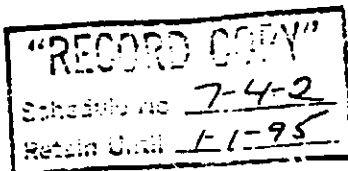




To D. Onkka



T.O. Number	N23361
Date of Order	10/16/89
Test Auth. No.	
Work Task No.	T2L10
Test Dates	10/23/89 11/09/89
Date Reported	11/29/89

Subject : Steady state and transient handling properties of a 1989 Bronco II Eddie Bauer, 1989 Chevy Blazer 4x4, and a 1990 UN46 3 Dr. at two tire pressures.

Requested By : Light Truck Dynamics-D. Onkka

Object : To determine and compare the vehicle understeer coefficient, roll gradient, lateral acceleration frequency response, yaw rate frequency response, lateral acceleration response times and yaw rate response times of the these subject vehicles.

Summary : The test results are summarized in Tables 1 through 3, which appear on pages 3 to 5 of this report.

1. Constant Radius Handling Test

- A. The UN46 at both tire pressures have a higher body roll gradient in left turns than in right turns.
- B. The Chevy Blazer has the highest body roll gradient of the vehicles tested. The UN46 has higher body roll gradient than the Bronco II.
- C. The Bronco II and the UN46 both exhibit high levels of front suspension jacking. The jacking increases slowly with lateral acceleration to about 0.4 G (0.25 inches jacking) and then the rate of increase accelerates. At 0.65 G the jacking is about 2.5 inches. In comparison the Chevy Blazer increases slowly with lateral acceleration to about 0.25 inches @ 0.65 G lateral acceleration.
- D. The UN46 at both tire pressures requires the highest steering wheel angle input to maintain a lateral acceleration level. The Bronco II and the Chevy Blazer require similar steering wheel inputs at any lateral acceleration levels until the higher G levels, where the Bronco II requires more steering wheel angle.

- E. In right turns the UN46 @ 35/35 psi requires less steering wheel angle input than the UN46 @ 26/26 psi. This difference increases with lateral acceleration. In left turns the difference, although smaller are reversed.
- F. The Blazer requires more steering wheel torque than any of the other vehicle although the overall level is not very high.

2. Random Steer Test

- A. The Chevy Blazer has the most predictable and flattest yaw rate response.
- B. Performance of all parameters degrade as the speed increases from 45 to 60 mph.
- C. All vehicles display similar lateral acceleration response.
- D. The UN46 has the least roll damping of the group.
- E. Yaw rate to lateral acceleration response characteristics are best in Chevy Blazer.
- F. Overall transient handling characteristics are very similar although the data indicates the Blazer is the best.

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A thank you to Jerry Holmes, Kevin Markham, and Len Richter, the test drivers and technicians who instrumented and drove the vehicle for the following tests.

TABLE 1 : SUMMARY OF STEADY STATE HANDLING PROPERTIES

PARAMETERS	VEHICLE							
	UN46 3 Dr. @ 26/26 psi		UN46 3 Dr. @ 35/35 PSI		BRONCO II (EDDIE BAUER)		CHEVY BLAZER 4x4	
	Left	Right	Left	Right	Left	Right	Left	Right
Maximum Lateral Acceleration ( G's )	.647	.658	.702	.678	.656	.697	.692	.684
Body Roll Gradient ( Degrees / G )	6.23	5.61	6.37	5.22	5.46	5.30	6.44	6.42
Total Roll Gradient ( Degrees / G ) ( average )	6.66		6.34		6.48		6.69	
Steer Torque Gradient @ 0.25 G's ( inch-lbs / G )	30.97	27.30	28.32	29.19	38.25	47.76	38.48	30.31
Understeer Coefficient @ G level								
0.2 G's	3.30	4.60	3.38	4.18	3.99	3.59	3.77	3.47
0.25 G's	3.72	4.68	3.85	4.18	4.35	3.79	3.72	4.05
0.3 G's	4.58	5.12	5.24	4.71	4.92	4.14	3.94	4.74
0.4 G's	7.58	7.06	10.76	7.34	6.63	5.30	5.22	6.45
0.5 G's	8.20	10.41	19.93	12.05	12.5	7.05	7.59	8.59
0.6 G's	56.2	41.1	31.3	29.2	43.9	25.0	24.5	25.3
0.7 G's	NA	118.2	43.7	89.3	130.4	77.2	119.7	53.3
0.8 G's	NA	NA	NA	NA	NA	NA	NA	NA

TABLE 2 : SUMMARY OF RANDOM STEER TEST RESULTS

PARAMETERS	CONDITION: 45 MPH			
	Vehicles			
	UN46 3 Dr. @ 26/26 psi	UN46 3 Dr. @ 35/35 psi	Bronco II Eddie Bauer	Chevy Blazer 4x4
Yaw Rate :				
Peak Magnitude (Deg./sec/100 deg. SWA)	21.26	21.11	21.24	22.41
Peak Magnitude/SS Mag.	1.4106	1.3410	1.3374	1.1623
Peak Frequency (Hz.)	1.0948	1.0948	1.1730	.9775
-3 dB Frequency (Hz.)	1.8115	1.8384	2.1545	2.1387
45 Deg. Phase Lag Time (seconds)	.1279	.1296	.1307	.1374
Lateral Acceleration:				
Low Frequency Gain (G's/100 deg. SWA)	.5269	.5507	.5655	.6671
-3 dB Frequency (Hz.)	1.1662	1.1179	1.0984	1.0474
45 Deg. Phase Lag Time (seconds)	.1717	.1714	.1652	.1730
Roll Angle:				
Resonant Frequency (Hz.)	2.346	2.4633	2.3069	2.3460
Yaw Rate to Lat. Accel. Lead Time @ 1 Hz. (secs.)	.0746	.0685	.0499	.0458

TABLE 3 : SUMMARY OF RANDOM STEER TEST RESULTS

PARAMETERS	CONDITION: 60 MPH			
	Vehicles			
	UN46 3 Dr. @ 26/26 psi	UN46 3 Dr. @ 35/35 psi	Bronco II Eddie Bauer	Chevy Blazer 4x4
Yaw Rate :				
Peak Magnitude (Deg./sec/100 deg. SWA)	23.86	24.35	24.31	25.06
Peak Magnitude/SS Mag.	1.6761	1.5877	1.6943	1.3463
Peak Frequency (Hz.)	.9775	.8602	.8211	.8993
-3 dB Frequency (Hz.)	1.7027	1.8983	1.9072	1.8713
45 Deg. Phase Lag Time (seconds)	.1295	.1328	.1393	.1432
Lateral Acceleration:				
Low Frequency Gain (G's/100 deg. SWA)	.6428	.6861	.6846	.8265
-3 dB Frequency (Hz.)	1.0686	1.0272	.9454	.9186
45 Deg. Phase Lag Time (seconds)	.1826	.1862	.1857	.2021
Roll Angle:				
Resonant Frequency (Hz.)	2.346	2.5024	2.3460	2.3069
Yaw Rate to Lat. Accel. Lead Time @ 1 Hz. (secs.)	.1042	.1012	.0838	.0760

UN46 VEHICLE HANDLING COMPARISON TEST

VEHICLE DESCRIPTION:

Make and Model: 1990 UN46 3 Dr.  
Vehicle Number: 316T008  
V.I.N.: N/A

Wheelbase: 102 inches

Track; Front:58.5 inches  
Rear:58.0 inches

Suspension Type; Front:Independent w/stab. bar  
Rear:Solid Axle w/stab. bar

Engine: 4.0 L V-6 EFI

Transmission: AOD

Steering System: Power Assisted rack & pinion

Overall Steering Gear Ratio: 23.5 : 1 for tire pressure of 26/26 psi  
21.7 : 1 for tire pressure of 35/35 psi

Tires: Firestone ATK M+S

Tire Pressure; Front: 26 psi and 35 psi There were 2 tire  
Rear: 26 psi and 35 psi pressures used in tests.

Test Weights; Test Wt.  
Left Front:1164  
Right Front:1118  
Left Rear: 983  
Right Rear: 905  
Total:4170 lbs.

WT. Distribution (as tested): 54.7 % Front  
45.2 % Rear

Other: The tires were new for the test with 50 miles break in. The tread depth was 13/32 inches for all tires.

UN46 VEHICLE HANDLING COMPARISON TEST

VEHICLE DESCRIPTION:

Make and Model: 1989 Chevy Blazer 4x4 High Country  
Vehicle Number: 309T653  
V.I.N.: 1GNCT18Z4K8168202

Wheelbase: 101 inches

Track; Front: 56.25 inches  
Rear: 55.0 inches

Suspension Type; Front: Independent w/stab. bar  
Rear: Solid Axle w/leaf

Engine: 4.3 L V-6

Transmission: Automatic with overdrive/4x4

Steering System: Power Assisted rack & pinion

Overall Steering Gear Ratio: 18.6 : 1 as determined on a 195 ft radius circle.

Tires: Uniroyal Laredo M+S

Tire Pressure; Front: 35 psi  
Rear: 35 psi

Test Weights; Test Wt.  
Left Front: 1040  
Right Front: 1073  
Left Rear: 940  
Right Rear: 948  
Total: 4001 lbs.

WT. Distribution (as tested): 52.8 % Front  
47.1 % Rear

Other: The tires were new for the test with 50 miles break in. The tread depth was 14/32 inches for all tires.

UM46 VEHICLE HANDLING COMPARISON TEST

VEHICLE DESCRIPTION:

Make and Model: 1989 Bronco II Eddie Bauer Edition  
Vehicle Number: 316T656  
V.I.N.: 1FMCU14T5KUB11002—

Wheelbase: 94 inches

Track; Front: 57.0 inches  
Rear: 56.875 inches

Suspension Type; Front: Independent w/stab. bar  
Rear: Solid Axle w/stab. bar

Engine: 2.9 L V-6 EFI

Transmission: Manual 4 speed with overdrive

Steering System: Power Assisted rack & pinion

Overall Steering Gear Ratio: 22.3 : 1 as determined on a 195 ft radius circle

Tires: Firestone FR480

Tire Pressure; Front: 35 psi  
Rear: 35 psi

Test Weights; Test Wt.  
Left Front: 979  
Right Front: 1015  
Left Rear: 932  
Right Rear: 910  
Total: 3836 lbs.

WT. Distribution (as tested): 51.9 % Front  
48.0 % Rear

Other: The tires were new for the test with 50 miles break in. The tread depth was 11/32 inches for all tires.

UN46 VEHICLE HANDLING COMPARISON TEST

INSTRUMENTATION:

- \* Humphrey Gyroscopic Platform No. CF70-0101-1 (serial number K2) to measure corrected lateral acceleration and roll angle. The unit was mounted where the front passenger seat is normally located.
- \* Humphrey Yaw Rate Gyro No. RG51-0106-1 (full scale range = +-40 deg/sec)
- \* Sensor Development Steering Wheel Angle and Torque Transducer Model 01002-1
- \* Fifth wheel used to measure longitudinal velocity
- \* 4 Reyelco string potentiometers to measure vertical wheel deflection relative to the body
- \* Magdac data acquisition system to collect data from the string potentiometers
- \* Signal Conditioning Package
- \* Motorola 6809 based data acquisition system to collect and preprocess data
- \* Kyowa RTP-501 Phillips cassette type FM recorder on some tests to record data
- \* Terniflex HT-3 Terminal for communication with the microprocessor

## DISCUSSION OF TEST RESULTS

### A. Constant Radius Handling Method

The test results are summarized in Table 1. Comparison plots of the test data output are in Appendix A. The plots and data analysis reports with predicted gains for each individual vehicle at each test condition are in Appendices B, C, and D. One test weight was used for these tests. The test weights for each vehicle are listed on the vehicle information pages 6-8. The constant radius handling plots contain only the UN46 @ tire pressure of 26/26 psi unless otherwise noted on the graph.

It should be noted the total vehicle roll and body roll numbers may not show direct correlation with each other, specifically with regard to turn direction. Part of this is due to the way that the stable platform works and to the condition of the platform installed in the vehicle. Increased bearing friction in the gyro gimbals adds to the operation of the gyro. This problem is not as apparent in the trucks tested, as shown by the roll gradient numbers on Table 1.

The body roll vs. lateral acceleration comparison plots are in Appendix A. The plots of the individual vehicles in appendices B, C, and D show linear response for all the vehicles. The Bronco II and Chevy Blazer exhibit symmetric response between left and right turns. The UN46 at both tire pressures has a higher body roll gradient in left turns than in right turns. The Blazer has the highest body roll gradient of all the vehicles tested. The Chevy Blazer and the UN46 @ 26/26 psi have the highest total roll gradient of all the vehicles tested. The UN46 has more body roll than the Bronco II.

Front jacking plots indicate a large difference between the UN46, Bronco II, and the Chevy Blazer. The front jacking on the Bronco II and UN46 slowly increases until about 0.4 G lateral acceleration and then the rate of increase accelerates. As an example for the Bronco II @ 0.4 G the amount of jacking is 0.25 inches, and then at 0.65 G the jacking is at 2.5 inches. In comparison the Chevy Blazer increases slowly with lateral acceleration to about 0.25 inches @ 0.65 G.

Rear jacking in both turn directions is low for all test vehicles. There appears to be little difference in rear jacking between left and right turns.

The steer torque gradient @ 0.25 G's in left turns is lowest for the UN46 at both tire pressures as compared to the other vehicles tested. In right turns the Bronco II has the highest steer torque gradient with the UN46 and Blazer about the same. The steering wheel torque magnitudes are highest for the Chevy Blazer.

The steering wheel angle vs. lateral acceleration numbers indicate that the UN46 at both tire pressures requires the highest steering wheel angle input to

maintain a lateral acceleration level. The UN46 at both tire pressures, also requires the highest steering wheel angle input to maintain a lateral acceleration level in right turns as compared to the Bronco II and Chevy Blazer.

The steering wheel angle vs. lateral acceleration plots indicate that the UN46 with tire pressure of 35/35 psi starts to develop large understeer at about -.55 G's for left turns. In left turns the Bronco II, Chevy Blazer and UN46 @ 26/26 psi all begin extreme understeer at about -0.6 G's or above. The Chevy Blazer reaches the highest lateral acceleration level before extreme understeer occurs. In right turns for the steering wheel angle vs. lateral acceleration plots all the vehicles seem to have similar shape with understeer increasing gradually to about 0.4 G before beginning a more rapid increase. The understeer starts to increase dramatically between 0.5 and 0.6 G depending on the vehicle. The Blazer requires the least steering wheel angle to attain any cornering levels. The Bronco II requires similar angles to the Chevy Blazer.

For left turns the steering wheel torque vs. lateral acceleration plots reveal that the Blazer is the only vehicle that gives an indication that the vehicle is approaching, or is in extreme understeer. This can be seen by the decrease in steering wheel torque which gives feedback to the driver. The Bronco II and UN46 both have increasing steering wheel torque which does not give any feedback to the driver. In right turns all the vehicles have a decrease in steering wheel torque in extreme understeer.

Special notes on the vehicles. Front left tire lift was observed in the left turn of the Constant Radius Test with the Bronco II. This occurred at lateral acceleration levels above about -0.63 G's. The UN46 @ 26/26 psi experienced extreme understeer at the higher G levels.

To summarize the Constant Radius Handling Test results, the Chevy Blazer displays the most favorable constant radius handling characteristics. The Blazer has very low front jacking, moderate steer torque gradient, and symmetric body roll between turns.

#### B. RANDOM STEERING METHOD

The comparison plots in Appendix A. contain the frequency response functions of each output parameter (yaw rate, lateral acceleration, roll angle) with respect to steering wheel angle at 45 and 60 mph for the test weight. In addition, the frequency response plots of roll angle with respect to lateral acceleration are also included. The plots for each individual vehicle are contained in Appendices B, C, and D. The frequency response plots include magnitude, phase and lag time functions. Some important parameters are summarized in Table 2 for the 45 mph test speed, and Table 3 for the 60 mph test speed.

The vehicle properties associated with the shapes of these curves applies only to the linear or "normal" driving range of the vehicle performance near the test speed, although extrapolation of vehicle character extends into the nonlinear range in many cases. Vehicles with good (i.e. sporty) handling characteristics

exhibit flatter frequency response curves of both yaw rate and lateral acceleration with the "knee" or downturn of the curve at a higher frequency and they have lag time curves that are lower and flatter than a poor handling vehicle. This constant gain factor and short time lag independent of how fast the steering wheel is turned is believed to be associated with sporty vehicle handling characteristics.

One method of quantifying the frequency response curves that has been suggested in the literature uses the frequency at which the lateral acceleration frequency response is reduced by 3 dB and the frequency at which the yaw rate frequency response curve shows a resonant peak to characterize a vehicle response. In each, a higher frequency, in general represents a desirable yaw rate frequency response. Another factor used to determine "flatness" is the peak to steady state ratio of the parameter. In this case a lower number indicates a flatter curve. Other researchers use the lag time at a 45 degree phase shift to quantify handling quality. In this case a shorter time is more desirable. Table 2 and 3 shows the results of these analysis at all the test conditions. In general, these methods work well to categorize gross vehicle differences but more subtle changes require analysis of the whole functions as described in a previous paragraph.

The comparison graph's in Appendix A show that the Chevy Blazer 4x4 has the flattest yaw rate frequency response curve. The peak frequency of all the vehicles are similar. The yaw rate peak to steady state magnitude ratio is lower for the Chevy Blazer as compared to the other vehicles tested. This parameter is a measure of yaw damping, and in conjunction with the -3 dB down point also gives an indication of flatness. The Bronco II and Chevy Blazer have the widest bandwidth of the vehicles. Looking at the yaw rate frequency response graph and these two parameters show the UN46 @ tire pressure of 26/26 psi has the peakiest yaw rate response and the least favorable yaw rate response of the vehicles tested. The yaw rate frequency response curve for the Blazer does not fall as quickly as the UN46 at either tire pressure and the Blazer has a higher frequency content than the other vehicles. All of this shows that the Blazer has the most predictable and flattest yaw rate frequency response, and the UN46 @ 26/26 psi has the least of the vehicles.

The time delay plots for yaw rate/steering wheel angle in Appendix A show that below 1 Hz. the Chevy Blazer has the longest lag time of all the vehicles. Above 1 Hz. the lag times are comparable for all the vehicles. But the Blazer also has the flattest time delay curve of any of the other vehicles, which is more important than a low lag time as long as the response time is not too long. A vehicle that displays a quick change in lag time is less predictable than a vehicle with a flat time delay curve. The time delay curve for yaw rate/steering wheel angle at 60 mph shows that the problem is worse than at 45 mph. The Bronco II and UN46 display similar yaw rate/steering wheel angle time delay curves.

The time delay plots of yaw rate to lateral acceleration in Appendix A provide an indication of the lag and lead relation between yaw rate and lateral acceleration. When the curve is positive, the yaw rate leads the lateral

acceleration and the vehicle yaws prior to moving laterally. A low constant lead time is thought to indicate a favorable handling vehicle. The Chevy Blazer followed closely by the Bronco II have the lowest lead times, with the UN46 at both tire pressures having the highest. The UN46 @ 35/35 psi is slightly quicker than the UN46 @ 26/26 psi.

The frequency response function of lateral acceleration to steering wheel angle curves in Appendix A show that all the vehicles have similar lateral acceleration response shapes. The UN46 @ tire pressure of 26/26 psi has the widest bandwidth for lateral acceleration frequency response. The Chevy Blazer has the highest gain. All the vehicles exhibit a hump before the downturn in the curve. This is unusual and the cause is not known. The hump is larger on the UN46 and Bronco II than on the Blazer. The frequency response curves all fall off at similar rates, so there isn't a major difference in the frequency response curves between the vehicles.

The time delay plots of lateral acceleration to steering wheel angle show that like the time delay plot of yaw rate to steering wheel angle, the Chevy Blazer has the longest time delay below about 1 Hz. The Blazer also has the flattest time delay curves which make it the most predictable vehicle of the four tested for this parameter.

The roll to lateral acceleration frequency response curves display a major difference between vehicles. The amplitude of the roll resonant for the UN46 at both tire pressures are the highest of the vehicles tested. The amplitude and width of the peak indicate roll damping. Roll damping is greatest on the Blazer followed by the Bronco II. The UN46 @ 26/26 psi has the least roll damping. All the roll resonant frequencies are grouped between 2.3 and 2.5 Hz. The Bronco II has the highest roll resonant frequency at both speeds with 2.4633 Hz. at 45 mph and 2.5024 Hz. at 60 mph. All of these numbers are listed in Tables 2 and 3.

The test results show that all the test parameters degrade as the vehicle speed is increased from 45 to 60 mph.

The test results show the Chevy Blazer 4x4 has more favorable Random Steer handling characteristics than the other vehicle tested.

**APPENDICES: UN46 VEHICLE HANDLING COMPARISON TEST**

- A. Vehicle Handling Comparison Plots
- B. UN46 3 Dr. Handling Results
- C. Bronco II Eddie Bauer Handling Results
- D. Chevy Blazer 4x4 Handling Results
- E. 1990 UN46 3 Dr. vs. UN46 March 1989 Test Results
- F. Vehicle Handling Test Procedures

