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Comparison of Tire Friction Test Methodologies Used in Accident Reconstruction

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ABSTRACT

Many accident reconstructions rely on the use of friction factors for the analysis of vehicle speeds. Measurement of the friction factor, or coefficient of friction, at the accident site is usually an important step in achieving a more accurate estimate of the friction factor at the time of the accident. Over the years several on site test methodologies have emerged within the accident reconstruction community. However, little has been published which compares the data and results from the different methods.

This paper presents a comparison of some methodologies. A g-analyst[1] accelerometer, a VC•2000[2] accelerometer, and a bumper chalk gun[3]/radar gun[4] are compared for locked wheel friction values under different speed and road surface conditions. Data from the two on board systems are recorded simultaneously. Measurements are made for several stops at each of the speeds and two road surface conditions. Statistical analysis is performed on each test method for each set of test conditions to determine repeatability of that test method. These statistical analyses also indicate what real differences can be attributed to the experimental factors.

INTRODUCTION

The friction factor is one of the most frequently used values in determining vehicle speed in an accident analysis. It is a variable which can be greatly affected by numerous factors, and conducting vehicle tests is one of the best methods of estimating an accurate value for a specific set of conditions.

The three methodologies examined here are:

- g-analyst accelerometer system
- VC•2000 accelerometer system
- chalk gun and radar gun to measure speed and stopping distance

All of these require data processing. The accelerometer signals were analyzed by numerical integration to determine the average acceleration value over each stop.

Another method that is used by some accident reconstructionists involves manually dragging a weighted tire and measuring the pull force. This is often called the drag tire method. This method was not included because it has been found to be inaccurate (Lock, et al., 1985)[11] and its use discouraged.

When vehicle brakes are applied sufficiently to cause wheels to lock, the frictional force between the tires and the road surface initially is zero, rises to some sustained level that depends on the road, tires, etc., and eventually returns to zero when the vehicle comes to rest. The frictional force varies with time and, consequently the acceleration, a(t), varies with time. The term friction factor in this paper means the number representing the value of the coefficient of friction between the vehicle tires and the roadway as the vehicle skids to a stop. By equating initial kinetic energy to the work of friction for a car with an initial velocity, V_o, skidding on a level road for a distance, d

$$V_0^2 = 2\mu g d \tag{1}$$

$$\mu = \frac{V_0^2}{2gd} \tag{2}$$

where g is the acceleration of gravity and μ is the friction factor. For a vehicle skidding up or down a grade with angle q, a drag factor, f, can be shown to be

$$f = \mu \cos q \pm \sin q \tag{3}$$

and thus f would be used in place of μ in (eg.1) and (eq. 2). Throughout this paper, the sign of acceleration is considered positive when referring to braking, or deceleration.

The bumper gun method has been used in the engineering community for decades. The device is triggered by a signal from the vehicle's brake light circuit or a pressure sensitive switch mounted on the brake pedal. The braking distance can easily be determined for a given test by measuring from the pigment mark to the gun position at rest. Some devices have multiple guns and a shot can be fired after the vehicle comes to a stop, allowing the vehicle to be moved off the roadway. The braking distance can then be measured between the two marks. The friction factor (μ) can be calculated from equations (2) and (3).

More recently the use of accelerometer based instrumentation has become popular. The g-analyst marketed by Valentine Research and the VC•2000 / VC•2000PC marketed by Varicom Computer Inc. are commonly used in accident reconstruction. Both devices provide acceleration data which allow for evaluation of braking, acceleration and handling performance of vehicles.

The two devices were operated simultaneously for all tests conducted. The paper explores procedures for analyzing the output data and evaluates the sensitivities and repeatability for each unit.

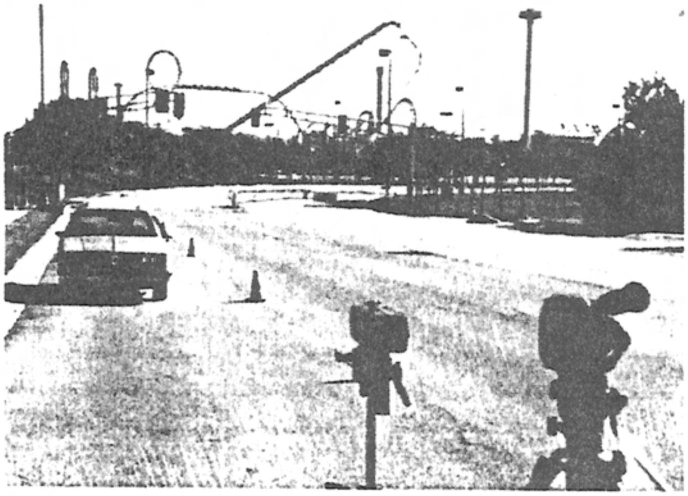


Figure 1

TEST PROCEDURE

Two different vehicles, two speeds and two surface conditions were used to evaluate the methodologies. At least 5 tests of each condition were conducted.

Vehicles - The vehicles tested included a 1986 Oldsmobile Cutlass Supreme (VIN 1G3GM69Y0GR36 4407) equipped with Firestone 721 (P205/75 R14 M&S) tires. The vehicle was chosen because of its typical family sedan characteristics and common tires. The second vehicle was a 1992 Eagle Talon (VIN 4E3CT6 4U3NE045344) equipped with V rated (205/55 VR16) performance tires on low profile rims. This vehicle was chosen because of its sporty character and its performance oriented tires.

Surfaces - To ensure good repeatability, the two surfaces selected were dry asphalt. A traffic worn surface and a low traveled more aggressive surface were selected. The traffic polished surface had an average daily traffic volume in the range of 50 to 100 times the volume of the less traveled road.

Speeds - In order to evaluate a large spread, speeds of 20 mph and 45 mph were tested. It was felt that 45 mph was the greatest speed at which such tests could reasonably and safely be conducted. Speed was measured with a Stalker Sport[4] radar gun mounted on a tripod directly in front of the tested vehicle. The gun is capable of 25 speed updates per second and has a rated accuracy of ± .1 mph. The gun readout and test vehicle were videotaped simultaneously so the speed at initial braking could be documented (Fig. 1). A brake activated signal light was mounted on the front bumper of the test vehicle to identify the initiation of braking for video analysis. Each speedometer was also calibrated to assist the driver in achieving the desired test speed. A second laser type speed measuring gun was used to check the accuracy of the Sport Stalker.

Bumper gun - The bumper gun was mounted to the rear bumper of each test vehicle (Fig. 2) and a pressure sensitive trigger switch was taped to the brake pedal. The braking distance was measured after each test with a 100' fiberglass tape.

g-analyst® - The g-analyst was mounted according to the manufacturer's recommendations. In both vehicles, the transducer was mounted under the passenger seat close to the C.G. The unit was calibrated and leveled according to the manual's procedures. Leveling involves positioning the vehicle twice in the exact same location but at opposite headings to permit the instrument to determine when the vehicle is level. The roll and pitch compensation values were set as follows:

<u>Oldsmobile Cutlass</u>
Roll: 7.5 degrees/g
Pitch: 2.4 degrees/g

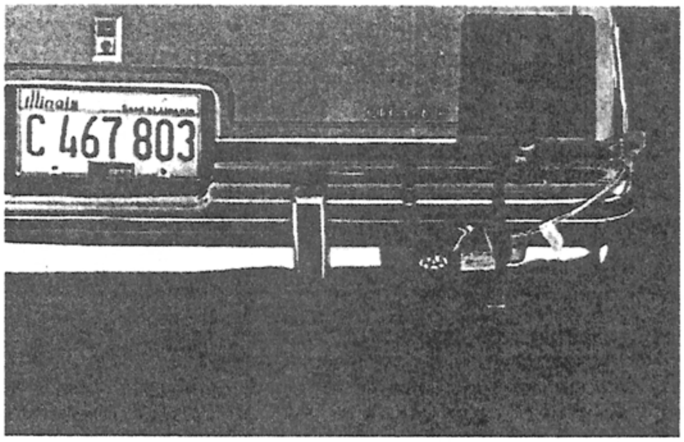


Figure 2

Suspension type		Roll deg/g	Pitch deg/g
very soft	Economy and basic family transportation, both domestic and import.	8.5	2.5
soft	Basic family transportation, domestic and import after 1975.	7.5	2.4
semi-soft	Contemporary middle-market sedans, domestic and import.	7.0	2.1
semi-firm	Imported sport sedans.	6.0	2.1
firm	Domestic sport sedans.	5.0	2.0
very firm	High performance domestic, such as Camaro Z28 and Firebird Trans Am.	4.2	1.8
extremely firm	Contemporary very high-performance sport, such as Corvette, and street cars extensively modified to increase roll stiffness.	3.0	1.7
hard	Racing cars only.	1.5	1.0

Table 1

Eagle Talon
Roll: 4.2 degrees/g
Pitch: 1.8 degrees/g

The g-analyst operating instructions provide a table for pitch and roll compensation (Table 1). Data recording was started with the push of a button just prior to braking and stopped with the push of the stop button after the vehicle came to rest.

VC•2000 - The VC•2000PC was mounted with suction cups to the windshield of each vehicle as directed by the manufacturer (Fig. 3). The transducer, microprocessor and display are all contained in one package. The unit is set approximately level with a bubble level. The external brake switch requires a 12 volt signal which was accessed via the brake light wires. The vehicle was positioned on the roadway in the area where the stop was to be made. The device zeroed itself prior to the run. The pitch calibration was left at the default setting as recommended by the manufacturer for all highway vehicles with suspension systems. Data recording can be started with the application of braking through the brake light voltage. If no signal voltage is received by the instrument, a .2 g level of braking starts the recording. For the tests in this study, the Oldsmobile triggered the VC•2000 with a .2 g level of braking, and the Eagle used brake light voltage as the trigger.

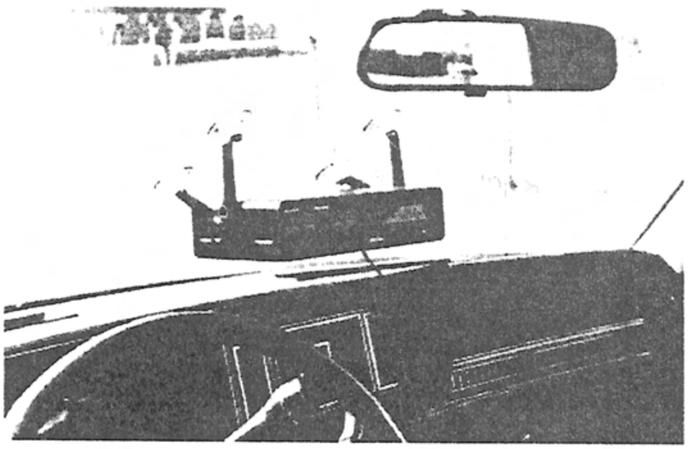


Figure 3

THEORY OF OPERATION FOR THE g-analyst AND THE VC•2000

The g-analyst is a computer based device that utilizes three orthogonally aligned force re balance servo accelerometers. Voltage is applied to the spring mass-system to keep the mass at a central position when acted upon by varying acceleration. The voltage required is proportional to the acceleration level. Low pass anti-alias filters are utilized to prevent resonance in the over damped system. The instrument samples and records data 10 times per second. Eight minutes of recorded data can be played back and viewed on the instrument display unit or data can be downloaded to a PC with optional g-analyst software. The data consists of the lateral and longitudinal acceleration values plotted versus time. The data is also available in ASCII format. No integration routine is provided by the manufacturer.

The VC•2000 is a computer based acceleration measuring device. It utilizes a spring - mass accelerometer and measures voltage which is proportional to the spacing between flat plates separated by springs. It is a critically damped system which records acceleration levels 100 times per second. It integrates acceleration over time and displays braking time, initial speed, braking distance and average acceleration for the stop. The integration process begins at the time the device is triggered and stops .2 sec. before the end of the recording (when acceleration level settles to zero). Peak acceleration can also be displayed. The data can be downloaded to a PC with the VC•2000 PC version of the device. Data can then be displayed in tabular form, graphic form or in ASCII format. The software package provided also allows multiple runs to be averaged. Note that the method of calibration subtracts out any portion of the acceleration reading attributable to the incline of the road surface thereby providing the drag factor in the plane of the road as opposed to the friction factor of the tire/ roadway interface.

RESULTS

Table 2 summarizes the results obtained for all the tests

RUN #	RADAR SPEED mph	BRAKING DISTANCE ft.	SKID MARK LENGTH ft.	SPEED, mph			AVERAGE FRICTION FACTOR				
				G ANALYST	VC-2000 PROFILE	VC-2000 MODIFIED INTEGR.	TOTAL BRAKING DISTANCE	SKID MARK DISTANCE	G ANALYST	VC-2000 PROFILE	VC-2000 MODIFIED INTEGR.
OLDSMOBILE CUTLASS											
O4	**19.5**	17.6	15.8	19.0	18.12	20.3	0.72	0.80	0.67	0.76	0.75
O5	**18.7**	16.7	13.1	19.2	17.70	20.0	0.70	0.89	0.67	0.80	0.79
O6	**20.4**	19.3	16.3	20.4	18.78	21.2	0.72	0.85	0.72	0.83	0.82
O7	**19.4**	17.1	14.4	19.7	18.13	20.3	0.74	0.87	0.69	0.81	0.76
O8	**19.7**	17.8	13.7	20.3	18.85	21.0	0.73	0.95	0.71	0.83	0.80
O9	**44.7**	93.7	79.8	45.6	43.41	45.0	0.71	0.84	0.74	0.76	0.75
O10	**46.2**	97.3	87.0		45.33		0.73	0.82		0.80	
O11	**45.3**	97.6	70.7				0.70	0.97			
O12	**44.4**	86.6	77.8	45.5	43.78	47.0	0.76	0.85	0.77	0.82	0.78
O13	**45.4**	92.7	70.1	46.6	45.32	47.0	0.74	0.98	0.73	0.78	0.77
O14	**46.3**	92.2	OBSCURED - OTHER MARKS	47.5	45.86	49.7	0.78		0.80	0.86	0.82
O15	**47.2**	101.5	85.0	48.4	46.84	48.6	0.73	0.88	0.73	0.78	0.77
OG1	**21.0**	20.8	NO SKID MARK VISIBLE	20.8	20.21	22.4	0.71		0.73	0.83	0.81
OG2			NO VIDEO	18.7	18.69	20.7			0.78	0.86	0.83
OG3	**20.7**	20.3	NO SKID MARK VISIBLE	20.2	19.54	21.7	0.71		0.71	0.81	0.79
OG4	**20.5**	17.3	NO SKID MARK VISIBLE	19.7	19.21	21.8	0.81		0.75	0.87	0.80
OG5	**20.0**	17.7	NO SKID MARK VISIBLE		18.98		0.75		0.75	0.87	
OG6	**18.8**	16.3	NO SKID MARK VISIBLE	18.3	17.64	20.6	0.72		0.76	0.86	0.75
OG7	**41.2**	74.4	58.3	40.6	40.05	41.8	0.76	0.97	0.77	0.83	0.82
OG8	**45.9**	91.3	70.0	45.8	44.98	47.0	0.77	1.01	0.80	0.88	0.86
OG9	**46.0**	93.4	NO MARK - SIDE SLIP	45.8	45.32	47.3	0.76		0.77	0.86	0.84
OG10	**46.4**	89.1	70.3	46.2	45.69	47.6	0.81	1.02	0.78	0.86	0.85
OG11	**47.4**		NO CHALK MARK		46.90				0.76	0.82	
OG12	**45.6**	91.2	TIRE MARKS OBSCURED		45.63		0.76			0.81	
OG13	**44.7**	86.8	67.0	44.1	43.77	45.5	0.77	1.00	0.77	0.82	0.81
EAGLE TALON											
E4	**21.6**	18.8	15.4	21.0	19.92	21.9	0.83	1.01	0.68	0.76	0.79
E5	**20.3**	16.7	12.0				0.82	1.15			
E6	**19.5**	15.3	11.6	19.6	18.26	20.1	0.83	1.09	0.64	0.76	0.78
E7	**21.4**	18.9	13.0	21.3	19.75	21.7	0.81	1.18	0.65	0.76	0.78
E8	**45.5**	83.8	56.7	45.2	43.95	45.8	0.83	1.22	0.74	0.79	0.80
E9	**43.7**	80.1	67.3	42.8	41.59	43.4	0.80	0.95	0.73	0.77	0.78
E10	**44.7**	83.3	70.8	44.1	43.02	45.1	0.80	0.94	0.74	0.78	0.78
E11	**43.7**	79.1	67.0	43.1	42.26	44.2	0.81	0.95	0.73	0.77	0.76
E12			NO VIDEO							0.78	
E13	**46.0**	88.9	69.3	45.7	44.28	46.2	0.79	1.02	0.72	0.76	0.76

"VC•2000 Profile" indicates values produced by the instrument display and Profile software
"VC•2000 modified integration" indicates values obtained by our integration over a time interval at which deceleration levels exceed .2 g

Table 2

conducted with the Oldsmobile and the Eagle. The table lists run number, initial speed before braking (from radar gun), the total braking distance measured from the chalk gun mark and the longest visible skid mark. Computed speeds and average friction factors are shown.

The run number prefixes "O" represent the aggressive surface and "OG" represent the more polished surface for the Oldsmobile. The run number prefix "E" represents the Eagle tests which were conducted on only the aggressive surface. Run numbers O1 - O3 and E1 - E3 were disregarded because of set-up difficulties.

Speed was computed from VC•2000 data using two different methods. The column labelled "VC•2000 Profile" presents the speed from the PC software output which is the same as that presented by the instrument display. It is derived by numerical integration of the acceleration data. The start of the integration interval for the Eagle tests was the time at which the brake light was actuated. The start of the integration interval for the Oldsmobile tests was at a .2 g deceleration level. The end of the integration interval was .2 seconds before the acceleration settled to zero.

The column labelled "VC•2000 modified integration" presents speeds computed by integrating over a time interval at which deceleration levels were above .2 g. The column labelled g-analyst presents speeds computed by integrating acceleration data over a time interval at which deceleration levels were above .1 g.

The last five columns show average friction factors. The friction factors for total braking distance and skidmark length are computed utilizing equation (2) and inputing the radar speed as V_o.

OBSERVATIONS

Simultaneous video recording of the radar gun display and the test vehicle appears to be an accurate method for determining speed before braking. Average drag factor can be accurately computed using the radar gun speed and bumper gun distance, but the process is awkward and time consuming.

Both accelerometer systems were easy to use and directly provide acceleration values. The g-analyst provides only acceleration values and any speed or distance results must be post processed by the user. The VC•2000 has an internal integrator which gives immediate values of initial speed and total braking distance as well as average drag factor.

The VC•2000 measures drag factor in the plane of the road while the g-analyst measures friction factor (coefficient of friction). All tests were conducted on a level surface, making the drag factor equal to the friction factor.

The VC•2000 acceleration measurements can be affected by vehicle yaw and sideslip since it only measures the component along the heading of the vehicle. If a stop involves significant sideslip and/or yaw as in some of the 45 mph runs (Fig. 4), significant error is introduced. The g-analyst measures acceleration in both the longitudinal and lateral directions simultaneously. The combined vector should be used to determine the frictional drag factor.

Figure 4

The VC•2000 automatically starts recording data when triggered by a brake signal or a .2 g acceleration threshold. The g-analyst requires manual input to start recording. Because it can significantly affect the results, the range used for integration should be carefully selected.

Vehicle pitch caused by the suspension system reaction to acceleration adds to deceleration readings. The VC•2000 utilizes a single default compensation for all vehicles. The g-analyst and the VC•2000PC have programmable pitch compensation. The VC•2000 transducer is typically mounted above the vehicle center of gravity. The g-analyst is typically mounted below the C.G. The effect of mounting location requires further study.

Analysis of the results obtained for the Oldsmobile on the two different surfaces indicated no significant difference in average friction factor. Therefore the road surface condition was dropped in the evaluation. The results are, however presented in the table.

STATISTICAL ANALYSIS OF BRAKING TEST DATA

The experiments were organized and conducted according to a factorial design (Guttman, et al., 1982)[13] with 3 factors, each at 2 levels and with replications.

Response Variable - The response variable used in this study is the average acceleration a, (presented as deceleration, i.e., positive values). A value was calculated by integration of the time histories of the g-analyst and VC•2000PC records for each stop. Each value was obtained by integration using a threshold of 0.1 g for the g-analyst data and 0.2 g for the VC•2000 data. The value of 0.1 g was selected for the g-analyst because the instrument measures every 0.1 sec, where as, the VC•2000 measures every 0.01 sec and the Oldsmobile record is started when the acceleration reaches 0.2 g. The formula used is:

$$\bar{a} = \frac{1}{T}\int_{0}^{T} a(t)\, dt \qquad (4)$$

The values for the response variable are the same as the friction factors presented in table 2. They can be found under column headings "g-analyst" and "VC•2000 Modified Integration"

Factors - The three factors used in the statistical analysis are:

Factor 1: Vehicle (V), Eagle (-) and Oldsmobile (+)
Factor 2: Nominal initial Speed (S), 20 mph (-) and 45 mph (+)
Factor 3: Instrument (I), VC•2000 (-) and G-Analyst (+)

Minus and plus signs indicate "low" and "high" values of the factors, respectively. The experiments included 5 measurements of each combination of conditions (5 replications of each combination)

Results of ANOVA (analysis of variance) - Table 3 shows the results of an analysis of variance. The critical, or threshold, "F-statistic" (5% level of significance) is 4.154 for this analysis. Any value in the column entitled F-Ratio that exceeds this critical value has a significant effect on the response (average acceleration) of the corresponding factor. According to the data, those factors that show a significant effect are the Speed (9.881 > 4.154), the Instrument (85.438 > 4.154) and the interaction of Speed and Instrument (24.009 > 4.154). All other factors such as the vehicle and the other interactions do not exert a significant influence over the average acceleration. As mentioned earlier, this implies that any differences in suspension (or other vehicle characteristics for that matter) do not interact with the two instruments to play a joint role in influencing the acceleration levels. Note that the average friction factor computed from the chalk gun distance was not included in this ANOVA analysis.

The results of the ANOVA indicate that the effects of speed and measuring instrument are significant. By far, the differences in acceleration values are due to the differences in the g-analyst and VC•2000 Instruments. Though the effects of speed differences are real, they are considerably smaller than the effects of the instruments. In addition, the significance of the Speed-Instrument interaction indicates that the relative performance of each instrument changes with speed.

One of the important results from these experiments is the estimate of the mean square error of the measured friction factors. This is indicated at the bottom of the Mean Squares column to the right of SE in the Table 4 with a value of 0.00055. The square root of this, 0.0235, is the standard deviation of the measurement "error" and indicates the level of precision of the average acceleration. If it is assumed that the uncontrolled variations due to factors other than those above that are intentionally controlled and changed) have a normal statistical distribution, then the value of 0.0235 is the estimate of the standard deviation of that distribution.

The effects of changes of significant factors can be estimated from their average values in the Main Effects column. For example, the effect of increasing the test speed from 20 to 45 mph caused an average increase of about 0.023 in average acceleration. A significant change in friction factor with speed, particularly an increase, is ordinarily not expected for dry pavements. The higher percentage of acceleration build-up and fall-off durations for the 20 mph tests may explain this phenomenon.

Source	Sum of Squares	Degrees of Freedom	Mean Squares	F-ratio	Main Effects
Vehicle	0.00100	1	0.00100	1.803	0.00998
Speed	0.00545	1	0.00545	9.881	0.02336
VS interaction	0.00005	1	0.00005	0.094	0.00228
Instrument	0.04716	1	0.04716	85.438	-0.06868
VI interaction	0.00069	1	0.00069	1.256	0.00833
SI interaction	0.01325	1	0.01325	24.009	0.03641
VSI interaction	0.00009	1	0.00009	0.159	0.00297
SE	0.01766	32	0.00055		
Total	0.08536	39		4.154	

Table 3

The negative Main Effect, -0.06868, associated with the instrument factor indicates that when the friction factor values furnished by integration of the VC•2000 data are compared to those of the g-analyst, on average the g-analyst values are lower than the VC•2000. This is seen from the average values going from 0.783 to 0.714, a change of -0.069. The sensitivity of the Speed-Instrument interaction can be seen by the way the values of acceleration given by the VC•2000 decreased from 0.789 to 0.777 when the test speed went from 20 to 45 mph whereas the values of acceleration given by the g-analyst increased from 0.685 to 0.744 with the speed change. This discrepancy is best explained by the belief that the g-analyst is overly damped. Overdamping explains the general tendency for the g-analyst to yield lower average acceleration values than the VC•2000 and its sensitivity to speed because of its lack of response to the acceleration build-up and fall-off. Instrument differences can also be caused by the difference in the sampling times of the two instruments. The g-analyst gives values every 0.1 sec while the VC•2000 records them every 0.01 sec. This also has implications in the accuracy of the integration as well. The difference between the instruments was 0.104 for 20 mph and only 0.033 for 45 mph.

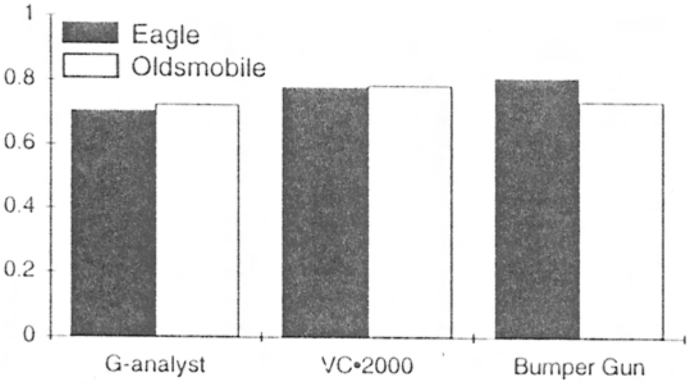


Figure 5

Analysis of the average acceleration values for the bumper gun method showed that the average acceleration for the two vehicles differed by about 0.08 g's. Fig. 5 shows that the two accelerometer methods did not identify this difference. The only explanation for the discrepancy is that the combination of over damping of the g-analyst and inaccurate pitch compensation of both instruments. The two vehicles tested do exhibit substantially different pitch characteristics.

PITCH COMPENSATION

As indicated earlier, both of the accelerometer based methods are affected by pitching of the vehicle. Forward pitching will cause both of the devices to read higher than actual deceleration values because gravity acts on the nonlevel accelerometer. Both devices offer some compensation for the pitch. The g-analyst and the VC•2000PC allow for some variable compensation, whereas the VC•2000 only provides for a coarse estimate. Neither device has the ability to actually measure pitch.

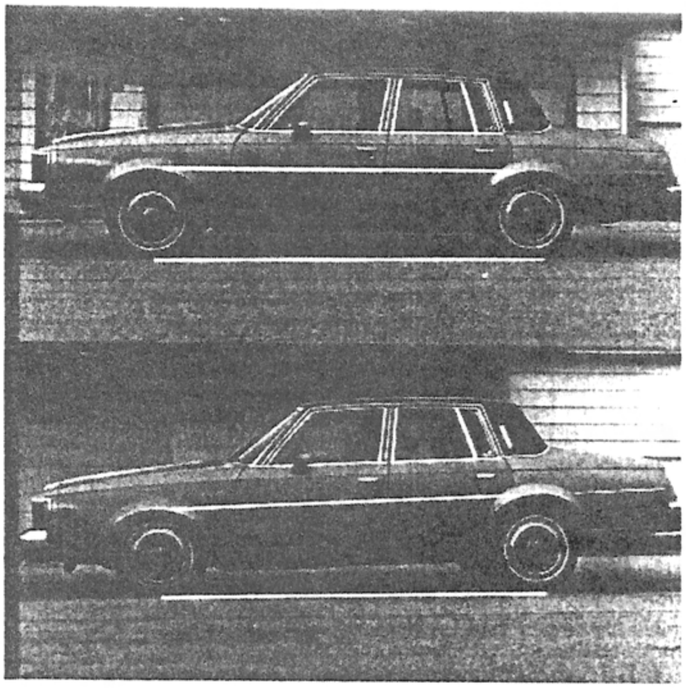


Figure 6

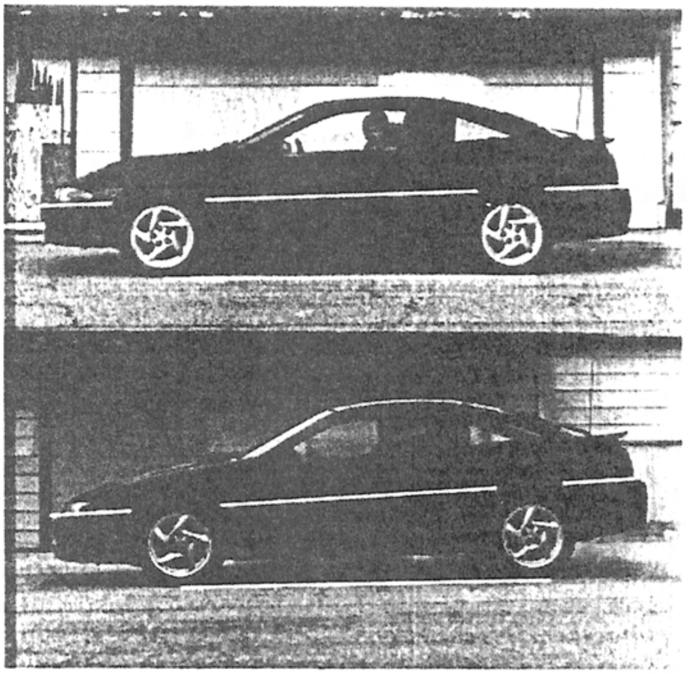
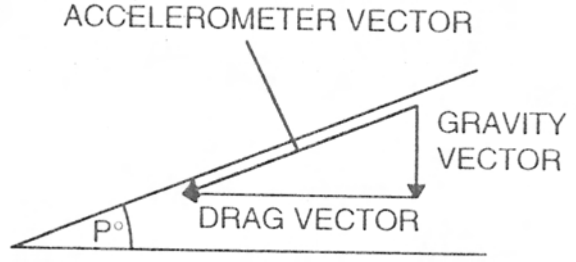


Figure 7

The pitch experienced by both vehicles in this study was measured using a photographic technique. Side elevation photographs of each vehicle were taken with the vehicle stationary and under steady state locked wheel braking. The angle created between a line drawn through the front and rear wheel/ground contact points and the body line is compared for each condition. The difference is the pitch of the vehicle during locked wheel braking. Figs. 6 and 7 show the photographs taken for the Oldsmobile and Eagle tested in this study. About 2.4° and 1° of pitch was measured for the Oldsmobile and Eagle, respectively. A 2.4° pitch will increase the



ACCELEROMETER VECTOR = DRAG VECTOR COS P
+ GRAVITY VECTOR SINE P

Figure 8

uncompensated accelerometer reading by .042 g. and a 1.0° pitch will increase the uncompensated accelerometer reading by .017 g. The effect of pitch is shown in Fig. 8.

APPLICATION OF DRAG FACTOR TEST RESULTS TO SKID MARK ANALYSIS

Although test results showed changes of friction factor with speed, vehicle and instrumentation effects, these variations may be small compared to the potential error produced in estimating speed from skid marks. The use of average friction factors obtained from the g-analyst and the VC•2000 accelerometers to reconstruct speeds will always yield conservative (lower than actual) speed estimates when applied to field measured skid marks because the skid mark does not accurately represent the actual braking distance. The difference varies substantially, but in all cases the skid mark distance is significantly shorter than the actual braking distance.

To exemplify this, consider run number E10 from table 2. The measured average friction factor was .74 and .78 for the g-analyst and the VC•2000, respectively. The actual average friction factor was .80 based on the bumper gun test. Applying these friction factors to the measured skid mark of 70.8 ft., the speed estimates are 39.6 mph for the g-analyst, 40.7 mph for the VC•2000, and 41.2 mph for the bumper gun. The actual measured radar speed was 44.7 mph.

Partial compensation for this error can be achieved by utilizing the speed calculation methodology suggested by Neptune, et. al.[5]. This technique considers some of the energy dissipated in the braking prior to skid mark appearance, and will improve the accuracy of the speed estimate.

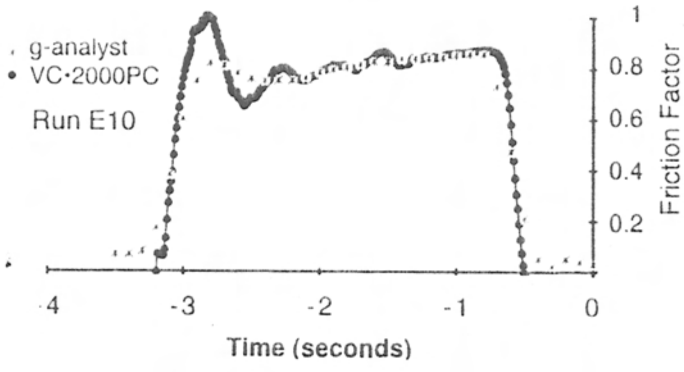


Figure 9

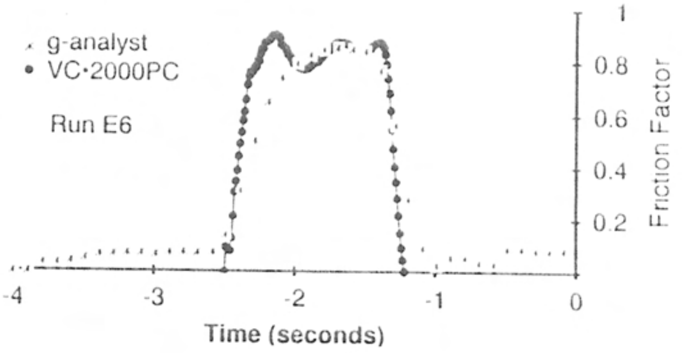


Figure 10

Another compensating technique which will improve accuracy is use of the friction factor measured during the period when a visible skid mark is being generated during the test. The results obtained in this study suggest that the higher speed test (45 mph) will produce an acceleration curve (Fig.9) which exhibits a well defined plateau during the time a skid mark is being generated. The 20 mph data (Fig. 10) did not generate as distinctive a plateau because of its relatively short time duration. Use of this plateau as a range for deceleration during locked wheel skidding will produce a more accurate result. In the above example, the plateau range was .76 to .86 for the g-analyst and .82 to .88 for the VC•2000. The resulting speed calculations were 40.1 mph to 42.7 mph for the g-analyst and 41.7 mph to 43.2 mph for the VC•2000, still significantly conservative.

Similarly, the "CHP Method" and "Best Fit" techniques[6] provide higher friction factor values than the average values when applied to acceleration data. These higher values also improve the accuracy of speed calculations based on skid mark measurements.

CONCLUSIONS

The statistical analysis of the test data indicates that significant differences in average friction factor existed from instrument to instrument and speed to speed, and that there can be an interaction between test speed and the instrument. The effect of speed, however, was small, less than about 3%. The instrument difference between the g-analyst and the VC•2000 was larger at just under 10%, with the g-analyst typically giving lower average values than the VC•2000. It appears that the over damped characteristic of the g-analyst and it's lower sampling rate are the major causes for this difference.

Application of measured friction factors to skid mark measurements will typically result in conservative (lower than actual) speed estimates. A more accurate value is that measured during the steady state locked wheel portion of the test when skid marks are being generated. In order to create a well defined locked wheel plateau, higher speed tests greater than 30 mph may be necessary. Use of algorithms incorporating pre-skid energy will also improve the calculation accuracy.

None of the methods are ideal and the user should be aware of the limitations of each. The following is a summary of the advantages and disadvantages of each method.

g-analyst

Advantages:
- Easy to install
- Easy to calibrate and set up
- Separate readout and transducer can be mounted near C.G. or on a surface isolated from vibration
- Bi-directional (Considers vehicle rotation)
- Immediate reading
- Ability to connect to a computer
- Variable pitch and roll compensation
- Gives steady-state g level
- Gives deceleration profile

Disadvantages:
- Over damped
- No direct pitch measurement
- No internal integration for speed and distance
- Low sample rate: measures every .1 seconds
- Requires external 12 volt power source

VC•2000PC

Advantages:
- Easy to install
- Has internal integration for speed and distance
- Computes and immediately displays initial speed, braking distance and average acceleration
- Easy to calibrate and set up
- Measures at .01 second intervals
- Ability to connect to a computer
- Gives steady-state g level
- Gives deceleration profile
- Automatically starts and stops recording
- Variable pitch compensation through "Profile" software
- Has internal NiCad batteries for alternate power source

Disadvantages:
- Transducer and readout integral which limits mounting location
- Single longitudinal accelerometer does not allow for yaw compensation
- No direct pitch measurement

Bumper Gun

Advantages:
- Direct easy to understand methodology
- Not affected by vehicle pitch
- Not affected by vehicle rotation
- Gives direct average deceleration level with easy calculation

Disadvantages:
- Cumbersome to use
- Requires another device to accurately measure initial speed and to compute average factor
- No deceleration profile
- No steady-state deceleration level

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Reviewer's Discussion
By John Hunter, Investigative Training Service
SAE #980367

Comparison of Tire Friction Test Methodologies used in Accident Reconstruction

Donald F. Rudny, David W. Sallmann, Raymond M. Brach, Authors

There were three methods of obtaining the coefficient of friction for collision analysis presented in this paper. All three were compared by documenting the result of two vehicles when tested at two different speeds on two different surfaces. Each of the test instruments setup procedure and operation were explained in detail. A comparison based on ease of use, data collection ability and sensitivity to pitch and yaw was completed. The advantages and disadvantages of each method were listed in the conclusion.

There are several "methods" for evaluating the data from the instruments and this paper does an excellent job in discussing some of those methods. There is an additional instrument available to the reconstructionist, which could also be compared. The Stalker ATS, an advanced version of the speed measuring device used in these tests, has the ability to record and plot the deceleration of a skidding vehicle similar to the graphs shown in figures 9 and 10. Perhaps future work could include this type of comparison.

Reviewer's Discussion
By Nicholas Tumbas, Tumbas and Associates
SAE #980367

Comparison of Tire Friction Test Methodologies used in Accident Reconstruction

Donald F. Rudny, David W. Sallmann, Raymond M. Brach, Authors

The authors compare the results from braking tests using two commercial accelerometers against a radar gun and chalk detonator under somewhat varying circumstances. An analysis of variance determined that the instrument itself affected the results much more than such common considerations as type of vehicle and initial speed. Indeed, vehicle type made no significant difference in this experiment oriented toward straight line, limit braking. Any generalization of this finding, perhaps should be made with caution, particularly in test situations where the coming properties of tires may play a larger role.

The gAnalyst reported lower average friction factors than the VC-2000; however, both under-reported the value relative to the total braking distance. In addition, the VC-2000 systematically under-reported the initial speed relative to the radar speed. The data from the gAnalyst allowed for a more accurate determination of initial speed, but required post-processing by the authors who also modified the integral to improve the results for the VC-2000. A careful reader will note differences in threshold values and, in turn, times for integration of the average acceleration.

In summary, it appears one must be careful not to over rely on a single instrument, especially if data being recorded represents most but not all of an event like limit braking. At this time, a supplemental system such as radar and a chalk detonator, while more cumbersome, will lend more credibility to the results.