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PARATRANSIT VEHICLE TEST AND EVALUATION
Volume III: Handling Tests

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FINAL REPORT

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16. Abstract

The vehicles presently available for paratransit service do not cover the full spectrum of required characteristics necessary for public transportation. Therefore, specifications were developed by the U.S. Government for a vehicle specifically for use in paratransit service. Prototype vehicles were manufactured for the Government by two different manufacturers (ASL Engineering and Dutcher Industries). Dynamic Science, Inc., conducted an independent series of tests and evaluations of the two prototype vehicles. The program was structured to provide performance data on the prototypes compared to a baseline vehicle that will be used to upgrade future redesigns. The program consisted of five separate test series: 1) Ride Comfort and Quality; 2) Acceleration and Interior Measurement; 3) Handling; 4) Fuel Economy; and 5) Noise. The results of the program are documented in a five-volume technical report, and each volume corresponds to one of the individual test series.

This volume (Volume III) presents the test procedures and results of the handling test series. The test determined the steering and handling characteristics of the two paratransit prototypes and a production baseline vehicle. The tests assessed each vehicle's understeer/oversteer characteristics during cornering, ability to return to a straight line from a turn, capability of safely maintaining lateral accelerations, ability to be maneuvered near its lateral traction limits, and stability and controllability during rapid control reversals.

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PREFACE

This final report, Volume III, summarizes the handling tests on the Paratransit Evaluation and Testing Contract. The program was structured to provide performance data on the prototypes compared to a baseline vehicle that will be used to upgrade future redesigns.

The program was conducted by Dynamic Science, Inc. under Contract DOT-TSC-1241 with the Transportation Systems Center (TSC) of Cambridge, Massachusetts for the Urban Mass Transportation Administration. The contract was technically managed by Mr. Jim Kakatsakis and Mr. Joe Picardi of TSC.

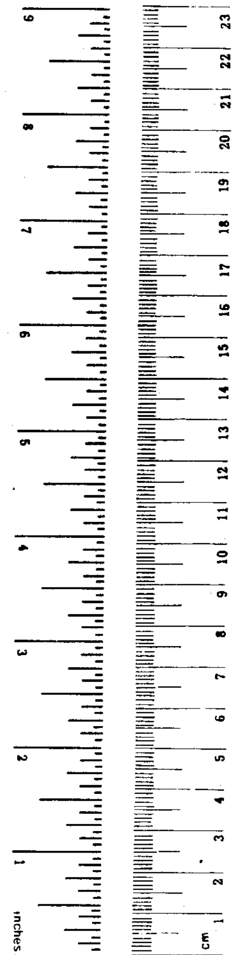
The opinions and findings expressed in this publication are those of the authors and not necessarily those of the Government.

METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in = 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.



Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F

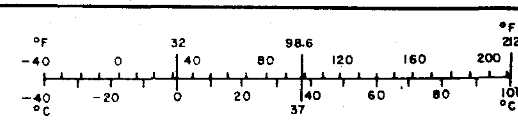


TABLE OF CONTENTS

Page

TABLE OF CONTENTS (CONTD)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTD)

LIST OF ILLUSTRATIONS (CONTD)

LIST OF TABLES

LIST OF TABLES (CONTD)

1.0 INTRODUCTION

The paratransit mode of transportation provides an alternative between transit in privately owned and operated vehicles and scheduled mass transit systems. Paratransit includes such systems as dial-a-ride, taxi, and jitney service. It is of vital importance to people without individual cars or ready access to regular mass transit and to people of limited mobility. The vehicles presently available for paratransit service, however, do not cover the full spectrum of required characteristics. They are slightly modified versions of vehicles designed for different purposes. As such, they are not as efficient in their operation nor as easy to enter and exit as is desirable in this type of transportation.

Therefore, the Urban Mass Transportation Administration (UMTA), working through the Transportation Systems Center (TSC), developed specifications for a vehicle specifically for use in paratransit which combines a number of desirable features without compromising important performance parameters. Prototype vehicles were manufactured for UMTA by two different manufacturers (ASL Engineering and Dutcher Industries) according to these specifications. The primary features of the vehicles are a low pollution, quiet, efficient propulsion system combined with a body designed for the comfort and convenience of both the passengers and driver. The vehicles include provisions for easy ingress and egress for the general public as well as the elderly and handicapped, including the easy ingress/egress and accomodation of a wheelchair passenger.

Dynamic Science, Inc. was selected by UMTA to conduct an independent series of tests and evaluations of the two prototype paratransit vehicles (PTV). These tests were designed to provide additional information on the ride quality and comfort, fuel economy, performance, and handling characteristics of the two vehicles. A compact passenger car (Chevrolet Nova) was utilized as a baseline test vehicle throughout the test series to furnish comparative data for the evaluations.

The paratransit vehicle testing and evaluation program consisted of six major tasks. The first task consisted of initial vehicle inspection, test preparation, and driver familiarization efforts conducted upon delivery of the vehicles to the Dynamic Science test facility. The remaining five tasks consisted of conducting and evaluating the results of five separate test series. These series were:

- Ride Comfort and Quality Test Series which measured the ride characteristics of the test vehicles to determine if and how well they satisfy accepted standards of ride quality.
- Acceleration and Interior Measurement Test Series which determined the acceleration characteristics and available interior space of the vehicles in order to evaluate their suitability for urban paratransit use.
- Handling Test Series which determined the steering and handling characteristics of the PTVs and allowed their characteristics to be compared with those of the baseline test vehicle.
- Fuel Economy Test Series which obtained fuel economy data for the PTVs under actual road conditions with various driving cycles.
- Noise Test Series which measured the acoustic noise generated by the vehicles and the noise environment inside the passenger and driver compartments.

The Paratransit Test and Evaluation Program is documented in five separate volumes as follows:

Volume 1 Ride Comfort and Quality Tests

Volume 2 Acceleration and Interior Measurement Tests

Volume 3 Handling Tests

Volume 4 Fuel Economy Tests

Volume 5 Noise Tests.

This volume (Volume 3) presents the test procedures and results of the handling tests conducted on the two PTV prototypes and the baseline vehicle.

2.0 TEST DESCRIPTION

2.1 TEST OBJECTIVES

This test series was designed to determine the steering and handling characteristics of the prototype paratransit vehicles and a production baseline vehicle. The tests assessed each vehicle's understeer/oversteer characteristics during cornering, ability to return to a straight line from a turn, capability of safely maintaining lateral accelerations, ability to be maneuvered near its lateral traction limits, and stability and controllability during rapid control reversals.

2.2 TEST DESIGN

The handling test series was composed of the following six tests:

- Steady State Yaw tests which determined the vehicle's response in steady state turns at a constant lateral acceleration of 0.4G and speeds of 25, 40, and 55 mph.
- Transient Yaw tests which measured the vehicle's transient yaw response when entering a steady state turn of 0.4G lateral acceleration at speeds of 25 to 50 mph.
- Returnability tests which assessed the vehicle's ability to return to a straight line course after steering wheel release during a 100-foot radius turn at 25 mph.
- Maximum Lateral Acceleration tests which measured the vehicle's maximum steady state velocity around a 100-foot radius turn without breaking away. Tests were conducted on both dry and wet surfaces.
- Breakaway Control tests which determined how fast the driver could return to a 100-foot radius turn after the vehicle had been accelerated to the point where it had moved radially 10 feet from its original path.
- Slalom Course tests which measured how fast the vehicle could be driven successfully through a 1,000-foot slalom course with traffic cones positioned at 100-foot intervals. The course was run at 25, 40, and maximum speed not exceeding 55 mph.

Tests were run with two loading conditions: 300 and 650 pounds, including driver and instrumentation. The 650-pound condition included an instrumented Alderson VIP-50 anthropomorphic dummy in the wheelchair position of the paratransit prototypes and in the right front seat of the baseline vehicle. Ballast was added as necessary in the passenger compartment to achieve the 650-pound load.

2.3 SCOPE OF TEST SERIES

The scope of the handling test series is shown in Table 1. The series consisted of 94 tests at two loading conditions for a total of 188 tests on each test vehicle.

TABLE 1. HANDLING TEST SERIES

Test Type	Test Condition per Load	Turning Directions	Test Repeats	Loading* Conditions	Number of Tests
Steady State Yaw	3 velocities	2	3	2	36
Transient Yaw	2 velocities	2	5	2	40
Returnability	1 velocity	2	3	2	12
Maximum Lateral Acceleration	2 surfaces	2	5	2	40
Breakaway Control	1 course	2	6	2	24
Slalom Course	3 velocities	2	3	2	36
				Total	188

*Only one loading condition for Dutcher prototype.

3.0 TEST VEHICLES

The test vehicles consisted of two prototype paratransit vehicles (one manufactured by ASL Engineering and the other by Dutcher Industries) and one baseline vehicle (Chevrolet Nova). These vehicles are shown in Figure 1.

3.1 ASL PARATRANSIT VEHICLE

The ASL PTV (Figure 2) is a front engine, front drive vehicle which can accommodate a maximum of five seated passengers or three seated passengers plus a wheelchair. Ingress/egress is accomplished through remotely operated sliding doors on each side of the vehicle. An electrically powered loading ramp may be extended on the right side of the vehicle to permit unassisted ingress and egress for wheelchair passengers.

The driver's compartment is separated from the passenger compartment by a bullet-resistant partition. An intercom system is provided for communication between the two compartments. All seating positions are equipped with belt restraints and a restraint system is also provided to fasten the wheelchair securely to the vehicle.

3.2 DUTCHER PARATRANSIT VEHICLE

The Dutcher PTV (Figure 3) is a rear engine, rear drive vehicle which also accommodates five seated passengers or four seated passengers plus a wheelchair. Hydraulically actuated bifold doors on each side of the vehicle permit passenger ingress and egress. An electrically powered loading ramp extending on the right side of the vehicle allows wheelchair ingress and egress.

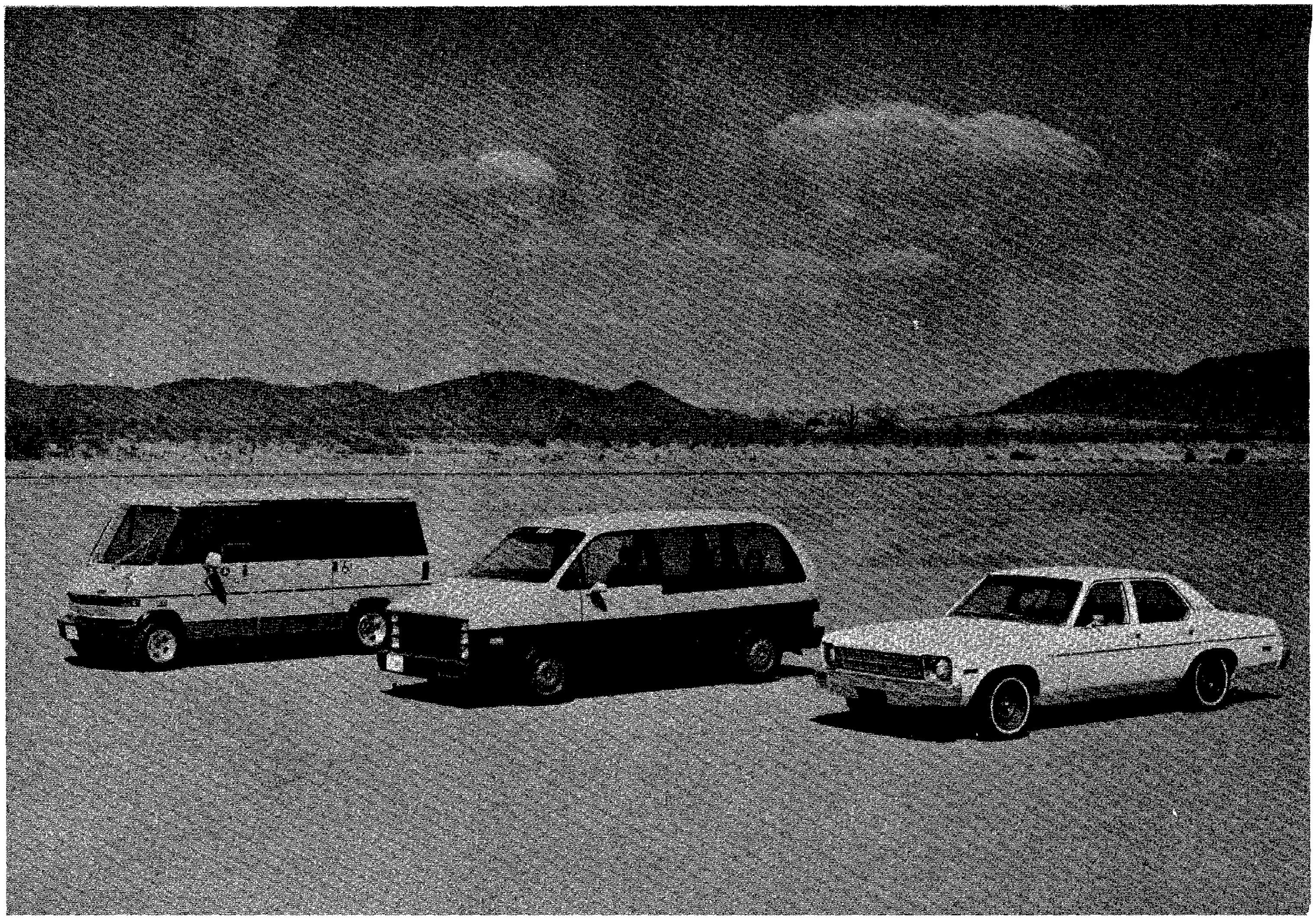


Figure 1. Test Vehicles Left-to-Right: Dutcher PTV, ASL PTV, Chevrolet Nova.

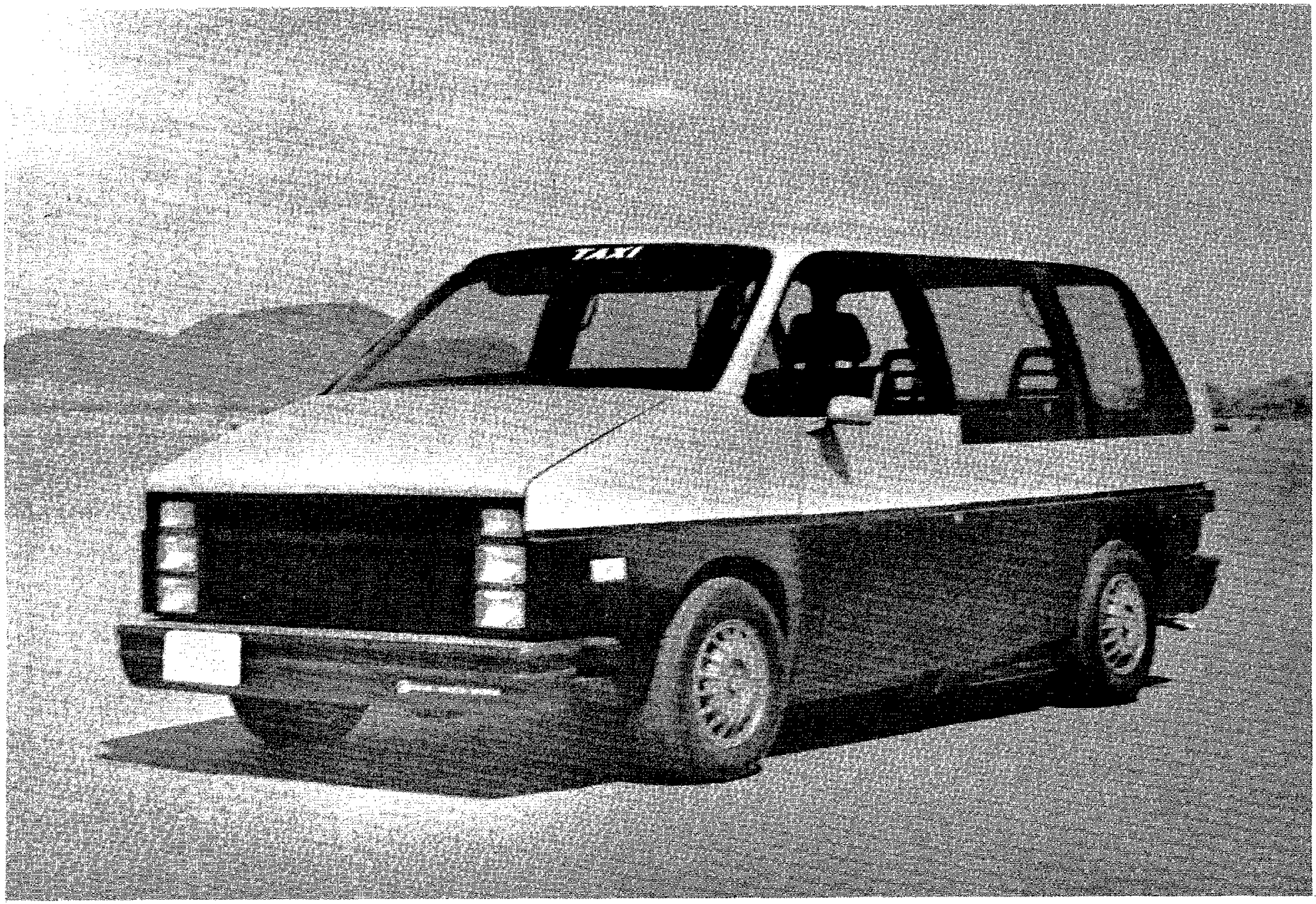


Figure 2. ASL Paratransit Vehicle.

Figure 3. Dutcher Paratransit Vehicle.

As in the ASL PTV, the Dutcher PTV contains a driver compartment which is completely separated from the passenger compartment by a transparent partition. Communication between passengers and driver is accomplished through an intercom system. Restraints are provided for all seating positions and for the wheelchair.

3.3 BASELINE TEST VEHICLE

The baseline test vehicle which was used for comparative evaluation of the PTV test results was a 1977 Chevrolet Nova 6. The criteria for the selection of the baseline vehicle were:

- Compact Size
- 4-Door Passenger Car
- 6-Cylinder Engine
- Automatic Transmission
- Air Conditioning System
- Radial Tires
- Weight, Width, and Length Comparable to the Paratransit Vehicle
- Mileage Less Than 5,000 Miles.

The Nova was selected because it fulfills all of the above requirements and, in addition, is more prevalent and more commonly known than any of the other vehicles which met the criteria.

3.4 COMPARISON OF BASIC VEHICLE CHARACTERISTICS

The basic test vehicle characteristics are listed in Table 2. The characteristics of the two PTV vehicles are similar in most instances. The major differences between the two vehicles lie in the engine location/drive configuration and in the front-to-rear weight ratio (1.59 for the ASL and 0.60 for the Dutcher).

TABLE 2. BASIC TEST VEHICLE CHARACTERISTICS			
Vehicle Parameter	ASL PTV	Dutcher PTV	Nova (Baseline)
1. Dimensions			
Height (in.)	70.8	80.1	55.1
Width (in.)	72.5	72.8	73
Length (in.)	184	172.5	197.1
Wheelbase (in.)	108.3	106.8	111.4
Track			
- Front (in.)	63.4	63.5	61
- Rear (in.)	63.2	61.9	59.3
2. Weight			
Curb Weight (lb)	3510	3021	3450
- Front Rear Ratio	1.59	0.60	1.23
3. Minimum Turning			
Diameter (ft)	37.5	33.8	40.2
4. Engine			
Location	Front	Rear	Front
No. of Cylinders	4	4	6
Displacement ($in.^3$)	114.5	120.3	250
Horsepower	95	86	110
Compression Ratio	8:1	7.6:1	8.25:1
5. Transmission			
Automatic/Manual	Automatic	Automatic	Automatic
No. of Forward Speeds	3	3	3
6. Brakes			
Power/Manual	Power	Manual	Power
Front	Disc	Disc	Disc
Rear	Drum	Drum	Drum
7. Tire Size	ER78-14	Front BR78-13 Rear ER78-14	FR78-14
8. Steering			
Power/Manual	Power	Manual	Power
Type	Rack & Pinion	Rack & Pinion	Standard
9. Drive			
Front/Rear	Front	Rear	Rear
Ratio	4.11	4.57	2.73
10. Fuel Capacity (gal)	15	15	21

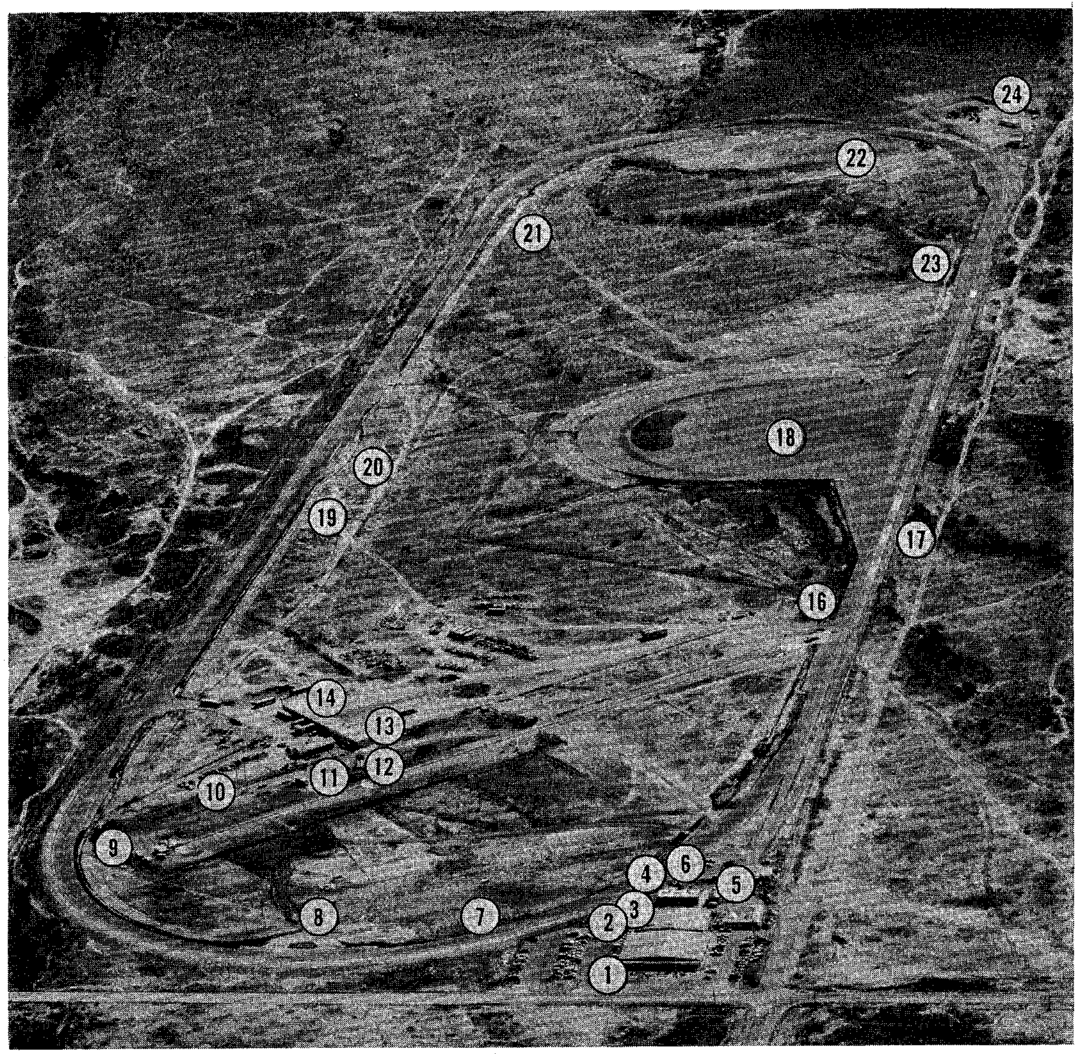
4.0 TEST FACILITIES

The handling tests were performed on the skid pad portion of the Dynamic Science test facility (Item 18 of Figure 4). The skid pad is a large, flat (runout less than 0.25 inch in ten feet), asphaltic concrete area adjoining the south straightaway of the two-mile oval. It covers ten acres and has a maximum width and length of 600 feet each.

The skid pad contains permanently marked circles of 100- and 110-foot radii which were used for the returnability, lateral acceleration, and breakaway control tests (see Figure 5). The initiation point for the steady state and transient yaw tests was marked with traffic cones. The slalom course was laid out on the entrance region to the skid pad, parallel to the south straightaway of the oval track. The course was marked with traffic cones positioned in line every 100 feet as shown in Figure 6.

Skid numbers are monitored periodically by a skid trailer which meets the ASTM-274 requirements. The skid numbers obtained at the time of the handling tests were:

- Skid pad, dry = 74.0
- Skid pad, wet = 51.7
- Skid pad entrance region = 77.0



1. ENGINEERING/ADMINISTRATION CENTER
2. MECHANICAL/INSTRUMENTATION SHOPS
3. DUMMY CALIBRATION LABORATORY
4. GARAGE/MAINTENANCE SHOP
5. ENVIRONMENTAL CHAMBER
6. STATIC CRUSH FACILITY
7. TWO-MILE OVAL
8. TURNAROUND (TYPICAL OF TWO)
9. BARRIER IMPACT FACILITY
10. DROP TOWER/SLED TEST FACILITY
11. CENTRAL DATA ACQUISITION AND CONTROL STATION
12. PENDULUM FACILITY
13. NONMETALLICS LABORATORY
14. TEST SERVICE FACILITY
15. VEHICLE-TO-VEHICLE TEST FACILITY
16. ROLLOVER TEST FACILITY
17. RIDE QUALITY COURSE
18. SKID PAD
19. HIGH AND LOW SKID NUMBER BRAKING LANES
20. SALT WATER TROUGH
21. BELGIAN BLOCK
22. PARKING BRAKE TEST RAMP
23. PULL-OFF AREA (TYPICAL OF THIRTEEN)
24. BALLISTIC TEST RANGE

Figure 4. Dynamic Science, Inc. Deer Valley Facility.

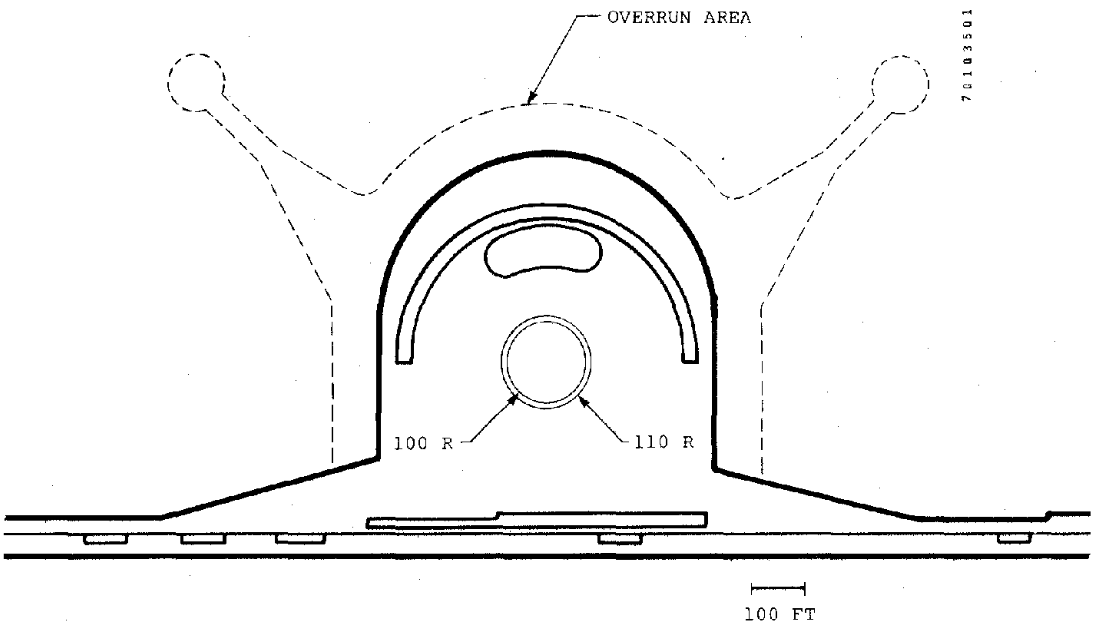


Figure 5. Skid Pad.

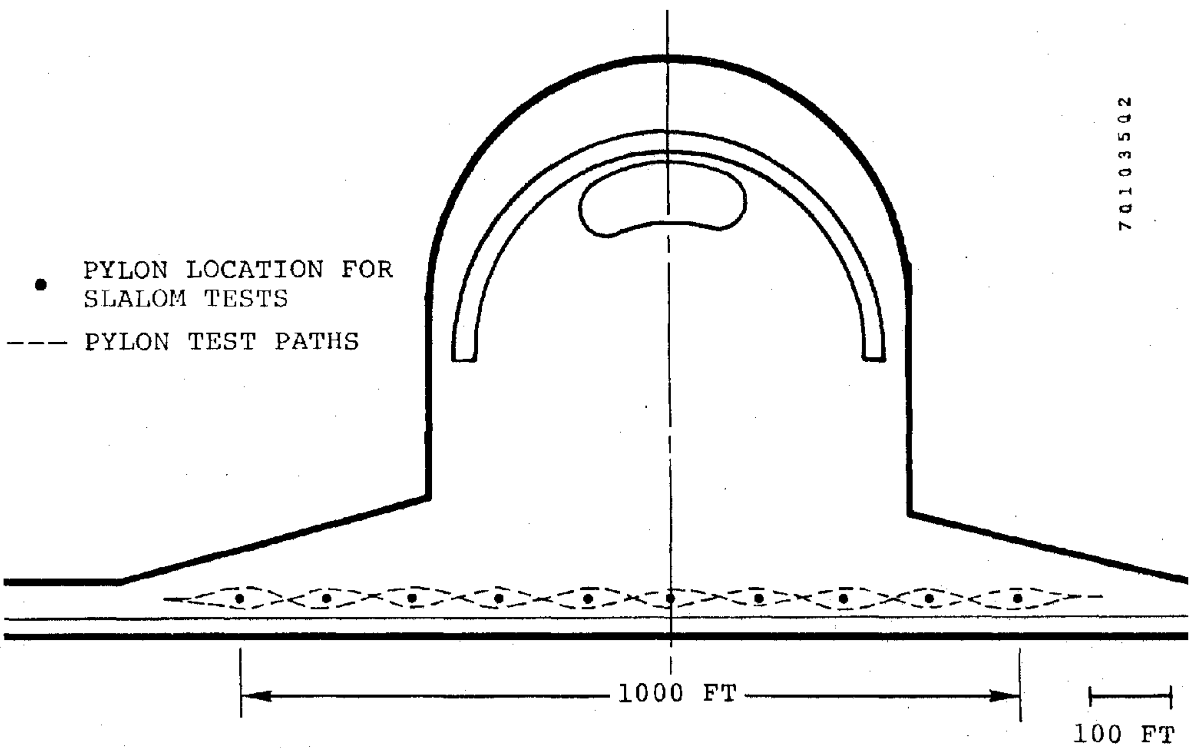


Figure 6. Slalom Course.

5.0 TEST PROCEDURES

5.1 TEST INSTRUMENTATION

5.1.1 <u>Required Measurements</u>

The primary variables measured during the testing were:

1. Velocity
2. Lateral acceleration
3. Yaw rate
4. Front wheel angle
5. Heading angle
6. Steering wheel angle
7. Triaxial dummy chest acceleration (wheelchair position).

Vehicle variables measured during each test series are listed in Table 3. Dummy chest accelerations were obtained for all of the tests.

5.1.2 <u>Instrumentation Specifications</u>

Table 4 presents the instrumentation specifications for the handling tests.

A Labeco fifth wheel was used to measure vehicle velocity. The output of the fifth wheel was inputted into a Weston 901 speedometer for visual display of velocity. A Meter Master mill meter, paralleled with the Weston 901, allowed expansion of the desired velocity scale for more accurate speed control.

TABLE 3. VEHICLE MEASUREMENTS FOR EACH TEST SERIES

Test Type	Variables Measured
Steady State Yaw	Front wheel angle, yaw rate, and velocity
Transient Yaw	Front wheel angle, yaw rate, velocity, and steering wheel angle
Returnability	Heading angle, yaw rate, and velocity
Maximum Lateral Acceleration	Lateral acceleration and velocity
Breakaway Control	Time, velocity, and lateral acceleration
Slalom Course	Time, velocity, and lateral acceleration

Vehicle dynamics were measured by gyros and accelerometers. These instruments were part of a self-contained Humphrey gyro package. The steering input was measured at the steering wheel and at one of the front wheels.

One Alderson VIP-50 anthropomorphic dummy was instrumented with three orthogonal accelerometers mounted in its chest cavity to measure dummy referenced vertical, lateral, and longitudinal accelerations.

An event marker triggered by the driver upon starting and completing a test provided an impulse signal on the recording system. The time to transverse the course or return to the original course during the slalom and breakaway control tests was measured with a stopwatch.

TABLE 4. HANDLING TEST INSTRUMENTATION LIST

Measurand	Type Transducer	Manufacturer and Model	Full-Scale Range	Full-Scale Transducer Accuracy	Qty	Remarks
Vehicle Velocity	Fifth Wheel	Labeco TT481 with Weston 901 readout	100 mph	0.5%	1	
Longitudinal* Acceleration	Force Balance Accelerometer	Kistler 3036	±1.0G	±0.01G	1	
Lateral* Acceleration	Force Balance Accelerometer	Kistler 3036	±1.0G	±0.01G	1	
Vehicle Yaw* Rate	Rate Gyro	Humphrey RG51-0343	±40°/sec	±0.5°/sec	1	
Vehicle* Heading Angle	Position Gyro	Humphrey 18-0902-1	±178°	±0.2°	1	
Roll Angle*	Position Gyro	Humphrey 18-0902-1	±45°	±0.5°	1	
Steering Wheel Angle	Linear Poten-tiometer	Celesco PT-101-30C	30 in.	±0.05 in.	1	
Front Wheel Angle	Linear Poten-tiometer	Celesco PT-101-15C	15 in.	±0.05 in.	1	
Dummy Acceleration	Strain Gauge Accelerometer	Bell and Howell 4-203-0107	5G	0.75%	3	1 dummy
Elapsed Time	Stopwatch	Breitling	N/A	0.05 sec	1	
Time Marker	Switch	N/A	N/A	N/A	1	

*Part of Humphrey gyro package Model CF18-0900 series.

5.1.3 Data Acquisition System

The data acquisition system for the handling tests is shown schematically in Figure 7. The signal conditioning equipment was mounted on board the vehicle in a location which did not interfere with the testing procedures. All data were transmitted to the Central Data Acquisition Control Station (CDACS) via a telemetry system. At the CDACS, the data were recorded on a tape recorder for a permanent record of the test as well as for access at a future date. The data were also discriminated and displayed on a recording oscillograph for the purpose of obtaining quick-look evaluation data. These quick-look data provided a check as to whether test conditions had been achieved and also provided a view of the critical test parameters to ensure that good data were obtained during each test run.

5.1.4 Calibration Procedures

Pre- and post-test electrical calibrations of the instrumentation/data acquisition system were obtained for each set of test runs. In addition, the following physical tests were performed on a daily basis to check the calibration of the instruments:

- The fifth wheel was spun up using the calibration motor. Tire pressure was adjusted to yield the desired calibration value.
- Velocity, lateral acceleration and yaw rate were correlated with each other by driving the vehicle around a 100-foot radius circle at constant speed. The correlation equations are:

$$A_y = V^2/R$$

$$W = \frac{A_y}{V} K$$

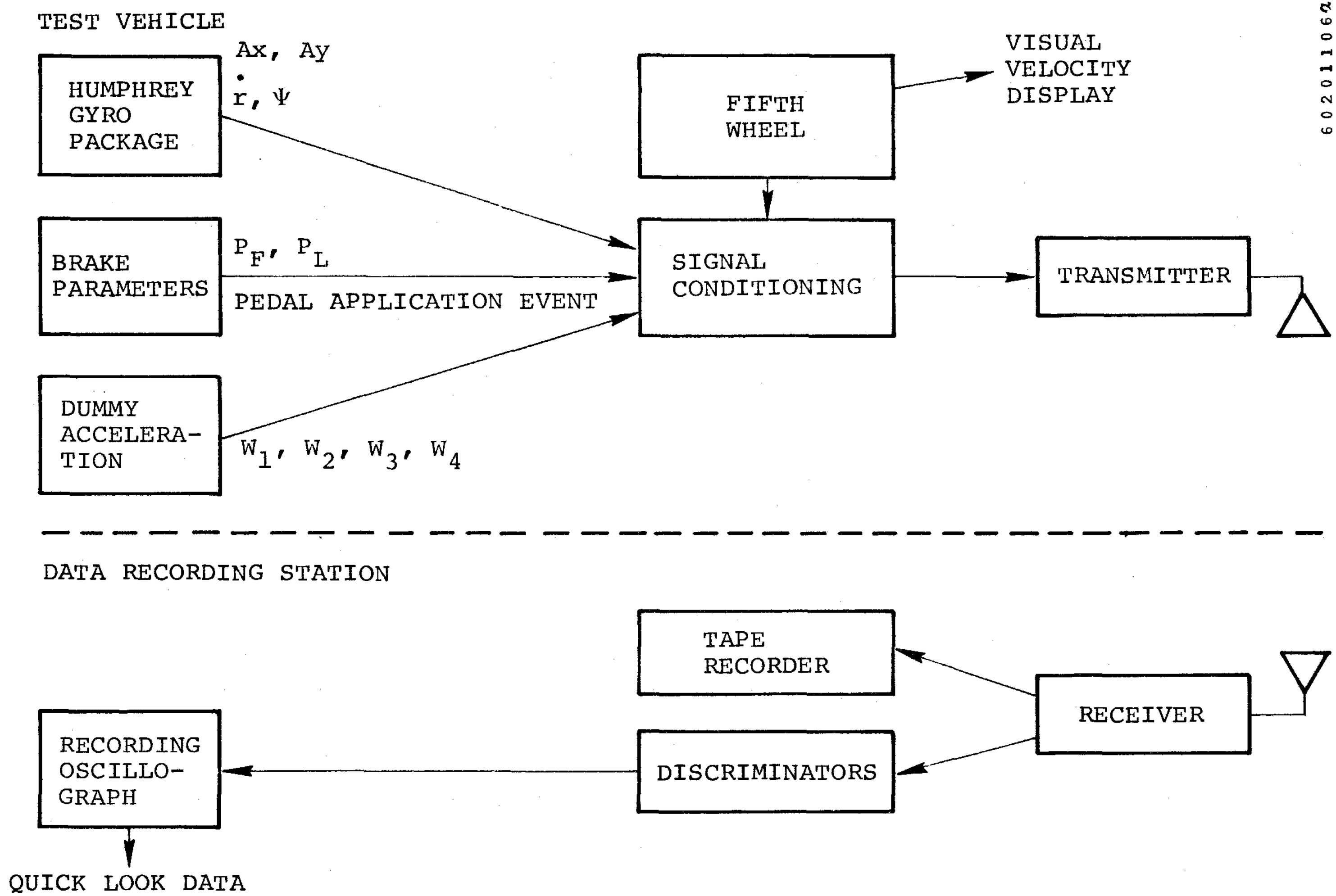


Figure 7. Data Acquisition System Schematic.

602011062

where A_Y = lateral acceleration, G

V = vehicle velocity, ft/sec

R = radius of circle = 100 feet

W = yaw rate, deg/sec

K = constant = 857.66

- Yaw Rate and heading were also correlated with each other by driving the vehicle around a 100-foot radius circle at constant speed. The correlation equation is:

$$W = \text{change in heading/change in time}$$

- The steering wheel and front wheel potentiometers were also calibrated while driving around the 100-foot radius circle and comparing the electrical outputs with those obtained from known steering and front wheel turn angles determined before testing.

5.1.5 Data Reduction

The vehicle data from the steady state yaw, transient yaw, and returnability tests were digitized and processed by the Dynamic Science handling program (AVOID) for further data analysis. The largest frequency of interest for the analysis is around 5 Hz, thus the data were presample filtered to 5 Hz to eliminate any unwanted noise. The sample rate of the digitizing was 20 samples/second per data channel.

The remaining data for the handling test series were reduced directly from the oscillograph traces.

5.2 VEHICLE PREPARATION

The vehicles were prepared for the handling tests by installing the instrumentation listed in Section 5.1.2 and by ballasting to the prescribed loading conditions.

5.2.1 Instrumentation/Equipment Installation

The Labeco fifth wheel was mounted to the rear bumper of the vehicle as shown in Figure 8. The visual displays from the fifth wheel were mounted for easy viewing by the driver as illustrated in Figure 9.

The Humphrey gyro package was mounted near the vehicle's center of gravity and the exact locations of the gyros with respect to the vehicle were measured and recorded. Figure 10 shows the Humphrey package, power supply and signal conditioning equipment mounted in the ASL prototype. The control box for the gyro package was installed near the driver as shown in Figure 11.

The linear potentiometers used to measure steering wheel angle and front wheel angle were attached to the steering shaft and front wheel as illustrated in Figures 12 and 13, respectively.

An automatic steering machine was used to provide the prescribed steering input during the steady state and transient yaw tests. A typical steering machine installation is shown in Figure 14.

5.2.2 Vehicle Loading

Two vehicle loading conditions were used during the handling tests - 300 pounds and 650 pounds.

The 300-pound load included the driver and all instrumentation. The 650-pound load included driver, instrumentation, instrumented dummy in wheelchair, and ballast as necessary.

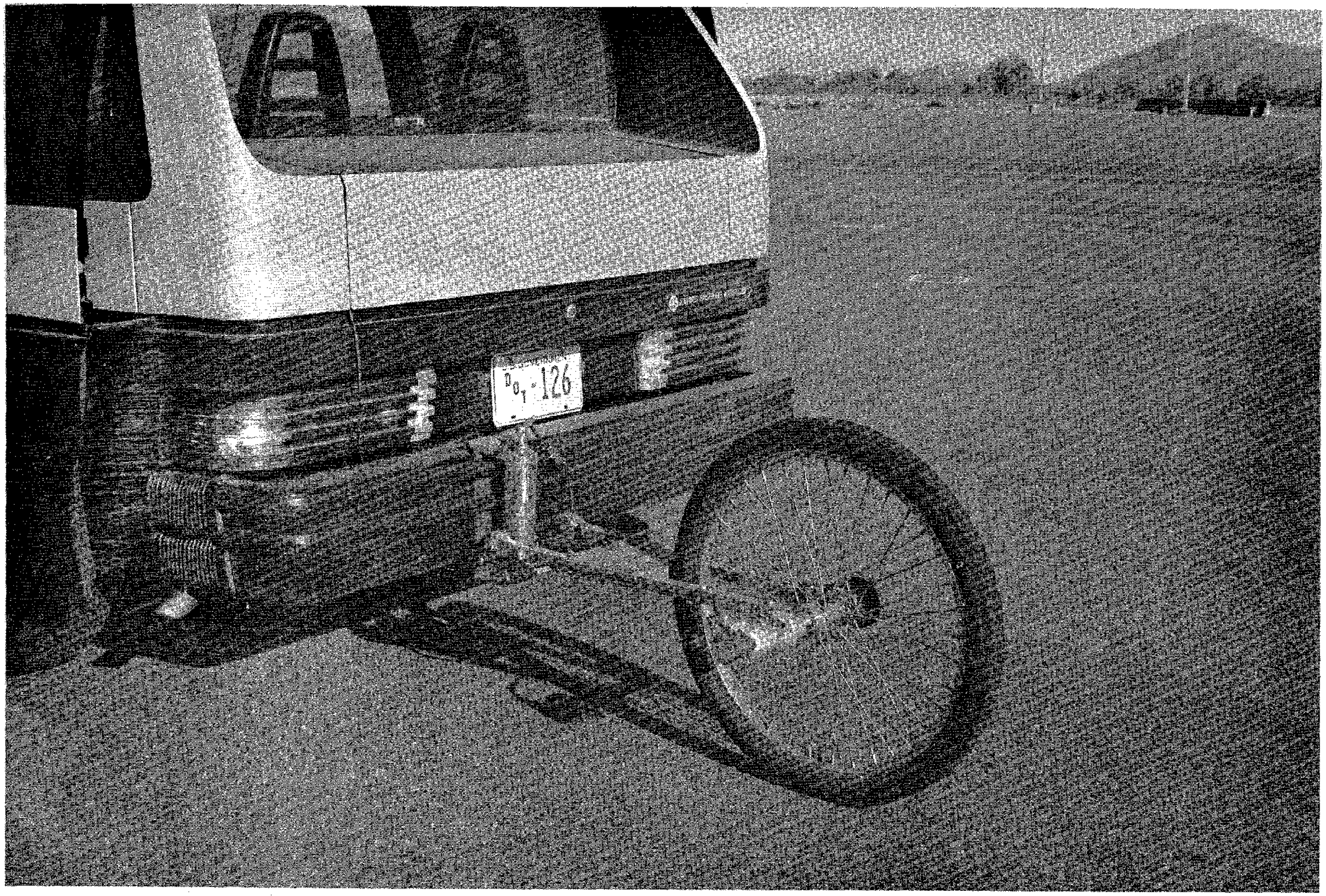


Figure 8. Typical Fifth Wheel Installation.

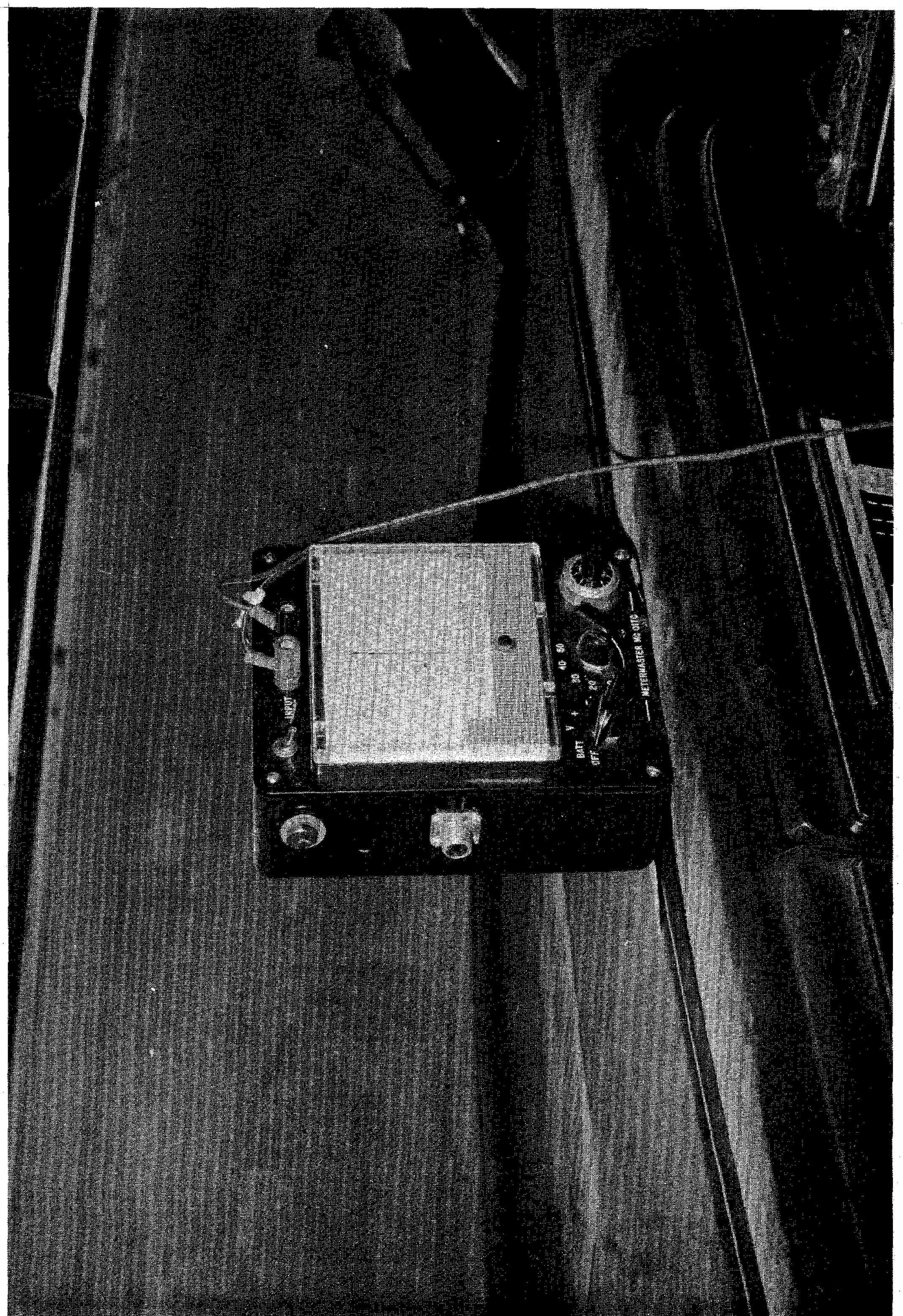


Figure 9. Visual Displays From Fifth Wheel Mounted in ASL Prototype.

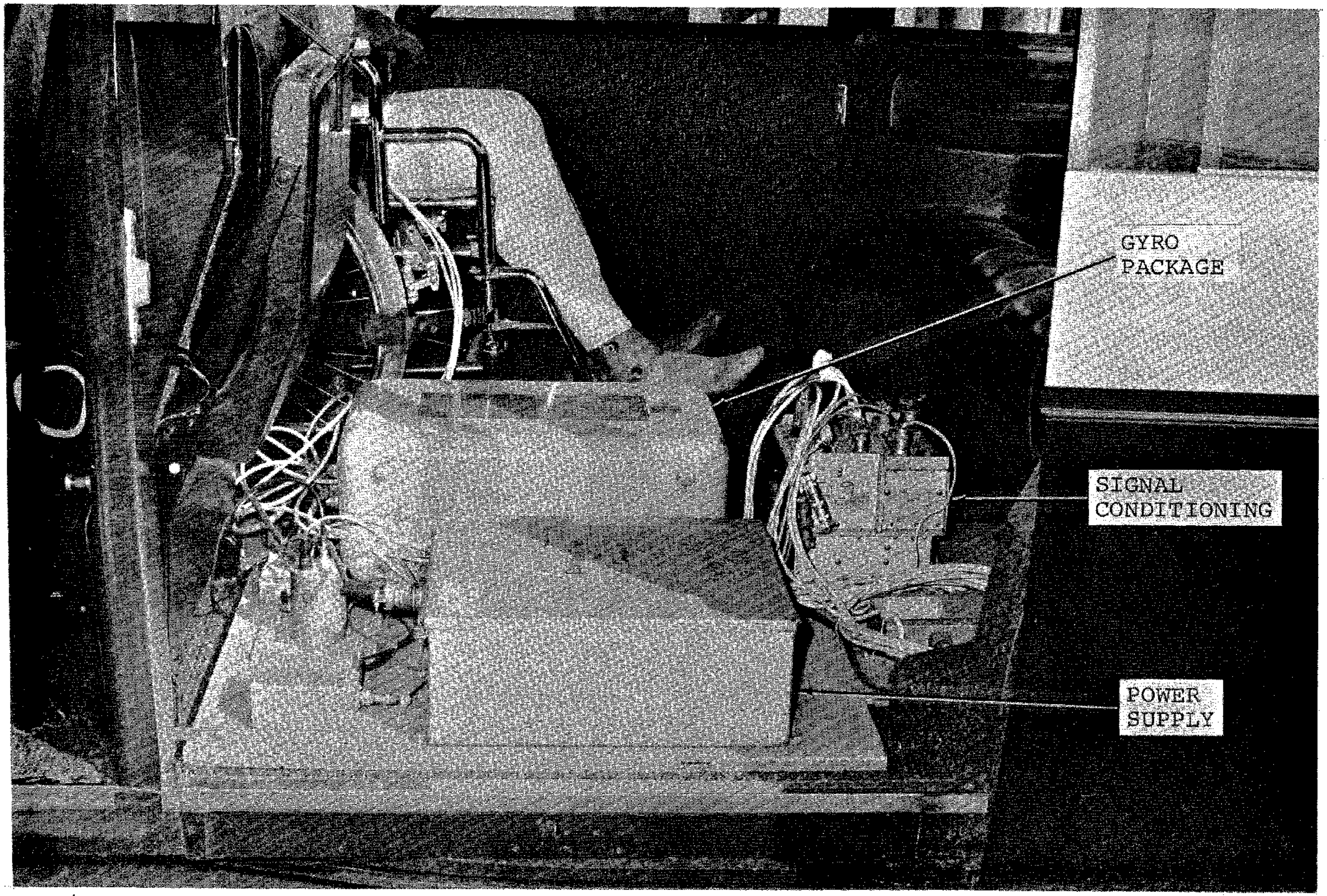


Figure 10. Gyro Package and Signal Conditioning Equipment Mounted in ASL Prototype.

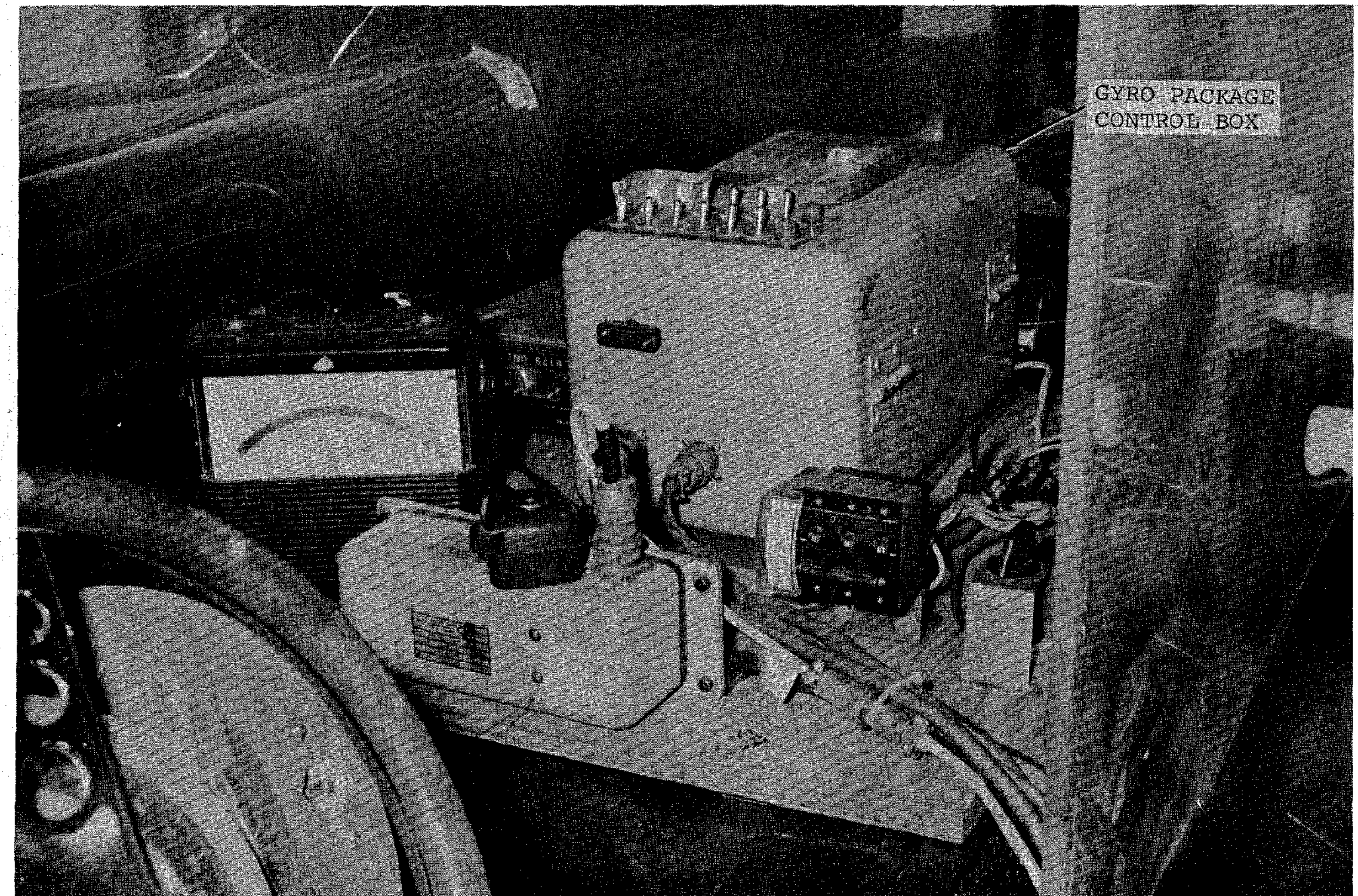


Figure 11. Control Box for Gyro Package Installed in ASL Prototype.

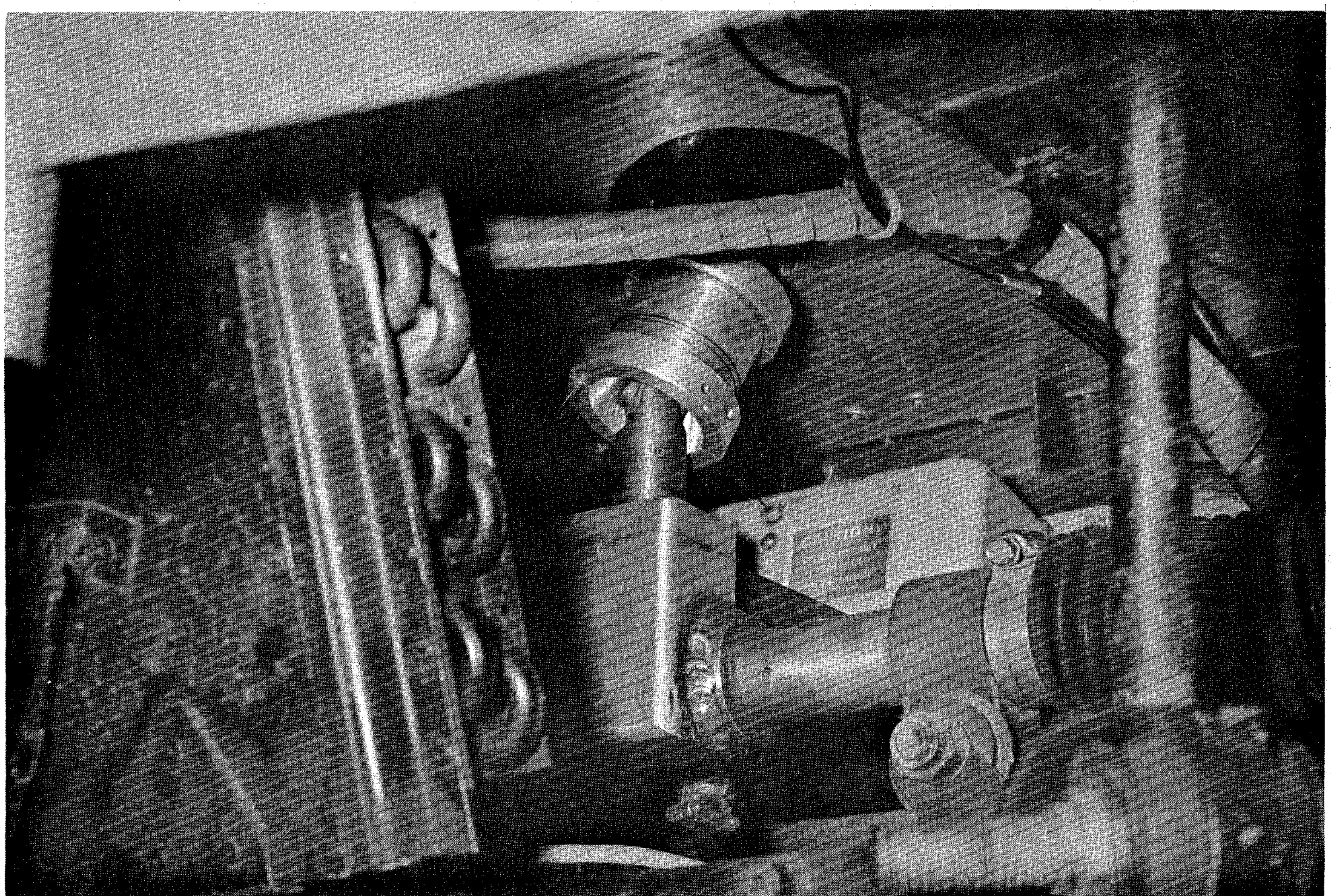


Figure 12. Steering Wheel Potentiometer Installed in Dutcher Prototype.

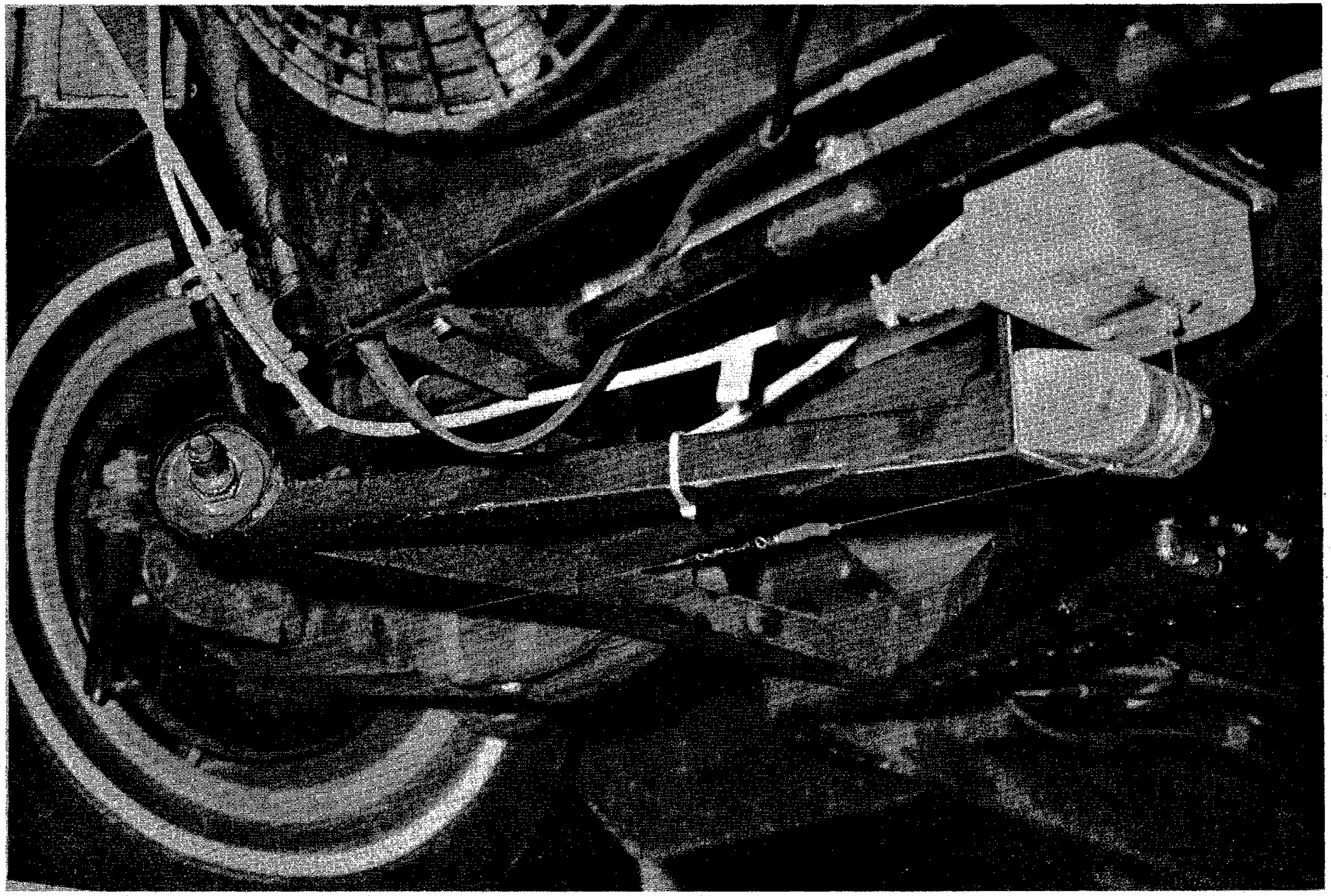


Figure 13. Front Wheel Potentiometer Installed in Dutcher Prototype.

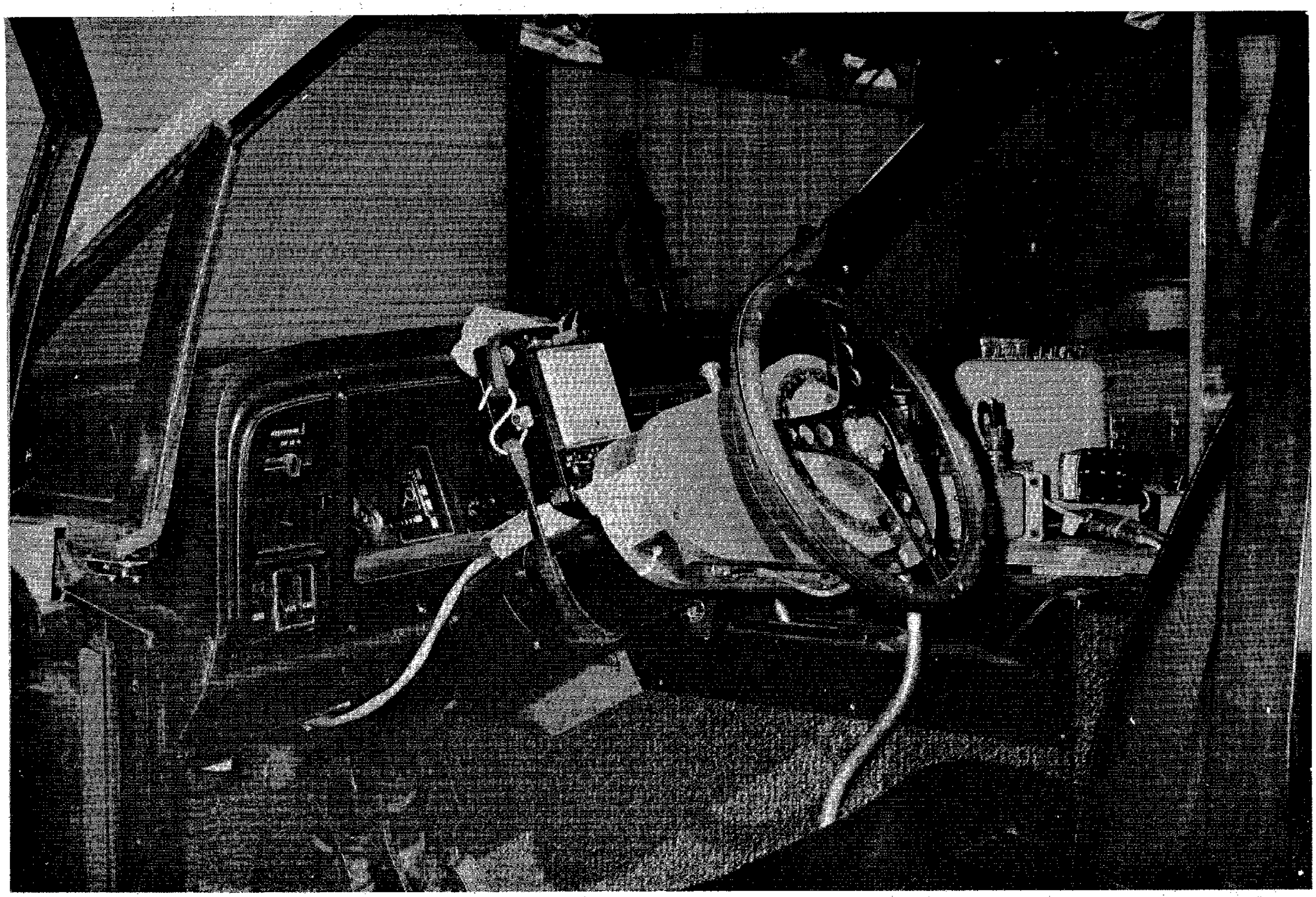


Figure 14. Typical Steering Machine Installation.

The Dutcher prototype was tested in the heavily loaded condition only due to a tendency of the vehicle to lift the inside front wheel during turning maneuvers at lightly loaded conditions. The manufacturer adjusted the vehicle suspension and added ballast to the front of the vehicle in addition to the weight of the dummy and wheelchair to keep the wheel from lifting.

The vehicle test weights are listed in Table 5.

TABLE 5. VEHICLE TEST WEIGHTS FOR HANDLING TEST SERIES

Specified Test Load (lb)	Vehicle Test Weight (lb)		
	Nova (Baseline)	ASL Prototype	Dutcher* Prototype
300	3,756	3,830	-
650	4,090	4,154	3,639

*Tested at 650-pound load only.

5.3 TEST CONDUCT

5.3.1 General Test Procedures

The handling test schedule is given in Table 6. The tests were run alternately in each direction for each test type and condition.

A test was repeated if the test conditions were not met or maintained sufficiently for a valid test. The specification on test speed was ±2 mph on initial velocity and ±4 mph during the test. The specification on lateral acceleration during the yaw tests was ±0.04G.

Testing was suspended if the steady wind speed exceeded 10 mph or if gusts exceeded 15 mph.

TABLE 6. HANDLING TEST SCHEDULE (FOR EACH VEHICLE)

	Light Weight		Loaded Weight	
	Clockwise	Counter-clockwise	Clockwise	Counter-clockwise
Steady State Yaw, .4G				
25 mph	3	3	3	3
40 mph	3	3	3	3
55 mph	3	3	3	3
Transient Yaw, .4G				
25 mph	5	5	5	5
50 mph	5	5	5	5
Returnability				
25 mph	3	3	3	3
Maximum Lateral Acceleration				
Dry Surface	5	5	5	5
Wet Surface	5	5	5	5
Breakaway Control	6	6	6	6
Slalom Course				
25 mph	3	3	3	3
40 mph	3	3	3	3
Maximum velocity not to exceed 55 mph	3	3	3	3

5.3.2 Steady State and Transient Yaw Tests

The steering machine installed in the vehicle was set prior to the test run for the steering wheel angle that would yield a 0.4G turn at the designated test speed. The driver approached the skid pad at the prescribed test speed. At the test initiation point, he engaged the steering machine while holding the throttle in the same position. After five seconds, the steering machine was disengaged and the vehicle manually controlled to remain on the paved surface of the skid pad while it was brought to a stop. Figure 15 shows the ASL prototype beginning a yaw test.

5.3.3 Returnability Tests

The vehicle was driven around the 100-foot radius circle on the skid pad at 25 mph. The driver monitored the vehicle speed until it was stabilized while maintaining the course. The steering wheel was then released while the vehicle's speed was maintained. After five seconds, the vehicle was brought under manual control to remain on the paved surface and brought to a complete stop.

5.3.4 Maximum Lateral Acceleration Tests

The vehicle was driven around the 100-foot radius circle at an initial speed of 25 mph. The speed was slowly increased until the maximum speed at which the course could be maintained was reached. Data recording then began and continued while the vehicle completed one circle on course, maintaining maximum speed. The test was then terminated and the vehicle brought to a stop. Figure 16 shows the ASL prototype during a maximum lateral acceleration test.

5.3.5 Breakaway Control Tests

The vehicle was driven around the 100-foot radius circle at an initial speed of 25 mph. The speed was slowly increased until the maximum speed at which the course could be maintained was reached. Data recording then began. The vehicle velocity was increased until the 110-foot circle was reached. When any part

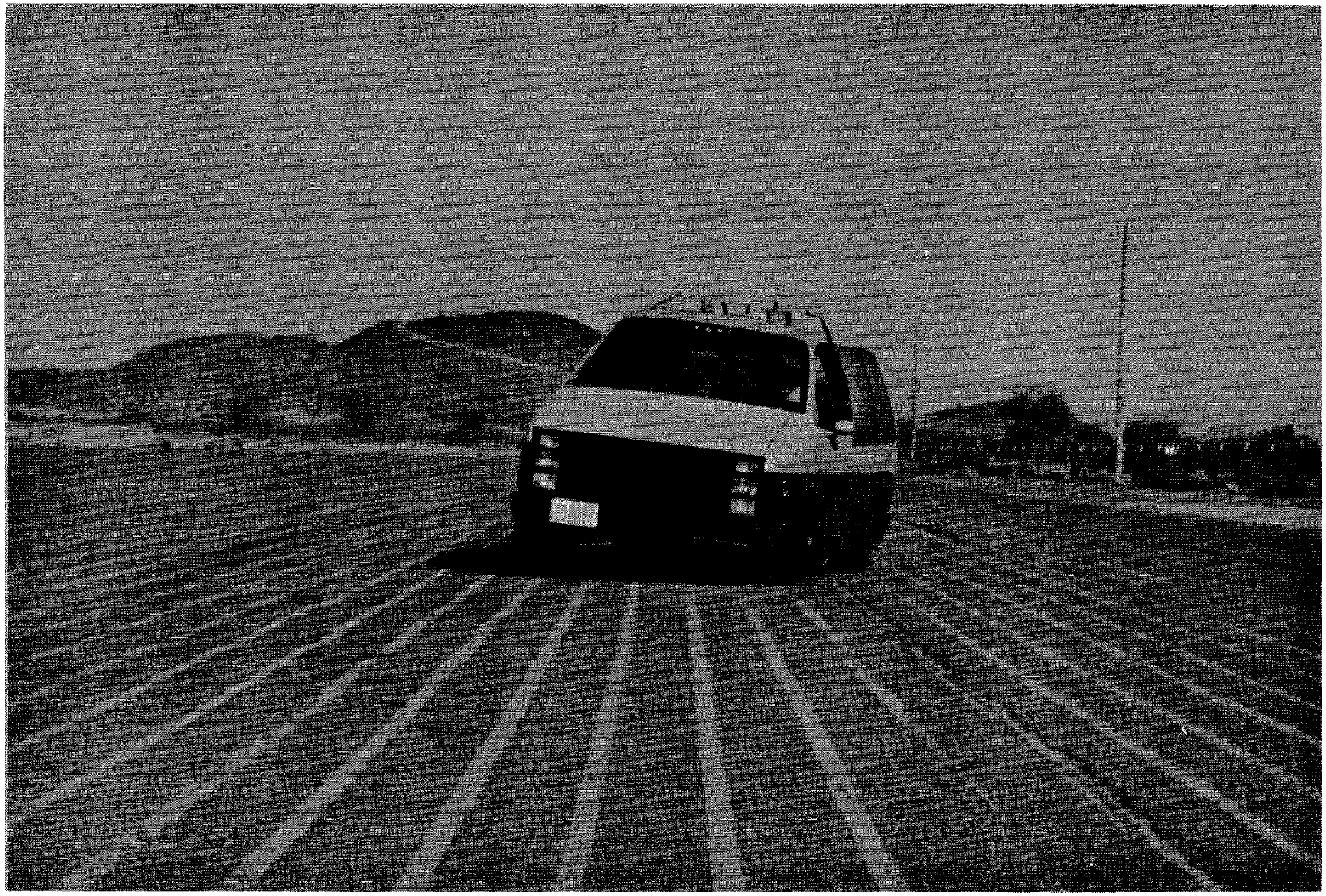


Figure 15. ASL Prototype Beginning a Yaw Test.

Figure 16. ASL Prototype During Maximum Lateral Acceleration Test.

of the vehicle became tangent to the 110-foot circle, the driver engaged the event switch, started the stopwatch, released the throttle, and steered the vehicle to regain course on the 100-foot circle as quickly as possible without braking or applying power. Upon returning to the original course, ±2 feet, the event switch was disengaged and the stopwatch stopped, terminating the test.

5.3.6 Slalom Tests

The driver approached the slalom course at the prescribed test speed. At the test initiation point, the driver engaged the event switch and a ground-based observer started timing. The vehicle was driven through the course, passing the cones alternately on the right and left, while maintaining the designated test speed. Upon passing the final cone, the event switch was disengaged and timing stopped. The tests were run with alternating initial right and left turn directions.

5.4 PROBLEMS ENCOUNTERED DURING TESTING

The tendency of the Dutcher prototype to lift the inside front wheel during turning maneuvers was reduced by ballasting the vehicle and testing only at the 650-pound load condition (refer to Section 5.2.2). The ballasting did not completely eliminate the problem, however, especially when approaching limit conditions. Thus, the maximum speeds attained during the breakaway control and lateral acceleration tests were limited to prevent wheel lift-off from occurring.

The ASL prototype encountered several minor problems during the handling tests. One of these involved the steering linkage spacer. The spacer had become loose during the previous noise test series, causing the vehicle to lose the proper front wheel alignment. The spacer was tightened and the vehicle realigned before the handling tests were started. No further problems were encountered with the spacer.

Problems with the ASL fuel system vapor-locking, causing hard starts, had also been noticed during the noise tests. The vehicle was taken to an Audi dealer for fuel system repairs/ adjustments before the handling tests started. Although the fuel system performed satisfactorily after this, in regard to the vapor-locking and hard starting, fuel starvation and engine stall were encountered during left turns with a lateral acceleration of 0.25G or more. Personnel from ASL Engineering reoriented the fuel pump accumulator system which eliminated this particular problem. However, minor problems were still periodically encountered with the fuel system during the testing. The fuel pump appeared to be generating air bubbles in the fuel line. Shaking the pump relieved this situation.

6.0 TEST RESULTS

6.1 STEADY STATE YAW TESTS

The results of the steady state yaw tests are summarized for each of the vehicles in Tables 7 through 9. The steering gain values were computed from the following equation:

$$\text{Steering Gain (ft/sec)} = \frac{\text{Yaw Rate x Wheelbase (deg/sec x ft)}}{\text{Front Wheel Angle (deg)}}$$

The tolerance interval is defined as that interval within which 90 percent of the samples will fall with a 90 percent confidence level.

The steering gains for each vehicle are plotted and compared with the PTV specification in Figures 17 through 21. As may be seen from these figures, all three vehicles were within the specification limits for all the test conditions.

Turn direction and load condition did not significantly affect the steering gain of either the Nova or ASL vehicles; nor was there any significant difference between the steering gains of the two vehicles.

The Dutcher prototype, however, exhibited significant differences in the steering gain compared to the other two vehicles.

It also showed significant differences during the clockwise and counterclockwise tests at 40 mph. Part of the difference between the data from the two different turn directions might be due to the ballasting that was necessary to keep the right wheel from lifting off. This ballast was placed on the right side of the vehicle in the luggage area, and could thus affect the vehicle behavior differently during right and left turns. There is no ready explanation of why this effect did not also show up during the higher speed tests at 55 mph.

TABLE 7. SUMMARY OF STEADY STATE YAW TESTING FOR THE NOVA (BASELINE)

Nominal Test Velocity (mph)	Turn Direction (cw/ccw)	Average Peak Dummy Acceleration (G)		Steering Gain (ft/sec)					
				300-lb Load			650-lb Load		
		Longitudinal	Lateral	Average Value	Standard Deviation	Tolerance Interval	Average Value	Standard Deviation	Tolerance Interval
25	cw	0.04	0.52	27.797	.265	1.547	26.381	.356	2.084
25	ccw	0.07	0.45	32.057	.518	3.029	32.961	.756	4.422
40	cw	0.06	0.53	30.836	.295	1.724	28.122	.299	1.747
40	cw	0.05	0.53	32.887	1.281	7.491	31.250	.492	2.877
55	cw	0.05	0.48	29.320	3.087	18.051	28.107	.451	2.639
55	ccw	0.07	0.46	27.875	.855	5.000	27.292	.019	.305

*cw = Clockwise.
ccw = Counterclockwise.

TABLE 8. SUMMARY OF STEADY STATE YAW TESTING FOR THE ASL PROTOTYPE

Nominal Test Velocity (mph)	Turn Direction (cw/ccw)*	Average Peak Dummy Acceleration (G)		Steering Gain (ft/sec)					
				300-lb Load			650-lb Load		
		Longitudinal	Lateral	Average Value	Standard Deviation	Tolerance Interval	Average Value	Standard Deviation	Tolerance Interval
25	cw	0.00	0.51	29.421	.255	1.296	30.006	.135	.809
25	ccw	0.06	0.57	29.583	.450	2.655	27.765	.423	2.457
40	cw	0.00	0.50	35.766	2.115	12.375	35.046	.405	2.394
40	ccw	0.12	0.59	30.096	.468	2.754	28.170	.477	2.772
55	cw	0.08	0.46	27.594	3.888	22.725	32.031	1.827	10.674
55	ccw	0.13	0.63	32.643	1.458	8.505	24.813	1.053	6.156

*cw = Clockwise.
ccw = Counterclockwise.

TABLE 9. SUMMARY OF STEADY STATE YAW TESTING FOR THE DUTCHER PROTOTYPE

Nominal Test Velocity (mph)	Turn Direction (cw/ccw)*	Average Peak Dummy Acceleration (G)		Steering Gain (ft/sec) 650-lb Load		
		Longitudinal	Lateral	Average Value	Standard Deviation	Tolerance Interval
25	cw	0.03	0.43	33.554	6.230	36.427
25	ccw	0.04	0.42	33.026	6.538	38.192
40	cw	0.11	0.61	50.490	7.341	42.923
40	ccw	0.16	0.76	42.155	1.268	7.417
55	cw	0.00	0.56	68.068	6.811	39.776
55	ccw	0.17	0.47	70.198	5.993	35.024

*cw = Clockwise.
ccw = Counterclockwise.

The dummy responses for the vehicles are compared in Table 10. Although there are some variations in the data, there is no overall significant difference in the dummy accelerations in the three vehicles.

6.2 TRANSIENT YAW TESTS

The results of the transient yaw tests are summarized in Tables 11 through 15. The steering gain ratios in percentages, were computed from the following equation:

$$\text{Steering Gain Ratio (\%)} = \frac{\text{Steering Gain (transient)}}{\text{Steering Gain (steady state)}} \times 100$$

The times for which the steering gain ratios are reported are based on time zero occurring when 50 percent of the steering input has been made.

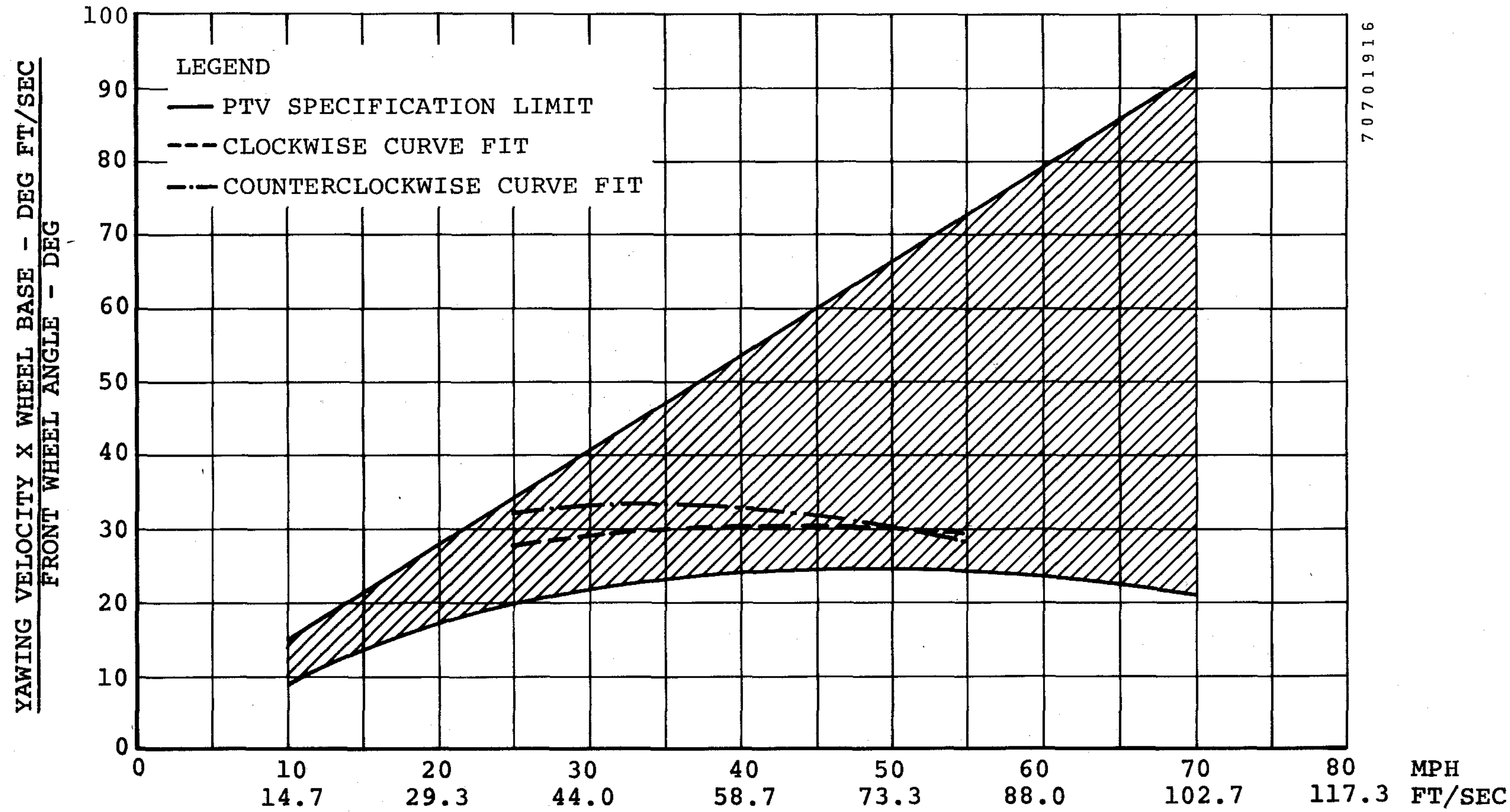


Figure 17. Steady State Yaw Response Versus Tangential Velocity for Nova (Baseline) at 300-pound Load.

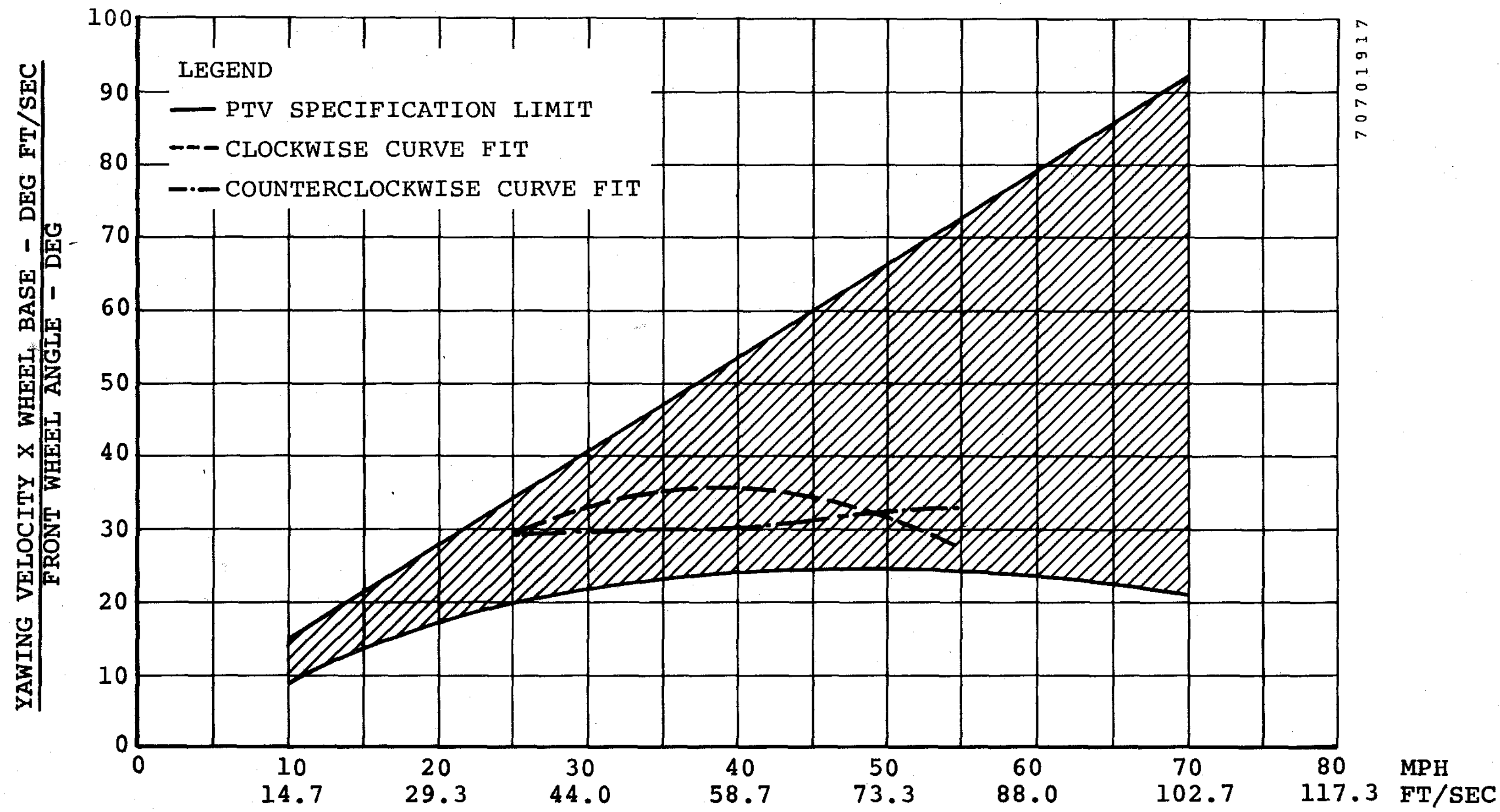


Figure 18. Steady State Yaw Response Versus Tangential Velocity for ASL Prototype at 300-pound Load.

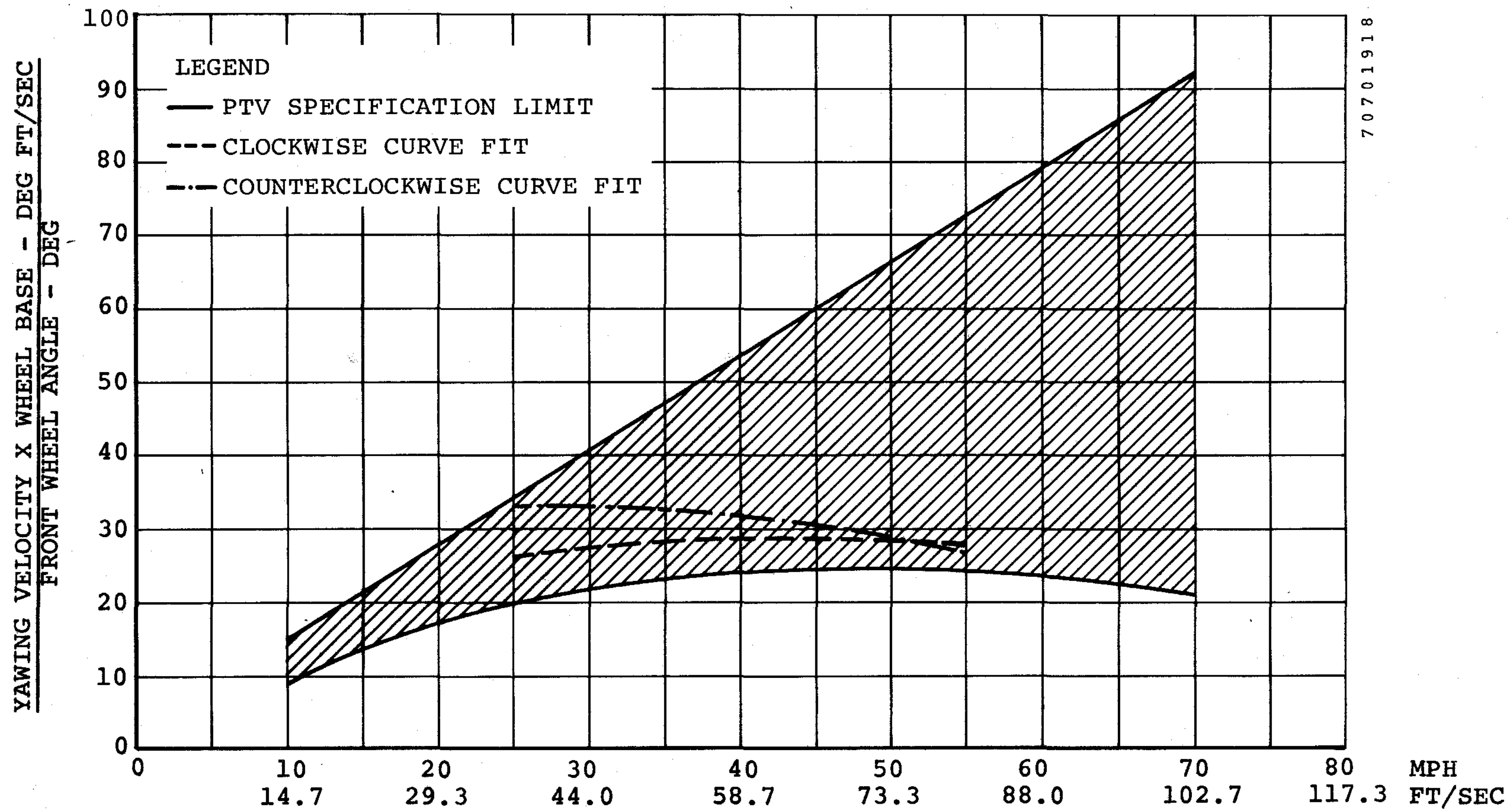


Figure 19. Steady State Yaw Response Versus Tangential Velocity for Nova (Baseline) at 650-pound Load.

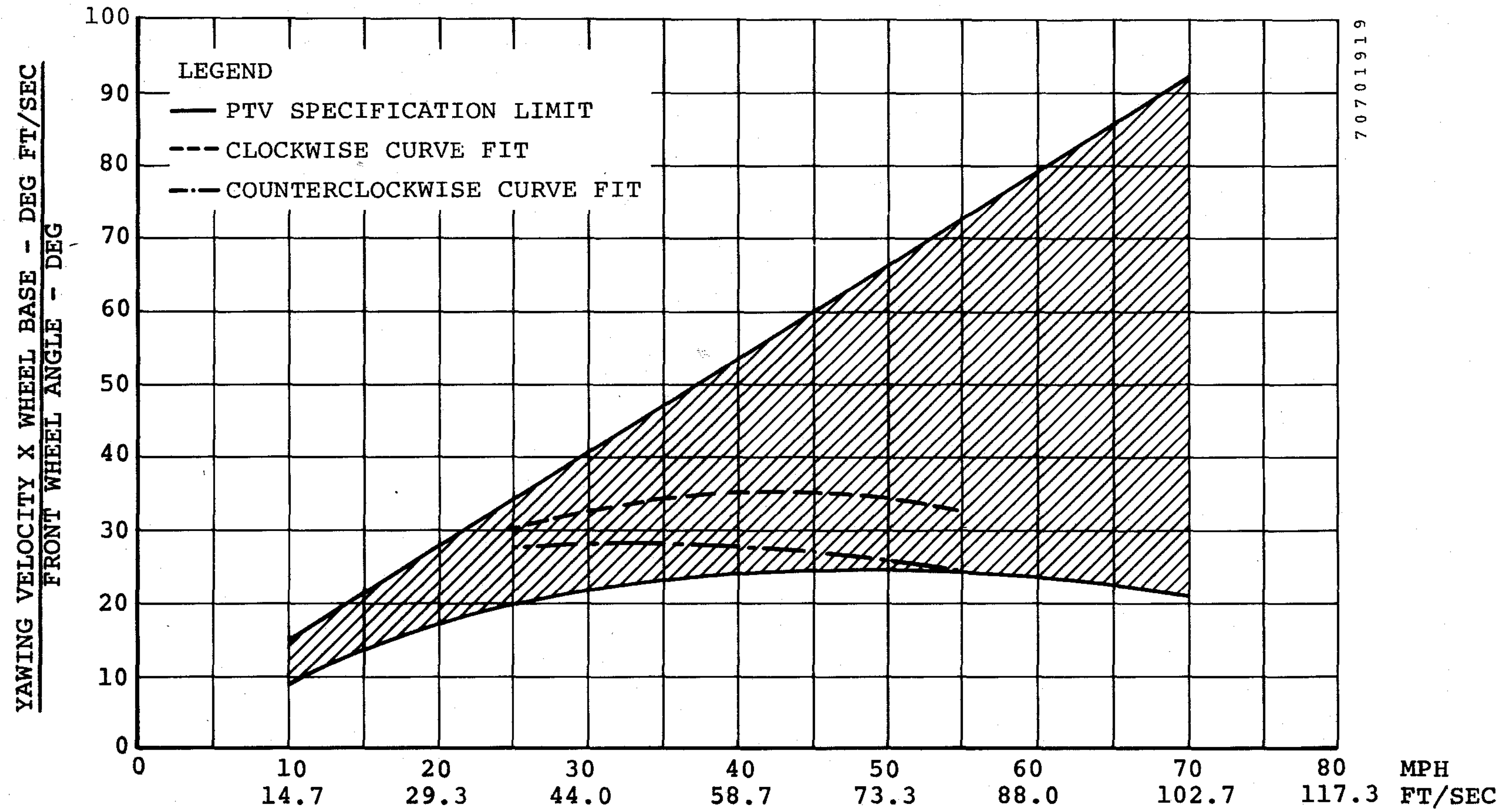


Figure 20. Steady State Yaw Response Versus Tangential Velocity for ASL Prototype at 650-pound Load.

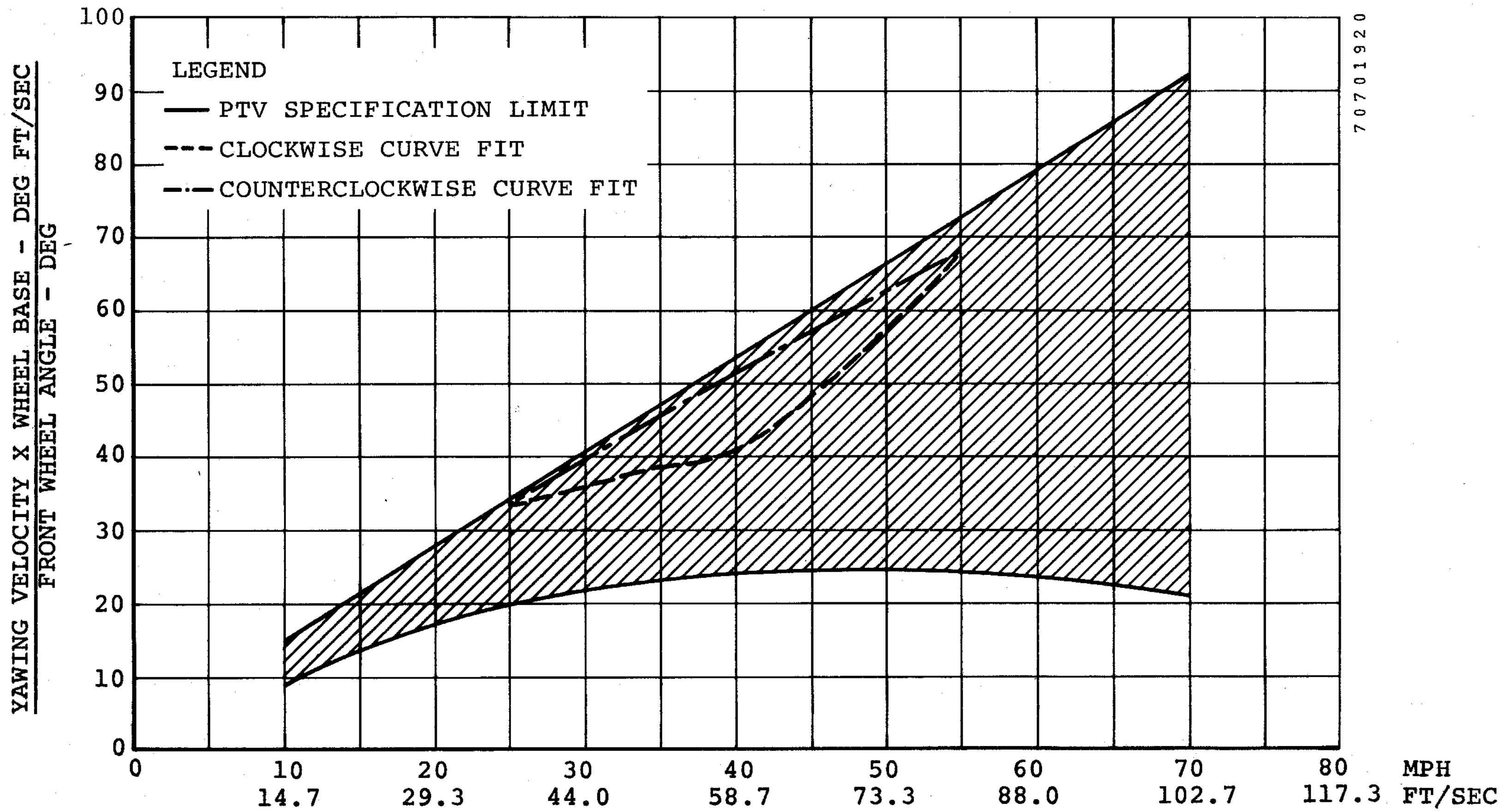


Figure 21. Steady State Yaw Response Versus Tangential Velocity for Dutcher Prototype at 650-pound Load.

TABLE 10. COMPARISON OF DUMMY RESPONSE DURING STEADY STATE TESTING

Nominal Test Velocity (mph)	Direction of Turn	Longitudinal Acceleration (G) Nova (Baseline)	Longitudinal Acceleration (G) ASL Prototype	Longitudinal Acceleration (G) Dutcher Prototype	Lateral Acceleration (G) Nova (Baseline)	Lateral Acceleration (G) ASL Prototype	Lateral Acceleration (G) Dutcher Prototype
25	cw*	0.04	0.00	0.03	0.52	0.51	0.43
25	ccw**	0.07	0.06	0.04	0.45	0.57	0.42
40	cw	0.06	0.00	0.11	0.53	0.50	0.61
40	ccw	0.05	0.12	0.16	0.53	0.59	0.76
55	cw	0.05	0.08	0.00	0.48	0.46	0.56
55	ccw	0.07	0.13	0.17	0.46	0.63	0.47

*Clockwise.
**Counterclockwise.

The steering gain ratios are plotted at 0.1 second intervals and compared with the PTV specification in Figures 22 through 31. In general, all of the vehicles were within the specification limits until the time at which the steering ratio overshoot should cease and the vehicle approaches the steady state yaw condition (1.6 seconds). All of the vehicles were close to or within the specification as they entered the steady state condition at the 25-mph speed. However, all of the vehicles oscillated in and out of the steady state range at 50-mph speeds. This oscillation was greatest for the ASL, followed by the Nova. The Dutcher prototype was nearly within the specification for return to steady state conditions.

No noticeable overshoot occurred with any of the vehicles at 25 mph. There was no significant difference in the average peak value of the overshoot between the three vehicles; however, both

TABLE 11. SUMMARY OF TRANSIENT YAW TESTING FOR THE NOVA (BASELINE) AT 300-POUND LOAD

Parameter	Value of Parameter for the Nominal Test Velocity			
	25 mph		50 mph	
	CW Direction	CCW Direction	CW Direction	CCW Direction
Steering Gain Ratio at				
0.2 Seconds				
- Average	70	65	70	78
- Standard Deviation	5.216	4.817	11.437	5.357
- Tolerance Interval	18.22	16.83	39.96	18.72
0.6 Seconds				
- Average	102	94	131	132
- Standard Deviation	1.414	1.304	9.072	7.503
- Tolerance Interval	4.941	4.556	31.697	26.217
0.8 Seconds				
- Average	105	97	122	120
- Standard Deviation	1.140	1.517	7.649	4.087
- Tolerance Interval	3.98	5.30	26.72	14.28
1.6 Seconds				
- Average	105	96	102	100
- Standard Deviation	1.304	2.302	9.555	8.204
- Tolerance Interval	4.56	8.04	3.49	28.66
Peak Overshoot				
- Average	105.8	97.4	136	139
- Standard Deviation	1.304	0.548	7.969	8.532
- Tolerance Interval	4.556	1.914	27.84	29.81
Time of Peak Overshoot of Steering Gain Ratio	0.83	0.85	.58	.48

TABLE 12. SUMMARY OF TRANSIENT YAW TESTING FOR THE NOVA (BASELINE) AT 650-POUND LOAD

Parameter	Value of Parameter for the Nominal Test Velocity			
	25 mph		50 mph	
	CW Direction	CCW Direction	CW Direction	CCW Direction
Average Peak Dummy Acceleration				
Longitudinal	0.10	0.07	0.08	0.04
Lateral	0.50	0.45	0.59	0.37
Steering Gain Ratio at				
0.2 Seconds				
- Average	72	68	92	86
- Standard Deviation	3.317	7.810	13.126	10.035
- Tolerance Interval	11.59	27.29	45.86	35.06
0.6 Seconds				
- Average	107	92	144	136
- Standard Deviation	2.683	2.191	3.808	8.289
- Tolerance Interval	9.375	7.655	13.305	28.960
0.8 Seconds				
- Average	108	97	123	114
- Standard Deviation	1.817	2.074	6.870	4.764
- Tolerance Interval	6.35	7.25	24.00	16.65
1.6 Seconds				
- Average	107	93	115	105
- Standard Deviation	1.517	2.168	8.532	7.791
- Tolerance Interval	5.30	7.57	29.81	27.22
Peak Overshoot				
- Average	109.6	97.8	147	149
- Standard Deviation	1.140	1.789	2.302	5.612
- Tolerance Interval	3.983	6.25	8.04	19.61
Time of Peak Overshoot of Steering Gain Ratio	6.90	0.66	0.51	0.44

TABLE 13. SUMMARY OF TRANSIENT YAW TESTING FOR THE ASL PROTOTYPE AT 300-POUND LOAD

Parameter	Value of Parameter for the Nominal Test Velocity			
	25 mph		50 mph	
	CW Direction	CCW Direction	CW Direction	CCW Direction
Steering Gain Ratio at				
0.2 Seconds				
- Average	70	65	75	84
- Standard Deviation	9.576	5.595	5.079	15.017
- Tolerance Interval	33.46	19.55	17.75	52.47
0.6 Seconds				
- Average	100	97	133	116
- Standard Deviation	1.140	2.000	13.027	11.261
- Tolerance Interval	3.984	6.988	45.516	39.344
0.8 Seconds				
- Average	101	98	124	105
- Standard Deviation	1.92	1.871	7.328	10.545
- Tolerance Interval	6.72	6.54	25.60	36.84
1.6 Seconds				
- Average	102	98	108	104
- Standard Deviation	1.788	1.871	4.550	4.817
- Tolerance Interval	6.25	6.54	15.90	16.83
Peak Overshoot				
- Average	102.4	98.4	141.0	124
- Standard Deviation	1.140	2.608	11.832	16.799
- Tolerance Interval	3.984	9.111	41.342	58.700
Time of Peak Overshoot of Steering Gain Ratio	0.40	0.60	0.46	0.55

TABLE 14. SUMMARY OF TRANSIENT YAW TESTING FOR THE ASL PROTOTYPE AT 650-POUND LOAD

Parameter	Value of Parameter for the Nominal Test Velocity			
	25 mph		50 mph	
	CW Direction	CCW Direction	CW Direction	CCW Direction
Average Peak Dummy Acceleration				
Longitudinal	0.00	0.07	0.01	0.11
Lateral	0.52	0.60	0.46	0.62
Steering Gain Ratio at				
0.2 Seconds				
- Average	65	65	69	97
- Standard Deviation	6.595	3.209	12.280	13.027
- Tolerance Interval	23.04	11.21	42.91	45.52
0.6 Seconds				
- Average	98	97	122	131
- Standard Deviation	3.362	2.739	7.829	11.432
- Tolerance Interval	11.745	9.569	27.356	39.945
0.8 Seconds				
- Average	99	94	119	110
- Standard Deviation	2.646	3.209	14.082	14.363
- Tolerance Interval	9.24	11.21	49.20	50.18
1.6 Seconds				
- Average	98	99	99	98
- Standard Deviation	2.449	1.517	11.149	12.071
- Tolerance Interval	8.56	5.30	38.95	42.17
Peak Overshoot				
- Average	101.0	102.0	126.2	147.0
- Standard Deviation	2.915	3.240	7.155	7.396
- Tolerance Interval	10.187	11.322	25.001	25.84
Time of Peak Overshoot of Steering Ratio	0.83	0.44	0.65	0.40

TABLE 15. SUMMARY OF TRANSIENT YAW TESTING FOR THE DUTCHER PROTOTYPE AT 650-POUND LOAD

Parameter	Value of Parameter for the Nominal Test Velocity			
	25 mph		50 mph	
	CW Direction	CCW Direction	CW Direction	CCW Direction
Average Peak Dummy Acceleration				
Longitudinal	0.03	0.05	0.04	0.14
Lateral	0.44	0.42	0.54	0.59
Steering Gain Ratio at				
0.2 Seconds				
- Average	92	88	92	87
- Standard Deviation	4.930	12.235	14.046	18.863
- Tolerance Interval	17.22	42.75	49.08	65.91
0.6 Seconds				
- Average	97	95	114	124
- Standard Deviation	3.362	4.037	14.950	15.437
- Tolerance Interval	65.441	14.106	52.235	53.937
0.8 Seconds				
- Average	102	97	95	103
- Standard Deviation	1.483	2.608	22.21	20.586
- Tolerance Interval	5.18	9.11	77.60	71.93
1.6 Seconds				
- Average	101	97	107	92
- Standard Deviation	1.673	0.837	12.570	11.000
- Tolerance Interval	5.85	2.92	43.92	38.43
Peak Overshoot				
- Average	104.2	99.8	124.8	142.6
- Standard Deviation	1.095	1.789	8.044	9.864
- Tolerance Interval	3.827	6.250	28.104	34.465
Time of Peak Overshoot of Steering Gain Ratio	0.99	0.89	0.61	0.43

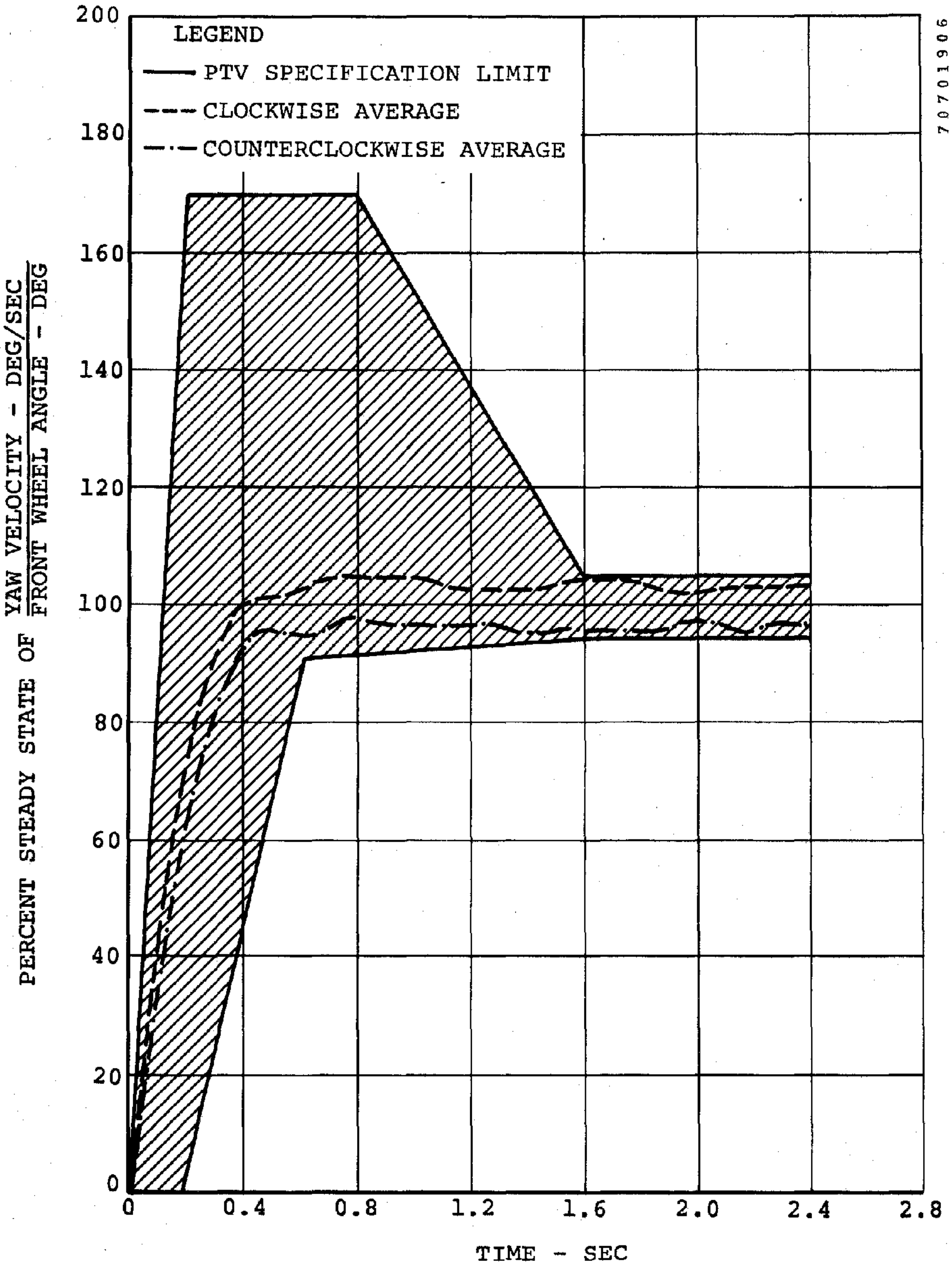


Figure 22. Transient Yaw Response Versus Time for Nova, 300-pound Load, 25 mph.

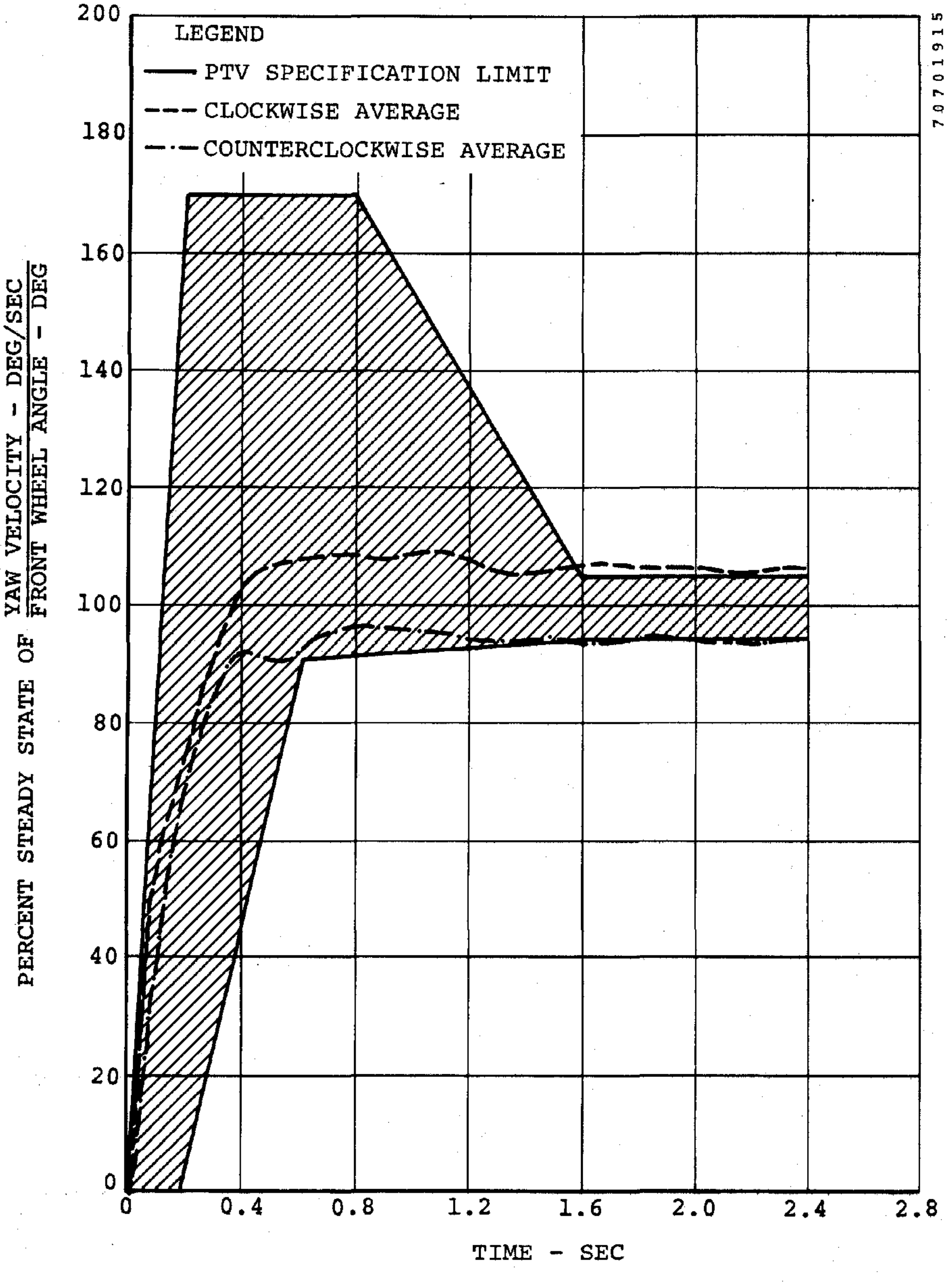


Figure 23. Transient Yaw Response Versus Time for Nova, 650-pound Load, 25 mph.

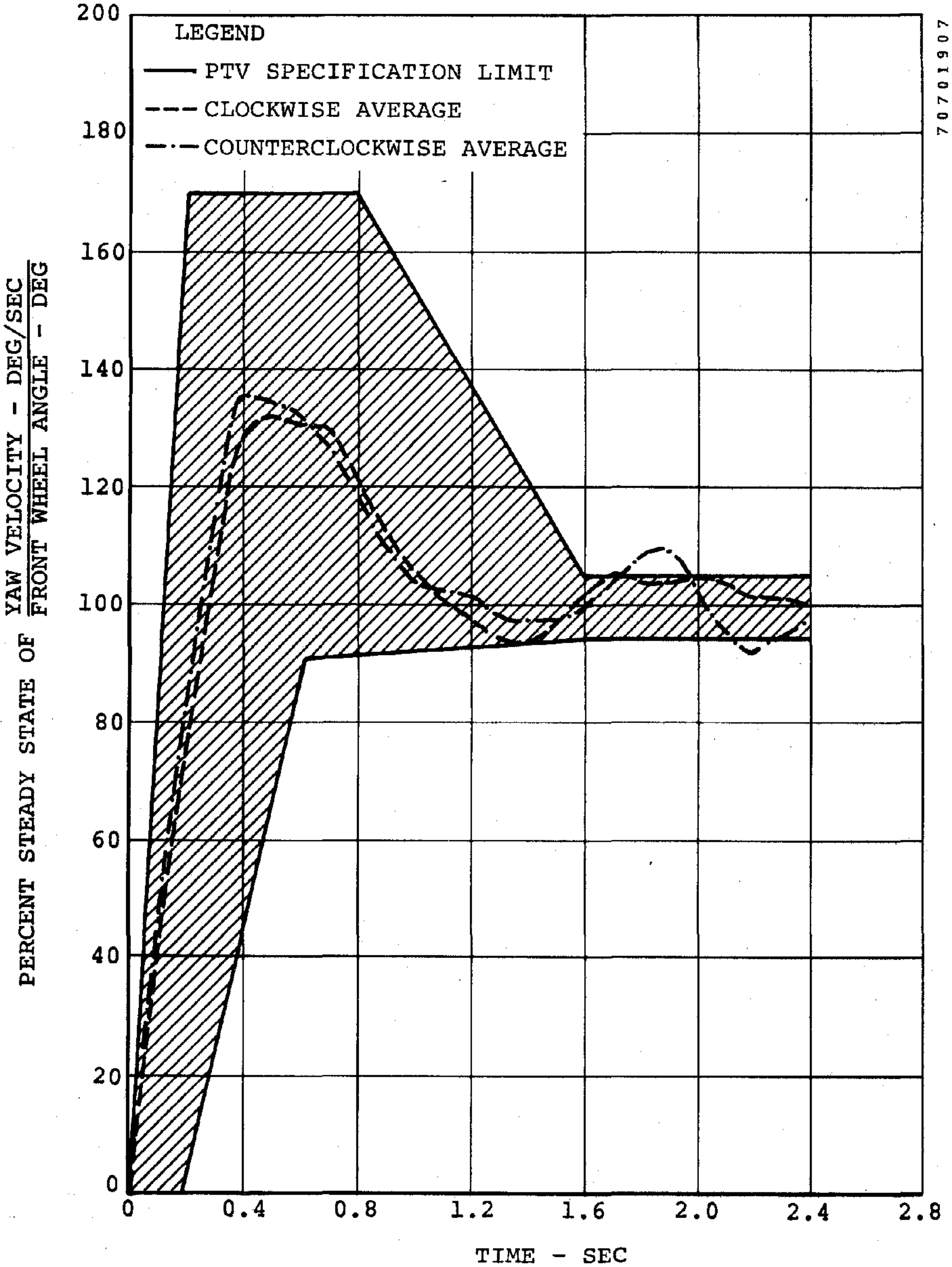


Figure 24. Transient Yaw Response Versus Time for Nova, 300-pound Load, 50 mph.

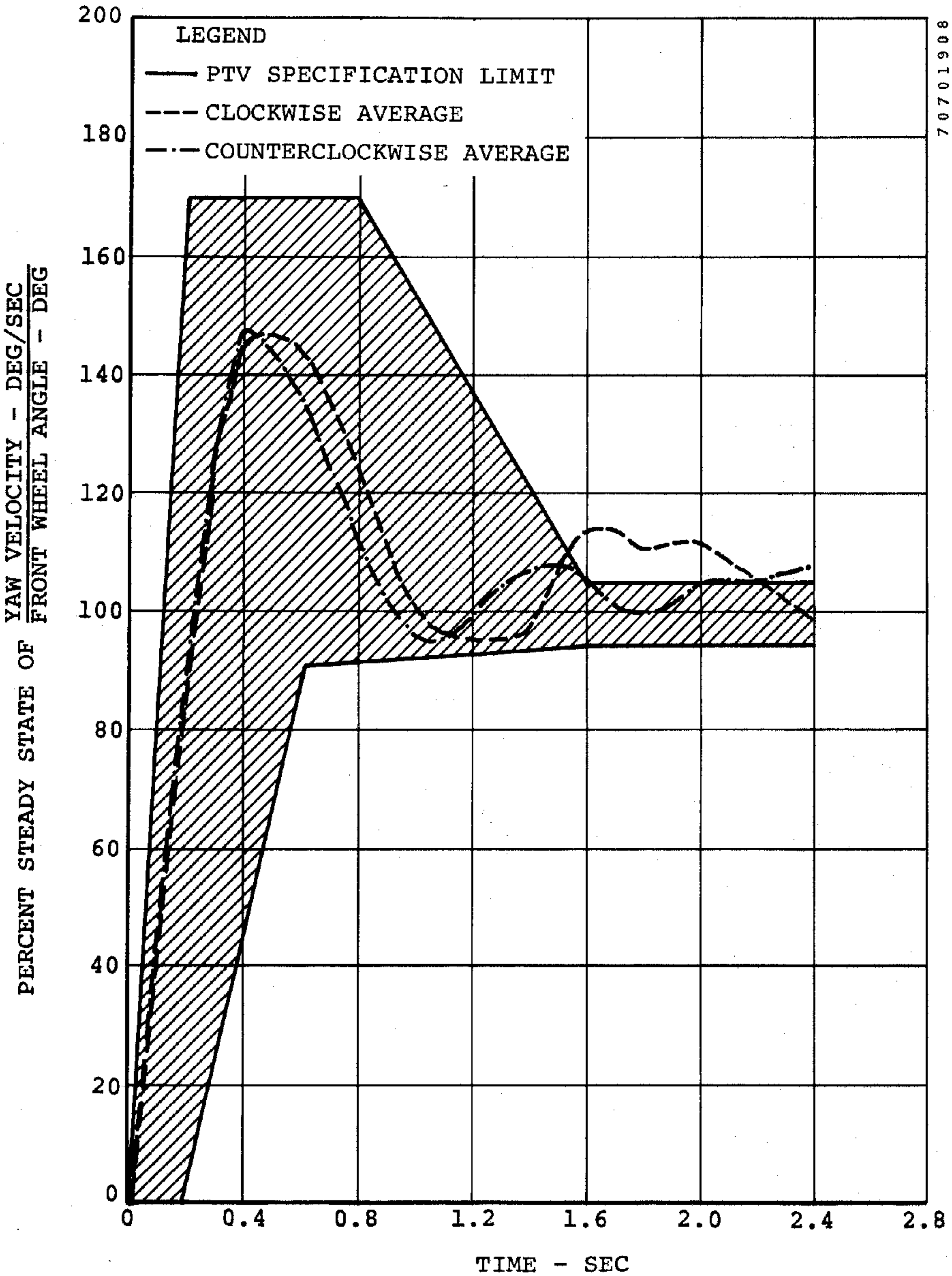


Figure 25. Transient Yaw Response Versus Time for Nova, 650-pound Load, 50 mph.

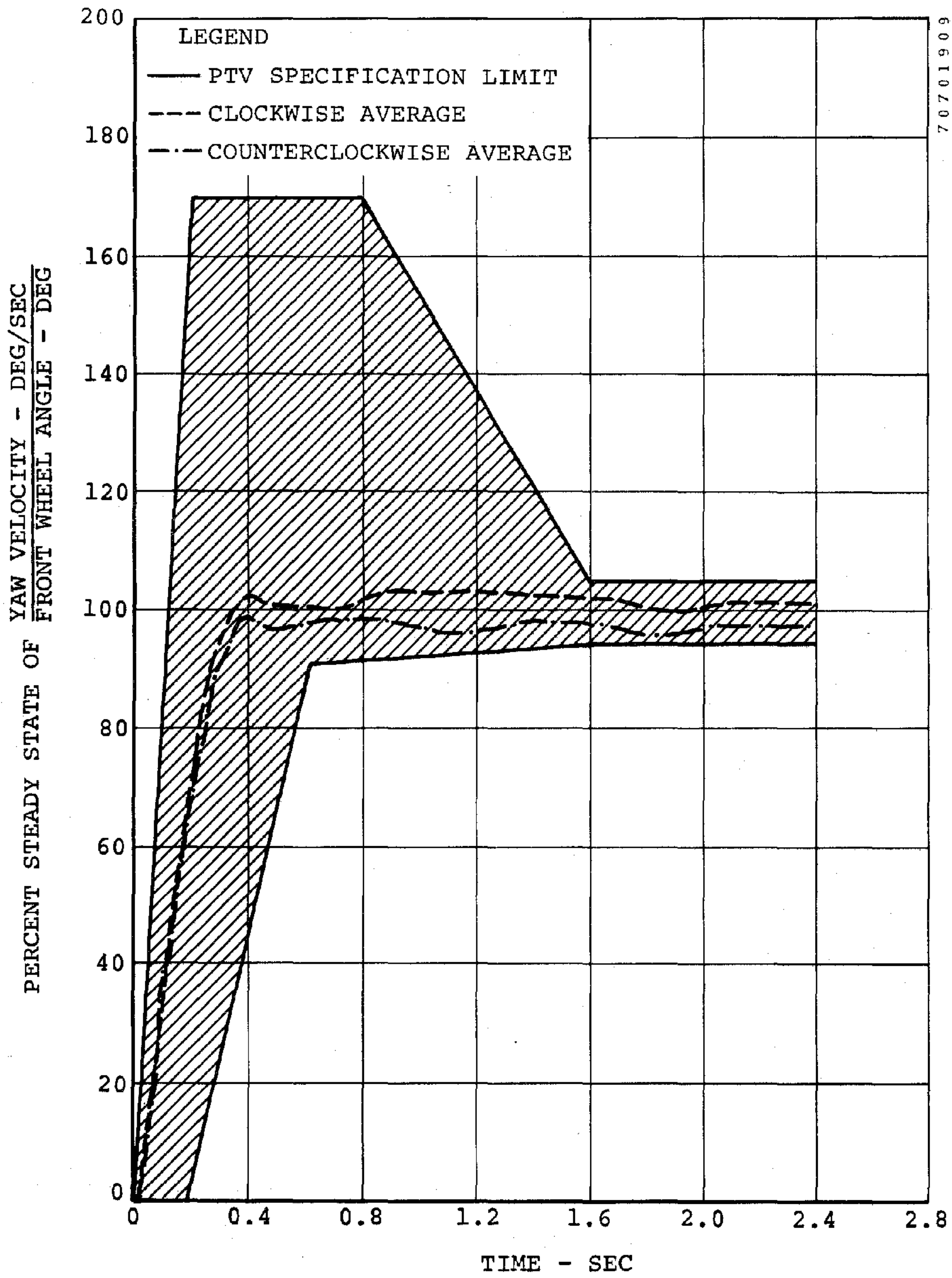


Figure 26. Transient Yaw Response Versus Time for ASL Prototype, 300-pound Load, 25 mph.

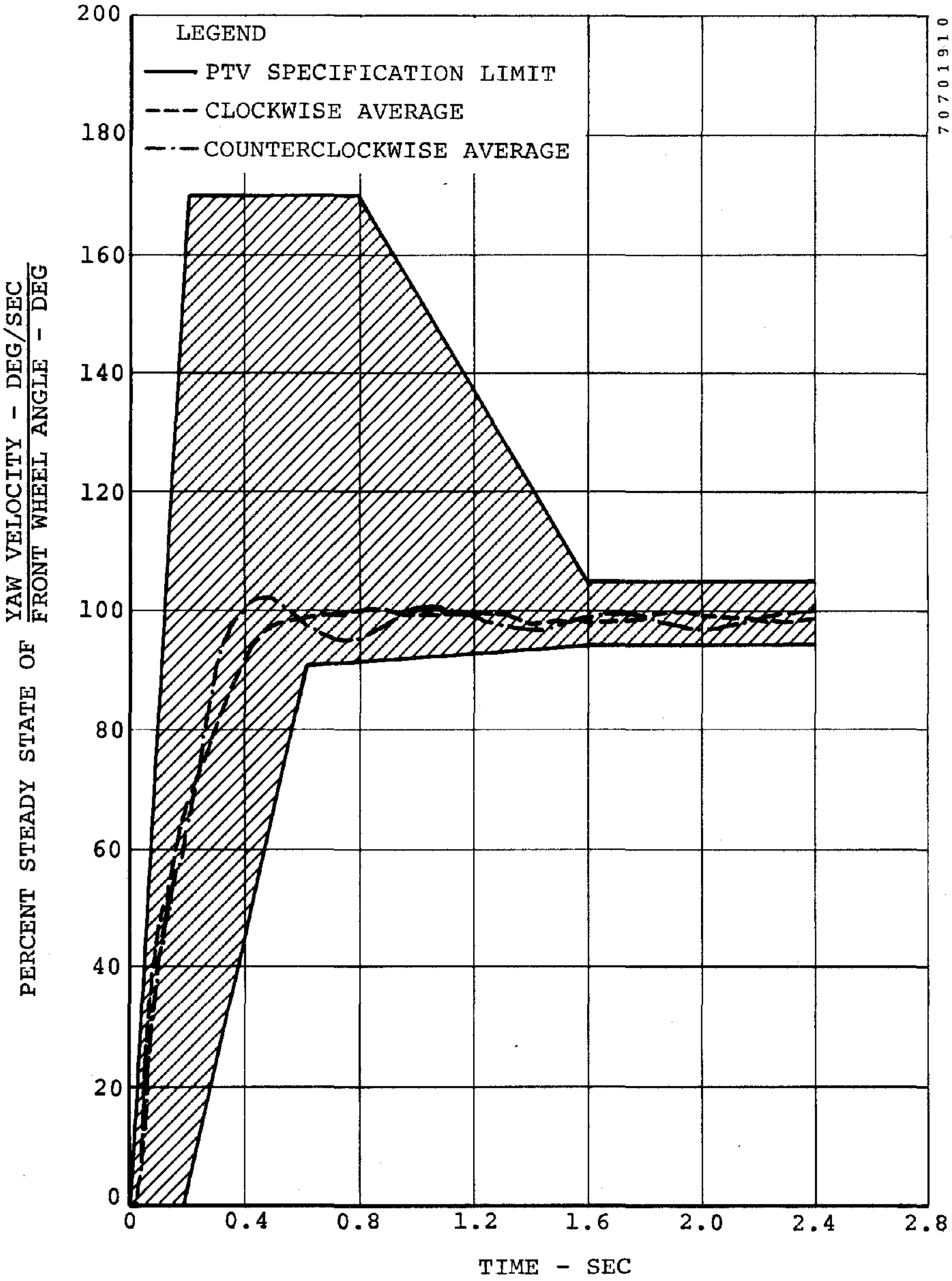


Figure 27. Transient Yaw Response Versus Time for ASL Prototype, 650-pound Load, 25 mph.

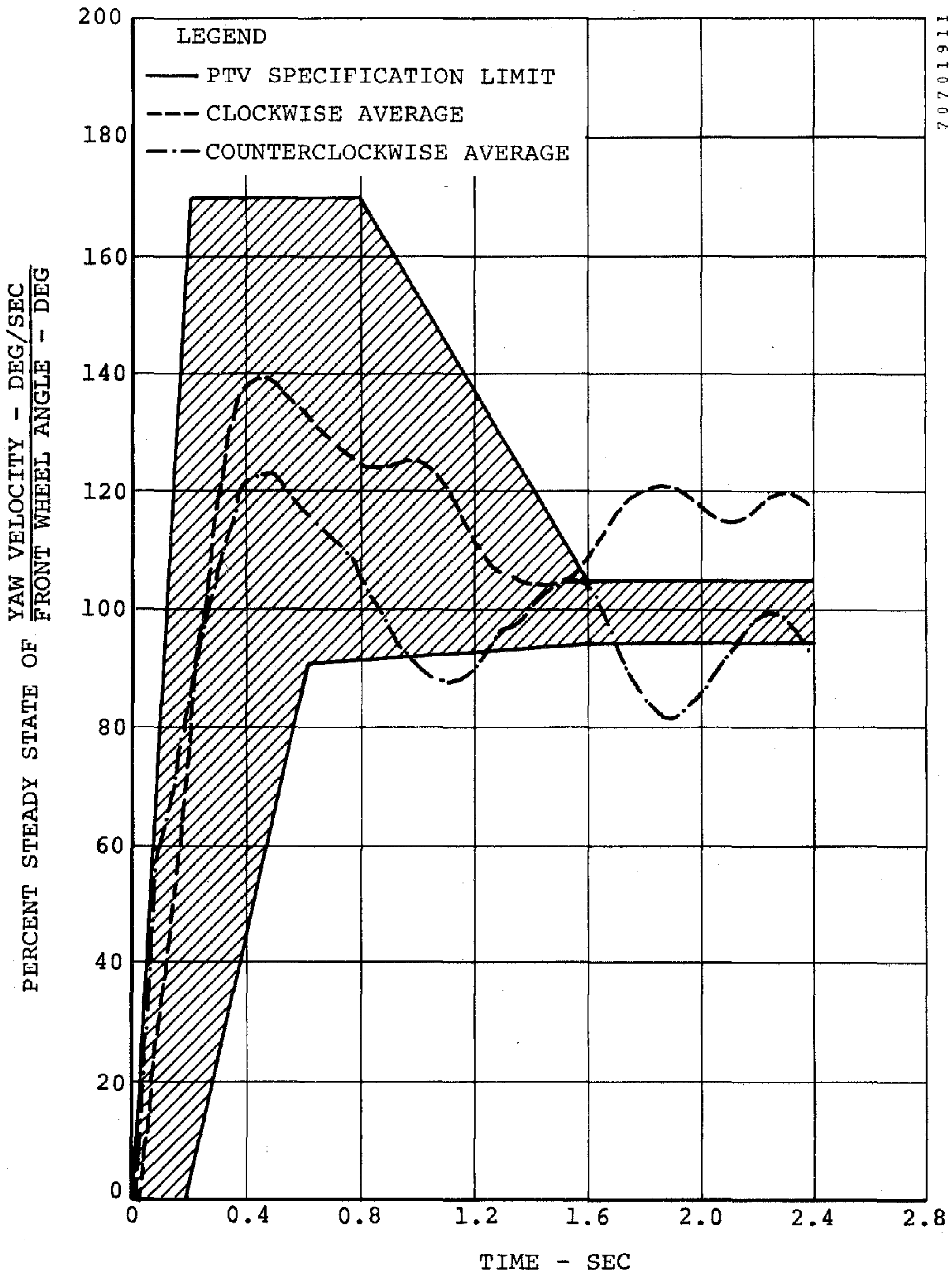


Figure 28. Transient Yaw Response Versus Time for ASL Prototype, 300-pound Load, 50 mph.

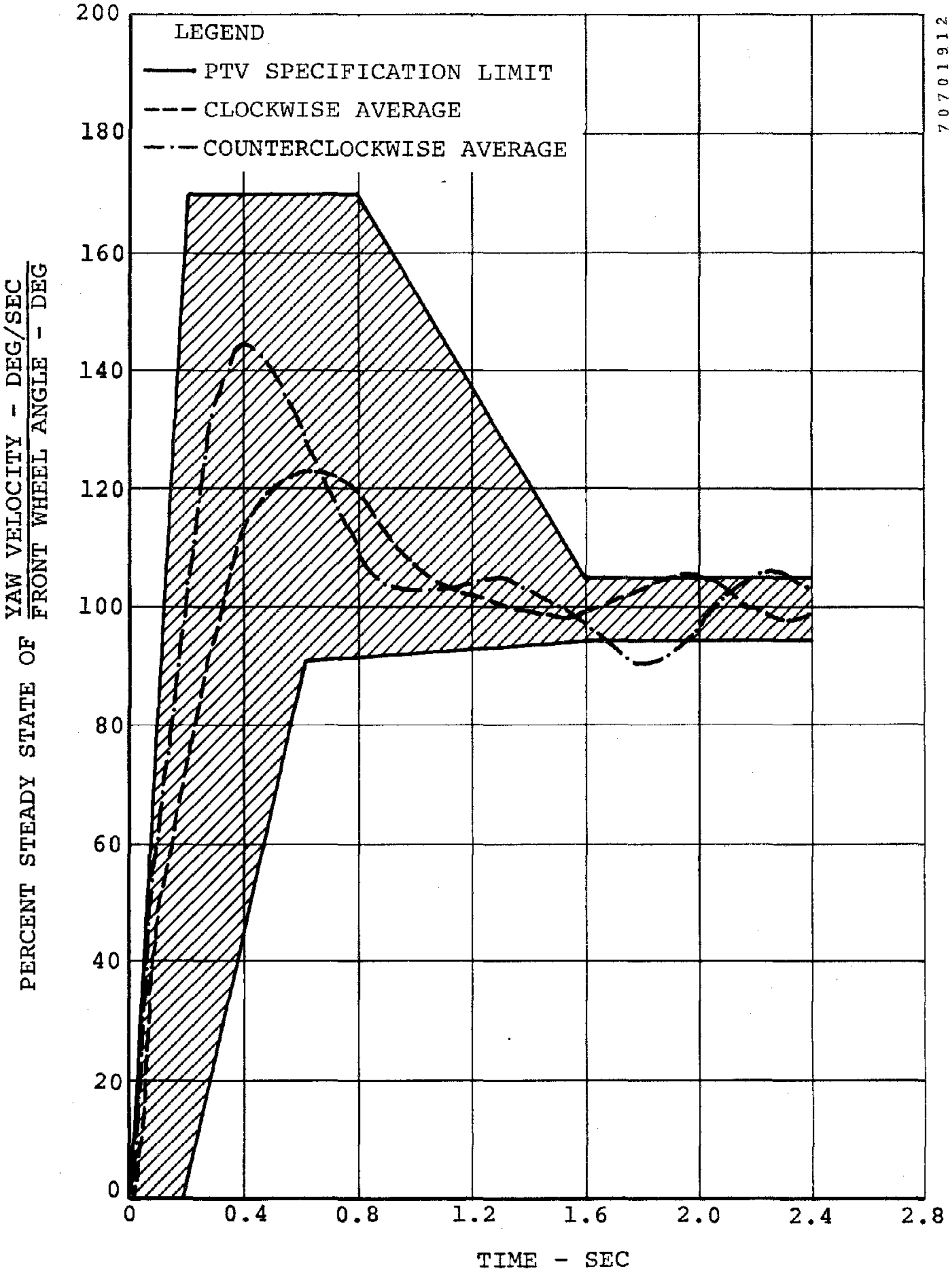


Figure 29. Transient Yaw Response Versus Time for ASL Prototype, 650-pound Load, 50 mph.

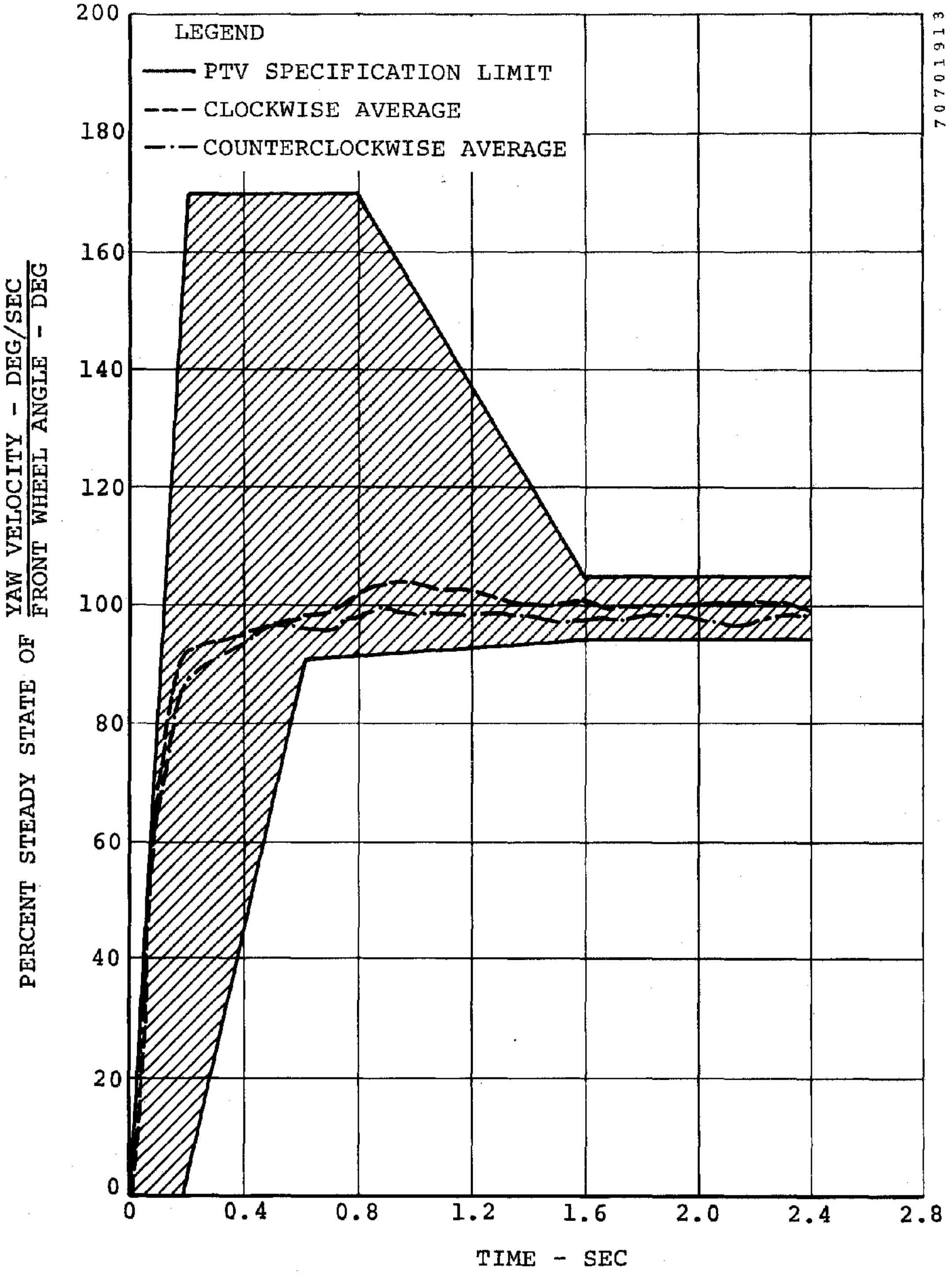


Figure 30. Transient Yaw Response Versus Time for Dutcher Prototype, 650-pound Load, 25 mph.

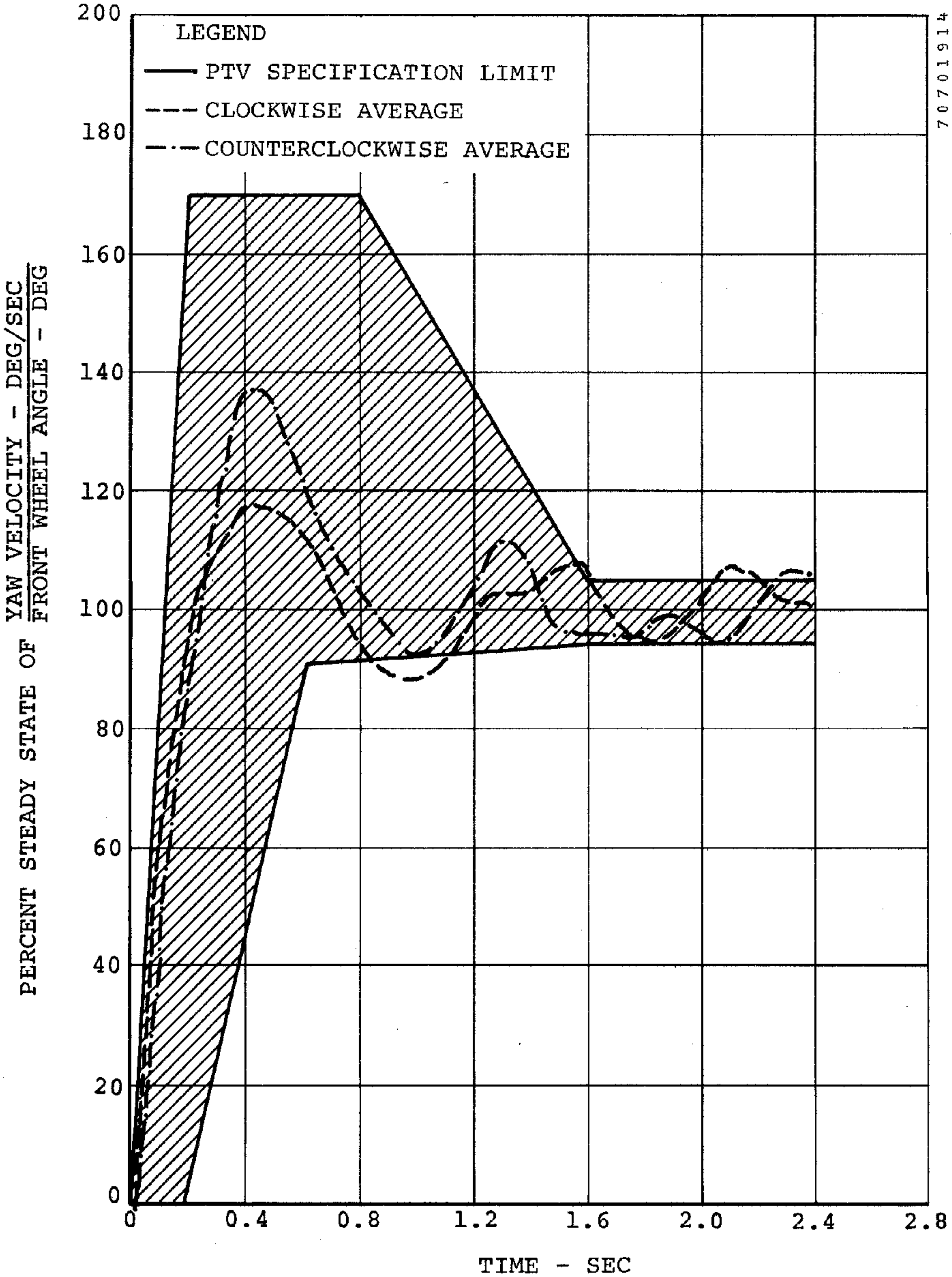


Figure 31. Transient Yaw Response Versus Time for Dutcher Prototype, 650-pound Load, 50 mph.

prototypes showed significant differences in the overshoot values depending on the turn direction, while the overshoot of the Nova was essentially identical for both clockwise and counterclockwise turns.

The dummy accelerations obtained during the transient yaw tests are compared in Table 16. These values are close to those obtained during the steady state yaw tests and do not vary significantly from vehicle to vehicle.

TABLE 16. COMPARISON OF DUMMY RESPONSE DURING TRANSIENT YAW TESTING

		Longitudinal Acceleration (G)			Lateral Acceleration (G)		
Nominal Test Velocity (mph)	Direction of Turn	Nova (Baseline)	ASL Prototype	Dutcher Prototype	Nova (Baseline)	ASL Prototype	Dutcher Prototype
25	cw*	0.10	0.00	0.03	0.50	0.52	0.44
25	ccw*	0.07	0.07	0.05	0.45	0.60	0.42
50	cw	0.08	0.01	0.04	0.59	0.46	0.54
50	ccw	0.04	0.11	0.14	0.37	0.62	0.59

*Clockwise.
**Counterclockwise.

6.3 RETURNABILITY TESTS

The average yaw rates versus time for the three vehicles are plotted, along with the PTV specification, in Figures 32 through 36. These figures show that both prototypes met the PTV specification easily and that there were no significant differences in the returnability characteristics of the two vehicles. Their performance was considerably better than that of the Nova, which did not meet the specification during either load condition.

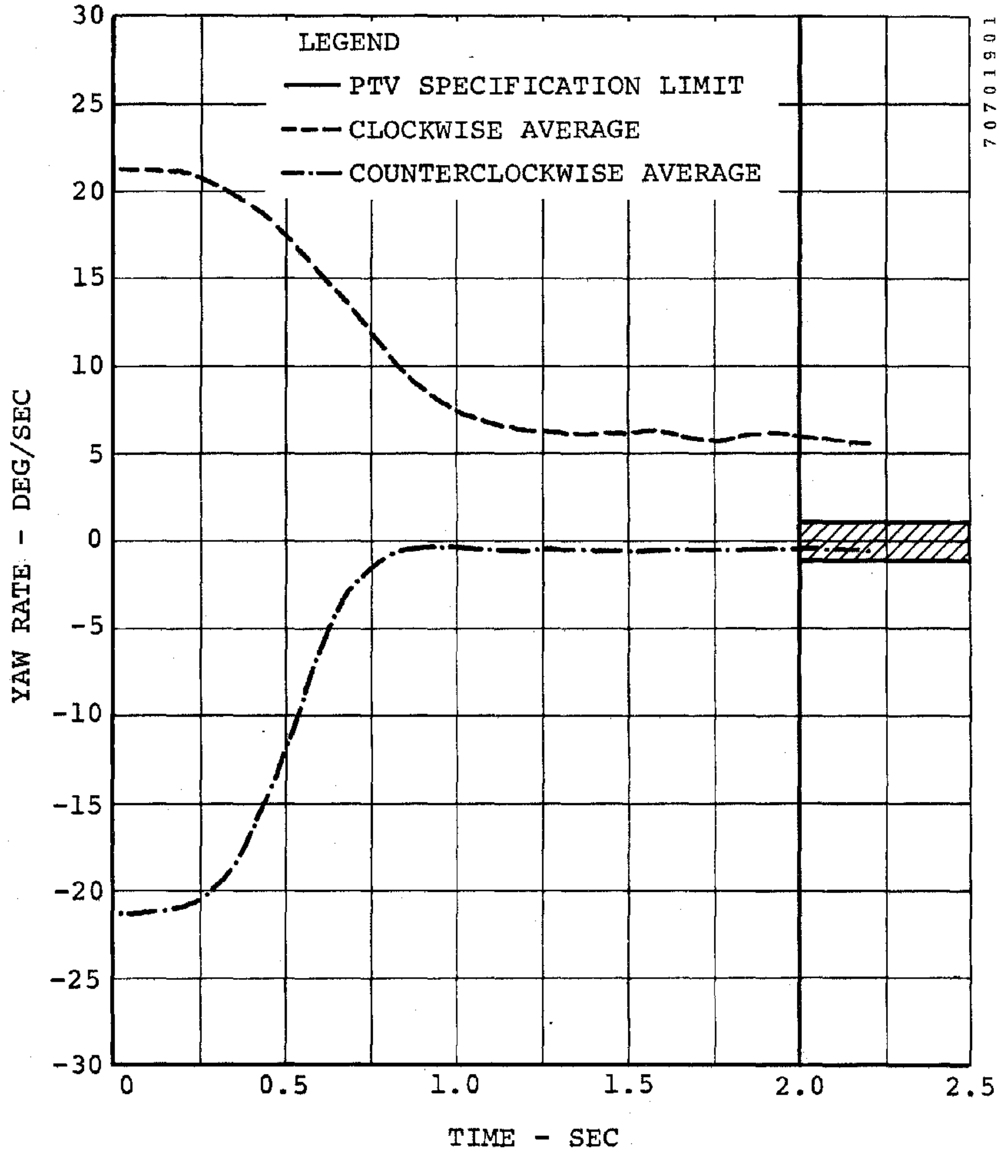


Figure 32. Returnability Performance in Terms of Yaw Rate for the Nova (Baseline) at 300-pound Load.

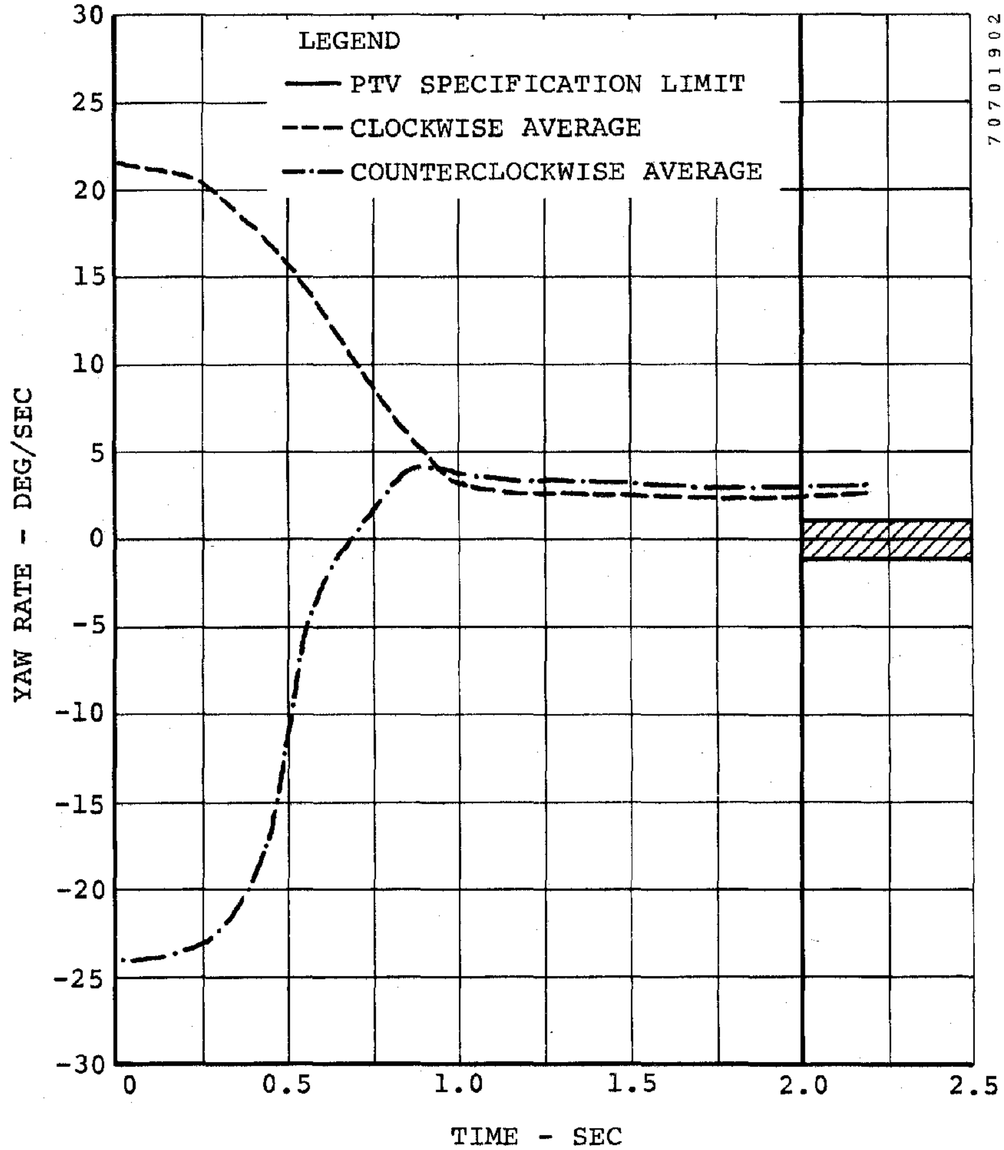


Figure 33. Returnability Performance in Terms of Yaw Rate for the Nova (Baseline) at 650-pound Load.

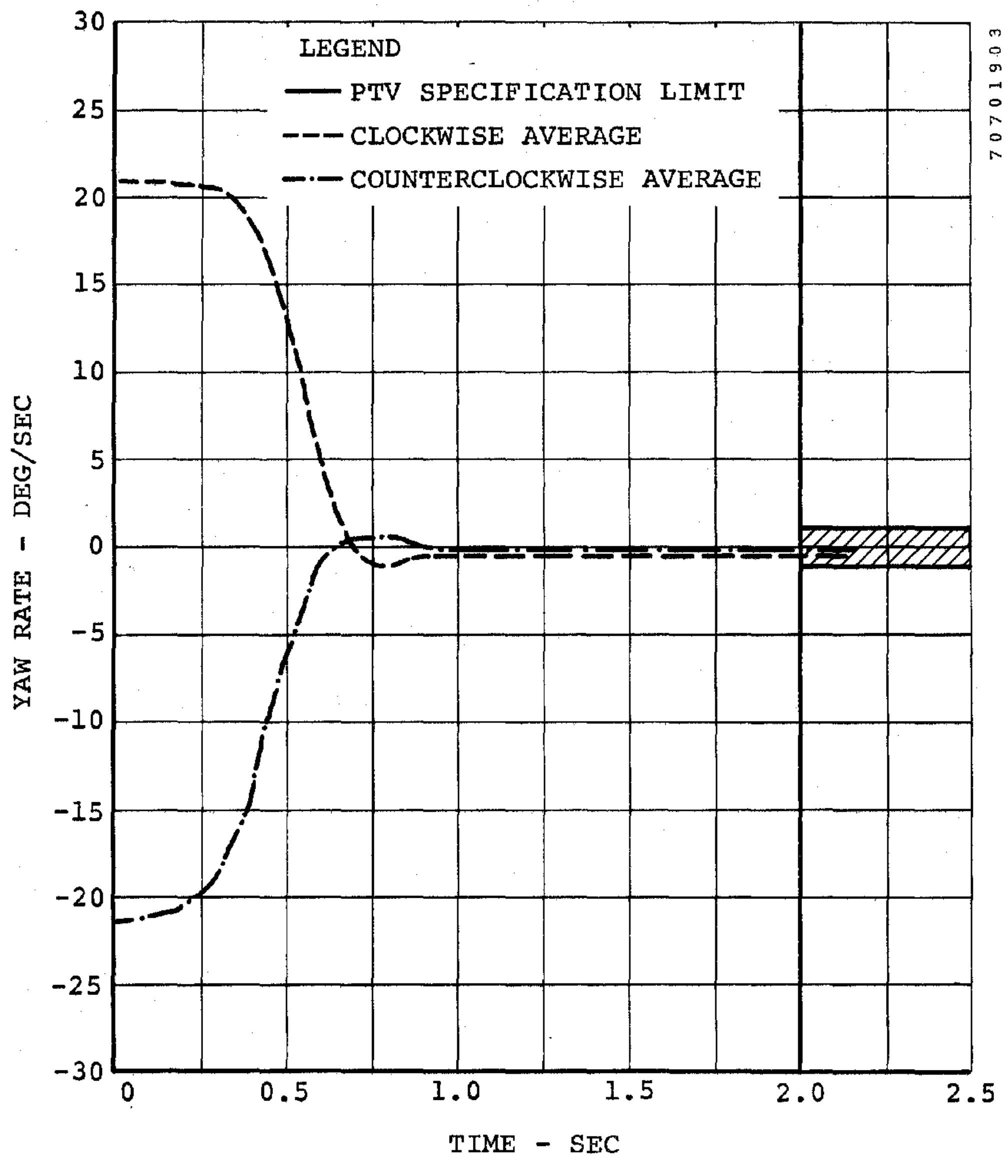


Figure 34. Returnability Performance in Terms of Yaw Rate for the ASL Prototype at 300-pound Load.

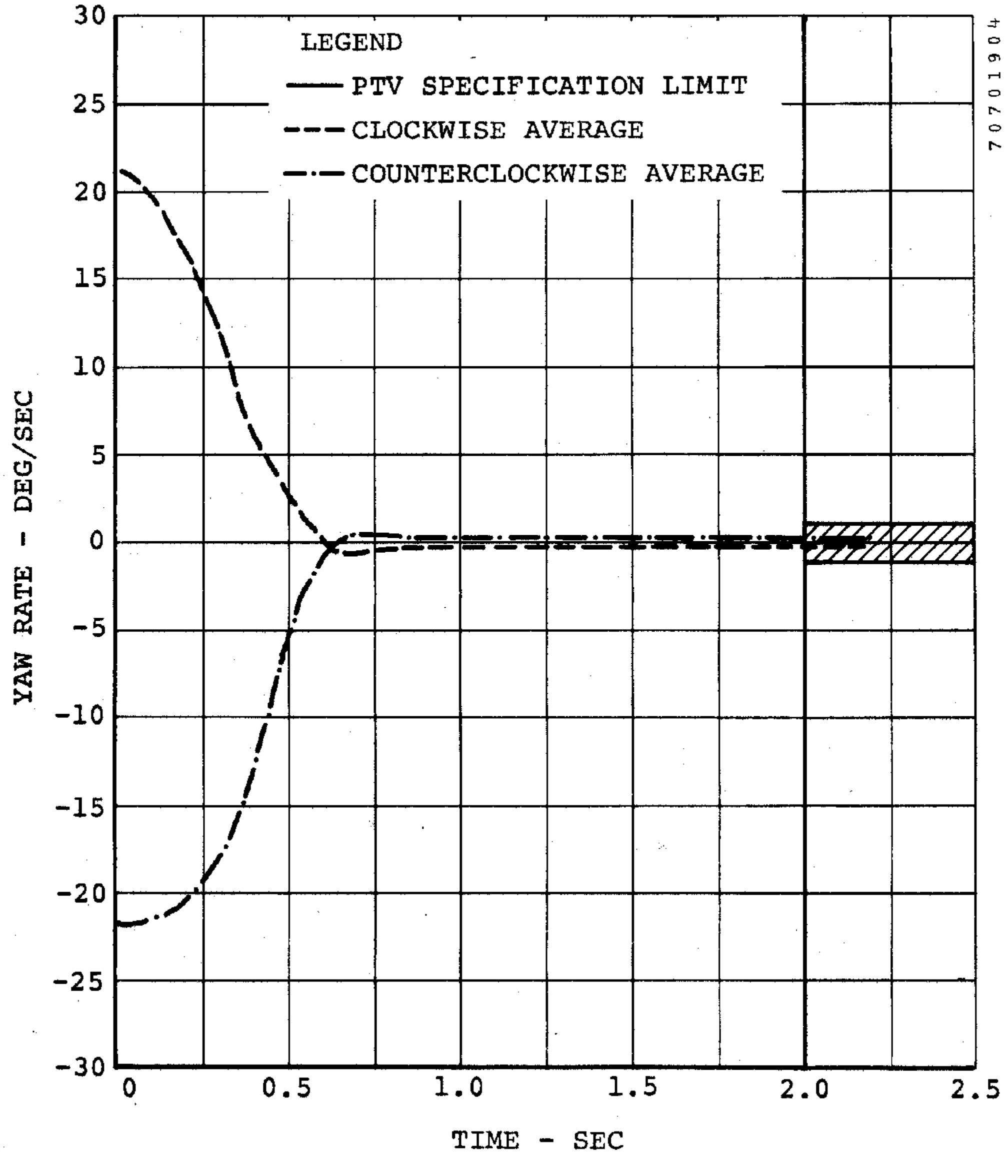


Figure 35. Returnability Performance in Terms of Yaw Rate for the ASL Prototype at 650-pound Load.

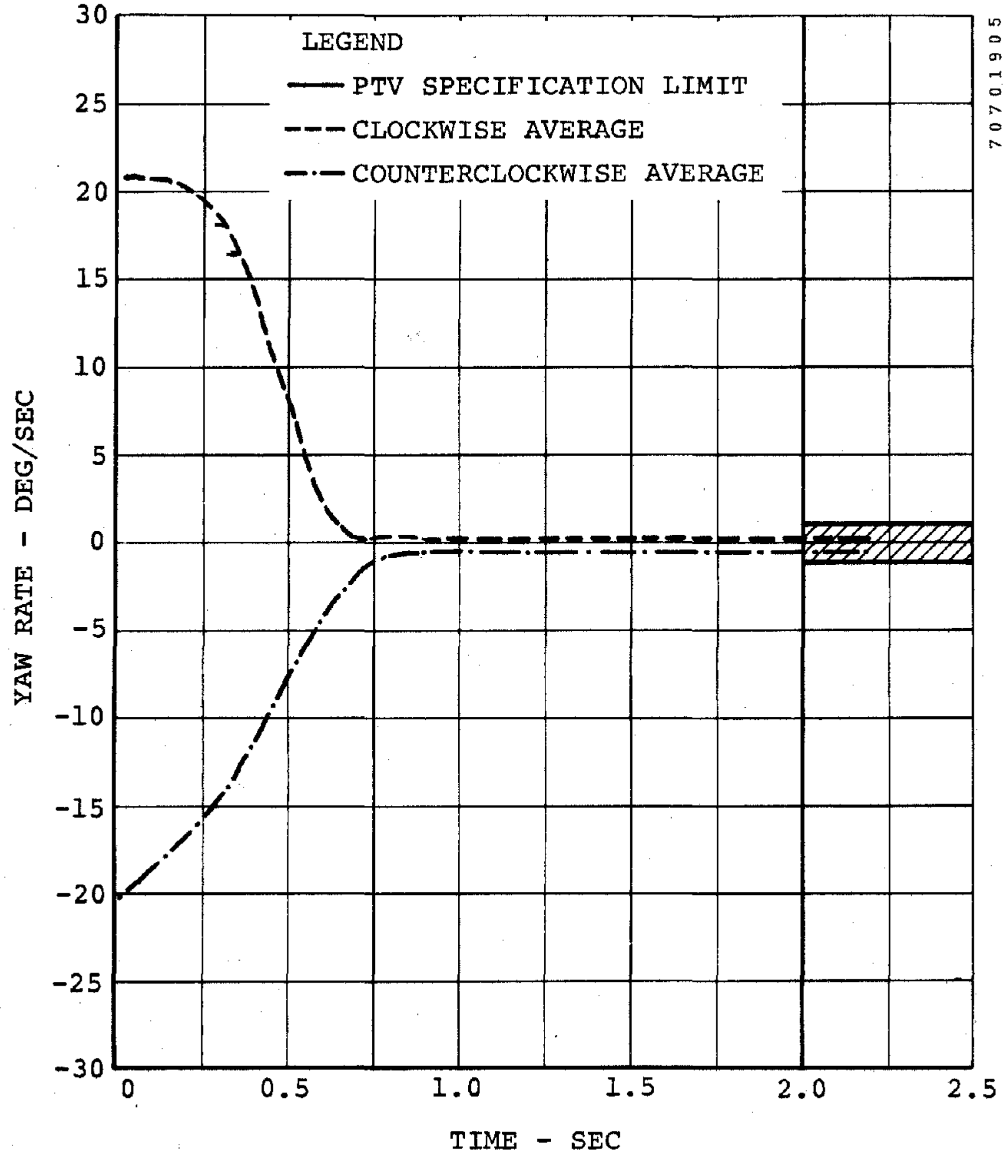


Figure 36. Returnability Performance in Terms of Yaw Rate for the Dutcher Prototype at 650-pound Load.

TABLE 17. COMPARISON OF DUMMY RESPONSE DURING RETURNABILITY TESTING

		Longitudinal Acceleration (G)			Lateral Acceleration (G)		
Test Velocity (mph)	Direction of Turn	Nova (Baseline)	ASL Prototype	Dutcher Prototype	Nova (Baseline)	ASL Prototype	Dutcher Prototype
25	cw*	0.05	0.07	0.13	0.50	0.34	0.52
25	ccw*	0.04	0.12	0.09	0.47	0.43	0.53

*Clockwise.
**Counterclockwise.

TABLE 18. SUMMARY OF MAXIMUM LATERAL ACCELERATION PERFORMANCE FOR THE NOVA (BASELINE)

			Average Peak Dummy Acceleration (G)		Maximum Lateral Acceleration (G)			
Loading Condition (lb)	Pavement Condition (Dry/Wet)	Turn Direction	Longitudinal	Lateral	Average	Standard Deviation	Tolerance Interval	PTV Specification
300	Dry	cw*	-	-	0.652	0.016	0.057	0.60
300	Dry	ccw**	-	-	0.644	0.017	0.055	0.60
300	Wet	cw	-	-	0.654	0.006	0.019	0.41
300	Wet	ccw	-	-	0.622	0.022	0.076	0.41
650	Dry	cw	0.19	0.85	0.656	0.022	0.077	0.60
650	Dry	ccw	0.10	0.76	0.596	0.009	0.031	0.60
650	Wet	cw	0.16	0.79	0.615	0.013	0.054	0.41
650	Wet	ccw	0.10	0.70	0.576	0.015	0.053	0.41

*Clockwise.
**Counterclockwise.

The returnability characteristics of the vehicles were also plotted using relative heading angles versus time. These data are contained in Figures 37 through 41. The specification used for the Ford Experimental Safety Vehicle (ESV) evaluation is also shown on these plots for comparative purposes.

These figures show that the ASL had the best returnability performance according to the ESV criteria, meeting the ESV specification at both load conditions. The Dutcher performance was better than that of the Nova, as it exceeded the ESV specification to a small degree during the counterclockwise tests, while the Nova exceeded the specification to a much greater extent during the clockwise tests.

The dummy accelerations during the returnability tests are compared in Table 17. The Dutcher and Nova dummies experienced comparable accelerations while those of the ASL dummy were slightly lower.

6.4 MAXIMUM LATERAL ACCELERATION TESTS

The data for the maximum lateral acceleration tests for the three vehicles are summarized in Tables 18 through 20. These data are compared in Table 21.

All three vehicles passed the PTV specifications for the wet and dry conditions, with one exception. Neither the Nova nor ASL met the specification during the counterclockwise tests on dry pavement with a 650-pound load. The Dutcher met the specifications during all the tests at this load.

Although there were some variations for certain test conditions, the Nova generally achieved slightly higher lateral accelerations before breaking away than did the two prototypes.

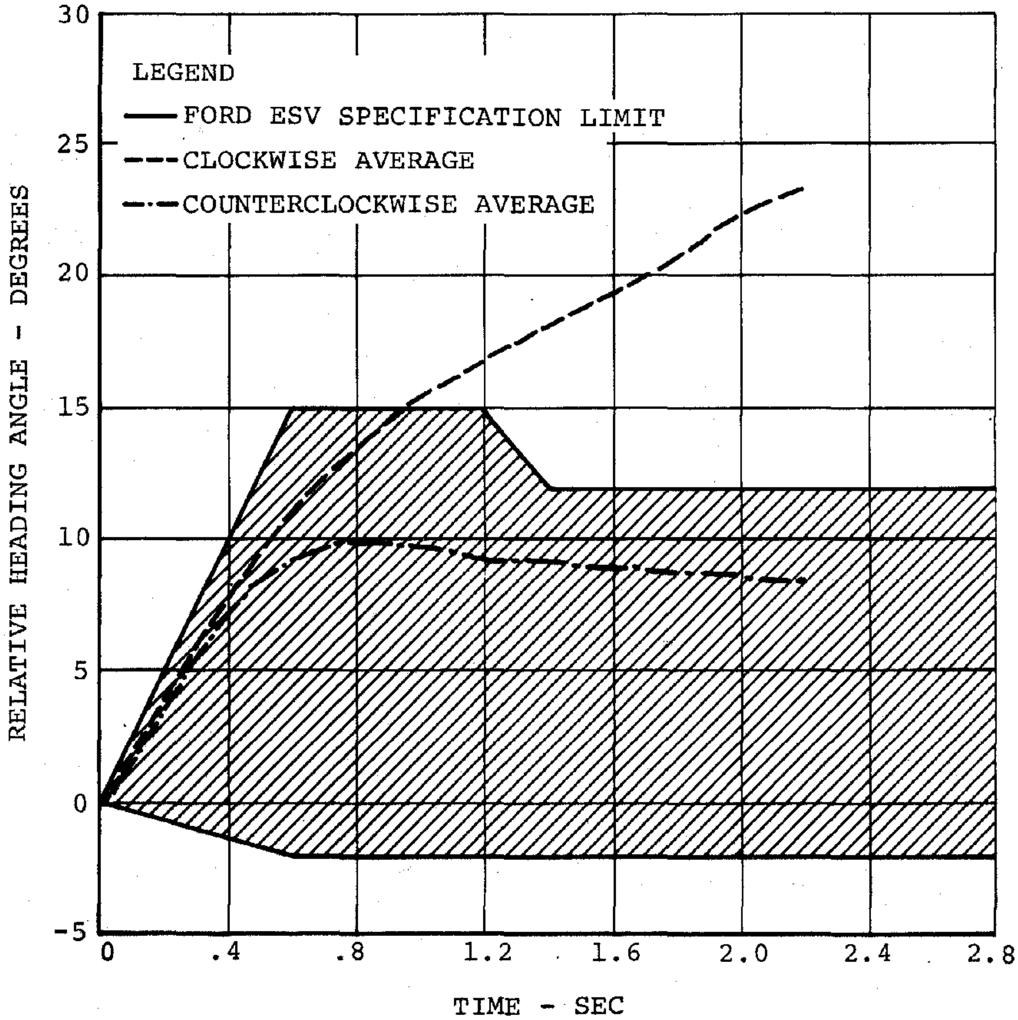


Figure 37. Returnability Performance in Terms of Heading for Nova (Baseline) at 300-pound Load.

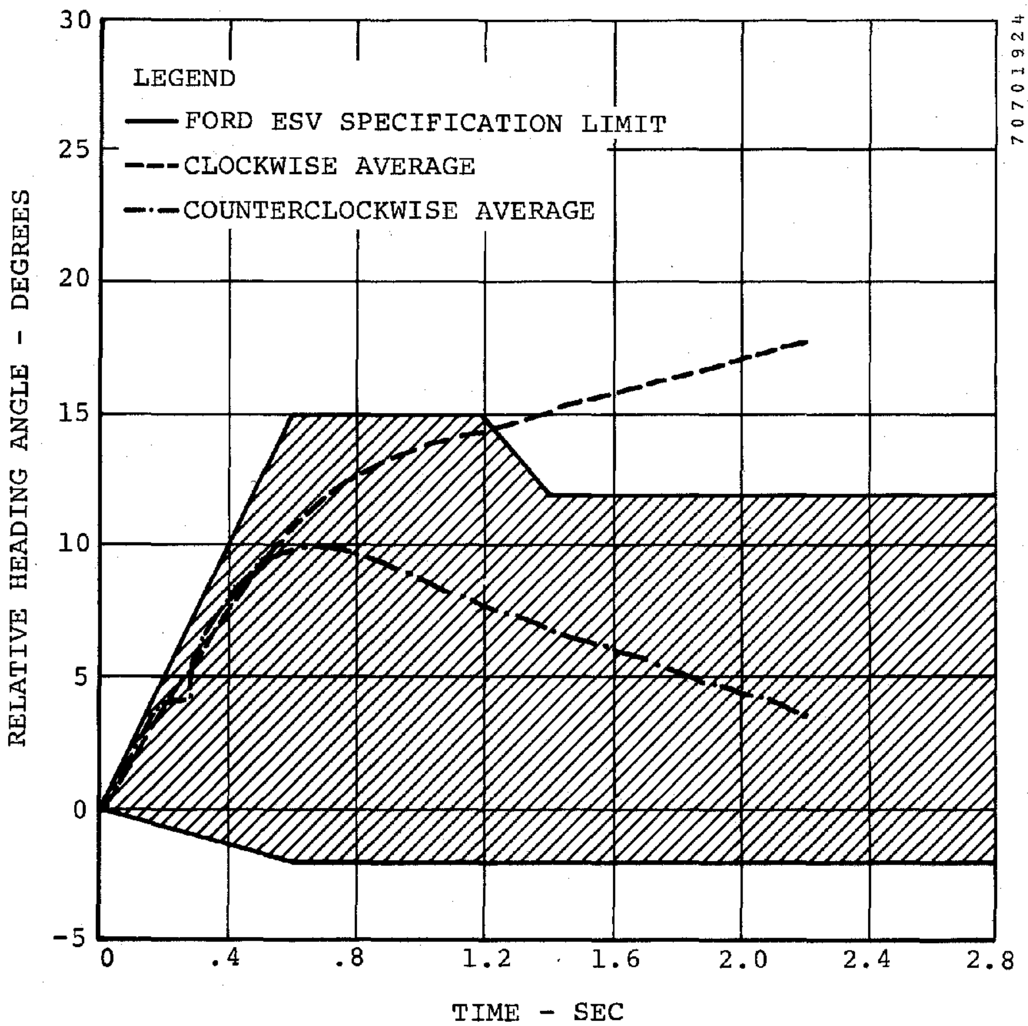


Figure 38. Returnability Performance in Terms of Heading for Nova (Baseline) at 650-pound Load.

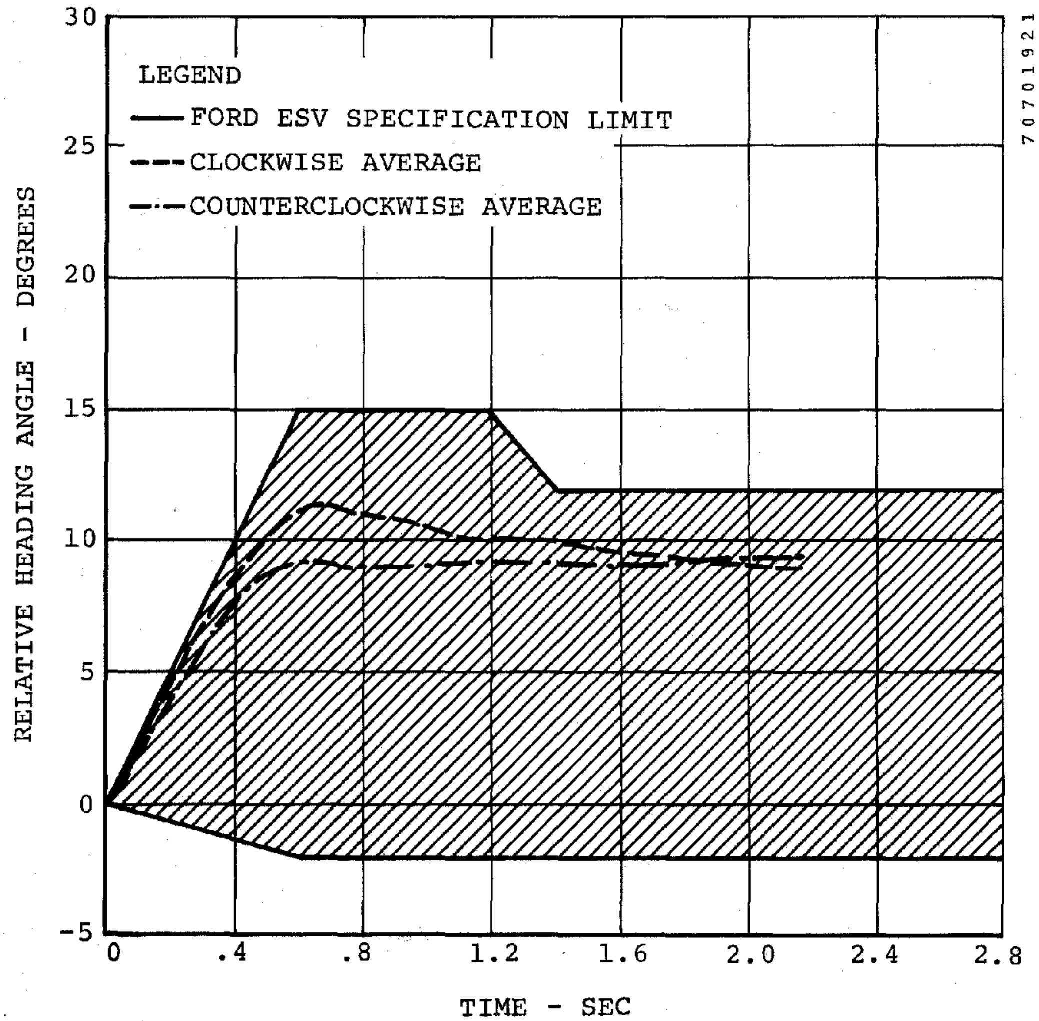


Figure 39. Returnability Performance in Terms of Heading for ASL Prototype at 300-pound Load.

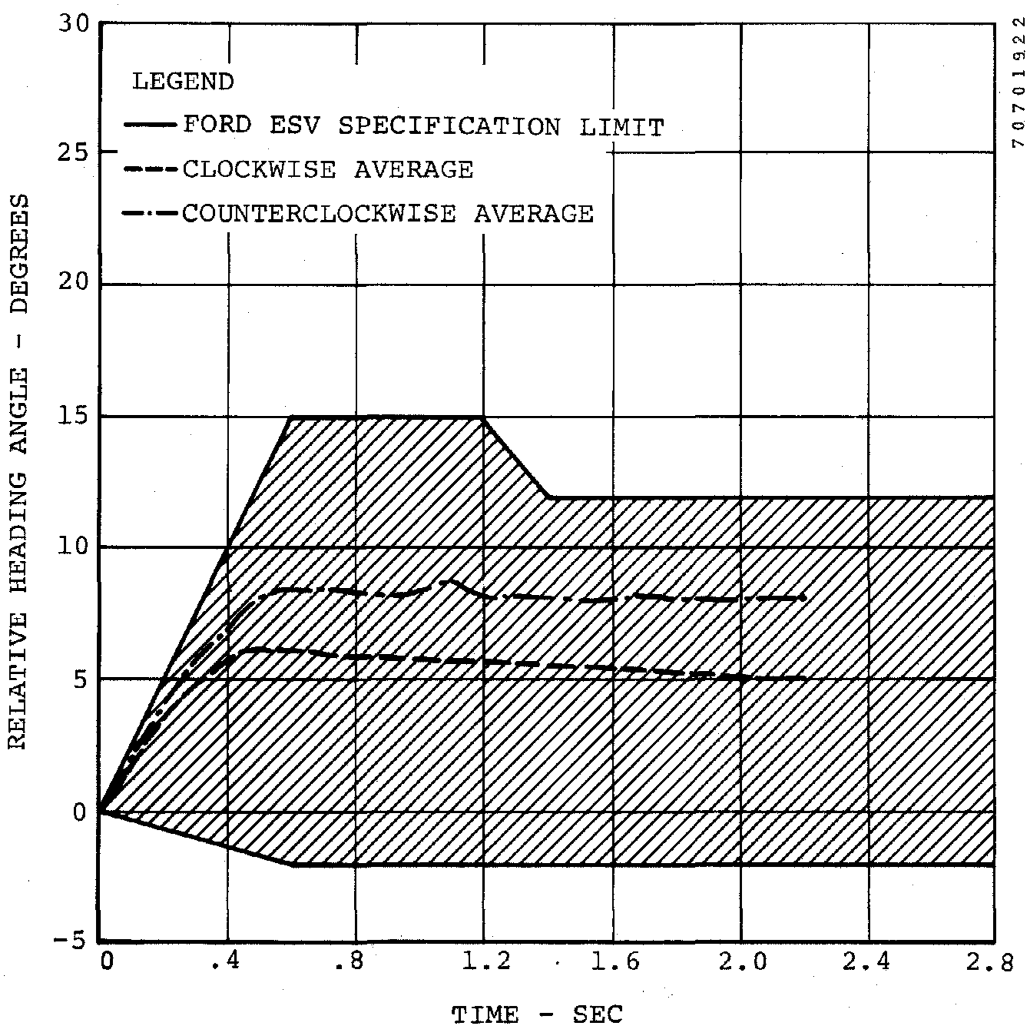


Figure 40. Returnability Performance in Terms of Heading for ASL Prototype at 650-pound Load.

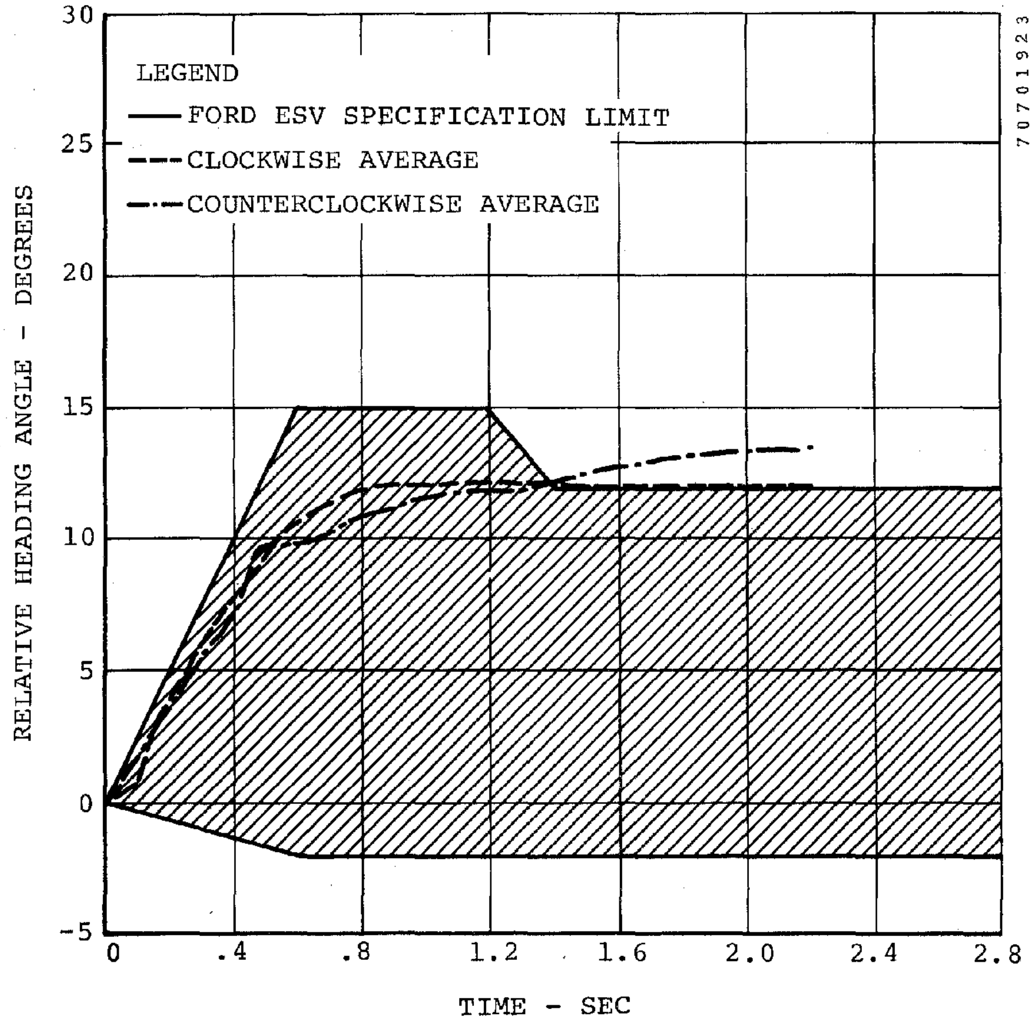


Figure 41. Returnability Performance in Terms of Heading for Dutcher Prototype at 650-pound Load.

TABLE 19. SUMMARY OF MAXIMUM LATERAL ACCELERATION PERFORMANCE FOR THE ASL PROTOTYPE

Loading Condition (lb)	Pavement Condition (Dry/Wet)	Turn Direction	Average Peak Dummy Acceleration (G)		Maximum Lateral Acceleration (G)			
			Longitudinal	Lateral	Average	Standard Deviation	Tolerance Interval	PTV Specification
300	Dry	cw*	–	–	0.666	0.022	0.076	0.60
300	Dry	ccw**	–	–	0.606	0.026	0.091	0.60
300	Wet	cw	–	–	0.592	0.061	0.213	0.41
300	Wet	ccw	–	–	0.534	0.052	0.181	0.41
650	Dry	cw	0.06	0.82	0.620	0.026	0.089	0.60
650	Dry	ccw	0.18	0.81	0.566	0.027	0.094	0.60
650	Wet	cw	0.05	0.79	0.578	0.019	0.067	0.41
650	Wet	ccw	0.16	0.89	0.562	0.052	0.182	0.41

*Clockwise.
**Counterclockwise.

TABLE 20. SUMMARY OF MAXIMUM LATERAL ACCELERATION PERFORMANCE FOR THE DUTCHER PROTOTYPE

Loading Condition (lb)	Pavement Condition (Dry/Wet)	Turn Direction	Average Peak Dummy Acceleration (G)		Maximum Lateral Acceleration (G)			
			Longitudinal	Lateral	Average	Standard Deviation	Tolerance Interval	PTV Specification
650	Dry	cw*	0.08	0.81	0.606	0.015	0.053	0.60
650	Dry	ccw**	0.14	0.96	0.644	0.013	0.045	0.60
650	Wet	cw	0.23	0.76	0.556	0.030	0.104	0.41
650	Wet	ccw	0.15	0.89	0.572	0.008	0.029	0.41

*Clockwise.
**Counterclockwise.

TABLE 21. COMPARISON OF MAXIMUM LATERAL ACCELERATION TESTING

			Average Peak Dummy Acceleration (G)						Maximum Lateral Acceleration (G)			
			Longitudinal			Lateral						
Loading Condition (lb)	Pavement Condition (Dry/Wet)	Turn Direction	Nova (Base-line)	ASL Proto-type	Dutcher Proto-type	Nova (Base-line)	ASL Proto-type	Dutcher Proto-type	Nova (Base-line)	ASL Proto-type	Dutcher Proto-type	PTV Specifi-cation
300	Dry	cw*	-	-	-	-	-	-	0.652	0.666	**	0.600
300	Dry	ccw***	-	-	-	-	-	-	0.644	0.606	**	0.600
300	Wet	cw	-	-	-	-	-	-	0.654	0.592	**	0.410
300	Wet	ccw	-	-	-	-	-	-	0.622	0.534	**	0.410
650	Dry	cw	0.19	0.06	0.08	0.85	0.82	0.81	0.656	0.620	0.606	0.600
650	Dry	ccw	0.10	0.18	0.14	0.76	0.81	0.96	0.596	0.566	0.644	0.600
650	Wet	cw	0.16	0.05	0.23	0.79	0.79	0.76	0.615	0.578	0.556	0.410
650	Wet	ccw	0.10	0.16	0.15	0.70	0.89	0.89	0.576	0.562	0.572	0.410

*Clockwise.
**Testing not performed.
***Counterclockwise.

The Dutcher achieved higher accelerations than the ASL on dry pavement with 650 pounds of load, while the reverse was true on wet pavement. The Nova and ASL achieved higher accelerations in the clockwise direction, while the Dutcher's higher accelerations were obtained in the counterclockwise direction.

Peak dummy accelerations were slightly higher in the Dutcher than in the other two vehicles. The Nova dummy accelerations were slightly lower than those in the prototypes.

6.5 BREAKAWAY CONTROL TESTS

The data from the breakaway control tests for the three vehicles are presented in Tables 22 through 24 and compared in Table 25. All the vehicles passed the PTV specification easily.

TABLE 22. SUMMARY OF BREAKAWAY CONTROL PERFORMANCE FOR THE NOVA (BASELINE)

Loading Condition (lb)	Turn Direction	Average Peak Dummy Acceleration (G)		Return Time (sec)			
		Longitudinal	Lateral	Average	Standard Deviation	Tolerance Interval	PTV Specification
300	cw*	–	–	2.315	0.207	0.724	4.0
300	ccw**	–	–	2.000	0.332	1.041	4.0
650	cw	0.31	0.76	2.766	0.494	1.546	4.0
650	ccw	0.14	0.85	2.496	0.377	0.181	4.0

*Clockwise.
**Counterclockwise.

TABLE 23. SUMMARY OF BREAKAWAY CONTROL PERFORMANCE FOR THE ASL PROTOTYPE

Loading Condition (lb)	Turn Direction	Average Peak Dummy Acceleration (G) Longitudinal	Average Peak Dummy Acceleration (G) Lateral	Return Time (sec) Average	Return Time (sec) Standard Deviation	Return Time (sec) Tolerance Interval	Return Time (sec) PTV Specification
300	cw*	-	-	2.510	0.075	0.236	4.0
300	ccw**	-	-	2.480	0.098	0.308	4.0
650	cw	0.13	0.93	2.380	0.075	0.236	4.0
650	ccw	0.06	1.06	2.410	0.260	0.813	4.0

*Clockwise.
**Counterclockwise.

TABLE 24. SUMMARY OF BREAKAWAY CONTROL PERFORMANCE FOR THE DUTCHER PROTOTYPE

Loading Condition (lb)	Turn Direction	Average Peak Dummy Acceleration (G) Longitudinal	Average Peak Dummy Acceleration (G) Lateral	Return Time (sec) Average	Return Time (sec) Standard Deviation	Return Time (sec) Tolerance Interval	Return Time (sec) PTV Specification
650	cw*	0.24	1.05	2.870	0.112	0.350	4.0
650	ccw**	0.19	1.03	2.737	0.296	0.928	4.0

*Clockwise.
**Counterclockwise.

TABLE 25. COMPARISON OF BREAKAWAY CONTROL TESTING

		Average Peak Dummy Acceleration (G)						Return Time (sec)			
		Longitudinal			Lateral						
Loading Condition (lb)	Turn Direction	Nova (Baseline)	ASL Prototype	Dutcher Prototype	Nova (Baseline)	ASL Prototype	Dutcher Prototype	Nova (Baseline)	ASL Prototype	Dutcher Prototype	PTV Specification
300	cw*	-	-	-	-	-	-	2.315	2.510	**	4.0
300	ccw***	-	-	-	-	-	-	2.000	2.480	**	4.0
650	cw	0.31	0.13	0.24	0.76	0.93	1.05	2.766	2.380	2.870	4.0
650	ccw	0.14	0.06	0.19	0.85	1.06	1.03	2.496	2.410	2.737	4.0

*Clockwise.
**Testing not performed.
***Counterclockwise.

The Nova returned to the original course without braking faster than the ASL prototype in the lightly loaded condition (300 pounds). However, the ASL return time in the heavily loaded condition (650 pounds) was faster than that of the Nova. The returnability of the Dutcher was the slowest of the three vehicles at 650-pound load.

Peak dummy lateral accelerations were lower in the Nova than in either of the prototypes. The Dutcher dummy's lateral acceleration was greater than the ASL's during the clockwise tests but the same as the ASL's during the counterclockwise tests.

6.6 SLALOM TESTS

The individual vehicle data from the slalom tests are presented in Tables 26 through 28. A comparison of the data is presented in Table 29.

The Nova negotiated the slalom course above the 45-mph PTV specification during both the light and heavy load tests. The ASL prototype exceeded 45 mph with the light load but was approximately 0.5 mph under the specification with the heavy load. The Dutcher prototype was well under the specification at the heavy load condition, successfully negotiating the course at a maximum speed of only 42 mph.

Peak dummy accelerations varied between the vehicles during different test conditions and no pattern is obvious except at maximum speed. The Dutcher dummy longitudinal and lateral accelerations are lower at maximum speed than are those of the other two vehicles. This is consistent with the lower maximum speed attained by the Dutcher during the tests.

TABLE 26. SUMMARY OF SLALOM COURSE TESTING FOR THE NOVA (BASELINE)

		650-lb Load				300-lb Load	
		Average Peak Dummy Acceleration (G)					
Nominal Test Velocity (mph)	Initial Turn Direction (L/R)	Longitudinal	Lateral	Average Test Time (sec)	Average Test Velocity (mph)	Average Test Time (sec)	Average Test Velocity (mph)
25	Left	0.06	0.28	27.2	25.2	27.5	25.3
25	Right	0.08	0.27	27.3	25.1	27.6	25.1
40	Left	0.18	0.89	16.9	40.6	17.1	40.0
40,	Right	0.18	0.89	16.8	40.7	17.3	39.9
maximum*	Left	0.43	1.52	14.4	46.7	13.8	49.8
maximum*	Right	0.39	1.63	14.7	47.8	14.0	48.7

*PTV specification is 45 mph.

TABLE 27. SUMMARY OF SLALOM COURSE TESTING FOR THE ASL PROTOTYPE

		650-lb Load				300-lb Load	
		Average Peak Dummy Acceleration (G)					
Nominal Test Velocity (mph)	Initial Turn Direction (L/R)	Longitudinal	Lateral	Average Test Time (sec)	Average Test Velocity (mph)	Average Test Time (sec)	Average Test Velocity (mph)
25	Left	0.08	0.31	27.8	24.7	27.6	25.8
25	Right	0.09	0.37	28.0	24.7	27.4	25.8
40	Left	0.08	0.81	17.5	39.7	17.6	39.4
40	Right	0.21	0.83	17.5	39.6	17.7	39.7
maximum*	Left	0.35	1.58	15.1	44.6	14.2	49.5
maximum*	Right	0.27	1.42	15.2	44.5	14.2	49.3

*PTV specification is 45 mph.

TABLE 28. SUMMARY OF SLALOM COURSE TESTING FOR THE DUTCHER PROTOTYPE

		650-lb Load			
		Average Peak Dummy Acceleration (G)			
Nominal Test Velocity (mph)	Initial Turn Direction (L/R)	Longitudinal	Lateral	Average Test Time (sec)	Average Test Velocity (mph)
25	Left	0.10	0.38	27.2	24.9
25	Right	0.10	0.37	27.2	25.1
40	Left	0.15	0.79	16.7	40.2
40	Right	0.13	0.92	16.8	40.1
maximum*	Left	0.19	1.33	16.1	42.0
maximum*	Right	0.15	1.23	15.9	41.8

*PTV specification is 45 mph.

TABLE 29. COMPARISON OF SLALOM COURSE PERFORMANCE

		Average Peak Dummy Acceleration (G)						Average Test Velocity (mph)					
		Longitudinal			Lateral			300-lb Load			650-lb Load		
Nominal Test Velocity (mph)	Initial Turn Direction	Nova (Base-line)	ASL Proto-type	Dutcher Proto-type	Nova (Base-line)	ASL Proto-type	Dutcher Proto-type	Nova (Base-line)	ASL Proto-type	Dutcher Proto-type	Nova (Base-line)	ASL Proto-type	Dutcher Proto-type
25	Left	0.06	0.08	0.10	0.28	0.31	0.38	25.3	25.8	*	25.2	24.7	24.9
25	Right	0.08	0.09	0.10	0.27	0.37	0.37	25.1	25.8	*	25.1	24.7	25.1
40	Left	0.18	0.08	0.15	0.89	0.81	0.79	40.0	39.4	*	40.6	39.7	40.2
40	Right	0.18	0.21	0.13	0.89	0.83	0.92	39.9	39.2	*	40.7	39.6	40.1
Maxi-mum**	Left	0.43	0.35	0.19	1.52	1.58	1.33	49.8	49.5	*	46.7	44.6	42.0
Maxi mum**	Right	0.39	0.27	0.15	1.63	1.42	1.23	48.7	49.3	*	47.8	44.5	41.8

*Testing not performed.
**PTV specification is 45 mph.

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