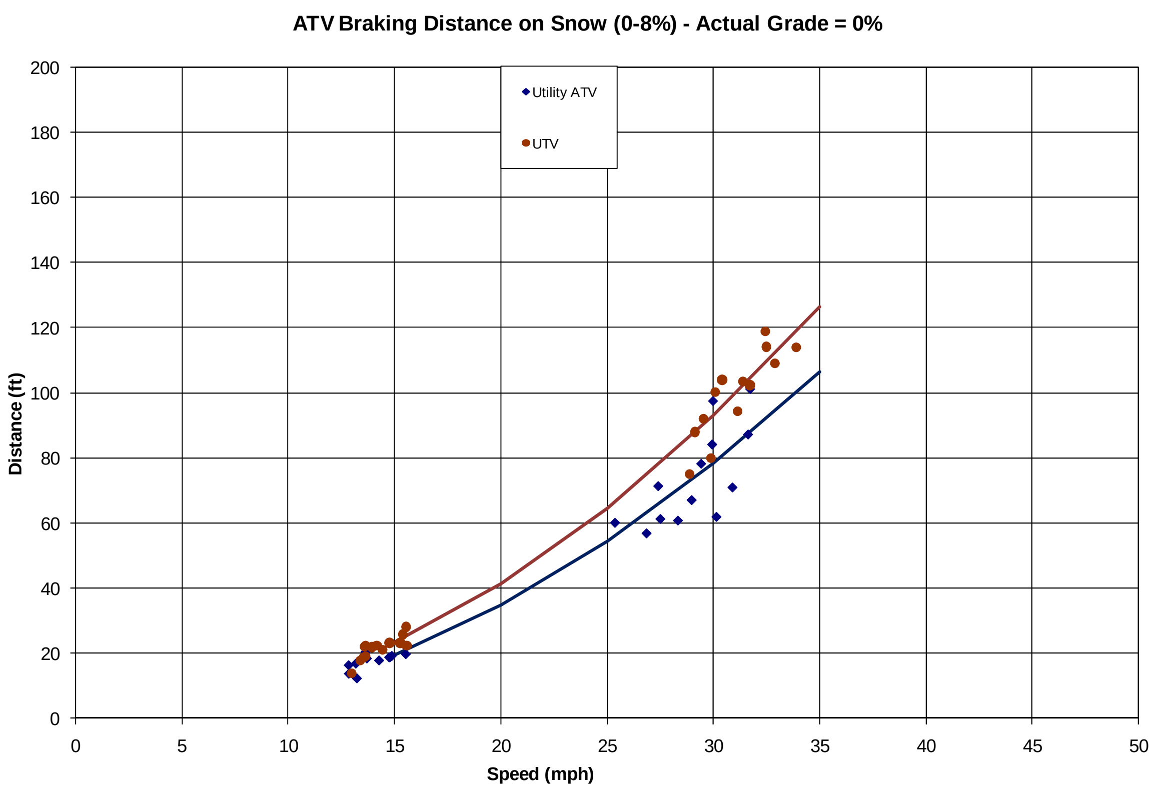



Figure 50 Plot of braking data for utility ATV and UTV with curve fits on flat packed snow.

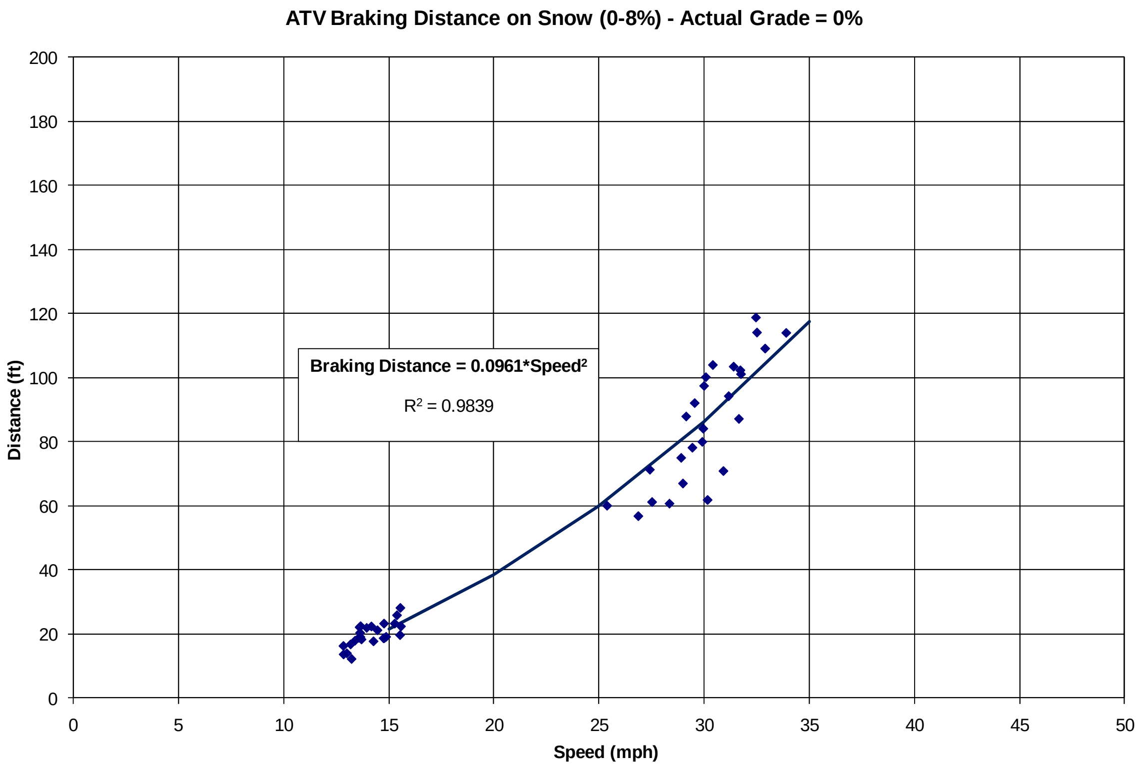



Figure 51 Plot showing all utility ATV and UTV braking data curve fit for flat packed snow.

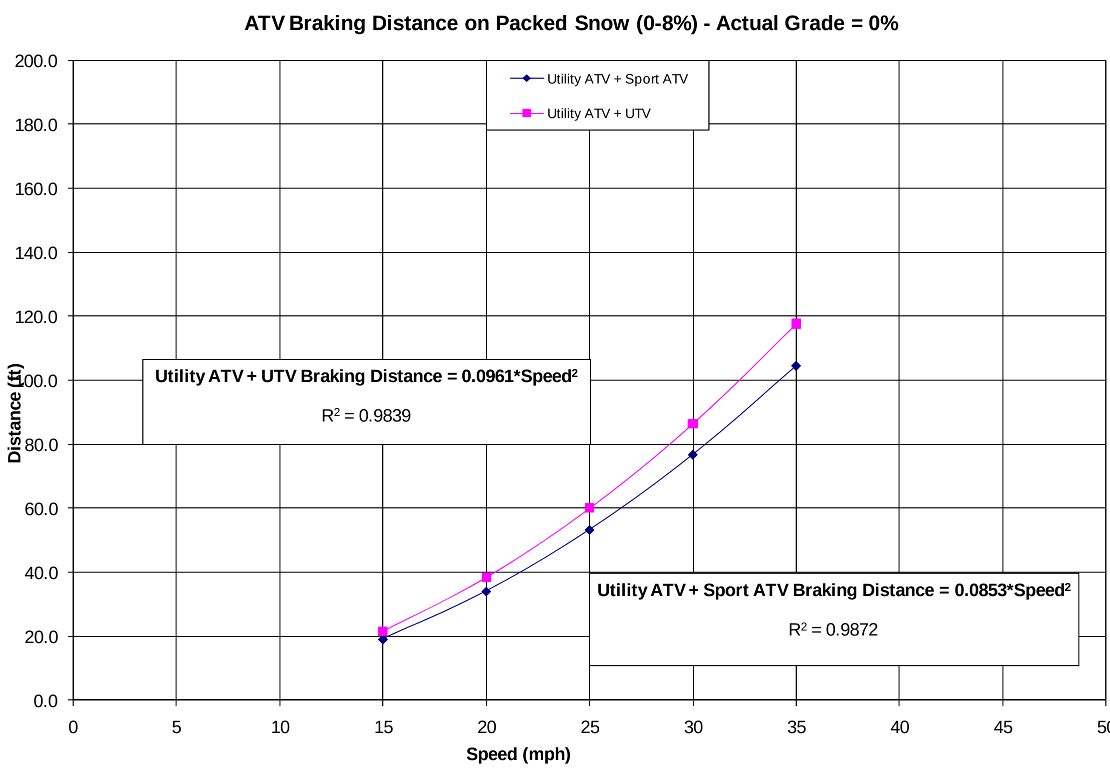



Figure 52 Plot of utility ATV+sport ATV and utility ATV+UTV curve fit data for flat packed snow.

### 2.2.9 ATV Braking on 10.7% Packed Snow Grade

Both the utility and sport ATVs and, on a separate day, the utility ATV and UTV vehicles were tested on the 10.7% grade that was used for sandy loam testing but this time the surface was packed snow. The packed snow top layer was a little deeper and a little softer than the packed snow on the flat road.

Figure 53 is a plot showing the data for the utility and sport ATVs and both rider types on the 10.7% packed snow grade. The data was very consistent at the lower speeds and then spread out at the higher speeds. The braking distances were less consistent for the 10.7% grade than for the flat surface, possibly due to the grade. The novice rider had shorter stopping distances than the experienced rider but it was noted during testing that the novice rider would lock his brakes and quite often the ATV would yaw to one side or the other. The experienced rider appeared to have better control during braking as he would not always lock his brakes or not lock them for extended periods of time.

Figure 54 is a plot showing the utility and sport ATVs braking data and the curve fits independent of rider type. The curves were very close, as the novice and experienced rider balanced each other out. Figure 55 shows a plot of all data with the overall general curve fit for the utility and sport ATVs data together.

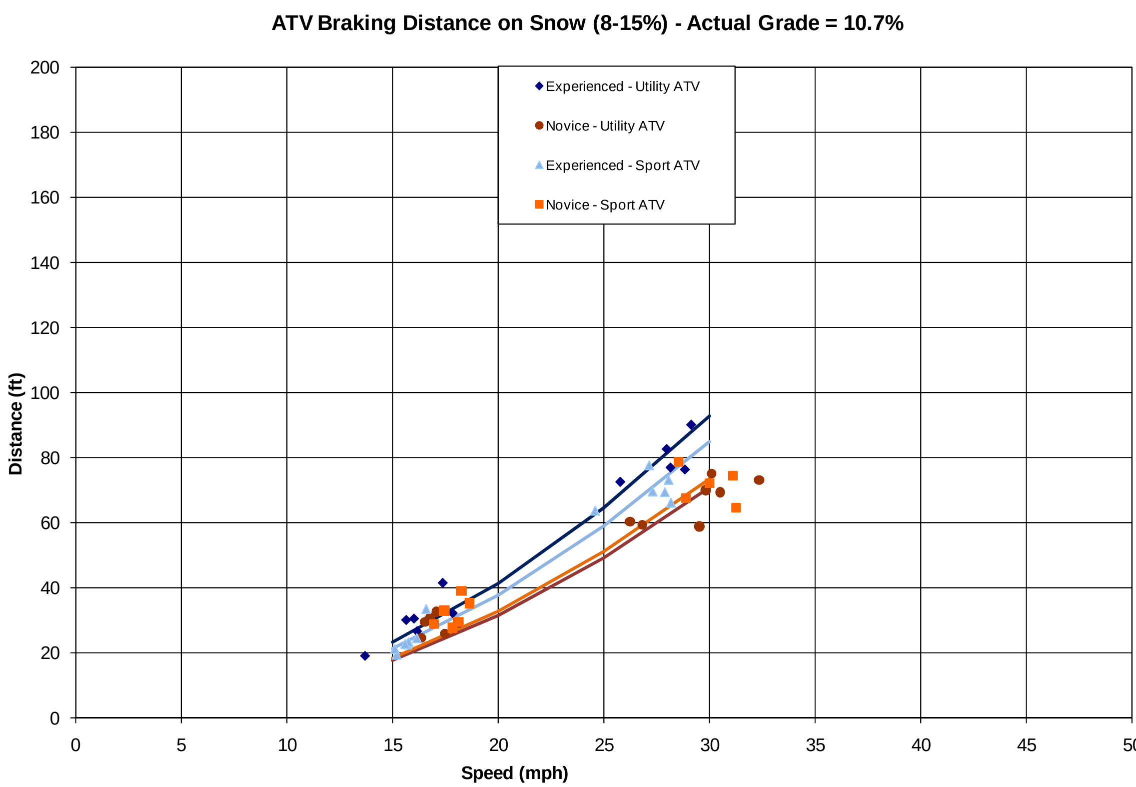



Figure 53 Plot of utility and sport ATV braking data, for both rider types, on 10.7% packed snow.

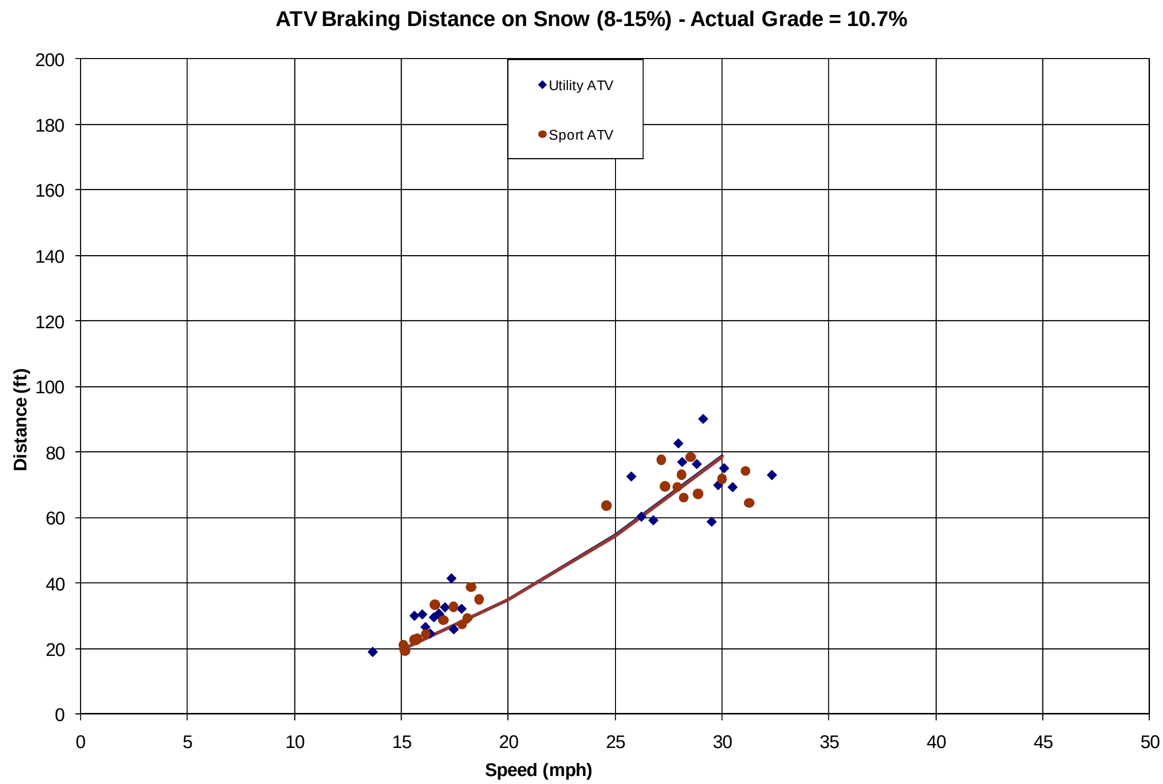



Figure 54 Plot of utility and sport ATV braking data and curve fits for 10.7% snow grade.

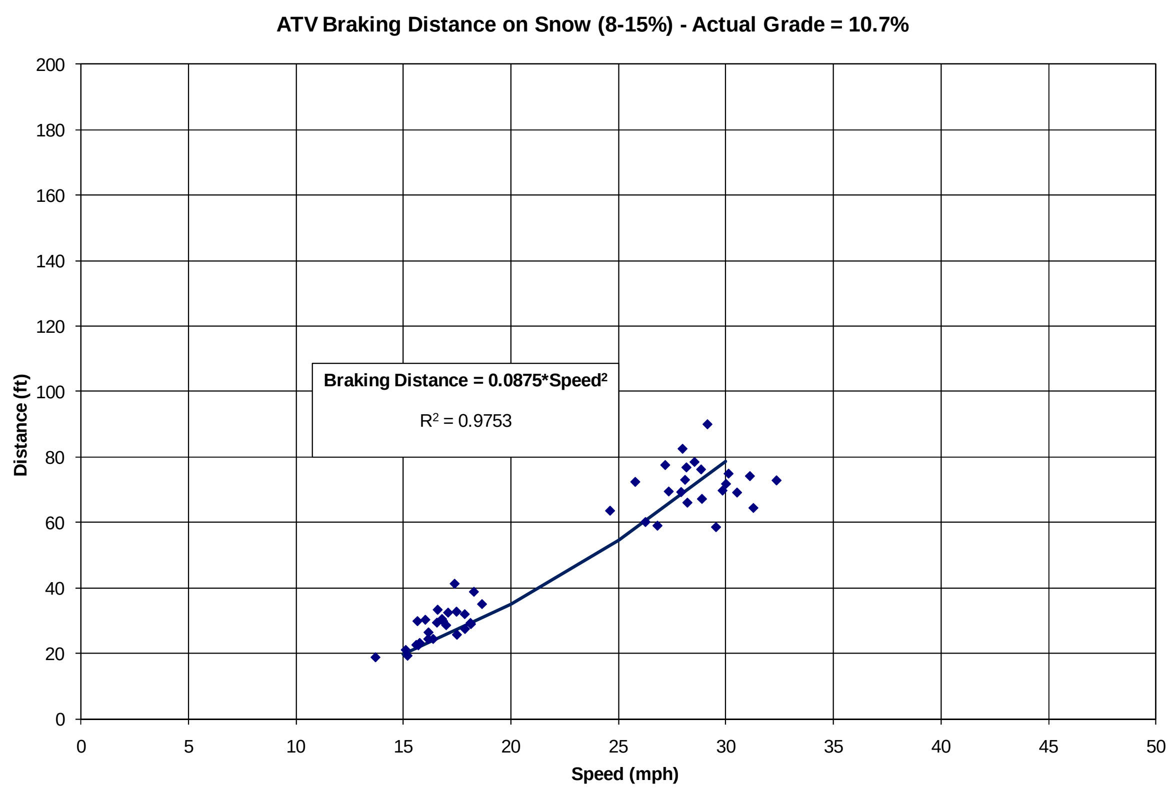



Figure 55 Plot of all utility and sport ATV braking data curve fit for 10.7% packed snow.

Figure 56 is a plot showing data for both the utility ATV and UTV and both rider types for 10.7% packed snow. The data was very consistent at the lower speeds and then spread out at the higher speeds. The braking distances were less consistent for the 10.7% grade than for the flat surface, possibly due to the grade. The novice rider in the utility ATV had the shortest braking distance at the higher speeds. The other braking distances were similar.

Figure 57 is a plot showing the braking data for the utility ATV and UTV and the curve fits independent of rider type. The curves spread a little bit at the higher speeds. Figure 58 shows a plot of all data with the overall general curve fit for the utility ATV and UTV data together.

Figure 59 is a plot of the utility ATV+Sport ATV braking curve fit data to the utility ATV+UTV curve fit data showing that there was very little difference in braking at the lower speeds and as the speeds increased the braking distances varied a small amount.

Figure 60 is a photograph of the UTV during braking on the snow covered grade.

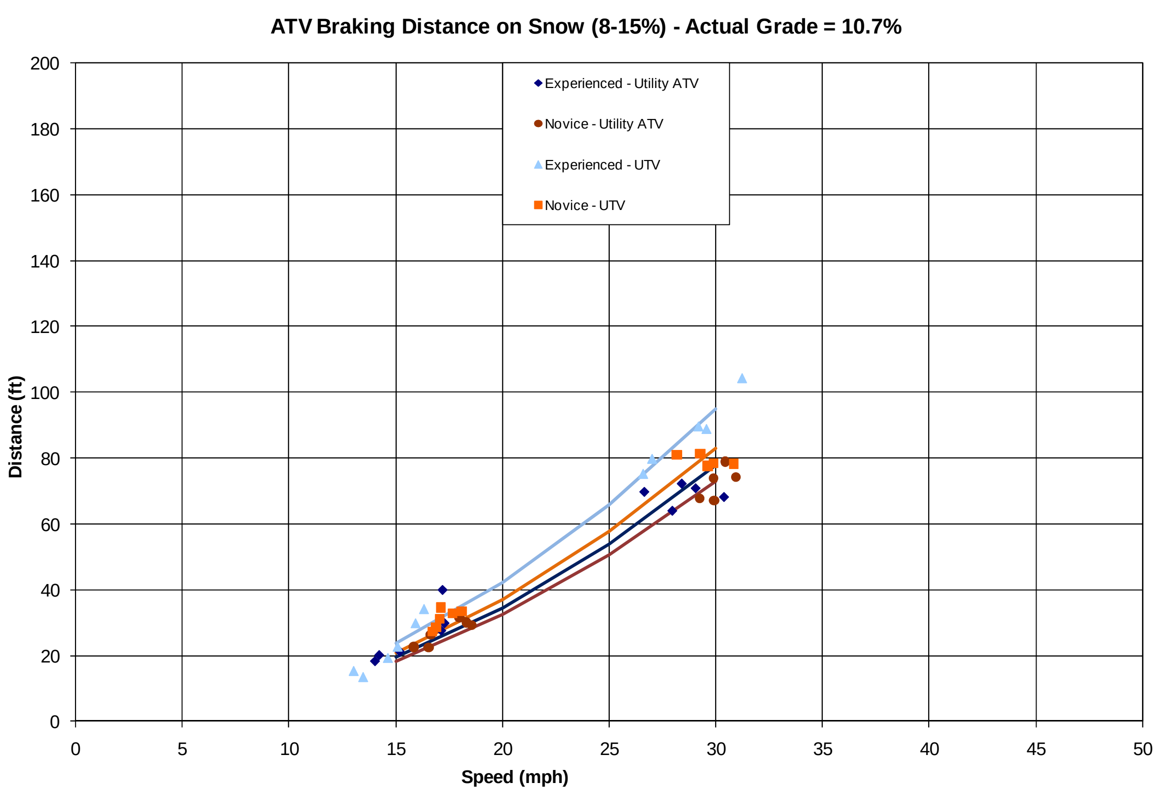



Figure 56 Plot of utility ATV and UTV braking data, for both rider types, on 10.7% snow grade.

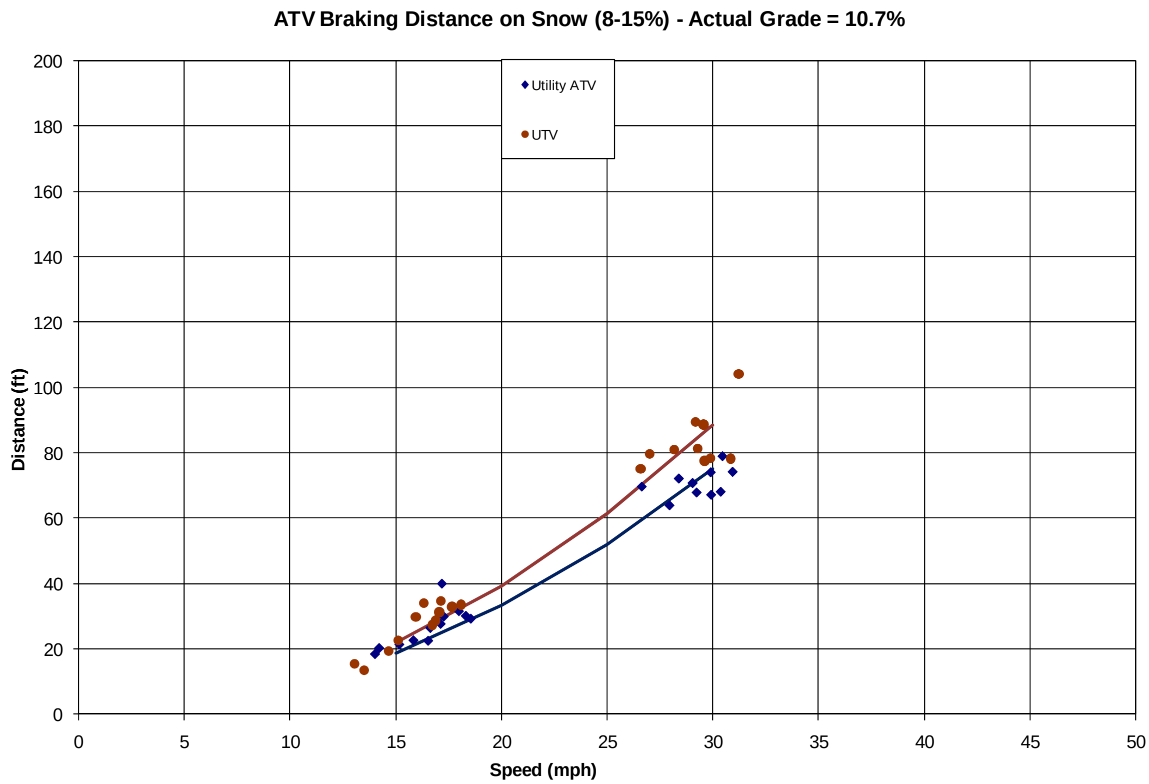



Figure 57 Plot of the utility ATV and UTV braking data and curve fits for 10.7% snow grade.

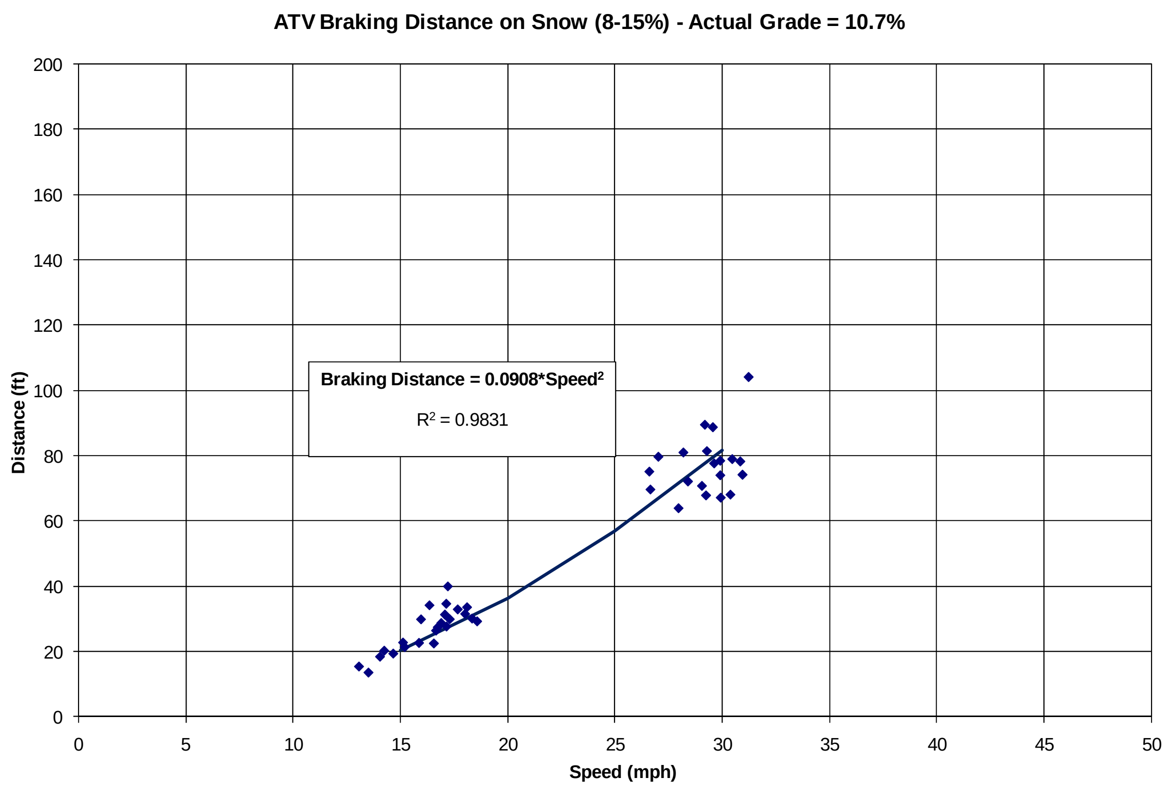



Figure 58 Plot of all utility ATV and UTV braking data curve fit for 10.7% snow grade.

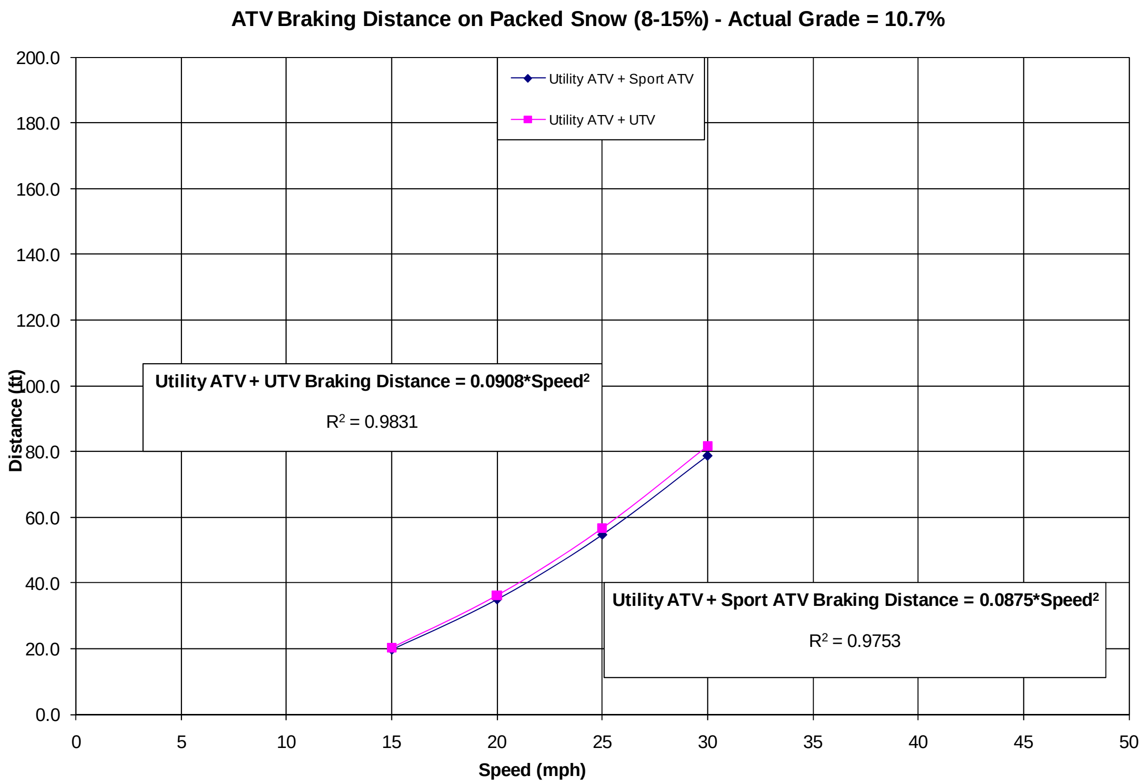



Figure 59 UtilityATV-sport ATV and utility ATV-UTV curve fit data for 10.7% snow.


Figure 60 Photograph of the UTV during the 10.7% packed snow grade braking test.

### 2.2.10 ATV Braking on 18.4% Packed Snow Grade

The utility and sport ATVs were also tested on the 18.4% grade but the UTV was not.

There was not much variation in the utility and sport ATV braking data for the 18.4% grade on packed snow. The riders had a difficult time reaching 30 mph prior to the top of the grade. This was due, in part, to the low coefficient of friction of the snow and in part to the slight horizontal curve in the trail just prior to the top of the grade.

Figure 61 is a plot showing data for both the utility and sport ATVs and both rider types for the 18.4% packed snow grade. The data was fairly consistent for the small range of speeds attainable on this grade and didn't appear to spread out as the speed increased. The novice rider had shorter stopping distances than the experienced rider on the utility ATV, but on the sport ATV there was no significant differences between riders.

Figure 62 is a plot showing the utility and sport ATVs braking data and the curve fits for the 18.4% packed snow grades independent of rider type. The curves were very close, as the novice and experienced riders balanced each other out for the utility ATV and were very similar for the sport ATV. Figure 63 shows a plot of all data with the overall general curve fit for the utility and sport ATVs data together.

Braking distances on the packed snow surfaces were longer than on the gravel due to the coefficient of the packed snow.

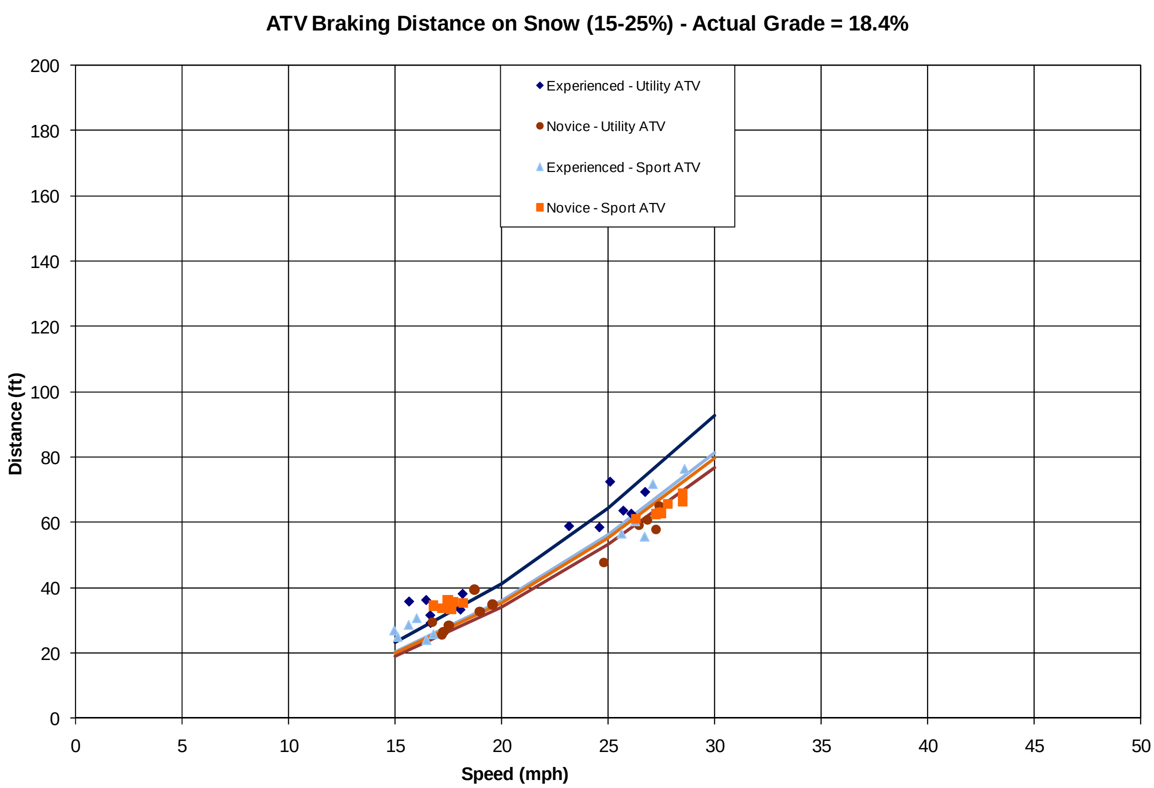



Figure 61 Plot of utility and sport ATV braking data, for both rider types, on 18.4% snow.

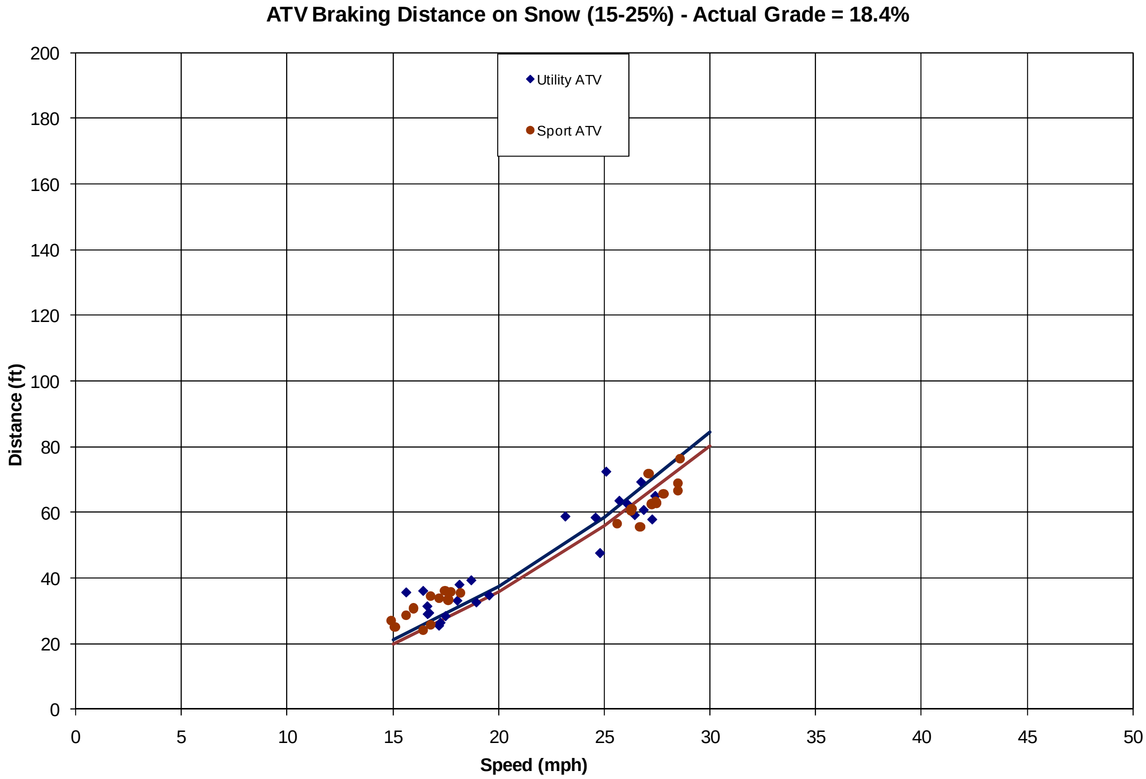



Figure 62 Plot of utility and sport ATV braking data and curve fits for 18.4% snow grade.

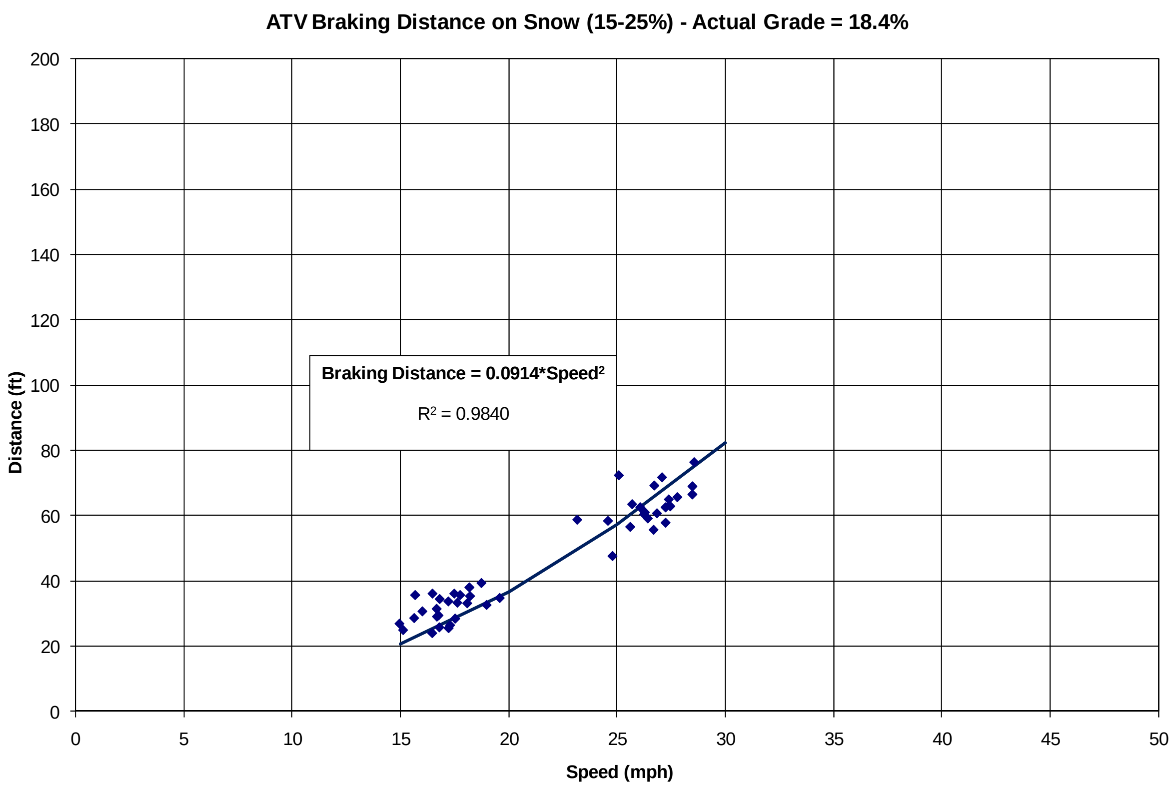



Figure 63 Plot of all utility and sport ATV braking data curve fit for 18.4% snow grade.

### 2.3 ATV Braking Test Summary

There are several different curves shown in the analysis. The data shows that there is not much difference between the utility ATV+Sport ATV curves and the utility ATV+UTV curves so in effect; the UTV is much like any ATV as far as braking is concerned. Therefore, it would be justifiable to review only the utility ATV+Sport ATV data. Figure 64 is a plot of all utility+sport ATV parabolic curve fits to all the data. These are the combined utility+sport ATV and novice+experienced data that were curve fit for each surface type and each grade range.

Table 1 shows the parabolic curve fit average braking distances, for the speeds that were tested and for the different surfaces and grades in the study. In some cases, especially at low speeds it looks as though the grade doesn't make a difference but the user needs to be cautioned that the coefficient of friction of the terrain can make a significant difference and therefore this should be considered when considering sign placement.

Braking distances on sandy loam and loose sand were generally shorter than braking distances on gravel. The braking distances on packed snow were longer than on gravel.

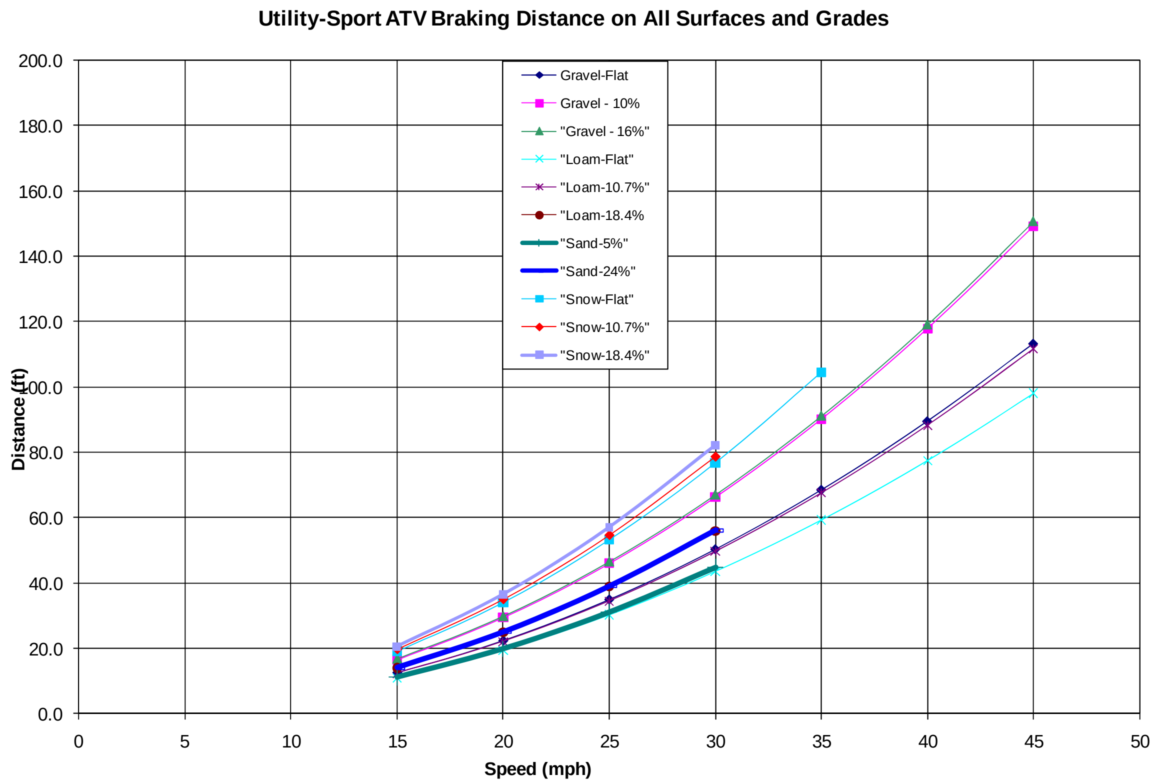



Figure 64 Plot of all utility-sport ATV curve fits for all surfaces and grades tested.

Table 1 ATV Braking Distances From Curve Fit Equations

| Speed in mph | ATV Braking Distances For Different Surfaces And Grades, Distances In Feet | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gravel | | | Sandy Loam | | | Loose Sand | | Packed Snow | | |
| | 0-8% | 8-15% | 15-25% | 0-8% | 8-15% | 15-25% | 0-8% | 15-25% | 0-8% | 8-15% | 15-25% |
| **15** | 12.6 | 16.6 | 16.7 | 10.9 | 12.4 | 14.0 | 11.2 | 14.0 | 19.2 | 19.7 | 20.6 |
| **20** | 22.4 | 29.5 | 29.8 | 19.4 | 22.1 | 24.9 | 20.0 | 25.0 | 34.1 | 35.0 | 36.5 |
| **25** | 35.0 | 46.0 | 46.5 | 30.3 | 34.5 | 38.9 | 31.2 | 39.0 | 53.3 | 54.7 | 57.1 |
| **30** | 50.4 | 66.3 | 67.0 | 43.6 | 49.6 | 56.0 | 44.9 | 56.1 | 76.7 | 78.7 | 82.2 |
| **35** | 68.6 | 90.3 | 91.1 | 59.3 | 67.6 | | | | 104.4 | | |
| **40** | 89.5 | 117.9 | 119.0 | 77.5 | 88.2 | | | | | | |
| **45** | 113.3 | 149.2 | 150.6 | 98.1 | 111.7 | | | | | | |

## 3.0 ATV SIGN RECOGNITION

Another part of this study was to determine the sign recognition/reaction distance for different types and sizes of signs for motorized trails. Before reacting to a sign a rider needs to be able to comprehend what the sign is telling them to do. Signs come in a variety of sizes. Some of the most common sign sizes are 12 by 12 inches, 18 by 18 inches and 24 by 24 inches. The trails need to be signed so the riders can safely recognize and react to the message on the sign. Signs need to be visible in all types of conditions such as day time, night time, in rain and fog, and when it is snowing and there is not much contrast, etc.

Signs were purchased in the three sizes noted above. They included STOP, Stop Ahead words, Stop Ahead symbol, Chevrons, Arrow, One Way with Arrow and Speed Limit. Some signs were purchased without any specific reflective coating, some with standard reflective coating and a couple in the super reflective coating.

### *3.1 ATV Sign Recognition Course*

Prior to the ATV study a snowmobile sign recognition study was conducted on a narrow and bumpy trail which resulted in slow vehicle speeds. In addition, several of the signs had a limited site distance so there was not much difference in the site recognition distance between the 12, 18 and 24 inch signs. This was a preliminary and an informative study. Therefore, it was decided to make the ATV study have higher speed sections and longer site recognition distances, and follow the same general procedure that was used in the snowmobile sign recognition study. Figure 65 is the layout of the course and signs used along with direction of travel.

The first sign is a worded reflective one-way with an arrow followed by a reflective symbol intersection sign and then an arrow sign with no special reflective coating. After this there is a reflective stop sign, partially concealed by foliage, and then after turning a corner with a long straight stretch there is a reflective speed limit sign. Shortly after the speed limit sign is a right turn and a long stretch to a stop sign with no special reflective coating. Further on there is a chevron with no special reflective coating and finally a reflective stop ahead symbol type of sign.

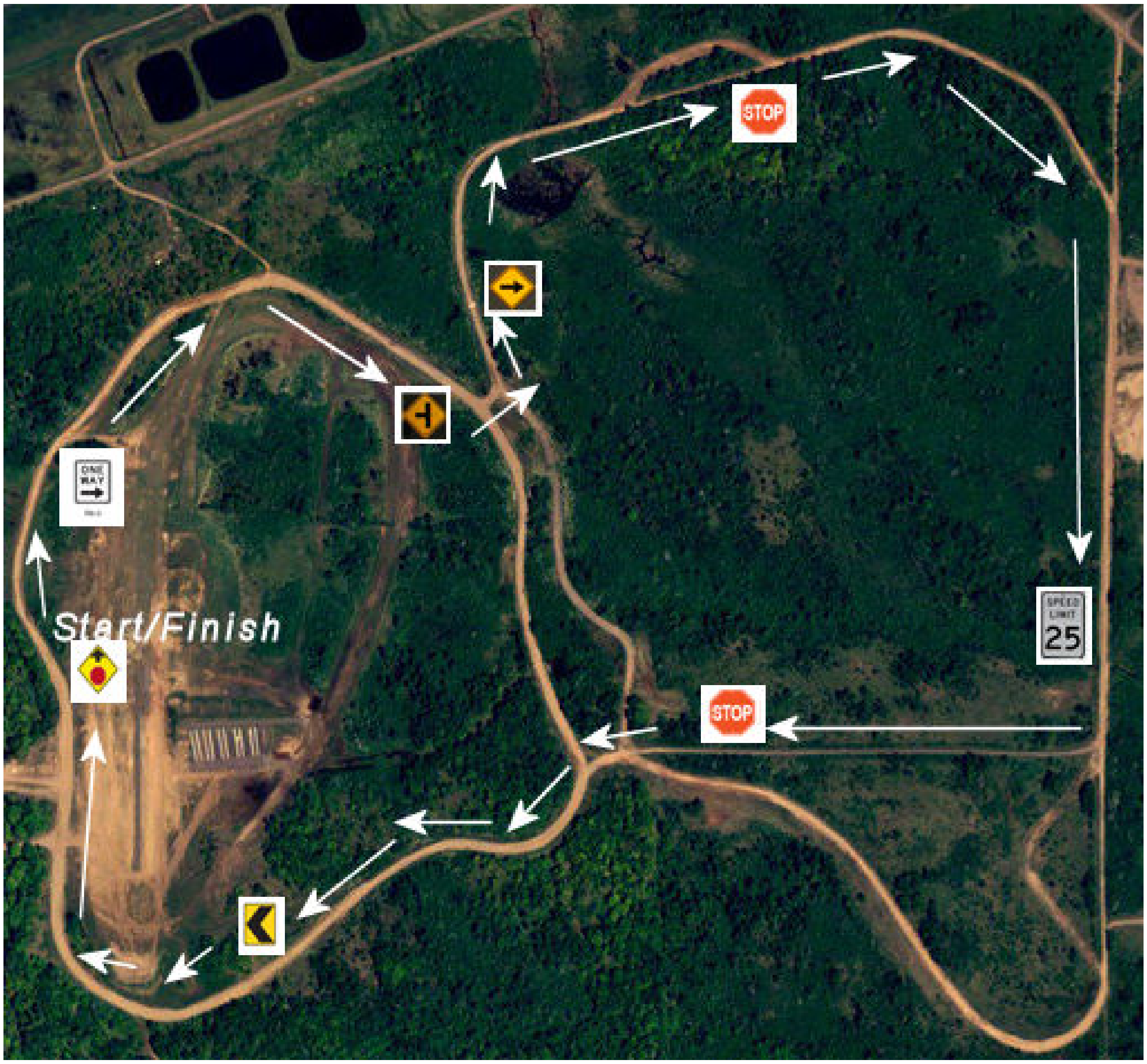


Figure 65 Layout of the ATV sign recognition course.

The following photographs show the signs from the site distance limits – approximately where a rider can first see that a sign is on the trail. The camera was adjusted to try to mimic what the human eye could see at each position. These photographs are used for typical examples of how an ATV rider might see and comprehend signs. Figure 66 is a photo showing how a rider might see the first sign and Figure 67 is a photo showing where a rider might be able to read or comprehend what the sign means. Figure 68 is a photograph of the intersection sign and Figure 69 is a photograph of the arrow sign. Figure 70 is the first stop sign in the study. Figure 71 shows the long straight stretch where the driver could see the speed limit sign and Figure 72 shows where one might be able to read the speed limit sign. At certain light levels and in this particular background the speed limit sign is difficult to see.

Figure 66 Photograph of the first sign (one-way with arrow) in the ATV sign recognition study.


Figure 67 Photograph of the first sign (one-way with arrow) where the rider can comprehend sign meaning.

Figure 68 Photograph of the second sign (stop ahead symbol) in the ATV sign recognition study.

Figure 69 Photograph of the third sign (arrow) in the ATV sign recogniton study.

Figure 70 Photograph of the fourth sign (stop sign) in the ATV sign recognition study.

Figure 71 Photograph of the fifth sign (speed limit sign) at a long distance that was difficult to see.

Figure 72 Photograph of the fifth sign where the rider of the ATV can read the numbers.

Figures 73, 74 and 75 are the last three signs in the ATV Sign Recognition study.

Figure 73 Photograph of the sixth sign (stop sign) in the ATV sign recognition study.

Figure 74 Photograph of the seventh sign (chevron) in the ATV sign recognition study.

Figure 75 Photograph of the eighth sign (stop ahead) in the ATV sign recognition study.

### *3.2 ATV Sign Recognition Data Acquisition*

Both the utility and sport ATVs were set up with the same data acquisition for the sign recognition testing as they were for the braking testing. A switch was added to the left handle bar. The riders were instructed to press the switch when they first saw that there was a sign and press it a second time when they could read or understand what the sign was saying. The speed limit sign was the only anomaly as the riders were told to push the button first when they could see the sign, press it a second time when they could read the larger speed limit numbers and press it a third time when they could read the writing on the sign.

### *3.3 ATV Sign Recognition Testing*

The signs were placed following the basic International Association of Snowmobile Administrators (IASA) guidelines of distance from the trail (three to five feet) and height above the ground surface (two to seven feet) for snowmobile trails as this had appeared to be a good methodology to use [2].

Each rider drove two laps of the loop with the 12-inch signs, then the signs were switched to 18-inch signs and two more laps were driven. Finally, the signs were switched to 24-inch signs and each rider drove two laps again. The speed limit and one way signs were two sizes, 12 by 18 inches and 18 by 24 inches, respectively. For the final 4 laps the speed limit and one way signs were the same size. The arrow sign never changed size as there was only one size available. The second stop sign, which was non-reflective, was only available in the 18 and 24-inch sizes.

A total of 22 different riders ranging in age from 20 to over 60 years old ran the ATV sign recognition loop. Each rider completed six laps, two laps for each sign size, for a total of 126 files of data. In addition, six of the riders ran the signs at night in a separate set of runs to determine visibility at night. In the data for each file the main data items considered were:

- Distance to sign and time when rider first saw the sign
- Distance to sign and time when rider could understand sign
- Average speed during sign recognition process

The final data is the distance to the sign from where the rider could understand the sign. The other data was used to help determine if, for example, the data was good or bad, i.e., if the data made sense such as if the distance was greater than the available sight distance or the time was too short for the trail and speed of the vehicle.

### *3.4 ATV Sign Recognition Data*

The tabulation of all sign recognition data is shown in Figure 76 as an error bar type of chart. The sign type is shown at the bottom and each sign had three sizes, 12, 18 and 24 inches. The Y axis shows the distance to the sign. The horizontal bars show the average distance for all of the riders to understand what the sign wanted them to do. The vertical bars are the calculated standard deviation from the center horizontal bar. The numbers directly above each set of three bars is the furthest measured distance a rider could see that there was a sign along the trail, in other words, the available sight distance.

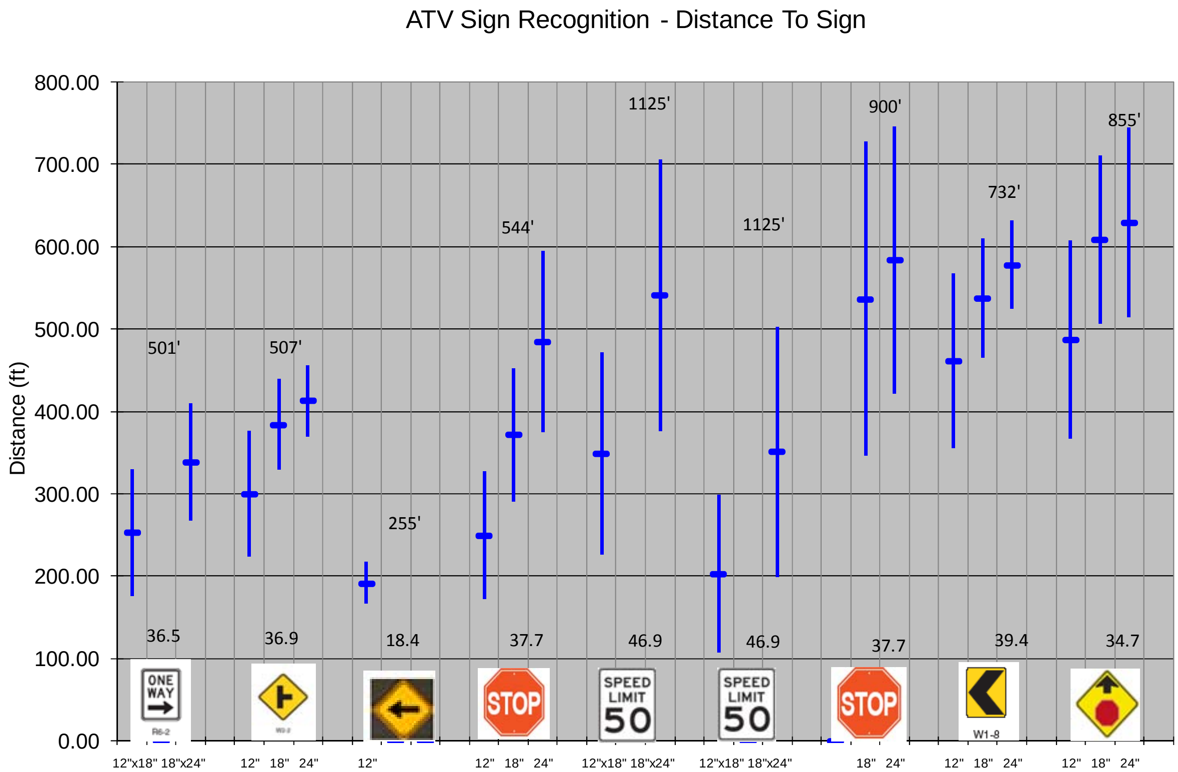



Figure 76 Plot of ATV sign recognition data for each sign type, for all test data.

The number directly above each sign was the average speed for that particular section of trail as measured during the sign recognition data acquisition period.

It is evident that this data captured a good range of vehicle speeds. The trail was wider than a normal ATV trail on U.S. Forest land, but the signs were located very similar to the way they are on trails, with foliage backgrounds and with foliage blocking or partially blocking the signs.

Some riders consistently saw and read the signs at a great distance (good distance vision) and some riders were much closer to the signs before they could read or understand the signs.

The following are some basic statements of the results shown in Figure 76:

1. As one would expect, the sight recognition distances increased as the sign size increased. The second stop sign was the only anomaly other than the arrow because the 12-inch size was not available and the 18-inch sign was used during the 12-inch sign test. All data for the second stop sign when using the 18-inch sign were averaged on the plot and shown as an 18-inch result.
2. The arrow sign didn’t make much difference because the available sight distance was too short and it was only available in the 12-inch size so the data were averaged.
3. The symbol type signs could be seen and understood at further distances than the worded signs. In general, the worded signs like one way and the worded part of the speed limit sign required the rider to be closer to understand them than the symbol

signs. The arrow symbol on the one way sign may have allowed the rider to understand the sign at a greater distance than the speed limit sign.

4. The first stop sign, as shown in Figure 70, was partially blocked by foliage and on windy days may have been more difficult to see.
5. One comment made by many of the riders was that the sun angle and sign placement affected reading the sign. For example, when driving toward the speed limit sign the rider was heading east. In the early morning testing the riders tended to have a difficult time seeing the white sign with black letters with the sun behind the sign.
6. Riders in the study covered all levels of experience from the novice (rarely, if ever drove an ATV) to highly experienced (people that have raced in ATV events).

### *3.5 ATV Sign Recognition at Night*

One group of six (6) riders completed the sign recognition test in the dark to determine how reflective signs may help or not help the rider understand the signs. Figure 77 is a plot showing the night rider data and comparing it to the average for all riders. The overall averages are shown in blue and the night rider averages are shown in red. The average speed for each group is shown just below the sign labels.

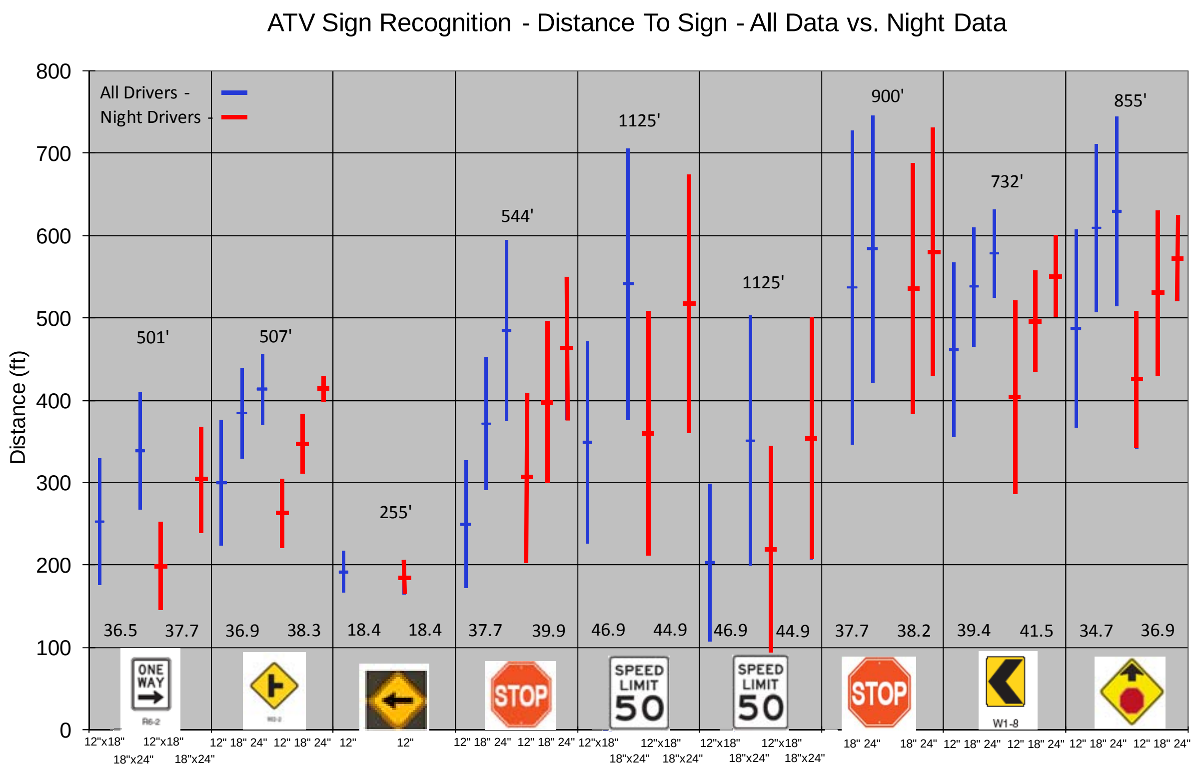



Figure 77 Plot showing the sign recognition distance for night riders versus all riders.

From the plot shown in Figure 77 and the testing a number of statements can be made:

1. The arrow sign was only available in the 12-inch size and the sight distance was too short to determine any noticeable difference.
2. The reflective one way sign, intersection sign, chevron sign and stop-ahead symbol sign were not understood as soon during the night testing as they were during the daylight testing. In other words the rider had to be closer to the sign in the dark than they were in the daylight to understand what the intended meaning of the sign was.
3. The reflective stop sign (first stop sign) and the reflective speed limit sign were understood sooner in the night testing than in the daylight testing.
4. The non-reflective stop sign (second stop sign on the course) was limited to two sizes and was understood at about the same distance in the daylight as in the night.
5. Riders subjectively felt that a reflective sign could be seen from a longer distance due to the headlights light reflecting on the sign than in the daylight but that in many cases the headlights washed out the intended meaning until the rider was closer to the sign than in the daylight.
6. In general, every 12-inch sign could be understood, on average, 200 feet from the sign or farther.

### *3.6 Sign Recognition Study Considerations*

Since the riders ran through the trail twice for each sign size they knew where the signs were and may have biased the study. But riders were told to look for signs and hit the button when first seeing the sign and then when they comprehended the sign. Nobody hit the button where the sign could not be seen. The data was generally consistent from run to run. Smaller signs were run first so they were not biased in the results from running larger signs first because the smaller signs were the main question.

On average, day or night, riders could read and understand every sign at 200 feet or greater. To be on the safe side it is recommended to use a sight distance of 175 feet based on the data collected in the ATV sign recognition study. It’s interesting to note that 175 feet is the standard sign recognition distance from signs with five inch standard D type lettered signs from the manual on uniform traffic control devices (MUTCD) based on studies done for the National Highway Traffic Safety Administration (NHTSA) and the American Association of State Highway Traffic Officials (AASHTO) [3]. The 175 foot sign recognition distance is sited in several places if one looks on the internet.

The MUTCD uses the 175 foot recognition distance in conjunction with perception, identification, emotion, volition (PIEV) time. One internet source that refers to MUTCD for sign placement guidelines uses a 2.5 second PIEV time and a coefficient of friction of between 0.3 and 0.4 sighting a 1990 AASHTO policy [3]. For example, if the sign is to be used to warn of an upcoming stop condition it allows a 2.5 second PIEV time, assume a coefficient of friction between 0.3 and 0.4 (which could be a wet pavement or in some cases a snow covered pavement) and then use a form of the equation presented at the beginning of this report. Finally, it subtracts the 175 foot sign recognition distance.

MUTCD presents a table of values derived from a combined braking and sight distance equation but reference a deceleration rate in place of a coefficient of friction and a slightly different format of the combined braking and sight distance equation. This is also reported in an addendum to a Massachusetts Highway Design Manual to be in conformance with AASHTO [4]. The Massachusetts Highway Design Manual states, "Studies documented in the literature show that most riders decelerate at a rate greater than 14.8 ft/sec$^2$ when confronted with the need to stop for an unexpected object in the road way. Approximately 90 percent of all riders decelerate at rates greater than 11.2 feet/sec$^2$. Such decelerations are within the rider's capability to stay within his or her lane and maintain steering control during a braking maneuver on wet surfaces. Therefore, 11.2 feet/sec$^2$, a comfortable deceleration for most riders, is recommended as the deceleration threshold for determining stopping sight distance." Both references discussed here show columns for "Heavy Traffic" or "High Judgment Area", stopping completely and then slowing down to 10, 20, 30 mph, etc.

## 4.0 ATV VALIDATION

Based on the data collected from the ATV braking and the ATV sign recognition study and the information discussed above from MUTCD and IASA, a table was developed for sign placement. It is important that the warning signs be placed far enough in advance of the particular location they are warning for, but not too far. The distance has to be long enough for an ATV to brake safely from the average speed for that section of trail. If the signs are placed too far in front of the location that is being warned for, the rider may forget that there is a place that they will have to slow down or stop for, or may think that the trail was signed improperly and actually speed up.

For the type of braking and sign recognition data collected in this study it is most appropriate to use a form of the equation that includes coefficient of friction (mu value) such as the equation presented in the braking section of this report (see page 4). Using the equation presented in the braking section, the curve fit average braking data was used to calculate the braking coefficient of friction of the various surfaces that were tested on for braking performance. The formula was rearranged to solve for the mu value. For grades, the percent grade was used.

To be safe, a coefficient lower than the average calculated from the braking data was used to determine sign placement distances, as this follows the pattern used by others such as the deceleration rate discussed in the last section. A lower coefficient of friction will result in a longer braking distance, a longer total stopping distance and a longer distance between the warning sign and the event. The different types of terrains were not treated the same as described in the following paragraphs.

The coefficient of friction for gravel surfaces in these tests averaged 0.59. Since gravel can vary quite a bit due to the type of gravel, either sharp edged rock or round rock, it is felt that a fairly large safety margin should be included in the final sign placement distances for gravel. A coefficient of friction of 75% of the calculated average measured value was used as a safety factor for gravel in the final sign placement calculations.

For sandy loam, the coefficient of friction for these tests averaged 0.71. This number can vary depending on how packed the surface is and how much moisture is on the surface. Sandy loam didn't vary as much as gravel but it can vary some. A coefficient of friction of

85% of the calculated average measured value was used as a safety factor for sandy loam in the final sign placement calculations.

The coefficient of friction for loose sand averaged 0.73 in these tests. The loose sand material doesn't seem to vary as much as any of the other surfaces as demonstrated by the consistency of the braking test data and therefore the safety factor doesn't have to be as great as the other surfaces in this study. A coefficient of friction of 90% of the calculated average measured value was used as a safety factor for loose sand in the final sign placement calculations.

For packed snow the coefficient of friction averaged 0.48 for these tests. Snow can vary significantly depending on a number of factors including sun load, ambient temperature, traffic load, etc. As in the snowmobile study, a coefficient of friction of 75% of the calculated average measured value was used as a safety factor for packed snow in the final sign placement calculations.

With this in mind a table was developed for sign placement guidelines for ATVs on different trail surfaces, conditions and grades by combining the braking distance equation with a stopping sighting distance equation [5]. The equation takes the form shown below:

$$D = 3.67V_o + 0.033\frac{\left(V_o^2\right)}{(\mu \pm grade)} - 175$$

where:

D = Total distance of warning sign placement relative to object in feet.
$V_o$ = Vehicle speed for trail in mph.
μ = Coefficient of friction of trail – dimensionless.
grade = Grade of trail in percent. Subtract grade for downhill stops.

As mentioned above, a coefficient of friction for each type of surface was chosen below the calculated average coefficients of friction to be safe and used in the calculation of sign placement distances. The 2.5 second PIEV time is incorporated in the first term of the equation and the 175 is the sight recognition distance found in the sign recognition study for 12-inch signs. Using these values a table was developed for warning sign placement on ATV trails and is shown in Table 2 below. The calculated values were rounded up to the next five foot interval to add in another factor of safety. Note that the distances shown in Table 2 assume a minimum sight distance of at least 175 feet to the warning sign. It is recommended to use a minimum warning sign placement distance of 30 feet from the object for speed/terrain combinations where distance is not specified in Table 2.

The particular terrain needs to be considered when placing warning signs. Hills and curves may obstruct sign viewing and therefore it may be best to put the warning sign prior to the hill or curve in the trail.

Table 2 ATV Trail Warning Sign Placement Distances from an Object or Event (It is recommended to use a minimum warning sign placement distance of 30 feet from the object or event for speed/terrain combinations where distance is not specified)

| Speed in mph | ATV Trail Warning Sign Placement Distance From Object, Distances In Feet | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Gravel | | | Sandy Loam | | | Loose Sand | | | Packed Snow | | |
| | 0-8% | 8-15% | 15-25% | 0-8% | 8-15% | 15-25% | 0-8% | 8-15% | 15-25% | 0-8% | 8-15% | 15-25% |
| 15 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| 20 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 |
| 25 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 55.0 |
| 30 | 30.0 | 30.0 | 55.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 30.0 | 35.0 | 65.0 | 135.0 |
| 35 | 55.0 | 75.0 | 115.0 | 30.0 | 40.0 | 55.0 | 30.0 | 30.0 | 45.0 | 85.0 | 130.0 | 225.0 |
| 40 | 100.0 | 130.0 | 185.0 | 70.0 | 85.0 | 105.0 | 60.0 | 70.0 | 90.0 | 145.0 | 200.0 | 325.0 |
| 45 | 155.0 | 190.0 | 260.0 | 110.0 | 130.0 | 160.0 | 100.0 | 115.0 | 140.0 | 210.0 | 275.0 | 440.0 |

## *4.1 ATV Validation Test Layout*

Based on the information in the previous section, a trail sign validation study was conducted to ensure that the warning sign distances were safe and appropriate. All terrain conditions could not be met due to the variety of terrain and speeds covered in Table 2. A trail was established on property that had limited access and was laid out to have narrow sections like a U.S. Forest Service trail and wider faster sections like some of the standard trails found in the mid-west. Both 12-inch and 18-inch signs were used in the validation study. The trail was a winding loop with the 12-inch signs in one direction of travel and the 18-inch signs in the opposite direction. The trail layout is shown in Figure 78.

All of the signs purchased for this project were used in this study. Some of the stop signs were modified to have an arrow pointing to the direction of travel so that the volunteer participants knew where to go on some of the turns, as it may not have been obvious.

The ATVs used for this study were the same two utility and sport ATVs that were used for the braking tests. The riders were instructed to follow and do what the signs asked. They were also told to drive at their "comfortable" speed and to come to a complete stop at each stop sign using the brakes (it was thought that some might just release the throttle to slow down).

There were three stop signs in each direction/each sign size. In the 12-inch direction, a worded stop-ahead was used first and the second two warning signs were symbol stop ahead signs. In the 18-inch direction a worded stop-ahead sign was used on the first stop sign, followed by a symbol stop ahead and finally, another worded stop-ahead was used with the last stop sign. The trail layout for the 12-inch signs is shown photographically in the Figures 79 through 100.


Figure 78 ATV sign validation trail layout. Distance shown between stop-ahead and stop signs.


Figure 79 View for rider starting out on 12-inch sign trail (note back of 18-inch sign).


Figure 80 View of first stop-ahead - stop sign combination - placement distance is 150 feet.

Figure 81 View of trail after making left at stop sign - no sign used here - rider follows trail.

Figure 82 View coming on to the pipeline trail - note back of arrow sign on stake.


Figure 83 View of 12 by 18-inch speed limit sign on slow trail section - note glare from sun.

Figure 84 View of next arrow sign and back of 18 by 24-inch speed limit sign.

Figure 85 View of 12-inch arrow sign from a closer view point.

Figure 86 View of the second stop-ahead - stop sign combination (67 feet between signs).


Figure 87 Close up view of the stop-ahead - stop sign combination.


Figure 88 View just after stop-right arrow turn on slow section of trail.

Figure 89 View after making right at the previous chevron and driving a short distance.

Figure 90 View of the third 12-inch stop-ahead sign - placement was 120 feet from stop sign but placed before the last curve.

Figure 91 View of the stop sign from the location of the stop-ahead sign (120 feet).

Figure 92 View after making left turn at stop sign - moderate speed trail.

Figure 93 View on moderate speed trail of upcoming 12-inch intersection sign.

Figure 94 Close-up of the 12-inch intersection sign with glare from the sun.

Figure 95 View of 12-inch arrow sign on slow speed section of trail, note glare from the sun.

Figure 96 View of trail after making left turn at arrow.  Note back of another sign.

Figure 97 View of one way sign partially blocked by trees while traveling up slight grade.


Figure 98 View of one-way sign at 4-way intersection.

Figure 99 View of slow winding trail just after one-way arrow sign and right turn.

Figure 100 View of 12-inch chevron coming off of slow trail in woods. Trail end seen after making this left.

Note that some signs were not placed in good positions. For example, the stop-ahead sign shown in Figures 86 and 87 on a higher speed section of trail was only 67 feet from the stop sign and it was past the apex of the corner. This sign could have been placed 160 feet from the stop sign according to Table 2. It would have been visible well before the corner and still be close enough for the rider to remember to stop. Another poorly placed sign was the one way with arrow at the top of the hill in Figures 96 through 98. If the one way with arrow was moved back slightly from the intersection/turn then the arrow would have been clearly viewed from a longer distance.

The 18-inch sign validation study was completed by travelling in the reverse direction on the same trail. The photographs are not shown here but are similar to the photographs of the 12-inch sign validation trail. The first 18-inch stop-ahead sign was a word sign 170 feet from the stop sign. The second stop-ahead sign was a symbol type that was only 105 feet from the stop. The final stop-ahead sign was a word sign that was placed 180 feet from the stop sign. This was a high speed section of the trail with a bend at about 175 feet from the stop sign so it was critical that the stop-ahead sign be placed before the bend in the trail.

## *4.2 ATV Validation Test Results*

A total of 27 volunteer riders took part in the ATV validation testing. Six females and 16 males drove the 12-inch and the 18-inch sign trail once. Seven males drove the motorcycle. The ages ranged from 19 to 62 years old. The experience levels ranged from novice to those who had raced ATVs and or driven motorcycles often. After each run the riders were questioned about the signs and sign placement. Subjective comments were probably just as important as the objective data collection.

### 4.2.1 Validation Study Subjective Comments

All volunteer riders reported that the signs were easy to follow and that they had no problems with stop-ahead sign placement distance from the stop sign. There were a few comments that were very helpful in the analysis. The comments all dealt with proper sign use or missing signs, and nothing to do with being able to understand the signs in time to stop. The comments are listed below.

1) Some of the riders said that the first left arrow at the 4 way intersection on the 18-inch sign trail could not be seen very well and should have been placed further ahead of the left turn. Also, at this intersection there was a sharp left and a trail that went mostly straight across but did angle slightly to the left. Some riders thought they should go on the trail slightly to the left which made for a bad run because they then repeated a portion of the 12-inch sign trail.
2) Another highly experienced rider said a stop sign was partially covered with brush. This was the first stop sign on the 18-inch sign trail and it was, but the stop-ahead sign was 170 feet from the stop sign. The trail was narrow and it was partially obscured by brush but nobody else made this comment.
3) A few riders noted that there was no sign telling them the direction to go in when turning off of the pipeline section of trail back on to the last section of dirt trail, on the 18-inch sign trail. At this point in the circuit there was only one way to go and it really didn't need a sign.

4) Some riders only ran at 25 mph after reading the speed limit sign and not seeing another speed limit sign.

Even though some stop-ahead signs were placed closer than Table 2 suggests, nobody missed a stop or had trouble stopping in time.

### 4.2.2 ATV Validation Test Objective Data

The objective data recorded during the validation tests was not as clean as the braking data taken during the braking study or the sign recognition data study. On many, if not most of the rider data, at least one of the three stop sign location GPS speeds dropped out making it difficult to get an accurate speed at brake point or proper stopping distance.

The data was thoroughly studied and the data analysis included going into each file and attempting to determine location at the braking point and the location at the stop to determine total stopping distance. Due to the GPS drop outs (most likely due to tree cover) a good stopping distance or deceleration analysis was difficult to perform but the data acquired from the study was useful. Maximum speeds with the ATVs on the 12-inch sign trail ranged from 24 to 59 mph and on the motorcycle they ranged from 37 to 54 mph. On the 18-inch sign trail they ranged from 21 to 49 mph for those that drove ATVs and for the motorcycles 39 to 56 mph.

No rider said he or she could not stop in time and from the data it appears that all participants were able to stop at each point, although there were some riders that did not come to a complete stop. Since all riders could stop in plenty of time, even with the 12-inch stop signs, the braking distances were acceptable. Another way to look at the data would be to look at deceleration rates. Previously, it was mentioned that a deceleration rate of 11.2 ft/sec$^2$ was within the rider's capability to stay within his or her lane and maintain steering control during a braking maneuver on wet surfaces for automobiles. The ATV and motorcycle decelerations were analyzed and are presented in Table 3.

Table 3 ATV 12" Validation Data Showing Deceleration Rates

| Stop Ahead - Stop Sign Braking Data for 12" Signs During ATV Validation Test | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Set 1 - High Speed Section | | | | | Set 2 - Medium Speed Section | | | | | Set 3- Low to Medium Speed Section | | | | |
| ATV | MaxSpd | Speed1 | Distance 1 | BrakePt1 | StopPt1 | Decel 1 | Speed2 | Distance 2 | BrakePt2 | StopPt2 | Decel 2 | Speed3 | Distance 3 | BrakePt3 | StopPt3 | Decel 3 |
| TstdA409 | 29.9 | 13.0 | 16.2 | 44.9 | 46.8 | 4.7 | 15.0 | 24.8 | 140.1 | 142.1 | 6.2 | 11.9 | 21.9 | 183.5 | 185.7 | 4.3 |
| TstdA411 | 31.7 | 15.9 | 46.9 | 46.3 | 50.4 | 2.9 | 19.8 | 93.7 | 151.9 | 157.5 | 3.0 | 11.3 | 15.7 | 203.2 | 205.4 | 3.2 |
| TstdA413 | 39.5 | No braking data or not a complete stop | | | | | 4.5 | 3.4 | 244.5 | 245.2 | 6.9 | 15.2 | 79.8 | 292.6 | 297.8 | 3.0 |
| TstdA416 | 38.4 | 24.6 | 51.4 | 32.8 | 36.4 | 3.9 | 34.6 | 169.7 | 145.8 | 152.3 | 4.0 | 10.4 | 10.2 | 204.0 | 205.5 | 4.9 |
| TstdB405 | 34.9 | 6.9 | 5.0 | 37.8 | 38.7 | 6.1 | 10.4 | 17.8 | 130.1 | 132.4 | 3.4 | 11.0 | 9.1 | 170.5 | 171.7 | 6.9 |
| TstdB408 | 42.3 | 28.6 | 120.7 | 46.7 | 50.7 | 7.7 | 14.6 | 70.7 | 124.6 | 129.0 | 3.7 | No braking data or not a complete stop | | | | |
| TstdB410 | 59.2 | 18.4 | 42.6 | 345.7 | 349.6 | 2.9 | 21.6 | 77.3 | 440.5 | 444.9 | 4.1 | 16.2 | 70.6 | 492.9 | 498.1 | 2.6 |
| TstdA418 | 29.6 | No braking data or not a complete stop | | | | | 10.9 | 9.3 | 120.0 | 121.3 | 5.5 | No braking data or not a complete stop | | | | |
| TstdA424 | 33.9 | 17.7 | 23.3 | 51.1 | 53.8 | 3.1 | 18.6 | 65.8 | 138.1 | 142.4 | 3.6 | 11.2 | 20.8 | 185.5 | 187.8 | 4.1 |
| TstdB413 | 48.3 | 14.1 | 24.9 | 54.4 | 56.8 | 4.1 | 42.8 | 252.7 | 127.6 | 134.3 | 5.6 | 18.3 | 65.3 | 166.5 | 170.6 | 3.9 |
| TstdB417 | 30.0 | 16.0 | 43.6 | 49.5 | 53.3 | 3.1 | No braking data or not a complete stop | | | | | 12.7 | 41.2 | 189.6 | 193.2 | 3.2 |
| TstdB420 | 24.4 | 6.2 | 3.5 | 56.4 | 57.4 | 3.5 | 13.9 | 24.5 | 184.4 | 186.7 | 4.4 | 12.6 | 27.8 | 229.8 | 233.9 | |
| TstdB422 | 31.3 | 19.3 | 34.0 | 226.4 | 229.0 | 5.0 | 20.6 | 45.5 | 332.7 | 335.9 | 4.3 | No braking data or not a complete stop | | | | |
| TstdA430 | 29.5 | 11.8 | 10.8 | 56.7 | 58.1 | 5.5 | No braking data or not a complete stop | | | | | 14.6 | 39.4 | 184.7 | 188.5 | 2.7 |
| TstdA432 | 32.6 | 10.6 | 23.1 | 44.4 | 47.5 | 2.3 | 16.4 | 50.8 | 141.2 | 145.5 | 2.7 | 12.9 | 58.7 | 188.8 | 192.9 | 3.5 |
| TstdA436 | 22.1 | 4.2 | 3.3 | 59.0 | 60.6 | 1.3 | No braking data or not a complete stop | | | | | 15.8 | 342.2 | 178.4 | 198.5 | 0.9 |
| TstdA450 | | 8.0 | 8.8 | 63.7 | 65.9 | 1.8 | 8.6 | 17.5 | 181.5 | 184.6 | 1.9 | No braking data or not a complete stop | | | | |
| **Motorcycle** | | | **ATV Average Decel** | | | **3.9** | | **ATV Average Decel** | | | **4.2** | | **ATV Average Decel** | | | **3.6** |
| 111010a1 | 54.1 | 51.1 | 260.3 | 96.9 | 103.9 | 5.4 | 30.5 | 295.3 | 181.7 | 190.5 | 3.9 | 16.2 | 43.2 | 228.0 | 230.8 | 5.5 |
| 111110a1 | 44.4 | 32.4 | 239.3 | 28.4 | 35.4 | 4.8 | 21.2 | 232.4 | 96.5 | 104.2 | 3.9 | 18.8 | 64.9 | 132.6 | 135.5 | 7.8 |
| 111110a6 | 37.2 | 35.7 | 190.0 | 844.4 | 850.8 | 4.6 | 9.0 | 6.9 | 931.9 | 932.6 | 12.7 | No braking data or not a complete stop | | | | |
| | | | **Motorcycle Average Decel** | | | **5.0** | | **Motorcycle Average Decel** | | | **6.8** | | **Motorcycle Average Decel** | | | **6.6** |
| | | | **Overall Average Deceleration** | | | **4.4** | | **Overall Average Deceleration** | | | **5.5** | | **Overall Average Deceleration** | | | **5.1** |

Data for the 12-inch sign validation test that were not shown in the table were lost or the data didn't make sense, such as those that missed turns and did not run the complete loop. Table 3 data shows that on average the decelerations were in the 3.6 to 4.2 ft/sec$^2$ range for the ATV and in the 5.1 to 6.8 ft/sec$^2$ range for the motorcycle. If signs were difficult to comprehend there would have been deceleration rates much closer to the 11.2 ft/sec$^2$ referenced previously. Therefore, the study validates Table 2 placement distances.

## 5.0 SUMMARY AND CONCLUSIONS

ATV braking data was measured and recorded with novice and experienced riders using three typical machines on the market, a utility type ATV and a sport type ATV along with one UTV. This was done for flat gravel, a 10% and 16.6% gravel grade, flat sandy loam, a 10.7% and 18.4% sandy loam grade, a flat loose sand, a 24% grade on loose sand, a flat packed snow surface, 10.7% and a 18.4% packed snow grade. This data was used to form a table of average ATV braking distances and from that data the coefficient of friction was determined for typical trail surface types and grade ranges.

A sign recognition test was conducted to determine the sign sight recognition distance for riders on various lengths of trail sections.

Finally, a sign placement table was developed following similar methods used by the MUTCD and AASHTO. The braking data and standard physics equations were used to calculate the coefficient of friction for each of the surfaces and then a lower coefficient of friction (safety factor) and physics equation, similar to the equation used by AASHTO, were used to develop a sign distance placement table. See page 60, Table 2. A recognition/reaction time of 2.5 seconds following AASHTO's recommended PIEV time was used in the equation and finally, the 175 foot recognition distance was used to determine the final sign placement distance that was shown in Table 2.

The sign placement distances in Table 2 were validated in a final validation study with a unique trail layout for both 12 and 18-inch signs. Both objective data and subjective data from the validation study revealed that for general ATV purposes the sign placement information in Table 2 was adequate and that 12-inch signs can be used for safe trail marking.

From this project some conclusions can be made:

1.) Even though most of the braking results are consistent and covered a broad range of rider types, the reader is cautioned that the coefficient of friction of the surfaces may vary significantly depending on a number of factors. Therefore, the values shown in this report are not absolute and should not be understood to be absolute in value.

2.) Riders can easily read and understand signs 175 feet from a 12-inch sign.

3.) Symbol type signs are easier to read and understand than worded signs.

4.) Highly reflective signs may or may not be understood at a greater distance than non-reflected signs at night because the reflective signs sometimes are so bright that the vehicle headlights wash out the wording or symbols.

5.) A table of sign placement distances for warning signs was developed for this project but because the braking distances were based on testing in limited coefficients of friction range surfaces the values are not necessarily absolute but are recommended as a guide line for the user.

## REFERENCES

[1] Fundamentals of Physics, David Halliday and Robert Resnick, Revised Printing, 1974, John Wiley & Sons, Inc., page 82.

[2] “Guidelines for Snowmobile Trail Signing & Placement 2000”, International Association of Snowmobile Administrators.

[3] Manual on Uniform Traffic Control Design, 2003 Edition including Revision 1, November 2004 and Revision 2, December 2007.

[4] ADDENDA to the 1997 MassHighway Highway Design Manual, Interim Guidance for conformance with AASHTO “A Policy on Geometrid Design of Highways and Streets 2001”, April 2003, pg. 6.

[5] National Cooperative Highway Research program, Report 400, “Determination of Stopping Sight Distances”, pg. 19, D. B. Fambro, K. Fitzpatrick, R. J. Koppa, Texas Transportation Institute, Texas A&M University, College Station, TX, National Academy Press, Washington, D.C. 1997